RELATIONSHIP BETWEEN TREE AGE AND SAPWOOD/HEARTWOOD WIDTH IN *POPULUS TREMULOIDES* MICHX.

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(Received January 1990)

ABSTRACT

Populus tremuloides Michx. has become a major commercial species within the last decade. The proportion of sapwood and heartwood has a significant impact on various uses. The relationship between tree age and sapwood/heartwood width was studied using 101 trees of *Populus tremuloides* Michx. The sample trees were grown at various stand densities in the Lakehead University woodlot, Thunder Bay, Ontario. The ages of the trees ranged from 5 to 90 years at breast height. The boundary of sapwood and heartwood was delineated with the IKI technique. Sapwood and heartwood widths were expressed by ring count and by linear measurement. The sapwood basal area was calculated and expressed as the difference between stem basal area and heartwood basal area. It was found that sapwood width (ring count basis) increases with increasing tree age. A curvilinear relation between sapwood width and tree age was found. Sapwood basal area increased linearly with increasing tree age. Heartwood width, both in ring count and linear measurement, showed a positive relationship with tree age. Heartwood started to be formed at age 5. The average rates of sapwood and heartwood expansion were found to be 0.40 and 0.60 ring per year, respectively. It is concluded that tree age is an important factor that affects sapwood/heartwood width and sapwood basal area in *P. tremuloides*.

Keywords: Sapwood/heartwood width, tree age, basal area, *Populus tremuloides*.

INTRODUCTION

Populus tremuloides Michx has become a major commercial species within the last decade. The wood of *Populus* is used as a source of pulpwood, sawlogs, veneer logs, and as raw material for particleboard and waferboard. The proportion of sapwood and heartwood has a significant impact on these uses because of the biochemical and physical differences between these wood zones. It is proposed here that the proportion of sapwood and heartwood is a function of tree age. Because of the lack of knowledge on the subject, we chose to examine the relation between sapwood/heartwood widths (in ring count and area) to tree age.

Sapwood and heartwood width varies considerably between families, genera, and species (Hillis 1987). Environmental factors such as site (Nelson 1976), elevation (Lassen and Okkonen 1969), and climate (Chalk 1951) have some impact on the sapwood and heartwood width. The age of a tree may or may not affect the sapwood and heartwood width. Benic (1956) reported in *Fagus angustifolia* Glasn that the number of sapwood rings increases with tree age. In *Quercus rubra* Du Roi (Corona 1970) and in *Juglans nigra* L. (Nelson 1976), a positive relationship between the sapwood width in a linear measurement and tree age was also reported. Moreover, a close relationship between heartwood width and tree age was reported by Hillis (1962) in *Eucalyptus*. On the other hand, Todorovski

Wood and Fiber Science, 23(2), 1991, pp. 247–252

(1966) reported that the proportion of sapwood was not a function of tree age in *Pinus sylvestris* L. and *Pinus nigra* Arnold. MacKinney and Chaiken (1935) reported in *Pinus taeda* L. that heartwood width did not correlate with tree age. The relationship between sapwood width and tree age is still unclear. Hunter and Goggans (1968) reported in *Liquidambar styraciflua* L. that heartwood width is related to tree age. It was reported by Hillis (1972) in *Robinia* spp. and in *Eucalyptus* that after reaching breast height, heartwood was formed between 2 to 3 years and 5 to 7 years later, respectively. Todorovski (1968/69) observed in *Quercus conferta* L. and *Quercus sessiliflora* Salisb. that trees differed in the rate of heartwood formation. These *Quercus* species may form heartwood at a rate of only part of a ring to 2 or more rings per year.

MATERIALS AND METHODS

Twelve millimeter increment cores, free from heart rot, were extracted from the south aspect of *Populus tremuloides* Michx. at breast height during the summer. The sample trees were grown under various stand densities in the Lakehead University woodlot, 30 km north of Thunder Bay, Ontario.

One hundred and one increment cores were extracted and collected from trees of various tree ages (5 to 90 years) at breast height. The tree ages were classified in 10 diameter classes at 10-year intervals. Ten to twelve cores were extracted from each 10-year age class. The actual age of the tree at breast height was counted after the core was extracted.

Sapwood and heartwood widths were expressed by the number of rings and a linear measurement (mm). Sapwood basal area was expressed in dm^2. The boundary of sapwood and heartwood was delineated with the IKI staining technique. The width of the two zones expressed by the number of rings in sapwood (SNR), sapwood width (SWD), and number of rings in heartwood (HNR) was plotted against tree age (T). Second degree polynomial functions in tree age (T) for the response variables SNR, SWD, and HNR were fitted to illustrate these relationships. Only for SWD was the second degree term significant. For SNR and HNR the model was reduced to a straight line fit. The heartwood width (HWD) (radius) was plotted against tree age (T). A linear equation HWD = a + bT was used to demonstrate this relationship. Sapwood basal area (BA) was expressed as the difference between stem basal area and heartwood basal area. A linear function BA = a + bT was used to show this relationship. The functions are shown in Table 1.

A square area is shown in Fig. 1-A. In this area, the tree age indicates the formation of the first heartwood ring. Correlation coefficients among the variables SNR, SHD, BA, HNR, and HWD were obtained and are shown in Table 2.

The rates of both sapwood and heartwood expansion can be read off directly from their respective regression equations, for the regression coefficients are the rates of expansion. Thus, for sapwood, the rate of expansion is 0.40 rings per year and that for heartwood 0.60 rings per year.

RESULTS AND DISCUSSION

Number of sapwood rings vs. tree age

Figure 1-A shows the relationship between the number of sapwood rings and tree age. In general, the number of sapwood rings increased with increasing tree

TABLE 1. *Relationship between tree age (T) and number of rings in sapwood (SNR), sapwood width (SWD), sapwood basal area (BA), number of wings in heartwood (HNR) and heartwood width (HWD) of 101* Populus *trees.*

Equation	R^2
SNR = 4.26 + 0.400T	0.8854
SWD = 10.50 + 1.3586T − 0.01059T^2	0.3673
BA = 0.015 + 0.0459T	0.5664
HNR = −4.26 + 0.600T	0.9457
HWD = −2.308 + 1.0582T	0.7690

age. As shown in Fig. 1-A, and Table 1, the relationship appears linear. It should be noted that the number of rings in sapwood increases continuously to tree age 90. This finding is in agreement with that reported by Nelson (1976) in *Juglans nigra* L. and *Prunus serotina* Ehrh. This continuing trend of adding sapwood rings over time is different from many conifers, such as *Pinus ponderosa* Dougl. ex Laws and *Pinus contorta* Loud. (Lassen and Okkonen 1969) and *Larix lariciana* K. Koch. (Yang et al. 1985). In these species the number of rings in sapwood increases to a certain age and thereafter the number of growth rings in sapwood remains constant.

As the number of sapwood rings increases with increasing tree age, the rate of sapwood expansion averaged 0.40 ring per year. This may mean that a *Populus* tree forms a new ring annually as the result of cambial cell division, while only a portion of the ring at the inner sapwood is transformed into heartwood. Based on this reasoning, sapwood width in a ring count expands annually.

Sapwood width vs. tree age

A curvilinear relationship between sapwood width (mm) and tree age is shown in Fig. 1-B and their correlation in Table 2. As shown in Fig. 1-B, sapwood width increases to about 70 years, well past its prime harvest time. Past age 70, the curve starts to decline. This decline might be due to narrower growth rings which are normally produced in older trees. It should be pointed out that Wellwood (1955) found that sapwood width in *Pseudotsuga menziesii* (Mirb.) Franco was not affected by tree age. However, Lassen and Okkonen (1969) studied the same

TABLE 2. *Correlation coefficients among the variables tree age (T), number of rings in sapwood (SNR) and heartwood (HNR), sapwood (SWD) and heartwood width (HWD), and sapwood basal area (BA). Values in parentheses indicate the probability of no correlation between the variables.*

Variable	SNR	SWD	BA	HNR	HWD
T	0.9410 (0.000)	0.5387 (0.000)	0.7526 (0.000)	0.9725 (0.000)	0.8769 (0.000)
SNR		0.6253 (0.000)	0.7561 (0.000)	0.8362 (0.000)	0.7573 (0.000)
SWD			0.8713 (0.000)	0.4424 (0.000)	0.4513 (0.000)
BA				0.6988 (0.000)	0.7438 (0.000)
HNR					0.8995 (0.000)

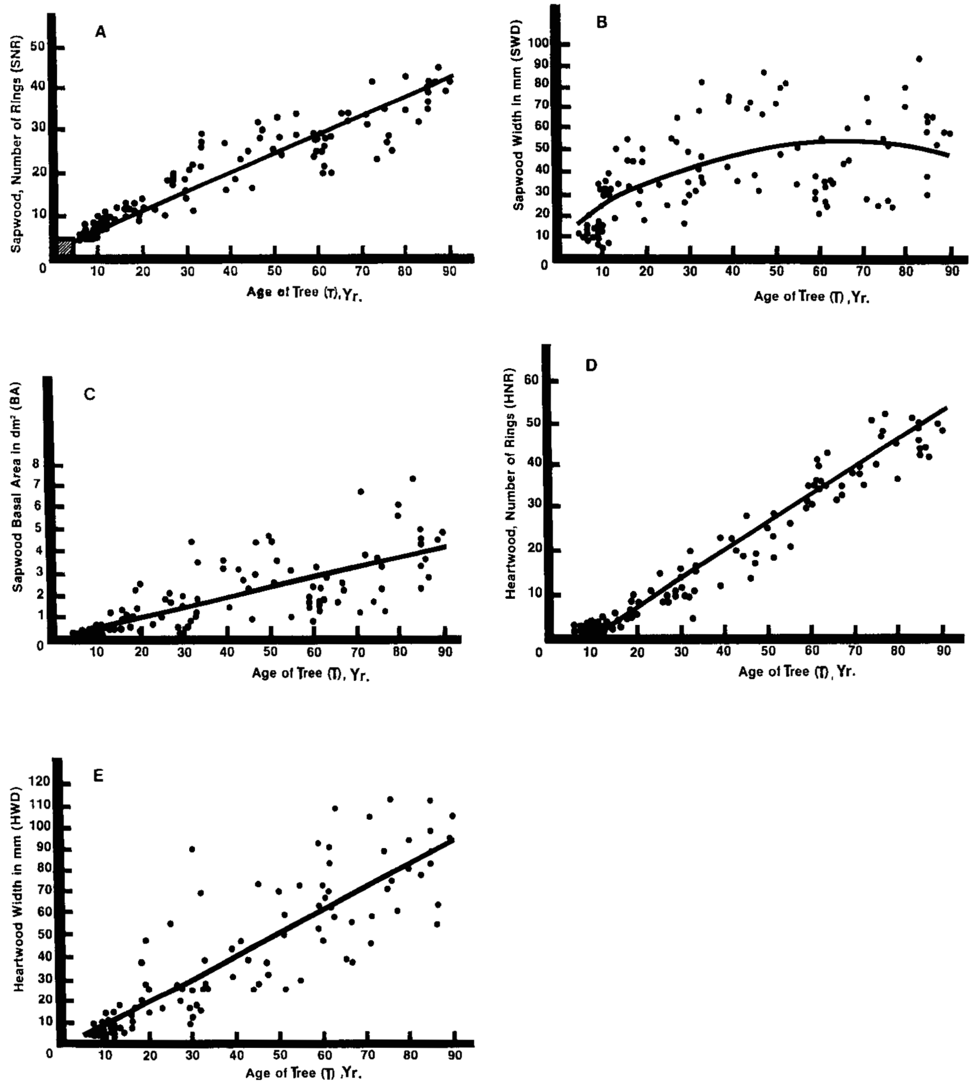

FIG. 1. Relationship between tree age and A: the number of sapwood rings (SNR), B: sapwood width (SWD), C: sapwood basal area (BS), D: the number of heartwood rings (HNR) and E: heartwood width (HWD) in *Populus tremuloides* Michx.

species and found that a curvilinear relationship between sapwood width and tree diameter does exist. The discrepancy of these findings remains unexplained.

Sapwood basal area vs. tree age

A linear relation between sapwood basal area and tree age is shown in Fig. 1-C and the correlation in Table 2. A high degree of variation between sapwood basal area and tree age might be attributed to forest conditions, since the sampled trees were grown under various stand densities. The amount of tree crown varies accordingly with the available space (Long and Smith 1987). Many researchers (Grier and Waring 1974; Rogers and Hinckley 1979; Whitehead et al. 1984) reported that the sapwood basal area of a tree stem is strongly associated with the amount of tree crown and foliage.

It has to be mentioned here, as shown in Fig. 1-A, that the number of sapwood rings increases with increasing tree age to age 90, while the ring width is narrow in these older trees. The sapwood basal area was not greatly affected by these narrow ring widths in older trees. As a result, a linear relationship between sapwood basal area and tree age is seen.

Number of heartwood rings vs. tree age

The number of heartwood rings increases with increasing tree age (Fig. 1-D and Table 1). The correlation coefficient ($r = 0.9725$) between the number of heartwood rings and tree age is highly significant ($P \leq 0.000$). Such a strong positive relationship between the number of heartwood rings and tree age was also reported in other species, such as *Quercus* spp. (Dadswell and Hillis 1962), *Liquidambar styraciflua* L. (Hunter and Goggans 1968) and *Pinus radiata* D. Don (Hillis and Ditchburne 1974).

As shown in Fig. 1-A and 1-D, the transformation of sapwood into heartwood begins at age 5. In *Eucalyptus* species (Hillis 1972, 1987) the trees start to form heartwood between 5 and 8 years. The average rate of heartwood expansion was found to be 0.58 ring per year. However, in *Quercus* the tree may form from 0 to 2 or more rings of heartwood per year (Todorovski 1968/69).

Heartwood width vs. tree age

Figure 1-E and Table 1 show a linear relation between heartwood width (in mm) and tree age.

Many researchers (Hunter and Goggans 1968; Hillis and Ditchburne 1974) also found a similar relationship between heartwood width and tree age. A fast-growing tree may possess wide heartwood as indicated by a 30-year-old tree with a heartwood radius of 90 mm as shown in Fig. 1-E, but the number of rings in heartwood in these big trees might be still the same as that in a slow-growing tree. This implies that tree age is a major factor to control heartwood formation, although external factors such as site, spacing, elevation and location may also play a role in sapwood/heartwood transformation.

Correlation between and among variables

Correlation coefficients among various variables are shown in Table 2. The number of sapwood and heartwood rings and also sapwood basal area are all significantly and positively correlated with tree age. An interesting correlation ($r = 0.8362$) between the SNR and HNR was found. This relationship can probably be attributed to a continuing increase in the number of sapwood and heartwood rings simultaneously with tree age.

Theoretically, sapwood basal area has nothing to do with heartwood width. However, the correlation coefficient indicates a highly significant relationship between these two variables. This relationship could not be explained. A strong, positive correlation between the HNR and the HWD was expected and is shown in Table 2. This is due to an increase in heartwood radius with an increase in the number of heartwood rings.

CONCLUSION

From our investigation we conclude that a positive relationship exists between sapwood and heartwood width and tree age. This relation is expressed as a straight line for both the number of sapwood and heartwood rings. For both regressions, the slopes or rates of increase are highly significant statistically. Sapwood width as a function of tree age is a parabola but shows considerable variation. As a consequence, sapwood basal area as a function of tree age was not a particularly good fit. The relationship of heartwood width and tree age was clearly a straight line and explained 88% of the total variation in the variable.

The average sapwood and heartwood expansion rates are 0.40 ring and 0.60 ring per year, respectively. The transformation of sapwood into heartwood takes place at or after the age of 5 years. It can be concluded that tree age is an important factor that influences sapwood/heartwood width and sapwood basal area in *P. tremuloides* Michx.

REFERENCES

BENIC, R. 1956. Investigation on the proportion, and some physical properties, of the sapwood and heartwood of *Fagus angustifolia* Glasn. Sumske Pokuse 12:13–104. *In* For. Abstr. 18:400. 1957.

CHALK, L. 1951. Water and growth of Douglas-fir. Q. J. Forestry 45(4):237–242.

CORONA, E. 1970. Sapwood rings in oak stem. Ital. For. Mont. 25(3):156–158.

DADSWELL, H. E., AND W. E. HILLIS. 1962. Wood. Pages 3–55 *in* W. E. Hillis, ed. Wood extractives. Academic Press, New York.

GRIER, C. C., AND R. H. WARING. 1974. Conifer foliage mass related to sapwood area. Forest Sci. 20(3):205–206.

HILLIS, W. E. 1962. Wood extractives and their significance to the pulp and paper industries. Academic Press, New York. 513 pp.

———. 1972. Properties of eucalypt woods of importance to the pulp and paper industry. Apita 26: 113–122.

———. 1987. Heartwood and tree exudates. Springer-Verlag, New York. 268 pp.

———, AND N. DITCHBURNE. 1974. The prediction of heartwood diameter in radiata pine trees. Can. J. For. Res. 4:524–529.

HUNTER, A. G., AND J. F. GOGGANS. 1968. Variation in specific gravity, diameter growth and colored heartwood of sweetgum in Alabama. Tappi 51:76–79.

LASSEN, L. E., AND E. A. OKKONEN. 1969. Sapwood thickness of Douglas-fir and five other western softwoods. USDA, Forest Serv. Res. pap. FPL 124.

LONG, J. N., AND F. W. SMITH. 1987. Leaf area-sapwood area relations of lodgepole pine as influenced by stand density and site index. Can. J. For. Res. 17:247–250.

MACKINNEY, A. L., AND L. E. CHAIKEN. 1935. Heartwood in second growth loblolly pine. USDA, Appalachian For. Expt. Sta., Tech. Note No. 18.

NELSON, N. D. 1976. Gross influences on heartwood formation in black walnut and black cherry trees. USDA, Forest Serv. Res. pap. FPL 268.

ROGERS, R., AND T. M. HINCKLEY. 1979. Foliar weight and area related to current sapwood area in oak. Forest Sci. 25(2):298–303.

TODOROVSKI, S. 1966. (Effect of certain factors on the proportion of sapwood and heartwood in the stem of *Pinus sylvestris* and *Pinus nigra*.) Summary from Forest Abstr. 1968. No. 2908.

———. 1968/69. (Heartwood formation in *Quercus conferta* and *Quercus sessiliflora*) God. Zborn. Zemj.-Sum. Fak. Univ. Skopje (Sum.) 22:41–49.

WELLWOOD, R. W. 1955. Sapwood-heartwood relationships in second-growth Douglas-fir. Forest Prod. J. 5(2):108–111.

WHITEHEAD, D., W. R. N. EDWARDS, AND P. G. JARVIS. 1984. Conducting sapwood area, foliage area, and permeability in mature trees of *Picea sitchensis* and *Pinus contorta*. Can. J. For. Res. 14:940–947.

YANG, K. C., G. HAZENBERG, G. E. BRADFIELD, AND J. R. MAZE. 1985. Vertical variation of sapwood thickness in *Pinus banksiana* Lamb. and *Larix laricina* (Du Roi) K. Koch. Can. J. For. Res. 15: 822–828.