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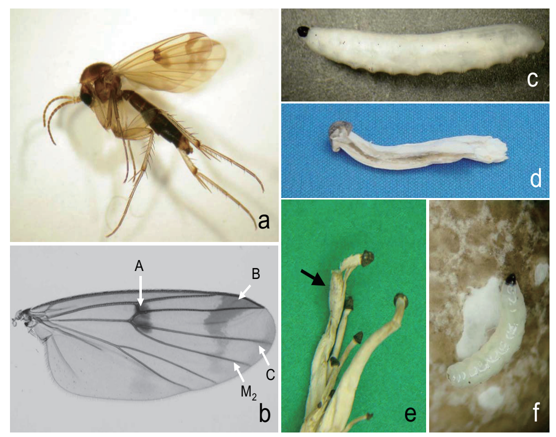

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表紙写真　Photograph in Cover

長野県上高地のカラマツ林
Japanese larch trees in Kamikochi, a highland basin surrounded by high mountains in Nagano Prefecture.

群馬県水上町の落葉広葉樹林(遠景)
Distant view of deciduous broadleaved forest in Minakami, Gunma Prefecture.

(本文123ページ)
Mycetophila rosularia Ostroverkhova (a-c, f) とそれによるブナシメジの被害(d, e).
Mycetophila rosularia Ostroverkhova (a-c, f) and infested Hypsizigus marmoreus (d, e).

担 当 者　　御 中
To the person concerned

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論　文（Original article）

Effects of typhoons on leaf fall in hinoki cypress (*Chamaecyparis obtusa* Endlicher) plantations in Shikoku Island

Yoshiyuki INAGAKI[1)*], Shigeo KURAMOTO[2)], and Hidehisa FUKATA[3)]

Abstract

Leaf fall was measured for 5 years (2002-2006) in adjacent thinned and unthinned plantations of hinoki cypress (*Chamaecyparis obtusa* Endlicher) at two different elevations in Kochi Prefecture, Shikoku Island, Japan. The region was hit by severe typhoons in 2004 and annual leaf fall in that year was 1.17- 2.25 times greater than that in the pre-typhoon period (2002-2003). The effect of the typhoons on annual leaf-fall was greater at the higher elevation. At each elevation, the effect was greater in the thinned plots than in the unthinned plot. Post-typhoon annual leaf-fall (2005-2006) was 1.05- 1.41 times greater than that in the pre-typhoon period (2002-2003). Although the impact of typhoons was greater in the thinned plots, the recovery of leaf litter was not different between the thinned and unthinned plots. The time of leaf fall in the typhoon year became earlier in forests at the higher elevation. At the lower elevation, leaf-fall duration increased in 2004 but the time of leaf fall did not change. The results indicate that susceptibility to strong winds is different between higher and lower elevations: greater leaf fall occurs immediately after strong winds at higher elevations, whereas leaves do not fall immediately after strong winds and damaged leaves fall gradually at lower elevations. These results suggest that the annual leaf fall can be recovered rapidly and that new leaf production may increase substantially after typhoon disturbance.

Key words : hinoki cypress; leaf litter; phenology; recovery; thinning; typhoon

1.Introduction

Typhoons are a major cause of climatic damage to Japanese forests (Kuboyama et al., 2003; Kamimura and Shiraishi, 2007). Many studies have been conducted on uprooting and stem breakage by strong winds and their relation to topography, soil and forest conditions (Kuboyama et al., 2003; Saito and Sato, 2007; Kamimura and Shiraishi, 2007; Kato and Zushi, 2008). In 2004, Japan was struck by many severe typhoons (Typhoon Research Department, 2006) and some forests were critically damaged (Kamimura and Shiraishi, 2007; Kato and Zushi, 2008). Strong winds can cause defoliation of crowns (Takeuchi et al., 2007; Inagaki et al., 2008a).

Defoliation by strong winds can be evaluated by litterfall measurement. Previous studies have investigated the effect of storms on leaf and branch fall in tropical ecosystems (Vogt et al., 1996; Harrington et al., 1997; Herbert et al., 1999) and evergreen hardwood forests (Xu et al., 2004; Sato, 2004), and conifer plantations in Japan (Saito, 1981; Takeuchi et al., 2007, Inagaki et al., 2008a, 2008b). In hinoki cypress plantations, the effects of typhoons have been evaluated by long-term observations of a single stand (Saito, 1981; Inagaki et al., 2008b) and by comparison of several forests in relation to slope direction (Takeuchi et al., 2007) or thinning practices (Inagaki et al., 2008a). Inagaki et al. (2008a) have revealed that the impact of severe typhoons in 2004 was greater in thinned plots than in adjacent unthinned plots in a hinoki cypress plantation in Kochi Prefecture. However, there is no information on leaf litter production after the disturbance and its relation to thinning practices.

The time of leaf fall becomes earlier when forests suffer strong winds (Inagaki et al., 2008a, 2008b). If trees are damaged by strong winds, there would be a significant change in leaf-fall phenology. Several studies have reported that the time of leaf-fall is related with slope position (Tateno et al., 2005) whereas leaf-fall duration is related precipitation (del Alco et al., 1991) or solar radiation (Inagaki et al., 2008b). These studies indicate that leaf-fall phenology is related with water stress of plants as well as temperature. If trees are damaged, trees suffer severe water stress (Muramoto et al., 1998; Ueda and Shibata, 2004) and the time of leaf fall may occur earlier or the leaf fall duration may become longer.

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In the present study, the leaf and branch fall for 5 years including typhoon disturbances in the third year are reported following the results by Inagaki et al. (2008a). We selected hinoki cypress (*Chamaecyparis obtusa* Endlicher) forests at two different elevations. Within each forest we established two adjacent study plots (20m × 20m): a thinned plot and an unthinned plot on the same slope. Annual leaf-fall in heavily defoliated forests was expected to be lower after the typhoon disturbances. The objectives of this study were to determine if 1) annual leaf fall after typhoons is lower in heavily defoliated forests, 2) pattern of leaf-fall phenology changes due to sever damage by strong winds.

2. MATERIALS AND METHODS

2.1 Study Site

The study was conducted in hinoki cypress plantations in two areas, Tengu (33° 28´ N, 133° 0´ E) and Furumiya (33° 26´ N, 133° 1´ E), in the upper part of the Shimanto Basin on Shikoku Island in southern Japan. Hinoki cypress is an evergreen conifer and widely planted for timber production in the region. The general stand characteristics are presented in Table 1. Tengu (TNG) is located at 1,150 m in elevation and is among the highest sites for hinoki cypress plantations on Shikoku Island. The mean annual temperature and annual precipitation are 9.6 °C and 3,140 mm. Hinoki cypress trees were planted on former grassland that was often burned. The plantation was 42 years old in 2002. The soil parent material of the study site is volcanic ash over limestone. The soil is classified as Andisol in soil taxonomy (Soil Survey Staff, 1998) and as a drier subtype of moderately moist black forest soil (BlD(d)) in the Japanese classification of forest soils (Forest Soil Division, 1976).

Furumiya (FMY) is located at an elevation of 710 m. The mean annual temperature and annual precipitation are 13.1 °C and 3,270 mm. Hinoki cypress trees were planted on a former hinoki cypress plantation. The plantation was 23 years old in 2002; some trees remained from a previous rotation (aged 46 years). The soil parent material of the study site is sedimentary rock. The soil is classified as Dystrudept in soil taxonomy and as moderately moist brown forest soil (BD) in the Japanese classification of forest soils.

2.2 Thinning

Two adjacent study plots (20m × 20m) were established at both TNG and FMY. These were of the same contour elevation and had similar stand and soil characteristics (Table 1). A summary of the thinning is provided in Table 2. Thinning was conducted in one plot before the growth period in 2002 (in

Table 1
Summary of the study sites

Study site	TNG	FMY
Elevation (m)	1150	710
Mean annual temperature(°C)	9.6	13.1
Mean annual precipitation (mm)	3140	3270
Slope (degree) *	30(30)	30(30)
Slope aspect*	S25W(S60W)	N70W(N50W)
Stand age in 2002 (yr) **	42	23(46)
Parent material	Volcanic ash	Sedimentary rock

*Control plot (thinned plot), **In FMY, there are some 46-year-old trees.

Table 2
Summary of thinning in the study sites.

Plot	Tree number(/400m^2)			Stem volume (m^3/ha)		
	Before thinning	After thinning	Percent thinning	Before thinning	After thinning	Percent thinning
TNG control plot	41	41	0	353	353	0
TNG thinned plot	35	17	51	341	178	48
FMY control plot	68	68	0	190	190	0
FMY thinned plot	65	34	48	219	83	62

April 2002 at TNG, and in December 2001 at FMY), and no trees were cut in the control plots. Felled trees were randomly selected from size classes. The stem volume was decreased by 48% at TNG and by 62% at FMY after thinning (Table 2). This percentage of tree removal is considered to be high because the percentage of tree removal in forests is generally kept to 30% or less as a general rule in Japan.

After thinning, most of the large stems and branches were removed from the study plot, but some woody materials remained in the plot. Most of the small branches and leaves were scattered within the plot. Further information about the thinning practices and forest growth after thinning is given in Fukata (2006) and Inagaki et al. (2008a).

2.3 Litterfall

The leaf litterfall was collected by litter traps. Eight litter traps of 0.5 m^2 each were placed in each plot in two lines at regular intervals (about 4 m). Litterfall was collected every month from July 2002 to June 2007 except during winter snowfall from January to February. We did not collect litterfall in winter because the area had snow cover, especially in TNG at the higher elevation.

The annual litterfall was determined from July to June of the next year since the litterfall rate was lowest in July. The collected litterfall was divided into leaves, small branches, and other organs. The diameter of small branches was less than 5 cm. From July 2002 to June 2005, the sample of each trap was divided into organs. After July 2005, samples from the 8 traps at each collection site were combined into one sample and a part of the combined sample (more than 30 g) was divided into organs. Samples were dried for 48 hours at 75 °C and weighed. The annual leaf-fall biomass and nitrogen input were calculated by summing the monthly leaf fall between July and the following June. Leaves of hinoki cypress are fallen mainly in winter and the leaf-fall during winter was calculated by summing up monthly leaf fall between October and April in the following year. Percentage of winter leaf-fall was calculated as winter leaf-fall divided by annual leaf-fall.

The leaf-fall time for the hinoki cypress in each year was evaluated using the following logistic equation developed by Dixon (1976):

$$W(t) = \frac{W_{year}}{1 + \exp((2.2/T_{10-50})(T_{50} - t))}$$

where W = cumulative leaf fall (in g·m^{-2}), W_{year} = total annual leaf fall (in g·m-^{2}), T_{50} = time of maximum leaf-fall rate or time of 50% of annual leaf fall (in days), T_{10-50} = time between 10% and 50% of annual leaf fall (in days), t = time (in days). The date corresponding to t = 0 was set at July 1. In this model, the time of leaf-fall and leaf-fall duration (gradualness of leaf-fall) are determined.

Leaf and branch fall was measured for 5 years (2002-2006). As there were several occurrences of severe typhoons, we divided 5 years into three periods: pre-disturbance period (2002-2003), year of disturbance (2004) and post-disturbance period (2005-2006). Means of annual leaf and branch fall in each period were calculated. The disturbance index is defined as the ratio of annual leaf-fall in 2004 to pre-disturbance annual leaf fall. The recovery index is defined as the ratio of post-disturbance annual leaf fall to pre-disturbance annual leaf-fall.

Pattern of leaf-fall is related with the attacks of typhoons. Because we did not measure the wind speed in the study area, we defined the date of strong winds as being when records of maximum wind velocity at two weather stations (Sukumo and Shimizu, Meteorological Agency Japan) both exceeded 25 m s^{-1}. Although these stations are relatively far from the study area (70-75 km), we considered the data of weather stations along the Pacific Ocean to reflect the impacts of typhoons in the region. There were 7 days in 2004 that had strong winds, which was much greater than in the other 4 years (average of less than 1 day).

2.4 Statistical analysis

Pearson correlation coefficients were determined between disturbance index and recovery index. Properties of leaf-fall phenology (T_{50}, T_{10-50} and percentage of winter leaf-fall) were compared between the control and thinned plots using liner regression analysis (n=5).

3. RESULTS

3.1 Amount of leaf and branch fall

The seasonal pattern of leaf fall rate showed clear seasonality, being higher in winter (Fig. 1). The time of strong winds recorded at the weather station is indicated by plus signs. In the control plots, pre-typhoon annual leaf fall (2002-2003) was greater at TNG than at FMY (Table 3). At each forest, pre-typhoon annual leaf fall was smaller in the thinned plots than in the unthinned plots. The ratio of annual leaf fall in 2004 to pre-typhoon leaf fall (Disturbance index) ranged from 1.17 to 2.25. The disturbance index of leaf fall was greater at the higher elevation and greater in the thinned plots than in the control plots (Table 4). The ratio of post-typhoon leaf fall (2005-2006) to pre-typhoon leaf fall (Recovery index) ranged from 1.05 to 1.41. We did not find a negative correlation between disturbance index and recovery index ($p > 0.05$, Fig. 2). The disturbance index of branch fall ranged from 1.25 to 4.41. The recovery index of branch fall ranged from 0.56 to 2.4. The recovery index of branch fall was smaller where the disturbance index was greater ($r = -0.96$, $p = 0.04$, n =4, Fig. 2).

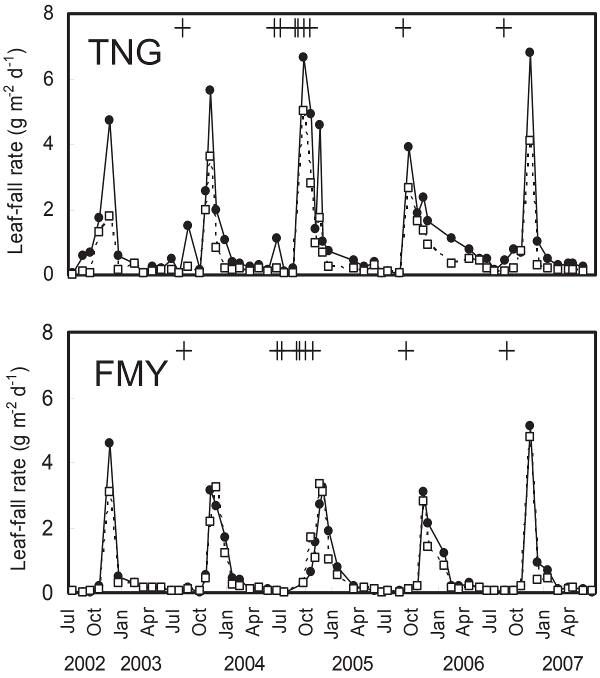

Fig. 1 Temporal changes in leaf-fall rate in the thinned (open squares) and unthinned plots (closed circles). The date of strong winds is indicated by the plus symbols at the upper part of the graphs.

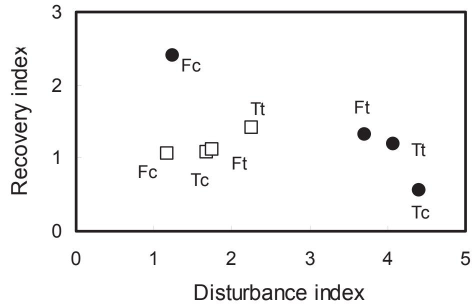

Fig. 2 The relationships between disturbance index and recovery index of leaf fall (open square) and branch fall (closed circle). Abbreviations of the study plots are as follows: TNG control (Tc); TNG thinning (Tt); FMY control (Fc); FMY thinning (Ft). The recovery index of branch fall is negatively correlated with the disturbance index (r=-0.96, p=0.04), whereas no significant relationship was found for leaf fall (p>0.05).

Table 3 Annual leaf-fall and branch-fall in the thinning experiment

year	TNG control	TNG thinning	Thinning /control	FMY control	FMY thinning	Thinning /control
Leaf-fall (g m^{-2} yr^{-1})						
2002	317.4	140.1	0.44	208.1	147.7	0.71
2003	312.1	146.6	0.47	190.3	158.0	0.83
2004	530.4	323.0	0.61	233.6	266.3	1.14
2005	332.4	219.7	0.66	194.9	151.9	0.78
2006	346.9	184.1	0.53	224.9	189.1	0.84
Mean	367.9	202.7	0.55	210.4	182.6	0.87
Branch-fall (g m^{-2} yr^{-1})						
2002	36.6	11.1	0.30	4.9	15.8	3.22
2003	45.7	17.6	0.38	15.9	17.0	1.07
2004	181.5	58.5	0.32	13.0	60.8	4.68
2005	29.2	17.1	0.58	17.9	15.7	0.88
2006	16.8	17.0	1.01	32.0	28.0	0.87
Mean	62.0	24.2	0.39	16.8	27.4	1.64

Table 4 Indices of disturbance and recovery in leaf litter and small branches

		TNG control	TNG thinning	FMY control	FMY thinning	Mean
Leaf litter (g m^{-2} yr^{-1})						
2002-2003	a	314.8	143.3	199.2	152.9	202.5
2004	b	530.4	323.0	233.6	266.3	338.3
2005-2006	c	339.7	201.9	209.9	170.5	230.5
Disturbance index	b/a	1.69	2.25	1.17	1.74	1.67
Recovery index	c/a	1.08	1.41	1.05	1.12	1.14
Branch (g m^{-2} yr^{-1})						
2002-2003	a	41.1	14.4	10.4	16.4	20.6
2004	b	181.5	58.5	13.0	60.8	78.4
2005-2006	c	23.0	17.0	25.0	21.8	21.7
Disturbance index	b/a	4.41	4.08	1.25	3.71	3.81
Recovery index	c/a	0.56	1.19	2.4	1.33	1.05

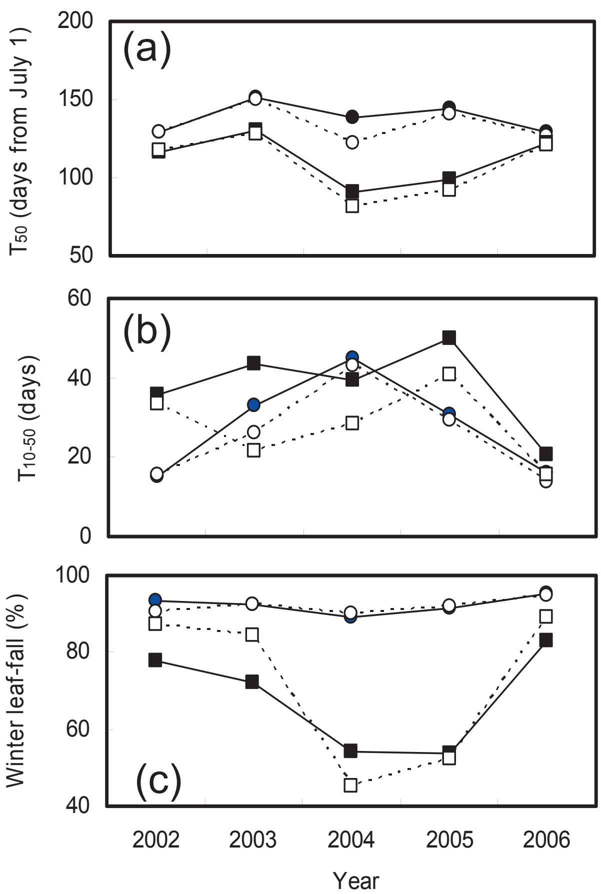

Fig. 3 Yearly variation in time of leaf-fall(T_{50})(a), leaf-fall duration ($T_{10\text{-}50}$)(b) and the percentage of winter leaf-fall (c) in the TNG control plot (closed square), TNG thinned plot (open square), FMY control plot (closed circle) and FMY thinned plot (open circle).

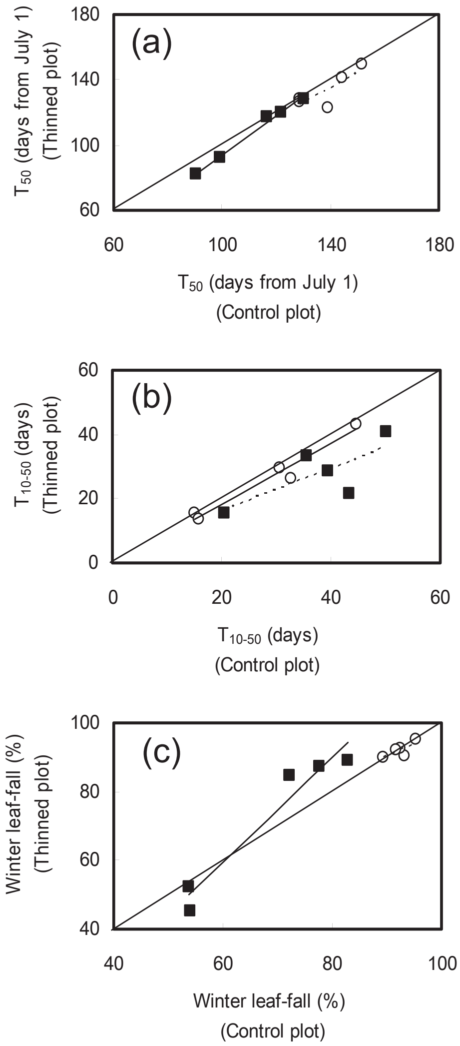

Fig. 4 The relationships of time of leaf-fall (a), leaf-fall duration (b) and the percentage of winter leaf-fall (c) between control and thinned plots at TNG (closed square) and FMY (open circle). Significant relations are indicated by solid lines.

3.2 Leaf fall phenology

In 2004, the time of leaf fall (T_{50}) in TNG was more than 30 days earlier than in the pre-disturbance period whereas the time of leaf fall in FMY did not change appreciably (Fig. 3a). In contrast, the leaf-fall duration ($T_{10\text{-}50}$) in 2004 at FMY became longer (43-45 days, Fig. 3b). For five years the time of leaf-fall was similar between control and thinned plots (Fig. 3a). Leaf-fall duration in the thinned plot at TNG was 5-22 days shorter than that in the control plot except in 2002 but no clear difference was found at FMY (Fig. 3b). The percentage of winter leaf-fall was lower at TNG than FMY (Fig. 3c). The percentage in the control plot at TNG was lower than that in the thinned plot in the pre-disturbance period (2002-2003) but no clear difference was found after typhoon disturbance. At FMY, the percentage was not different between the control and thinned plot.

The time of leaf-fall in the control and thinned plots at TNG was linearly correlated (Fig 4a, Table 5) but was not correlated at FMY. The leaf-fall duration in the control and thinned plots at FMY was linearly correlated (Fig. 4b, Table 5). Percentage of winter leaf-fall in the control and thinned plot was linearly correlated at TNG but not at FMY (Fig. 4c, Table 5)

Table 5 The results of leaner regression analysis. The regression line is indicated in Fig. 4.

Properties	site	slope	intercept	r^2	p
T_{50}	TNG	1.2	-25.8	0.99	0.001
T_{50}	FMY	0.92	5.7	0.66	0.09
$T_{10\text{-}50}$	TNG	0.67	2.8	0.55	0.15
$T_{10\text{-}50}$	FMY	0.94	-0.5	0.96	0.004
Winter leaf-fall (%)	TNG	1.52	-31.6	0.94	0.006
Winter leaf-fall (%)	FMY	0.7	27.4	0.6	0.12

4. DISCUSSION

4.1 Amount of leaf and branch fall

When affected by the severe typhoons, annual leaf-fall in 2004 increased by 1.17-2.25 fold, corresponding to an increase of 34-215 g m^{-2}. Takeuchi et al. (2007) reported that the amount of leaf fall of four hinoki cypress forests by the storm events in 2004 was 20-100 g m^{-2} in the Kyushu District. Saito (1981) measured litter fall for 10 years at hinoki cypress forests in Shiga Prefecture, central Japan. The annual leaf fall in 1972, when a severe typhoon affected the area, was 1.17 times higher than the average of leaf fall for 10 years. Typhoons did not increase annual leaf fall clearly although the time of leaf fall became earlier when the area had strong winds. Because other climatic factors can also affect annual leaf fall (Saito, 1981), it is sometimes difficult to isolate the typhoon effect only. Nonetheless, it was concluded that the effects of the typhoons at TNG of this study were greater than those in previous studies.

The effect at FMY was similar to that in previous studies. The typhoon effect at TNG was large, probably due to three reasons. First, there were many severe typhoons in 2004 (Typhoon Research Department, 2006). Secondly, winds in TNG areas at higher elevations were higher than in previous studies. We did not measure the wind speed directly but we found indirect evidences of strong winds at TNG; damage of litter traps by winds and soil observation. The soil in TNG has a strong nutty structure in subsurface horizon that indicates soil is dry due to higher transpiration affected by strong winds (Forest Soil Division, 1976). Thirdly, typhoon effects also related with the slope direction. As located at slope of south west direction, plots in TNG might have strong winds. Greater effect of typhoon on defoliation in south facing slope was previously reported in Takeuchi et al. (2007).

Post-disturbance annual leaf fall recovered to the level of the pre-disturbance period (Table 4). Although we expected slower recovery in the highly disturbed forest, the recovery was not related with the disturbance index (Fig 2). These results are different from Sato's (2004) study of an evergreen hardwood forest where annual leaf fall decreased significantly after disturbance. Previous studies on hinoki cypress did not find a clear reduction after typhoon disturbances (Saito, 1981, Inagaki et al., 2008b). There are two main reasons for the small reduction of annual leaf fall after typhoon disturbance. First, leaf biomass in the crown of hinoki cypress is large because leaf longevity of hinoki leaves is 5-7 years (Saito and Tamai, 1989). Takeuchi et al. (2007) reported that less than 8% of the leaves in the crown were defoliated by typhoons in 2004. In this study, higher percentage of leaves in TNG sites would be fallen than previous studies but the percentage would be still low. Secondly, the production of new leaves may increase rapidly after typhoon disturbance. Supporting evidence is presented by Fukata et al. (2009), who reported that the relative light intensity of a forest floor was increased by typhoon disturbance, but it decreased gradually following the disturbance. This result suggests that leaf production accelerates after a typhoon disturbance. However we did not evaluate the leaf production in this study. Further study is needed to evaluate the leaf production by direct measurement of leaf area index using canopy analyzer (Miyamoto et al., 2009).

The disturbance index of branch fall ranged from 1.25 to 4.41. These values are higher than those of leaf fall. The reason of higher branch fall is that the branch fall includes dead branches that have no leaves. The mean of the recovery index for branch fall was 1.05. This indicates that the recovery of branch fall was relatively rapid, although the index varied among forests. The recovery index was negatively correlated with the disturbance index (Fig 2). This pattern is different from that for leaf fall. These results suggest that the recovery of branch fall was slower when large amount of branch was fallen by strong winds.

4.2 Leaf fall phenology

In 2004, the study area was hit by many typhoons (Typhoon Research Department, 2006). The leaf-fall phenology in 2004 was determined by occasional strong winds. This situation is different from previous studies that generally evaluated the impact of strong winds from a single storm (Vogt et al., 1996; Harrington et al., 1997; Herbert et al., 1999; Xu et al., 2004; Sato, 2004).

The response of leaf fall pattern to the typhoons was different between the two elevations (Fig 3). The time of leaf fall became earlier at the higher elevation and the leaf-fall duration became longer at the lower elevation. At the higher elevation, a large amount of leaves could fall immediately in response to strong winds (Fig.1) and the time of leaf-fall in the control and thinned plots was significantly correlated (Fig. 4a). In contrast, leaves at the lower elevation did not fall immediately in response to strong winds; instead, the damaged leaves fell gradually after the typhoon events. Leaf-fall duration in the control and thinned plots at FYM was significantly correlated. The results suggest that changes of leaf-fall duration are more important than the time of leaf-fall in response to typhoon disturbance at the lower elevation (FMY).

This difference cannot be explained only by the strength of the wind. The intrinsic resistance of leaves to strong winds may differ between the two elevations. Leaf morphology such as leaf thickness can be related with leaf longevity (Reich et al., 1992; Wright et al., 2005) and possibly resistance to strong winds. Therefore, environmental factors that determine leaf morphology can be involved with the resistance of leaves to strong winds. Longer leaf longevity is often characterized as an adaptation to a nutrient-poor environment (Chapin, 1980, Chabot and Hicks, 1982, Aerts and Chapin, 2000). Nitrogen was less available at the lower elevation (Inagaki et al., 2008a) and trees there may have had leaves of longer longevity and higher resistance to strong winds. Inagaki et al. (2010) compared leaf-fall phenology in 17 hinoki cypress forests and showed that the time of leaf-fall of hinoki cypress forests varied 86 days and could not be explained solely by temperature. The results implied that intrinsic resistance of leaves can vary greatly in hinoki cypress forests. This evidence is indirect and further study is needed to investigate intrinsic resistance for winds and leaf longevity of hinoki cypress across wide range of climatic and soil conditions.

After disturbance, leaf-fall phenology may change due to water stress by strong winds. However in this study the time of leaf fall after a typhoon-disturbance generally returned to their respective values in the pre-typhoon period (Fig.3). These results suggest that the effect of sever typhoons was not critical and hinoki trees can recover to the pre-disturbance condition rapidly. After disturbance, the time of leaf-fall was similar between thinned and unthinned plots (Fig.3). Leaf-fall in the thinned plots returned to values in the pre-typhoon period. From these findings we concluded that the thinned forest in this study was not critically damaged by sever typhoons although the disturbance index was greater in the thinned plots and at higher elevations. In TNG at higher elevation, the effect of typhoons was larger than previous studies (Saito, 1981; Takeuchi et al., 2007) but leaf-fall recovered rapidly. The results suggest that leaf fall by strong winds may not cause critical damages for hinoki cypress plantations generally.

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四国のヒノキ人工林において台風が落葉動態に及ぼす影響

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要 旨

四国地域の標高の異なる２つのヒノキ林において、間伐区と対照区を設定し、落葉量の動態を 5 年間評価した（2002-2006 年）。この地域には 2004 年に多くの台風が接近したが、この年の年間落葉量は台風前 (2002-2003 年) の 1.17 − 2.25 倍の値を示した。台風の影響は高標高域で低標高域よりも大きく、間伐区で対照区よりも大きかった。一方、台風後（2005-2006 年）の年間落葉量は、台風前 (2002-2003 年) の 1.05—1.41 倍を示した。台風の影響は間伐林分で大きかったものの、台風後の回復は間伐区と対照区の間に差が認められなかった。高標高域では 2004 年の落葉時期（落葉が年間量の 50% に達する時期）が早い傾向が認められた。一方、低標高域では 2004 年の落葉時期は変化せずに落葉期間（落葉が年間量の 10% から 50% に達するまでの期間）が長かった。この結果は、台風に対する落葉の反応が標高によって異なることを示す。すなわち、高標高域では、台風後直ちに落葉するが、低標高域では台風後にすぐには落葉せず、しばらく経過してから徐々に落葉した。これらの結果、ヒノキ人工林において台風後に落葉生産は速やかに回復しており、台風後に新しい葉の生産が急速に増加することが示唆された。

キーワード：ヒノキ；落葉；季節性；回復；間伐；台風

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短 報（Note）

Comparison of the characteristics of five quantum sensors

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Abstract

Five quantum sensors were tested and compared to evaluate their individual characteristics and their degradation due to aging by using an artificial light source and natural sunlight. The results confirm that the accuracy and stability of each sensor are within the manufacturer-specified range. However, some sensors produce erroneous readings when solar elevation angle is low. The outputs from the various types of sensors differ from each other, and the differences between some sensor types may be greater than the individual differences between the same type of sensors. These results suggest the necessity of examining the instrumental differences when comparing measurements of photosynthetically active radiation conducted with sensors of different types.

Key words : aging degradation, azimuthal angle, incident angle, instrument difference, quantum sensor, wavelength

Introduction

Photosynthetically active radiation (PAR), which ranges from 400 to 700 nm, is one of the principal factors in photosynthetic carbon fixation, and photosynthesis is one of the most important components of the carbon cycle in terrestrial ecosystems. Synthetic analysis and comparative research on carbon budgets of terrestrial ecosystems (see, e.g., Hirata *et al*., 2008) have been actively promoted worldwide. Thus, an accurate and consistent method to measure PAR is required for an accurate evaluation of carbon assimilation. Several types of quantum sensors are available to measure PAR, but there is no global standard for quantum sensors in terms of accuracy, inherent characteristics, and degradation through aging.

The most frequently used quantum sensor is the LI-190 (LI-COR) (Mizoguchi *et al*., 2009) because it is a vanguard of PAR sensor and provides a wealth of technical information, and Fluxnet-Canada recommends this model in their measurement protocols (Fluxnet-Canada, 2003). However, AmeriFlux is adopting PAR Lite (Kipp & Zonen, Netherlands) as their standard system (AmeriFlux, 2009). Thus, at the present time a standard sensor does not exist because of the lack of universal standards, such as those existing for pyranometers. In such a situation, the only source of information regarding the reliability of these sensors is the documentation provided by the manufacturers.

In this study, five commonly used quantum sensors are compared, and the inherent characteristics, instrument differences, and degradation through aging of each sensor are evaluated using an artificial light source (i.e., solar simulator) and tested for degradation due to exposure in the field. This study should supply basic information for the development of a standard sensor and for calibration of data measured using different types of quantum sensors.

Methods

Types of quantum sensors

Although there are several manufacturers of quantum sensors worldwide, the basic elements of the devices are essentially the same. Typically, a sensor consists of a diffuser panel for diffusing light, an optical filter for blocking light outside the 400- to 700-nm range, and a silicon photodetector. In this study, we compare five different sensors: the ML-020P (EKO, Japan), the PAR Lite (Kipp & Zonen, the Netherlands), the IKS-27 (KOITO, Japan), the PAR-01 (PREDE, Japan), and the most commonly used sensor, the LI-190 (LI-COR, USA). The bottom of the LI-190 was coated by sealant to waterproof it before the experiments. All sensors used in this study are commercial products and individual differences among sensors of same type were not considered prior to the experiments.

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Laboratory tests

For the laboratory tests, a solar simulator (model ESS-80, EKO, Japan) with a 300-W xenon arc lamp was used as an artificial light source. The irradiation power ranges from 700 to 1000 Wm^{-2} and the stability has a margin of error of ±3%. The available irradiation area is 80 mm × 80 mm and the irradiation distribution has a margin of error of ±5%. The instrument covers the spectral range from 350 to 1100 nm. The performance of the solar simulator is classified as class A in Japanese Industrial Standards. The sensors were placed 20 cm from the light source, and the irradiation power was set at 1000 Wm^{-2} which is the maximum power for this simulator because solar radiation in summer reaches 1000 Wm^{-2} or more. Four measurements were carried out to evaluate the inherent characteristics and instrument differences.

The first set of measurements gives the output of the sensors relative to the incident angle of illumination, which means the zenith angle. The output of the sensors was recorded twice for each 10-degree increment of the incident angle α (see Fig. 1). The second set of measurements gives the output of the sensors relative to the azimuthal angle for a fixed incident angle of 60° (see Fig. 2). The cable-installation position for each sensor was set to the zero-degree point of the azimuthal angle. The sensors were rotated around their vertical axis and the output was recorded twice for each 10-degree increment of the azimuthal angle. The third set of measurements was to check the sensitivity characteristic as a function of incident wavelength by placing a glass filter between the sensor and the light source, with the light at normal incidence (Fig. 3). Output from the sensors was recorded once for each filter. The filters used were RG695, RG715, and RG780 (SCHOTT, Germany) and their thicknesses were 2, 2, and 1 mm, respectively. Fig. 4 shows the filter transmittance spectra quoted by the specification sheets of the glass filters. The filter model number indicates the minimum wavelength that is transmitted through the filter, although light at shorter wavelengths is weakly transmitted. The fourth set of measurement compares each sensor before and after a field experiment with a reference sensor from EKO Instruments Co. Both before and after the field experiments, sensor outputs were recorded three times.

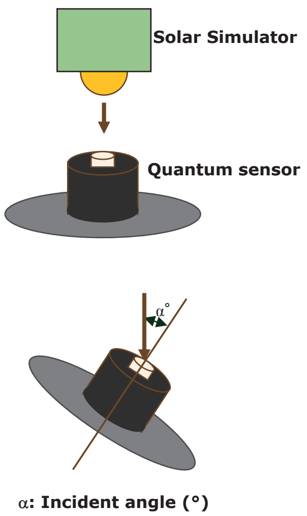

Fig. 1. Diagram of the incident angle test.

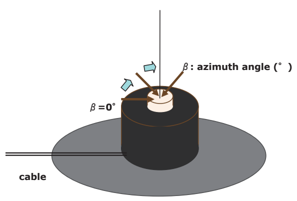

Fig. 2. Diagram of azimuthal angle test.
Incident angle (α) is 60°.

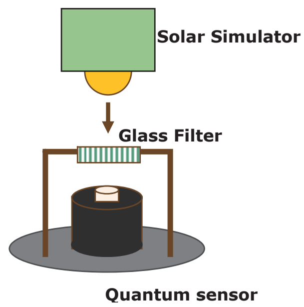

Fig. 3. Diagram of spectral sensitivity test.

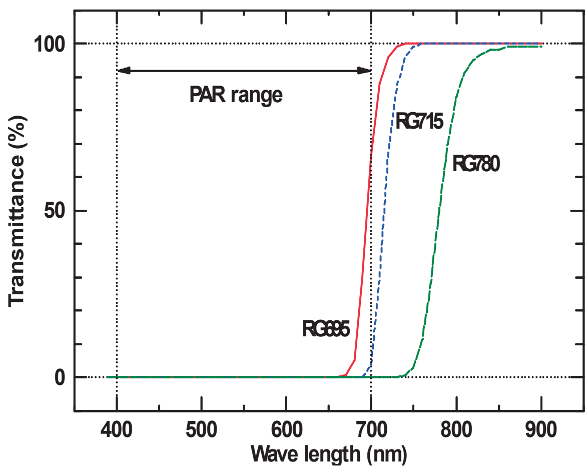

Fig. 4. Manufacturer-specified transmittance of glass filters.

Field experiments

After laboratory tests, the five sensors described above and the optional sensor LI-190 (LI-COR, USA), which was used as a benchmark (hereinafter referred to as LI-190BM) for degradation due to aging, were placed atop a 32-m tower at Fujiyoshida forest meteorology research site for comparison (lat. 35.45°N, long. 138.77°E, 1030-m elevation) (Ohtani *et al.*, 2001). Measurements were taken continuously over two weeks in September 2006, after which LI-190BM was withdrawn and kept in completely dark conditions to serve as a benchmark for degradation through aging. It was put back on the tower 12 months later to compare its output with that of the other sensors. The diffusion panels of the five sensors were cleaned every three weeks for the duration of the exposure. Precipitation and mean air temperature for this period was 1910 mm and 9.9 °C, respectively.

In addition to the experiment just described, two field experiments were conducted using LI-190s. These experiments consisted of exposure experiments using a non-coated LI-190 sensor for 30 months at Fujiyoshida, and a comparative test of eight LI-190s on a rooftop in Tsukuba (lat. 36.00°N, long. 140.12°E, 24-m elevation).

Results and discussions

Incident-angle characteristics

Fig. 5 shows the result of the incident-angle test. It shows the ratio of the output at each incident angle α to the output at zero incident angle. For each target sensor, both measurements yield equivalent values except for PAR Lite at α = 60°. The value reported for PAR Lite at 60° is the average, and thus there is a possibility of measurement error at this point. For each sensor, the output ratio decreases as α increases for α ≤ 50°. We find that the influence of the incident angle for ML-020P and PAR-Light is similar to the cosine response described in the manufacturer's specifications (the cosine response for ML-020P, PAR-Light, and LI-190 was provided). The influence of the incident angle for LI-190 was slightly larger than given graphically in the catalogue. The output ratios of PAR-01 (0.9 at α = 40° and 0.8 at α = 60°) and IKS-27 (0.9 at α = 40°), in particular, are less than those of the other sensors for α ≥ 40°. The output ratio of IKS-27 is considerably greater than unity at α = 85°, whereas the output ratios of the other sensors are less than 0.5. Therefore, the cosine-correction method of the IKS-27 may be different from the method used by the other sensors. When the solar altitude is low, such as in the morning or evening and during the winter, the PAR measured with PAR-01 and IKS-27 may be lower or higher than that measured with the other sensors.

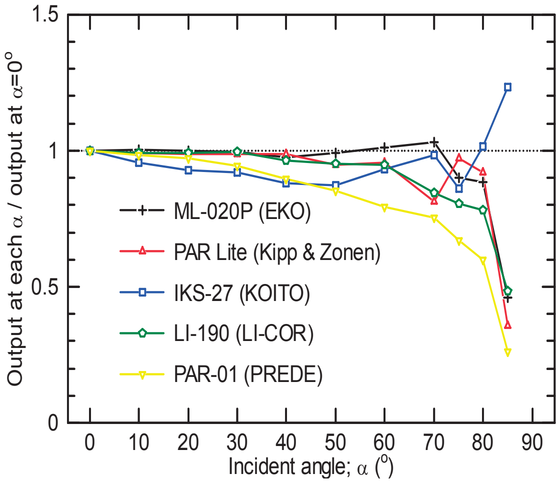

Fig. 5. Dependence of output on incident angle for each sensor.

Azimuthal angle characteristics

The ratio of the sensor outputs to the average of all outputs (0° to 180º) is shown in Fig. 6 as a function of azimuthal angle β. The outputs vary as a function of β for each sensor except for the outputs of ML-020P and LI-190, which vary less than 1%. The photodiode shape and the filter installed in the sensor may cause this β-dependent variation. Although a large variation in β may cause a detection error with a diurnal alteration, the variation was less than 5% for α = 60° for all sensors. Overall, the results of this test indicate that the influence on the sensor output of the azimuthal angle β is not as significant as the influence of the incident angle α.

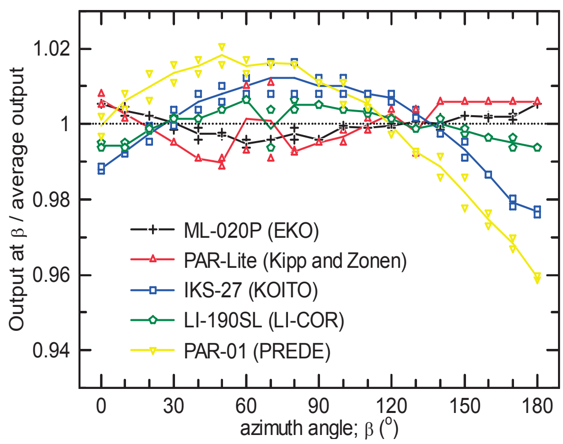

Fig. 6. Dependence of output on azimuthal angle for each sensor.
The symbols indicate measured values, and the lines represent the averages of two easurements.

Sensitivity characteristic as a function of avelength

The wavelength of PAR ranges from 400 to 700 nm. Thus, the ideal situation would be for the quantum sensor to measure only wavelengths in this range. Fig. 7 shows the ratio of the readout due to filtered light to the readout due to unfiltered light (the filter transmittance). When using the RG780 filter, the sensor output should be zero because this filter blocks all PAR wavelengths. However, the actual situation is different because all sensors detect small amounts of light with this filter in place. When using the RG695 filter, which should transmit a small band of light with wavelengths less than 700 nm (see Fig. 1), LI-190 produces the smallest output. This result indicates that the response of LI-190 to wavelengths just below 700 nm is less than that of the other sensors.

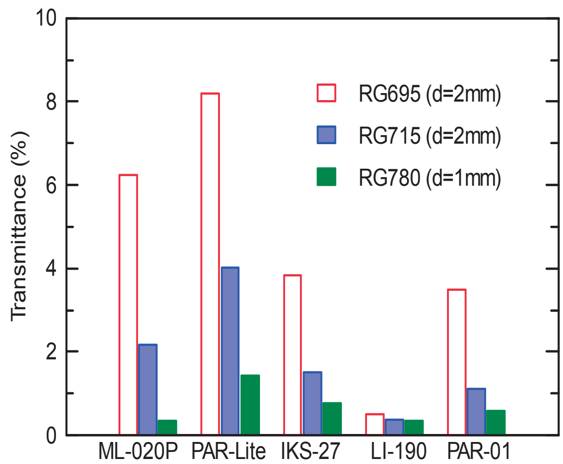

Fig. 7. Transmittance of filters measured by each sensor. Transmittance is defined as the ratio of the sensor output for the filtered light to the output for the unfiltered light.

Although the documentation for all sensors state that the measurement range is between 400 and 700 nm, high-pass filters installed in the sensor cause differing outputs among the sensors near the upper PAR wavelength range. It is possible that a similar effect occurs at the lower PAR wavelength range, so similar experiments should be performed near 400 nm.

Instrument differences

To judge instrument differences, Tables 1 and 2 show the ratio of the output from test sensors to the output of a benchmark sensor under artificial and natural light sources, respectively. The results for the laboratory tests are averages of three measurements at the incident angle α = 0°, and the benchmark sensor was the EKO reference sensor. The LI-190BM sensor was not checked under an artificial light source before the field experiment. The numbers in parentheses in Table 1 result from assuming that the relation between the EKO reference sensor and LI-190BM is maintained over the entire 12-month period of this experiment. The standard deviation for each sensor is less than 0.4 and the variability between three measurements for each sensor is small. For the field experiment, values averaged over two hours centered on the culmination time were used, because the incident-angle effect is smallest at the culmination time, and LI-190BM was adopted as the benchmark for judging instrument differences. Table 3 shows the results of comparison tests for eight LI-190s. The values are normalized by the output of sensor "e," and the letters in the left-hand column of the table identify each instrument.

The maximum instrument difference between sensors is approximately 8% for the solar simulator and 17% for sunlight, and the maximum instrument difference for the eight LI-190s

Table 1. Outputs from five sensor types illuminated by solar simulator and differences in the outputs before and after the field experiment.

Model	Manufacturer	EKO reference sensor			LI-190BM		
		Jul.25,2006	Oct.25,2007	Differences	Jul.25,2006	Oct.25,2007	Differences
ML-020P	EKO	99.67	96.72	-2.95	(98.39)	95.48	-2.91
PAR-Lite	Kipp & Zonen	106.70	105.86	-0.84	(105.33)	104.50	-0.83
IKS-27	KOITO	100.45	90.88	-9.57	(99.16)	89.71	-9.45
LI-190	LI-COR	102.51	92.49	-10.02	(101.20)	91.31	-9.89
LI-190BM	LI-COR	(101.30)	101.30	-	-	-	-
PAR-01	PREDE	99.45	91.64	-7.81	(98.17)	90.47	-7.71

The values listed are normalized by the outputs of EKO reference sensor and LI190BM. The numbers in parentheses result from assuming that the relation between the EKO reference sensor and the LI-190BM is maintained.

Table 2. Ratios of sensor outputs to the output of the benchmark sensor LI-190BM and differences in the average outputs before and after the field experiment.

Model	Manufacturer	Sep. 22 to Oct. 01, 2006		Sep. 20 to Sep. 29, 2007		Differences of averages
		Average	Standard deviation	Average	Standard deviation	
ML-020P	EKO	99.450	3.652	96.838	2.848	−2.611
PAR-LITE	Kipp & Zonen	96.172	1.630	93.963	1.624	−2.208
IKS-27	KOITO	82.532	0.855	85.970	1.041	3.437
LI-190	LI-COR	95.784	0.766	93.346	0.977	−2.439
PAR-01	PREDE	85.000	1.123	83.793	0.783	−1.207

The results listed represent an average over two hours centered on the culmination time for 10 days.

Table 3. Individual differences between several LI-190 sensors.

Sensor	Average	Standard Deviation
a	99.84	0.235
b	97.84	0.369
c	99.72	0.367
d	100.44	0.245
e	100.00	-
f	101.82	0.286
g	101.47	0.253
h	100.53	0.292

Measurement period is from April 7 to 12, 2009. Data among two hours that centered at the culmination time are used.

is less than 5% (Table 3) for sunlight, which is within the manufacturer-specified range. Instrument differences for the five sensors are large, when the individual difference of each type sensor is similar to that of LI-190. In addition, the instrument differences measured using the artificial light source are smaller than those measured using natural sunlight.

These comparison tests, which were conducted under identical conditions, may suggest that the cause of instrument differences is the spectral characterization of each sensor. Therefore, it is necessary to compare the sensors as a function of illumination wavelength to clarify the origin of the differences for each sensor.

Degradation due to aging

The outputs of a new LI-190 and an LI-190 that was used for 30 months were compared over a 10-day period from December 25, 2001 to January 3, 2002. The latter one (old sensor) was not waterproofed by sealant. The output of the old sensor was significantly less than that of the new sensor (see Fig. 8). The average output over a 10-day period from two-hour measurements that were centered on the culmination time of the old sensor are about 75% of that of the new sensor. This degradation due to aging is large even if individual differences are considered because these two sensors were not compared with each other before the old sensor was put in use 30 months ago.

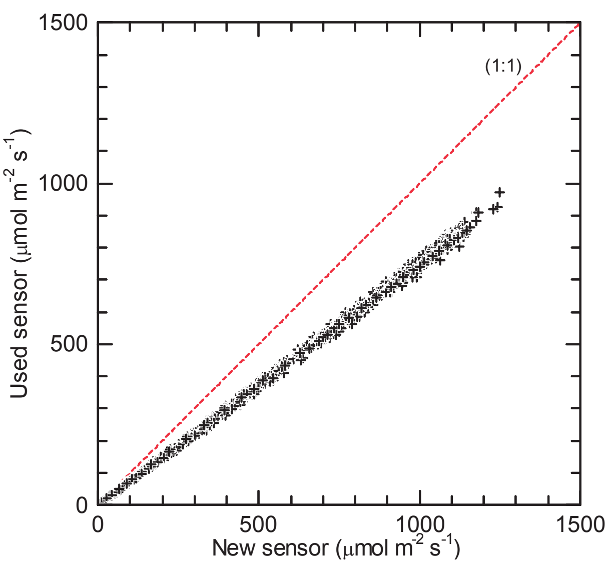

Fig. 8. Comparison between a new LI-190 and a used LI-190. The used LI-190 was not waterproofed by sealant, and the measurement period spanned from December 25, 2001 to January 3, 2002.

Tables 1 and 2 also show sensor outputs compared to the benchmark sensor LI-190BM after a 12-month field experiment, and at the end of the experiments under artificial and natural light sources, respectively. The LI-190BM sensor was exposed only briefly to sunlight, so it is assumed not to have degraded. The two LI-190s used in this experiment were waterproofed by sealant before the experiment. In the laboratory experiments, the sensor outputs decreased from 1% to 10% after 12 months. In the field experiments, the sensor outputs decreased from 1% to 3%, except for IKS-27, for which the output increased by about 3%. The difference in the results of the field experiment and the laboratory experiment may suggest that calibrating the sensor with an artificial light source will not a guarantee the accuracy of the sensor output. For each sensor, degradation after 12 months in the field experiment falls within the manufacturer-specified range, but the extent of degradation over a longer period is still unknown. If sensors are to be used for over 12 months, regular testing of their output may be necessary.

Conclusion

Quantum sensors have no global standards, such as is the case for other radiation sensors (e.g., pyranometers). Thus, the specifications published by manufacturers are the only verification of the sensor output. Through experimentation, the accuracy and stability of several different sensors were confirmed to lie within the manufacturer-specified range. However, each sensor has different characteristics with regards to the incident angle, azimuthal angle, and wavelength. The instrument differences among the target sensors may be larger than the individual differences between different individual sensors of the same type. Additional strict examination is required to evaluate the instrument difference between sensors definitely, because the number of target sensors was insufficient in this study. Furthermore, the degradation due to aging after 12 months is unknown, and we observe severe degradation of LI-190 by moisture (before waterproofing treatment), requiring additional waterproofing of the sensor. Humid areas are widespread in Asia and durability in terms of water resistance is required. Therefore, degradation due to aging longer than 12 months and durability under severe conditions are issues to be addressed in the future.

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We are grateful to Kenichi Kawabata (formerly of EKO Instruments Co., Ltd.), Akihiro Yorisaki (Climatec, Inc.), and Yasumi Fujinuma (Tottori University of Environmental Studies) for suggesting this study and to the members of the Yamanashi Institute of Environmental Sciences, including Takashi Nakano, for help in managing the Fujiyoshida site. This study was supported in part by the Special Coordination Funds for

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各種光量子センサの特性比較

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油田さと子 [2), 高梨聡 [2), 岩田拓記 [4), 中井裕一郎 [2)

要 旨

5 種類の光量子センサを対象に、人工光源を使用した室内実験および屋外での比較測定を行い、それぞれのセンサの特性と出力の経時変化を測定した。その結果、各センサの精度は仕様書に示された範囲内に収まっていることが確認された。ただし、一部の測器に太陽高度の低いときに誤差が生じやすいことがわかった。各センサ間の器差は、同タイプの個体差以上の差を生じる可能性があり、タイプの異なるセンサを使用した光合成有効放射量の比較の際には、器差補正が必要なことが示された。

キーワード：経年変化、方位角、入射角、器差、光量子センサ、波長

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短 報（Note）

ブナシメジ子実体を食害するキノコバエ

末吉昌宏 1)*

A record of fungus-gnat pest of cultivated *Hypsizigus marmoreus*

Masahiro SUEYOSHI[1)*]

Abstract

A new insect pest of *Hypsizigus marmoreus, Mycetophila rosularia* Ostroverkhova (Diptera, Mycetophilidae), is recorded from Japan. It is similar to *M. penicillata* Sasakawa and *M. dististylata* (Sasakawa) in general appearance. However, it is distinguished from these two species as follows: body length 4.7mm and wing length 4.6mm; gonostylus with eight robust setae on inner surface; wing with distinct dark brown markings at middle and no dark markings on posterior margin. The larvae inhabited and pupated inside of the sporophore of *H. marmoreus*. No larvae were found in the medium. I suggested that it was a native mycetophilid species inhabiting wild mushrooms in Japan. This is the first record of *Mycetophila* from *Hypsizigus* of Tricholomataceae.

Key words : cultivated mushroom, Diptera, Japan, *Mycetophila rosularia*, Mycetophilidae,

はじめに

ブナシメジ *Hypsizigus marmoreus* は国内のきのこ年間生産量の 20 % 近くを占める約 108, 000t あまりが生産される (林野庁 , 2009)、主要な食用きのこのひとつである。長野県はその生産戸数と生産量が国内で最も多く、2008 年度には 392 戸の生産者が 47,000t を生産している (林野庁 , 2009)。このきのこは商業生産では菌床栽培が主流となっている (角田 , 2001)。菌床の基質にはオガコ、米ぬか、大豆皮、フスマ、コーンコブミール、乾燥オカラなどが用いられる (角田 , 2001)。その害虫としてダニ類や線虫類が知られており (岡部 , 2006; 日本応用動物昆虫学会 , 2006)、キノコバエ類の幼虫がビン栽培ブナシメジを食害することが知られている (長野県経済連 , 1995)。しかし、このキノコバエ類の成虫の確認および種の同定はされていなかった。2007 年に長野県北信地方の生産者出荷物から見つかった、子実体内部を食害するキノコバエ類がナミキノコバエ属 *Mycetophila* Meigen の日本未記録種と同定されたので報告する。

害虫の特徴とその被害

ヤマタナミキノコバエ (新称) *Mycetophila rosularia* Ostroverkhova, 1979

分布：ロシア共和国（沿海州）、日本 (本州)。

供試標本：成虫 (5 ♂ 5 ♀)、幼虫 (1 老熟個体)。これらは 99 % アルコール中に保存され、森林総合研究所九州支所 (熊本市) に保管されている。

成虫・幼虫の形態と他種からの区別点

成虫 (Fig.1a) の体長 (頭頂から腹部末端まで) の平均は 4.7 mm であり、前翅長 (前翅前縁基部から前翅先端まで) の平均は 4.6 mm であった。触角と頭部および胸部は褐色、脚は全体に淡褐色で各基節、腿節、脛節の末端は黒褐色、腹部は末端の褐色部を除き黒褐色である。胸部背面前半部は褐色であるが、後半部は広く淡褐色で、前半部から続く三条の褐色の縦走斑紋を有する。前翅 (Fig. 1b) は黄みがかり、中央部に明瞭な黒褐色の斑紋 (暗色斑) を有する。雄の交尾器の生殖端節 gonostylus 内面に生えている長剛毛の数は 8 本である (Fig. 2a, b)。

成熟した幼虫 (Fig. 1c) の体長は 11.6 mm であり、黒色の頭部と白色の胸部および腹部を備える。前胸と腹部前方の 7 節の側面に 1 対の黒色の気門を持つ。また、腹部腹面には匍匐帯(黒色の横帯;移動に用いる)を持つ。

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本種は *M. penicillata* Sasakawa, 2005 (和名なし) あるいはトビモンナミキノコバエ *M. dististylata* (Sasakawa, 1964) に外観が酷似している。*M. penicillata* の成虫は前翅の長さは 3.5 mm であり、生殖端節 gonostylus 内面に生えている長剛毛の数は 3 本である (Sasakawa, 2005)。トビモンナミキノコバエの成虫は体長 4.3-4.6 mm であり、前翅後端部に暗色部を持ち、生殖端節の辺縁にはほぼ均一な長さの長剛毛が背面から先端にかけて掌状に 8 本並ぶ。その他の日本産ナミキノコバエ属の種とは、前翅亜端部と中央に明瞭な暗色斑と端部に不明瞭な暗色部をもち、亜端部の斑紋が第 2 中脈 M_2 を越えて、前翅後縁に延伸する (Fig. 1b) といった諸点で区別される。

被害

幼虫は子実体基部から菌傘にかけて、菌柄組織を食害しながら成長した (Fig. 1d)。老熟幼虫は、子実体内で繭をつくり蛹化し (Fig. 1e)、羽化した。老熟幼虫が子実体を食い破って這い出す例も観察された (Fig. 1f)。 基質から幼虫が見出されることはなかった。集荷調整後、商品のパッケージ中に這い出す場合と、栽培中の生育室の通路に大量の死骸が残り、栽培室を汚染する事例が見られた。

考察

ヤマタナミキノコバエはロシア共和国沿海州から知られている (Hackman et al., 1988; Zaitzev, 1999) が、これまで日本で記録されたことはなかった。被害発生地では、栽培施設の換気扇や排水口への防虫ネットの設置、出入り口の補修などの対策が採られ , 被害が沈静化した (伊藤ら , 2008) ため、本種は施設外から侵入したと考えられている (伊藤ら , 2008, 2009)。また、飼育試験では雌成虫がブナシメジ幼菌に産卵し、収穫時に幼虫が子実体から脱出する (伊藤ら , 2009) ため、施設外から持ち込んだ菌床基材に卵あるいは幼虫が混入していた可能性は低い。したがって、被害を与えたヤマタナミキノコバエは野外できのこ類に寄生する土着の個体群に由来すると考えられる。

本種の寄主きのこは未知であった。また、キシメジ科 Tricholomataceae を寄主キノコとするナミキノコバエ属の種はいくつか知られている (Dely-Draskovits, 1974; Chandler, 1978; Hackman & Meinander, 1979; Yakovlev & Zaitzev, 1990; Kurina, 1991) が、シロタモギタケ属 *Hypsizigus* からの記録はない。本種の寄主きのことしてブナシメジは、また、ナミキノコバエ属の寄主きのことしてシロタモギタケ属は、初めての記録となる。

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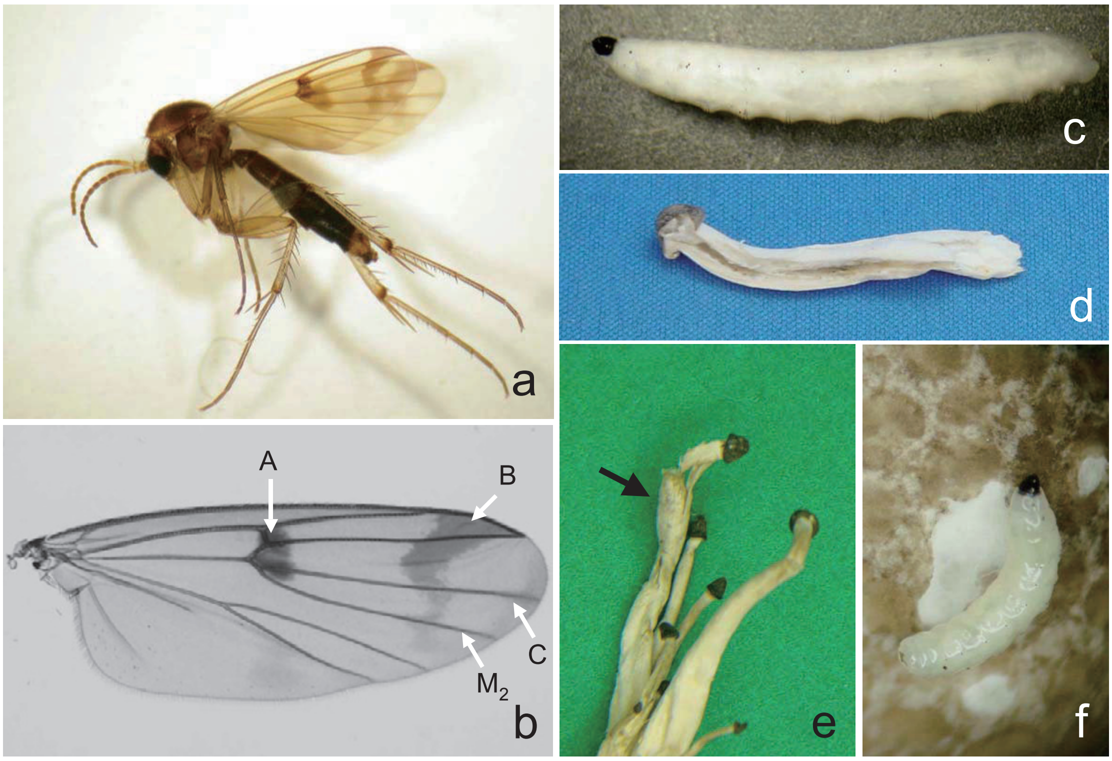

図 1. *Mycetophila rosularia* Ostroverkhova (a-c, f) とそれによるブナシメジの被害 (d, e).
a, ♂成虫左側面 ; b. 右前翅背面 (A, 中央の暗色斑 ; B, 亜端部の暗色斑 ; C, 端部の暗色斑 ; M_2, 第 2 中脈); c, 老熟幼虫左側面 ; d, 被害を受けた菌柄内部 ; e. 被害を受けた株と *M. rosularia* の繭 (矢印); f, 菌傘から這い出た幼虫 .

Fig. 1. *Mycetophila rosularia* Ostroverkhova (a-c, f) and infested *Hypsizigus marmoreus* (d, e).
a, adult male in left lateral view; b, right wing in dorsal view (A, dark marking at middle; B, dark marking at subapical portion; C, dark marking at apex; M_2, vein M_2); c, matured larva in left lateral view; d, infested stem of *H. marmoreus,* e, infested sporophore and cocoon of *M. rosularia* (arrow); f, larva escaped from sporophore.

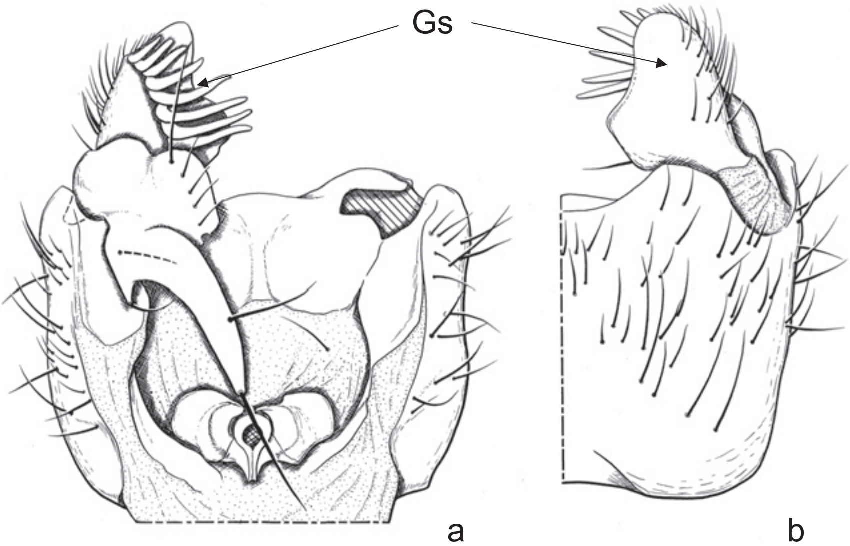

図 2. *Mycetophila rosularia* Ostroverkhova の♂交尾器 . a, 背面 ; b, 右半腹面 . Gs, 生殖端節 .

Fig. 2. Male genitalia of *Mycetophila rosularia* Ostroverkhova. a, dorsal view; b, ventral view of right half. Gs, gonostylus.

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研究資料（Research material）

ベイヒバ製材品の強度性能 —曲げ、縦圧縮、縦引張り、せん断、めり込み—

井道裕史 [1)*]、長尾博文 [1)]、加藤英雄 [1)]

Strength of yellow cypress lumber - Bending strength, compressive strength parallel to the grain, tensile strength parallel to the grain, shear strength parallel to the grain, and compressive strength perpendicular to the grain -

Hirofumi IDO[1)], Hirofumi NAGAO[1)] and Hideo KATO[1)]

Abstract

Recently, the use of yellow cypress (*Chamaecyparis nootkatensis*) has been increasing in constructing the foundations of a house due to its durability. However, at present, the standard strength requirements of yellow cypress that is essential for structural design have not been determined, and there is an urgent need to set rectify this. In this study, various tests were conducted on the strength of yellow cypress lumber and we collected data for use in determining its standard strength. After conducting tests on the bending strength, the compressive strength parallel to the grain, the tensile strength parallel to the grain, the shear strength parallel to the grain and the compressive strength perpendicular to the grain, we have concluded that yellow cypress should be added to the current non-graded lumber category and included among karamatsu (Japanese larch), hiba (false arborvitae), hinoki (Japanese cypress) and Port Onford cedar.

Key words : yellow cypress, strength, bending strength, compressive strength parallel to the grain, tensile strength parallel to the grain, shear strength parallel to the grain, compressive strength perpendicular to the grain

要 旨

近年、耐久性が高いという利点から、住宅の土台等としてベイヒバ (*Chamaecyparis nootkatensis*) の利用が拡大している。しかし、ベイヒバは現時点では構造設計に不可欠な基準強度が設定されておらず、その設定が強く求められている。そこで本研究ではベイヒバ製材品の強度試験を行い、基準強度を設定するための基礎データを実験的に明らかにすることを目的とした。強度試験は、曲げ、縦圧縮、縦引張り、せん断、めり込み試験を行った。実験結果から、ベイヒバを現在の無等級材の樹種群に追加する場合、からまつ、ひば、ひのき、べいひと同じ樹種群が適当であると考えた。

キーワード：ベイヒバ、強度、曲げ、縦圧縮、縦引張り、せん断、めり込み

1. はじめに

通常、建築物の設計をする場合、国土交通省が樹種あるいは樹種群ごとに定めた基準強度を用いる。近年、耐久性が高いという利点から、住宅の土台等としてベイヒバ (*Chamaecyparis nootkatensis*) の利用が拡大している。しかし、ベイヒバは Table 1 (建設省 , 2000)、Table 2 (国土交通省 , 2001) に示したように、現時点では基準強度が設定されておらず、その設定が強く求められている。そこで本研究ではベイヒバ製材品を用いて強度試験を行い、基準強度を設定するための基礎データを実験的に明らかにすることを目的とした。

2. 実験

2.1 供試材

材長が 4000mm、断面寸法が 105mm × 105mm のベイヒバ製材品 200 本を供試材とした。すべての供試材は北米から輸入された丸太を国内で製材 (内地挽き) し、人工乾燥したものを購入した。なお、供試材の木取りは心持ち材と心去り材が混在していた。

2.2 各強度試験への供試材の振り分け

すべての供試材に対して縦振動法によるヤング係数を測定した。その結果、供試材の平均値は 10.3kN/mm^2、変動係数は 15.2% であった。これらの供試材を、縦振

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動法によるヤング係数の平均値と変動係数がほぼ等しい2グループ各100本に分け、一方を曲げ、縦圧縮、せん断、めり込みの試験を行うグループ(曲げ・縦圧縮・せん断・めり込み試験体グループ)、もう一方を、縦引張り試験を行うグループ(縦引張り試験体グループ)とした。各グループの密度(ρ)と縦振動法によるヤング係数($E_{\text{fr-l}}$)の平均値と変動係数をTable 3に示すとともに、供試材からの各試験体の採取位置をFig. 1に示す。

2.3 強度試験

曲げ、縦圧縮、縦引張り、めり込み試験は「構造用木材の強度試験法」(日本建築学会, 2003)に従った。せん断試験は井道ら(2004)の方法に従い、実大いす型せん断方式とした。試験体には心持ち材と心去り材とが混在していたため、各強度試験の加力方向は無作為とした。ただし、Fig. 1に示した曲げ試験の加力方向とめり込み試験の加圧方向は同じ材面になるようにし、せん断試験のせん断面も曲げ試験の中立軸と同一になるようにした。また、実大いす型せん断試験体を除くすべての試験体に対して、試験前に縦振動法によるヤング係数を測定した。

2.3.1 曲げ試験

曲げ試験に先立ち、「製材の日本農林規格」(農林水産省, 2007)に準じて、試験体全長および支点間距離における目視等級区分を行うため、節、集中節、丸身、割れを測定した。また、引掻き式の繊維走行測定器を用いて繊維走行の傾斜比を測定した。

曲げ試験は、荷重点間を材せいの6倍(630mm)、支点間距離を材せいの18倍(1890mm)とした3等分点4点荷重方式で行った。容量が10tf(約98kN)の材料試験機(NMB製、TCM-10000)で載荷した。クロスヘッド速度は10mm/minとした。試験体の側面中央部に変位計(東京測器製、CDP-100)を設置し試験体の全たわみを測定するとともに、試験体の圧縮面上に変位計(東京測器製、CDP-10)を取り付けた袴型治具(スパン400mm)を乗せ、荷重点間における曲げたわみを測定した。試験終了後、全たわみから求めた見かけの曲げヤング係数、荷重点間のたわみから求めた真の曲げヤング係数、曲げ比例限度応力および曲げ強度を算出した。破壊部近傍から含水率測定用試験体を切り出し、全乾法で含水率を測定した。半数の試験体から気乾密度測定用の試験体を切り出し、温度20℃、関係湿度65%RHの恒温恒湿室内で調湿して密度を測定した。

2.3.2 縦圧縮試験

縦圧縮試験は材長を断面の6倍(630mm)とした短柱圧縮試験体で行った。最大容量が3000kNの圧縮試験機(前川製作所製、A-300-B4)をレンジ600kNに設定して載荷し、最大荷重に達するまでの時間が約5分になるように荷重速度を調整した。試験体の長さ方向における中央部の平行な2材面に、標点間距離が150mmで変位計(東京測器製、CDP-10)を設置して変形を測定した。両変位の平均を標点間での試験体の変位とした。試験終了後、縦圧縮ヤング係数、縦圧縮比例限度応力および縦圧縮強度を算出した。破壊部近傍から含水率測定用試験体を切り出し、全乾法で含水率を測定した。

2.3.3 縦引張り試験

縦引張り試験に先立ち、「製材の日本農林規格」に準じて、つかみ部分を除いたチャック間距離における目視等級区分を行うため、節、集中節、丸身、割れを測定した。試験終了後、チャック部分をプレーナーで平滑にして繊維傾斜を測定し、試験体の繊維傾斜と見なした。

縦引張り試験はチャック間距離を長辺の20倍(2100mm)、片側のつかみ部分の長さを950mmとした。最大容量が2000kNの横型引張り試験機(前川製作所製、HZS-200-LB4)で試験を行った。試験体の長さ方向における中央部の平行な2材面に、標点間距離が1000mmで変位計(東京測器製、CDP-10)を設置して変形を測定した。両変位の平均を標点間での試験体の変位とした。試験終了後、縦引張りヤング係数、縦引張り比例限度応力および縦引張り強度を算出した。破壊部近傍から含水率測定用試験体を切り出し、全乾法で含水率を測定した。すべての試験体から気乾密度測定用の試験体を切り出し、温度20℃、関係湿度65%RHの恒温恒湿室内で調湿して密度を測定した。

2.3.4 せん断試験

せん断試験は実大いす型せん断治具(井道ら, 2004)を用いて行った。切り欠き部分のない側の試験体長さは150mm、切り欠き部分の長さは45mm、せん断面積は105×105mmとした。最大容量が3000kNの圧縮試験機(前川製作所製、A-300-B4)をレンジ150kNに設定して載荷し、最大荷重に達するまでの時間が約5分になるように荷重速度を調整した。試験終了後、せん断強度を算出した。破壊部近傍から含水率測定用試験体を切り出し、全乾法で含水率を測定した。

2.3.5 めり込み試験

めり込み試験は長さが断面の6倍(630mm)の試験体に対し、長さ90mmの鋼製荷重ブロックを試験体中央部の上下に設置する上下加圧方式で行った。最大容量が3000kNの圧縮試験機(前川製作所製、A-300-B4)をレンジ300kNに設定して載荷し、最大荷重に達するまでの時間が約5分になるように荷重速度を調整した。試験体の長さ方向の中央部付近両脇に2か所に変位計(東京測器製、CDP-50)を設置し、クロスヘッドの移動量を測定した。両変位計の平均をめり込み変形量とした。試験終了後、めり込み強度、めり込み降伏強度、めり込み剛性を算出した。ただし、槌本(2008)によると、「めり

込みの基準強度は、実大材に対する材幅と同じ幅の荷重ブロック（クロスヘッド）で載荷した場合に、材料が破壊した応力度または材厚の 5% めり込んだときの応力度のうち、低い方の信頼水準 75% の 95% 下側許容限界値を定めた数値である。」とあるため、5% 変形時の応力も合わせて算出した。破壊部近傍から含水率測定用試験体を切り出し、全乾法で含水率を測定した。

3. 結果と考察

曲げ、縦圧縮、縦引張り、せん断、めり込みのすべての試験結果を Table 4 ～ 8 に示す。また、以下に各強度試験についての結果を示す。

3.1 曲げ試験

曲げ試験結果の概要を Table 9 に示す。試験後に測定した気乾密度の平均値は 508kg/m^3、変動係数は 7.64% であった。見かけの曲げヤング係数の平均値は 9.34kN/mm^2 であった。データ集の文献値 (強度性能研究会 , 2005) と比較すると、ヒノキの平均値 11.01kN/mm^2、ヒバの平均値 9.93kN/mm^2 に比べて若干低い値を示したが、「日本建築学会木質構造設計規準」普通構造材の繊維方向特性値 (日本建築学会 , 2006) に示された基準弾性係数 E_0 と比較すると、ヒノキとヒバの値 9.0kN/mm^2 を上回った。一方、ベイヒバの曲げ強度の平均値を同様にデータ集と比較すると、ヒノキ 56.9N/mm^2、ヒバ 47.0N/mm^2 に対してベイヒバは 49.6N/mm^2 であり、ヒノキには及ばないもののヒバの平均値を上回った。また、構造用材料の基準強度特性値は一般に 5% 下限値とされるため (日本建築学会 , 2006) 、ノンパラメトリック法により曲げ強度の 5% 下限値を算出した。その結果、ベイヒバの曲げ強度の 5% 下限値は 26.8N/mm^2 となり、ヒノキ、ヒバが属する針葉樹 II 類の曲げ基準強度 26.7N/mm^2 と同程度であった。

「製材の日本農林規格」の甲種構造材 II の目視等級区分に従った等級ごとの曲げ強度試験結果を Table 10 に示す。全長における等級の割合は、1 級が 8 本 (または %、以下同じ) 、2 級が 34 本、3 級が 42 本、等級外が 16 本であった。また、Table 4 に示したように荷重点間で格付けすると等級は全体的に上がり、1 級が 28 本、2 級が 41 本、3 級が 26 本、等級外が 5 本であった。各等級の試験体数は十分ではないが、Table 10 に示した全長において 5% 下限値を算出すると、1 級 42.4N/mm^2、2 級 35.5N/mm^2、3 級 29.4N/mm^2、等級外 19.2N/mm^2 であった。なお、ここでの 5% 下限値は正規分布を仮定して算出したものである。これを JAS の目視等級に対応した曲げ基準強度 (建設省 , 2000) と比較すると、ヒノキ 1 級 38.4N/mm^2、2 級 34.2N/mm^2、3 級 28.8N/mm^2、ヒ バ 1 級 34.8N/mm^2、2 級 34.8N/mm^2、3 級 29.4N/mm^2 とほぼ同等の結果となった。また、見かけの曲げヤング係数に関しては、等級に従った段階的な値の違いは認められなかった。

3.2 縦圧縮試験

縦圧縮試験結果の概要を Table 11 に示す。縦圧縮強度の平均値は 28.5N/mm^2 であった。データ集と比較すると、無等級材の基準強度で針葉樹 II 類に属するヒノキの平均値 33.1N/mm^2、カラマツの平均値 32.5N/mm^2 に対して低い値を示し、さらには針葉樹 IV 類に属するスギの平均値 28.9N/mm^2 に対しても低い値を示した。また、ベイヒバの縦圧縮強度の 5% 下限値は 20.4N/mm^2 であった。これを、無等級材の基準強度と比較すると、ベイヒバはカラマツ、ヒバ、ヒノキ、ベイヒを含む針葉樹 II 類の基準強度 20.7N/mm^2 にほぼ相当するが、わずかに下回っていた。ただし、本試験では含水率による各強度値の補正は基本的に実施していないが、縦圧縮強度は含水率の影響を大きく受けることが知られている (長尾 , 1996) 。そのため、ASTM D-2915-98 (ASTM International, 1998) に従って縦圧縮強度を含水率 15% 時の値に補正した。その結果、縦圧縮強度の平均値は 31.9N/mm^2 となり、データ集のカラマツ相当の値となった。なお、データ集の強度は含水率を 15% に補正した値である。同様にベイヒバの 5% 下限値は 21.7N/mm^2 となり針葉樹 II 類の基準強度を満足する値となった。

3.3 縦引張り試験

縦引張り試験結果の概要を Table 12 に示す。試験後に測定した気乾密度の平均値は 506kg/m^3、変動係数は 6.54% であった。縦引張り強度の 5% 下限値は 17.7N/mm^2 であった。これを無等級材の基準強度と比較すると、アカマツ、クロマツ、ベイマツの属する針葉樹 I 類の基準強度 17.7N/mm^2 に相当した。

「製材の日本農林規格」の甲種構造材 II の目視等級区分に従った等級ごとの縦引張り強度試験結果を Table 13 に示す。等級の割合は、1 級が 12 本、2 級が 31 本、3 級が 39 本、等級外が 18 本であった。曲げ試験体と同様、各等級の試験体数は十分ではないが、5% 下限値を算出すると、1 級 18.6N/mm^2、2 級 18.3N/mm^2、3 級 14.5N/mm^2、等級外 8.79N/mm^2 であった。なお、ここでの 5% 下限値は正規分布を仮定して算出したものである。これを JAS の目視等級に対応した縦引張り基準強度 (建設省 , 2000) と比較すると、ヒノキ 1 級 22.8N/mm^2、2 級 20.4N/mm^2、3 級 17.4N/mm^2、ヒバ 1 級 21.0N/mm^2、2 級 21.0N/mm^2、3 級 18.0N/mm^2 であり、ヒノキとヒバの基準強度に対しては若干低い値を示したが、ヒノキ、ヒバと同じ針葉樹 II 類のカラマツ 1 級 18.0N/mm^2、2 級 15.6N/mm^2、3 級 13.8N/mm^2 に対してはいずれの等級も基準強度を上回った。また、曲げ試験の結果とは異なり、縦振動法のヤング係数、縦引張りヤング係数ともに等級に従った段階的な値の違いが認められた。

また、含水率による強度補正をしない状態での曲げ・縦圧縮・縦引張り強度特性値の相対比は 1：0.76：0.66 であった。

3.4 せん断試験

せん断試験結果の概要を Table 14 に示す。せん断強度の 5% 下限値は 5.21N/mm^2 であった。これを無等級材の基準強度と比較すると、無等級材の針葉樹 I 類の基準強度 2.4N/mm^2 を大きく上回っていた。また、同じ実大いす型試験方式で行った各樹種（井道ら , 2006）との比較を Table 15 に示す。なお、文献値の 5% 下限値は正規分布を仮定したものである。すべての樹種で 5% 下限値は各樹種の基準強度を大きく上回っていたが、ベイヒバの 5% 下限値は II、III 類に属するヒノキ、ベイツガ（ともに基準強度 2.1N/mm^2）と、スギの属する IV 類（基準強度 1.8N/mm^2）の 5% 下限値の間にあった。

3.5 めり込み試験

めり込み試験結果の概要を Table 16 に示す。5% 変形時の応力から算出しためり込み強度の 5% 下限値は 4.79N/mm^2 であった。Table 2 に示しためり込みの基準強度と比較すると、ヒバを含む樹種群の基準強度 7.8N/mm^2 を下回っていた。ただし、本試験で採用しためり込み試験方式は、ISO 13910 (ISO, 2005) の試験方式と同様のものだが、この方式では 20mm めり込んだ時の応力か破壊時の応力の低い方からめり込み強度を算出することになっている。この方法によるベイヒバのめり込み強度 $f_{c,90}$ について 5% 下限値を算出した。同じ試験方法で行ったカラマツ (伊東ら , 2005) 、ヒバ (鈴木・松元 , 2006) 、スギ (田中・荒武 , 2005) 、ベイツガ (Ido et al., 2007) の結果から下限値の値が記載されているものはその値を、下限値の値が記載されていないものは正規分布を仮定し 5% 下限値を求めた。ベイヒバとの比較を Table 17 に示す。その結果、5% 変形時の応力と基準強度との比較とは異なり、ベイヒバのめり込み強度 $f_{c,90}$ の 5% 下限値はヒバとほぼ同等の値となった。

4. まとめ

ベイヒバの基準強度設定の基礎データを得ることを目的として、各種強度試験を行った。曲げ、縦圧縮、縦引張り、せん断、めり込み試験の結果から総合的に判断すると、ベイヒバを現在の無等級材の樹種群に追加する場合、からまつ、ひば、ひのき、べいひと同じ樹種群に含めることが適当であると考えられた。

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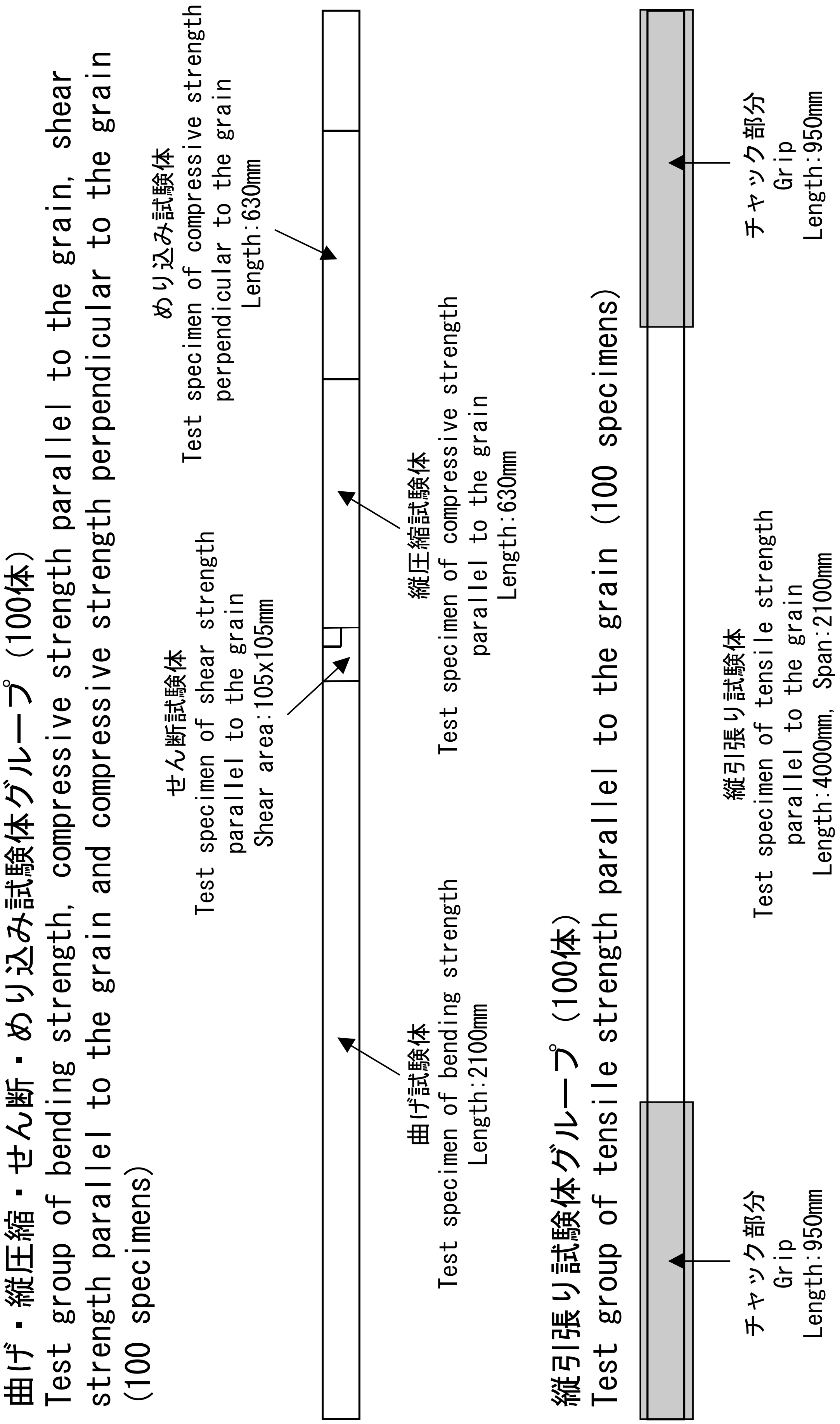

Fig.1. 各試験体の採取位置 Test specimen collection sites

Table 1. 無等級材の基準強度

Standard strength requirements for non-graded lumber

樹種 Species			基準強度 Standard strength requirements (N/mm^2)			
			縦圧縮 Compression parallel to the grain	縦引張り Tension parallel to the grain	曲げ Bending	せん断 Shear parallel to the grain
針葉樹 Softwood	I 類	あかまつ、くろまつ、べいまつ Akamatsu, Kuromatsu, Douglas fir	22.2	17.7	28.2	2.4
	II 類	からまつ、ひば、ひのき、べいひ Karamatsu, Hiba, Hinoki, Port Onford cedar	20.7	16.2	26.7	2.1
	III 類	つが、べいつが Tsuga, Western hemlock	19.2	14.7	25.2	2.1
	IV 類	もみ、えぞまつ、とどまつ、べにまつ、すぎ、べいすぎ、スプルース Momi, Ezomatsu, Todomatsu, Benimatsu, Sugi, Western red cedar, Spruce	17.7	13.5	22.2	1.8
広葉樹 Hardwood	I 類	かし Kashi	27.0	24.0	38.4	4.2
	II 類	くり、なら、ぶな、けやき Kuri, Nara, Buna, Keyaki	21.0	18.0	29.4	3.0

Table 2. 製材のめり込みの基準強度

Standard requirements for compressive strength perpendicular to the grain for lumber

樹種 Species		基準強度 Standard strength requirements (N/mm^2)
針葉樹 Softwood	あかまつ、くろまつ、べいまつ Akamatsu, Kuromatsu, Douglas fir	9.0
	からまつ、ひば、ひのき、べいひ Karamatsu, Hiba, Hinoki, Port Onford cedar	7.8
	つが、べいつが、もみ、えぞまつ、とどまつ、べにまつ、すぎ、べいすぎ、スプルース Tsuga, Western hemlock, Momi, Ezomatsu, Todomatsu, Benimatsu, Sugi, Western red cedar, Spruce	6.0
広葉樹 Hardwood	かし Kashi	12.0
	くり、なら、ぶな、けやき Kuri, Nara, Buna, Keyaki	10.8

Table 3. 各グループの見かけの密度と縦振動法によるヤング係数の平均値

Average of apparent density and Young’s modulus by longitudinal vibration method in each group

	見かけの密度 Apparent ρ (kg/m^3)	縦振動法のヤング係数 $E_{fr\text{-}l}$ (kN/mm^2)
曲げ・縦圧縮・せん断・めり込み試験体グループ Test group of bending strength, compressive strength parallel to the grain, shear strength parallel to the grain and compressive strength perpendicular to the grain	523 (6.82)	10.3 (15.3)
縦引張り試験体グループ Test group of tensile strength parallel to the grain	521 (6.46)	10.3 (15.2)

ρ: 密度 Density, $E_{fr\text{-}l}$: 縦振動法のヤング係数 Young’s modulus by longitudinal vibration method.
カッコ内の値は変動係数 (%) を示す Value in the parentheses is coefficient of variance.

Table 4. 曲げ試験結果 Test results on bending strength

試験体番号 Test piece No.	含水率 MC (%)	見かけの密度 Apparent ρ (kg/m^3)	縦振動法のヤング係数 $E_{fr\text{-}l}$ (kN/mm^2)	見かけの曲げヤング係数 Apparent E_b (kN/mm^2)	真の曲げヤング係数 True E_b (kN/mm^2)	曲げ比例限度応力 σ_{bp} (N/mm^2)	曲げ強度 σ_b (N/mm^2)	JAS の目視等級甲 II（荷重点間） JAS visual grading (in loading span)	JAS の目視等級甲 II（全区間） JAS visual grading (in full length)
3	16.9	590	11.7	11.1	12.1	36.7	50.1	3 級	3 級
7	16.4	529	10.9	10.4	10.6	41.2	58.4	2 級	2 級
9	16.4	524	12.3	11.2	12.0	43.0	59.1	3 級	3 級
12	22.5	584	7.83	7.35	7.32	28.6	37.3	1 級	3 級
13	19.1	548	9.32	8.19	9.49	21.7	26.5	等級外	等級外
14	16.3	551	12.0	11.0	12.0	44.9	72.1	2 級	2 級
15	17.1	503	11.4	10.3	11.6	44.9	63.5	2 級	2 級
16	15.4	489	8.31	7.63	8.33	25.5	31.1	1 級	2 級
17	17.4	489	9.18	8.32	8.31	35.2	39.0	等級外	等級外
18	17.1	502	9.44	8.67	9.95	37.6	49.5	等級外	等級外
19	18.9	560	9.52	8.58	9.39	22.8	22.8	2 級	等級外
20	17.9	590	13.6	11.6	11.9	45.2	61.8	3 級	3 級
21	17.9	510	10.7	9.51	10.4	35.3	57.2	2 級	2 級
23	17.3	475	10.0	9.13	9.78	40.9	56.7	1 級	1 級
24	16.8	535	12.8	10.6	11.7	47.4	68.1	2 級	3 級
25	18.2	528	9.35	8.50	9.16	42.2	62.0	3 級	3 級
26	16.6	515	12.1	10.9	12.0	41.3	57.2	3 級	3 級
27	19.2	525	12.3	10.9	12.0	40.6	53.3	2 級	2 級
32	17.7	499	9.56	8.52	9.23	35.4	54.7	3 級	等級外
33	18.2	552	9.19	8.09	7.88	29.2	60.4	1 級	2 級
37	17.9	533	9.42	8.32	8.21	33.2	58.4	2 級	2 級
39	20.6	518	10.3	9.51	10.0	33.8	48.0	3 級	3 級
40	17.6	601	11.7	11.1	11.9	39.7	58.4	2 級	3 級
41	17.3	544	12.5	11.0	12.1	39.7	52.9	2 級	3 級
42	16.8	485	8.07	7.15	7.72	20.9	24.7	3 級	3 級
44	20.2	539	8.97	8.07	7.99	31.0	44.1	3 級	3 級
48	17.4	503	10.4	9.30	9.56	32.9	42.7	等級外	等級外
49	19.5	541	10.8	9.82	10.7	38.0	54.8	1 級	3 級
50	16.3	471	10.1	9.19	10.0	38.6	42.8	2 級	2 級
54	19.2	484	10.9	10.0	10.9	37.5	54.2	1 級	2 級
55	19.6	504	11.8	10.2	10.9	40.4	52.3	2 級	2 級
56	19.2	504	9.64	8.38	7.87	28.3	45.1	3 級	3 級
57	17.7	502	11.5	10.3	10.8	44.5	51.8	2 級	3 級
58	17.4	508	12.5	10.7	12.3	38.0	51.6	2 級	3 級
59	17.5	494	11.2	10.4	11.1	41.7	56.2	3 級	3 級
61	18.2	534	11.6	11.0	11.1	33.8	56.7	2 級	2 級
63	19.8	514	9.47	8.71	9.05	36.0	55.8	3 級	3 級
69	18.8	494	10.2	9.30	10.0	35.4	57.5	2 級	等級外
71	18.3	514	10.6	9.80	10.2	37.2	51.4	1 級	等級外
72	17.9	477	10.2	8.99	9.62	38.3	51.7	1 級	2 級

Table 4. 曲げ試験結果（続き）Test results on bending strength (cont.)

試験体番号 Test piece No.	含水率 MC (%)	見かけの密度 Apparent ρ (kg/m^3)	縦振動法のヤング係数 $E_{fr\text{-}l}$ (kN/mm^2)	見かけの曲げヤング係数 Apparent E_b (kN/mm^2)	真の曲げヤング係数 True E_b (kN/mm^2)	曲げ比例限度応力 σ_{bp} (N/mm^2)	曲げ強度 σ_b (N/mm^2)	JASの目視等級甲II（荷重点間）JAS visual grading (in loading span)	JASの目視等級甲II（全区間）JAS visual grading (in full length)
74	17.2	525	11.2	9.42	10.5	32.6	52.0	3 級	等級外
75	17.3	522	11.4	10.0	11.0	43.3	59.3	3 級	3 級
76	21.1	449	8.59	7.61	7.34	21.1	29.0	等級外	等級外
77	21.9	535	7.84	7.10	6.52	19.9	26.8	2 級	等級外
78	20.1	538	7.88	7.07	6.90	23.6	41.2	3 級	等級外
80	19.1	586	11.4	10.4	10.7	35.1	54.2	2 級	2 級
83	16.7	466	8.59	7.80	8.14	27.6	43.0	2 級	3 級
86	18.7	535	11.9	10.9	11.5	42.3	59.7	1 級	1 級
90	17.1	532	11.8	10.5	11.6	45.4	64.1	2 級	等級外
93	18.6	558	13.8	12.1	13.0	45.3	57.6	3 級	3 級
94	17.6	582	10.7	9.48	8.89	30.9	42.1	3 級	等級外
96	19.7	566	11.9	10.8	12.2	38.7	46.7	3 級	等級外
102	17.3	493	7.56	6.84	7.33	30.9	46.2	1 級	2 級
107	18.3	551	8.61	7.73	7.81	33.4	50.6	1 級	2 級
109	17.0	458	10.9	9.65	10.6	36.8	54.0	1 級	2 級
111	15.4	443	10.7	9.76	10.6	40.7	56.6	2 級	2 級
113	16.9	488	9.16	8.56	9.26	32.0	47.5	2 級	3 級
115	19.1	566	9.42	8.71	8.73	29.7	42.7	3 級	3 級
116	17.7	469	9.86	9.29	10.2	34.0	49.2	1 級	3 級
118	18.0	519	10.5	9.52	6.97	34.9	47.5	1 級	2 級
123	18.3	488	5.53	5.10	5.39	22.7	31.0	2 級	2 級
126	18.0	580	13.1	11.2	11.9	43.1	60.6	2 級	2 級
127	16.0	456	11.3	10.3	11.4	41.6	60.0	1 級	1 級
129	17.2	460	7.66	7.03	8.49	20.7	30.4	3 級	3 級
131	16.6	511	13.9	12.7	14.4	48.5	67.6	3 級	3 級
133	17.5	530	10.5	10.4	10.4	40.7	63.5	3 級	3 級
138	17.6	556	11.1	10.1	10.4	35.6	45.0	1 級	2 級
143	19.9	520	10.4	9.32	11.0	29.6	39.9	2 級	2 級
144	18.5	514	9.28	8.55	8.50	34.9	57.7	2 級	等級外
146	18.3	526	11.5	10.1	12.1	35.4	35.4	1 級	3 級
149	18.7	539	11.6	9.32	12.1	30.2	51.0	3 級	3 級
151	18.5	538	13.3	11.8	13.0	42.3	67.3	2 級	2 級
152	18.6	542	9.22	8.64	9.26	28.9	49.7	2 級	3 級
153	18.4	476	8.94	7.87	8.20	33.8	48.9	1 級	1 級
159	20.0	562	8.99	7.27	7.16	27.1	39.3	2 級	3 級
161	17.3	562	12.1	10.6	11.0	32.4	32.6	2 級	3 級
162	16.9	492	9.25	8.56	9.84	27.6	37.6	2 級	3 級
163	17.3	539	8.61	7.83	7.85	29.3	41.8	2 級	3 級
165	17.2	562	7.70	7.19	7.46	34.9	51.7	2 級	2 級
168	19.5	492	10.0	9.07	9.93	37.3	55.5	1 級	2 級

Table 4. 曲げ試験結果（続き）Test results on bending strength (cont.)

試験体番号 Test piece No.	含水率 MC (%)	見かけの密度 Apparent ρ (kg/m^3)	縦振動法のヤング係数 $E_{fr\text{-}l}$ (kN/mm^2)	見かけの曲げヤング係数 Apparent E_b (kN/mm^2)	真の曲げヤング係数 True E_b (kN/mm^2)	曲げ比例限度応力 σ_{bp} (N/mm^2)	曲げ強度 σ_b (N/mm^2)	JAS の目視等級甲 II（荷重点間）JAS visual grading (in loading span)	JAS の目視等級甲 II（全区間）JAS visual grading (in full length)
169	18.3	489	8.13	7.78	8.14	34.2	52.0	1 級	3 級
170	17.4	529	9.75	8.86	8.94	35.2	52.2	2 級	2 級
172	17.6	470	10.6	9.33	10.2	37.0	55.2	2 級	3 級
173	18.5	524	9.66	8.45	8.54	30.5	48.5	3 級	3 級
174	18.9	497	9.90	8.77	9.32	32.0	48.1	2 級	2 級
176	18.7	536	12.8	10.8	12.9	44.0	50.7	1 級	1 級
177	17.5	538	7.89	7.14	7.47	32.7	50.9	1 級	1 級
178	17.9	551	10.6	9.34	9.69	34.4	49.6	2 級	2 級
181	18.9	549	13.8	12.4	13.9	39.9	57.1	1 級	2 級
182	18.1	529	9.93	9.26	10.4	32.8	41.0	3 級	3 級
183	20.8	603	15.1	12.8	13.7	42.7	56.6	2 級	3 級
187	18.1	544	7.62	6.64	7.23	28.5	42.0	1 級	2 級
190	17.2	507	9.33	8.88	9.33	33.8	45.1	2 級	2 級
191	19.4	540	13.5	11.5	12.8	44.2	59.9	1 級	2 級
193	18.1	469	7.02	6.76	6.58	20.4	29.6	2 級	3 級
195	20.8	455	10.1	8.79	10.1	29.6	39.4	2 級	3 級
196	18.9	527	12.8	11.0	11.6	38.3	47.5	1 級	1 級
197	18.4	555	13.2	11.8	12.4	42.1	61.0	1 級	1 級
198	18.4	467	8.60	7.37	7.55	23.4	36.9	3 級	3 級
199	18.6	509	9.01	8.62	8.37	29.9	43.9	1 級	2 級
試験体数 TP No.	100	100	100	100	100	100	100		
平均値 Mean	18.2	521	10.4	9.34	10.0	35.0	49.6		
変動係数 CV (%)	7.13	6.94	17.2	16.2	19.0	19.5	21.0		
最小値 Min.	15.4	443	5.53	5.10	5.39	19.9	22.8		
最大値 Max.	22.5	603	15.1	12.8	14.4	48.5	72.1		

MC：含水率 Moisture content, ρ ：密度 Density, $E_{fr\text{-}l}$：縦振動法のヤング係数 Young's modulus by longitudinal vibration method, E_b：曲げヤング係数 Bending Young's modulus, σ_{bp}：曲げ比例限度応力 Bending stress at the proportional limit, σ_b：曲げ強度 Bending strength, JAS：製材の日本農林規格 Japanese agricultural standards for sawn lumber, CV：変動係数 Coefficient of variance

Table 5. 縦圧縮試験結果 Test results on compressive strength parallel to the grain

試験体番号 Test piece No.	含水率 MC (%)	見かけの密度 Apparent ρ (kg/m^3)	縦振動法のヤング係数 $E_{fr\text{-}l}$ (kN/mm^2)	縦圧縮ヤング係数 E_c (kN/mm^2)	縦圧縮比例限度応力 σ_{cp} (N/mm^2)	縦圧縮強度 σ_c (N/mm^2)	試験体番号 Test piece No.	含水率 MC (%)	見かけの密度 Apparent ρ (kg/m^3)	縦振動法のヤング係数 $E_{fr\text{-}l}$ (kN/mm^2)	縦圧縮ヤング係数 E_c (kN/mm^2)	縦圧縮比例限度応力 σ_{cp} (N/mm^2)	縦圧縮強度 σ_c (N/mm^2)
3	16.0	579	14.2	15.9	19.7	39.1	74	16.2	499	9.38	8.17	14.1	23.5
7	16.5	539	10.0	9.26	14.5	28.7	75	15.9	477	9.78	8.77	20.2	25.8
9	15.8	496	11.9	11.4	23.7	34.4	76	17.5	429	9.91	10.0	9.67	22.5
12	16.9	554	7.76	5.90	13.7	26.0	77	17.4	522	8.65	7.88	8.21	18.9
13	16.5	540	9.94	10.7	9.93	25.0	78	16.9	523	9.29	11.2	12.8	22.3
14	17.6	548	11.2	13.2	19.4	30.9	80	16.6	564	9.41	9.14	14.6	32.3
15	16.9	517	12.2	12.2	17.0	34.9	83	16.5	444	8.59	7.50	12.1	23.1
16	15.8	534	7.41	5.96	13.0	27.1	86	17.5	525	11.9	10.6	33.3	33.8
17	15.7	494	9.78	9.14	16.6	30.4	90	17.9	547	12.2	13.0	24.2	34.6
18	16.3	515	10.4	10.7	16.7	29.7	93	17.0	545	11.5	14.5	12.6	29.2
19	16.5	545	9.46	8.80	14.9	27.7	94	16.1	567	12.2	10.2	24.5	34.4
20	16.6	590	13.0	11.6	32.0	34.4	96	17.3	547	9.91	12.2	14.8	27.3
21	16.1	505	10.7	10.3	16.0	32.0	102	16.4	488	8.12	6.89	13.3	26.2
23	17.7	468	9.78	8.88	15.2	29.1	107	16.8	557	9.33	8.41	14.4	29.5
24	16.9	533	11.4	10.9	14.4	32.0	109	17.7	468	11.3	10.5	16.6	31.8
25	16.6	507	9.07	8.65	18.9	28.6	111	17.5	449	9.83	8.69	25.1	28.3
26	15.8	510	9.59	8.31	25.9	31.5	113	16.3	500	8.54	8.35	19.7	23.3
27	15.8	521	10.4	9.53	13.4	28.7	115	17.1	562	11.0	10.8	14.1	31.3
32	16.4	477	8.92	7.96	20.9	27.1	116	17.2	468	11.4	10.1	17.5	30.0
33	17.3	561	10.9	8.84	15.2	26.3	118	17.5	522	9.56	6.85	11.0	23.5
37	17.5	520	10.3	8.97	14.9	30.5	123	17.2	454	6.24	5.01	14.2	21.7
39	16.6	484	9.52	7.78	10.4	24.9	126	17.3	543	7.86	6.89	16.9	29.5
40	18.5	570	12.3	11.4	13.7	32.1	127	16.4	482	12.4	11.4	18.2	33.8
41	17.8	526	11.7	10.5	13.6	31.3	129	16.1	464	7.72	5.48	8.58	20.4
42	18.2	505	7.31	6.73	17.6	20.8	131	15.4	506	13.1	12.3	28.7	39.2
44	18.0	511	9.83	9.19	14.9	25.3	133	15.5	495	11.5	10.7	17.9	34.3
48	17.7	503	9.52	7.11	13.3	22.8	138	17.5	542	11.7	10.8	17.3	30.8
49	17.0	515	11.7	11.3	20.8	33.2	143	17.3	511	8.70	8.40	16.8	22.8
50	17.6	495	9.16	9.29	11.0	27.0	144	17.5	513	10.2	8.92	23.6	28.6
54	16.5	498	10.0	9.66	12.1	24.4	146	17.5	531	10.4	14.7	10.4	24.0
55	17.2	520	11.8	12.0	14.9	29.4	149	18.0	539	11.7	11.5	13.2	27.5
56	17.7	481	9.93	10.4	13.0	27.7	151	18.1	546	12.7	12.5	19.8	38.1
57	16.9	505	11.5	10.8	18.8	33.5	152	18.0	528	8.96	9.34	10.4	25.4
58	17.4	496	11.6	14.2	15.6	28.6	153	16.9	446	8.52	7.10	13.1	25.2
59	16.7	513	9.95	9.51	13.8	23.7	159	17.4	519	10.5	9.72	19.1	25.9
61	17.4	518	10.9	-	-	25.2	161	16.7	563	11.1	11.8	12.7	28.0
63	17.0	521	8.10	7.35	12.7	24.9	162	16.9	479	10.4	10.9	13.5	26.8
69	16.7	481	7.85	7.43	12.2	25.1	163	16.7	534	9.69	8.64	17.8	31.0
71	17.0	510	10.9	10.5	21.9	30.9	165	16.3	545	8.90	8.65	19.9	27.8
72	16.7	478	10.6	8.34	16.4	28.4	168	16.3	472	10.5	9.48	28.1	31.0

Table 5. 縦圧縮試験結果（続き）Test results on compressive strength parallel to the grain (cont.)

試験体番号 Test piece No.	含水率 MC (%)	見かけの密度 Apparent ρ (kg/m^3)	縦振動法のヤング係数 $E_{fr\text{-}l}$ (kN/mm^2)	縦圧縮ヤング係数 E_c (kN/mm^2)	縦圧縮比例限度応力 σ_{cp} (N/mm^2)	縦圧縮強度 σ_c (N/mm^2)
169	16.9	497	6.94	6.62	13.1	27.2
170	16.7	509	9.92	9.79	14.7	28.3
172	16.2	487	11.3	9.83	20.3	31.6
173	16.9	543	8.59	7.70	11.3	24.9
174	17.6	486	9.76	9.47	18.3	26.4
176	16.4	521	11.7	10.3	13.9	27.2
177	17.1	537	11.2	10.2	11.3	29.1
178	16.8	564	9.06	8.90	20.4	29.9
181	17.2	530	13.2	15.2	18.8	35.8
182	16.7	510	10.3	11.5	24.7	30.5
183	18.8	628	15.9	14.9	25.8	41.4
187	16.0	532	7.95	7.57	11.6	27.1
190	17.2	510	9.04	8.20	12.3	25.5
191	17.5	519	12.5	13.0	16.5	31.2
193	16.9	444	8.29	4.88	8.70	19.9
195	17.8	452	9.33	7.70	12.3	21.1
196	17.0	516	13.4	18.5	15.3	37.8
197	17.4	542	12.3	11.0	20.2	34.1
198	16.6	440	9.05	7.57	15.5	24.4
199	17.2	515	8.93	11.6	9.36	19.7
試験体数 TP No.	100	100	100	99	99	100
平均値 Mean	16.9	514	10.3	9.81	16.4	28.5
変動係数 CV (%)	3.99	6.90	16.3	24.6	30.5	16.1
最小値 Min.	15.4	429	6.24	4.88	8.21	18.9
最大値 Max.	18.8	628	15.9	18.5	33.3	41.4

MC：含水率 Moisture content, ρ：密度 Density, $E_{fr\text{-}l}$：縦振動法のヤング係数 Young's modulus by longitudinal vibration method, E_c：縦圧縮ヤング係数 Compressive Young's modulus, σ_{cp}：縦圧縮比例限度応力 Compressive stress at the proportional limit, σ_c：縦圧縮強度 Compressive strength parallel to the grain, CV：変動係数 Coefficient of variance

Table 6. 縦引張り試験結果 Test results on tensile strength parallel to the grain

試験体番号 Test piece No.	含水率 MC (%)	見かけの密度 Apparent ρ (kg/m^3)	縦振動法のヤング係数 $E_{fr\text{-}l}$ (kN/mm^2)	縦引張りヤング係数 E_t (kN/mm^2)	縦引張り比例限度応力 σ_{tp} (N/mm^2)	縦引張り強度 σ_t (N/mm^2)	JAS の目視等級甲 II（チャック間） JAS visual grading (between the grips)
1	17.6	556	13.9	12.9	66.9	67.5	2 級
2	16.3	526	12.2	12.4	37.7	37.7	1 級
4	17.7	491	9.54	9.03	30.3	30.6	3 級
5	18.1	462	9.65	9.55	36.1	36.1	3 級
6	16.6	496	9.22	8.98	16.8	20.1	等級外
8	16.0	489	10.5	10.1	33.8	35.1	3 級
10	15.6	493	8.54	9.93	10.4	15.5	等級外
11	17.9	484	9.68	8.95	40.0	40.9	2 級
22	18.9	524	9.36	8.68	29.6	33.2	2 級
28	19.1	564	8.35	7.63	20.4	20.7	3 級
29	18.4	532	9.85	8.67	25.2	25.2	3 級
30	17.7	520	7.03	6.81	21.1	21.1	2 級
31	18.2	476	8.63	7.88	38.6	38.6	2 級
34	-	548	8.81	7.89	31.9	32.2	3 級
35	18.6	516	11.4	10.9	28.8	30.8	2 級
36	19.6	570	11.1	10.0	35.9	37.4	1 級
38	18.2	547	9.58	9.12	21.5	31.6	等級外
43	19.9	615	9.84	9.58	27.2	28.5	3 級
45	19.3	524	10.1	10.9	33.5	49.0	2 級
46	18.7	565	12.4	12.2	39.5	39.5	3 級
47	16.8	514	10.8	10.2	42.9	43.3	3 級
51	17.5	502	11.6	10.9	29.8	30.3	3 級
52	19.0	521	10.9	9.52	22.0	27.5	等級外
53	19.2	506	11.7	11.4	44.0	44.0	1 級
60	16.9	475	10.6	10.4	29.6	29.6	2 級
62	19.4	474	7.99	6.98	14.3	17.0	3 級
64	17.5	530	7.99	7.39	30.1	30.2	3 級
65	20.1	542	12.5	11.6	47.7	48.3	2 級
66	21.3	590	7.64	7.03	25.8	25.8	2 級
67	19.0	541	7.70	6.69	19.1	19.1	3 級
68	17.9	514	10.4	10.2	25.7	26.4	3 級
70	18.2	523	10.2	9.41	9.55	23.9	3 級
73	17.8	477	11.5	10.8	51.6	51.6	1 級
79	19.3	505	10.7	9.34	9.05	22.5	3 級
81	17.8	544	11.3	11.2	54.9	54.9	1 級
82	17.7	475	9.87	8.79	29.2	29.2	等級外
84	21.6	498	8.93	8.23	28.6	41.2	等級外
85	22.0	542	10.7	10.4	34.1	38.7	1 級
87	19.1	539	10.2	10.2	45.8	50.5	2 級
88	17.3	533	9.32	9.62	9.14	19.2	等級外

Table 6. 縦引張り試験結果 (続き) Test results on tensile strength parallel to the grain (cont.)

試験体番号 Test piece No.	含水率 MC (%)	見かけの密度 Apparent ρ (kg/m^3)	縦振動法のヤング係数 $E_{fr\text{-}l}$ (kN/mm^2)	縦引張りヤング係数 E_t (kN/mm^2)	縦引張り比例限度応力 σ_{tp} (N/mm^2)	縦引張り強度 σ_t (N/mm^2)	JAS の目視等級甲 II（チャック間） JAS visual grading (between the grips)
89	17.8	493	12.6	11.4	19.4	48.7	等級外
91	16.5	447	8.19	8.95	25.6	33.9	3 級
92	17.4	483	6.34	6.16	28.2	28.2	等級外
95	18.3	586	11.4	10.4	19.6	28.5	3 級
97	18.6	547	10.8	10.3	18.1	21.6	3 級
98	18.7	549	13.5	12.9	65.1	69.2	1 級
99	21.4	565	11.8	9.34	16.6	17.5	等級外
100	20.4	556	11.5	11.2	22.2	22.6	3 級
101	17.4	524	12.6	12.0	19.4	23.3	1 級
103	18.0	543	12.2	12.0	42.7	56.1	2 級
104	17.9	522	11.7	11.2	30.4	30.4	2 級
105	16.7	542	9.09	9.28	16.4	18.0	等級外
106	18.3	479	10.8	10.4	37.2	45.0	3 級
108	17.2	482	9.19	8.81	31.4	31.4	2 級
110	17.6	480	11.3	11.0	37.0	40.7	2 級
112	17.6	529	10.3	9.40	18.9	21.5	3 級
114	17.2	475	8.92	7.80	25.6	25.6	2 級
117	17.8	512	10.4	9.75	29.9	30.4	3 級
119	17.8	516	9.68	8.87	26.1	27.7	3 級
120	18.0	515	12.3	11.7	49.0	50.0	2 級
121	18.2	556	11.2	11.4	48.4	49.7	2 級
122	19.6	526	9.63	9.17	19.0	27.6	2 級
124	19.2	564	12.3	12.9	49.3	49.8	等級外
125	19.0	559	8.90	8.51	33.1	38.6	2 級
128	16.9	480	8.75	8.97	40.1	43.0	2 級
130	17.8	506	8.94	8.51	16.2	18.1	3 級
132	17.2	485	9.52	8.59	18.8	23.8	等級外
134	20.8	558	8.59	7.72	34.4	34.4	等級外
135	17.5	470	9.45	9.74	48.8	53.1	1 級
136	16.7	481	9.81	8.20	15.2	25.0	3 級
137	17.0	502	10.7	10.2	32.0	32.0	3 級
139	18.8	511	9.93	9.62	35.2	35.5	2 級
140	18.4	544	12.8	12.3	37.7	37.7	1 級
141	19.3	508	10.5	9.89	29.8	37.3	2 級
142	20.3	544	10.9	10.4	35.6	40.5	3 級
145	18.0	487	9.10	8.60	22.4	31.1	2 級
147	18.2	588	10.8	10.2	26.3	26.3	3 級
148	18.9	555	12.8	12.3	43.9	47.3	2 級
150	18.3	571	13.6	13.3	36.4	36.4	3 級
154	18.7	522	8.44	7.42	15.1	17.7	等級外

Table 6. 縦引張り試験結果 (続き) Test results on tensile strength parallel to the grain (cont.)

試験体番号 Test piece No.	含水率 MC (%)	見かけの密度 Apparent ρ (kg/m^3)	縦振動法のヤング係数 $E_{fr\text{-}l}$ (kN/mm^2)	縦引張りヤング係数 E_t (kN/mm^2)	縦引張り比例限度応力 σ_{tp} (N/mm^2)	縦引張り強度 σ_t (N/mm^2)	JASの目視等級甲II（チャック間） JAS visual grading (between the grips)
155	18.6	571	11.7	10.3	14.4	36.5	3 級
156	19.0	505	11.6	11.1	14.4	30.3	2 級
157	20.1	575	10.4	9.29	24.3	35.5	等級外
158	20.2	572	14.6	13.7	50.0	54.8	3 級
160	18.5	537	10.0	10.3	26.1	26.1	2 級
164	17.8	501	9.18	8.57	21.0	21.0	3 級
166	19.2	514	8.35	7.59	31.9	35.1	等級外
167	17.8	478	10.4	10.1	24.6	29.2	2 級
171	17.2	497	9.66	9.34	29.8	30.2	1 級
175	18.1	504	9.00	8.27	23.2	27.2	3 級
179	17.8	542	12.0	11.4	47.0	48.8	1 級
180	18.1	508	8.98	9.21	31.0	31.2	2 級
184	18.4	541	8.06	7.56	28.1	35.0	3 級
185	19.3	555	12.0	11.7	35.5	50.1	2 級
186	18.1	478	9.20	9.09	37.2	37.2	3 級
188	19.2	496	9.60	9.48	38.3	40.0	2 級
189	18.9	518	10.0	9.57	35.2	49.3	3 級
192	18.5	515	10.0	10.1	23.7	23.7	3 級
194	18.3	485	9.47	9.06	34.7	34.7	3 級
200	19.4	542	10.3	10.6	33.4	33.7	等級外
試験体数 TP No.	99	100	100	100	100	100	
平均値 Mean	18.4	521	10.3	9.80	30.5	34.3	
変動係数 CV (%)	6.45	6.46	15.2	16.1	38.3	32.8	
最小値 Min.	15.6	447	6.34	6.16	9.05	15.5	
最大値 Max.	22.0	615	14.6	13.7	66.9	69.2	

MC：含水率 Moisture content, ρ：密度 Density, $E_{fr\text{-}l}$：縦振動法のヤング係数 Young's modulus by longitudinal vibration method, E_t：縦引張りヤング係数 Tensile Young's modulus, σ_{tp}：縦引張り比例限度応力 Tensile stress at the proportional limit, σ_t：縦引張り強度 Tensile strength parallel to the grain, JAS：製材の日本農林規格 Japanese agricultural standards for sawn lumber, CV：変動係数 Coefficient of variance

Table 7. せん断試験結果 Test results on shear strength parallel to the grain

試験体番号 Test piece No.	含水率 MC (%)	見かけの密度 Apparent ρ (kg/m^3)	せん断強度 σ_s (N/mm^2)
3	15.6	597	6.98
7	16.0	535	8.37
9	15.9	541	6.54
12	16.6	600	8.08
13	16.2	558	5.38
14	16.6	532	6.67
15	15.8	518	7.76
16	15.8	568	7.41
17	15.6	496	6.78
18	15.7	513	5.48
19	15.9	529	7.19
20	15.9	600	7.36
21	16.0	492	6.19
23	16.3	484	6.27
24	16.3	527	5.28
25	15.2	509	6.74
26	15.9	516	6.44
27	16.2	509	5.33
32	16.2	462	7.04
33	16.7	544	7.83
37	15.8	513	6.54
39	16.3	478	6.10
40	16.8	537	7.23
41	16.3	525	6.85
42	17.1	525	5.36
44	16.7	520	5.90
48	16.2	503	5.34
49	16.6	529	6.52
50	16.6	512	6.23
54	16.4	505	7.21
55	15.9	503	7.02
56	16.2	483	6.56
57	15.6	531	6.79
58	16.1	490	6.43
59	15.8	517	6.64
61	15.9	526	6.50
63	16.2	537	6.41
69	16.3	476	6.13
71	16.1	514	7.54
72	15.9	464	5.57

試験体番号 Test piece No.	含水率 MC (%)	見かけの密度 Apparent ρ (kg/m^3)	せん断強度 σ_s (N/mm^2)
74	15.9	496	6.53
75	15.9	456	5.13
76	15.9	432	5.33
77	16.0	525	7.29
78	15.5	501	6.30
80	16.1	558	6.75
83	16.0	425	5.27
86	15.5	521	7.30
90	16.2	540	6.93
93	15.5	554	6.54
94	15.6	593	5.97
96	15.6	521	6.36
102	16.1	471	7.25
107	16.0	559	7.32
109	15.8	470	5.79
111	15.3	436	5.96
113	16.2	494	5.93
115	15.9	540	6.48
116	16.1	467	5.95
118	16.4	509	7.39
123	15.5	447	7.80
126	16.3	534	8.53
127	15.8	473	5.61
129	16.1	436	6.10
131	15.3	518	7.11
133	15.3	484	5.98
138	16.3	522	7.76
143	16.4	498	6.50
144	16.3	513	6.21
146	16.0	529	5.95
149	16.2	534	8.36
151	16.9	550	7.95
152	17.2	529	6.24
153	16.9	452	6.27
159	16.0	572	5.22
161	16.6	565	5.93
162	15.9	487	5.94
163	15.6	571	9.00
165	15.8	544	6.61
168	15.5	466	5.93

試験体番号 Test piece No.	含水率 MC (%)	見かけの密度 Apparent ρ (kg/m^3)	せん断強度 σ_s (N/mm^2)
169	16.3	489	8.22
170	15.7	518	8.06
172	15.5	487	6.93
173	16.6	534	4.68
174	16.6	507	6.01
176	16.1	494	6.29
177	15.9	538	7.22
178	16.4	558	7.76
181	16.4	540	6.04
182	15.8	526	8.40
183	17.2	635	8.40
187	15.9	512	7.03
190	16.6	494	8.07
191	16.0	514	6.50
193	16.0	491	7.90
195	16.1	446	5.64
196	16.5	512	6.79
197	16.4	537	8.18
198	16.0	425	5.03
199	16.5	494	6.56
試験体数 TP No.	100	100	100
平均値 Mean	16.1	514	6.66
変動係数 CV (%)	2.59	7.71	13.9
最小値 Min.	15.2	425	4.68
最大値 Max.	17.2	635	9.00

MC：含水率 Moisture content, ρ：密度 Density,
σ_s：せん断強度 Shear strength parallel to thegrain, CV：変動係数 Coefficient of variance

Table 8. めり込み試験結果 Test results on compressive strength perpendicular to the grain

試験体番号 Test piece No.	含水率 MC (%)	見かけの密度 Apparent ρ (kg/m^3)	縦振動法のヤング係数 $E_{fr\text{-}l}$ (kN/mm^2)	5% 変形時の応力 $\sigma_{cv\text{-}5\%}$ (N/mm^2)	めり込み強度 $f_{c,90}$ (N/mm^2)	めり込み降伏強度 $f_{c,90,y}$ (N/mm^2)	めり込み剛性 $K_{c,90}$ (N/mm^3)
3	15.6	577	12.2	7.83	10.8	7.52	3.91
7	14.7	542	8.70	9.31	13.8	8.95	5.44
9	14.4	519	10.8	7.79	9.90	7.47	3.63
12	16.4	540	10.0	7.76	10.4	7.46	3.78
13	15.7	550	8.70	10.2	13.8	9.80	5.42
14	16.4	548	11.9	7.90	10.5	7.33	5.73
15	15.1	510	11.7	6.43	8.93	6.19	2.77
16	15.0	510	8.07	7.82	9.95	7.53	3.43
17	15.2	494	9.85	7.85	10.6	7.45	4.11
18	15.1	498	9.85	6.54	8.31	6.40	2.75
19	15.8	564	9.56	8.38	11.0	7.96	4.28
20	15.5	591	12.6	11.9	14.5	11.3	5.85
21	16.1	510	10.5	7.25	8.38	7.14	2.69
23	15.5	473	9.77	6.22	7.85	5.98	2.65
24	15.6	530	12.4	7.91	8.99	7.50	4.16
25	15.8	502	8.78	7.40	9.87	7.20	2.94
26	14.9	506	9.91	6.92	9.14	6.69	2.85
27	15.4	517	11.2	7.07	8.42	6.87	3.44
32	15.6	486	9.59	8.05	10.2	7.68	4.24
33	16.1	575	11.3	8.82	12.2	8.57	3.73
37	16.4	513	10.4	8.43	9.74	7.98	4.39
39	15.2	488	10.3	6.58	8.27	6.70	2.66
40	16.6	588	12.0	9.33	12.5	8.96	4.34
41	16.4	542	11.3	6.93	9.05	6.48	3.44
42	17.1	472	8.32	5.89	8.10	5.76	2.59
44	16.4	509	9.52	-	-	-	-
48	16.1	502	10.3	8.54	11.4	8.02	5.48
49	15.8	541	12.0	7.43	10.0	7.32	3.14
50	16.4	476	9.48	5.93	8.72	5.75	2.64
54	15.9	488	10.6	5.41	8.08	5.36	2.50
55	15.7	508	12.2	6.94	9.78	6.61	3.42
56	16.5	497	9.90	6.19	8.22	5.89	3.90
57	15.7	501	11.5	7.53	9.22	7.35	3.46
58	16.3	490	11.4	6.06	8.41	5.89	2.92
59	14.9	505	9.17	7.63	9.68	7.20	4.61
61	16.1	521	11.8	6.24	8.18	6.02	3.35
63	16.6	514	9.40	7.17	10.5	6.81	3.77
69	16.0	487	9.78	6.75	9.17	6.40	3.33
71	15.4	511	11.1	7.24	9.79	6.91	3.33
72	15.3	476	10.7	6.69	8.73	6.30	3.27

Table 8. めり込み試験結果（続き）Test results on compressive strength perpendicular to the grain (cont.)

試験体番号 Test piece No.	含水率 MC (%)	見かけの密度 Apparent ρ (kg/m^3)	縦振動法のヤング係数 $E_{fr\text{-}l}$ (kN/mm^2)	5% 変形時の応力 $\sigma_{cv\text{-}5\%}$ (N/mm^2)	めり込み強度 $f_{c,90}$ (N/mm^2)	めり込み降伏強度 $f_{c,90,y}$ (N/mm^2)	めり込み剛性 $K_{c,90}$ (N/mm^3)
74	15.7	482	10.4	6.27	8.71	5.80	3.57
75	15.4	502	10.4	6.23	8.79	5.91	2.75
76	16.0	436	8.93	4.62	6.79	4.34	2.09
77	16.0	504	11.0	6.11	7.09	5.81	3.17
78	15.5	504	9.98	6.39	8.59	6.33	2.62
80	15.8	564	9.93	8.21	11.5	8.30	3.81
83	16.2	447	9.02	6.05	7.52	5.90	2.70
86	16.1	517	11.6	6.49	8.71	6.45	2.57
90	16.3	552	9.58	10.4	14.2	9.82	6.50
93	16.4	551	10.7	7.98	10.8	7.44	5.82
94	15.8	578	10.9	8.27	11.2	7.80	4.50
96	15.8	546	10.2	6.53	7.96	6.43	2.43
102	16.2	475	8.97	5.97	7.94	5.80	2.73
107	16.8	546	9.49	8.02	10.7	7.77	3.48
109	17.1	474	12.1	5.48	7.88	5.19	2.60
111	16.5	439	9.37	6.23	8.33	5.76	3.77
113	16.8	490	9.56	6.64	8.41	6.28	3.91
115	16.7	567	8.07	7.74	10.7	7.24	4.06
116	16.9	469	10.7	5.65	7.46	5.44	2.43
118	16.8	512	11.2	6.74	8.88	6.39	3.21
123	16.2	444	6.80	5.86	8.05	5.55	3.11
126	16.4	575	11.1	8.82	11.8	8.41	4.68
127	15.9	466	12.1	5.87	7.42	5.62	2.67
129	16.8	474	9.16	6.74	8.60	6.41	4.15
131	14.6	503	13.4	7.05	9.38	6.71	3.89
133	14.9	504	10.7	8.73	11.3	8.14	4.95
138	16.8	539	12.4	8.36	11.4	7.91	5.38
143	16.8	509	9.00	6.46	8.44	6.24	3.62
144	16.8	494	9.96	7.55	10.1	6.93	5.32
146	16.6	527	10.4	7.41	10.1	7.22	3.16
149	16.8	539	10.5	7.13	8.93	6.80	3.27
151	17.4	541	13.3	6.84	9.66	6.77	3.39
152	16.6	519	9.62	6.73	9.33	6.51	3.05
153	16.7	451	8.80	5.65	7.86	5.43	3.83
159	15.9	523	10.1	6.09	7.99	5.85	2.75
161	16.1	572	10.9	7.62	9.96	7.16	4.22
162	15.9	477	9.84	7.02	8.94	6.67	3.50
163	15.9	542	9.78	8.25	10.6	8.04	4.78
165	15.4	544	9.58	9.16	11.2	8.82	4.28
168	15.9	483	9.62	5.80	7.54	5.66	2.51

Table 8. めり込み試験結果（続き）Test results on compressive strength perpendicular to the grain (cont.)

試験体番号 Test piece No.	含水率 MC (%)	見かけの密度 Apparent ρ (kg/m^3)	縦振動法のヤング係数 $E_{fr\text{-}l}$ (kN/mm^2)	5% 変形時の応力 $\sigma_{cv\text{-}5\%}$ (N/mm^2)	めり込み強度 $f_{c,90}$ (N/mm^2)	めり込み降伏強度 $f_{c,90,y}$ (N/mm^2)	めり込み剛性 $K_{c,90}$ (N/mm^3)
169	16.5	492	6.83	7.02	9.36	6.73	3.19
170	15.9	511	9.59	7.43	9.59	7.13	3.51
172	15.7	476	11.2	5.69	7.12	5.48	2.81
173	16.2	535	9.72	7.44	11.0	6.99	4.54
174	16.3	488	10.2	6.50	8.86	6.20	2.98
176	16.1	521	12.6	6.63	9.43	6.45	2.93
177	15.7	534	9.26	7.04	9.96	6.97	2.86
178	16.1	560	10.9	8.48	12.5	8.11	4.57
181	16.1	541	13.5	5.96	8.83	5.90	2.28
182	16.4	529	10.4	6.39	9.44	6.14	3.13
183	17.6	631	15.1	8.71	12.0	8.67	3.94
187	15.6	527	8.08	8.47	11.1	8.09	4.31
190	16.7	508	9.53	7.17	9.98	6.97	3.53
191	16.4	524	13.0	6.46	8.10	6.32	2.78
193	16.0	456	7.01	4.79	6.67	4.50	2.29
195	15.8	450	9.42	4.75	5.94	4.65	2.00
196	16.3	514	12.6	6.35	8.00	6.03	3.30
197	17.1	558	12.3	8.51	10.9	8.05	4.68
198	16.3	438	9.35	4.32	6.08	4.21	1.74
199	16.5	505	9.45	6.01	8.43	5.61	3.05
試験体数 TP No.	100	100	100	99	99	99	99
平均値 Mean	16.1	513	10.4	7.13	9.48	6.84	3.58
変動係数 CV (%)	3.86	7.30	14.2	17.7	17.8	17.5	26.8
最小値 Min.	14.4	436	6.80	4.32	5.94	4.21	1.74
最大値 Max.	17.6	631	15.1	11.9	14.5	11.3	6.50

MC：含水率 Moisture content, ρ：密度 Density, $E_{fr\text{-}l}$：縦振動法のヤング係数 Young's modulus by longitudinal vibration method, $\sigma_{CV\text{-}5\%}$：5% 変形時の応力 Compressive stress perpendicular to the grain at 5% deflection, $f_{c,90}$: めり込み強度 Compressive strength perpendicular to the grain, $f_{c,90,y}$: めり込み降伏強度 Yeild strength of compression perpendicular to the grain, $K_{c,90}$: めり込み剛性 Stiffness of compression perpendicular to the grain, CV：変動係数 Coefficient of variance

Table 9. 曲げ試験結果の概要 Summary of test results on bending strengh

	含水率 MC (%)	見かけの密度 Apparent ρ (kg/m^3)	縦振動法のヤング係数 $E_{fr\text{-}l}$ (kN/mm^2)	見かけの曲げヤング係数 Apparent E_b (kN/mm^2)	真の曲げヤング係数 True E_b (kN/mm^2)	曲げ強度 σ_b (N/mm^2)	5% 下限値 5% lower limit (N/mm^2)
試験体数 TP No.	100	100	100	100	100	100	100
平均値 Mean	18.2	521	10.4	9.34	10.0	49.6	26.8
変動係数 CV (%)	7.13	6.94	17.2	16.2	19.0	21.0	
最小値 Min.	15.4	443	5.53	5.10	5.39	22.8	
最大値 Max.	22.5	603	15.1	12.8	14.4	72.1	

MC：含水率 Moisture content, ρ：密度 Density, $E_{fr\text{-}l}$：縦振動法のヤング係数 Young's modulus by longitudinal vibration method, E_b：曲げヤング係数 Bending Young's modulus, σ_b：曲げ強度 Bending strength, CV：変動係数 Coefficient of variance

Table 10. 目視等級区分ごとに見た曲げ試験結果

Test results on bending strength by visual grading according to Japanese agricultural standards for sawn lumber

甲種構造材 II 1 級 For bending member II 1st grade	含水率 MC (%)	見かけの 密度 Apparent ρ (kg/m^3)	縦振動法の ヤング係数 $E_{fr\text{-}l}$ (kN/mm^2)	見かけの曲げ ヤング係数 Apparent E_b (kN/mm^2)	曲げ強度 σ_b (N/mm^2)	5% 下限値 5% lower limit (N/mm^2)
試験体数 TP No.	8	8	8	8	8	8
平均値 Mean	18.0	512	11.1	9.87	54.4	42.4
変動係数 CV (%)	5.54	7.25	17.7	16.8	10.1	
最小値 Min.	16.0	456	7.89	7.14	47.5	
最大値 Max.	18.9	555	13.2	11.8	61.0	

甲種構造材 II 2 級 For bending member II 2nd grade	含水率 MC (%)	見かけの 密度 Apparent ρ (kg/m^3)	縦振動法の ヤング係数 $E_{fr\text{-}l}$ (kN/mm^2)	見かけの曲げ ヤング係数 Apparent E_b (kN/mm^2)	曲げ強度 σ_b (N/mm^2)	5% 下限値 5% lower limit (N/mm^2)
試験体数 TP No.	34	34	34	34	34	34
平均値 Mean	17.9	520	10.4	9.35	52.1	35.5
変動係数 CV (%)	6.38	6.52	17.6	16.8	17.2	
最小値 Min.	15.4	443	5.53	5.10	31.0	
最大値 Max.	19.9	586	13.8	12.4	72.1	

甲種構造材 II 3 級 For bending member II 3rd grade	含水率 MC (%)	見かけの 密度 Apparent ρ (kg/m^3)	縦振動法の ヤング係数 $E_{fr\text{-}l}$ (kN/mm^2)	見かけの曲げ ヤング係数 Apparent E_b (kN/mm^2)	曲げ強度 σ_b (N/mm^2)	5% 下限値 5% lower limit (N/mm^2)
試験体数 TP No.	42	42	42	42	42	42
平均値 Mean	18.2	523	10.5	9.42	48.7	29.4
変動係数 CV (%)	7.61	7.56	18.0	16.8	21.6	
最小値 Min.	16.4	455	7.02	6.76	24.7	
最大値 Max.	22.5	603	15.1	12.8	68.1	

甲種構造材 II 等級外 For bending member II out of grade	含水率 MC (%)	見かけの 密度 Apparent ρ (kg/m^3)	縦振動法の ヤング係数 $E_{fr\text{-}l}$ (kN/mm^2)	見かけの曲げ ヤング係数 Apparent E_b (kN/mm^2)	曲げ強度 σ_b (N/mm^2)	5% 下限値 5% lower limit (N/mm^2)
試験体数 TP No.	16	16	16	16	16	16
平均値 Mean	18.6	522	9.85	8.83	44.0	19.2
変動係数 CV (%)	7.81	6.41	12.5	12.2	28.5	
最小値 Min.	17.1	449	7.84	7.07	22.8	
最大値 Max.	21.9	582	11.9	10.8	64.1	

MC：含水率 Moisture content, ρ：密度 Density, $E_{fr\text{-}l}$：縦振動法のヤング係数 Young's modulus by longitudinal vibration method, E_b：曲げヤング係数 Bending Young's modulus, σ_b：曲げ強度 Bending strength, CV：変動係数 Coefficient of variance

Table 11. 縦圧縮試験結果の概要
Summary of test results on compressive strength parallel to the grain

	含水率 MC (%)	見かけの密度 Apparent ρ (kg/m^3)	縦振動法のヤング係数 $E_{fr\text{-}l}$ (kN/mm^2)	縦圧縮ヤング係数 E_c (kN/mm^2)	縦圧縮強度 σ_c (N/mm^2)	5% 下限値 5% lower limit (N/mm^2)
試験体数 TP No.	100	100	100	99	100	100
平均値 Mean	16.9	514	10.3	9.81	28.5	20.4
変動係数 CV (%)	3.99	6.90	16.3	24.6	16.1	
最小値 Min.	15.4	429	6.24	4.88	18.9	
最大値 Max.	18.8	628	15.9	18.5	41.4	

MC：含水率 Moisture content, ρ：密度 Density, $E_{fr\text{-}l}$：縦振動法のヤング係数 Young's modulus by longitudinal vibration method, E_c：縦圧縮ヤング係数 Compressive Young's modulus, σ_c：縦圧縮強度 Compressive strength parallel to the grain, CV：変動係数 Coefficient of variance

Table 12. 縦引張り試験結果の概要
Summary of test results on tensile strength parallel to the grain

	含水率 MC (%)	見かけの密度 Apparent ρ (kg/m^3)	縦振動法のヤング係数 $E_{fr\text{-}l}$ (kN/mm^2)	縦引張りヤング係数 E_t (kN/mm^2)	縦引張り強度 σ_t (N/mm^2)	5% 下限値 5% lower limit (N/mm^2)
試験体数 TP No.	99	100	100	100	100	100
平均値 Mean	18.4	521	10.3	9.80	34.3	17.7
変動係数 CV (%)	6.45	6.46	15.2	16.1	32.8	
最小値 Min.	15.6	447	6.34	6.16	15.5	
最大値 Max.	22.0	615	14.6	13.7	69.2	

MC：含水率 Moisture content, ρ：密度 Density, $E_{fr\text{-}l}$：縦振動法のヤング係数 Young's modulus by longitudinal vibration method, E_t：縦引張りヤング係数 Tensile Young's modulus, σ_t：縦引張り強度 Tensile strength parallel to the grain, CV：変動係数 Coefficient of variance

Table 13. 目視等級区分ごとに見た縦引張り試験結果
Test results on tensile strength parallel to the grain by visual grading according to Japanese agricultural standards for sawn lumber

甲種構造材 II 1 級 For bending member II 1st grade	含水率 MC (%)	見かけの密度 Apparent ρ (kg/m^3)	縦振動法のヤング係数 $E_{fr\text{-}l}$ (kN/mm^2)	縦引張りヤング係数 Apparent E_t (kN/mm^2)	縦引張り強度 σ_t (N/mm^2)	5% 下限値 5% lower limit (N/mm^2)
試験体数 TP No.	12	12	12	12	12	12
平均値 Mean	18.3	524	11.5	11.2	43.9	18.6
変動係数 CV (%)	8.00	5.86	10.4	10.1	28.2	
最小値 Min.	16.3	470	9.45	9.34	23.3	
最大値 Max.	22.0	570	13.5	12.9	69.2	

甲種構造材 II 2 級 For bending member II 2nd grade	含水率 MC (%)	見かけの密度 Apparent ρ (kg/m^3)	縦振動法のヤング係数 $E_{fr\text{-}l}$ (kN/mm^2)	縦引張りヤング係数 Apparent E_t (kN/mm^2)	縦引張り強度 σ_t (N/mm^2)	5% 下限値 5% lower limit (N/mm^2)
試験体数 TP No.	31	31	31	31	31	31
平均値 Mean	18.5	517	10.3	10.0	38.3	18.3
変動係数 CV (%)	5.22	6.00	15.3	15.6	28.1	
最小値 Min.	16.9	475	7.03	6.81	21.1	
最大値 Max.	21.3	590	13.9	12.9	67.5	

甲種構造材 II 3 級 For bending member II 3rd grade	含水率 MC (%)	見かけの密度 Apparent ρ (kg/m^3)	縦振動法のヤング係数 $E_{fr\text{-}l}$ (kN/mm^2)	縦引張りヤング係数 Apparent E_t (kN/mm^2)	縦引張り強度 σ_t (N/mm^2)	5% 下限値 5% lower limit (N/mm^2)
試験体数 TP No.	38	39	39	39	39	39
平均値 Mean	18.3	524	10.1	9.54	30.5	14.5
変動係数 CV (%)	5.48	7.24	14.6	15.8	28.5	
最小値 Min.	16.0	447	7.70	6.69	17.0	
最大値 Max.	20.4	615	14.6	13.7	54.8	

甲種構造材 II 等級外 For bending member II out of grade	含水率 MC (%)	見かけの密度 Apparent ρ (kg/m^3)	縦振動法のヤング係数 $E_{fr\text{-}l}$ (kN/mm^2)	縦引張りヤング係数 Apparent E_t (kN/mm^2)	縦引張り強度 σ_t (N/mm^2)	5% 下限値 5% lower limit (N/mm^2)
試験体数 TP No.	18	18	18	18	18	18
平均値 Mean	18.6	523	9.67	9.14	29.3	8.79
変動係数 CV (%)	9.06	6.11	15.9	16.7	35.9	
最小値 Min.	15.6	475	6.34	6.16	15.5	
最大値 Max.	21.6	575	12.6	12.9	49.8	

MC：含水率 Moisture content, ρ：密度 Density, $E_{fr\text{-}l}$：縦振動法のヤング係数 Young's modulus by longitudinal vibration method, E_t：縦引張りヤング係数 Tensile Young's modulus, σ_t：縦引張り強度 Tensile strength parallel to the grain, CV：変動係数 Coefficient of variance

Table 14. せん断試験結果の概要
Summary of test results on shear strength parallel to the grain

	含水率 MC (%)	見かけの密度 Apparent ρ (kg/m^3)	せん断強度 σ_s (N/mm^2)	5% 下限値 5% lower limit (N/mm^2)
試験体数 TP No.	100	100	100	100
平均値 Mean	16.1	514	6.66	5.21
変動係数 CV (%)	2.59	7.71	13.9	
最小値 Min.	15.2	425	4.68	
最大値 Max.	17.2	635	9.00	

MC：含水率 Moisture content, ρ：密度 Density, σ_s：せん断強度 Shear strength parallel to the grain, CV：変動係数 Coefficient of variance

Table 15. 実大いす型せん断試験による他樹種との比較
Comparison with other species using the full-scale block shear test

樹種 Species	密度の平均値 Mean ρ (kg/m^3)	せん断強度 σ_s 平均値 Mean (N/mm^2)	せん断強度 σ_s 5% 下限値 5% lower limit (N/mm^2)	せん断強度 σ_s 変動係数 CV (%)	基準強度 Standard strength requirements (N/mm^2)
ベイマツ Douglas fir	519	7.62	5.79	13.3	2.4
ヒノキ Hinoki	515	8.74	5.73	18.8	2.1
ベイツガ Western hemlock	477	7.50	5.42	15.3	2.1
ベイヒバ Yellow cypress	514	6.66	5.21	13.9	-
スギ Sugi	414	6.41	4.82	13.8	1.8

ρ：密度 Density, σ_s：せん断強度 Shear strength parallel to the grain, CV：変動係数 Coefficient of variance

Table 16. めり込み試験結果の概要
Summary of test results on compressive strength perpendicular to the grain

	含水率 MC (%)	見かけの密度 Apparent ρ (kg/m^3)	縦振動法のヤング係数 $E_{fr\text{-}l}$ (kN/mm^2)	5% 変形時の応力 $\sigma_{cv\text{-}5\%}$ (N/mm^2)	5% 下限値 5% lower limit (N/mm^2)
試験体数 TP No.	100	100	100	99	100
平均値 Mean	16.1	513	10.4	7.13	4.79
変動係数 CV (%)	3.86	7.30	14.2	17.7	
最小値 Min.	14.4	436	6.80	4.32	
最大値 Max.	17.6	631	15.1	11.9	

MC：含水率 Moisture content, ρ：密度 Density, $E_{fr\text{-}l}$：縦振動法のヤング係数 Young's modulus by longitudinal vibration method, $\sigma_{CV\text{-}5\%}$：5% 変形時の応力 Compressive stress perpendicular to the grain at 5% deflection, CV：変動係数 Coefficient of variance

Table 17. ISO めり込み試験方式による他樹種との比較
Comparison with other species by ISO test method

樹種 Species	試験体数 TP number	密度の平均値 Mean ρ (kg/m^3)	めり込み強度 $f_{c,90}$ 平均値 Mean (N/mm^2)	めり込み強度 $f_{c,90}$ 5% 下限値 5% lower limit (N/mm^2)	めり込み強度 $f_{c,90}$ 変動係数 CV (%)	基準強度 Standard strength requirements (N/mm^2)
カラマツ Karamatsu	15	-	9.28	7.77	8.2	7.8
ヒバ Hiba	31	500	11.1	6.52	17.3	7.8
ベイヒバ Yellow cypress	100	513	9.48	6.51	17.8	-
スギ Sugi	38	400	8.22	6.37	-	6.0
ベイツガ Western hemlock	50	483	9.37	5.03	25.6	6.0

ρ：密度 Density, $f_{c,90}$: めり込み強度 Compressive strength perpendicular to the grain, CV：変動係数 Coefficient of variance

「森林総合研究所研究報告」(Bulletin of FFPRI) Vol.9 No.3 (No.408) 149 - 151 September 2010

誤　植　：竜ノ口山森林理水試験地観測報告（2001 年 1 月～ 2005 年 12 月）

玉井 幸治，後藤 義明，小南 裕志，深山 貴文，細田 育広

本誌 7 巻 3 号に掲載された「竜ノ口山森林理水試験地研究報告（2001 年 1 月～ 2005 年 12 月）」の 137 頁～ 138 頁に記載された 2005 年 1 ～ 12 月の南谷と北谷の日流出量データを入れ違って印刷していましたので、訂正いたします。
正しくは１５０頁～１５１頁のとおりです。

Erratum to: Hydrological Observation Reports in Tatsunokuchi-yama Experimental Watershed (January, 2001 – December, 2005)

Koji TAMAI, Yoshiaki GOTO, Yuji KOMINAMI,
Takafumi MIYAMA and Ikuhiro HOSODA

An error was published in Bulletin of FFPRI, Vol.7 No.3, 125-138. The daily runoff data from Kitatani and Minamitani catchments were misplaced each during January – December, 2005 (published in page 137 and 138). The corrected data is shown below.

Table 3. 南谷および北谷流域の日降水量・日流出量 （つづき）
Daily precipitaion and runoff of MINAMI-TANI and KITA-TANI watershed. (Continued)

（単位 Unit : mm ）

項目 Item	２００５年 １月～ ６月 (January - June,2005)																	
	１月 Jan.			２月 Feb.			３月 Mar.			４月 Apr.			５月 May.			６月 June.		
	降水量 Precipi-tation	流出量 Runoff		降水量 Precipi-tation	流出量 Runoff		降水量 Precipi-tation	流出量 Runoff		降水量 Precipi-tation	流出量 Runoff		降水量 Precipi-tation	流出量 Runoff		降水量 Precipi-tation	流出量 Runoff	
日 Day	露場 Meteoro-logical station	南谷 MINAMI-TANI	北谷 KITA-TANI	露場 Meteoro-logical station	南谷 MINAMI-TANI	北谷 KITA-TANI	露場 Meteoro-logical station	南谷 MINAMI-TANI	北谷 KITA-TANI	露場 Meteoro-logical station	南谷 MINAMI-TANI	北谷 KITA-TANI	露場 Meteoro-logical station	南谷 MINAMI-TANI	北谷 KITA-TANI	露場 Meteoro-logical station	南谷 MINAMI-TANI	北谷 KITA-TANI
1	3.8	0.786	0.907	0.0	0.277	0.171	0.0	1.283	1.083	0.0	0.683	0.576	7.7	0.329	0.190	0.0	0.153	0.050
2	0.0	0.562	0.604	0.0	0.261	0.163	0.0	0.576	0.483	0.0	0.601	0.481	0.0	0.287	0.156	0.8	0.170	0.062
3	1.3	0.524	0.484	0.0	0.259	0.156	2.0	0.552	0.435	5.9	0.655	0.521	0.0	0.249	0.129	0.0	0.171	0.064
4	0.0	0.610	0.500	0.0	0.254	0.148	3.9	0.666	0.570	0.0	0.522	0.408	0.0	0.235	0.118	0.0	0.161	0.056
5	0.0	0.476	0.430	0.0	0.248	0.142	0.0	0.546	0.465	0.0	0.451	0.351	0.0	0.229	0.110	0.0	0.147	0.048
6	2.3	0.467	0.411	0.0	0.243	0.135	0.0	0.488	0.400	0.0	0.425	0.321	11.9	0.277	0.156	0.0	0.138	0.040
7	0.0	0.469	0.415	2.5	0.237	0.127	0.0	0.442	0.352	0.3	0.421	0.308	6.3	4.741	4.731	0.0	0.140	0.048
8	0.0	0.428	0.364	6.2	0.323	0.239	0.0	0.420	0.321	0.0	0.412	0.299	0.0	1.091	0.882	0.0	0.138	0.039
9	0.0	0.409	0.325	0.0	0.277	0.179	0.0	0.407	0.308	0.0	0.366	0.267	0.0	0.625	0.391	0.0	0.133	0.038
10	0.0	0.377	0.300	3.8	0.351	0.248	0.0	0.407	0.293	7.6	0.371	0.264	0.0	0.418	0.225	0.0	0.134	0.046
11	0.0	0.361	0.287	0.0	0.295	0.201	0.0	0.415	0.286	3.9	0.560	0.459	0.0	0.336	0.166	16.2	0.358	0.170
12	0.0	0.352	0.272	0.0	0.278	0.181	0.5	0.400	0.262	4.2	0.487	0.389	0.8	0.324	0.156	0.3	0.195	0.063
13	0.0	0.340	0.253	0.0	0.257	0.173	0.0	0.350	0.229	0.6	0.462	0.377	0.0	0.294	0.137	0.0	0.163	0.050
14	0.0	0.331	0.240	0.0	0.246	0.162	0.0	0.318	0.215	0.0	0.407	0.323	0.0	0.256	0.114	0.0	0.151	0.043
15	0.5	0.326	0.234	11.7	0.305	0.227	0.8	0.291	0.202	0.0	0.378	0.287	0.0	0.243	0.106	0.0	0.147	0.055
16	2.5	0.327	0.234	5.7	1.299	1.513	0.0	0.285	0.198	0.0	0.355	0.259	0.0	0.227	0.094	0.0	0.148	0.053
17	4.6	0.426	0.358	0.3	0.937	1.146	6.0	0.365	0.249	0.0	0.334	0.239	0.0	0.215	0.090	0.0	0.142	0.046
18	0.0	0.329	0.267	19.8	1.509	1.719	0.3	0.343	0.227	0.0	0.317	0.227	1.0	0.238	0.103	0.0	0.136	0.033
19	1.8	0.336	0.259	13.3	9.445	12.193	0.0	0.296	0.200	0.0	0.294	0.212	0.0	0.227	0.096	0.0	0.129	0.038
20	0.0	0.316	0.241	0.0	6.316	6.133	0.0	0.286	0.188	11.1	0.495	0.379	0.0	0.202	0.077	0.0	0.122	0.027
21	0.0	0.302	0.227	0.0	2.435	2.215	0.0	0.284	0.183	0.0	0.425	0.305	0.0	0.198	0.071	0.0	0.115	0.024
22	0.0	0.302	0.216	0.0	1.368	1.236	10.7	0.460	0.338	0.0	0.356	0.237	3.0	0.221	0.090	0.0	0.116	0.027
23	0.0	0.299	0.211	0.0	1.053	0.890	12.3	1.575	1.642	0.0	0.317	0.208	0.0	0.222	0.092	0.0	0.116	0.026
24	0.0	0.299	0.211	3.4	0.911	0.798	0.3	1.816	2.186	0.0	0.297	0.195	0.0	0.191	0.072	0.0	0.110	0.025
25	2.7	0.314	0.223	8.7	1.330	1.454	0.0	1.076	1.094	0.0	0.290	0.191	0.0	0.179	0.064	0.0	0.103	0.022
26	0.0	0.313	0.224	0.0	1.304	1.400	0.0	0.753	0.708	0.0	0.289	0.178	0.3	0.172	0.063	0.0	0.102	0.019
27	0.0	0.291	0.211	0.0	1.021	1.024	5.7	0.624	0.548	0.0	0.274	0.162	0.0	0.170	0.065	0.0	0.100	0.019
28	0.0	0.290	0.211	0.0	1.587	1.380	8.9	1.693	1.921	0.0	0.272	0.154	0.0	0.166	0.061	0.0	0.096	0.015
29	0.0	0.290	0.201				0.0	1.711	1.864	0.0	0.263	0.134	0.0	0.158	0.053	2.3	0.178	0.061
30	0.0	0.277	0.192				0.0	1.260	1.162	0.0	0.253	0.128	0.0	0.162	0.057	0.0	0.141	0.035
31	0.0	0.267	0.179				0.0	0.919	0.789				0.0	0.158	0.055			
計 Total	19.5	11.796	9.691	75.4	34.626	35.753	51.4	21.307	19.401	33.6	12.032	8.839	31.0	13.040	8.970	19.6	4.353	1.342

Table 3. 南谷および北谷流域の日降水量・日流出量 （つづき）
Daily precipitaion and runoff of MINAMI-TANI and KITA-TANI watershed. (Continued)

項目 Item	２００５年 ７月～１２月 (July - December,2005) ７月 July.			８月 Aug.			９月 Sep.			１０月 Oct.			１１月 Nov.			１２月 Dec.		
	降水量 Precipi-tation	流 出 量 Runoff		降水量 Precipi-tation	流 出 量 Runoff		降水量 Precipi-tation	流 出 量 Runoff		降水量 Precipi-tation	流 出 量 Runoff		降水量 Precipi-tation	流 出 量 Runoff		降水量 Precipi-tation	流 出 量 Runoff	
日 Day	露場 Meteoro-logical station	南谷 MINAMI-TANI	北谷 KITA-TANI	露場 Meteoro-logical station	南谷 MINAMI-TANI	北谷 KITA-TANI	露場 Meteoro-logical station	南谷 MINAMI-TANI	北谷 KITA-TANI	露場 Meteoro-logical station	南谷 MINAMI-TANI	北谷 KITA-TANI	露場 Meteoro-logical station	南谷 MINAMI-TANI	北谷 KITA-TANI	露場 Meteoro-logical station	南谷 MINAMI-TANI	北谷 KITA-TANI
1	24.4	1.769	0.771	0.0	0.285	0.074	0.0	0.127	0.021	0.0	0.110	0.013	0.0	0.126	0.033	0.0	0.125	0.032
2	21.1	2.094	0.722	4.3	0.620	0.285	0.0	0.114	0.017	0.0	0.120	0.016	0.0	0.123	0.031	0.0	0.126	0.033
3	32.1	3.441	2.571	0.0	0.563	0.142	0.0	0.118	0.017	0.0	0.113	0.014	0.0	0.124	0.035	0.0	0.126	0.034
4	25.6	4.646	5.057	0.0	0.264	0.059	6.1	0.133	0.023	4.1	0.150	0.039	0.0	0.128	0.042	1.5	0.132	0.040
5	1.3	2.708	2.736	0.0	0.203	0.046	40.2	0.846	0.351	6.9	0.199	0.064	0.0	0.132	0.039	0.0	0.138	0.041
6	0.3	0.800	0.622	0.0	0.181	0.042	35.9	2.157	0.835	0.5	0.155	0.029	17.7	0.342	0.161	6.9	0.175	0.087
7	16.2	1.440	1.310	0.0	0.169	0.041	2.7	1.386	0.489	0.0	0.134	0.024	0.0	0.163	0.060	0.0	0.148	0.047
8	0.3	2.247	2.255	0.0	0.159	0.051	0.0	0.365	0.080	0.0	0.134	0.023	0.0	0.119	0.043	0.3	0.125	0.040
9	5.6	0.934	0.757	2.3	0.156	0.051	0.0	0.256	0.051	0.0	0.123	0.021	0.0	0.107	0.041	0.0	0.113	0.040
10	6.2	0.773	0.715	5.1	0.394	0.141	0.8	0.214	0.038	0.0	0.118	0.015	0.0	0.110	0.040	0.0	0.110	0.040
11	8.8	2.314	2.911	0.0	0.225	0.059	5.9	0.233	0.073	0.0	0.116	0.013	24.5	0.508	0.265	0.0	0.110	0.043
12	7.3	2.103	2.345	0.0	0.184	0.053	0.0	0.191	0.050	0.0	0.116	0.014	1.0	0.673	0.279	0.0	0.108	0.045
13	0.0	1.074	0.911	0.0	0.164	0.047	0.0	0.164	0.045	0.0	0.111	0.016	0.0	0.219	0.088	0.0	0.104	0.045
14	0.0	0.542	0.380	0.8	0.315	0.120	0.0	0.164	0.050	5.6	0.120	0.018	0.0	0.165	0.083	0.0	0.100	0.048
15	0.0	0.343	0.189	12.4	0.622	0.206	0.0	0.155	0.035	39.7	1.471	0.684	0.0	0.143	0.069	0.0	0.092	0.048
16	0.0	0.275	0.110	0.0	0.343	0.074	0.0	0.151	0.032	0.0	0.596	0.164	0.0	0.133	0.055	0.0	0.091	0.048
17	0.0	0.246	0.084	0.0	0.221	0.044	0.0	0.156	0.029	0.0	0.206	0.054	0.0	0.124	0.049	0.0	0.091	0.044
18	0.0	0.215	0.064	0.0	0.174	0.039	0.0	0.140	0.029	0.0	0.156	0.049	0.0	0.126	0.048	0.0	0.087	0.045
19	0.0	0.202	0.055	0.0	0.161	0.034	0.0	0.140	0.029	0.0	0.137	0.036	0.0	0.124	0.045	0.0	0.088	0.044
20	0.0	0.189	0.049	0.0	0.159	0.040	0.0	0.139	0.029	0.0	0.129	0.032	0.0	0.124	0.038	0.0	0.091	0.044
21	0.5	0.178	0.047	3.4	0.167	0.048	0.0	0.129	0.023	0.0	0.131	0.034	0.0	0.124	0.045	0.3	0.094	0.044
22	0.0	0.167	0.046	0.0	0.171	0.054	0.0	0.132	0.021	0.3	0.140	0.033	0.0	0.124	0.051	1.5	0.097	0.044
23	0.0	0.161	0.042	0.0	0.153	0.040	0.0	0.130	0.023	0.0	0.128	0.033	0.0	0.125	0.049	0.0	0.097	0.044
24	0.0	0.152	0.039	0.0	0.146	0.035	0.0	0.122	0.022	0.3	0.129	0.035	0.0	0.134	0.044	0.0	0.097	0.044
25	0.0	0.150	0.040	0.0	0.137	0.027	0.0	0.113	0.022	0.0	0.129	0.033	0.0	0.129	0.042	0.0	0.097	0.044
26	0.0	0.152	0.047	0.0	0.128	0.021	0.0	0.112	0.015	0.0	0.122	0.035	0.0	0.124	0.040	0.0	0.102	0.044
27	0.0	0.140	0.035	0.0	0.124	0.017	0.0	0.105	0.016	0.3	0.123	0.038	0.0	0.123	0.040	0.0	0.104	0.042
28	0.0	0.140	0.034	0.0	0.126	0.019	0.0	0.103	0.022	0.0	0.122	0.043	0.0	0.125	0.033	0.0	0.104	0.038
29	0.0	0.143	0.030	0.0	0.120	0.019	0.0	0.109	0.013	10.3	0.205	0.093	0.0	0.128	0.031	0.0	0.104	0.036
30	0.0	0.135	0.028	2.2	0.138	0.018	0.0	0.105	0.011	0.0	0.132	0.046	0.0	0.132	0.035	0.0	0.104	0.036
31	8.0	0.970	0.423	0.0	0.146	0.024				0.0	0.131	0.035				0.0	0.107	0.036
計 Total	157.7	30.843	25.425	30.5	7.118	1.970	91.6	8.509	2.511	68.0	6.006	1.796	43.2	5.081	1.954	10.5	3.387	1.340