IMPACT OF SPACING ON WIDTH AND BASAL AREA OF JUVENILE AND MATURE WOOD IN *PICEA MARIANA* AND *PICEA GLAUCA*

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ABSTRACT

Ten trees of *Picea mariana* (Mill.) B.S.P. and *Picea glauca* (Moench.) Voss grown at each of three spacings—1.8 m × 1.8 m, 2.7 m × 2.7 m, and 3.6 m × 3.6 m—were randomly selected for study of impact of spacing on juvenile and mature wood width. The plantation located in northwestern Ontario was established in 1951 and was sampled in 1989. Tree diameter and tree basal area at breast height, juvenile and mature wood width, both as a ring count and as a linear measurement, basal area and its percentage of juvenile and mature wood, and growth rate in juvenile and mature wood were measured. Data were analyzed with an *F*-test and the Student-Newman-Keuls test. Correlation coefficients among various variables were also calculated. It was found that impact of spacing on wood properties is more pronounced in *Picea glauca,* which is considered a fast-growing tree in comparison to *Picea mariana,* than in *P. mariana.* The number of growth rings in juvenile wood of *P. mariana* and *P. glauca* were counted as 14 to 16 growth rings and 12 to 16 growth rings, respectively, depending upon the spacing. Statistically, there are no differences in juvenile wood growth rings of *P. mariana* at various spacings, but analysis shows more growth rings in *P. glauca* juvenile wood at the widest plantation spacing. A tendency of increasing juvenile wood width with increasing spacing was observed. The percentage of juvenile wood basal area was 37% to 62% in *P. glauca.* A positive relationship between the percentage of juvenile wood basal area and the plantation spacing was found in *P. glauca* but not in *P. mariana.* In *P. mariana,* the percentage of juvenile wood basal area was 50% and was independent of spacing. Growth rate of juvenile wood in both species shows a positive relation with the spacing. The growth rate in juvenile wood is two to three times higher than that of mature wood. The impact of spacing on the properties of mature wood is similar to that of juvenile wood, except that mature wood width in *P. mariana* shows no difference among spacings. It is concluded that plantation spacing has various degrees of impact on juvenile and mature width, and its impact is also species-specific.

Keywords: Juvenile wood, mature wood, spacing, *Picea mariana, Picea glauca.*

INTRODUCTION

Most forest geneticists believe that the properties of wood can be maintained or enhanced through genetic manipulation (Aldridge and Hudson 1959; Bridgwater 1984; Keith and Kellogg 1986). However, environmental factors can also play an important role in determining wood properties. This environmental impact is especially true in a plantation tree. In general, a larger percentage of juvenile wood was found in plantation trees comparable in size to natural grown trees (Bendtsen 1978; McKee 1984; Zobel and Kellison 1984; Senft et al. 1985; Saucier and Cubbage 1990). Clark and Schmidtling (1988) reported that cultivation plus fertilization did not change the length of the juvenile period of *Pinus taeda,* but the fertilization alone did increase the juvenile period of *Pinus elliotti* by 2 years and *Pinus palustris* by 4 years. They also found that fertilization increased the basal area of juvenile wood in all three species. Kučera (1994) reported that the juvenile period of *Picea abies* was 18–19 years and 28–29 years at the spacings 2.25 m × 2.25 m and 5.5 m × 3.0 m, respectively. Clark and Saucier (1989) found that there is a tendency of increasing the juvenile wood period from the south to the north in *Pinus taeda* and *Pinus elliottii.* Saucier (1990) reported that the size and percentage of basal area of juvenile wood core in *Pinus taeda* have a positive relation with the planting spacing. In *Pinus elliottii,* the diameter of juvenile wood core increases with increasing spacing, but the percentage of juvenile wood basal area decreases with increasing spacing. This illustrates that the response of juvenile wood formation to planting space is very species-specific in nature. A generalization of the impact of spacing on juvenile wood could not be established.

Picea mariana and *P. glauca* are two of the most important commercial trees in eastern Canada for pulpwood and sawlogs. The wood properties of these two species have been thoroughly studied by many researchers, such as Hall (1963, 1964), Ladell (1966, 1971), Barbour (1987, 1988), Barbour and Chauret (1988), and Barbour et al. (1989). However, no study could be found regarding the influence of spacing on the size of spruce juvenile wood in a natural stand and a plantation forest. It is known that the properties of juvenile wood are inferior to those of mature wood (Brazier 1977; Bendtsen 1978; Senft 1984; Semke 1984; Keith and Kellogg 1986). A better understanding of the impact of spacing on juvenile wood is needed by tree growers and forest managers in their forest management plans in order to minimize the loss due to high content of the juvenile wood core.

MATERIALS AND METHODS

A spacing trial plantation that was established in 1951, near Stanley, 30 km west of Thunder Bay, Ontario, was chosen for this study. Ten trees of *Picea mariana* and *P. glauca* at three spacings, i.e., 1.8 m × 1.8 m, 2.7 m × 2.7 m, and 3.6 m × 3.6 m, were randomly selected for core extraction in 1989. The cores were extracted with a 12-mm-diameter increment borer from the south aspect of each tree at breast height. These cores included the bark, wood, and pith. The cores were smoothed with a sharp razor blade. The earlywood portion of the growth ring was split from every ring from the pith to the bark. These earlywood splinters were macerated with Franklin's (1945) method to produce pulp. Two temporary microscope slides were prepared. Thirty fibers were measured for each ring. The tracheid length variation as used by Yang et al. (1986) was employed for demarcation of the boundary of juvenile and mature wood. The point of the boundary was determined by an intersection of two linear regression lines of juvenile and mature wood.

The widths of juvenile and mature wood were expressed by a ring count and a length measure (mm). It was assumed that these plantation trees were cylindrical in shape. Using this assumption, the basal area of juvenile and mature wood can be calculated with one radius of the tree. Therefore, juvenile wood basal area (JWB) in cm^2 was calculated as JWB = $\pi(r_j)^2$, and mature wood basal area (MWB) in cm^2 was calculated as follows: $\pi[(r_t)^2 - (r_j)^2]$, where r_t = the radius of a tree trunk inside bark in cm, and r_j = radius of juvenile wood in cm.

The various wood properties in juvenile and mature wood and tree trunk measured are presented in Table 1. The impact of spacing on these wood properties, which included diameter at breast height (DBH), basal area at breast height (TBA), width and ring number of juvenile and mature wood, and basal area of juvenile and mature wood, were analyzed with an *F*-test as shown in Table 2. A further analytical process with a Student-Newman-Keuls (S-N-K) test was also carried out to show the difference between the spacings (Table 1). Correlation coefficients among the variables were also calculated as shown in Tables 3 and 4. The changes of wood properties due to spacing were also assessed as presented in Table 5.

RESULTS AND DISCUSSION

Tree diameter and basal area at breast height

The range of diameters of the tree at breast height in *Picea mariana* and *P. glauca* is 13

TABLE 1. *Various juvenile and mature wood ten tree mean statistics at breast height for* Picea mariana *and* P. glauca *from a 38-year-old plantation at three spacings.*

			Juvenile wood					Mature wood				
Spacing (m)	DBH (cm)	Basal area at breast height (cm^2)	No. of rings	Width (radius, mm)	Basal area (cm^2)	Basal area (%)	Growth rate (mm/ring)	No. of rings	Width (radius, mm)	Basal area (cm^2)	Basal area (%)	Growth rate (mm/ring)
Picea mariana												
1.8 × 1.8	13.4*a	145.9a	14.2a	45.2a	66.2a	46.0a	3.2a	15.8a	21.6a	79.7a	54.0a	1.4a
2.7 × 2.7	17.2b	239.5b	16.3a	60.9b	120.1b	50.6a	3.8b	15.7a	25.1a	121.0ab	49.4a	1.6b
3.6 × 3.6	19.1b	294.4b	15.3a	66.5b	149.6b	48.5a	4.3c	14.8a	29.2a	146.2b	51.5a	2.0b
Picea glauca												
1.8 × 1.8	13.4a	150.1a	12.3a	39.6a	52.0a	36.7a	3.2a	16.5a	27.7a	98.1a	63.3a	1.6a
2.7 × 2.7	21.9b	390.1b	13.6a	70.3b	160.2b	42.0a	5.2b	17.9a	38.7b	229.9b	58.0a	2.2b
3.6 × 3.6	24.4b	472.3c	16.1b	96.1c	297.3c	62.3b	6.0b	13.9b	25.6a	174.9b	37.7b	1.9ab

* Values followed by the same letter are not statistically significantly different within the species at the $\alpha = 0.05$ level as determined by the Student-Newman-Keuls test.

cm to 19 cm and 13 cm to 24 cm, respectively. An *F*-test (Table 2) shows a statistically significant difference of tree diameter and basal area at breast height in both species. In both species, a larger diameter and basal area were found in wider spaced trees (Fig. 1). This is similar to results obtained for other species by forest scientists in other geographic areas (Smith et al. 1961; Clark and Saucier 1989; Saucier 1990). An S-N-K test (Table 1) indicates that, in terms of the DBH, the difference was found only between the 1.8 m × 1.8 m and two wider spacings for both species. There is no difference between the 2.7-m × 2.7-m and 3.6-m × 3.6-m plantation. In the basal area of *P. mariana,* a significant difference was

TABLE 2. *Analysis of variance of various wood properties at three spacings in the 38-year-old* Picea mariana *and* Picea glauca *trees.*

			Picea mariana			*Picea glauca*		
Wood properties	Source	df	SS	*F*	*P*	SS	*F*	*P*
DBH (cm)	Between	2	279.8	19.0	0.00	729.5	31.0	0.00
	Within	27	198.8			313.5		
Tree basal area at breast height (cm^2)	Between	2	115,154.2	9.05	0.00	553,501.0	25.33	0.00
	Within	27	171,685.2			294,990.9		
Number of juvenile wood rings	Between	2	22.07	1.64	0.21	74.60	6.65	0.00
	Within	27	181.80			151.40		
Juvenile wood width (mm)	Between	2	2,441.38	6.36	0.01	16,062.99	44.26	0.00
	Within	27	5,178.41			4,899.75		
Juvenile wood basal area (cm^2)	Between	2	35,779.0	5.20	0.01	303,579.3	34.12	0.00
	Within	27	96,806.3			120,129.9		
Juvenile wood basal area (%)	Between	2	121.15	0.37	0.70	3,469.96	12.61	0.00
	Within	27	4,463.97			3,713.86		
Number of mature wood rings	Between	2	6.07	0.33	0.72	82.40	6.69	0.00
	Within	27	249.30			166.30		
Mature wood width (mm)	Between	2	286.29	1.57	0.23	830.41	3.85	0.03
	Within	27	2,457.51			2,912.74		
Mature wood basal area (cm^2)	Between	2	22,570.5	4.68	0.02	73,094.0	9.17	0.00
	Within	27	65,063.3			107,666.5		
Mature wood basal area (%)	Between	2	121.15	0.37	0.70	3,469.96	12.61	0.00
	Within	27	4,463.97			3,713.86		

TABLE 3. *Correlation coefficients among the variable spacing (SPA), diameter at breast height (DBH), tree basal area at breast height (TBA), juvenile wood growth ring (JWR), juvenile wood width (JWW), juvenile wood basal area (JWB), juvenile wood basal area percentage (JWP), juvenile wood growth rate (JWG) in* Picea mariana.

Variables	DBH	TBA	JWR	JWW	JWB	JWP	JWG
SPA	0.648[a]	0.636	0.172	0.546	0.520	0.083	0.667
DBH		0.988	0.447	0.850	0.820	0.145	0.853
TBA			0.463	0.857	0.851	0.157	0.826
JWR				0.762	0.748	0.776	0.166
JWW					0.983	0.626	0.753
JWB						0.614	0.712
JWP							0.182

[a] df = 29; $t_{0.05}$ = 0.355; $t_{0.01}$ = 0.456.

also found only between the narrowest spacing to the two wider spacings, whereas the basal area of *P. glauca* was found statistically significant between each spacing.

The diameter and growth rate of *P. glauca* are about the same as those of *Picea mariana* at the 1.8-m × 1.8-m spacing, but the diameter and growth rate of *P. glauca* are larger than those of *P. mariana* at the 2.7-m × 2.7-m and 3.6-m × 3.6-m spacings. The degree of impact of spacing on the diameter and basal area of a tree seems greater in a fast-growing tree than in a relatively slow-growing tree, or the difference is due mainly to the species response difference. Further study is needed for confirming this observation.

Number of growth rings in juvenile wood

The number of growth rings in juvenile wood of *Picea mariana* and *P. glauca* are 14 to 16 rings and 12 to 16 rings, respectively, depending upon the spacing. In *P. mariana*, an *F*-test and an S-N-K test (Tables 1 and 2) indicate that there is no statistically significant difference in the ring numbers in juvenile wood between various spacings. A similar result, i.e., that the period of juvenility is unaffected by initial planting density, was also reported by Saucier (1990). In *P. glauca*, an *F*-test shows that there is a statistically significant difference of ring numbers in juvenile wood between various spacings. Further data analysis with an S-N-K test reveals that the difference was found only between the widest spacing and two narrower spacings. A similar observation was also reported by Kučera (1994) in *Picea abies* in Norway. There is no statistically significant difference between the 1.8-m × 1.8-m and 2.7-m × 2.7-m spacings. In comparing two species at the 1.8-m × 1.8-m spacing, fewer juvenile wood rings were found in *P. glauca*, (12) than in *P. mariana* (14). In this study, *P. glauca* is considered a faster growing species than *P.*

TABLE 4. *Correlation coefficients among the variable spacing (SPA), diameter at breast height (DBH), tree basal area at breast height (TBA), juvenile wood growth ring (JWR), juvenile wood width (JWW), juvenile wood basal area (JWB), juvenile wood basal area percentage (JWP), juvenile wood growth rate (JWG)* in Picea glauca.

Variables	DBH	TBA	JWR	JWW	JWB	JWP	JWG
SPA	0.779[a]	0.764	0.565	0.873	0.844	0.668	0.881
DBH		0.992	0.605	0.905	0.866	0.407	0.903
TBA			0.633	0.912	0.889	0.419	0.878
JWR				0.803	0.800	0.825	0.467
JWW					0.983	0.745	0.890
JWB						0.741	0.837
JWP							0.517

[a] df = 29: $t_{0.05}$ = 0.355: $t_{0.01}$ = 0.456.

TABLE 5. *Gain and loss of stem diameter, basal area, juvenile and mature wood of* Picea mariana *and* P. glauca, *in terms of percentage, from one plantation spacing to a wider plantation spacing.*

Spacing (m)	DBH (cm)	Basal area (cm^2)	Juvenile wood: Ring No.	Juvenile wood: Width (radius, mm)	Juvenile wood: Basal area (cm^2)	Juvenile wood: Basal area (%)	Juvenile wood: Growth rate (mm/ring)	Mature wood: Ring No.	Mature wood: Width (mm)	Mature wood: Basal area (cm^2)	Mature wood: Basal area (%)
Picea mariana											
1.8 → 2.7	28.4*	64.2	14.8	34.7	81.4	10.0	18.6	−0.6	16.2	51.8	−8.5
2.7 → 3.6	11.0	22.9	−6.1	9.2	24.6	−4.2	14.9	−5.7	16.3	20.8	4.3
1.8 → 3.6	42.5	101.8	7.7	47.1	126.0	5.4	36.3	−6.3	35.2	83.4	−4.6
Picea glauca											
1.8 → 2.7	63.4	159.9	10.6	77.5	208.1	14.4	61.9	8.5	39.7	134.4	−8.4
2.7 → 3.6	11.4	21.1	18.4	36.7	85.6	48.3	15.4	−22.3	−23.6	−23.9	−35.0
1.8 → 3.6	82.1	214.7	30.9	142.7	471.7	69.8	86.9	−15.8	7.6	78.3	−40.0

* Percentage.

—, Underline indicates a statistically significant difference at $\alpha \le 0.05$, Student-Newman-Keuls test.

mariana. Within a genus, whether a fast-growing tree possesses fewer juvenile wood rings is a question that remains to be answered.

The number of juvenile wood rings in *P. mariana* at breast height grown in a natural stand was 37 rings (Yang unpublished data, average ten trees). This ring number is three times more than that in a plantation tree. Thomas and Kellison (1990) stated that plantation-grown trees have fewer growth rings in juvenile wood than natural-grown pines. Moreover, as mentioned by Büsgen (1929) and Rendle (1958), unfavorable conditions of tree growth may prolong the juvenile period. The results of this study strengthen their findings that the vigor of tree growth has a negative impact on the number of growth rings in juvenile wood.

The number of growth rings in juvenile wood of *P. mariana* has no statistically significant difference between the spacings. This finding can be used to support the observation of Zobel et al. (1959) that there is a strong tendency for the number of rings in corewood to remain relatively constant for any given individual tree. In contrast, in *P. glauca*, this relationships between the growth rate of the tree and the number of growth rings in juvenile wood does not hold. As shown in Table 1, the number of growth rings in juvenile wood of *P. glauca* increases with increasing spacing and growth rate. The correlation coefficient between the juvenile wood ring and spacing is 0.565 in *P. glauca*. Briggs and Smith (1986) explained that young trees grown in a widely spaced plantation have a comparatively large active tree crown and produce a greater number of juvenile wood rings. This positive relation cannot be seen in *P. mariana*, but is true in *P. glauca*. The lack of a positive relationship between juvenile wood rings and spacing may be attributed to the small size and shape of the crown in *P. mariana*. This assumption remains to be tested in the future.

The variation of tracheid length was used in this study for demarcation of juvenile and mature wood. When different criteria are used, such as the tracheid length, growth rate, relative density, and the cell diameter of tracheid, the results are different. Bodie (1988) studied *Pinus banksiana* and found that the number of growth rings in juvenile wood were 13, 17, and 9 when the tracheid length, growth rate, and relative density were used as demarcation criteria, respectively. Jenkins (1957) reported that rapidly grown trees of *P. glauca* attain their maximum diameter sooner than slowly grown trees. A recent study done by Foreman (1993) confirmed this observation. When the tangential diameter of tracheid was used in the

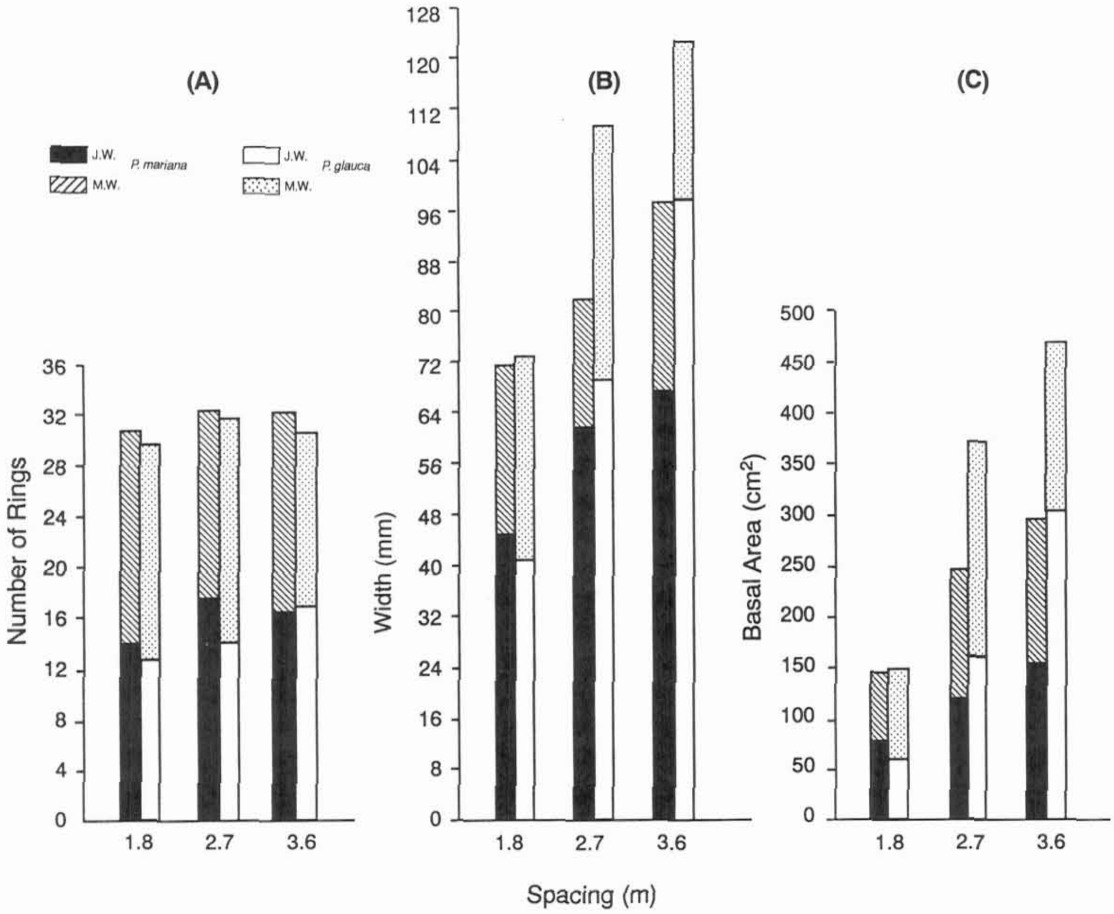

FIG. 1. Juvenile (J.W.) and mature wood (M.W.) in *Picea mariana* and *Picea glauca* expressed by (A) number of rings, (B) radius width, and (C) basal area at breast height of the tree at three spacings.

P. mariana, the number of growth rings in juvenile wood for plantation- and natural-grown trees were 9 and 21, respectively. It should be noted here that the duration of the juvenile period may be roughly proportional to the normal life cycle of a tree as suggested by Trendelenburg and Mayer-Wegelin (1955), Dadswell (1958), Thomas (1984), and Thomas and Kellison (1990). However, no study was done in this regard, i.e., relationship between the number of juvenile wood rings and longevity of a tree.

Width in juvenile wood

The mean width of *Picea mariana* juvenile wood at the 1.8-m × 1.8-m, 2.7-m × 2.7-m, and 3.6-m × 3.6-m spacings are 45.2 mm, 60.9 mm, and 66.5 mm, respectively (Table 1). In *P. glauca* the corresponding values for the three spacings are 39.6 mm, 70.3 mm, and 96.1 mm. A tendency of positive relationship between the width of juvenile wood and spacing was found (Fig. 1). This positive relationship between these two variables is more obvious in *P. glauca.* An *F*-test (Table 2) indicated that there is a statistically significant difference of juvenile wood width between various spacings. A more detailed data analysis using an S-N-K test (Table 1) indicated that in *P. mariana,* the difference was found only between the narrowest spacing and the two wider spacings. There is no significant difference of juvenile wood width between the 2.7-m × 2.7-m and 3.6-m × 3.6-m spacing. In *P. glauca,* the difference was found between each spacing level. This finding is in agreement with Polge (1969), who reported that more juvenile wood was found in a wide plantation space. The generalization of Zobel and Van Buijtenen (1989) that wider spaced plantation trees have larger juvenile cores may be applied to *P. glauca,* but not to *P. mariana.* This indicates that the impact of plantation spacing on wood properties is species-specific. A general statement may mislead to a certain degree of error and should be avoided.

Juvenile wood basal area

A general trend of increasing juvenile wood basal area with increasing plantation spacing was found in both species (Fig. 1). An F-test showed that there is a statistically significant difference in juvenile wood basal area between various spacings (Table 2). In *P. mariana,* the statistically significant difference was not found between 2.7 m × 2.7 m and 3.6 m × 3.6 m (Table 1). Zobel et al. (1959) stated that the size of juvenile wood depends upon two things: (1) the rate of tree growth during the formation of juvenile wood, and (2) the number of growth rings in juvenile wood. In *P. mariana,* the number of growth rings in juvenile wood at the three spacings did not differ but the size and basal area of the juvenile wood were found to be greatest at the widest spacing where the tree has a fast growth rate. In *P. glauca,* a large size of juvenile wood is attributable to both fast growth rate and a greater number of growth rings in juvenile wood. Briggs and Smith (1986) share a view similar to Zobel's as to the cause of size of juvenile wood.

In this study of trees from a 38-year-old plantation, the proportion of juvenile wood was found to be approximately 50% of the basal area in *P. mariana.* In *P. glauca,* the percentage of juvenile wood increases from 37% at the 1.8-m × 1.8-m spacing to 62% at the 3.6-m × 3.6-m spacing. A similar observation of increasing juvenile wood percentage with increased spacing was also reported by Saucier (1990) in *Pinus taeda,* but in *Pinus elliottii* the percentage of juvenile wood decreased with increasing spacing. In comparing the two species studied at the same spacing, the percentage of juvenile wood in *P. glauca* at the 1.8-m × 1.8-m plantation was lower than that of *P. mariana* at the same spacing, whereas at the 3.6-m × 3.6-m plantation, the percentage of juvenile wood in *P. glauca* is greater than that of *P. mariana.* This result illustrates that the impact of spacing on juvenile wood basal area is also species-specific in nature.

Number of growth rings in mature wood

There is no statistically significant difference in the number of growth rings in mature wood between various spacings in *P. mariana,* but a difference was found in *P. glauca* (Table 2). However, the S-N-K test showed that in *P. glauca* the difference was found only between two narrow spacings and the widest spacing where a fewer number of growth rings in mature wood were counted. Since the specimens studied were all collected from a 38-year-old plantation, the impact of spacing on the properties of mature wood is similar to that of juvenile wood.

Mature wood width

Table 2 indicates that there were no statistically significant differences of mature wood width between the spacings in *P. mariana.* In *P. glauca* the mature wood was the widest in the 2.7-m × 2.7-m plantation but not in the widest spacing (Table 1). Figure 1 also illustrates the widest mature wood zone at the 2.7-m × 2.7-m spacing of *P. glauca.*

Mature wood basal area

An F-test (Table 2) showed that there were statistically significant differences of the mature wood basal area between spacings in both species. Further statistical analyses indicated that in *P. mariana,* the statistically significant difference was found only between the widest and narrowest spacings (Table 1). In *P. glauca,* the difference was found between 1.8 m × 1.8

m and 2.7 m × 2.7 m. In terms of percentage of mature wood basal area, there was no difference in *P. mariana,* but it showed a significant difference in *P. glauca* (Table 2). However, in *P. glauca* the difference was found at the widest spacing to two narrow spacings.

Growth rate in juvenile and mature wood

In both species, the growth rate of juvenile and mature wood increases with increasing spacing (Table 1 and Fig. 1). A similar relation was also reported by Schönau (1973) in *Eucalyptus grandis.* Briggs and Smith (1986) indicated that there is usually little difference in the properties of wood formed at the same age. However, evidence presented here with trees from a 38-year-old plantation indicated that the properties of wood show some degree of difference at various spacings at the same age class. It is clearly indicated that spacing is another parameter that will influence the growth rate of the tree. This general statement can be applied equally to the juvenile and mature wood of both species studied. It should be remembered that the properties of wood are a result of combined genetic, environmental, and age influences (Panshin and deZeeuw 1980; Haygreen and Bowyer 1989). The findings of this study strengthen the combined influence assumption that the properties of wood are not influenced by a single parameter of tree growth.

In both wood zones, i.e., juvenile and mature wood, the growth rate of *P. glauca* is greater than that of *P. mariana.* The growth rate in juvenile wood is 2 to 3 times higher than that of mature wood. The impact of spacing on growth rate is more pronounced in *P. glauca* than that in *P. mariana.* This finding leads us to draw a general conclusion that a fast-growing tree is more sensitive to its growing environment. Whether this general statement can be applied to other silvicultural treatments, such as fertilization, irrigation, and pruning, remains to be answered.

Relationship among various variables

Correlation coefficients among variables in juvenile wood of *P. mariana* and *P. glauca* were estimated and are shown in Tables 3 and 4. In *P. mariana,* the spacing (SPA) has a strong positive relationship to most of the variables except the juvenile wood growth ring (JWR) and juvenile wood basal area percentage (JWP). This result is in agreement with the finding of the S-N-K test (Table 1). It is interesting to note here that the JWP is independent of diameter at breast height (DBH), tree basal area at breast height (TBA), and juvenile wood growth rate (JWG). No correlation between the JWR and JWG could be established. The rest of the variables were highly correlated with each other. In *P. glauca,* the picture of relationship among various variables shows little difference from that of *P. mariana.* In *P. glauca,* the SPA shows a positive significant impact on the properties of juvenile wood including the JWR and JWP. However, in *P. glauca,* a weak positive relationship between the JWP and DBH, TBA was found, while in *P. mariana,* no correlation among the same variables was calculated. In comparing Tables 3 and 4, a stronger relationship among various variables was found in *P. glauca.* This finding strengthens the statement that was presented in the previous section that impact of spacing on the properties of wood is species-specific.

Gain and loss of impact of spacing on properties of wood

As discussed earlier, the spacing shows a different degree of impact on the properties of wood in *P. mariana* and *P. glauca.* Table 5 displays gain and/or loss of wood properties in terms of percentage due to change of spacing. The percentage as shown in Table 5 may or may not be statistically significant. The greatest gain due to change of spacing was found at the *P. glauca* juvenile wood basal area in cm^2 from the 1.8-m × 1.8-m to 3.6-m × 3.6-m spacing, which shows a four times gain. The greatest loss due to change of spacing was located at the *P. glauca* mature wood basal area in percentage. In both species, the change from the 2.7-m × 2.7-m to 3.6-m × 3.6-m plantation shows the least percentage change. The values presented in Table 5 confirm the fact again that a fast-growing tree, in this study *P. glauca,* is more sensitive to environmental change than a slow-growing tree.

CONCLUSIONS

1. The degree of impact of spacing on juvenile and mature wood is different between *P. mariana* and *P. glauca. Picea glauca* is a fast-growing tree and is more sensitive to environmental change than *P. mariana.*
2. The number of growth rings in juvenile wood of *P. mariana* (approximately 15) is independent of the spacing, whereas in *P. glauca,* the number of growth rings in juvenile wood shows no statistically significant difference between the two narrower spacings; but a greater ring number of juvenile wood was found at the widest spacing.
3. In *P. mariana,* the juvenile wood width was found to have a statistically significant difference between the narrowest spacing and the two wider spacings. In *P. glauca,* the juvenile wood width was found to be different at each spacing.
4. Spacing shows a similar impact on tree basal area, juvenile wood basal area, and juvenile wood width. However, the percentage of juvenile wood basal area in both species is the same in all three spacings, except in the 3.6-m × 3.6-m plantation of *P. glauca,* which shows the largest percentage of juvenile wood.
5. Growth rate of juvenile wood in both species shows a statistically significant difference among all three spacings. A higher growth rate was found in a widely spaced plantation. This phenomenon is more pronounced in *P. glauca* than in *P. mariana.*
6. The impact of spacing on mature wood is similar to that of juvenile wood. However, mature wood width in *P. mariana* shows no difference among spacings.

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