IMPACT OF SPACINGS ON SAPWOOD AND HEARTWOOD THICKNESS IN *PICEA MARIANA* (MILL.) B.S.P. AND *PICEA GLAUCA* (MOENCH.) VOSS

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ABSTRACT

The impact of spacing on sapwood and heartwood thickness was studied in a 38-year-old plantation in northern Ontario. Ten trees each of *Picea mariana* (Mill.) B.S.P. and *Picea glauca* (Moench.) Voss grown at spacings 1.8 m × 1.8 m, 2.7 m × 2.7 m, and 3.6 m × 3.6 m were randomly selected for the study. Tree diameter, sapwood and heartwood thickness, both as a ring count and as a length measure, and sapwood and heartwood basal area were measured. For both species, it was found that the effect of the 1.8-m × 1.8-m spacing usually was significantly different from that of the other two levels. Only for sapwood basal area in *Picea mariana* were all three levels of spacing declared statistically significant from each other. Sapwood basal area increased with increased spacing for this species. For *Picea glauca,* the maximum sapwood basal area occurred at the second level of spacing. Sapwood basal area occupied approximately half of the total tree basal area at age 38. The number of sapwood rings in *Picea glauca* showed no significant differences over the levels of spacing. It is concluded that spacing plays an important role and has various degrees of impact on tree diameter and heartwood and sapwood thickness.

Keywords: Spacing, sapwood thickness, heartwood thickness, *Picea mariana, Picea glauca.*

INTRODUCTION

The thickness of sapwood sometimes becomes an important selection criterion for forest industries. Wide sapwood is desirable for wood preservation and pulp and paper manufacturing because of the high permeability of sapwood. In contrast, wide heartwood is profitable to some forest industries such as in the use of colored heartwood for lumber manufacture.

The amount of sapwood and heartwood varies with species and age of tree (Smith et al. 1966; Yang and Hazenberg 1991a, b; Hazenberg and Yang 1991a, b). The thickness of sapwood is also influenced by external factors such as site (Wellwood 1955), climate (Chalk 1951), elevation (Lassen and Okkonen 1969), and other environmental factors (Paul 1959). A fast-growing tree usually possesses wider sapwood than a slow-growing tree (Lassen and Okkonen 1969; Carrodue 1972; Yang et al. 1985). Also, a healthy tree has a larger portion of sapwood than a diseased tree (Shortle and Bauch 1986). Long and Smith (1987) studied *Pinus contorta* Dougl. and found that a negative relationship existed between the sapwood basal area and the density of the stand, i.e., the tree with small sapwood basal area usually grew in a highly dense stand. It is known that sapwood conducts water and minerals from the root to the tree crown for leaf photosynthesis. Sapwood thickness/basal area shows a strong

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TABLE 1. *Various sapwood and heartwood statistics at breast height for two species from a 38 year old plantation at 3 spacings.*

Spacing (m)	DBH (cm)	Age at breast height (yr)	Sapwood Ring (no.)	Sapwood Thickness (mm)	Sapwood Basal area (cm)	Sapwood Basal area (%)	Sapwood Growth rate (mm/ring)	Heartwood Ring (no.)	Heartwood Thickness (mm)	Heartwood Basal area (cm)	Heartwood Basal area (%)	Heartwood Growth rate (mm/ring)
					Picea mariana							
1.8 × 1.8	13.5 a*	28.2	14.5 a	19.8 a	72.9 a	49.9	1.33	13.7 a	47.7 a	73.3 a	50.1	3.54
2.7 × 2.7	18.5 b	30.3	13.7 a	22.4 ab	116.6 b	41.9	1.65	16.6 b	70.2 b	161.7 b	58.1	4.23
3.6 × 3.6.	20.8 b	28.2	12.2 b	27.2 b	154.5 c	45.0	2.23	16.0 b	76.8 b	189.0 b	55.0	5.83
					Picea glauca							
1.8 × 1.8	14.1 a	27.3	16.5 a	29.7 a	107.4 a	66.2	1.81	10.8 a	40.8 a	54.8 a	33.8	3.66
2.7 × 2.7	24.1 b	30.1	16.0 a	39.5 b	250.1 b	53.6	2.51	14.1 b	81.0 b	216.1 b	46.4	5.72
3.6 × 3.6	25.0 b	28.2	14.6 a	33.6 ab	232.3 b	46.4	2.29	13.6 b	91.4 b	268.3 b	53.6	6.82

* Values followed by the same letter are not statistically different ($P < 0.05$) as determined by the Student-Neuman-Keuls test.

positive relationship with the leaf area and tree crown, i.e., the larger the tree crown, the greater the amount of sapwood (Kaufmann and Troendle 1981; Whitehead et al. 1984; Espinosa-Bancalari et al. 1987; Ryan 1989).

Increasingly, the forest industries will depend on plantation-grown trees in the future because of the depletion of natural forests. For tree growers and forest managers, it is beneficial to know to what degree spacing has an impact on the wood properties of a tree.

MATERIALS AND METHODS

Trees of *Picea mariana* (Mill.) B.S.P. and *Picea glauca* (Moench.) Voss grown at a spacing trial plantation at Stanley, 30 km west of Thunder Bay, Ontario, were used for the study. The plantation was established in 1951. Ten trees of each of 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 12-mm diameter increment cores were extracted from the south aspect of each tree at breast height. These cores included sapwood, heartwood, and pith. The cores were marked with a pencil and smoothed with a sharp razor. The diameter inside bark at breast height (DBH) of each tree was measured along the radius at the south aspect of the tree. The boundary of sapwood and heartwood was determined with water enhancement methods as described by Yang (1987). The images of growth ring and sapwood/heartwood boundary were copied with a paper copying machine. These copied ring images were further used for sample checking and discussion purposes. Measurements to the nearest 0.01 mm were carried out with a digimicrometer on these copied images. The thicknesses of sapwood and heartwood were expressed by a ring count and a length measure (mm). It was assumed that these plantation trees are cylindrical in shape. The basal area can be calculated with one radius of the tree. Therefore, sapwood basal area was calculated as follows: $SBA = \pi[(r_T)^2 - (r_h)^2]$, where: SBA = sapwood basal area in cm^2; r_T = the radius of a tree trunk inside bark in cm; r_h = radius of heartwood in cm. The heartwood basal area in cm^2 was calculated as $\pi(r_h)^2$.

The various wood properties measured are presented in Table 1. The impact of spacing on these wood properties, i.e., diameter, thickness and ring number of sapwood and heartwood, basal area of sapwood and heartwood were analyzed with an F-test (Table 2). A further analytical process with the Student-Newman-Keuls (S-N-K) test was also carried out to pinpoint the difference between the spacings (Table 1).

RESULTS AND DISCUSSION

Tree diameter

Table 2 indicates that in both species the F-test shows a statistically significant differ-

TABLE 2. *Analysis of variance of various wood properties at three spacings in* Picea mariana *(Mill.) B.S.P. and* Picea glauca *(Moench.) Voss.*

Wood properties	Source	df	*Picea mariana* SS	*Picea mariana* F	*Picea mariana* P	*Picea glauca* SS	*Picea glauca* F	*Picea glauca* P
Diameter (mm)	Among	2	279.84	19.01	0.00	729.47	31.02	0.00
	Within	27	198.76			313.47		
Number of sapwood rings	Among	2	27.27	5.24	0.01	19.40	2.17	0.13
	Within	27	70.20			120.90		
Sapwood Thickness (mm)	Among	2	286.58	4.29	0.02	484.35	3.29	0.05
	Within	27	902.63			1,990.27		
Sapwood basal area (cm)	Among	2	33,307.29	10.99	0.00	120,852.91	13.17	0.00
	Within	27	40,926.65			123,904.67		
Number of heartwood rings	Among	2	46.87	3.75	0.04	63.27	6.06	0.00
	Within	27	168.50			140.90		
Heartwood thickness (mm)	Among	2	4,659.34	16.02	0.00	14,272.44	33.77	0.00
	Within	27	3,926.68			5,705.08		
Heartwood basal area (cm)	Among	2	73,160.72	12.44	0.00	247,797.18	23.36	0.00
	Within	27	79,379.94			143,181.34		

ence among the spacings. Figure 1B indicates that for both species trees grown at a wider spacing yield larger diameters; trees grown at spacing 3.6 m × 3.6 m have bigger tree diameters than those grown at spacing 2.7 m × 2.7 m. However, based on an S-N-K test (Table 1), tree diameters between these two wider spacings do not show statistically significant differences. This finding is different from that reported by Clark and Saucier (1989) for species *Pinus taeda* L. and *Pinus elliottii* Engelm., who found that a direct linear relationship and statistically significant differences between the tree diameters exist at wider spacings from 3.3 m × 3.3 m to 4.5 m × 4.5 m. This discrepancy may be attributed to the species difference and geographical location. For our two species, a spacing of 2.7 m × 2.7 m may be optimum for growing sawlogs, because at this spacing suitable diameter and number of trees in a given area can be obtained for lumber manufacture.

Number of sapwood rings

For both species the number of sapwood rings decreased with increased spacing (Fig. 1A). In natural stands, fewer sapwood rings and a greater sapwood volume were found in dominant trees than in suppressed trees (Trendelenburg and Mayer-Wegelin 1955; Harris and Kripas 1959). In *Pinus banksiana* Lamb. and *Larix laricina* (DuRoi) K. Koch, a strong, negative relationship between sapwood radial growth rate and the number of sapwood rings was reported (Yang et al. 1985). In contrast, as reported by Tischler (1976), a fast-grown eucalypt has a wide sapwood width, but the number of sapwood rings remains small, about 4 to 6 rings. This more or less constant number of sapwood rings in a species regardless of its growth rate was also reported in India in *Eucalyptus tereticornis* (Purkayastha et al. 1980) and in Australia in *Eucalyptus* spp. (Hillis 1987). In the present study, no difference in the number of sapwood rings among spacings was found in *Picea glauca,* but a significant difference was calculated in *Picea mariana* between 2.7 m × 2.7 m and 3.6 m × 3.6 m (Tables 1 and 2). However, a tendency of the number of sapwood rings to decrease from a narrow spacing to a wider spacing was noted.

Sapwood thickness

Sapwood thickness at breast height in *Picea mariana* and *Picea glauca* at various spacings is in the range of 20 mm to 27 mm and 30 mm to 40 mm, respectively (Table 1 and Fig. 1B). A tendency of sapwood thickness to in-

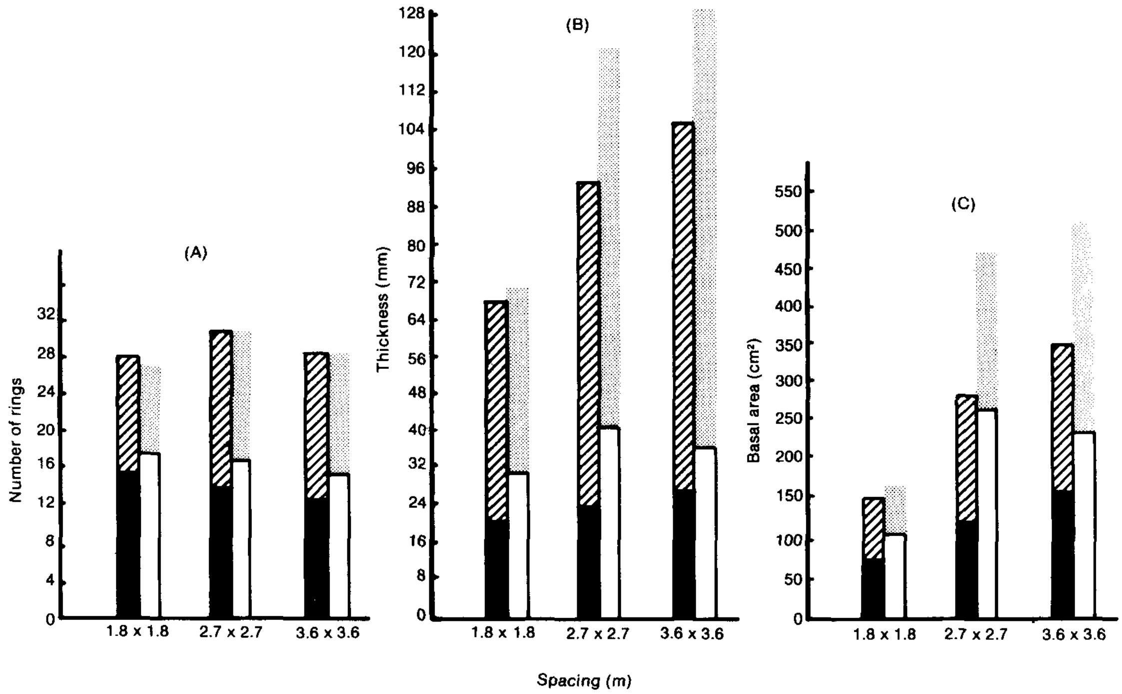

FIG. 1. Sapwood and heartwood in *Picea mariana* and *Picea glauca* expressed by (A) number of rings, (B) radius thickness and (C) basal area at breast height of the tree at three spacings. The sapwood of *P. mariana* and *P. glauca* is indicated by solid black and white bars, respectively, whereas the heartwood of *P. mariana* and *P. glauca* are expressed by bars with diagonal lines and dots, respectively.

crease with increasing spacing was noted. However, the widest sapwood among three spacings was observed in *Picea glauca* at the spacing 2.7 m × 2.7 m. The *F*-test shows that a significant difference was found among spacings (Table 2). An S-N-K test indicates that sapwood thickness in *Picea mariana* is significantly different between the spacings 1.8 m × 1.8 m and 3.5 m × 3.5 m. In *Picea glauca,* a significant difference was found between the spacings 1.8 m × 1.8 m and 2.7 m × 2.7 m (Table 1). A positive relationship between sapwood thickness and spacing was also reported by Paul (1952) in *Pinus* species. In general, a large crown is always found in wide open stands. This positive relationship between sapwood thickness and spacing may be attributed to a large crown volume in a wider spacing as reported by many authors (Trendelenburg and Mayer-Wegelin 1955; Grier and Waring 1974; Waring et al. 1977; Marchand 1984).

Sapwood basal area

Sapwood basal area in *Picea mariana* increased significantly with increased spacings (Table 2). An S-N-K test indicates that in *Picea glauca,* the difference of the sapwood basal area was found to be statistically significant between the spacing 1.8 m × 1.8 m and two wider spacings, but the difference between the 2.7-m and 2.7-m and 3.6-m × 3.6-m spacing was not significant (Table 1). However, the greatest sapwood basal area in *Picea glauca* was found for the 2.7-m × 2.7-m spacing, not at the widest spacing. Long and Smith (1987) studied *Pinus contorta* var. *latifolia* Dougl. and established a curvilinear relationship between sapwood basal area at breast height and the density of stand. The smallest basal area was found in trees grown in high density stands. The reason for the largest basal area in *Picea glauca* at spacing 2.7 m × 2.7 m is still unknown.

As mentioned previously, a large crown is always found in wide open stands. A positive relationship between sapwood basal area and tree crown or foliage mass was also reported by many researchers in other coniferous species such as *Pinus ponderosa* (Grier and Waring 1974), *Tsuga heterophylla* (Waring et al. 1982), *Pseudotsuga menziesii* (Long et al. 1981, Espinosa-Bancalari et al. 1987), *Pinus contorta* (Kaufmann and Troendle 1981) *Abies balsamea* and *Picea rubens* (Marchand 1984), and *Picea engelmannii* and *Abies lasiocarpa* (Ryan 1989). However, Whitehead et al. (1984) indicated that the relationship between foliage area and sapwood basal area depends upon the permeability of sapwood, which was also confirmed by Pothier et al. (1989).

Number of heartwood rings

In both species, more heartwood rings were found in trees grown at a wider spacing (Fig. 1 and Table 1). An *F*-test indicates that there is a significant difference among spacing (Table 2). However, an S-N-K test shows that a significant difference was found only between the 1.8-m × 1.8-m spacing and two wider spacings (Table 1). Although no significant difference between the 2.7-m × 2.7-m and 3.6-m × 3.6-m spacing was found, a larger number of heartwood rings was recorded in the 2.7-m × 2.7-m spacing for both species. This larger number of heartwood rings may be attributed to an older age at breast height. A direct positive relationship between the number of heartwood rings and tree age was reported by Hazenberg and Yang (1991b) in *Picea mariana,* Trendelenburg and Mayer-Wegelin (1955) in *Picea* species, and in other species (Ihara 1972; Hillis and Ditchburne 1974; Puritch 1977; Yang and Hazenberg 1991a, b; Hazenberg and Yang 1991a).

Heartwood thickness

The *F*-test shows that there is significant difference of heartwood thickness among spacings (Table 2). In general, trees with wider heartwood were found in wider-spaced trees (Fig. 1). The S-N-K test shows that heartwood thickness in 1.8-m × 1.8-m spacing is statistically narrower than that of two wider spacings (Table 1). At the two wider spacings, there is no statistically significant difference in heartwood thickness. In *Picea glauca* heartwood thickness in 1.8-m × 1.8-m spacing is half that of the wider spacings. In *Picea mariana,* this difference was less pronounced. The impact of spacing on heartwood thickness has not been reported previously; however, a positive direct relationship between the heartwood thickness and tree age was reported by Hazenberg and Yang (1991a).

Heartwood basal area

Heartwood basal area in *Picea glauca* is larger than that of *Picea mariana* at the two higher levels of spacing (Fig. 1 and Table 1). In both species, a larger heartwood basal area was found at wider spacing. An *F*-test indicates that there is a significant difference among spacings (Table 2). However, an S-N-K test shows that there is no significant difference in heartwood basal area between the two wider spacings, but a significant difference was observed between the narrowest spacing, i.e., 1.8 m × 1.8 m and the two wider spacings (Table 1). The proportion of heartwood varies directly with tree age (Hillis and Ditchburne 1974). However, in an even-aged stand, the trees of *Pinus taeda* L. with a small tree crown or from a closely stocked area had a higher percentage of heartwood basal area than a larger-crowned tree (Paul 1932). In the present study, a lower percentage of heartwood was found at the narrow spacing, i.e., 1.8 m × 1.8 m than at the wider spacings (Table 1). These two different findings contradict each other. The question whether the low percentage of heartwood at a narrow spacing is attributed to a relatively low growth rate as indicated in Table 1 or is caused by other factors remains to be answered.

CONCLUSIONS

The plantation spacing shows various degrees of impact on diameter growth and the thickness of sapwood/heartwood. In general, there are no statistically significant differences in tree diameter, sapwood/heartwood thickness, the number of heartwood rings, and heartwood basal area between the 2.7-m × 2.7-m and 3.6-m × 3.6-m spacings, whereas for trees grown at a narrow spacing, i.e., 1.8 m × 1.8 m, differences in the variables are significant from those trees grown at wider spacing. The number of sapwood rings is statistically quite constant among the three spacings, except for *Picea mariana* at the 3.6 × 3.6-spacing, which appears with fewer sapwood rings than other two spacings. However, a tendency to a decreasing number of sapwood rings with increasing spacing was found in both species. Sapwood basal area was affected significantly by spacing, except in *Picea glauca* where no significant difference was found between the 2.7-m × 2.7-m and 3.6-m × 3.6-m spacings.

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