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Aims and Scope

Journal of Forest Planning is a peer-reviewed periodical that publishes articles, reviews, and short communications. It covers all aspects of forest management, modeling, and assessment such as forest inventory, growth and yield modeling, remote sensing and geospatial information technologies for forest management, forest management planning, forest zoning, evaluation of ecosystem services, managerial economics, and silvicultural systems. Manuscripts regarding forest policy, forest economics, forest environmental education, landscape management, climate change mitigation and adaptation strategies, and drone applications for forest management are welcome. The Journal aims to provide a forum for international communication among forest researchers and forestry practitioners who are interested in the above-mentioned fields.

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Article

Effect of Japanese Larch Arable Land Windbreaks on Wind Damage Reduction in the Early Spring Cultivation Season: A Case Study in Kamioribe District, Shihoro Town, Eastern Hokkaido

Masahiko Nakagawa[1,*]

ABSTRACT

A case study on the effect of Japanese larch (*Larix kaempferi* Carr.) arable land windbreaks on the reduction of wind damage in Kamioribe District, Shihoro Town, eastern Hokkaido, Japan, is reported. Wind damage occurred on May 8, 2016. Buds of larches were supposed to be just opened, and the leaves on short shoots were still extending at that time. The percentage of severe damage was high on arable lands outside sheltered areas. In contrast, it was low on lands within areas 15 to 20 times the heights of windbreaks leeward to Japanese larch arable land windbreaks. These differences were statistically significant. The results of this study indicate that Japanese larch arable land windbreaks are effective for the reduction of wind damage during the early spring cultivation season, regardless of if its buds are closed or its leaves are not fully extended.

Keywords: arable land windbreak, Japanese larch, spring cultivation season, Tokachi spring wind, wind shielding effect

INTRODUCTION

Historically, the Tokachi Plain in Tokachi Subprefecture (eastern Hokkaido) was covered with primeval forests of daimyo oak trees (*Quercus dentata* Thunb.). These forests have since been cleared as the land has been converted for cultivation. The soil in the plain is an Andosol composed of volcanic ash. Strong western or northwestern winds blow across the plain from late autumn to late spring. By mid-April, the snow melts and the soil dries. Volcanic ash soils of the Tokachi Plain are prone to wind erosion caused by strong western foehn winds (called the Tokachi spring wind), which end in mid-June (Shikaoichoushihensan-iinkai, 1994; Otofukechoushihensan-iinkai, 2002; Shimizuchoushihensan-iinkai, 2005).

Planting stocks of sugar beets are planted — or its seeds are sown — from late April to early May (Shimizuchoushihensan-iinkai, 2005). Newly planted stocks and small seedlings are prone to wind damage due to being hit by small particles of soil blown by the wind, strong winds pulling young plants from the soil, or the removal of soil from around plant roots.

On the Tokachi Plain, arable land windbreaks are often planted to protect the cultivation fields. These arable land windbreaks consist of one to several rows of trees to reduce wind velocity. Japanese larch (*Larix kaempferi* Carr.) accounts for about 78% of the planted species and is chosen for use in arable land windbreaks because it is rapid-growing (Tsuji et al., 2005).

Larch buds on the Tokachi Plain start to open in early May (Ohshima et al., 2002), and it takes about three weeks from the bud opening for the full extension of leaves on short shoots (Hirokawa and Suzuki, 2006). During half of the high risk period of wind damage, larch buds are either not open or open, but do not have fully extended leaves (Tsuji et al., 2005; Tsuji et al., 2007). Thus, Torita et al. (2003) suggested that Japanese larch arable land windbreaks were insufficiently effective in spring because the wind velocity reduction effect of a trunk line windbreak of deciduous Manchurian ash (*Fraxinus mandshurica* var. *japonica* Maxim.) was much lower in winter than in summer. They (Torita et al., 2003) stated that "Presence of leaves would be very important in arable land windbreaks which are planted in about one to three rows." They also stated that "It is difficult to find a tree species which open buds just after melting of snow in April. Thus, evergreen trees are candidates for species with high wind shielding effects in spring cultivation season" (Torita et al., 2003). Tsuji et al. (2005) described the disadvantage of larch trees: "The main disadvantage is that the growth of this tree between the end of April and the beginning of May, the period with high risk of wind erosion in this area, is not sufficient to provide maximum wind shielding effects." Tsuji et al. (2007) suggested that Japanese larch arable land windbreaks were insufficiently

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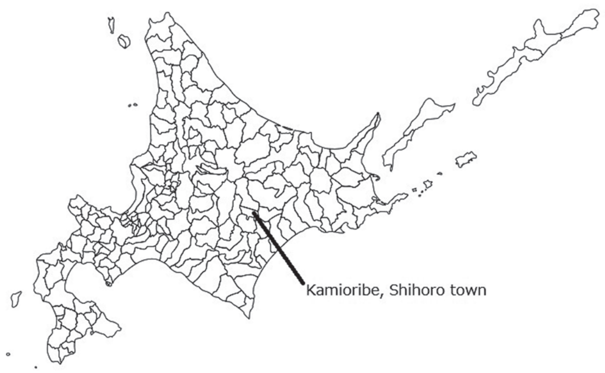

Fig. 1 Location of Kamioribe, Shihoro Town, Hokkaido.

Table 1 Daily maximum wind speed on May 4-12, 2016 at Kamishihoro, the nearest weather station to Shihoro Town, Hokkaido

Date	Wind direction	Wind speed (m/s)
May 4	West	5.7
May 5	West-southwest	7.7
May 6	West-southwest	5.4
May 7	West-southwest	6.8
May 8	West-northwest	10.1
May 9	West-southwest	6.2
May 10	South-southwest	3.1
May 11	North-northeast	3.7
May 12	West	6.7

(Japan Meteorological Agency, 2016)

effective in spring because the buds were closed or the leaves on short shoots were still extending, and proposed changing the species of arable land windbreaks to evergreen trees such as Sakhalin fir (*Abies sachalinensis* [F.Schmidt] Mast.) and Sakhalin spruce (*Picea glehnii* Masters). Akama et al. (2007) posted a photograph of either a Sakhalin fir or Sakhalin spruce arable land windbreak and gave the following caption: "Conifers which are effective for Tokachi wind in spring." In contrast to the reports of Torita et al. (2003), Tsuji et al. (2005, 2007), and Akama et al. (2007), it was reported that snow banks of similar sizes formed leeward to deciduous Japanese larch and evergreen Sakhalin fir arable land windbreaks in winter, suggesting that the wind velocity reduction effects of these two types of windbreak are similar (Ohshima et al., 2003; Hokkaido Forestry Research Institute, 2005). Thus, it is necessary to resolve this contradiction. This study was conducted to clarify the relationship between Japanese larch arable land windbreaks and the reduction of wind damage during the early spring cultivation season.

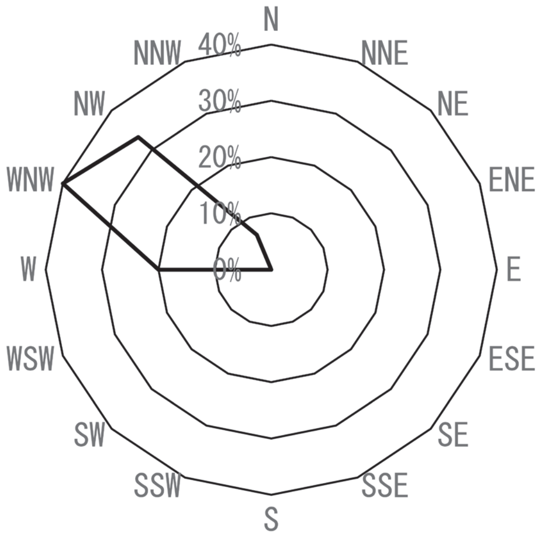

Fig. 2 Proportion of wind (exceeding 10 m/s) direction on May 8, 2016 in Shihoro Town, Hokkaido (measured by Shihoro Town Office).

MATERIALS AND METHODS

Study Site

The study was conducted in Kamioribe District, Shihoro Town, Tokachi Subprefecture, eastern Hokkaido (Fig. 1) (43° 9' 23"–43° 12' 39" N, 143° 16' 23"–43° 22' 13" E). Kamioribe District is essentially a flat area of arable land. The soil in this area is Andosol consisting of volcanic ash (National Land Agency, 1977). In Shihoro, 540 × 540 m townships were created; these lie in the east-southeastern to west-northwestern and north-northeastern to south-southwestern directions. On May 8, 2016, a strong wind blew across the Tokachi Plain (Table 1, Japan Meteorological Agency, 2016). The main wind direction was west-northwest and was therefore exactly perpendicular and parallel to the orientation of the townships (Fig. 2). Wind damage to sugar beets was caused by this Tokachi spring wind. A summary of the damage survey carried out by the Shimizu Sugar Factory, Hokuren Group, is shown in Table 2. The damage was severe in Kamioribe (10.6% of the area damaged) and Sakura (12.2%) districts in Shihoro Town, and the damaged area was the greatest in Kamioribe. Therefore, Kamioribe was chosen for this case study.

A summary of arable land windbreaks (one to six rows of trees planted by farmers on arable land) is shown in Table 3, and that for trunk line windbreaks (most of them are 40–70 m wide and owned by Shihoro Town) is shown in Table 4. The main direction of arable land windbreaks was north-northeast to south-southwest, just perpendicular to the main direction of the strong wind that occurred on May 8. The main directions of trunk line windbreaks were north-northeast to south-southwest, and east-southeast to west-northwest. The main species for both types of windbreaks was Japanese larch.

Table 2 Wind damage to sugar beets in Shihoro town, Hokkaido on May 8, 2016

District	Number of farmers who planted sugar beets	Number of farmers who suffered wind damage	Area of sugar beets planted or sown (ha)	Area of sugar beets with wind damage (ha)
Nakashihoro	19	3	192	8.5
Shihorominami	52	8	469	31.5
Shihorokita	36	5	298	19.1
Sakura	16	4	120	14.6
Kamioribe	78	21	613	65.1
Shimooribe	19	1	165	1.7
Nakaotofuke	9	1	79	6.0
Nitta	3	1	34	2.0
Nishikami	13	1	194	6.0
Total	245	45	2,164	154.5

Methods

The four main crops cultivated on the Tokachi Plain are sugar beets, potatoes, beans, and wheat. From late April, the planting or sowing of sugar beets and planting of potato tubers start, then the sowing of soybeans, red beans, and kidney beans continue from mid-May (Shimizuchoushihensan-iinkai, 2005). Thus, by May 8, 2016, almost all sugar beets were either planted or sown. Figure 3 is a photograph taken in Shihoro Town on May 13, 2016, showing a slightly green larch stand. Wind damage occurred on May 8, five days before the photograph was taken. Thus, it can be deduced that either the buds of larches had been closed, or had just opened, and its leaves on short shoots had just started to extend on May 8, 2016. Therefore, the year 2016 was suitable for this study.

A map showing the degree of wind damage to sugar beet for Kamioribe District was provided by the Shimizu Sugar Factory (Hokuren Group) (part of which is shown in Fig. 4). Fields in which sugar beets were cultivated in 2016 were colored on the map. There were five categories on the map: no damage, replanting some stocks, replanting all stocks, re-sowing all seeds, and abandoning sugar beets and cultivating other plants. Sugar beet fields were classified into three groups: no damage, mild damage (replanting some stocks), and severe damage (replanting all stocks, re-sowing all seeds, or abandoning sugar beets and cultivating other plants). The map covers a total of 236 fields; one field was excluded from this study because it was on the leeward side of a barn; 205 fields showed no damage, 5 had mild damage, and 25 had severe damage.

The tree species and visually estimated diameter at breast height (DBH) of arable land windbreaks and trunk line windbreaks were recorded in Kamioribe District in the autumn of 2016. The representative height of dominant and codominant trees was measured for each windbreak using a Vertex IV height measuring instrument (Haglöf Sweden AB) in the fall of 2017, setting the transponder of the Vertex IV on a road adjacent to each windbreak. However, for arable land windbreaks that were not adjacent to roads, the representative heights were visually estimated. A visual estimation of the DBH and height was necessary, as it was impossible to gain access to the arable land windbreaks because of the potential risk of soil-borne disease.

Windbreaks were categorized as arable land windbreaks of larch, trunk line windbreak of larch, arable land windbreak other than larch, and trunk line windbreak other than larch.

The area within 10, 15, 20, and 30 times the windbreak height east-southeast (exactly opposite to the main wind direction) to a windbreak were defined as "sheltered areas", to clarify the effective sheltered areas leeward to the windbreaks. Agricultural fields were classified into two types: within a sheltered area or outside a sheltered area. If more than half of the field was included in a sheltered area, then it was judged to be within the sheltered area; otherwise, the field was judged to be outside the sheltered area.

There were 13 fields that were close to windbreaks, of which the heights were visually estimated. For such fields, whether they were within or outside a sheltered area could be wrongly judged owing to the inaccuracy associated with visually estimating windbreak heights. To avoid possible wrong judgments, visually estimated heights were both divided by 1.5 and multiplied by 1.33, after which it was checked whether judgments for being within or outside the sheltered area were the same or not. Fields judged differently by the division by 1.5 or multiplication by 1.33 were excluded from each analysis associated with the multiplication number of windbreak heights.

Statistical Analyses

The 5 × 3 contingency tables were constructed for the χ^2 analyses. If there are many expected values less than 5.0, the calculated χ^2 could be biased (Quinn and Keough, 2002; Zar, 2010). In this case, "A secure practice is to have the mean expected frequency be at least 6.0 when testing α with as small as 0.05" (α being the significance level) (Zar, 2010). Since there were 231–235 samples, χ^2 analyses were performed with a 5 × 3 contingency table.

However, other statisticians recommend a different method: "Another solution to small observed frequencies is to collapse or combine some categories", so that "no more than 20% of the categories have expected frequencies less than about five" (Quinn and Keough, 2002). To assure objective analyses, the recom-

Table 3 Summary of arable land windbreaks in Kamioribe, Shihoro Town, Hokkaido in 2016

Species	Direction	Height (m)				Diameter at breast height (DBH) (cm)				Total length
		Average	SD	Max.	Min.	Average	SD	Max.	Min.	(m)
Larix kaempferi	NNE	16.7	5.8	29	0.5	19.3	6.4	34	0	30,200
Larix kaempferi	Other	16.8	2.9	20	13	18.7	5.0	25	12	1,335
Other than *Larix*	NNE	10.0	4.6	20	2	13.6	6.3	34	2	9,463
Other than *Larix*	ESE	7.5	5.9	14	2	10.5	10.7	25	2	358
Other than *Larix*	Other	10.4	2.7	13	7	19.4	6.3	24	12	825
Total										42,181

Table 4 Summary of trunk line windbreaks in Kamioribe, Shihoro Town, Hokkaido in 2016

Species	Direction	Height (m)				Diameter at breast height (DBH) (cm)				Total length
		Average	SD	Max.	Min.	Average	SD	Max.	Min.	(m)
Larix kaempferi	NNE	20.2	6.9	31	2	23.1	7.3	34	2	15,774
Larix kaempferi	ESE	16.6	4.4	26	8	24.6	6.3	34	10	20,024
Other than *Larix*	NNE	14.9	8.1	28	2	17.1	9.7	40	1	12,222
Other than *Larix*	ESE	9.4	6.5	24	2	13.4	10.3	40	2	17,266
Other than *Larix*	Other	5.0	—	5	5	4.0	—	4	4	175
Total										65,461

Note: One strip may consist of several sub-strips of different species. Thus, the total length was calculated to be much longer than the actual total length of the strips.

Fig. 3 Japanese larch trunk line windbreak in Kamioribe, Shihoro Town, Hokkaido on May 13, 2016, five days after the Tokachi spring wind had blown.

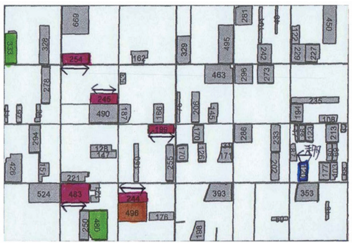

Fig. 4 Part of the wind damage map of sugar beets in Kamioribe, Shihoro Town, provided by Hokuren Group. One square block is 540 × 540 m. Each color indicates; gray, no damage; orange, replanting some stocks; red, replanting all stocks; green, re-sowing all seeds; and blue, abandoning sugar beets and cultivating other plants.

mendation of Quinn and Keough (2002) was also employed. To achieve this, two steps were necessary. First, windbreak categories were collapsed into three types: sheltered by arable land windbreaks of larch, sheltered by trunk line windbreaks of larch, and outside a sheltered area. Arable lands sheltered by windbreaks other than larch were excluded from the analyses because their sample sizes were small and the main interest in this study was the effectiveness of arable land windbreaks of larch in the early spring cultivation season. Second, damage groups were either collapsed or combined to make them into two categories. To avoid biases, all possible contingency tables were considered. Thus, three types of 3 × 2 contingency tables were reconstructed for each multiple number of windbreak heights. In the first type of table, the mild damage category was combined with no damage category to form the no or mild damage category, and in the second type of table, the mild damage category was collapsed, both to test the hypothesis "the severe wind damages occur independent of the windbreak category." In the third type of table, the mild damage category was combined with the severe damage category to form the mild or severe damage category, to test the hypothesis "the wind damages, both mild and severe, occur independent of the windbreak category." The χ^2 test was used for all tables.

RESULTS

The 5 × 3 contingency tables for the windbreak categories and wind damage to sugar beets are shown in Table 5. For cases in which 15 and 20 times windbreak heights were defined as

Table 5 Contingency table (5 × 3) for windbreak categories and wind damage to sugar beets in Kamioribe, Shihoro Town, Hokkaido on May 8, 2016

(a) The area 10 times that of windbreak height was defined as the sheltered area

Windbreak category	No damage	Mild damage	Severe damage
Sheltered by arable land windbreaks of *Larix*	39 (92.9%)	2 (4.8%)	1 (2.4%)
Sheltered by trunk line windbreaks of *Larix*	34 (94.4%)	0 (0.0%)	2 (5.6%)
Sheltered by arable land windbreaks other than *Larix*	7 (77.8%)	0 (0.0%)	2 (22.2%)
Sheltered by trunk line windbreaks other than *Larix*	2 (100.0%)	0 (0.0%)	0 (0.0%)
Outside a sheltered area	122 (84.1%)	3 (2.1%)	20 (13.8%)

Table 5 (b) The area 15 times that of the windbreak height was defined as the sheltered area

Windbreak category	No damage	Mild damage	Severe damage
Sheltered by arable land windbreaks of *Larix*	54 (91.5%)	4 (6.8%)*	1 (1.7%)*
Sheltered by trunk line windbreaks of *Larix*	45 (91.8%)	0 (0.0%)	4 (8.2%)
Sheltered by arable land windbreaks other than *Larix*	9 (90.0%)	0 (0.0%)	1 (10.0%)
Sheltered by trunk line windbreaks other than *Larix*	3 (100.0%)	0 (0.0%)	0 (0.0%)
Outside a sheltered area	92 (83.6%)	1 (0.9%)	17 (15.5%)**

Table 5 (c) The area 20 times that of the windbreak height was defined as the sheltered area

Windbreak category	No damage	Mild damage	Severe damage
Sheltered by arable land windbreaks of *Larix*	57 (91.9%)	4 (6.5%)**	1 (1.6%)**
Sheltered by trunk line windbreaks of *Larix*	51 (91.1%)	0 (0.0%)	5 (8.9%)
Sheltered by arable land windbreaks other than *Larix*	11 (78.6%)	0 (0.0%)	3 (21.4%)
Sheltered by trunk line windbreaks other than *Larix*	5 (83.3%)	0 (0.0%)	1 (16.7%)
Outside a sheltered area	80 (83.3%)	1 (1.0%)	15 (15.6%)*

Table 5 (d) The area 30 times that of the windbreak height was defined as the sheltered area

Windbreak category	No damage	Mild damage	Severe damage
Sheltered by arable land windbreaks of *Larix*	65 (91.5%)	4 (5.6%)	2 (2.8%)
Sheltered by trunk line windbreaks of *Larix*	55 (85.9%)	0 (0.0%)	9 (14.1%)
Sheltered by arable land windbreaks other than *Larix*	12 (80.0%)	0 (0.0%)	3 (20.0%)
Sheltered by trunk line windbreaks other than *Larix*	9 (90.0%)	0 (0.0%)	1 (10.0%)
Outside a sheltered area	64 (85.3%)	1 (1.3%)	10 (13.3%)

Note: * and ** denote statistically significant differences by residual analysis at significance levels of 0.05 and 0.01, respectively.

sheltered areas, the occurrence of wind damage was significantly different ($0.01 < p < 0.05$) depending on the windbreak category (Table 5b and c). The percentage of severe wind damage to sugar beets was significantly higher in arable lands outside a sheltered area (residual analysis, $p < 0.01$ for 15 times and $0.01 < p < 0.05$ for 20 times) (Table 5b and c). In contrast, it was significantly lower in fields sheltered by arable land windbreaks of larch (residual analysis, $0.01 < p < 0.05$ for 15 times and $p < 0.01$ for 20 times) (Table 5b and c). The percentage of mild wind damage was significantly higher in fields sheltered by arable land windbreaks of larch (residual analysis, $0.01 < p < 0.05$ for 15 times and $p < 0.01$ for 20 times) (Table 5b and c). For cases in which 10 and 30 times windbreak heights were defined as sheltered areas, the occurrences of wind damage were not significantly different ($0.25 < p < 0.5$ for 10 times and $0.1 < p < 0.25$ for 30 times) depending on the windbreak category (Table 5a and d).

The 3 × 2 contingency tables for windbreak categories and the reduction of wind damage (no and mild damages were grouped) are shown in Table 6. For cases in which 15, 20, and 30 times windbreak heights were defined as sheltered areas, the occurrence of severe wind damage was significantly different ($0.01 < p < 0.05$ for 15, 20, and 30 times) depending on the windbreak category (Table 6b, c, and d). The percentage of severe wind damage to sugar beets was significantly higher in arable lands outside of a sheltered area (residual analysis, $p < 0.01$ for 15 and 20 times) (Table 6b and c). In contrast, it was significantly lower in fields sheltered by arable land windbreaks of larch (residual analysis, $0.01 < p < 0.05$ for 15, 20, and 30 times) (Table 6b, c, and d). For cases in which 10 times windbreak height was defined as a sheltered area, the occurrence of severe wind damage was not significantly different ($0.05 < p < 0.1$) depending on the windbreak category (Table 6a).

The 3 × 2 contingency tables for windbreak categories and wind damage reduction (mild damage collapsed) are shown in Table 7. For cases in which 15 and 20 times windbreak heights were defined as sheltered areas, the reduction in wind damage was significantly different ($0.01 < p < 0.05$ for both) depending on the windbreak category (Table 7b and c). The percentage of

Table 6 Contingency table (3 × 2) for windbreak categories and reduction of wind damage (no and mild damages were grouped) to sugar beets in Kamioribe, Shihoro Town, Hokkaido on May 8, 2016

(a) The area 10 times that of the windbreak height was defined as the sheltered area

Windbreak category	No or mild damage	Severe damage
Sheltered by arable land windbreaks of *Larix*	41 (97.6%)	1 (2.4%)
Sheltered by trunk line windbreaks of *Larix*	34 (94.4%)	2 (5.6%)
Outside a sheltered area	125 (86.2%)	20 (13.8%)

Table 6 (b) The area 15 times that of the windbreak height was defined as the sheltered area

Windbreak category	No or mild damage	Severe damage
Sheltered by arable land windbreaks of *Larix*	58 (98.3%)*	1 (1.7%)*
Sheltered by trunk line windbreaks of *Larix*	45 (91.8%)	4 (8.2%)
Outside a sheltered area	93 (84.5%)**	17 (15.5%)**

Table 6 (c) the area 20 times that of the windbreak height was defined as the sheltered area

Windbreak category	No or mild damage	Severe damage
Sheltered by arable land windbreaks of *Larix*	61 (98.4%)*	1 (1.6%)*
Sheltered by trunk line windbreaks of *Larix*	51 (91.1%)	5 (8.9%)
Outside a sheltered area	81 (84.4%)**	15 (15.6%)**

Table 6 (d) The area 30 times that of the windbreak height was defined as the sheltered area

Windbreak category	No or mild damage	Severe damage
Sheltered by arable land windbreaks of *Larix*	69 (97.2%)*	2 (2.8%)*
Sheltered by trunk line windbreaks of *Larix*	55 (85.9%)	9 (14.1%)
Outside a sheltered area	65 (86.7%)	10 (13.3%)

Note: * and ** denote statistically significant differences by residual analysis at significance levels of 0.05 and 0.01, respectively.

severe wind damage to sugar beets was significantly higher in arable lands outside a sheltered area (residual analysis, $p < 0.01$ for 15 times and $0.01 < p < 0.05$ for 20 times) (Table 7b and c). In contrast, it was significantly lower in fields sheltered by arable land windbreaks of larch (residual analysis, $0.01 < p < 0.05$ for 15 and 20 times) (Table 7b and c). For cases in which 10 and 30 times windbreak heights were defined as sheltered areas, reductions in wind damage were not significantly different ($0.05 < p < 0.1$ for both) depending on the windbreak category (Table 7a and d).

The 3 × 2 contingency tables for windbreak categories and the elimination of wind damage (mild and severe damage groups) are shown in Table 8. The elimination of all degrees of wind damage was not significantly different ($0.1 < p < 0.25$ for 10, 15, and 20 times, $0.25 < p < 0.5$ for 30 times) depending on the windbreak category.

DISCUSSION

Concerning the appropriate number of times windbreak heights effective for reducing wind damage on the leeward side to windbreaks, the results of this study suggest that areas 15 and 20 times the windbreak heights are the most appropriate (Tables 5b, 5c, 6b, 6c, 7b, and 7c, statistically significant differences in all tables), whereas 30 times are much less appropriate (Tables 5d, 6d, and 7d, significant differences only in Table 6d), and 10 times is not appropriate (Tables 5a, 6a, 7a, no significant differences). Onodera et al. (1955) reported that wind velocity was reduced within 15 times leeward to the Japanese larch windbreak height in the Tokachi Plain. Torita et al. (2003) reported that wind speed was reduced by 18 to 20 times leeward to the windbreak height. The results of this study are consistent with these reports.

Although trunk line windbreaks consist of more than 10 rows of trees, the results of this study failed to demonstrate the effectiveness of Japanese larch trunk line windbreaks in the early spring cultivation season (Tables 5b, 5c, 6b, 6c, 7b, and 7c). The reason for the high effectiveness of larch arable land windbreaks was demonstrated, whereas that of larch trunk line windbreaks was not could not be made clear from this study. One of the possible reasons for this is that most trees in the larch trunk line windbreaks had lost lower branches because of crowding. The other possible reason is that larch trees standing adjacent to cultivation fields in trunk line windbreaks were heavily pruned because the fallen leaves and branches of larches are hated by farmers. The relationship between forest management and the effect of Japanese larch trunk line windbreaks on the reduction of wind damage in the spring cultivation season needs to be studied.

The results of this study suggest that Japanese larch arable land windbreaks are effective for reducing (Tables 5b, 5c, 6b, 6c, 7b, and 7c), but not eliminating (Table 8) wind damage on arable lands leeward to windbreaks during the early spring cultivation season. These results support those reported by Ohshima et al. (2003) and Hokkaido Forestry Research Institute (2005), but were contradictory to Torita et al. (2003), Tsuji et al.

Table 7 Contingency table (3 × 2) for windbreak categories and reduction of wind damage (mild damage collapsed) to sugar beets in Kamioribe, Shihoro Town, Hokkaido on May 8, 2016
(a) The area 10 times that of the windbreak height was defined as the sheltered area

Windbreak category	No damage	Severe damage
Sheltered by arable land windbreaks of *Larix*	39 (97.5%)	1 (2.5%)
Sheltered by trunk line windbreaks of *Larix*	34 (94.4%)	2 (5.6%)
Outside a sheltered area	122 (85.9%)	20 (14.1%)

Table 7 (b) The area 15 times that of the windbreak height was defined as the sheltered area

Windbreak category	No damage	Severe damage
Sheltered by arable land windbreaks of *Larix*	54 (98.2%)*	1 (1.8%)*
Sheltered by trunk line windbreaks of *Larix*	45 (91.8%)	4 (8.2%)
Outside a sheltered area	92 (84.4%)**	17 (15.6%)**

Table 7 (c) The area 20 times that of the windbreak height was defined as the sheltered area

Windbreak category	No damage	Severe damage
Sheltered by arable land windbreaks of *Larix*	57 (98.3%)*	1 (1.7%)*
Sheltered by trunk line windbreaks of *Larix*	51 (91.1%)	5 (8.9%)
Outside a sheltered area	80 (84.2%)*	15 (15.8%)*

Table 7 (d) The area 30 times that of the windbreak height was defined as the sheltered area

Windbreak category	No damage	Severe damage
Sheltered by arable land windbreaks of *Larix*	65 (97.0%)	2 (3.0%)
Sheltered by trunk line windbreaks of *Larix*	55 (85.9%)	9 (14.1%)
Outside a sheltered area	64 (86.5%)	10 (13.5%)

Note: * and ** denote statistically significant differences by residual analysis at significance levels of 0.05 and 0.01, respectively.

(2005, 2007), and Akama et al. (2007).

None of the literature against the high effectiveness of Japanese larch arable land windbreaks in the spring cultivation season is based on data. Torita et al. (2003) measured the wind velocity leeward to Manchurian ash trunk line windbreaks but not around Japanese larch arable land windbreaks. They surveyed wind damage to red beans, but the Tokachi spring wind blew on June 9 and 10 in the year they surveyed, so leaves on the short shoots of larches were supposed to have been fully extended by then (Ohshima et al., 2002; Hirokawa and Suzuki, 2006). Tsuji et al. (2007) analyzed the relationship between the densities of arable land windbreaks and the rate of wind damage and showed that the relationship was statistically non-significant. They did not state the names of the crops being investigated, nor the date when wind damage occurred. They also did not investigate the relationship between the species planted in arable land windbreaks and the extent of wind damage. Thus, their study did not examine the effectiveness of Japanese larch arable land windbreaks on the reduction of wind damage during the early spring cultivation season. The publication by Akama et al. (2007) was a pamphlet, not a scientific study.

Tsuji et al. (2005) studied wind damage to sugar beets and reported that "On the survey on wind erosion had confirmed that wind erosion damage occurs in areas outside the windbreaks, and not in the sheltered areas." They also reported that "The wind erosion damage ratio increased with the density of the windbreak networks becoming less in Otofuke. And, it was proven that there was a negative correlation between the density of the windbreak networks and the wind erosion damage ratio in Otofuke" (Tsuji et al., 2005). These reports are consistent with the results of this study. Tsuji and Saho (2006) also reported that most wind damage to sugar beet crops in 2001 occurred in arable lands outside a sheltered area, which is consistent with the results of this study. However, Tsuji et al. (2005) and Tsuji and Saho (2006) did not report the date when the wind damage occurred, and thus, it is impossible to deduce whether the leaves on short shoots of larch had been fully extended or not. If wind damage occurred in late May or early June, then the damage cannot be attributed to the deciduous nature of larch, as the leaves on short shoots would have been fully extended by then. Both reports did not analyze the relationship between the species in the arable land windbreak and the extent of wind damage. Thus, it is impossible to judge the effectiveness of Japanese larch arable land windbreaks in the spring cultivation season from these studies. In addition, a statement contradictory to the above-quoted statement is found in Tsuji et al. (2005), causing confusion: "On the other hand, erosion damage occurred near the windbreaks." Furthermore, the same first author (Tsuji et al., 2005, 2007) denies the high effectiveness of larch arable land windbreaks against wind damage caused by the Tokachi spring wind, causing further confusion.

Several studies have shown that farmers support the high effectiveness of Japanese larch arable land windbreaks in the

Table 8 Contingency table (3 × 2) for windbreak categories and elimination of wind damage (mild and severe damages were grouped) to sugar beets in Kamioribe, Shihoro Town, Hokkaido on May 8, 2016

(a) The area 10 times that of the windbreak height was defined as the sheltered area

Windbreak category	No damage	Mild or severe damage
Sheltered by arable land windbreaks of *Larix*	39 (92.9%)	3 (7.1%)
Sheltered by trunk line windbreaks of *Larix*	34 (94.4%)	2 (5.6%)
Outside a sheltered area	122 (84.1%)	23 (15.9%)

Table 8 (b) The area 15 times that of the windbreak height was defined as the sheltered area

Windbreak category	No damage	Mild or severe damage
Sheltered by arable land windbreaks of *Larix*	54 (91.5%)	5 (8.5%)
Sheltered by trunk line windbreaks of *Larix*	45 (91.8%)	4 (8.2%)
Outside a sheltered area	92 (83.6%)	18 (16.4%)

Table 8 (c) The area 20 times that of the windbreak height was defined as the sheltered area

Windbreak category	No damage	Mild or severe damage
Sheltered by arable land windbreaks of *Larix*	57 (91.9%)	5 (8.1%)
Sheltered by trunk line windbreaks of *Larix*	51 (91.1%)	5 (8.9%)
Outside a sheltered area	80 (83.3%)	16 (16.7%)

Table 8 (d) The area 30 times that of the windbreak height was defined as the sheltered area

Windbreak category	No damage	Mild or severe damage
Sheltered by arable land windbreaks of *Larix*	65 (91.5%)	6 (8.5%)
Sheltered by trunk line windbreaks of *Larix*	55 (85.9%)	9 (14.1%)
Outside a sheltered area	64 (85.3%)	11 (14.7%)

spring cultivation season. In questionnaire surveys carried out on the Tokachi Plain, 94%–98% (Nonokawa, 1991) and 86% (Torita et al., 2004) of farmers answered that arable land windbreaks were effective in preventing wind damage. Ueno (2003) developed an analytic hierarchy process model for the maintenance and management of arable land windbreaks based on the responses of farmers on the Tokachi Plain, and the prevention of soil erosion was assigned as the most important merit of windbreaks. Furthermore, Nakagawa (2018a) reviewed 156 local history chronicles from the Tokachi Plain and found deciduous larch arable land windbreaks that reduced wind damage during the spring cultivation season had been evaluated as highly effective by 31 literatures, whereas there were no negative statements regarding the use of this tree species in arable land windbreaks. Nakagawa (2018b) carried out a similar review of local history chronicles on the Shari plain, another major area prone to wind damage during the spring cultivation season in Hokkaido, and again found only positive conclusions from seven reports. Nakagawa (2018c) also found that Japanese larch arable land windbreaks during the spring cultivation season were evaluated to be highly effective in a pamphlet issued by the Forestry Department of Tokachi Subprefecture, Hokkaido Government.

From the results of this study and the above literature review, it can be concluded that arable land windbreaks of Japanese larch are effective at reducing wind damage in cultivation fields during the early spring cultivation season, even if larch buds are not open or the leaves on short shoots are not fully extended.

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Article

Current Status, Attitude, and Issues around Preserved Tree Systems, Identified through Surveying the Operators Managing the Trees

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ABSTRACT

The "preserved tree system" and "preserved forest system" aim to preserve trees and forests in cities in Japan, and are operated by local governments. We conducted a questionnaire of the operators of the preserved tree system to examine their awareness of the systems in Nagoya (215 operators) and Shizuoka (60 operators), and clarified the relationships among operators, local governments, and community residents not involved in tree management. Questionnaires were returned by 117 (Nagoya) and 30 (Shizuoka) operators. The results were as follows: 1) Although local governments and operators agreed on the goals of the system (green preservation, improving aesthetic appeal, and preservation of trees with historical and cultural value), there were concerns over the associated costs and economic burden faced by the management; 2) There was a risk of conflict between the operators and community residents because calls for preservation by neighboring residents increased when operators stopped tree management. For sustainable preservation of designated trees in the local environment, promotion of cooperation between community residents and operators is crucial.

Keywords: green preservation, historical and cultural values, preserved trees

INTRODUCTION

The "preserved tree system" and "preserved forest system" were initiated to preserve giant trees and forests in urban areas of Japan [1]. These systems aim to conserve trees and forests and improve favorable urban environments, with respect to the "Act on Preservation of Trees for Maintenance of Scenic Beauty of Cities" (Ministry of Justice, 2009a), and the related ordinances of each local government. At the end of 2017, approximately 65,000 preserved trees and approximately 8,200 preserved forests were covered by this system, under 378 local governments nationwide (Ministry of Land, Infrastructure, Transport, and Tourism: MLIT, 2017). The actual management is entrusted to the residents, while the local government assists with management costs and supplies.

A previous study on these systems by Ishizaki (1994), which investigated the species and geographical distribution of preserved trees in Tokyo, showed that they were affected by land ownership. Setsu et al. (1995) pointed out that excessive pruning of preserved trees to address concerns about fallen branches, conflicted with the idea of preserving trees chosen for their "aesthetic appeal" (Setsu et al., 1995). A survey of former owners of preserved trees (people who had previously owned preserved trees) by Sawaki and Kuwae (2002) showed that complaints from neighboring residents relating to the preserved trees became too onerous a responsibility; the survey also indicated that maintenance management activities and recreational use should be carried out collaboratively, based on a mutual understanding between the owner and neighboring residents.

Previous studies have focused on the constituent tree species of preserved tree systems and the attitude of their owners; however, little research has investigated the relationships between neighboring residents and local governments. A policy report on urban greening and green space conservation, published by the MLIT, stated "creating a place for collaboration with the participation of local residents and NPOs at each stage of conservation, creation, and management of greenery and open spaces" (MLIT, 2019). Previous studies on the relationship between the operators and neighboring residents are also lacking; basic research is also needed on the relationship between residents and owners, to promote "mutual understanding between owners and neighboring residents" (Sawaki and Kuwae, 2002). Setsu et al. (1995) showed that privately-owned trees are tended to be managed by individuals, while trees at shrines and temples are tended to be managed by service supporters such as parishioners and pres-

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Table 1 Data on preserved tree systems in Nagoya/Shizuoka

	Nagoya	Shizuoka
System started in	1973	2015
Number of Trees and Forests	Preserved Trees: 856 Preserved Forests: 2	Preserved Trees: 42 Preserved Forests: 39
Fixed subsidy amount per one Preserved Tree	3,000 yen	-
Subsidies to tree management	1/2 of the cost by application (up to 300,000 yen)	
Other subsidies	Tree diagnosis Signboard installation	Supplying materials (e.g., garbage bags) Signboard installation
Disclosure of information about Preserved Tree	Species	Species and Location

Source: Based on the description on each local government website in Nagoya and Shizuoka (City of Nagoya, 2020; City of Shizuoka, 2020).
Note: Subsidies in Nagoya include those from Nagoya City Green Association.

idents. A focus on the preserved trees at shrines and temples, therefore, will provide more insight into the behavior and involvement of local governments, the tree preservation managers, and neighboring residents.

The present study aimed to increase awareness of tree management and preservation systems, as well as investigate the relationships among operators [2], neighboring residents, and local governments. In addition, the study aimed to clarify issues within the system, based on a survey amongst the operators of preserved trees.

RESEARCH METHODOLOGY

The survey methods incorporated a literature review, interviews with the operators of preserved tree system, and questionnaire surveys. The literature review examined newspaper articles on preserved trees, as well as reports on the geological history and tree preservation systems of the survey sites. The newspaper article review focused on the "Asahi Shimbun," "Chunichi Shimbun/Tokyo Shimbun," "Nihon Keizai Shimbun," "Mainichi Shimbun," and "Yomiuri Shimbun" databases. A keyword search, using the term "preserved tree," resulted in 255, 187, 10, 165, and 175 articles for each respective database mentioned above.

We also searched internet-based homepages or greening policies of local governments for information on preserved tree species, owners, and aid provided for tree preservation, such as subsidies for management costs, installation of signboards, and tree vigor diagnoses (Hachinohe City, 2020). In the present study, we also quantitatively analyzed the annual payment per preserved tree. Each prefecture in each area is shown as below. Hokkaido: Hokkaido, Tohoku: Aomori, Iwate, Miyagi, Akita, Yamagata, Fukushima, Kanto: Ibaraki, Tochigi, Gunma, Saitama, Chiba, Tokyo, Kanagawa, Yamanashi, Chubu: Niigata, Toyama, Ishikawa, Nagano, Gifu, Shizuoka, Aichi, Kansai: Mie, Shiga, Kyoto, Osaka, Hyogo, Nara, Wakayama, Chugoku/Shikoku: Tottori, Okayama, Hiroshima, Yamaguchi, Kochi, Tokushima, Kagawa, Ehime, Kyushu: Fukuoka, Saga, Nagasaki, Kumamoto, Oita, Miyazaki, Kagoshima, Okinawa. There are no local governments operating this system in Fukui and Shimane.

Furthermore, we conducted a morphological analysis on the text describing this system on the homepage of each local government website, using the "KH Coder" text analysis software. Morphological analysis is finding morphemes (minimum sound patterns with meaning) from sentences and dividing them into units (Otsuki et al., 2018). Thus, we extracted words that were frequently used by local governments when explaining the system to residents and examined the awareness of the residents regarding the system used by their local governments. Data acquisition and analysis were conducted on November 12th and 13th, 2019, while the morphological analysis engine used was "MeCab."

The interview and questionnaire surveys were conducted in Nagoya (Aichi Prefecture) and Shizuoka (Shizuoka Prefecture). In Nagoya, trees in the preservation system have been registered since 1973 (City of Nagoya, 2020), while in Shizuoka, the system was introduced in 2015 (City of Shizuoka, 2016); these two sites were chosen for determining the correlation between years since the system started, and awareness of the system. Table 1 shows the current (as at 2020) state of implementation of the system.

In interview surveys, the views of operators on the historical and cultural value of trees were acquired. Interviews were conducted on 36 days between July 2017 and January 2019. In questionnaire surveys, we asked questions on difficulties relating to tree management; the existence and details of historical and cultural values; and the motives for introducing the system. In the design of the questionnaire, several questions were added or changed, based on questionnaire survey that was previously conducted in Nagoya on the owners of preserved trees, in 2009 (City of Nagoya, 2009). Although there are some differences from the present survey (the implementing respondents and the method of sending the questionnaire), it is provided here to clarify how their awareness has changed since 2009. The subjects of the present survey were the operators of preserved tree system and forests of shrines and temples in both cities (Nagoya: 215 operators, Shizuoka: 60 operators) [3]. The survey was conducted from November 2018 to February 2019; the questionnaire was distributed by visiting each shrine and temple physically, while the response was requested by mail.

In addition to the simple tabulation of the questionnaire, a cross-analysis was performed on questions with a large number of responses ("Yes," "No," "I think it is necessary," or "Neither can be said"), to clarify the presence or absence, and strength of the correlation amongst the responses. The Phi coefficient was used to determine the positive and negative correlations, and Cramer's V was used to determine the strength. According to previous research, a relatively strong correlation is indicated if Cramer's V is 0.2 or more (Hojo, 2010).

OVERVIEW OF PRESERVED TREE SYSTEMS

Transitions in Discussions on Preserved Tree Systems

The "Act on Preservation of Trees for Maintenance of Scenic Beauty of Cities" was initiated in 1962 to secure green spaces in cities (Tahara et al., 2011). The minutes of the Diet on this law confirmed references to the owners; however, there were no references made to the neighbors not involved in tree management. Before the enactment of the bill, there was specific concern regarding infringements on the rights of the owner, which stated that, "it is an infringement of private rights to any extent [4]." Twenty years after the enactment of the bill, there is still ongoing debate as to what kind of assistance is needed to prevent the de-designation of preserved trees [5].

Furthermore, there were records referring to the trees to be designated for preservation: "famous trees or old trees, which are not designated by the Act on Protection of Cultural Properties, can be specified by decisions by the mayor of each local government [6]," thus showing an intention to allow local government to exercise discretion on such trees. In addition, the "Act on Protection of Cultural Properties," which preserves and utilizes "cultural properties with a high historical or artistic value in Japan," (Ministry of Justice, 2009b) was stated; "famous trees or old trees" that have historical and cultural value were not excluded in the designation of this system.

Several local governments (Kasugai City, Aichi Prefecture) included hedges in the target. The testimony of local government officials was also obtained: "The preserved tree system is less restrictive than other systems, such as the green conservation areas [7]" As nearly 90% of designated cases (trees: 61,855, forests: 8,002) were based on the ordinances of each local government (MLIT, 2017), local governments were given a certain amount of discretion.

Several local governments specify conditions, such as "trees that have been popular as symbolic trees in the town" (Sendai City, Miyagi Prefecture), as requirements for designation. While the preserved tree system mainly targets greening and green preservation, the designation of trees with historical and cultural value is also made at the discretion of local governments.

In summary, the issues faced by operators changed, from concerns regarding infringements on private rights, to the need for assistance to maintain preserved trees. However, the relationship with neighboring residents was not considered by the Diet. In addition, discussions even before the enactment of the bill showed the intention to hand the discretion for the designation of trees with historical and cultural value to the local governments.

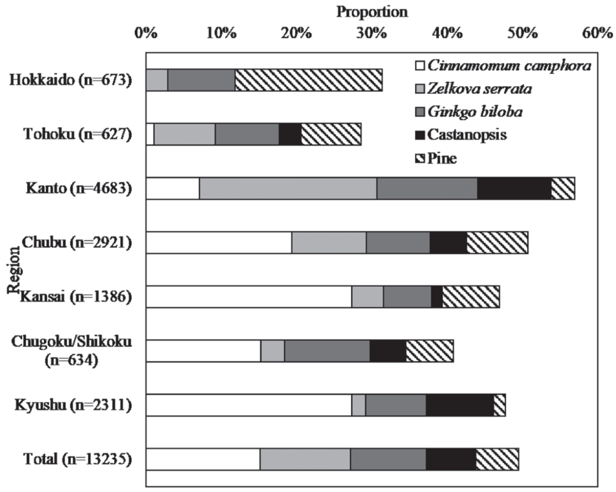

Fig. 1. Percentage of top five tree species by region.
Note: "n" stands for the number of preserved trees.
Source: Based on the description on each local government's website (City of Nagoya, 2020) etc.

This remains the same till date.

Current Characteristics of Preserved Tree Systems

We obtained the information regarding preserved trees from a number of local governments. The information obtained was as follows: species: 124 (32.8%); owners: 61 (16.1%); fixed-amount subsidies: 104 (27.5%); description of the system: 204 (54.0%).

Regarding the species of preserved trees, Nakajima (1986) pointed out the existence of the northern Japanese type, where *Zelkova serrata* is abundant, and the southwestern Japanese type, which is dominated by *Cinnamomum camphora*. The current trends seen in the top five species are displayed in Figs. 1 and 9. "Pine trees" are all trees with "Matsu (pine)" at the end. "Castanopsis" are *Castanopsis sieboldii* and *Castanopsis cuspidata* (Iokawa, 2016). The abundance of *Cinnamomum camphora* increased in a southern region, while that of pine trees decreased. *Zelkova serrata* was abundant in the Kanto region, but *Ginkgo biloba* did not show any significant changes in abundance. This is largely in line with trends in the 1980s (Nakajima, 1986).

The nationwide types of owners were roughly classified by Nakajima (1986) into private owners, religious facilities (temples, shrines, and churches), companies, and public land, and their ratios across different regions were calculated. Figure 2 shows the proportion of preserved tree owners in the above categories, across different regions: the proportion of public ownership was high in the Hokkaido and Tohoku regions. In addition, shrines and temples accounted for the ownership of more than 60% of the total population of preserved trees nationwide [8] In agreement with the observation made by Nakajima that half of the preserved trees exist in religious institutions, it was shown that the present day preserved tree system is especially prominent at shrines and temples.

Concerning fixed-quantity subsidies, the average amount

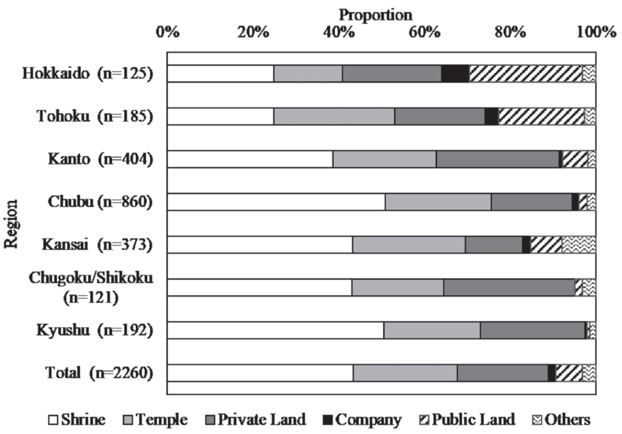

Fig. 2. Percentage of owners by region.
Note: "n" stands for the number of owners of preserved trees.
Source: Based on the description on each local government's website (City of Shizuoka, 2020) etc.

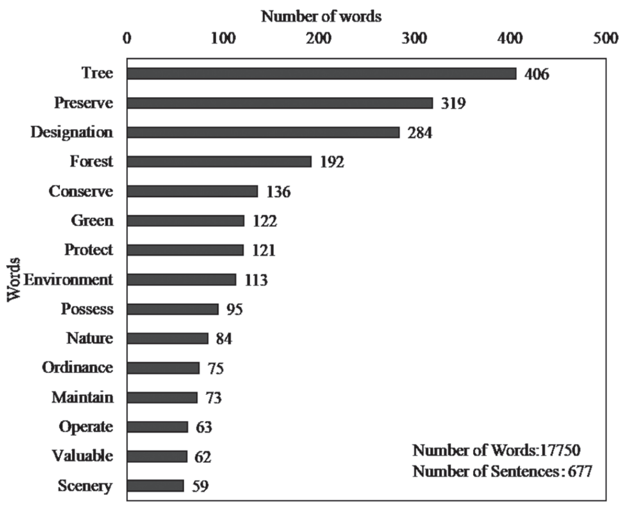

Fig. 3. Words that frequently appear in public relations about system of each local government.

was 4454 (± 3130) yen, the maximum was 20000 yen, and the minimum was 1000 yen. We focused on fixed-quantity subsidies because they are easy to analyze quantitatively. However, in the cases of Nagoya and Shizuoka (Table 1), which were our target areas for interviews and questionnaire surveys, further subsidies are allocated in addition to the fixed-quantity subsidy, such as subsidies for tree vigor diagnosis or the supply of materials. It is expected that the amount of subsidy differs in each local government.

Figure 3 shows the top 15 words most frequently used to describe the system in each local government. The more frequent use of the words "green" and "environment" than the word "scenery," means that the local government focuses on greening and green conservation, ahead of maintenance of scenery. Conversely, according to MLIT, "Old trees and famous trees that have been popular in the area" are specified by the ordinance,

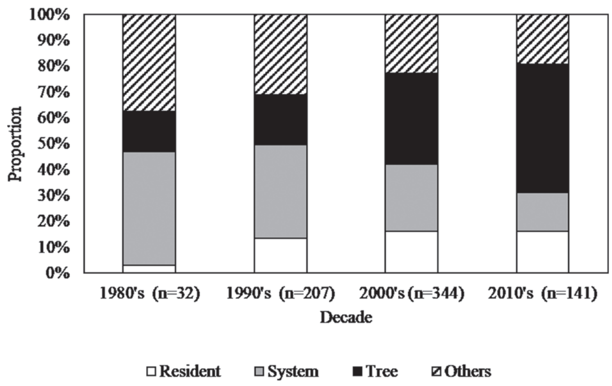

Fig. 4. Historical transition of newspaper article content.
Source: Based on the article contents on each newspaper article archive (Asahi Shimbun, 2019; Chunichi Shimbun, 2019; Mainichi Shimbun, 2019; Nihon Keizai Shimbun, 2019; Yomiuri Shimbun, 2019).

while those with historical and cultural value are also subject to conservation.

Furthermore, "while greenery is being lost due to urbanization, by designating famous trees and old trees in the city as preserved trees, the scenic beauty of the city is maintained by the citizens with cooperation of everyone" (City of Nagoya, 2020). In addition, "Trees or forests that need to be preserved are designated as 'preserved trees (or forests)' to preserve the greenery of giant trees and old trees" in accordance with the basic principles of the Shizuoka City Green Ordinance (City of Shizuoka, 2020). The purpose of this system is to preserve green areas, aesthetics, and historical and cultural values, as well as MLIT's state.

To summarize: (1) Approximately two-thirds of the owners of preserved trees are shrines and temples; (2) The amount of subsidies for preserved trees differs, depending on local governments; and (3) The aim of local governments is greening and green preservation, followed by scenery.

Relationships between Preserved Tree Operators and Neighboring Residents

In this section, we examine the relationships among preserved tree operators, and neighboring residents. From a survey of individual newspaper articles, there were three types of newspaper articles: (1) Those related to the movements of neighboring residents (e.g., Tokyo Shimbun, 2019); (2) Those related to systems, especially the movements of local governments (e.g., Yomiuri Shimbun, 2016); and (3) Those related to the introduction of preserved trees themselves and to the descriptions of damage to preserved trees caused by typhoons (e.g., Chunichi Shimbun, 2009). Figure 4 shows the transition of these descriptions over the decades. Many descriptions of systems, relating to the type (2) newspaper articles, were found in the 1990s, with most of them focusing on local governments that were newly designating trees or forests for preservation. The type (3) articles on preserved trees accounted for nearly half of those from the 2010s, which is thought to be due to the increase in reports of damage caused by natural disasters.

The type (1) articles on the movements of neighboring residents accounted for approximately 10% of articles since the 1990s; there were also articles relating to regional geography published by residents (e.g., Chunichi Shimbun, 1992) as well as articles on the systems used as a means of forest preservation (e.g., Asahi Shimbun, 2014).

We focused on articles in which residents were opposed to the logging of preserved trees. In these cases, neighboring residents mounted anti-logging protests, after operators voluntarily or unavoidably undertook de-designation; for example, Yomiuri Shimbun (2006) reported that after operators decided to cancel the designation of preserved trees, residents protested logging. Residents who carried out these protests claimed that preserved trees should be conserved as precious trees (Asahi Shimbun, 2005). Moreover, "shrines and temples are given preferential treatment as religious corporations" (Asahi Shimbun, 1991). Shrines and temples are religious institutions, and the articles suggested that there was some resistance to the inclusion of religious organizations in the scope of public systems.

The abovementioned situations demonstrated that neighboring residents may oppose the logging of preserved trees, as well as increase their calls for tree preservation, in cases of logging of preserved trees. Therefore, we discuss the current situation of preserved tree operators, based on the questionnaire and interview surveys in the present study.

RESULTS OF QUESTIONNAIRE SURVEY IN NAGOYA AND SHIZUOKA

Motivation for Registering for Preserved Tree System and its Impact

The number of valid responses from Nagoya was 117 (54.4%) and that from Shizuoka, 30 (50.0%).

The motives for registering for the preserved tree system are summarized in Fig. 5. More than 30% of the respondents in Nagoya answered, "I don't know/there is no particular reason." Of the 24 responses to open-ended questions, 15 respondents said that they had taken over from their predecessor and that the trees had already been registered. It can be assumed that, in Nagoya, attitude and awareness regarding the system have become entrenched and routine in the 40 years that have passed since the system was implemented. Conversely, in both cities, most respondents answered that, "I thought that old trees and famous trees in the area should be preserved" (preservation of famous trees), followed by, "I thought that it was necessary for the landscape of shrines and temples" (preservation of good landscape). Among the 107 responses to open-ended questions regarding the system, 28 were of the opinion that, "The shrine is a 'Mori' (forest) and trees are necessary," thus confirming that people wanted to preserve symbolic trees or forests. In addition, 27 stated that, "It is a precious big tree, and it is disheartening to lose it," thus emphasizing a greening aspect. The operators were inclined to value support from a cultural or spiritual perspective more than

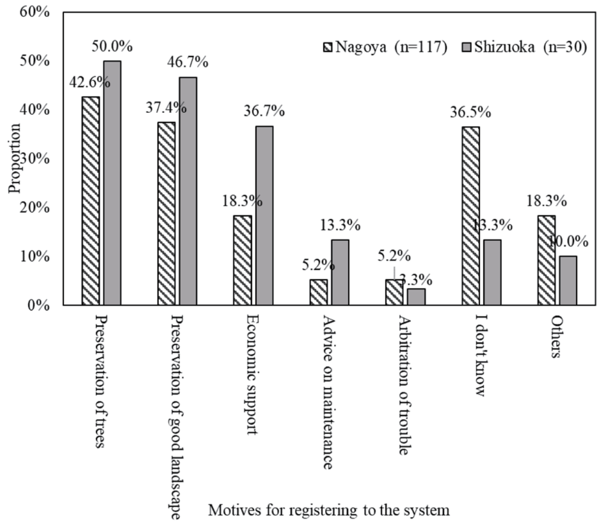

Fig. 5. Motives for registering to the system.
Note: multiple answers allowed except for "I don't know."

receiving assistance on practical matters such as "economic support" and "advice on maintenance."

Regarding the correlation between historical and cultural values, compared with other aspects (Table 2, shaded items), a weak positive correlation was found between a positive awareness of the system and the existence of application motives. There was a positive correlation between the existence of management difficulties and the presence of historical and cultural values.

Regarding motives for registration, assuming that historical and cultural values pre-existed, the system was introduced to preserve trees. In Nagoya, almost half of the historical values and cultural values relating to trees were unknown when they were first introduced; however, 13 of the 14 cases were regarded as historical and cultural trees before 1970, when institutional efforts began. It is, therefore, highly possible that historical and cultural values were effective in motivating the operators for the preservation of specific trees. Conversely, from the positive correlation between the existence of management difficulties and the presence of historical and cultural values, it appears that such difficulties will not disappear, even if the governing body understands the historical and cultural value of the preserved tree.

Relating to motives for registration, a chief priest of a shrine who was registered in the system in the past, but who deregistered due to dissatisfaction at the "deterioration of the tree," stated that, "Because it is a big tree, it is necessary to support it." Furthermore, a typhoon broke the trunk of the preserved tree, and a parishioner of the shrine, who canceled the application for registration, said "It is quite difficult to manage the preserved tree nowadays." Even at the local government level there is a concern about such a situation, with one of the people in charge saying, "We try to discuss with the operator as much as possible about the parts damaged by typhoons; it might be difficult, however."

Table 2 Correlation between survey responses in Nagoya

Question A	Question B	Correlation	
		Sign	Strength
Difficulties of tree maintenance	Presence of complaints	+	0.3354
Awareness of the system	Presence of motives toward the system	+	0.2560
Difficulties of tree maintenance	Presence of motives toward the system	+	0.2310
Difficulties of tree maintenance	Historical/ Cultural value	+	0.1646
Awareness of disclosing information	Presence of complaints	−	0.1606
Historical/ Cultural value	Presence of motives toward the system	+	0.1530
Awareness of the system	Presence of complaints	−	0.1463
Awareness of the system	Historical/ Cultural value	+	0.1438
Presence of complaints	Historical/ Cultural value	+	0.1340
Awareness of disclosing information	Presence of motives toward the system	+	0.1051

Note: Shaded items are related to historical and cultural values.

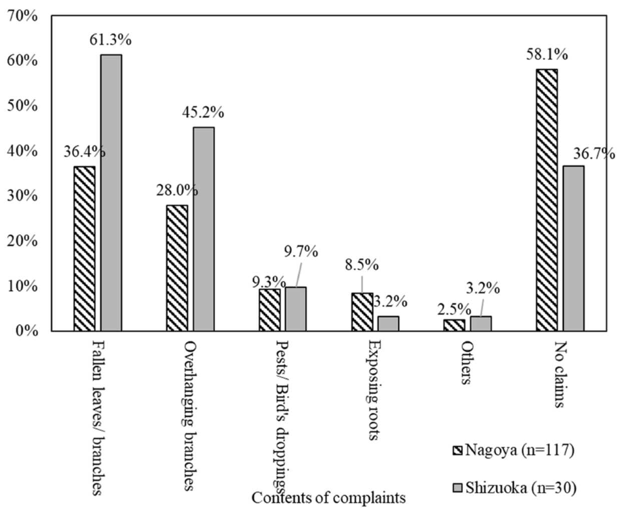

Fig. 6. Complaints from neighboring residents.
Note: multiple answers allowed except for "No claims."

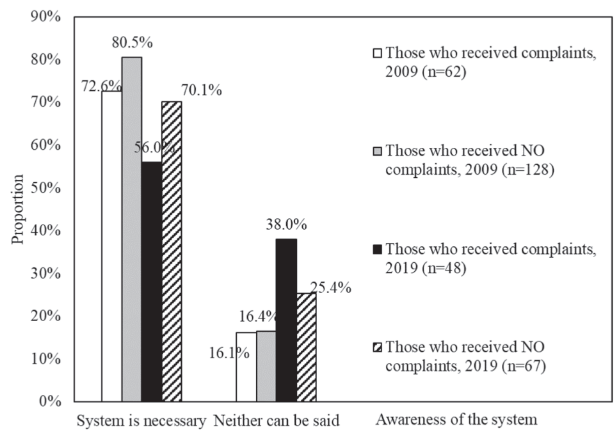

Fig. 7. Relationship between presence of complaints and the awareness of the system.
Note: Data in 2009 was collected by City of Nagoya (2009).

Relationship between Operators and Neighboring Residents

Figure 6 shows the complaints from neighboring residents and the reasons for these complaints. Of the respondents, 40% in Nagoya and 60% in Shizuoka answered that they had received complaints. Many of the complaints related to leaf fall and branch overhang. Of the 38 responses to open-ended questions, 21 respondents received complaints related to leaf litter, such as "deciduous leaves clogging the gutter of the neighboring house" or "herbicides were sprayed without our permission." Several respondents said, "As a local deity, a preserved tree is necessary, but I am worried about the impact on the surrounding area because of the large tree." Another answer was, "If there is no actual harm to you, 'save it,' if there is harm, 'cut it, or take care of it,'" thus showing the difficulty faced by the neighboring residents while maintaining the preserved tree.

Table 2 shows that there was a strong correlation between the difficulties in tree management and complaints from neighboring residents; the assumption cannot be made that receiving a complaint worsens the awareness of tree management, or that an aspect that makes it difficult to manage the tree (such as litter), is causing the complaint. It will nevertheless be necessary to introduce measures to resolve tree management difficulties and thus prevent complaints.

We also examined the differences between the questionnaire survey conducted in Nagoya in 2009 and the present survey; Figure 7 shows the relationship between the complaints and awareness of the system in 2009, compared with that in the present study in 2019. Even after receiving complaints, more than half of the respondents answered that the "System is necessary." However, the percentage of respondents who reported that they received complaints increased (in 2009: 32.6% while in 2019: 41.7%). In addition, respondents in this survey who received complaints were more likely to answer, "Neither can be said," than those in 2009.

Current Situation Associated with Problems Surrounding Operators

Relationships with neighboring residents were not the only difficulty faced by the managers. Figure 8 shows the age struc-

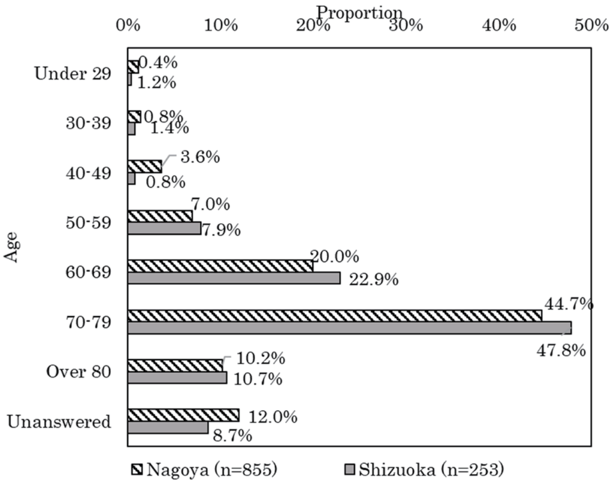

Fig. 8. Age structure of preservation tree operators.
Note: "n" stands for the number of operators.

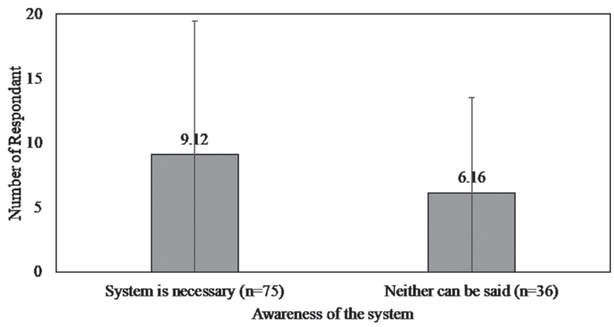

Fig. 9. Average number of operators and their awareness of the system in Nagoya.

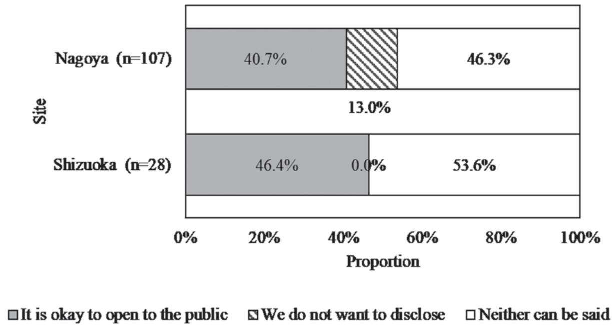

Fig. 10. Awareness of disclosing information on preserved trees.

ture of preserved tree operators; most managers in both cities were in their 60s or older. Even in the open-ended responses, there were opinions that, "I think that maintenance will become difficult in the future due to the declining birthrate and aging population." In addition, there were opinions that there was a shortage of management personnel, and that the continuity of independent management was being jeopardized by the aging population. To solve this problem regarding shortage of operators, a shrine in Nagoya confirmed that it was recruiting volunteers. Considering that nearly 70% of the shrines in Nagoya answered that they were managed by the parishioners, such recruitment efforts seem to be a new movement that is not bound by the historical management by parishioners.

The correlation between the number of operators and the responses revealed differences in the awareness of the system. Figure 9 shows the average number of operators in each response group for each response, related to their awareness of the system. Both the average number and maximum number of operators in the group, who stated that the "System is necessary," exceeded that of the group that answered, "Neither can be said." In contrast, there were no significant differences in the answers to the other questions about difficulties in management and the presence of complaints from neighboring residents. From the above results, it can be assumed that an increase in the number of operators improves the overall awareness of the system.

It seems difficult, however, to persuade owners to accept operators who are volunteers at all shrines and temples, as reflected by the reaction to the awareness of disclosing information on preserved trees (tree species composition and location) to third parties. In both cities, the responses were divided into two categories: "It is okay to open to the public," and "Neither can be said" (Fig. 10). In the open-ended responses, those who answered, "It is okay to open to the public" justified their answer as meaning, "It can be made known by making it public," and, "It is a public business, so there is no resistance to disclosing information." Respondents who answered, "Neither can be said," and, "We do not want to disclose," were concerned about the disadvantages of increasing the number of visitors or damage. There was also an opinion that, "the preserved trees of the shrine should be managed by the parishioners," and it is conceivable that there is a similar dichotomy regarding the widespread recruitment of operators.

DISCUSSION AND CONCLUSION

Relationships among Local Governments, Operators, and Neighboring Residents

In the "Act on Preservation of Trees for Maintenance of Scenic Beauty of Cities," preserved trees are designated for protection to "improve the sound environment of the city" and to "maintain aesthetic areas." (MLIT, 2017). As mentioned in results of questionnaire survey in Nagoya and Shizuoka, the aims of local governments are greening/green preservation, improving aesthetic appeal, and the preservation of trees of historical and cultural value. Considering that there were many survey answers such as, "I thought that old trees and famous trees in the area should be left," and, "I thought that it was necessary for the scenery of shrines and temples," there was clear consensus that local government should maintain a good landscape and preserve the historical and cultural values of trees. Conversely, several operators were dissatisfied with the designation of trees, when there was a deterioration in the number of trees.

The relationship between neighboring residents and operators, showed clear signs of potential conflict between them. Neighboring residents complained regularly to the operator but when the operator retired from management, residents expressed a stronger need for preservation of trees; the attitudes of the neighboring residents are therefore changeable.

The number of operators that received complaints has increased, with a strong correlation between the complaints and the difficulty in managing trees (Table 1). In addition, judicial decisions that prioritize the rights of adjacent landowners over the trees at shrines (Mainichi Shimbun, 2016; Morimoto, 2019) place even more pressure on operators of the preserved tree system.

Recommendations for Possible Inclusion of Neighboring Residents or Outsiders

Sawaki and Kuwae (2002) have reported that the expectations of former owners of preserved trees (people who used to own preserved trees) could be classified into two types: expectations for awareness, such as the level of understanding in neighboring resident groups, and expectations for financial support from the government.

Given that the greatest expectations of the operators were cultural and spiritual, and that public support was limited, this section describes the possibility of including neighbors and outsiders in tree preservation.

Our survey showed that the larger the number of operators, the more positive the awareness of the system (Fig. 9). To prevent conflicts between operators and neighboring residents, it is necessary to bridge the gap between them for better operation of the system.

Regarding the relationship between the community and religious institutions, Susaki (2017) pointed out that those who practice other religions may face barriers to involvement with shrines or temples. A system that considers the diversity of religion should therefore be created. Studies have also pointed out that the acceptance of visitors from the outside can reconfirm the significance of the folklore of an area (Kamei, 2015). Conversely, if historical and cultural values are already shared within the community, the entry of outsiders may lead to conflict (Yagihashi, 2015). In the discourse on multicultural coexistence, the coexistence of the majority group and minorities (newcomers) is desirable for the system (Kurimoto, 2016). Opinions on information disclosure, however, were divided (Fig. 10); certain responses indicated that the preserved trees of shrines should be managed by the parishioners, showing a reluctance at certain shrines and temples to accept outsiders; whereas, certain responses showed that disclosing the information to public would be beneficial. A system for accepting outsiders has not yet been established; therefore, it should be clarified at the time of registering for the system, whether the operator wishes to include outsiders or not. If operators can manage the trees without any difficulties, the trees are likely to be preserved. If, however, there are problems with the operation, it may be necessary to classify cases according to the actual conditions of the region, which may, for example, require additional support from external volunteers.

Impacts of Historical and Cultural Values on Preserved Trees

Based on the present study, we can conclude that the historical and cultural values of Nagoya were drivers in preserving certain trees; however, the question remains whether historical and cultural values will continue to be effective in preserving trees. Previous research has pointed out that folklore may not be passed down if there are changes in autonomous regions (Aiba and Harada, 2019). In Nagoya, one-third of the respondents answered, "I don't know/There is no particular reason," for the motive behind the application for registration (Fig. 5). Even if the historical and cultural values of trees were understood by operators, there could still be difficulties and complaints regarding their management. Hence, it might be expected that historical and cultural values will not be sufficient for tree preservation.

As for sacred trees, although the shrines and temples are trying to protect them, they are being lost due to lack of ecological considerations and deterioration of the surrounding environment, as seen in Tokyo (Poggendorf et al., 2007). Conversely, trees with historical and cultural value, including sacred trees, can be preserved by providing the support of an ecological approach for the system. Omoto (2016) also pointed out that the existence of an animal and/or plant species that symbolizes the region, called a flagship species, could be the basis for encouraging collaboration among various stakeholders in conservation activities. Conversely, however, Lynne et al. (2018) pointed out that sacred species only occur in abundance in sanctuary areas. Differing views that have been derived according to definitions of "religion" and "faith," which are affected by time and place, are unlikely to achieve a unified approach (Fujiwara, 2018). The impact of historical and cultural values on conservation depends on the situation and the influence of the historical and cultural values in that region; therefore, even if historical and cultural values are drivers of preservation at the present time, there is no guarantee that they will continue to be effective in the future.

Regarding long-term effects, it has been reported that the tree-planting plan, which had been proceeding smoothly under the leadership of religious organizations, came to a halt after the death of the leader (Ishinomori, 2019). Although our survey merely provides a picture of the awareness of the operators of the preserved tree system at a particular time, it also points to future research prospects for a more dynamic, long-term survey.

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NOTES

1. The name of this system is different in each local government, such as Protected Tree (Iwakura City, Aichi Prefecture), Hometown Famous Tree (Okazaki City, Aichi Prefecture.), and Citizen Tree (Kobe City, Hyogo Prefecture). In this paper, however, we specified the term "preserved tree" as in the case of MLIT.
2. Definition of "operators": "operators" refers to those who actually manage the preserved trees. As for the breakdown of respondents, the results of this questionnaire survey showed that nearly 80% of trees were managed by the owners themselves or the parishioners of shrines and temples. There were some cases where the operators asked landscaping companies to take care of their landscaping, but most of these requests were made on an irregular basis, such as requesting a high-altitude work truck once every five years. In most cases, the daily management (disposal of fallen leaves and branches, etc.) was performed by the owners themselves or by the parishioners of shrines and temples. Therefore, most of the "operators" in this study were owners or parishioners.
3. At this survey site, the number of privately owned trees was 28 out of 856 in City of Nagoya, 5 out of 42 preserved trees in Shizuoka City, and 1 out of 31 preserved forests.
4. "The Minutes of the 40th House of Councilors Construction Committee Meeting" (26), April 26, 1962. Remark by Hajime Tanaka.
5. "The 114th House of Representatives Construction Committee" (5), June 14, 1989. Remark by Kiyoshi Ohno.
6. "The Minutes of the 40th House of Councilors Construction Committee Meeting" (26), April 26, 1962. Remark by Tadashi Kuranari.
7. The Green Conservation Areas: Systems that also aim to improve a favorable urban environment, based on "Urban Green Space Conservation Act."
8. Regarding the inclusion of public land in the Preservation Tree System for private land, the Nakajima (1986) also shows that preserved trees were on public land. I cannot explain why public land is included; it can be considered that each local government applies the Preservation Tree System to public land.

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Appendix Information regarding preserved trees from each Local Governments

Area	Name of local governments	Number of trees	Number of owners	Subsidies (Yen/tree)	Description
Hokkaido	Hokkaido*	113	-	-	-
Hokkaido	City of Sapporo	103	36	5,000	1
Hokkaido	City of Hakodate	157	-	2,000	-
Hokkaido	Otaru City	33	13	-	1
Hokkaido	Muroran City	25	-	-	1
Hokkaido	Obihiro City	19	18	-	1
Hokkaido	Kitami City	72	36	-	-
Hokkaido	Tomakomai City	3	3	-	-
Hokkaido	Ebetsu City	109	-	2,500	1
Hokkaido	Fukagawa City	5	5	-	1
Hokkaido	Eniwa City	11	-	-	-
Hokkaido	Ishikari City	8	4	-	1
Hokkaido	Bihoro Town	15	10	-	-
Tohoku	Hachinohe City	44	-	-	1
Tohoku	Hirakawa City	106	-	-	-
Tohoku	Kitakami City	72	-	-	-
Tohoku	Sendai City	179	110	-	1
Tohoku	Tagajo City	16	15	9,000	1
Tohoku	Akita City	-	-	-	1
Tohoku	Yamagata City	-	-	-	1
Tohoku	Sakata City	-	-	-	1
Tohoku	Fukushima City	35	29	-	1
Tohoku	Aizuwakamatsu City	72	31	-	-
Tohoku	Iwaki City	103	-	-	1
Kanto	Mito City	102	45	3,000	1
Kanto	City of Takahagi	17	-	-	1
Kanto	Toride City	-	-	2,700	-
Kanto	City of Ushiku	37	21	-	1
Kanto	City of Hitachinaka	47	-	-	1
Kanto	Moriya City	33	22	5,000	1
Kanto	City of Naka	21	18	-	-
Kanto	Shirosato Town	5	5	-	-
Kanto	Tokai Village	-	-	-	1
Kanto	Ami Town	-	-	-	1
Kanto	Oyama City	-	-	2,000	1
Kanto	Moka City	-	-	-	1
Kanto	Maebashi City	-	-	-	1
Kanto	Takasaki City	-	-	3,000	1
Kanto	Kiryu City	13	18	-	-
Kanto	City of Ota	-	-	5,000	1
Kanto	Numata City	15	15	-	-
Kanto	Saitama Prefecture*	-	-	-	1
Kanto	Saitama City	-	-	7,500	1
Kanto	Kawagoe City	-	-	3,600	1
Kanto	Kawaguchi City	-	-	-	1
Kanto	Tokorozawa City	-	-	-	1
Kanto	Kazo City	63	-	3,000	1
Kanto	Honjo City	15	14	-	-
Kanto	Sayama City	-	-	2,200	1
Kanto	Konosu City	-	-	-	1
Kanto	Ageo City	-	-	-	1
Kanto	Soka City	144	-	-	1
Kanto	Koshigaya City	-	-	-	1
Kanto	Warabi City	-	-	-	1
Kanto	Toda City	-	-	-	1
Kanto	City of Asaka	-	-	2,400	1
Kanto	Wako City	633	-	4,000	1
Kanto	Niiza City	-	-	-	1
Kanto	Okegawa City	-	-	2,500	1
Kanto	Kuki City	-	-	1,800	1
Kanto	Kitamoto City	-	-	3,000	-
Kanto	Yashio City	-	-	2,000	1
Kanto	Fujimi City	64	-	3,000	1
Kanto	Misato City	-	-	-	1
Kanto	Hasuda City	-	-	3,000	-
Kanto	City of Sakado	-	-	-	1

Appendix (continued)

Area	Name of local governments	Number of trees	Number of owners	Subsidies (Yen/tree)	Description
Kanto	City of Tsurugashima	3	3	-	-
Kanto	Yoshikawa City	-	-	-	1
Kanto	Fujimino City	-	-	-	1
Kanto	Shiraoka City	7	-	5,000	1
Kanto	Miyoshi Town	-	-	-	1
Kanto	Moroyama Town	4	-	-	-
Kanto	Ogose Town	-	-	3,000	-
Kanto	Ranzan Town	-	-	5,000	-
Kanto	Ogawa Town	15	-	-	-
Kanto	Sugito Town	48	-	2,000	-
Kanto	Chiba City	-	-	3,000	1
Kanto	Ichikawa City	-	-	-	1
Kanto	Funabashi City	-	-	-	1
Kanto	Matsudo City	-	-	2,000	1
Kanto	Noda City	-	-	3,500	-
Kanto	Sakura City	177	87	3,000	1
Kanto	Narashino City	13	-	-	1
Kanto	Ichihara City	-	-	4,000	1
Kanto	Nagareyama City	126	89	-	-
Kanto	Kamagaya City	13	6	-	-
Kanto	Yachiyo City	81	-	-	1
Kanto	Kimitsu City	24	-	-	-
Kanto	Urayasu City	-	-	5,000	1
Kanto	Yotsukaido City	-	-	3,000	-
Kanto	Sodegaura City	-	-	1,000	1
Kanto	Chiyoda City	3	1	-	1
Kanto	Minato City	-	-	7,500	1
Kanto	Shinjuku City	-	-	-	1
Kanto	Bunkyo City	-	-	-	1
Kanto	Taito City	286	-	10,000	1
Kanto	Sumida City	-	-	-	1
Kanto	Koto City	-	-	5,000	1
Kanto	Shinagawa City	-	-	-	1
Kanto	Meguro City	-	-	6,000	1
Kanto	Ota City	-	-	8,400	1
Kanto	Setagaya City	-	-	-	1
Kanto	Shibuya City	560	-	-	1
Kanto	Nakano City	368	-	10,000	1
Kanto	Suginami City	-	-	5,500	1
Kanto	Toshima City	-	-	-	1
Kanto	Kita City	-	-	-	1
Kanto	Arakawa City	-	-	-	1
Kanto	Itabashi City	-	-	3,000	1
Kanto	Nerima City	-	-	-	1
Kanto	Adachi City	477	-	5,250	1
Kanto	Katsushika City	-	-	6,000	1
Kanto	Edogawa City	-	-	-	1
Kanto	Tachikawa City	-	-	4,500	1
Kanto	Musashino City	-	-	6,000	1
Kanto	Mitaka City	-	-	-	1
Kanto	Fuchu City	-	-	4,000	1
Kanto	Akishima City	-	-	-	1
Kanto	Chofu City	-	-	4,000	1
Kanto	Machida City	-	-	-	1
Kanto	Koganei City	-	-	2,000	-
Kanto	Kodaira City	-	-	-	1
Kanto	Higashimurayama City	-	-	-	1
Kanto	Kokubunji City	-	-	4,000	1
Kanto	Kunitachi City	-	-	-	1
Kanto	Fussa City	-	-	-	1
Kanto	Komae City	462	-	3,000	1
Kanto	Higashiyamato City	-	-	3,000	-
Kanto	Kiyose City	-	-	1,000	-
Kanto	Higashikurume City	-	-	3,100	1
Kanto	Musashimurayama City	-	-	4,500	1
Kanto	Tama City	-	-	4,000	1

Appendix (continued)

Area	Name of local governments	Number of trees	Number of owners	Subsidies (Yen/tree)	Description
Kanto	Inagi City	-	17	2,000	1
Kanto	Hamura City	27	-	5,000	1
Kanto	Nishitokyo City	-	-	-	1
Kanto	Mizuho Town	32	-	6,000	1
Kanto	City of Yokohama	590	-	-	1
Kanto	Kawasaki City	-	-	-	1
Kanto	Sagamihara City	-	-	-	1
Kanto	Hiratsuka City	67	43	4,000	1
Kanto	Kamakura City	-	-	1,800	1
Kanto	Fujisawa City	-	-	2,000	1
Kanto	Chigasaki City	61	-	4,500	1
Kanto	Hatano City	30	-	7,000	1
Kanto	Atsugi City	-	-	4,500	1
Kanto	Yamato City	-	-	1,500	1
Kanto	Isehara City	-	-	5,000	1
Kanto	Ebina City	-	-	4,000	1
Kanto	Ayase City	-	-	-	1
Kanto	Samukawa Town	-	-	8,000	-
Kanto	Oiso Town	-	-	-	1
Kanto	Kofu City	-	-	3,000	-
Kanto	Fuefuki City	-	-	-	1
Chubu	Niigata City	265	-	5,000	1
Chubu	Shibata City	42	-	-	-
Chubu	Toyama City	-	-	2,000	1
Chubu	Takaoka City	-	-	-	1
Chubu	Kanazawa City	420	191	10,000	1
Chubu	Nagano City	73	97	4,000	1
Chubu	Matsumoto City	-	-	-	1
Chubu	Komagane City	5	-	-	1
Chubu	Saku City	12	12	-	-
Chubu	Chikuma City	44	28	-	1
Chubu	Gifu City	175	89	5,000	1
Chubu	Takayama City	-	-	-	1
Chubu	Tajimi City	51	48	10,000	1
Chubu	City of Minokamo	14	-	-	1
Chubu	Kakamigahara City	-	-	4,000	1
Chubu	City of Shizuoka	78	55	-	1
Chubu	Hamamatsu City	58	51	10,000	1
Chubu	Fujinomiya City	72	-	-	-
Chubu	Kakegawa City	-	-	-	1
Chubu	City of Nagoya	856	234	3,000	1
Chubu	Okazaki City	92	-	-	1
Chubu	Handa City	50	20	2,000	1
Chubu	Kasugai City	292	-	-	1
Chubu	Hekinan City	-	-	2,500	-
Chubu	Kariya City	-	-	-	1
Chubu	Toyota City	223	-	-	1
Chubu	Anjo City	-	-	2,500	-
Chubu	Nishio City	-	-	-	1
Chubu	Inazawa City	-	-	1,500	1
Chubu	Tokai City	-	-	1,000	1
Chubu	Chita City	86	29	-	1
Chubu	Owariasahi City	-	-	2,500	1
Chubu	Iwakura City	-	-	2,000	1
Chubu	Nagakute City	9	6	3,000	1
Chubu	Togo Town	4	-	-	-
Chubu	Oguchi Town	-	-	1,500	1
Chubu	Higashiura Town	-	-	2,000	1
Kinki	Hikone City	12	-	-	1
Kinki	Otsu City	-	-	-	1
Kinki	Kusatsu City	85	29	-	1
Kinki	Higashiomi City	29	20	-	1
Kinki	Kyoto City	38	38	-	1
Kinki	Joyo City	38	27	-	1
Kinki	Nagaokakyo City	16	12	3,000	1
Kinki	Yawata City	-	-	5,000	-
Kinki	City of Osaka	-	-	-	1

Appendix (continued)

Area	Name of local governments	Number of trees	Number of owners	Subsidies (Yen/tree)	Description
Kinki	City of Osaka	-	-	-	1
Kinki	Neyagawa City	48	16	5,000	1
Kinki	Sakai City	165	95	-	1
Kinki	Toyonaka City	-	-	10,000	1
Kinki	Ikeda City	-	-	5,000	1
Kinki	Suita City	-	-	-	1
Kinki	Izumiotsu City	11	9	-	1
Kinki	Takatsuki City	29	-	-	1
Kinki	Hirakata City	-	-	-	1
Kinki	Ibaraki City	109	26	-	-
Kinki	Tondabayashi City	-	-	5,000	-
Kinki	Kawachinagano City	-	-	-	1
Kinki	Minoh City	80	13	20,000	-
Kinki	Osakasayama City	-	-	20,000	-
Kinki	City of Kobe	254	70	-	1
Kinki	Himeji City	-	-	-	1
Kinki	Amagasaki City	222	-	-	1
Kinki	Nishinomiya City	152	-	-	1
Kinki	Ashiya City	26	16	10,000	1
Kinki	Takasago City	19	-	-	-
Kinki	Tenri City	2	-	-	1
Kinki	Nara City	24	-	-	1
Kinki	Sakurai City	2	2	-	1
Kinki	Gose City	4	-	-	-
Kinki	Ikoma City	20	-	-	1
Kinki	Katsuragi City	1	-	-	-
Chugoku/Shikoku	Tottori City	27	24	-	1
Chugoku/Shikoku	Kurayoshi City	62	-	-	1
Chugoku/Shikoku	Okayama City	69	-	-	1
Chugoku/Shikoku	City of Hiroshima	73	57	-	1
Chugoku/Shikoku	City of Fukuyama	62	-	3,000	1
Chugoku/Shikoku	Shimonoseki City	38	-	-	1
Chugoku/Shikoku	Yamaguchi City	17	-	-	-
Chugoku/Shikoku	Hagi City	64	-	-	1
Chugoku/Shikoku	Kagawa Prefecture*	124	-	-	1
Chugoku/Shikoku	Takamatsu City	46	-	-	1
Chugoku/Shikoku	Marugame City	3	3	-	1
Chugoku/Shikoku	Sakaide City	24	17	-	-
Chugoku/Shikoku	Matsuyama City	25	20	-	1
Chugoku/Shikoku	Imabari City	-	-	5,000	-
Chugoku/Shikoku	Kochi City	-	-	-	1
Kyushu	City of Kitakyushu	130	64	5,000	1
Kyushu	Fukuoka City	1848	-	-	1
Kyushu	Omuta City	-	-	-	1
Kyushu	Kurume City	-	-	3,000	1
Kyushu	Chikugo City	-	-	-	1
Kyushu	Kasuga City	-	-	3,000	-
Kyushu	Onojo City	-	-	3,000	1
Kyushu	Asakura City	-	-	-	1
Kyushu	Saga City	70	54	-	1
Kyushu	Kumamoto City	-	-	-	1
Kyushu	Oita City	85	63	-	-
Kyushu	Beppu City	90	-	-	1
Kyushu	Hita City	-	-	-	1
Kyushu	Miyazaki City	-	-	-	1
Kyushu	Hyuga City	22	11	-	1
Kyushu	Takanabe Town	-	-	-	1
Kyushu	Kagoshima City	43	-	-	1
Kyushu	Amami City	12	-	-	-
Kyushu	Wadomari Town	11	-	-	-

Source: MLIT (2017) and each local government's website.

Note: Only the information provided by the local governments are listed.

Identified species of trees are only listed.

Number of trees mentioned in “Hokkaido”, “Saitama Prefecture”, and “Kagawa Prefecture” are not the subtotal of local governments.

The shaded number indicates the average annual amounts provided as subsidies from local governments. The size of the amounts depends on the factors such as number of years registered, size and length of trees etc.

Description of the system that local government were able to confirm are indicated as "1".

Short Communication

Stem Analysis of a Pollarded Wild Sugi (*Cryptomeria japonica*) Tree

Satoshi Tatsuhara[1,*], Keigo Tanaka[1], Koji Yamada[2], Hiromi Akashi[2] and Kimio Takeuchi[2]

ABSTRACT

This study proposes a way to apply stem analysis to pollarded trees and to show the relationship between the growth of a pollarded tree and topping the main trunk. As an example, we examined a pollarded wild sugi (*Cryptomeria japonica*) tree. The study tree was in a sugi plantation with scattered wild sugi trees in Tsunagi hamlet, Aga Town, Niigata Prefecture, Japan. The main trunk was thought to have been broken by heavy snow. The part of a coppiced tree that differs most from a single-stemmed tree is the area that connects the remaining trunk and the pollard shoots. Examining disks taken by slicing through part of the tree allows the budding location and timing of the formation of the shoots to be determined from the distribution of annual rings. This study showed that losing the upper part of the trunk had a great effect on the secondary growth of the remaining trunk, suggesting that topping a main trunk also affects the secondary growth of the remaining trunk. Competition between the shoots was found, suggesting that in order to obtain large, high quality logs from the remaining trunks, shoots that are likely to die are pruned before they put on much growth.

Keywords: Cryptomeria japonica, growth, pollard, pollard shoot, stem analysis

INTRODUCTION

The 'daisugi' system which is practiced in the Kitayama area, Kyoto, Japan, involves pollarding of sugi (*Cryptomeria japonica* D. Don): The trees are pruned 5–6 years after planting leaving only branches at about 0.6 m above the ground, above this the trunks are cut and pollard shoots allowed to grow from the remaining trunks; The shoots are selectively harvested, producing a standard size that is used for building materials (Shigemoto, 1950). In areas with heavy snow in the Tohoku region and Niigata Prefecture, Japan, there are pollarded beech (*Fagus crenata*) trees with multi-forked trunks that branch more than 2–3 m above the ground (Nakashizuka et al., 2000; Suzuki, 2019).

Scattered populations of pollarded wild sugi trees in Otokoro hamlet in Itoigawa City and Tsunagi and Nakanosawa hamlets in Aga Town, Niigata Prefecture, Japan, have a similar tree form to the 'daisugi', with multi-forked trunks that branch more than 2 m above the ground (Tatsuhara et al., 2017; Tatsuhara et al.,2020). Suzuki (2019) found rapid growth in terms of diameter in a disk taken from the remaining trunk of a pollarded wild sawara cypress (*Chamaecyparis pisifera*) tree and pointed out that cutting the main trunk stimulates the growth of the trunk that is left; thus, the pollarding system for wild sugi trees in the Katanami River headstream area is suited to obtaining large boards from the remaining trunks.

Ghahramany et al. (2017) assessed the effect of pollarding on the diameter growth of Lebanon oak (*Quercus libani* Oliv.) trees in Northern Zagros, Iran by measuring sample trees in a pollarded stand with sample trees in a less-disturbed stand. Dufour et al. (2018) also assessed the effect of pollarding on the diameter and height growth of hybrid walnut trees by examining pollarded trees and control trees four years after pollarding. Suzuki (2019) demonstrated a change of diameter growth with increment cores from remaining trunks and pollard shoots of wild sawara cypress trees. However, the growth of pollarded trees has rarely been studied in detail.

In this study we aimed to propose a way to apply stem analysis to pollarded trees and, using such analysis, to examine the growth of a wild sugi tree that has lost the upper part of its trunk. We examined the effect of losing the upper part of a trunk on the growth of the remaining trunk and the relationships between the growth of different pollard shoots.

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Fig. 1 Photograph of the pollarded wild sugi tree studied.

METHODS

Study Site

The study site was a sugi plantation with additional scattered wild sugi trees in Tsunagi hamlet, Aga Town, Niigata Prefecture, Japan (37° 48' N, 139° 26' E). This stand used to be a hardwood secondary forest with scattered wild sugi trees. In 1978, hardwood trees were harvested by clear-cutting and the wild sugi trees were left. There are no records that wild sugi trees were cut except trees with trunks damaged by snow.

In this hamlet, charcoal making was the main source of cash income until around 1965, and hardwood secondary stands used to be clear-cut in a 15 to 25 year-rotation (Tatsuhara et al., 2020). Nobody has reported pollarding of wild sugi in this hamlet (Tatsuhara et al., 2020). All forests in this hamlet are owned privately. Because the hamlet's commons were incorporated into the national forest in 1875, this hamlet initiated a lawsuit to get the forests back from the government in 1890, which they won in 1898 (Nihei, 1995).

Stem Analysis Procedure

A pollarded tree was divided into three parts: the remaining trunk, the pollard shoots, and the area between the remaining trunk and the pollard shoots. (i) Two disks are taken from the remaining trunk part; one from the bottom and one from the top part where it was unaffected by the shoots. The annual rings of the disks are measured. (ii) A reference level was set for each pollard shoot. Disks were taken from the shoots as if they were single trees and the reference levels were considered to be 0 m. Disks were taken from each shoot at the reference level, 1 m from the reference level, then at 2-m intervals above this and to within 3 m of the end of the shoot; in the final <3 m section, disks were collected every 1m. The last part was sampled differently to the standard method used in Japan, that is, if the final section after the 2-m interval samples was less than 3 m, a single additional disk was taken 1m along the stem (Osumi, 1987). Annual rings on the disks were measured. (iii) Some disks were taken from the part between the remaining trunk and shoots by slicing into it; annual rings were not measured but just counted because more than one stem is merged in each disk, so the shapes of disks and annual rings are complex and they vary greatly with height above the ground. Annual rings on both sides of the disks were counted in order to obtain more information with the same number of samples.

Practicing Stem Analysis

We chose one pollarded wild sugi tree in the stand (Fig. 1), and carried out stem analysis of the tree following the procedure described above. The tree was cut down and disks were taken from the tree on 13th September, 2019. According to the owner of this stand, the main trunk was broken by heavy snow. After the tree was cut, disks D0 and D1 were taken from the remaining trunk at 0.15 m and 1.13 m above the ground, respectively. The height 1.13 m was chosen because, at this point, the bulge caused by the shoots had little effect on the diameter of the remaining trunk. Three disks of D2, D3, and D4 were taken from the section between the remaining trunk and shoots, which was between 1.13 m and 2.13m above the ground. The heights of either side of disks D2, D3, and D4 were 1.43 m and 1.53 m, 1.73 m and 1.83 m, and 2.03 m and 2.13 m, respectively. The tree had four live shoots and three bases of dead shoots. The live shoots were numbered from 1 to 4 clockwise starting from the direction of the highest ground. The reference level (0 m) for each shoot was set at its base, which was as low as possible and as straight as possible. For each reference, the height above the ground was measured. Disks were then taken according to the procedure above. The dead shoots were numbered M1 to M3 clockwise starting from the direction of the highest ground.

Disks D0 and D1 and disks from the shoots were scanned at 300 dpi with an Epson ES-G11000 flatbed scanner and the widths of annual rings in the image files were measured with Dendro Measure (Nobori, 2005). Diameter and cross-sectional area for each year and each disk were calculated. Total height of the main trunk before it reached 1.13 m tall and height from the reference level of each shoot in each year was calculated using Stem Density Analyzer (Nobori et al., 2004). Volume for each year was calculated from cross-sectional area and total height. Pictures of both sides of disks D2, D3, and D4 from the area between the remaining trunk and the shoots as well as the upper side of D1 were taken with a Sony α NEX-5N digital camera. When annual rings were counted, the calendar year and the age when the main trunk and shoots reached the disk's height were determined.

Estimating the Year When the Main Trunk was Broken and its Height and Diameter outside Bark in that Year

The calendar year and age when the main trunk reached the height of each disk were determined from the difference in the number of annual rings between disk D0 at 0.15 m and each measured disk. We counted the number of annual rings of the remaining trunk from the uppermost disk for which the calendar year could be determined. Then the calendar year in which the main trunk was broken was estimated by adding the calendar year to reach the height of the uppermost disk to the number of annual rings in the remaining trunk in the uppermost disk at height above the ground as follows:

$$y = y' + n, \tag{1}$$

where y is the calendar year in which the main trunk was broken, y' is the calendar year to reach the height of the uppermost disk, and n is the number of annual rings in the remaining trunk in the uppermost disk. The height where the main trunk was broken was estimated as follows:

$$h = l + g \times n, \tag{2}$$

where h is the height at which the main trunk was broken, l is the height in calendar year y', and g is the annual height increment.

Furthermore, the diameter at 1.13 m in the year when the trunk was broken was estimated. Once the year had been estimated, the diameter inside the bark at 1.13 m in that year was determined. Knowing the bark thickness is necessary to estimate the diameter outside the bark from the diameter inside the bark. To estimate the ratio of the bark thickness of both sides to the diameter inside the bark (hereafter bark thickness ratio), the following equation was applied to the measurements of the diameter inside the bark and the bark thickness ratio of the disks from the four living shoots:

$$BTR = \alpha\, DIB^{-\beta}, \tag{3}$$

where BTR is bark thickness ratio and DIB is the diameter inside the bark. This equation was originally used to express the relationship between DBH and the mean bark thickness percentage at breast height (Nakayama, 1957). Next, bark thickness of both sides of the trunk at 1.13 m was estimated from the diameter inside the bark at 1.13 m with Eq. (3). The diameter at 1.13 m was estimated by adding the bark thickness of both sides to the diameter inside the bark.

Finding the Inflection Points in the Growth of the Tree

We determined one-year increments for the diameter and cross-sectional area at 0.15 m and 1.13 m on the main trunk and at the reference height for the four shoots as well as one-year increments of the heights of the main trunk and the four shoots from the stem analysis. Five-year increments were calculated from the one-year increments and plotted on graphs to display the growth trends in terms of diameter, cross-sectional area, and height. After identifying inflection points in the trends of periodic annual increments, we calculated regression equations based on the one-year increments before and after these points, then tested whether the regression coefficient after the point was statistically larger than the one before the point according to the t-statistic, as follows:

$$t = \frac{a_2 - a_1}{\sqrt{\dfrac{s_1 + s_2}{n_1 + n_2 - 4}}\sqrt{\dfrac{1}{S_{x1^2}} + \dfrac{1}{S_{x2^2}}}}, \tag{4}$$

$$s_1^2 = S_{y1^2}\left(1 - R_1^2\right),$$

$$s_2^2 = S_{y2^2}\left(1 - R_2^2\right),$$

Degrees of freedom = $n_1 + n_2 + 4$,

where a_i, S_{xi^2}, S_{yi^2}, R_i^2 and, n_i are the regression coefficient, the sum of the deviation squares of x_i, the sum of the deviation squares of y_i, the multiple regression coefficient, and the sample size of the i-th measurement group (i =1 before the inflection points or 2 after the inflection points) (Tomita and Uchiyama, 2004). When inflection points in the trends of total increments was found, we calculated the average of one-year increments before and after the inflection points, then we examined whether the average of the increments after the point was statistically larger than that before the point using Welch's t test based on the following statistic:

$$t = \frac{\bar{x}_2 - \bar{x}_1}{\sqrt{\dfrac{s_1^2}{n_1} + \dfrac{s_2^2}{n_2}}}, \tag{5}$$

$$\text{Degrees of freedom} = \frac{\left(\dfrac{s_1^2}{n_1} + \dfrac{s_2^2}{n_2}\right)^2}{\dfrac{s_1^4}{n_1^2\left(n_1 - 1\right)} + \dfrac{s_2^4}{n_2^2\left(n_2 - 1\right)}},$$

where $\bar{x}_i$, s_i, and n_i are the average, unbiased variance, and sample size of the i-th measurement group (i =1 before the inflection points or 2 after the inflection points).

RESULTS

Measurements of External Form

The girth of the study tree was 2.55 m at 0.8 m above the ground and its total height was 25.14 m. The heights, the heights to the bottom of the crown, and the reference levels of live shoots were measured and the locations of the three dead shoots were recoded (Table 1). Both live and dead shoots grew straight up. The tree had frost crack, which it made it difficult to count and measure annual rings on some disks.

Estimating the Year When the Main Trunk was Broken and its Height and Diameter outside Bark in that Year

There were 152 annual rings in disk D0 at 0.15 m and the

Table 1 Details of the pollard shoots

No.	Reference (m)	Height from the reference to the tip (m)	Total height (m)	Height from the reference to the bottom of crown (m)	Height to the bottom of crown (m)	Note
1	2.46	20.16	22.62	2.66	5.12	
M1						Dead, between 1 and 2
2	2.46	22.68	25.14	4.55	7.01	
3	1.96	9.67	11.63	1.66	3.62	Extend outward
M2						Dead, between 4 and main trunk
4	2.40	7.92	10.32	2.44	4.84	Extend outward
M3						Dead, between 4 and main trunk

central ring of the disk was found to have formed in 1868. Although the actual tree age is 152 plus the number of years it took the tree to reach 0.15 m, the tree was regarded as being 152 years old.

There were 127 annual rings in the main trunk on disk D1 at 1.13 m, and 120 annual rings in the main trunk on upper side of disk D3 at 1.83 m and the upper side of disk D2 at 1.53 m. The total height in 1893 and 1900 was determined to be 1.13 m and 1.83 m, respectively. Annual rings of the main trunk were not counted on the lower side of disk D3 at 1.73 m and the lower side of disk D2 at 1.43 m because of damage caused by frost cracking. The average annual height increment was 0.05 m during the five years just before the main trunk reached 1.13 m tall in 1893. The 6-year increment was estimated to be 0.3 m just after main trunk reached 1.13 m tall by multiplying 0.05 m by 6. It was for 6 years to grow from 1.13m to 1.43m on height. Main trunk was estimated to be 1.43m in 1899. Because this value was less than 1.53 m and consistent with the fact that the total height had already reached 1.53 m during the growth period of 1900, the total height in 1899 was determined to be 1.43 m. The annual height increment in 1900 was calculated to be 0.40 m·year^{-1}. There were 9 annual rings (n) of the remaining trunk in the uppermost disk at the height of 2.13 m (l). The calendar year when the main trunk reached 2.13 m tall was estimated to be 1901 (y'), based on the height difference between the two disks at 1.83 m and 2.13 m and the annual height increment of 0.30 m·year^{-1} (g), and the total height in 1901 was estimated to be 2.13 m. Therefore, the main trunk was estimated to have been broken as a result of heavy snow accumulation in 1910 (y) at 4.83 m (h), according to Eqs. (1) and (2). The age of the tree was 43 years from 1899 to 1900.

In 1910, the diameter inside the bark was 11.4 cm at 1.13 m. Parameters α and β of Eq. (3) were determined to be 0.166 and −0.381, respectively, and the bark thickness ratio and the bark thickness of both sides at 1.13 m were estimated to be 0.0657 and 0.75 cm, respectively. The diameter outside the bark at that height was estimated to be 12.2 cm, based on adding the bark thickness to the diameter inside the bark. The tree was 111 years old when hardwood trees were harvested and sugi seedlings were planted in the stand in 1978.

Secondary Growth of the Remaining Trunk and Primary Growth of the Pollard Shoots

The cross-sectional area increment at 0.15 m increased rapidly around the time when the main trunk was broken, followed by an increase in the cross-sectional area increment at 1.13 m around the age of 90 years (Fig. 2). Statistical tests showed the regression coefficients for the cross-sectional area increment at 0.15 m and 1.13 m to tree age were significantly different at the ages of 49 years and 88 years, respectively (Table 2). The diameter increment at 0.15 m also increased rapidly around the time that the main trunk was broken, and statistical tests showed the regression coefficients of the diameter increment at 0.15 m to tree age were significantly different before and after the age of 49 years (Table 2); although the diameter increment at 1.13 m was large from the time when the main trunk reached that height, it did not change after the main trunk was broken, and varied between 0.5 and 0.7 cm year^{-1} during the first 40 years (Fig. 3). Around the age of 85 years when the cross-sectional area increment at 0.15 m dropped (Fig. 2), the height increment of shoot 2 increased, and shoots 1 and 3 started to grow (Fig. 4). Statistical tests showed the average height increments of shoot 2 were significantly different before and after the age of 88 years (Table 2). In 1978 when hardwood trees were harvested and sugi seedlings were planted, at the age of 111 years, the height increment of shoot 3 increased (Fig. 4), and statistical tests showed the average height increments of shoot 4 were significantly different before and after the age of 112 years (Table 2). Moreover, the cross-sectional area increment at 0.15 m increased again, and this was followed by an increase in the cross-sectional area increment at 1.13 m (Fig. 2).

Budding and Growth of Pollard Shoots

Seven shoots were found based on the external form (Table 1). However, an additional shoot was identified when examining the photographs of disks D2, D3, and D4 (Fig. 5). This shoot was

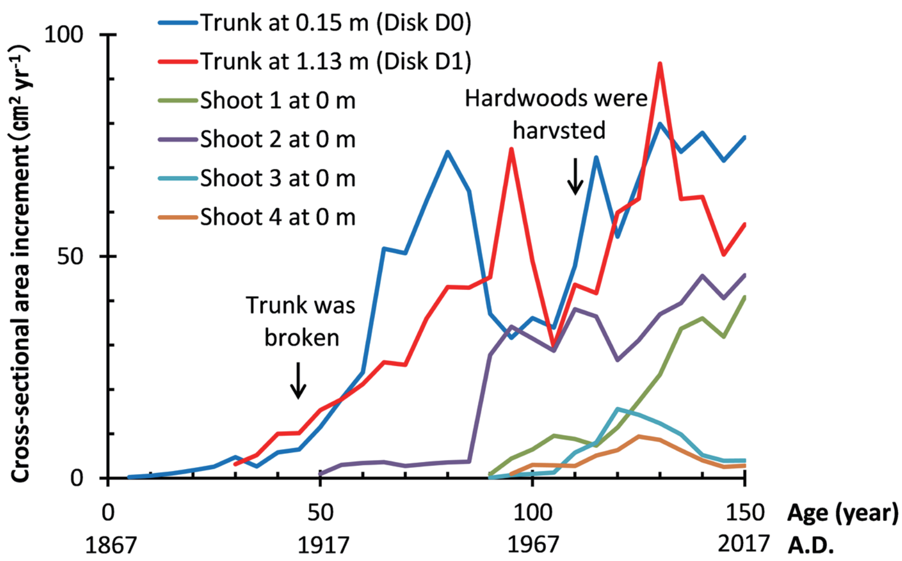

Fig. 2 Five-year increments of cross-sectional areas of the trunk and the bottoms of the pollard shoots.

Table 2 Results of statistical tests of difference in regression coefficients and average increments before and after the change points

Disk height (m)	Tree parameter	Calendar year	Age (year)	Number of observation	Regression coefficient	Degrees of freedom	*t*
0.15	Basal area	1896–1915	29–48	20	0.1864	36	7.72 **
		1916–1935	49–68	20	2.506		
1.13	Basal area	1945–1954	78–87	10	−0.022	16	2.13 *
		1955–1964	88–97	10	6.762		
0.15	Diameter	1896–1915	29–48	20	0.0008	36	5.07 **
		1916–1935	49–68	20	0.043		
Shoot No.	**Tree parameter**	**Calendar year**	**Age (year)**	**Number of observation**	**Average annual increment (m year^{-1})**	**Degrees of freedom**	***t***
2	Height	1935–1954	68–87	20	0.100	9	8.86 **
		1955–1964	88–97	10	0.447		
3	Height	1969–1978	102–111	10	0.104	18	5.69 **
		1979–1988	112–121	10	0.295		

** highly significant for a one-sided test; * significant for a one-sided test.

merged with shoot 1 (Table 3), so there had been a total of eight shoots, excluding small ones, which survived for some time. The three dead shoots budded on the remaining trunk between 1.13 m and 1.43 m, live shoots 3 and 4 budded on the remaining trunk at 1.43 m and 1.53 m, respectively, and live shoots 1 and 2 budded between 1.83 m and 2.03 m (Table 3). That is, the more dominant shoots appeared at higher position on the remaining trunk. Moreover, decay was found around the dead shoots (Fig. 5 and Table 3).

DISCUSSION

In this study, we carried out stem analysis on a pollarded tree. The part of a coppiced tree that differs most from a single-stemmed tree is the connecting area between the remaining trunk and the pollard shoots. The distribution of annual rings in this part varied greatly. In this study, we took pictures of six surfaces of three disks taken from this part of the tree (Fig. 5). This is an effective way to determine the budding location and timing of appearance of the pollard shoots based on the distribution of annual rings.

Furthermore, the year when the main trunk was broken and its height and diameter outside the bark at 1.13m in that year were estimated. We can be fairly certain about the year and the diameter because they were mainly based on the number and width of annual rings on disks. In contrast, the estimated height has high uncertainty. This is because its estimation makes use of the height growth at the juvenile stage, which is very slow, although annual rings of the main trunk could not be counted on

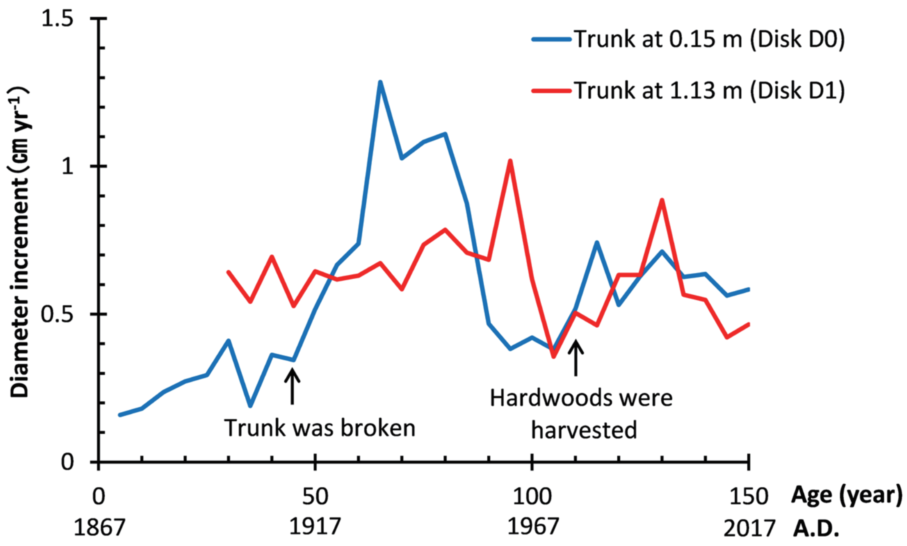

Fig. 3 Five-year increment of the trunk diameter.

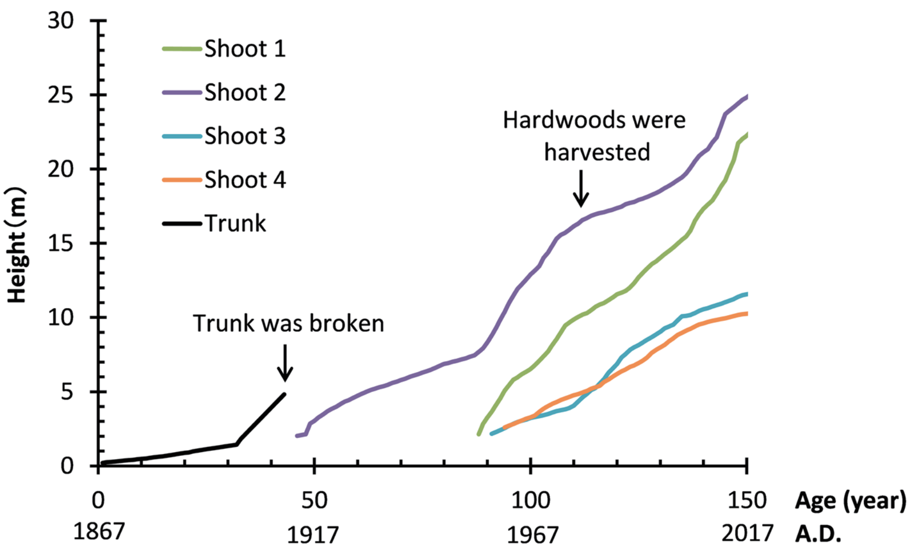

Fig. 4 Change in the total heights of the trunk and the shoots.

the two disk side, in addition to the number and width of annual rings. Nevertheless, the estimated height was consistently greater than 2.46 m, which was the highest shoot reference height.

The stem analysis showed that the cross-sectional growth and diameter growth visible in the disk taken at 0.15 m increased rapidly several years after the main trunk was broken (Figs. 2 and 3). This is consistent with Suzuki's (2019) observation of a disk from a remaining trunk of a pollarded wild sawara cypress tree. On the other hand, the diameter growth visible in the disk from 1.13 m was almost constant (Fig. 2), although the cross-sectional growth increased after the main trunk was broken (Fig. 3). Sawata et al. (2007) showed that the diameter growth of wild sugi trees varied between 0.24 and 0.52 cm year^{-1} and inferred that their growth increased after dominant trees in the stands were cut, thus releasing these understory trees. For the tree in this study, the diameter growth at 1.13 m was over 0.5 cm year^{-1} from the beginning (Fig. 3) and the height growth of the main trunk increased rapidly before the main trunk was broken (Fig. 4). This suggests that hardwood trees were harvested before the main trunk was broken and the tree grew rapidly once it reached a height of 1.13 m.

It was confirmed that shoot M2 (now dead) was present before 1900. Thus, a short branch which existed before the main trunk was broken grew straight up. Shoot 1-5 (merged with shoot 1) and shoot 2 started to grow around 1912–1913 (Table 3). Because this was after the main trunk was broken, there are two possibilities: that they sprouted anew or that very small branches grew straight up just after the main trunk was broken. In 1978, when hardwood trees were harvested and sugi seedlings were planted, the height of shoot 3 increased (Fig. 4). In contrast, the

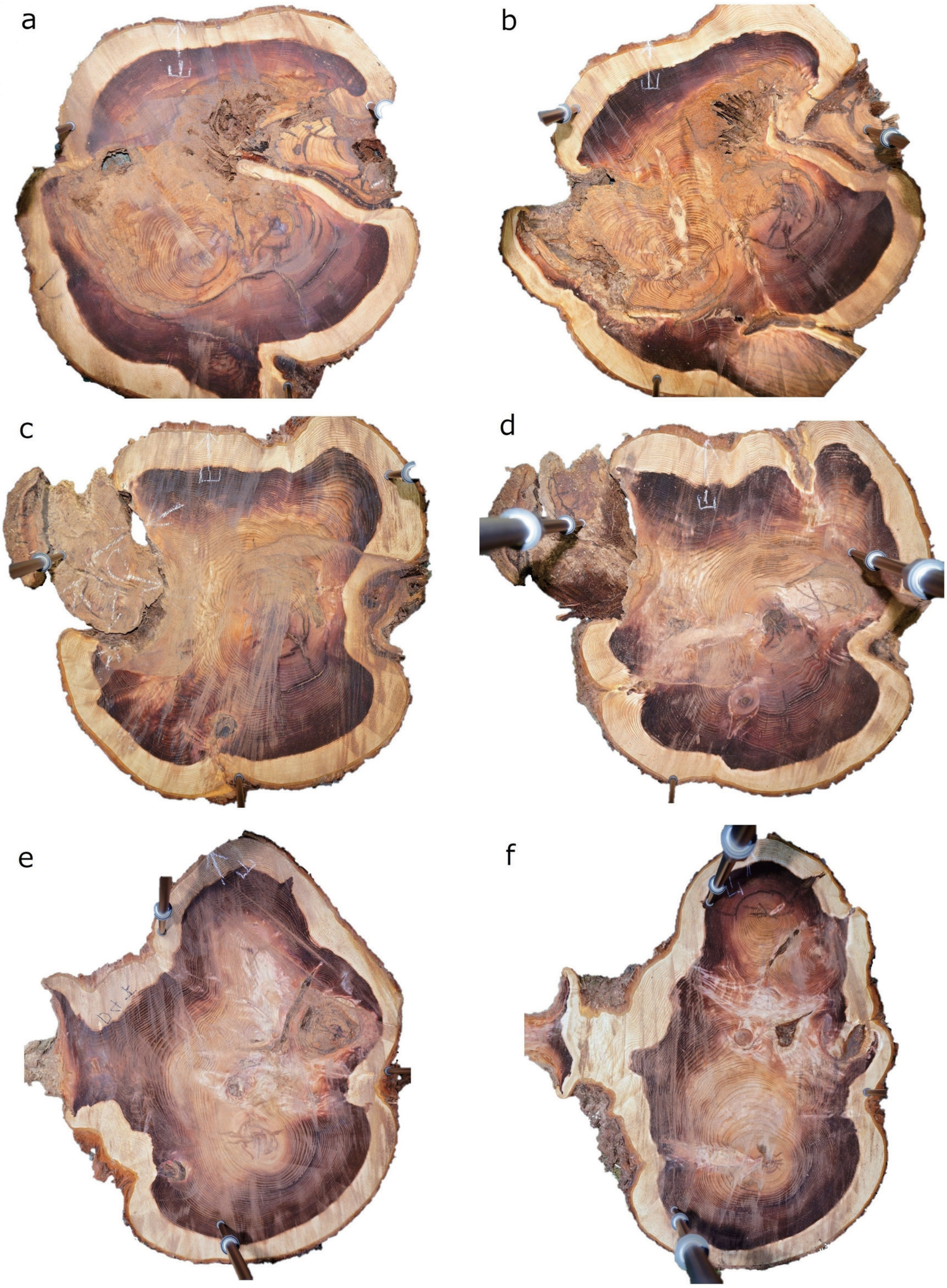

Fig. 5. Disks in the connecting part of the tree at 1.43 m (a), 1.53 m (b), 1.73 m (c), 1.83 m (d), 2.03 m (e) and 2.13 m (f) above the ground.
Disks a, c, and e were flipped horizontally so that their orientation was the same as disks b, d, and f. Disk images were clipped out of photographs using Paint 3D.

height of shoot 4 exhibited constant growth. This may because there were two more shoots, shoots M2 and M3 (now dead), beside shoot 4 at that time (Table 1), and the three shoots competed with each other. Shoots 1 and 3 started to grow around 1952–1953 and the height of shoot 2 increased faster from 1955. This was about 25 years before the surrounding hardwood trees were clearcut, so it is possible that, at this time, hardwood trees in the stand were also clearcut and light conditions got better for

Table 3 Results of stem analysis of the pollard shoots

No.	Height of the lowest disk that annual rings were found (m)	Number of annual rings from the center to the outermost	Height of budding (m)	The earliest year when annual rings were counted		Note
				Calendar year (year)	Age (year)	
1	2.03	68	1.83–2.03	1952	85	
1-2	2.03	69	1.83–2.03	1951	84	Merged with No.1
1-3	2.03	69	1.83–2.03	1951	84	Merged with No.1
1-4	2.03	68	1.83–2.03	1952	85	Merged with No.1
1-5	1.83	108	1.73–1.83	1912	45	Merged with No.1
M1	1.43	Decay	1.13–1.23			Dead
2	2.03	107	1.83–2.03	1913	46	
3	1.53	67	1.43	1953 *1	86 *1	
M2	1.43	Decay	1.13–1.23	1900 *2	33 *2	Dead
4	1.53		Around 1.53	1966 *3	99 *3	
M3	1.43	Decay	1.13–1.43			Dead

*1The year was determined from the disk at 1.96 m above the ground in the connecting part.
*2 The year was determined from the disk at 1.53 m above the ground in the connecting part.
*3 The year was determined from the disk at 2.4 m above the ground, the reference for the pollard shoot.

the remaining sugi trees.

Competition between the pollard shoots was found and the one that emerged from higher up the trunk was dominant over those from lower down the trunk. The dead shoots led to decay. This implies that the shoots which grew and then died caused decay in the remaining trunk. In order to obtain a high-quality large log from a remaining trunk, it is necessary to prevent this kind of mortality of shoots. Therefore, in the pollarding system for wild sugi trees, the shoots that are most likely to die should be pruned before they grow larger.

CONCLUSIONS

In this study we propose a method of stem analysis for pollarded trees, and show that breaking the top part of the main trunk has a large effect on the secondary growth of the remaining trunk. The data presented here suggest that topping the main trunk also affects the secondary growth of the remaining trunk. Competition among the pollard shoots was found, suggesting that shoots which are likely to die should be pruned before they grow much, in order to obtain large, high-quality logs from remaining trunks. However, we carried out the stem analysis on only one tree. Collecting more data is necessary to confirm the results of this study.

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(2) Tables: an editable file in MS Word (doc or docx) or MS Excel (xls of xlsx);
(3) Figures: High-quality image files (TIFF, JPEG, or PNG), an MS PowerPoint (ppt or pptx) file, or a PDF file.

(February 2019)

Guidelines on Publication Ethics

These guidelines are based primarily on the *Guidelines on Good Publication Practice* (COPE, 1999), the *Code of Conduct and Best Practice Guidelines for Journal Editors* (COPE, 2011), the *Recommendations for the Conduct, Reporting, Editing, and Publication of Scholarly Work in Medical Journals* (ICMJE, 2017), and the *International Standards for Authors* (Wager and Kleinert, 2011).

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LITERATURE CITED

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(March 2020)

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