

Age Structure and Development Process of a Secondary Deciduous Broadleaf Forest in Central Japan

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Abstract

Age structure and growth analyses were conducted to reconstruct the disturbance history of a secondary *Quercus crispula* forest in Nagano Prefecture, central Japan. Two belt plots were placed in the forest (140 m × 4 m each) for measurement of their age. Disks of target trees were collected at ground level for dendrochronological analysis; 124 disks were used. *Quercus crispula* and *Betula davurica* dominated in both plots. The age peak of *Q. crispula* and *B. davurica* is recognized at 60-69 years old. The frequency distribution of tree diameters at ground level was bell-shaped, which reflects regeneration after strong disturbances. Many of the *Q. crispula* were multi-stemmed and had sprouts. Many *Q. crispula* and *B. davurica* trees were established during the 1940s, indicating a stand-wide major disturbance in that area. Agricultural cultivation and logging for charcoal and fuel wood in the 1940s could have initiated the regeneration of many current trees. These trees remain to the present day, since forest use declined in the following period. This land-use history can also explain why this study site was a relatively young stand, less than 100 years old, while *Q. crispula* is known as a long-living species.

Key words: Human disturbance; *Quercus crispula*; Secondary forest; Yatsugatake Mountains

Introduction

It is widely accepted today that disturbance plays an important role in forest dynamics and regeneration, being a major force that drives vegetation mosaic structures (White 1979). Disturbances such as forest fires and windstorms strongly influence forest structure and composition. Human disturbances

function similarly, as partial logging creates canopy gaps and land-use change, changing the forest structure completely (Suzuki and Tsukahara 1987; Hannah 1999). The nature of the disturbance, intensity, frequency, and area impacts the population structure and course of succession (Foster et al. 1998). Many studies have revealed the significant influence of past land use on present forest vegetation

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of secondary forests (Foster 1992; White and Mladenoff 1994) and have confirmed the important role of historical human activities in determining the current distribution of species (Bellemare et al. 2002; Foster 2002; Motzkin et al. 2002).

Secondary forests are generally established under the strong influence of human disturbances. One type of secondary forest in Japan is characterized as a coppiced forest, which has been maintained by rotational logging for fuel wood and charcoal. Frequent and intensive disturbances have promoted the dominance of *Quercus* species (Abrams and Downs 1990). As a result, these forests are dominated by oak species known as *Quercus crispula* Blume, *Quercus serrata* Murray, and *Quercus acutissima* Carruth (Kimura et al. 1982). However, in the past several decades, the use of these forests has declined due to lifestyle changes in Japan. Some studies predict that *Q. crispula* will decline in density due to lack of human disturbance by self thinning (Masaki et al. 1992; Sano and Ohsawa 2008), while similar trends can be seen in eastern parts of the U.S.A. (Abrams and Downs 1990; Abrams 1992; Lorimer et al. 1994). On the other hand, *Quercus* species are sometimes considered to be late successional and an important component of mature forests (Koike 1988; Kanazawa 1983; Ishikawa and Ito 1989).

To examine successional trends and the development process, it is important to understand the impact of past disturbance events on the current forest structure, since the various types and scales of disturbance influence the forest structure differently. To estimate past tree growth, dendrochronological techniques are effective to understand the forest history. Abrupt increases in radial growth indicate releases due to the mortality of a former canopy tree (Sugita 1993), and the synchrony of establishment periods correspond with past disturbance events (Svoboda et al. 2012; Suzuki 1979). By combining these methods, it is possible to reconstruct the development process of the current forest structure.

In this study, age structure and radial

growth analyses were conducted to reconstruct the disturbance history of a secondary *Quercus crispula* forest in Nagano Prefecture, central Japan. The forests in this area are known to have had frequent contact with human activities. However, whether the development of the current forest structure was influenced by human or natural disturbance is still unknown. To clarify the above subjects, the specific objectives were to (1) examine the current stand structure, (2) estimate the impact of past disturbances by analysis of age structure and radial growth patterns, and (3) reveal the development history in a secondary forest in central Japan.

Methods

The study site

The study was conducted in the Yatsugatake Forest, University of Tsukuba, Minami-Maki, Nagano Prefecture, Japan (35°57'N, 138°28' E). The study area is located in a secondary broadleaf forest on a foothill at an elevation of approx. 1350-1450 m. Mean annual precipitation is approx. 1450 mm, and mean annual temperature from 2000 to 2010 is approx. 7°C (Inami et al. 2012).

Field methods

Two belt plots were placed (140-m × 4-m each) in the forest. Tree species and their location were recorded for all trees larger than 10 cm in girth at ground level. Basal area at ground level (BA_0 , $m^2 ha^{-1}$) was calculated as sum of diameter at ground height (D_0). The disk of the target trees were collected at ground level in 2009 for dendrochronological analyses. Disks were oven dried more than 48 hours at the laboratory.

Dendrochronological analysis

Tree rings were counted at four cardinal directions (NSEW), and the average of the four directions was used as the age to avoid missing rings. A total of 124 disks (55 from Belt-1 and 69 from Belt-2) were used. Five samples each of *Q. crispula* and *Betula davurica* Pall. were used

for radial growth analysis. To avoid climate influences, ring width was measured at each 5 years at four cardinal directions (NSEW), and the average of the four directions was used.

Results

Stand structure

Quercus crispula and *Betula davurica* dominated in both Belt-1 and Belt-2. In relative, BA_{00} , *Q. crispula* shared 17.8% in Belt-1 and 59.7% in Belt-2, and *B. davurica* shared 44.9% in Belt-1 and 13.4% in Belt-2 (Table 1). *Malus toringo* (Siebold) Siebold ex de Vriese shared 14.6% in Belt-1, and *Castanea crenata* Siebold et Zucc.

shared 9.6% in Belt-2.

Spatial distribution of stems with stem age is shown in Fig. 1. There were no apparent patches or relationships between age and location in either plot. In the two plots, 53.7% of *Q. crispula* stems and 50.0% of the *B. davurica* stems were multi-stemmed by sprout regeneration.

Fig 2 shows the frequency distribution of D_0 for Belt-1 and Belt-2. *Q. crispula*, *B. davurica*, and *C. crenata* show a bell-shaped distribution with a mode of 20-24 cm, 25-30 cm, and 15-20 cm. In comparison, *M. toringo* in Belt-1 and *Symplocos sawafutagi* Nagam. show an inverted J-shaped distribution.

Table 1 Relative basal area (BA_0), number of trees per plot and basal area of species in each belt plot.

Species	Belt 1			Belt 2		
	Relative (%)	No of trees /plot	(m^2/ha)	Relative (%)	No of trees /plot	(m^2/ha)
<i>Quercus crispula</i> Blume	17.80	6	10.71	59.73	35	37.68
<i>Betula davurica</i> Pall.	44.86	16	26.99	13.44	11	8.48
<i>Malus toringo</i> (Siebold) Siebold ex de Vriese	14.63	18	8.80	3.36	2	2.12
<i>Castanea crenata</i> Siebold et Zucc.	0.33	1	0.20	15.24	12	9.62
<i>Cerasus maximowiczii</i> (Rupr.) Kom	7.81	6	4.70	5.95	3	3.76
<i>Symplocos sawafutagi</i> Nagam.	1.43	7	0.86	1.81	6	1.14
<i>Salix udensis</i> Trautv. et C.A.Mey.	-	-	-	0.47	2	0.30
<i>Phellodendron amurense</i> Rupr.	1.65	2	0.99	-	-	-
<i>Larix kaempferi</i> (Lamb.) Carrière	2.64	1	1.59	-	-	-
<i>Carpinus cordata</i> Blume	4.94	1	2.97	-	-	-
<i>Pyrus ussuriensis</i> Maxim var. <i>hondoensis</i> (Nakai et Kikuchi) Rehder	3.91	1	2.35	-	-	-
Total	100	59	60.16	100	71	63.1

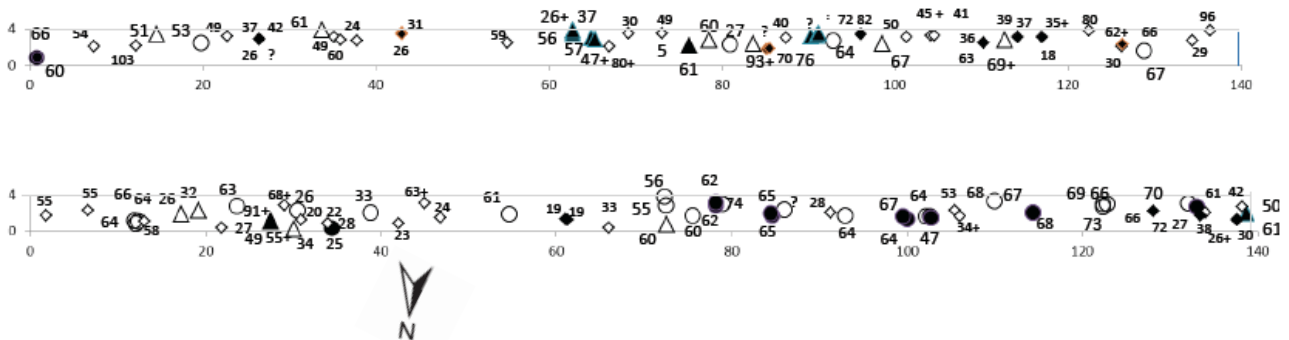


Fig.1 Spatial distribution of individual stems and age of *Q. crispula* (circle), *B. davurica* (triangle) and other species (diamond) in Belt-1 and Belt-2 (140 × 4 m plot). Open and colored shapes indicate single-stem and multiple-stem, respectively.

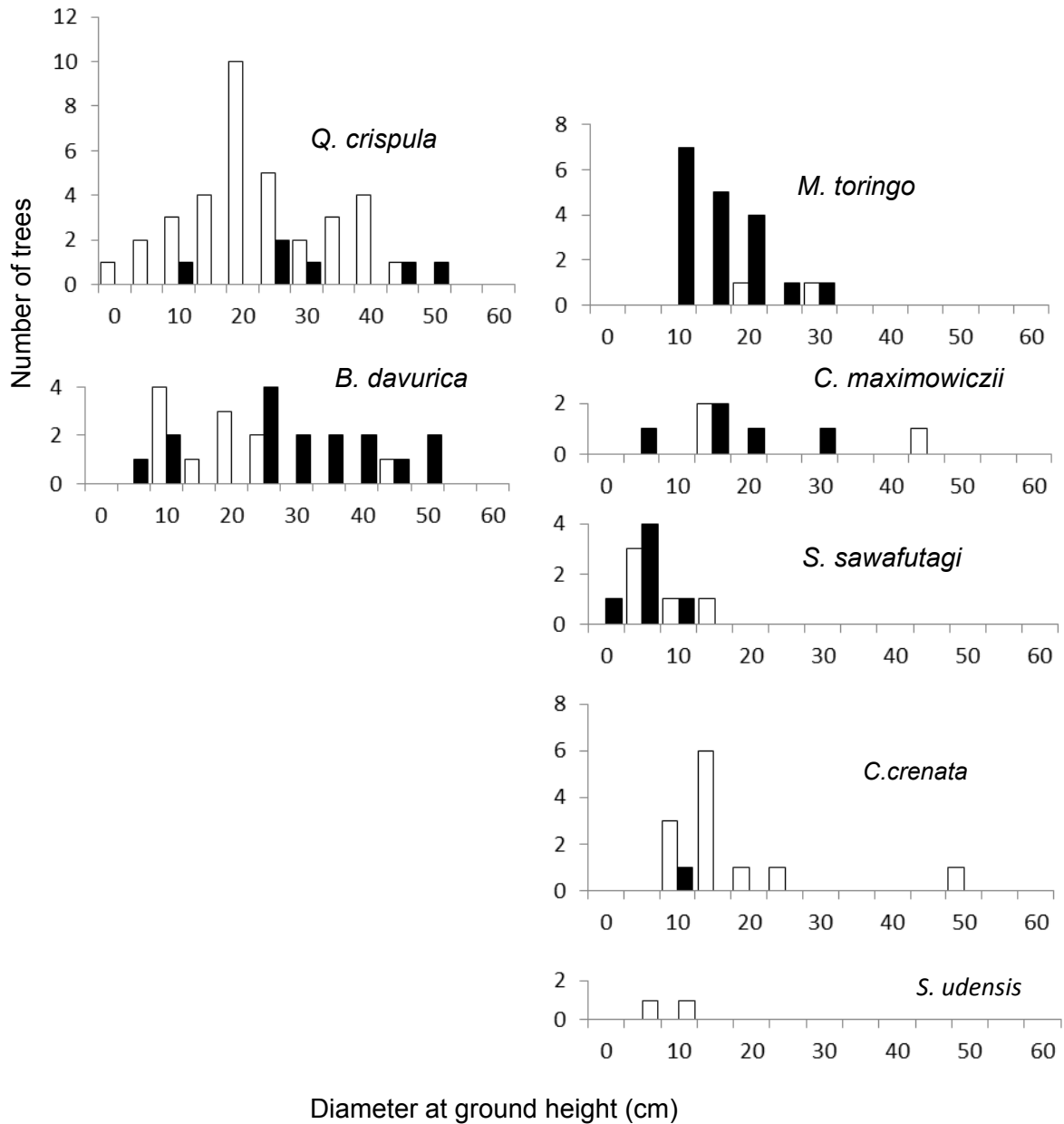


Fig.2 Distribution of diameter at ground height of tree species in Belt-1 and Belt-2 (tree species were excluded when number of trees were under two). Colored bars show Belt-1 and open bars show Belt-2.

Age structure

The age structure is shown of the two plots in Fig. 3. Annual rings of 15 samples could not be counted completely due to stem decay at the center. The peak of *Q. crispula* and *B. davurica* is recognized at 60-69 years old, and *M. toringo* in Belt-2 showed a slight peak at 50-59 years old, slightly delayed from the former two species. The oldest stem of *Q. crispula* was 74 years old in Belt-2, and the oldest stem of *B. davurica* was more than 93 years old in Belt-1 (unknown due to decay). The oldest stem of the research plots was *M. toringo* at 103 years old. Figure 4 shows the relationships between tree age and

diameter at ground level for each belt plot. There was no remarkable relationship between age and D_0 .

Growth curve of diameter at ground level

The growth curve of diameter at ground level for five samples each from both belt plots of *Q. crispula* and *B. davurica* are shown in Fig. 5. Remarkable growth change that indicates release from suppression by canopy trees could not be observed.

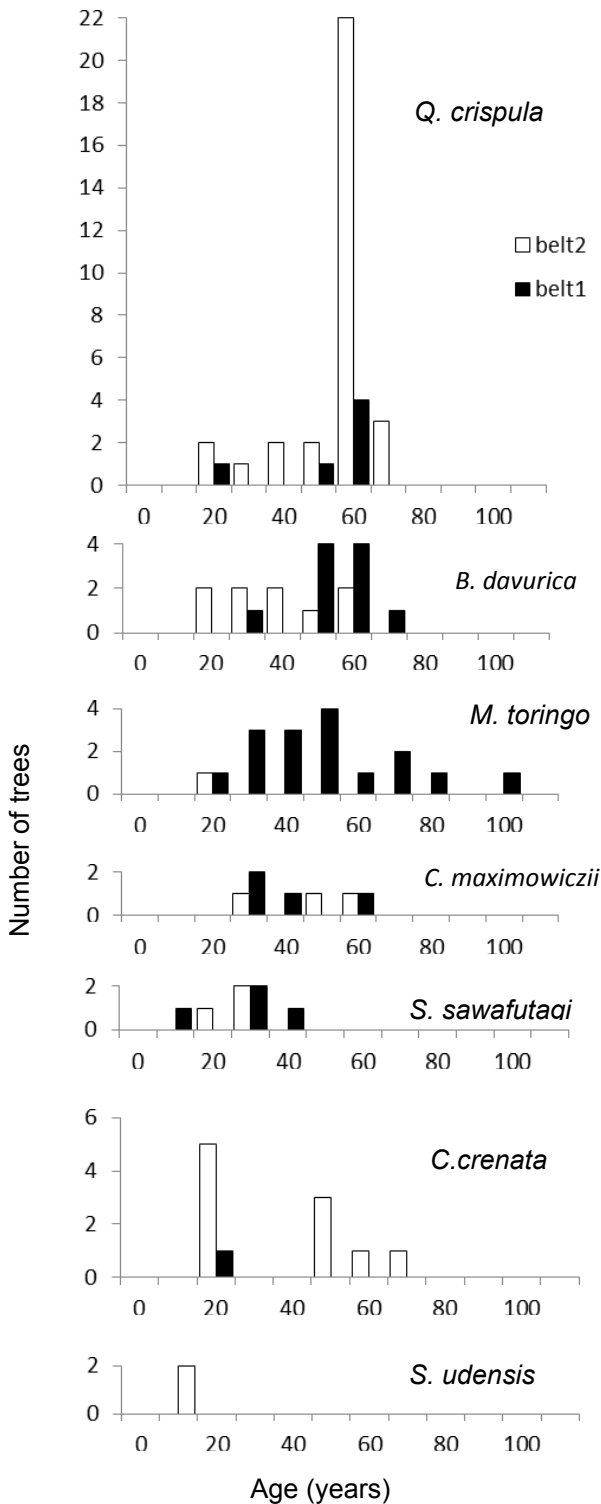


Fig.3 Age frequency distributions of tree species in Belt1 and 2 (tree species were excluded when number of trees were under two.)

Discussion

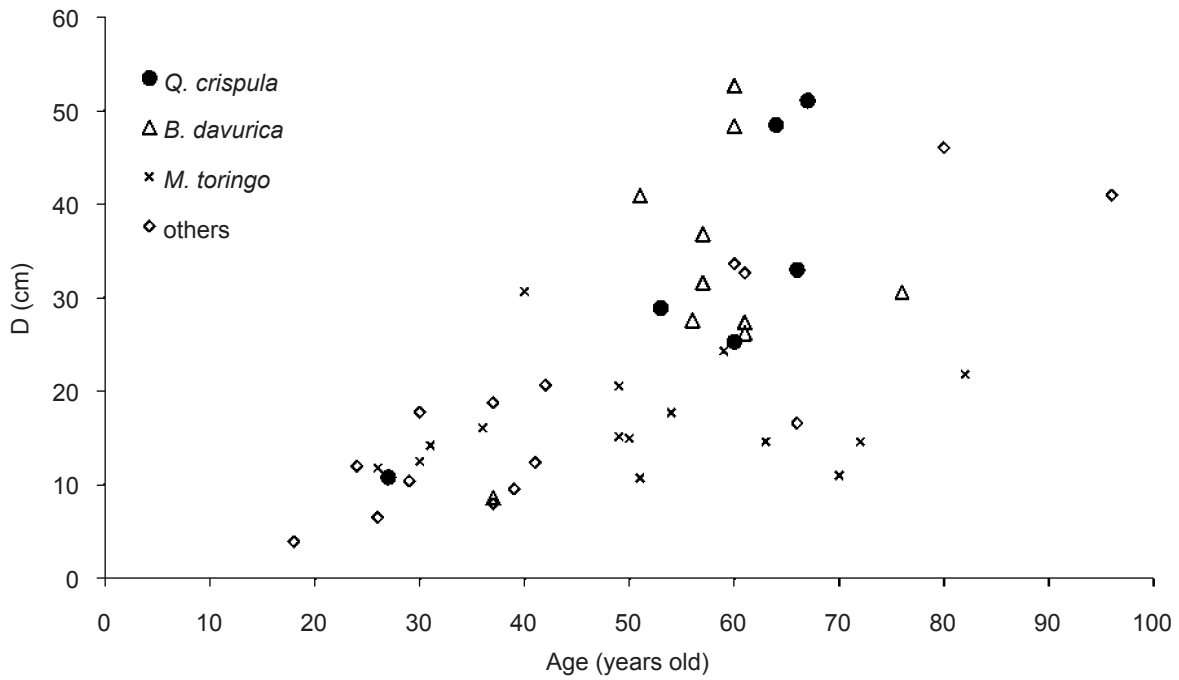
Quercus crispula and *Betula davurica* dominated in both belt plots. The distribution of tree diameter at ground level of *Q. crispula* and *B. davurica* was bell-shaped. In general, shade-tolerant species that can regenerate under

a closed canopy tend to show an inverted J-shaped distribution, and shade-intolerant sun trees that can only develop in open environments show a bell-shaped distribution (Lorimer and Krug 2011). It is known that *Q. crispula* in post-disturbance forest stands and *Betula* species show a bell-shaped distribution (Higo and Teramoto 1989), which reflects regeneration after strong disturbances (Higo 1990). Species that showed an inverted J-shaped distribution, *Malus toringo* and *Symploco sawafutagi*, were likely to regenerate continuously independent of disturbances, in contrast to the other species that seem to have a disturbance-dependent regeneration pattern. From the age structure of this study, *M. toringo* showed a wide range of ages, from 20 to 100 years old, which supports continuous regeneration. On the other hand, *S. sawafutagi* also showed an inverted J-shaped distribution, while the age structure showed a regeneration pattern that was characterized as disturbance dependent. Individuals that regenerated and established at a similar period tend to show a wide range in growth (Suzuki 1981), and this can be due to competition among individuals (Higo and Teramoto 1989).

Many *Q. crispula* at our study site were multi-stemmed. Single-stem trees can be considered to have originated from seedlings and multi-stemmed trees from stumps (Fujita and Sano 2000). Kanazawa (1983) discusses that continued existence and dominance of *Q. crispula* may attest to its longevity and vigorous sprouting ability. Since *Q. crispula* was found relatively young at this study site, we could not find evidence of advantages of longevity in this case. Meanwhile, some studies document that frequent and intense logging enhances the dominance of *Q. crispula* (Fujita and Sano 2000). Thus, historical use as a coppice forest benefited the sprouting ability of *Q. crispula* and could have promoted the dominance of *Q. crispula* through rotational logging.

In general, regeneration of Betulaceae is strongly affected by large-scale disturbances. For example, studies on mountainsides show that surface disturbances such as landslides

Belt-1



Belt-2

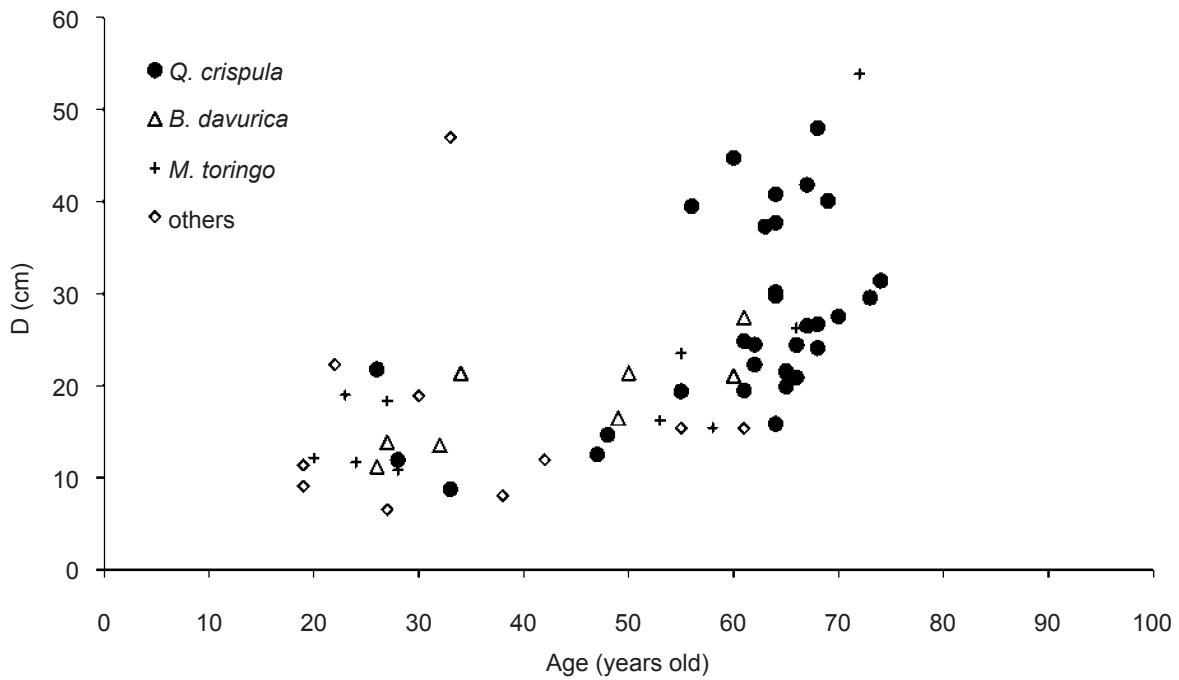


Fig. 4 Relationship between age and D_0 in Belt1 and Belt2.

are necessary for regeneration (Ogawa and Okitsu 2010), while *B. davurica* only exist as individual trees in canopy gaps in areas with a thick litter and humus layer and few surface disturbances (Ogawa and Okitsu 2011). Potential causes of surface disturbance that initiated the regeneration of *B. davurica* at this study site can include activities related to

logging, such as dragging the logged trees or creating temporary paths for logging operation. Similar to *Q. crispula*, many of the *B. davurica* trees at our study site were multi-stemmed and therefore are assumed to have originated from stumps. Thus, the ages of seed establishment of these individuals stretch back to earlier ages than the observed stem ages. Charcoal

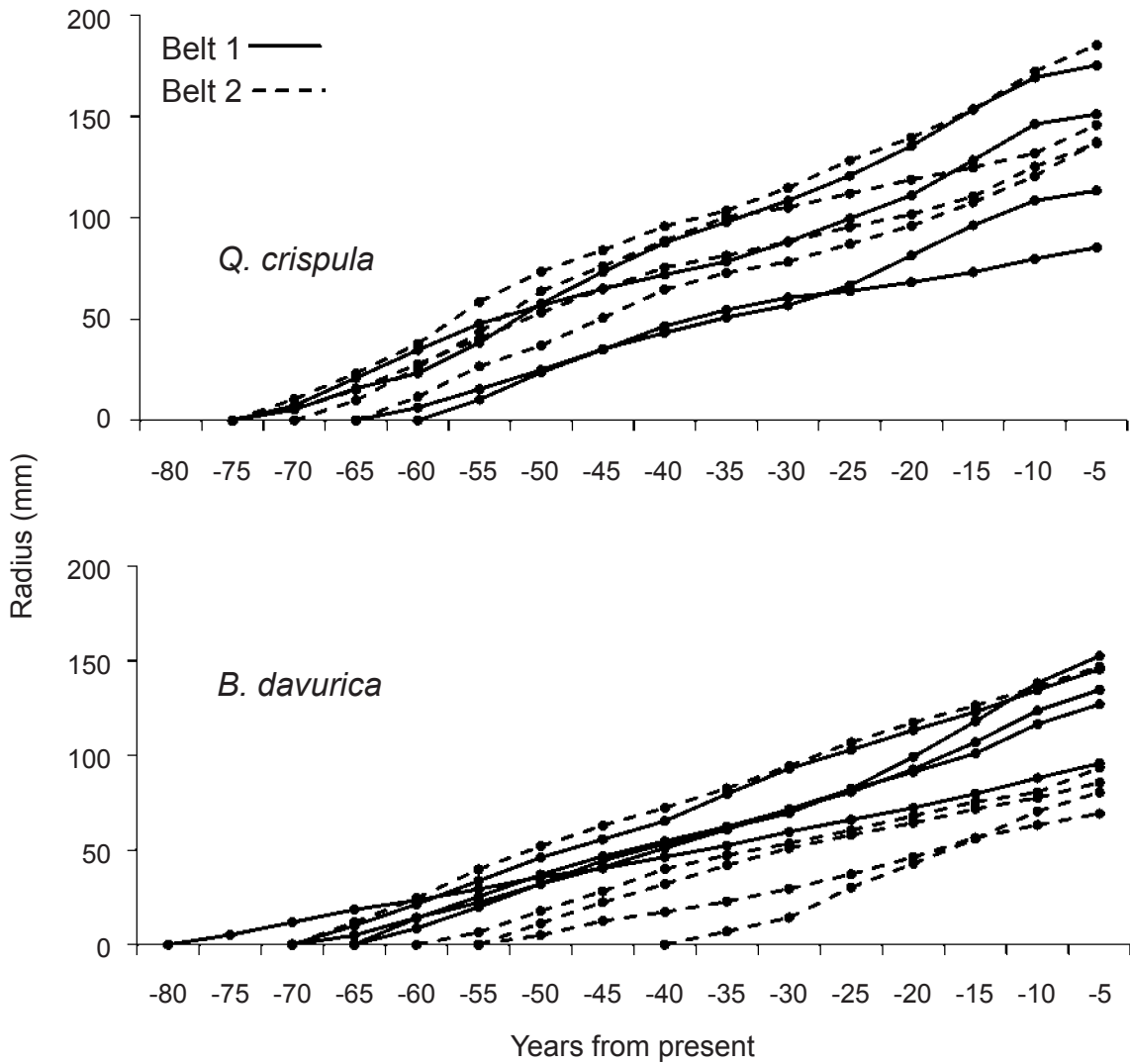


Fig. 5 Some examples of the growth curve of diameter at ground level, measured at each 5 years for *Q. crispula* and *B. davurica* in Belt-1 and Belt-2.

production has historically been an important local industry around this study site (Village History Publishing Association 1986). Hence, operations related to these logging activities may have caused surface disturbance and enhanced the establishment of *B. davurica* at this study site.

For both *Q. crispula* and *B. davurica*, age peaks were recognized at 60-69 years old, meaning that many trees were established during the 1940s. Therefore, a major disturbance is likely to have occurred around 1940. The slightly delayed peak of *M. toringo* can be a delayed response to the same disturbance event only due to species characteristics. No apparent growth change could be observed from individual growth curves (Fig. 5), thus it is most likely that there

was no major disturbance within the past 60-70 years in this forest stand. From the latter half of the 19th century to the period prior to World War II, charcoal production was one of the major industries in this region (Kawakami Village History Publish Association 1986; Minamimaki-sonshi Editing Committee 1986). During the war, while trees in the forest were logged for fuel wood, the land was later set as one of the exercise areas of the Japanese Army (Sunasaka 2006). After the WWII, the forest recovered from the exercise areas. Gradually, the amount of logging declined due to the replacement of wood with gas and electricity for fuel and due to lifestyle changes that decreased the demand for charcoal and fuel wood. The forest was established as the University Forest in 1956 and has been

managed by the staff of the University of Tsukuba since then. In conclusion, logging activities for charcoal and fuel wood and agricultural cultivation in the 1940s could be the major disturbance that initiated the regeneration of many trees constituting the current forest structure. The trees established during this period survive to the present day, since forest use declined in the following period. This land-use history can also explain why this study site was a relatively young stand, less than 100 years old, while *Q. crispula* is known as a long-living species (Higo and Teramoto 1989).

Acknowledgments

We are grateful to Drs. Toru Nakamura, Takashi Kamijo, and Kiyokazu Kawada for their advice and encouragement throughout this study. We also thank Akihiro Inami, Masanori Sugiyama, and Kenta Nasu for kind field assistance; and staff members of the Yatsugatake Forest, Agricultural and Forestry Research Center, University of Tsukuba, for kind support during our stay.

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中部日本の落葉広葉樹二次林における樹齡構造と林分の発達過程

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要 旨

長野県に位置する筑波大学農林技術センター八ヶ岳演習林のミズナラ二次林において、樹齡構造と成長解析から過去の攪乱履歴の再構成を行なった。八ヶ岳演習林内のミズナラ二次林に140m×4mのベルトプロットを二箇所設置し、プロット内の樹木から124個の円板を採取し、樹齡を測定した。その結果、ミズナラとヤエガワカンバが両プロットで優占し、両種とも樹齡60-69にピークをもつ分布となった。胸高直径階分布も両種とも鐘形の分布となり、強い攪乱の影響を受けたことを反映していた。ミズナラの多くは萌芽由来の幹から構成されていた。このことから、ミズナラとヤエガワカンバの多くは、1940年代に八ヶ岳演習林付近であった薪炭利用や造林による大規模な攪乱後に成立したと推測した。その後、薪炭利用や造林が行われなくなり、現在の林分はこの後に再生したものであろう。

キーワード：人為攪乱、二次林、ミズナラ、八ヶ岳連峰

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