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IMPACT OF A STRONG TYPHOON ON THE STRUCTURE AND DYNAMICS OF AN OLD-GROWTH BEECH (*FAGUS CRENATA*) FOREST, SOUTHWESTERN JAPAN

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Abstract: Typhoon no. 19 of 1991 (T9119) caused multiple treefalls and created large openings in an old-growth beech (*Fagus crenata*) forest at Mt. Daisen, in the Daisen Forest Reserve, southwestern Japan. The area of the largest opening was about 1.7 ha (300 m by 70 m).To predict the dynamics of the beech stand after the disturbance of T9119, we investigated the damage to the stand and the density and growth rate of trees with DBH = 5–10 cm in a 1-ha plot covering a large part of the largest opening and the adjacent closed canopy.

The beech did not regenerate immediately. The regeneration and growth rate of trees with DBH = 5–10 cm were related to the frequency of the typhoon attack for at least the past century. In beech forests, small gap formation is the prevailing mode of disturbance. Our results indicate that typhoons affect the structure and dynamics of this beech stand. We suggest that both small gap formation and large-scale disturbance are important for the maintenance of beech forest in some areas.

INTRODUCTION

Forest dynamics is affected by various kinds of natural disturbance (HENRY & SWAN 1974, OLIVER & STEPHENS 1977, WHITE 1979, PICKETT & WHITE 1985, FOSTER 1988, LORIMER 1989, SPIES & FRANKLIN 1989). Studies of forest disturbance have focused on small-scale disturbances such as small gap formation (e.g. RUNKLE 1981, 1990, BROKAW 1985). However, recent studies have revealed that large-scale disturbance also has an important role in forest dynamics (DUNN et al. 1983, LORIMER & FRELICH 1989, ZIMMERMAN et al. 1994, FERGUSON 1995, ABRAMS & ORWIG 1996). Typhoons are a major disturbance factor in forests in Japan (NAKA 1982, NAKASHIZUKA & YAMAMOTO 1987, BELLINGHAM et al. 1996). Yet there are few studies of the impact of large wind or typhoon disturbance on forest structure and dynamics (IDA & NAKAGOSHI 1998, IDA 2000).

Beech (*Fagus crenata* BLUME) is a dominant species in cool-temperate forests in Japan. Many studies of the dynamics or regeneration of beech forests have clarified that small gap formation is a prevailing mode of disturbance of natural forests (NAKASHIZUKA & NUMATA 1982, HARA 1985, YAMAMOTO 1989), and that gaps are easily filled by branch extension from canopy trees surrounding the gaps or by the recruitment of beech saplings present before gap formation (HARA 1985, YAMAMOTO 1989). Beech is a "primary species" (BROKAW 1985), and a beech forest is maintained by a "regeneration complex" (WATT 1947) or "mosaic cycle" (REMMERT 1991, EMBORG et al. 2000). Knowledge of gap dynamics, however, is lacking for gaps larger than 1000 m^2, so the role of large-scale disturbance in the dynamics or regeneration of beech forests has not yet been evaluated.

On 27 September 1991, Typhoon no. 19 (T9119) struck Japan with wind speeds exceeding 216 km . h^{-1} causing catastrophic wind disturbance in many areas in many forests. The beech forests in the Daisen Forest Reserve were severely disturbed; the damage was concentrated in old-growth stands around the Oyasumi-Pass.

The main objective of this study was to evaluate the role of the large-scale disturbance by T9119 on the dynamics of an old-growth beech stand. Specific objectives were as follows: (1) to describe the characteristics of the typhoon disturbance and forest damage, (2) to predict the regeneration process of beech stands after the disturbance, and (3) to evaluate and discuss forest dynamics of beech stands with respect to typhoon disturbance.

Nomenclature: OHWI (1972).

MATERIALS AND METHODS

Study area

The study site is an old-growth beech stand around the Oyasumi-Pass, Mt. Daisen (35° 21′ 77″ N, 133° 33′ 23″ E; 1713 m a.s.l.), in the Daisen Forest Reserve, Tottori Prefecture, southwestern Japan (Fig. 1). Mt. Daisen is an extinct, Pleistocene-age volcano. Oyasumi-Pass (1100 m a.s.l.) can be found at a saddle between Mt. Noda (about 1340 m a.s.l.) in the east and Mt. Yahazu (1358 m a.s.l.) in the west, and funnels wind strongly (ROBERT 1964, REBERTUS et al. 1997). The mean annual precipitation is about 3400–3500 mm, and the mean monthly maximum temperature is highest in August (26.5 °C) and lowest in February (-4.6 °C) at the Daisenji local meteorological observatory (ca. 800 m a.s.l.) about 3 km from the pass. The frost-free period occurs from May to September. Snow falls in November to April and reaches a depth of about 200–350 cm from January to March.

Beech stands around the pass contain trunks with a diameter at breast height (DBH) > 1 m and up to 250 years old (HASHIZUME 1994), and there are no signs of human disturbance. Dwarf bamboos (*Sasa* spp.) dominate the understory in some stands in the reserve, but we did not find them around the pass.

Field methods and data analysis

To estimate forest damage attributable to T9119, we assessed the location and size of large openings around the pass by comparing aerial photographs taken in 1989 and 1996, and chose the largest opening. The length (L) and width (W) of the opening were measured on the 1996 aerial photograph, and the area (A) was calculated from the following formula for an ellipse:

$$A = \pi LW / 4 \qquad (1)$$

The largest opening occurred on the north-facing slope of Mt. Noda. A 1-ha plot (50 × 200 m) covering a large part of the opening was set up in 1998. In the plot, we identified

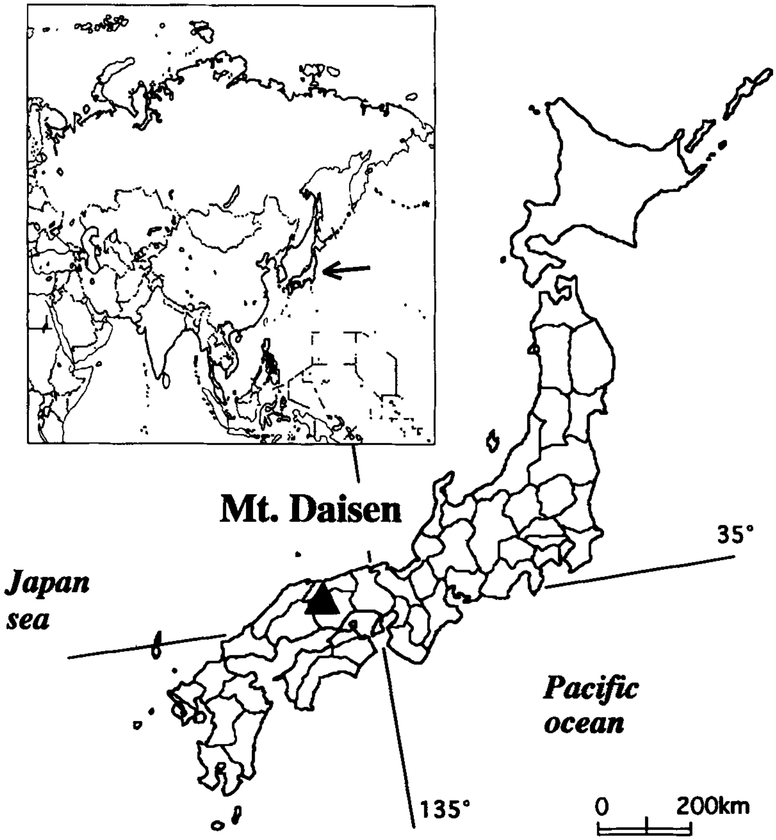

Fig. 1. Location of Mt. Daisen, southwestern Japan.

species, measured DBH, and mapped all trees with DBH ≥5 cm. Species of dead trunks were identified from their bark or sprouting shoots, if present. Tree damage caused by the typhoon was classified as snapped or uprooted. Uprooted stems whose roots were located in the plot were recorded as newly or previously uprooted based on the appearance of the root mound, root pit, and bark. The height and width of the mounds and the length and width of the pits were measured. The areas of the mounds and pits were calculated from formula (1). We categorized trees according to DBH: ≥ 30 cm, 10–30 cm, 5–10 cm, and 0–5 cm. Species with at least one stem taller than 10 m were defined as major tree species.

A canopy opening was defined as a quadrat (10 × 10 m) that had no trees with a DBH ≥ 30 cm. To estimate the opening area in the 1-ha plot, we divided the plot into 100 quadrats of 100 m^2 each. Canopy cover in the quadrats was assessed as closed (trees with DBH ≥ 30 cm present) or open (absent). Thus, the minimum size of openings detected was 100 m^2. A 2-m^2 (1 × 2 m) rectangular subquadrat was placed at the southern corner of each quadrat. The number of trees of major species with DBH = 0–5 cm was counted in each subquadrat, and the species were identified. Other subquadrats were also placed on the mounds and in the pits of uprooted trees (n = 22); the number of trees with DBH = 0–5 cm was counted in each, and the species were identified.

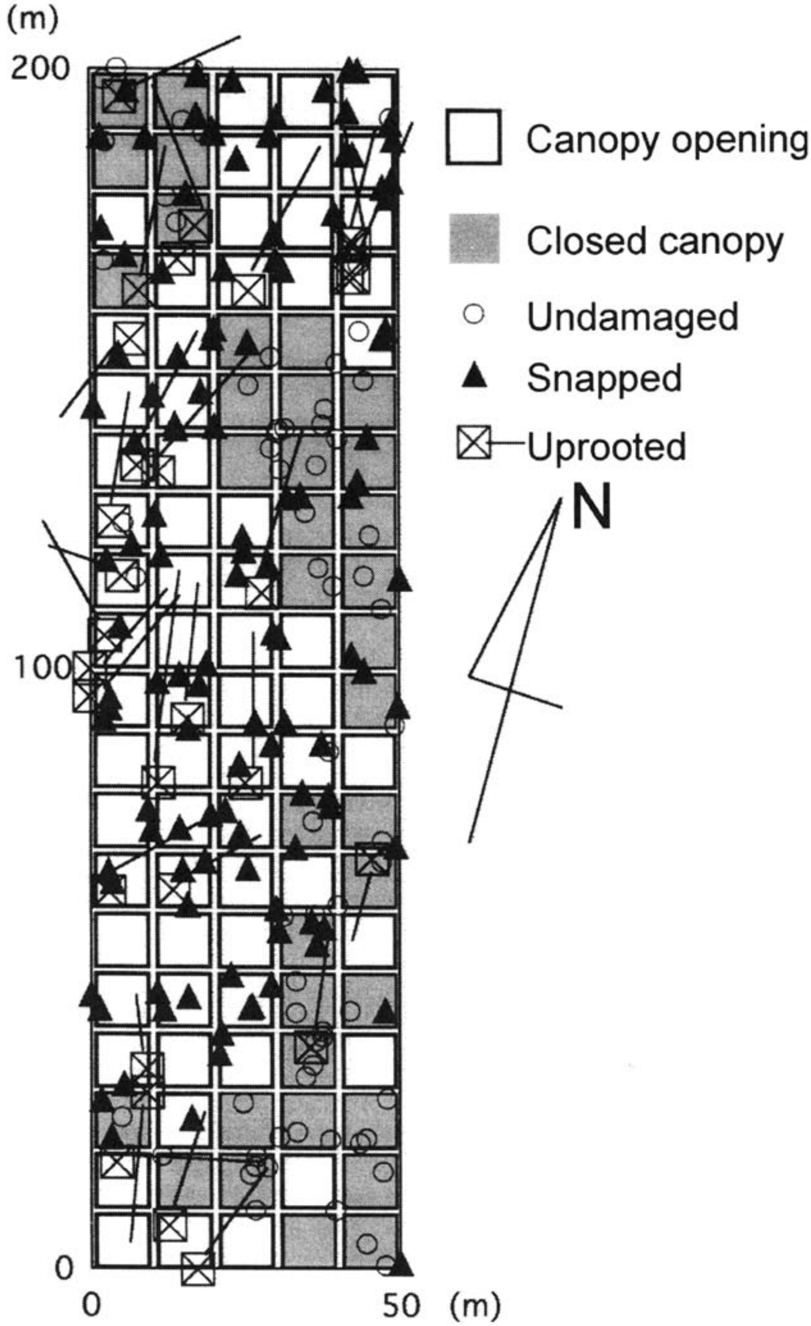

Fig. 2. Canopy conditions and locations of undamaged trees with DBH ≥ 30 cm, and of snapped and uprooted trees with DBH ≥ 5 cm.

Table 1. Number of trees damaged by T9119 in the opening, snapped or uprooted. Number of old uprooted trees are in parentheses.

	Number of damaged trees (ha^{-1})		
DBH (cm)	Snapped	Uprooted	Total
≥ 30	67	19 (4)	86 (4)
= 10–30	13	1	14
= 5–10	6	0	6
Total	86	20 (4)	106 (4)

Randomly sampled trees with DBH = 5–10 cm ($n = 45$) were cored at a height of 30 cm above the ground, and the ring widths of the cores were measured to the nearest 0.01 mm.

Meteorological data (METEOROLOGICAL BUSINESS SUPPORT CENTER 1998) were used to analyze the frequency of strong typhoons in the Daisen Forest Reserve region in the past century. We defined a strong typhoon as having a maximum wind velocity ≥ 20 m/s or central barometric air pressure ≥ 980 hPa, similar to or exceeding T9119.

An χ^2 test was used to compare the abundance of trees with DBH = 0–5 cm in openings and under closed canopy, and to assess their abundance on mounds and in pits.

RESULTS

Characteristics of typhoon disturbance and forest damage

The area of the largest opening created by T9119 was about 1.7 ha (300 m by 70 m). The opening accounted for 64 % of the 1-ha plot (Fig. 2). In the opening, trees fell in domino fashion (BORMANN & LIKENS 1979), and mostly to the north. Most of the damaged trees with DBH ≥ 30 cm were beech (Fig. 3). Of 86 damaged trees with a DBH ≥ 30, 67 (77.9%) were snapped and 19 (22.1%) were newly uprooted (Table 1). Some snapped trees (22) were still alive despite serious damage. Of the 30 uprooted trees in the plot, 24 lay in the opening, including 4 previously uprooted ones; the remaining 6 were found under the closed canopy and were all previously uprooted trees. Most of these 10 previously uprooted trees had also fallen to the north. The 20 new uprootings in the opening created 20 mound-pit pairs on the forest floor, covering about 2.5% of the forest floor in the opening. The effects of disturbance by T9119 concentrated on trees with DBH ≥ 30 cm (Table 1, Fig. 3). Two large trees with DBH > 1 m had stem breakage. Some trees with DBH = 5–30 cm also snapped (Table 1, Fig. 3).

Stand regeneration after typhoon disturbance

We found 24 living tree species with DBH ≥ 5 cm in the 1-ha plot (Table 2). Species richness was higher in the opening than under the closed canopy. In the opening, beech accounted for only 6.2% of the total number of living trees, while *Viburnum furcatum* and *Acer micranthum* dominated with 25.0% and 21.8%, respectively. Four *Acer* species accounted for 36.5% of the total number of living trees in the opening. In contrast, under the closed canopy, beech dominated with 23.7% of the total number of living trees, followed by five *Acer* species at 27.2%.

We found 12 major species and 2 newly colonized species of trees with DBH = 0–5 cm in the 1-ha plot (Table 3). The density was significantly higher under the closed canopy than in the opening. Both in the opening and under the closed canopy, *Acer micranthum* occurred

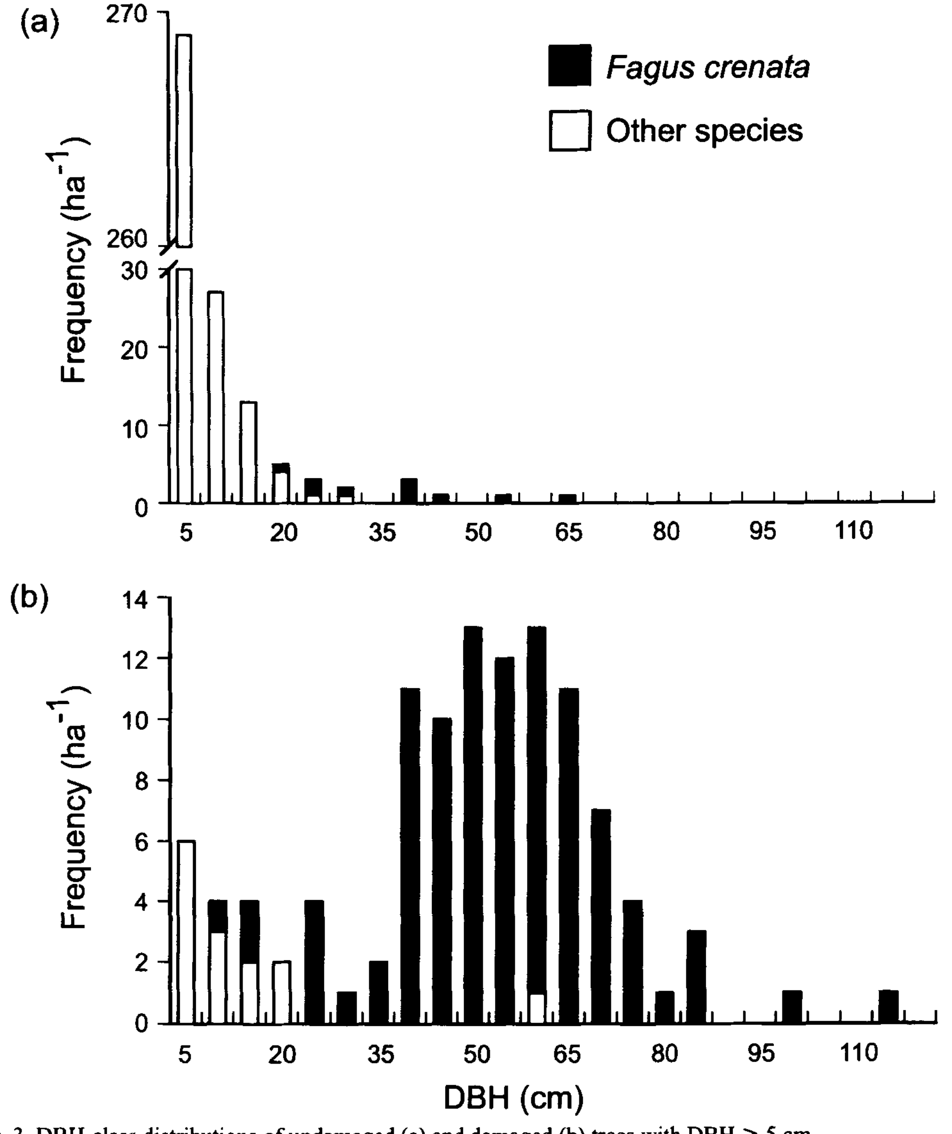

Fig. 3. DBH-class distributions of undamaged (a) and damaged (b) trees with DBH ≥ 5 cm.

most frequently. Beech occurred under the closed canopy twice as often as in the opening. *Acanthopanax sciadophylloides*, *Clethra barbinervis*, *Prunus grayana*, and *Sorbus commixta* also occurred more frequently under the closed canopy than in the opening.

In the areas with disturbed soil in the opening, we found 9 major species and 2 newly colonized species of trees with DBH = 0–5 cm (Table 4). The total density of these trees in the areas with disturbed soil was about half of that in the areas with undisturbed soil. There was no difference in the density between mounds and pits. As in the areas with undisturbed soil, *Acer micranthum* was the most important species both on mounds and in pits. *Betula grossa* trees

Table 2. Species composition, number and relative basal area of living trees with DBH ≥ 5 cm in the 1-ha plot. Values in parentheses are relative density of living trees.

Species	Number of living trees (ha^{-1}) Opening		Closed canopy		Relative basal area (%)
Acanthopanax sciadophylloides	13	(3.8)	16	(6.1)	0.8
Acer japonica	36	(10.6)	19	(7.3)	1.4
Acer micranthum	74	(21.8)	45	(17.2)	3.2
Acer mono	4	(1.2)	5	(1.9)	0.9
Acer nipponicum	10	(2.9)	1	(0.4)	1.1
Acer rufinerve	0	(0.0)	1	(0.4)	0.2
Aralia elata	1	(0.3)	0	(0.0)	0.0
Clethra barbinervis	15	(4.4)	5	(1.9)	0.3
Cornus controversa	3	(0.9)	2	(0.8)	0.1
Euonymus oxyphyllus	1	(0.3)	0	(0.0)	0.0
Evodiopanax innovans	1	(0.3)	1	(0.4)	0.4
Fagus crenata	21	(6.2)	62	(23.7)	85.1
Hamamelis japonica	2	(0.6)	0	(0.0)	0.0
Ilex geniculata	3	(0.9)	0	(0.0)	0.0
Kalopanax pictus	1	(0.3)	0	(0.0)	0.0
Lindera umbellata	6	(1.8)	4	(1.5)	0.1
Magnolia obovata	2	(0.6)	1	(0.4)	0.3
Magnolia salicifolia	16	(4.7)	23	(8.8)	0.8
Prunus grayana	17	(5.0)	13	(5.0)	1.5
Rhus trichocarpa	1	(0.3)	1	(0.4)	0.0
Sorbus alnifolia	4	(1.2)	1	(0.4)	0.5
Sorbus commixta	9	(2.7)	15	(5.7)	0.8
Stewartia pseudo-camellia	15	(4.4)	16	(6.1)	1.2
Viburnum furcatum	85	(25.0)	31	(11.8)	1.4
Total	340	(100.0)	262	(100.0)	100.0

with DBH = 0–5 cm occurred at low density on mounds and in pits in the opening, but those trees with a DBH ≥ 5 cm did not (Table 2).

Blowdown history of the stand

Radial growth curves of trees with DBH = 5–10 cm are illustrated in Fig. 4. These trees can be divided into two regeneration groups according to age: Group A, regenerated before 1946, and Group B, regenerated after 1946. Group B can be further divided into two subgroups based on differences in growth rates after regeneration: B1 showed faster growth from the 1980s, while B2 grew slowly until 1990 and then much faster after that.

Although typhoons have hit the Daisen Forest Reserve region every year for the past century, strong typhoons have occurred at intervals (Fig. 5), mainly in three periods: 1893–1918, 1937–1961, and 1980–1993. During 1937–1961, four typhoons stronger than T9119 occurred. During 1980–1993, strong typhoons, including T9119, hit repeatedly for three years. These periods of strong typhoons corresponded to the regeneration periods and changes of growth rates of trees with DBH = 5–10 cm (Figs. 4 and 5).

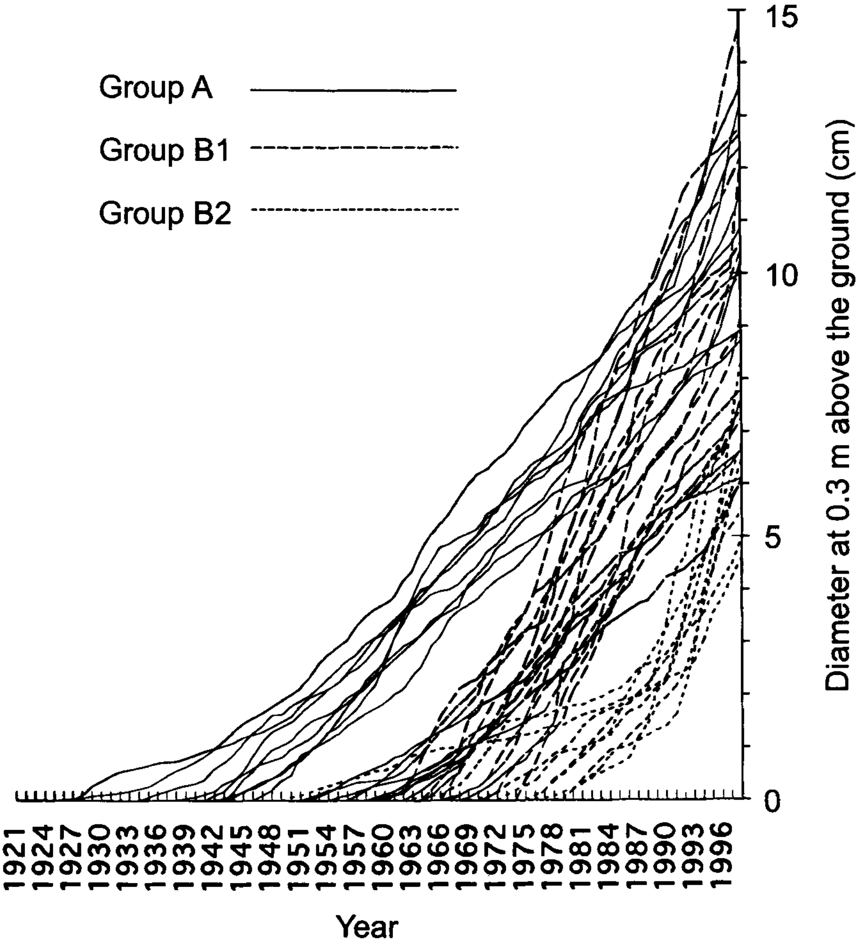

Fig. 4. Radial growth curves of trees with DBH = 5–10 cm at 0.3 m above the ground. Group A, regenerated before 1946 and Group B, regenerated after 1946. Group B can be divided into B1, which showed fast growth from the 1980s, and B2, showed slow growth until 1990 followed by much faster growth.

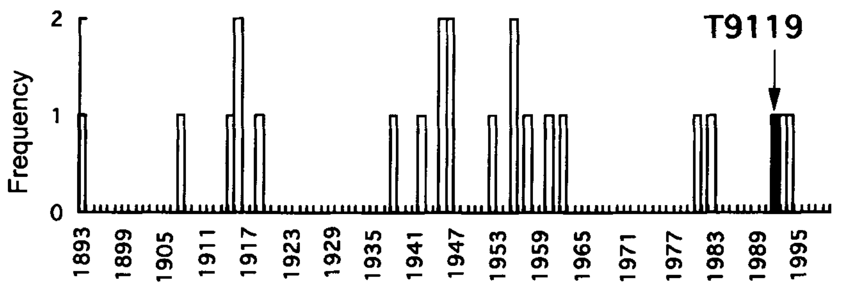

Fig. 5. Frequency of strong typhoons occurring in the Daisen Forest Reserve region. Strong typhoons are defined as maximum wind speed > 20 m/s or central barometric reading < 980 hPa.

Table 3. Species composition and density of trees with DBH = 0–5 cm in the opening and under the closed canopy in the 1-ha plot. (1) Species with no trees of DBH ≥ 5 cm. Based on χ^2-test, significant opening-dependence and closed canopy-dependence of each species are indicated by asterisks, $P < 0.01$.

Species	Density (m^{-2}) Opening	Closed canopy
Acer micranthum	2.69	2.96
Fagus crenata	1.01	2.19 **
Clethra barbinervis	0.64	1.11 **
Sorbus commixta	0.23	0.49 **
Acanthopanax sciadophylloides	0.08	0.42 **
Acer mono	0.23	0.17
Prunus grayana	0.06	0.29 **
Acer japonica	0.11	0.10
Stewartia pseudo-camellia	0.09	0.10
Acer shirasawanum(1)	0.09	0.07
Acer nipponicum	0.13 **	0.00
Sorbus alnifolia	0.08	0.04
Acer sieboldianum(1)	0.02	0.07
Cornus controversa	0.01	0.01
Total	5.33	7.87 **

Table 4. Species composition and density of trees with DBH = 0–5 cm on mounds and pits of uprooting trees in the opening of the 1-ha plot. (1) Species with no trees of DBH ≥ 5 cm. Based on χ^2-test, significant mound-dependence and pit-dependence of each species are indicated by asterisks, $P < 0.05$.

Species	Density (m^{-2}) Mound	Pit
Acer micranthum	1.89	1.63
Clethra barbinervis	0.74	0.76
Fagus crenata	0.41	0.58*
Sorbus commixta	0.16*	0.01
Acer mono	0.03	0.11*
Acer japonica	0.04	0.06
Betula grossa(1)	0.04	0.05
Acer nipponicum	0.08*	0.00
Prunus grayana	0.02	0.01
Cornus controversa	0.00	0.02
Acer shirasawanum(1)	0.00	0.01
Total	3.40	3.24

DISCUSSION

In beech forests, small gaps are frequently formed by the death of one or a few large trees (NAKASHIZUKA & NUMATA 1982, HARA 1985, YAMAMOTO 1989). In contrast, this study shows that typhoon disturbance produces huge gaps that are formed by abundant uprootings and falls of large trees in beech forests. There have been many reports of characteristics of openings formed by strong wind disturbance (PUTZ & SHARITZ 1991, BELLINGHAM et al. 1996, REBERTUS et al. 1997, IDA & NAKAGOSHI 1998, IDA 2000). The characteristics of the opening in this study (Figs. 2 and 3, Table 1) are similar to those in these reports. Other forests growing on similar sites as in our study area also experience wind disturbance repeatedly (ROBERT 1964, BOOSE et al. 1994, IDA & NAKAGOSHI 1998). So, we suggest that beech forests around the Oyasumi-Pass have been disturbed by strong winds many times in the past. The fact that the most previously uprooted large trees also fell to the north supports this suggestion.

Regeneration by advanced beech trees is usually effective in filling small gaps in a beech forest (HARA 1985, YAMAMOTO 1989). After typhoon disturbance, however, advanced trees may be seriously damaged (Table 2 and Fig. 3). We found abundant small *Acer micranthum* and *Viburnum furcatum* trees in the opening. Thus, the self-replacement of *F. crenata* that is frequently observed within gaps in beech forests (YAMAMOTO 1989) seems not to be the dominant mode of regeneration in this stand.

Soil disturbance contributes to species richness by promoting the colonization of species requiring bare soil for their seedling establishment (HENRY & SWAN 1974, MARKS 1974, PUTZ 1983, NAKASHIZUKA 1989, SHAETZL et al. 1989, PETERSON et al. 1990, PETERSON & PICKETT 1990). However, in our stand, only *Betula grossa* newly colonized the areas with disturbed soil in the opening. Moreover, species richness and the density of trees with DBH = 0–5 cm (Table 3) were lower in the areas with disturbed soil. Thus, soil disturbance was not so important for the dynamics of this stand. The likely reason is the shape of the mounds of the uprooted beech trees: beech has a shallow root system, so the mounds are tall and thin, and are easily broken. Soil-fall from mounds and accumulation of soil in pits may be an important factor inhibiting seedling survival there. We found no small trees on the mounds or in the pits of previous uprootings. This suggests that the mounds and pit of uprooted beech trees are not safe sites for tree establishment.

The occurrence of strong typhoons corresponded with regeneration periods and changes of growth pattern of trees with DBH = 5–10 cm (Figs. 4 and 5). However, the fast growth of trees found after T9119 could not be found after previous typhoons. This may be because in our study plot small gap formation prevailed in the past century before T9119 occurred. Before 1991, strong typhoons might have been the main cause of small-scale disturbances such as treefall gaps by one or a few large trees, and beech could successfully regenerate in these gaps.

In conclusion, we must pay attention to local and regional variations in disturbance regimes when considering the dynamics of beech forests. However, our study clearly shows that a large-scale disturbance is also important for the maintenance of beech forests in some areas. To understand the role of large-scale disturbances in forest dynamics, researchers need to monitor the regeneration process after large-scale disturbances in the much longer term.

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