VARIATION OF WOOD PROPERTIES WITHIN A DOMINANT AND A SUPPRESSED TREE OF TAMARACK [*Larix laricina* (Du Roi) K. Koch]

by

Jean K. Wong ©

ISBN 0-315-48207-9

A Graduate Thesis Submitted

in Partial Fulfillment of the Requirements

for the Degree of Master of Science in Forestry

School of Forestry

Lakehead University

May, 1987

Major Advisor

Reader

ISBN 0-315-48207-9

MAJOR ADVISOR'S COMMENTS

Signature ____________________

Date ________________________

LIBRARY RIGHTS STATEMENT

A CAUTION TO THE READER

ABSTRACT

Wong, Jean K. 1986. Variation of wood properties within a dominant and a suppressed tree of tamarack [*Larix laricina* (Du Roi) K. Koch]. 72 pp. Major Advisor: Professor K.C. Yang

Keyword: tracheid length, specific gravity, ring width, latewood percentage, within-tree variation, juvenile wood, *Larix laricina*.

Radial and axial variations of tracheid length, specific gravity, ring width, and latewood percentage were studied from the stems of a dominant and a suppressed tamarack tree. The trees were 81 and 83 years old respectively, grown in a natural stand near Thunder Bay, Ontario. Specimens were taken from every other ring from the pith to bark along the south and north aspect, at heights 0.15, 1.5, 4.5, 7.5, 10.5, 13.5, and 16.5 m in the tree stems. Juvenile wood and mature wood in the stem were distinguished by using the variation pattern of tracheid length as the criterion.

In the mature wood of the dominant and suppressed trees, the average tracheid lengths were 3.16 mm and 2.96 mm, specific gravities 0.48 and 0.45, ring widths 1.09 mm and 0.85 mm, and latewood percentages 36.7% and 35.1% respectively. In the juvenile wood of the two trees, the average tracheid lengths were 2.11 and 2.10 mm, specific gravities 0.48 and 0.44, ring widths 2.36 mm and 1.97 mm, and latewood percentages 29.7% and 33.1% respectively.

At all heights sampled, tracheid length increased radially from the pith outward, and leveled off at a certain ring age towards the bark. The rate of increase in tracheid length with ring age increased with height. The ring age at which tracheid length started to level off was used as the boundary of the juvenile and mature wood. The ring age of the boundary decreased with increasing height. Average tracheid length of the juvenile and mature wood increased axially from the base upward, reaching a maximum at the 4.5 m height, then decreasing to the top. Specific gravity and latewood percentage increased radially from the pith outward in the juvenile wood for most of the heights, while they fluctuated in the mature wood. Specific gravity and latewood percentage varied axially without a definite pattern with increasing height in the dominant tree, and they decreased upward in the suppressed tree. Ring width decreased radially from the pith outward in the juvenile wood, and fluctuated in the mature wood. Axially, the ring width decreased with increasing height slightly in the mature wood, and it increased in the juvenile wood with height from the 1.5 m height upward, reaching a maximum at the 4.5 to 7.5 m heights, and then decreasing to the top. The difference between the south and north aspect was not significant in tracheid length and ring width. Specific gravity and latewood percentage was significantly higher in the south than north aspect. The dominant tree on average had significantly higher values of tracheid length, specific gravity, and ring width than the suppressed tree.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ACKNOWLEDGEMENTS

I would like to express my gratitude to Professor K.C. Yang, the major advisor, for his invaluable guidance in this project throughout.

I also want to thank the members of the advisory committee, Dr. K.M. Brown, Professor C.A. Benson, and the Graduate Chairman Dr. H.G. Murchison for their time and encouragement. Dr. T. Hazenberg gave me much invaluable advice, I deeply appreciate his help.

This research was conducted under financial assistantship provided by the Canadian Forestry Service, Human Resources Development Program.

I am indebted to Mr. S. Elliott, for his assistance in my field and laboratory work.

I want to convey my deepest appreciation to my wife, Anita, for her help, and encouragement when I was fully engaged in this work.

I dedicate this work to the memory of my father, Z.X. Wong, a research scientist of the Institute of Optical and Fine Mechanical Instrument of the Chinese Academy of Sciences at Changchun, China, for his life long devotion to research.

Jean K. Wong

INTRODUCTION

Wood is a product of the metabolic activities of cambium in a living tree. The properties of wood are affected by such factors as aging of the tree, growth condition, and genetic inheritance during tree growth (Panshin and de Zeeuw, 1980). The variations in the wood properties within a tree directly affect the quality of the end products from the wood. Knowledge in these subjects is important not only for the successful conversion of wood into finished products, but also for guiding research on tree regeneration and wood quality improvement (Kandeel, 1971).

Wood properties can be specified by certain measurable anatomical features for a given end use. For instance, specific gravity has a direct relationship with many of the physical and mechanical properties of wood, such as strength, stiffness, and the ease of machining and drying. Both specific gravity and tracheid length of wood affect the qualities of pulp and paper products. For instance, high specific gravity generally results in a high pulp yield, but a hard chipping and pulping process. Long tracheids result in a high paper strength. Ring width and latewood percentage, two other useful features, are often used for evaluating tree growth, and for predicting wood quality.

Tamarack [*Larix laricina* (Du Roi) K. Koch] is a widely ranging species in North America (Roe, 1957). It grows rapidly and produces relatively strong and durable wood. The wood of tamarack is used in rough construction for posts, poles, ties, and mine timber. Recent research indicates that it is suitable for kraft pulp production (Kikuchi and Kayama, 1975; Isebrands et al. 1982; Hansmann and Sugden, 1983; Holder, 1983; and Einspahr et al. 1984). Tamarack is a potential species for forest regeneration in the future. However, the variation of wood properties within the tree stem has not been adequately studied to date.

The aim of this project is to study the variations of wood properties within the stems of a dominant and a suppressed tamarack tree. Four variables were included in the study: tracheid length, specific gravity, ring width, and latewood percentage.

LITERATURE REVIEW

TRACHEID LENGTH

Tracheid length in conifer trees is primarily determined by the length of the cambial initials, and secondly by cell elongation after the division (Ward and Gardiner, 1976). The literature on the variation of tracheid length was reviewed by Spurr and Hyvarinen (1954), Dinwoodie (1961), and Panshin and de Zeeuw (1980).

Radial Variation

It is generally agreed that at any height of the tree stem, tracheid length increases radially from the pith outward; it approaches or reaches a maximum in a certain range of ring age (the ring number counted from the pith) and beyond that, it follows one of the following patterns depending on species (Dinwoodie, 1961; Panshin and de Zeeuw, 1980):

(1) Tracheid length remains constant further outward after it obtains the maximum length. This is the most frequently reported trend in conifer species including *Larix spp. Picea abies, Pinus densiflora, P. elliottii, P. radiata, P. sylvestris, P. taeda, Pseudotsuga menziesii, P. taxifolia,* and *Sequoia sempervirens.*

(2) Tracheid length remains to increase slowly, but progressively, after it reaches the "initial maximum". This variation pattern was found in *Abies pindrow, Picea sitchensis, P. smithiana, Pinus caribaea, P. ponderosa, P. resinosa, P. strobus, P. taeda, Pseudotsuga taxifolia, Thuja plicata.* The tendency of the increasing length might extend over several hundred years in a tree.

(3) After the maximum length is reached, tracheid length decreases in the older portion of the stem. This pattern was found in *Chamaecyparis obtusa, Pinus sylvestris, Pseudotsuga taxifolia,* and *Sequoia sempervirens.*

Except from the variation patterns above, many authors reported a considerable fluctuation in tracheid length after the maximum length was reached. This is presumably caused by the varied growth conditions. The species studied include *Abies concolor, Larix spp. Picea sitchensis, Pinus palustris, P. strobus, P. contorta,* and *Thuja occidentalis.* The maximum tracheid length in the outer rings of conifer trees is generally three to five times greater than tracheid length near the pith (Dinwoodie, 1961).

Bannan (1967) related the radial variation pattern of tracheid length to the frequency of anticlinal division of the fusiform initials in the cambium. He explained that tracheid length was mainly determined by the length of these initials since the tracheids elongated relatively little after they were divided from the initials. More frequent anticlinal division of the fusiform initials resulted in shorter average length of tracheids. He pointed out that the frequency of the anticlinal division was higher near the pith, decreased outward with increasing ring age, and became basically stabilized in a certain range of ring age.

The inner stem, that shows a progressive change in wood properties with ring age, such as in the case of tracheid length which increases progressively, is often referred to as juvenile wood (or core wood). The wood beyond that portion that shows more stabilized properties with increase in ring age is referred to as mature wood (or adult wood) (Rendle, 1960). In studies of wood property variation within a tree, juvenile and mature wood must be considered as two distinct populations. This is because mature wood properties are considered normal for the species. Juvenile wood properties are generally inferior to those of mature wood and are undergoing changes with ring age (Panshin and de Zeeuw, 1980).

Several factors relative to the radial variation of tracheid length have been studied in the past. Anderson (1951) found that the radial variation of tracheid length could be related to the linear distance from the pith in some species of *Abies* and *Pseudotsuga*. Liang (1948) found in several *Larix* species that tracheid length was positively correlated with a ratio R2/R1 (where R2 and R1 were the distances from the pith to the outer and inner boundaries of the growth ring respectively), and, to a lesser extent, with ring age. Elliott (1960) considered that ring age affected tracheid length in juvenile wood, where tracheid length increased consistently. In mature wood where the rate of increase slowed down, the effect of ring age was superseded by that of the ring width. The ring width was negatively correlated with tracheid length in the mature wood.

Within a growth ring, the average tracheid length in latewood was consistently longer than in earlywood in several conifer species (Bisset and Dadswell, 1950; Ahmad, 1969). Cown (1975) recorded that the latewood tracheids were 0.5 mm longer than that of earlywood in *Pinus radiata*. However, some authors found that the difference between tracheid lengths of earlywood and latewood was not consistent throughout the tree stem in *Pinus ponderosa* (Voorhies and Jameson, 1969), and *P. taeda* (Taylor and Moore, 1981). Megraw (1985) reported that the difference in tracheid length of latewood and earlywood could be greater in juvenile wood than in mature wood.

Axial Variation

The studies of the axial variation of tracheid length may fall into two categories. First, the variation was determined within the same growth rings along the tree stem. Second, the variation was traced in the growth rings of a fixed number from the pith at the different heights. Following the same growth rings, some authors found that tracheid length increased from the stem base up to about one third of the stem height, then decreased up towards the top. This trend was found in *Eucalyptus regrans* (Bisset and Dadswell, 1949), *Pinus taeda* (Jackson, 1959), and *Picea sitchensis* (Chalk, 1930; Elliott, 1960). Authors who traced growth rings of a fixed number from the pith, found that tracheid length increased from the base upward, and then remained constant further up such as in *Tsuga heterophylla* (Wellwood, 1960), or decreased upward such as in *Pinus banksiana* (Kribs, 1928), *Picea smithiana* (Ahmad, 1969) and *P. engelmanii, Pinus contorta* (France and Mexal, 1980), or fluctuated such as in *Pinus taeda* (Greene, 1966) and *Abies pindrow* (Ahmad, 1970). It was reported that in *Sequoias*, the increase in tracheid length upwards from the stem base was paralleled by a decrease in the rate of anticlinal cell division (Bannan, 1966). At the stem base, tracheids were shorter because of the faster cell division associated with butt swell (Megraw, 1985).

In the growth rings next to the pith along the stem, tracheid length remained constant or varied little in *Pinus taeda* (Jackson, 1959; Greene, 1966). Bisset and Dadswell (1949) found a similar tendency in *Eucalyptus regrans.*

Variation with Aspect

Liese and Dadswell (1959) reported that tracheids in the north aspect were 0.35 mm longer than in the south aspect of stems of *Pinus radiata, P. pinaster* in the northern hemisphere, while the reverse was true in the southern hemisphere. It was concluded that the more intense solar radiation in the south aspect could cause more frequent cambial division, and result in shorter tracheids. Similar tendencies were found in *Pinus sylvestris* (Schultze-Dewitz, 1965), and *P. nigra* (Tsoumis and Panagiotidis, 1980). However, in *Pinus radiata* (Nicholls and Dadswell, 1962), and *P. wallichiana* (Jain and Seth, 1979), tracheid length was not significantly different at different aspects.

Effect of Ring Width

Tracheids in broad growth rings were found to be shorter than in narrow ones in the same stems of *Picea glauca,* and *P. sitchensis* (Hale and Fensom, 1931; Trendelenburg, 1935; Elliott, 1960; Ward and Gardiner, 1976), and *Abies pindrow* (Ahmad, 1970). Bannan (1967) indicated that the relationship between tracheid length and ring width was conditional. In *Pinus strobus* he found that the maximum tracheid length coincided with a ring width of about 1 mm within the tree stem. Growth rings either wider or narrower than 1 mm were associated with a reduced cell length. The correlation between tracheid length and ring width would be negative when growth rings exceeded the optimum width of 1 mm, and positive when they were narrower than the optimum width. The correlation would be weak or not significant when the ring width was around the optimum width.

SPECIFIC GRAVITY

Specific gravity of wood is a measure of the total amount of cell wall substances in a given volume of wood. It varies with cell wall thickness and structure, average cell dimensions, amount of resin and extractives, and the amount of non-fibrous elements such as rays (Elliott, 1970). Except for genetic inheritance, the variation of specific gravity within a tree is related to ring age, height in the stem, and their interactions. These factors reflect the distance from the tree crown (Megraw, 1985). The coefficient of variation in specific gravity within a species is about 10% in North America (Haygreen and Bowyer, 1982).

Specific gravity in *Pinus elliottii* was strongly influenced by latewood percentage, accounting for about 60% of the total specific gravity variation (Larson, 1957).

Radial Variation

In conifer species which have been studied, the radial variation patterns of specific gravity in the tree stem can be classified into three categories (Panshin and de Zeeuw, 1980):

(1) Specific gravity increases from the pith outward, then becomes basically constant after a certain ring age. The species in this category include *Larix spp., Picea abies, P. sitchensis, Pinus spp., P. resinosa, P. sylvestris, P. ponderosa,* and *Pseudotsuga menziesii.*

(2) Specific gravity decreases from the pith outward, then increases toward the bark. Species in this category are *Abies grandis, A. noordmaniana, A. pectinata, Picea abies, P. mariana, P. sitchensis, Pinus strobus, Thuja plicata,* and *Tsuga heterophylla.*

(3) Specific gravity decreases linearly or curvilinearly from the pith to bark. This pattern was found in *Chamaecyparis lewsoniana, C. obtusa, Cryptomeria japonica, Pinus echinata, P. michoacan,* and *Pseudotsuga menziesii.*

The radial variation in specific gravity of whole growth rings was jointly affected by the specific gravities of latewood and earlywood, and the proportions of each in the whole growth ring (Elliott, 1970). In *Pinus spp.,* the latewood specific gravity increased from the pith outward, whereas the earlywood specific gravity decreased (Paul, 1939; Taras, 1965; Koch, 1972; Megraw, 1985). In these species, the whole ring specific gravity increased from the pith outward. This pattern reflects the trend of latewood specific gravity, and is often found in species with a large proportion of latewood. In some other species, the whole ring specific gravity decreased from the pith outward. This pattern reflects the trend of earlywood specific gravity, which is often found in species with more earlywood.

Axial Variation

Specific gravity of a stem wood either decreases or increases from the stem base upward to the tree crown. The decreasing pattern was found in *Abies, Larix, Pinus, and Pseudotsuga* (Panshin and de Zeeuw, 1980). The increasing pattern was found in *Picea canadensis* (Hale and Fensom, 1931), *Tsuga heterophylla* (Krahmer, 1966), *Picea engelmannii, Tsuga heterophylla, Thuja plicata* (Okkonen, et al. 1972), *Picea glauca* (Taylor, et al. 1982), *Abies lasiocarpa, A. balsamea, Picea glauca, and P. mariana* (Singh, 1984). The axial variation of specific gravity interacts with the radial variation (Okkonen, et al. 1972). In species with pronounced latewood such as *Pinus* and *Larix,* specific gravity increased from the pith outward radially and tended to decrease from the base upward axially. In species with less or not pronounced latewood such as *Picea,* specific gravity decreased from the pith outward radially and tended to increase from the base upward axially.

An exception to the general tendencies stated above, is that higher specific gravity might be found in the stem in the crown region. This can be caused by the dense knots near the wood sampled in some pine species (Paul, 1939; Larson, 1957).

Variation with Aspect

Specific gravity in the west aspect throughout the stem height was significantly higher than that in the east in a single stem of *Picea sitchensis* (Ward and Gardiner, 1976). In contrast, the effect of aspect was not found to be significant in the stem of *Larix kaempferi* (Hirai, 1949), *Pinus taeda* (Zobel and Rhodes, 1955), *P. elliottii* (Sellers, 1962), and *Picea rubens* (Perng, 1983). However, Taras and Wahlgren (1963) studied increment cores taken around the tree stem, and found that the aspect had little or no effect on specific gravity.

Effect of Ring Width

Specific gravity of conifer trees with distinct latewood was found to be inversely related to ring width according to the earlier literature, summarized by Elliott (1970). Later studies indicated that, the ring width effect on specific gravity could be traced ultimately to that of ring age. This was because both specific gravity and ring width increased with ring age (Spurr and Hsiung, 1954; Elliott, 1970; Bendtsen, 1978). Rendle and Phillips (1958) reported that in rings of similar width in *Pseudotsuga taxifolia* and *Pinus nigra,* specific gravity increased with ring age, which was independent of ring width. Taylor (1982) found that in rings of the same age and different ring widths in *Pinus taeda,* the specific gravity was not significantly influenced by ring width within the first thirty-five years from the pith. Similar results were also reported by Pearson and Ross (1984) for the same species. Megraw (1985) considered that both variations of ring width and specific gravity were the results of the physiological influence of the tree crown. An inherent relationship between ring width and specific gravity did not exist. Fast grown and wide ring width did not necessarily imply lower specific gravity.

RING WIDTH

In the forest-grown trees, ring width normally decreases with ring age from the pith outward. Aside from aging, this basic variation pattern is related to the stand closure which causes decline in the wood formation. Superimposed on this basic pattern, ring width fluctuates as the results of changes in the environment, such as climate, removal of a neighboring tree, and heavy cone production (Larson, 1969).

The ring width (of juvenile wood) is generally very narrow in the upper most internodes of the stem, and then increases downward (Kozlowski, 1971). It was found that the maximum ring width occurred at least one internode above that bearing the maximum total leaf weight in *Picea sitchensis* (Denne, 1979). Below the crown, the variation in ring width with height depends on the crown class. In dominant trees, the ring width decreases downward below the crown and then increases again in the lower stem towards the stem base. In suppressed trees, the ring width similarly decreases downward below the crown, and does not increase again in the lower stem. In open grown trees, the ring width increases all the way down below the crown (Kozlowski, 1971).

Perng (1983) recorded that in a *Picea rubens* stem, the ring width decreased from the pith outward radially. It increased slightly with increasing height in the juvenile wood, and decreased in the mature wood axially. The effect of aspect on ring width within the tree stem was not significant and consistent throughout the stem height.

LATEWOOD PERCENTAGE

The latewood percentage in a given position in the tree stem depends basically on the distance from the vigorous crown. The crown is the source of photosynthesis which supplies materials for the cell wall thickening, and the source of auxins which are the hormones regulating the process of wood formation. At the beginning of the growing season, the earlywood starts to form at the top of the tree, and proceeds gradually downward. In the later growing season, latewood starts to form at the stem base, and proceeds gradually upward (Larson, 1969).

Latewood percentage increased radially with ring age in juvenile wood, and became more or less uniform in mature wood. Latewood percentage decreased axially with height in both juvenile and mature wood in *Pinus elliottii* (Larson, 1957; Taras, 1965), *Pinus sylvestris* (Schultze-Dewitz, 1958); *Pinus elliottii* (Koch, 1972), and *Pinus taeda* (Megraw, 1985). Latewood percentage increased faster with ring age at the lower height levels than it did at the higher levels. For the rings of the same number from the pith, latewood percentage was distinctly greater at the stem base than at the upper levels (Megraw, 1985).

MATERIALS AND METHODS

SPECIMEN COLLECTION

One dominant and one suppressed tamarack tree were selected and felled from the Jack Haggerty Forest, Lakehead University, 20 km north of Thunder Bay, Ontario. The dominant and suppressed trees were 81 and 83 years old respectively. Appendix I shows the field data of the stand, and Figure 1 shows the physical measurements of the trees, and illustration of the sampling points in the trees.

Wood disks 5 cm thick were cut from the tree stems at heights of 0.15, 1.5, 4.5, 7.5, 10.5, 13.5, and 16.5 m. The diameter of the top disks were about 5 cm. The south aspect was marked on each of the disks. The discs were labeled and brought to the laboratory in sealed plastic bags.

Figure 2 illustrates the specimen preparation and measurements in the laboratory. Wood strips 6 mm wide were cut from the disks along the south and north aspects. The wood strips were first used for ring width and latewood percentage measurement. Then, they were made into specimens for specific gravity and tracheid length determination.

DETERMINATIONS AND MEASUREMENTS

Ring Width and Latewood Percentage Measurement

In this study, *ring width* refers to the width of the growth (or annual) rings, and *latewood percentage* refers to the percentage of latewood width to the (whole) ring width.

Before the measurements were made, the surface of the cross section of the wood strips was smoothed with fine sand paper to help expose the growth rings. The cross section of the wood strips was photocopied on a Xerox machine. To increase the contrast of the boundary of

Height (m)	Diameter (cm) D	Diameter (cm) S	No. of Rings D	No. of Rings S
16.5	5.6		33	
13.5	9.7	4.9	39	41
10.5	14.5	9.6	45	49
7.5	18.1	12.5	53	55
4.5	20.7	14.7	57	63
1.5	25.0	16.6	75	81
0.15	34.2	27.2	81	83

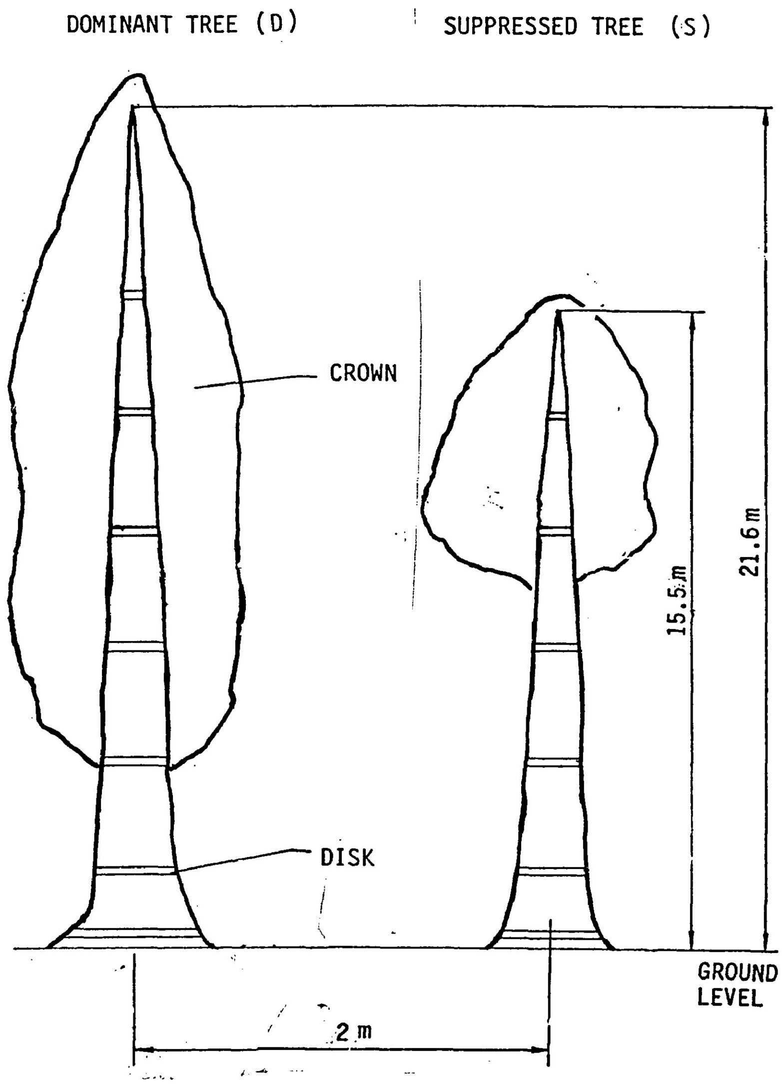

Figure 1. Physical data and sampling points in the dominant and suppressed trees.

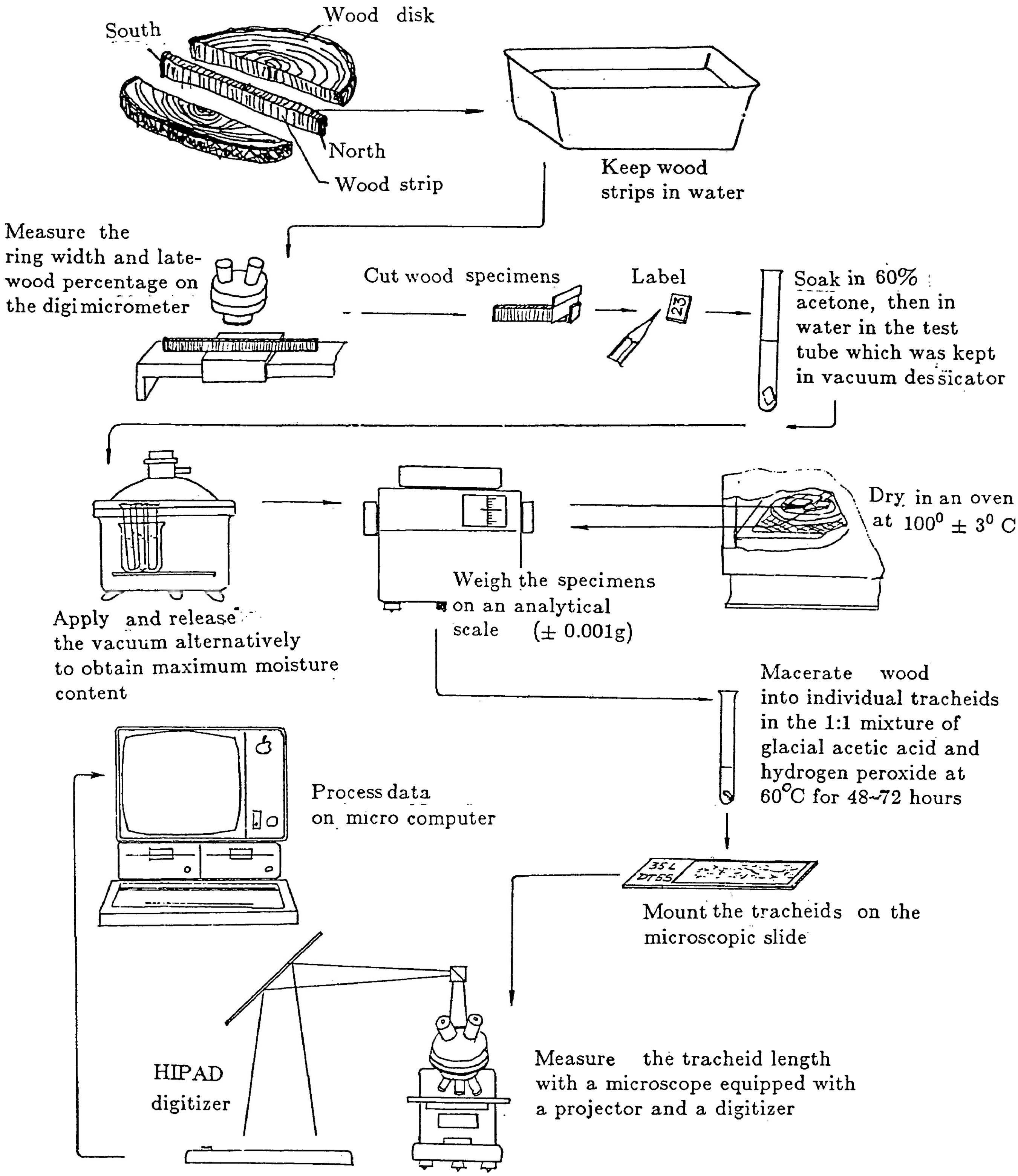

Figure 2. Illustration of the laboratory procedures.

the growth rings, water was applied to the surface of the strips before photocopying. The copies of wood strips were positioned on a sheet of paper according to their location in the tree. Lines were drawn to connect the same growth rings in the different strips (heights). The same growth rings were identified by counting the ring numbers from the bark (Figure 6).

With a Holman-digimicrometer (Clarke and Murchison, 1987), the width of the latewood and earlywood of each of the growth rings were measured. The sum of the two gave the whole ring width, the ratio of latewood width to the whole ring width gave the latewood percentage.

Specific Gravity Determination

Specific gravity refers to basic specific gravity which was determined on a green volume base. The maximum moisture content method (Smith, 1954) was used to determine the specific gravity on the whole growth ring base. The small wood sections were cut from the wood strips. Each of these sections contained one growth ring. Every other ring was sampled along the wood strips, beginning with the first ring at the bark inward to the inner most ring at the pith. If growth rings were too narrow to be cut into one section, i.e., less than 0.5 mm in width, several rings were cut into one section. The measurement from this section with narrow rings represented the average specific gravity of the growth rings contained.

The wood sections were soaked in a 60% acetone solution in the test tubes which were placed in a dessicator for about 48 hours to remove the extractives. Vacuum was applied and released from the dessicator alternatively to speed up the process of the acetone penetration in the wood sections. The sections were then rinsed several times with water to remove the acetone in wood, which was carried out with the same vacuuming operation for about 70 hours until the maximum moisture content (MMC) was reached in the wood sections. The MMC was reached when the weight of the wood sections remained unchanged in three consecutive measurements. An analytical scale (± 0.001 g) was used to determine the maximum weight (Wm) of each of the wood sections. After weighing the wood sections, the sections were dried in an oven at 100 ± 3^0C for about 48 hours until the weight of the sections remained unchanged. Each of the dried sections was then weighed on the same scale to determine oven-dry weight (Wo). The (basic) specific gravity (SG) of the wood sections was calculated with the formula given by Smith (1954):

$$SG=\frac{1}{\frac{Wm-Wo}{Wo}+\frac{1}{1.53}}.$$

Tracheid Length Measurement

Tracheid length of each growth ring refers to the average tracheid length of latewood and earlywood of that growth ring. The averaging was based on the width proportions of latewood and earlywood in the whole growth ring. The tracheid length of the latewood and earlywood was determined separately.

After the specific gravity determination, each of the wood sections was cut into two thin chips, one contained the latewood portion and the other contained the earlywood portion. These chips were about 1×3×10 mm in size. They were macerated into individual tracheids using Franklin's method (Franklin, 1945). Each of the wood chips was soaked in the 1:1 mixture of glacial acetic acid and hydrogen peroxide in a test tube. The test tubes were kept at 60^0C for about 48 to 72 hours until the wood chips turned white. The wood chips were then washed with water, and were shaken into individual tracheids. The tracheids from each chip were mounted on a microscopic slide, and covered with a cover slip. The edges of the cover slip were sealed with Coverbound. Each slide might contain several hundred tracheids.

A trial was made to determine the number of tracheids to be measured from one slide for average tracheid length of the latewood or earlywood of a growth ring (Appendix II). Tracheids in six slides sampled from earlywood and latewood at ring age 5, 20, and 68 were measured respectively. The result of the trial indicated that, if at least 17 tracheids in earlywood and 13 in latewood were measured, there would be a 5% probability to over- or underestimate the mean length by less than 10%. In this study, 20 tracheids were measured for both early-wood and latewood of all the growth rings sampled.

The tracheids were measured on a tablet of a Houston Instruments HIPAD digitizer. They were magnified with a microscope which projected the tracheids on the tablet. The digitizer was connected to an Apple microcomputer through an interface. The microcomputer recorded the tracheid length data measured and stored on floppy disks. The selection of tracheids to be measured on the tablet followed the method suggested by Taylor (1975).

DATA ANALYSIS

Variation of the four variables, tracheid length, specific gravity, ring width, and latewood percentage were analyzed with respect to several factors such as ring age, height, and aspect within the dominant and suppressed trees. The differences of the four variables were tested between the two trees. The dominant and the suppressed trees were considered as two different populations, and treated individually. A software package, SPSS (Statistical Package for the Social Sciences) on the main frame computer system VAX/780 was used for the statistical analyses.

Juvenile and Mature Wood Boundary

In order to distinguish the juvenile and mature wood in the analysis the boundary of the two zones was determined first. Tracheid length was used as the criterion for boundary determination. Juvenile wood and mature wood were visually divided according to the radial variation pattern of tracheid length for each height and aspect. The juvenile wood was in the portion where tracheid length progressively increased from the pith outward. The mature wood was beyond the juvenile wood, where the tracheid length became constant. When the data of juvenile and mature wood were obtained, two straight regression lines were determined in the juvenile and mature wood respectively for each of the heights and aspects. The intercept of two lines was treated as the new boundary point. The same regressions were then repeated using the data separated according to the new boundary. The regressions for the mature wood at those heights were either nonsignificant, or inconsistent for slope values (positive or negative). In order to simplify the analysis procedure, mean tracheid length of the mature wood was used to represent the tracheid length of the mature wood. The result of the last step was taken as the final boundary. The ring ages of the boundaries were determined and listed in the Xa column of Table 1, and plotted in Figure 5. Also, the juvenile and mature wood in the two trees were marked at the growth rings of the boundary in Figure 6. The final regression lines determined were graphed in Figure 3, with the sloped lines in the juvenile wood, and the horizontal lines in the mature wood.

For the four wood property variables of wood property in this study, the following analyses were based on the above classification of juvenile and mature wood.

Radial Variation

Radial variations of the four variables in the juvenile wood were examined using linear regression. With each of the data sets for one of the heights and aspects in the juvenile wood, a linear model $\hat{Y}_i = A + BX_i + e_i$ was tested to see the fitness of the model to the data. In the model, Y is the wood property variable, A is the intercept, B is the slope, X is ring age, and e is the residual term, and subscript i represents any one of the measurements (observation). The slope B represented the general variation trend of the wood property variable with ring age in the juvenile wood. The variation of the slope with height for tracheid length was graphed in Figure 4. The correlation coefficients between X and Y of the model, r was calculated for the data set of each height and aspect. How well the model fitted the data was determined by examining the r value and the scatterplots of e term (not presented in this paper) for each data set (Norusis, 1982). The linear equations obtained and r values are listed in Tables 1, 5, 8, and 11 for each of the four variables respectively. Those tables also include means of the variables of the mature wood.

Difference between Earlywood and Latewood Tracheid Length

The difference in tracheid length between latewood and earlywood was tested with the pairwise t test procedure (Table 2). The H_o: $\bar{D} = 0$, was tested as follows:

$$t=\frac{\bar{D}}{s_D/\sqrt{n}}.$$

where, $\bar{D}$ = the mean of the differences between earlywood and latewood tracheid length (the pair) in the same growth rings. The difference was declared significant if the calculated t value was greater than tabulated t value for the significant level α=0.05, and n-1 degree of freedom. This test accounted only for the difference within growth rings, but not that between or among the growth rings. Juvenile and mature wood were tested separately.

Axial Variation

Axial variations of the four variables were tested with the multiple comparison method on the series of height means for the juvenile wood and mature wood, in the dominant tree and suppressed tree. Each height mean was calculated from the data of two aspects of a given height. Juvenile and mature wood were tested separately. The multiple comparison identified the height mean (or means) which was (were) significantly different from others. Those height means that were significantly different from others were classified into one of the subgroups. The height means of different subgroups were significantly different from each other, those within a subgroup were not (Norusis, 1982). Tables 3, 6, 9, and 12 were constructed based on the multiple comparison analysis for the four variables respectively.

Difference Between Two Aspects and Two Trees

The difference between the means of the south and north aspects were tested with (student) t test for the four variables. The two means for each test were averaged from the south and north aspect combining data of all the heights; juvenile and mature wood were separated. The H_o: $\bar{Y}_1=\bar{Y}_2$, was tested as follows:

$$t=\frac{\bar{Y}_1-\bar{Y}_2}{s_{\bar{Y}_1-\bar{Y}_2}}.$$

Where $\bar{Y}_1$ and $\bar{Y}_2$ are the two means tested, and $s_{\bar{Y}_1-\bar{Y}_2}$ is the standard error of the difference. The calculation of $s_{\bar{Y}_1-\bar{Y}_2}$ depended on whether the two variances (estimated) associated with the two means were equal statistically (Norusis, 1982). If the variances were not equal, the method of the separate variance t test was applied in calculating the t value (Steel and Torrie, 1980). The details of the tests are listed in Tables 4, 7, 10, and 13 for each of the variables respectively.

The test of difference between the two trees was based on the overall means of the dominant and suppressed tree, separating juvenile wood and mature wood. The method was the same as that for the aspect, and the details of the tests were listed in the same tables.

Correlations of the Variables

Correlations between each pair of the following variables were tested: tracheid length, specific gravity, ring width, latewood percentage, and ring age. The tests were to examine the strength of linear association (Norusis, 1982) between every two of the above variables. The correlations were based on the data from the juvenile and mature wood of the whole tree for the dominant and suppressed trees respectively. Table 14 was constructed with the determined correlation coefficients (r) and their associated significance level.

RESULTS

TRACHEID LENGTH

Unless otherwise specified, the term tracheid length in the following sections refers to the average of latewood and earlywood tracheid length as defined in Materials and Methods.

Radial Variation

In both dominant and suppressed trees, tracheid length increased progressively from the pith outward, then leveled off at a certain ring age towards the bark (Figure 3). Tracheid length was about 1 mm at the pith, and increased up to 3 - 4 mm in the outer rings. The portion of wood with a progressive increase in tracheid length had been defined as juvenile wood, and that beyond it as mature wood (See Materials and Methods). The radial variation of tracheid length with ring age could be expressed by the linear equation $\hat{Y}=A+BX$ (Table 1). The fitted regression equations were all significant at the 1% level for all the heights and aspects.

The rate at which tracheid length increased with ring age from the pith outward increased with increasing height (Figure 4). This increase rate is expressed by the slope (B) of the linear equation (Table 1). The slope increased with increasing height from the stem base up to the 10.5 m height in both trees. Above the 10.5 m height in both trees, the slope increased continuously in the south aspect, while it decreased slightly upward in the north aspect. This slope-height relationship indicated that the tracheid length increased or matured with ring age more rapidly at the higher levels in the stem than at the lower levels.

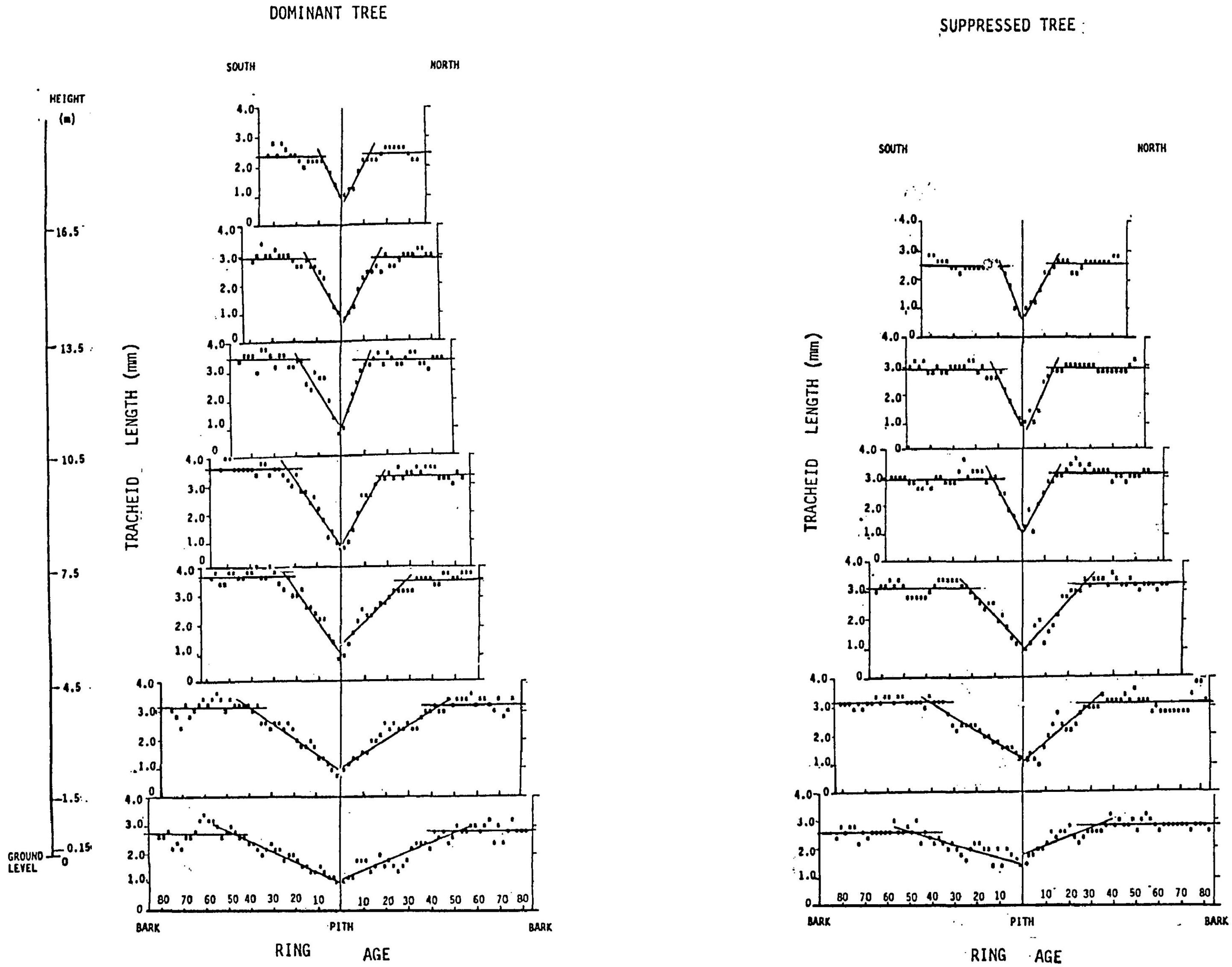

Figure 3. Variation of tracheid length with ring age at successive heights of the south and north aspects in the dominant and suppressed trees.

Table 1. Linear equations $\hat{Y}=A+BX$ representing the variation of tracheid length (Y) with ring age (X), the ring age of the juvenile and mature wood boundary (Xa), and mean tracheid length of mature wood (Y_M) for each of the heights for the south and north aspects of the dominant and suppressed trees.

Height (m)	Total No.of Ring	South A + BX	South r	South Y_M (mm)	South Xa (Year)	North A + BX	North r	North Y_M (mm)	North Xa (Year)
Dominant									
16.5	33	0.85+0.17X	0.98**	2.38	9	0.71+0.14X	0.96**	2.43	12
13.5	39	0.94+0.14X	0.96**	2.94	14	0.73+0.14X	0.97**	2.90	16
10.5	45	1.14+0.13X	0.84**	3.47	18	1.02+0.19X	0.98**	3.37	12
7.5	53	1.01+0.11X	0.97**	3.62	24	0.84+0.14X	0.97**	3.33	18
4.5	57	1.10+0.11X	0.96**	3.66	24	1.42+0.077X	0.94**	3.56	28
1.5	75	1.04+0.052X	0.97**	3.15	41	1.20+0.048X	0.95**	3.23	43
0.15	81	1.14+0.035X	0.95**	2.77	47	1.21+0.032X	0.89**	2.84	51
Suppressed									
13.5	41	0.61+0.21X	0.98**	2.49	9	0.66+0.15X	0.96**	2.59	13
10.5	49	1.04+0.16X	0.97**	2.94	12	0.65+0.16X	0.91**	2.93	14
7.5	55	1.10+0.16X	0.98**	2.94	12	0.99+0.14X	0.89**	3.14	15
4.5	63	1.37+0.082X	0.95**	3.17	22	1.00+0.086X	0.91**	3.26	26
1.5	81	1.36+0.046X	0.97**	3.22	41	1.28+0.063X	0.90**	3.16	30
0.15	83	1.55+0.023X	0.80**	2.61	47	1.93+0.028X	0.78**	2.82	32

A = the intercept of the linear equation, B = the slope of the linear equation, r = correlation coefficient of the regression, ** significant at $\alpha<0.01$; Y_M = mean tracheid length of the mature wood, Xa = the ring age at which the boundary of the juvenile and mature wood is defined.

Juvenile and Mature Wood Boundary

The ring ages of the juvenile and mature wood boundary, or number of growth rings in juvenile wood, determined using tracheid length as the criterion, decreased upward with increasing height in both trees (Figure 5). In the dominant tree for example, there were about 50 rings in juvenile wood at the stem base. This decreased rapidly to 10 rings at the 16.5 m height. The number of growth rings in the mature wood also decreased, but more slowly, with

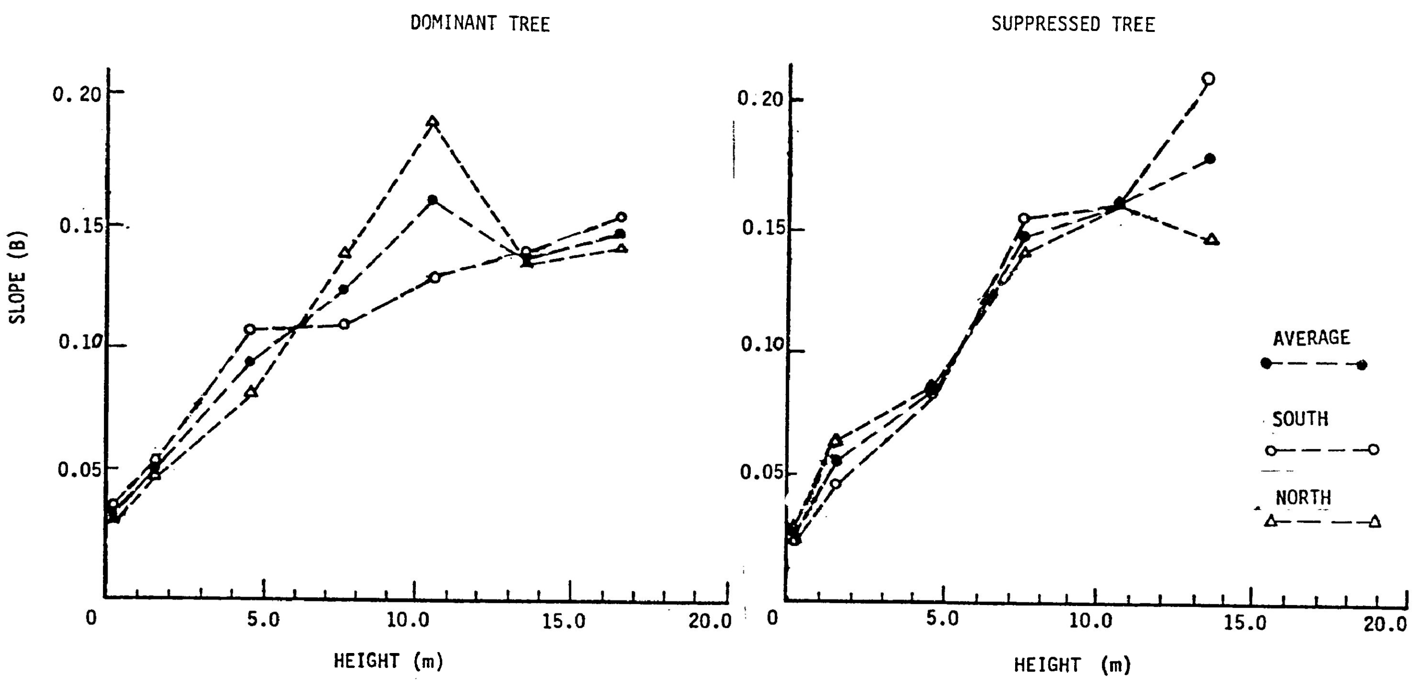

Figure 4. Relationship between the increase rate of tracheid length (slope B as in Table 1) and height in the dominant and suppressed trees.

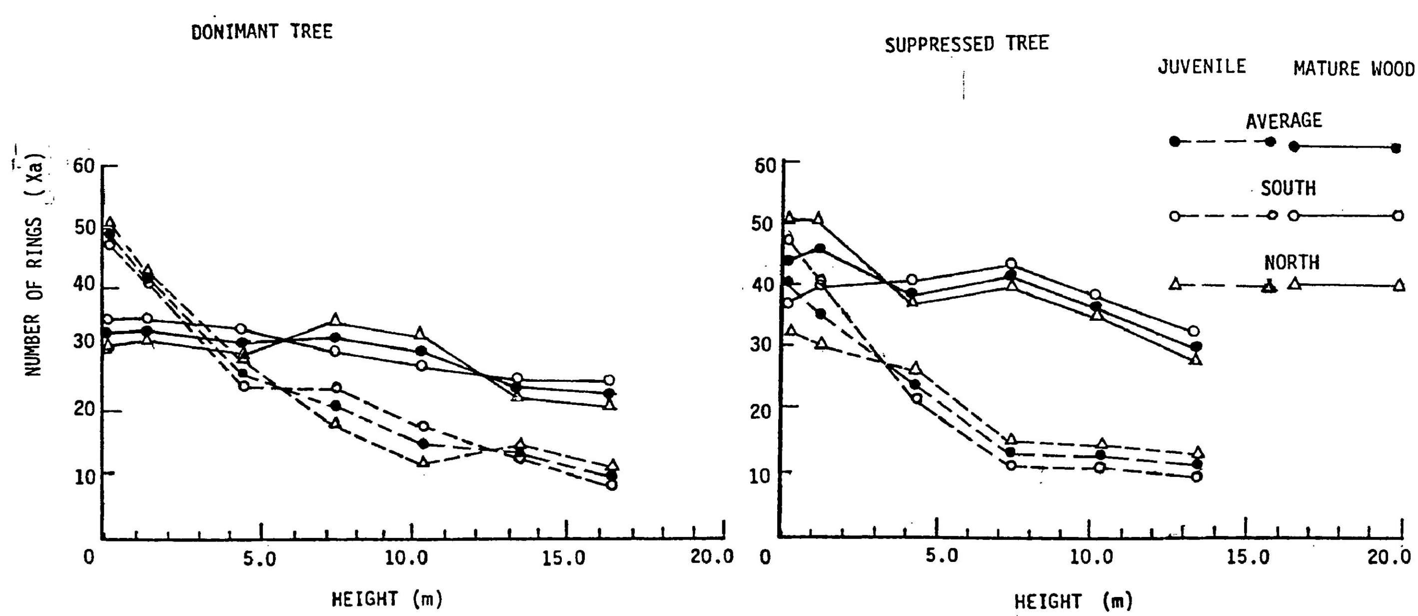

Figure 5. Relationship between number of rings and height in the juvenile wood and mature wood of the dominant and suppressed trees.

increasing height. They decreased from about 30 to 20 with increasing height in both dominant and suppressed trees.

Figure 6 illustrates the width of the juvenile and mature wood in the two tree stems. The width of the juvenile wood narrowed down with increasing height in the dominant and suppressed trees respectively. The distribution of the juvenile wood appeared a cone shape in the tree stems. The width of the mature wood decreased upward, but much more slowly than that of the juvenile wood (Figure 6).

Difference Between Latewood and Earlywood

Tracheid length of latewood was found to be significantly longer than that of the earlywood (Table 2). In the juvenile wood, the latewood tracheids were 12.8% and 13.4% longer than earlywood tracheids in the dominant and suppressed trees respectively. In the mature wood, the latewood tracheids were 9.5% and 9.4% longer than earlywood tracheids in the dominant and suppressed trees respectively.

The tracheid length of latewood and earlywood were positively correlated (r=0.79** to 0.95**, Table 2) in both trees. This indicated that the variations tended to be similar. Figure 7 illustrates radial variation patterns of latewood and earlywood with ring age at the 1.5 m height of the north aspect of the dominant tree.

Axial Variation

In the juvenile and mature wood of both trees, the mean tracheid length increased from the stem base upward. The mean tracheid length reached a maximum at the 4.5 m height, and then decreased to the top (Figure 8).

In the mature wood of the dominant tree, the means of the tracheid length of the 0.15 m and 13.5 m heights were not significantly different; the means of the 1.5 m, 7.5 m, and 10.5 m heights were not significantly different from each other (Table 3). For both trees, the mean

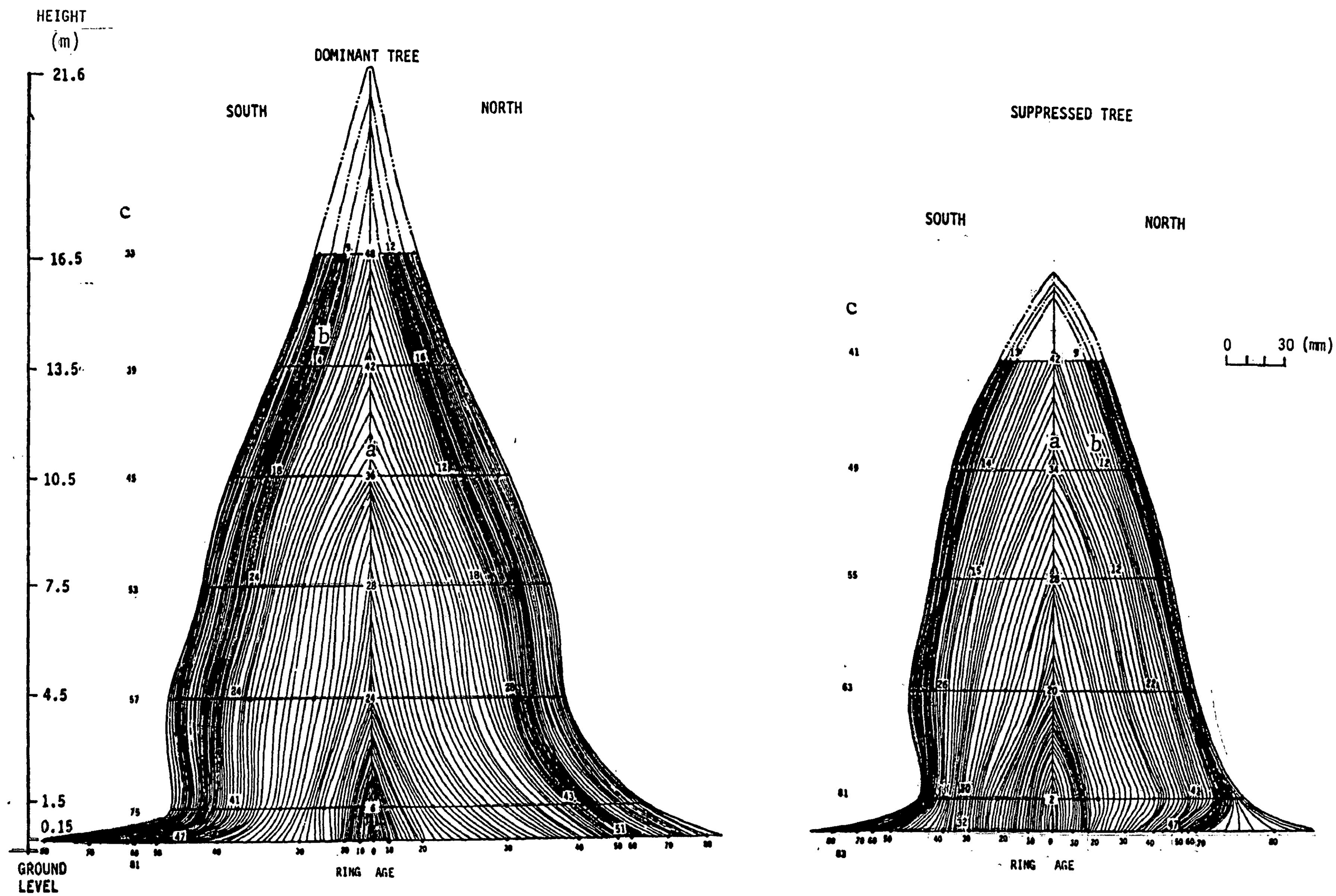

Figure 6. Distribution of ring width and juvenile wood in the stems of the dominant and suppressed tree. (a) tree age when the tree was at the designated height; (b) number of rings in juvenile wood at the designated height; (c) total number of rings at the designated height.

Table 2. T tests on the differences in tracheid length between latewood (L) and earlywood (E) in juvenile (J) and mature (M) wood of the dominant and suppressed trees.

Tree	J/M	L/E	n	Mean (mm)	$\bar{D}$ (mm)	$s_D/\sqrt{n}$ (mm)	r	t
Dominant	J	L E	181	2.29 2.03	0.26	0.017	0.95**	15.8**
	M	L E	209	3.33 3.04	0.29	0.024	0.82**	13.9**
Suppressed	J	L E	142	2.29 2.02	0.28	0.019	0.94**	14.9**
	M	L E	237 237	3.13 2.86	0.27	0.015	0.79**	19.7**

$\bar{D}$ = the mean difference between the latewood and earlywood tracheid length, s_D = the standard deviation of the difference (D); r = correlation coefficient between latewood and earlywood tracheid length; t = calculated t value of the test; ** significant at $\alpha < 0.01$.

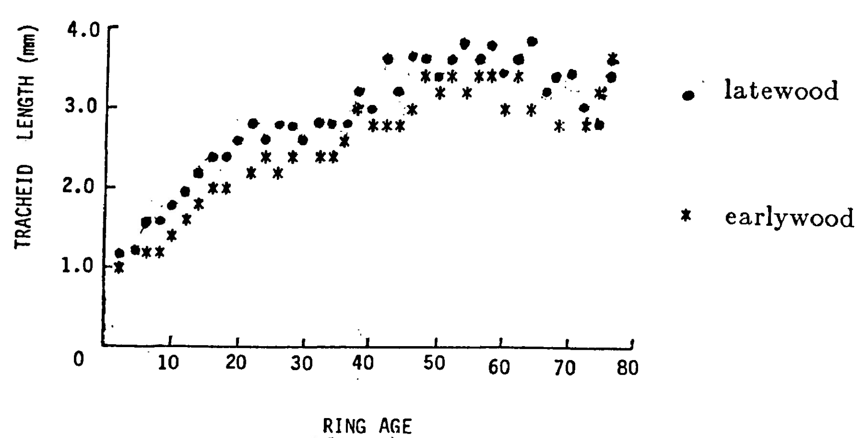

Figure 7. Comparison between latewood and earlywood tracheid length and their variations with ring age. The data were taken at the height 1.5 m of the north aspect of the dominant tree.

Table 3. Multiple comparisons of the means of tracheid length at various heights for testing the axial variations in tracheid length of juvenile and mature wood of the dominant and suppressed trees.

Height (m)	Dominant									Suppressed							
	Mature						Juvenile			Mature						Juvenile	
	Mean	A	B	C	D	E	Mean	a	b	Mean	A	B	C	D	E	Mean	a
16.5	2.40	A					1.61	a									
13.5	2.92		B				1.87	a	b	2.54	A					1.67	a
10.5	3.41				D		2.28	a	b	2.93			C			1.89	a
7.5	3.46				D		2.23	a	b	3.03				D		2.16	a
4.5	3.63					E	2.44		b	3.21					E	2.19	a
1.5	3.21			C			2.18	a	b	3.18					E	2.21	a
0.15	2.80		B				1.95	a	b	2.73		B				2.13	a

Mean = mean tracheid length (mm) of the height of two aspects; subgroups A, B, ... (for mature wood) and subgroups a, b, ... (for juvenile wood) = denote subgroups significantly different from each other, the height means within the subgroups are not significantly different. For example, in the mature wood of the dominant tree, subgroup A contains mean tracheid length 2.40 of the height 16.5, and is significantly different from subgroup B which contains the mean 2.92 of height 13.5 and 2.80 of height 0.15; the mean 2.92 and 2.80 are not significantly different.

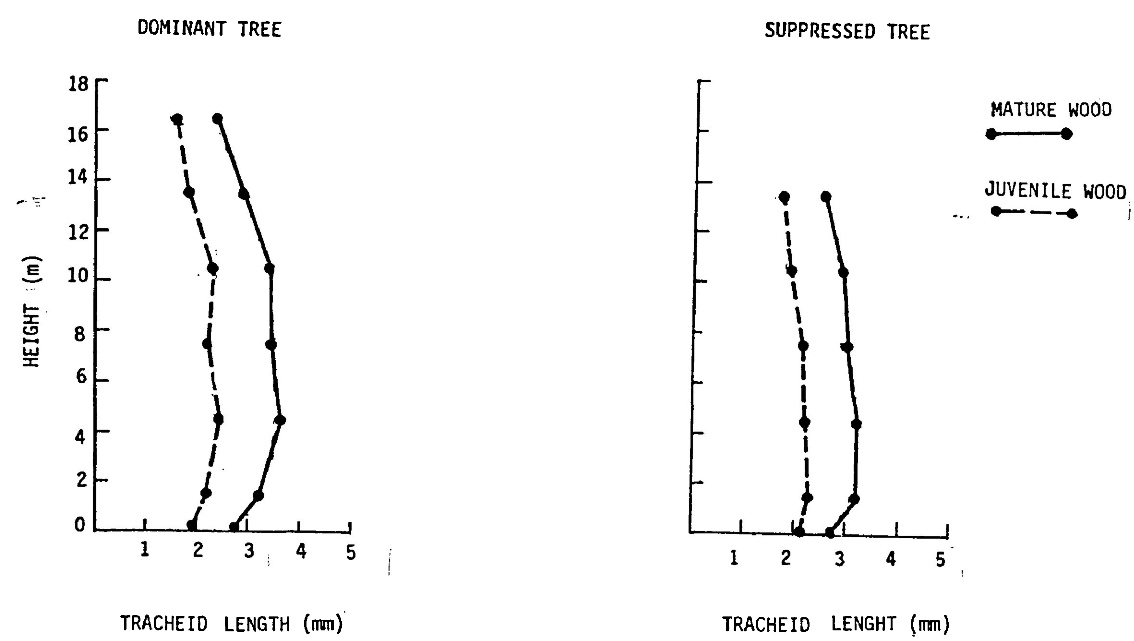

Figure 8. Variation of tracheid length with height in juvenile and mature wood of the dominant and suppressed trees.

tracheid lengths of the 4.5 m height was the longest, and that of the top (16.5 m in the dominant, 13.5 m in the suppressed) were the shortest. In the juvenile wood, the differences among the height means of tracheid length were not significant in the suppressed tree. Only heights 16.5 m and 4.5 m were significantly different in the dominant tree.

Difference Between Two Aspects

The mean tracheid lengthes of the south and north aspect were not significantly different, except in the mature wood of the suppressed tree (Table 4). In the mature wood of the suppressed tree, the mean tracheid length of the north aspect was 0.09 mm longer than that of the south aspect.

Table 4. T tests on the differences in tracheid length between the south and north aspects, and between the dominant and suppressed trees.

	Mature				Juvenile			
	n	Mean (mm)	s (mm)	t	n	Mean (mm)	s (mm)	t
				Dominant				
South	105	3.16	0.50	ns	90	2.11	0.70	ns
North	104	3.15	0.40		91	2.10	0.67	
				Suppressed				
South	116	2.91	0.32	2.30*	74	2.11	0.57	ns
North	121	3.00	0.28		68	2.10	0.65	
				Between Trees				
Dominant	209	3.16	0.45	5.37**	181	2.11	0.68	ns
Suppressed	237	2.96	0.30		142	2.10	0.60	

n = number of measurements; Mean = mean tracheid length; s = standard deviation; t = calculated t value of the test; ns not significant;
* significant at $\alpha<0.05$, ** $\alpha<0.01$ level.

Difference Between Two Trees

The overall mean tracheid length of the dominant tree is significantly longer than that of the suppressed tree for the mature wood (Table 4). It was not significant for the juvenile wood. In the mature wood, the mean tracheid length of the dominant tree was 0.20 mm longer than that in the suppressed tree. Tracheid length of the mature wood was on average longer in the dominant tree than that in the suppressed tree at every corresponding height (Table 3).

SPECIFIC GRAVITY

Radial Variation

Specific gravity in both trees generally increased with ring age from the pith outward in the juvenile wood. The variation pattern became less regular in the mature wood (Figure 9). The increase of specific gravity in the juvenile wood is especially obvious in the suppressed tree. In contrast, in the juvenile wood at the 0.15 m and 13.5 m heights in the suppressed tree, specific gravity decreased from the pith outward. In the mature wood, specific gravity decreased outward at the 10.5 m and 16.5 m heights but leveled off at the other heights in the dominant tree. Specific gravity of the mature wood fluctuated in the suppressed tree. Table 5 shows the linear equations expressing the radial variation of specific gravity with ring age in the juvenile wood. The slopes (B) of most of the linear equations were positive which indicated the increase of specific gravity with ring age (X) in the juvenile wood. The exceptions were at the 0.15 m and 13.5 m heights on the north where the slopes were negative which indicated a decrease. The regressions used to determine the linear equation were not significant for some heights in the two trees (Table 5).

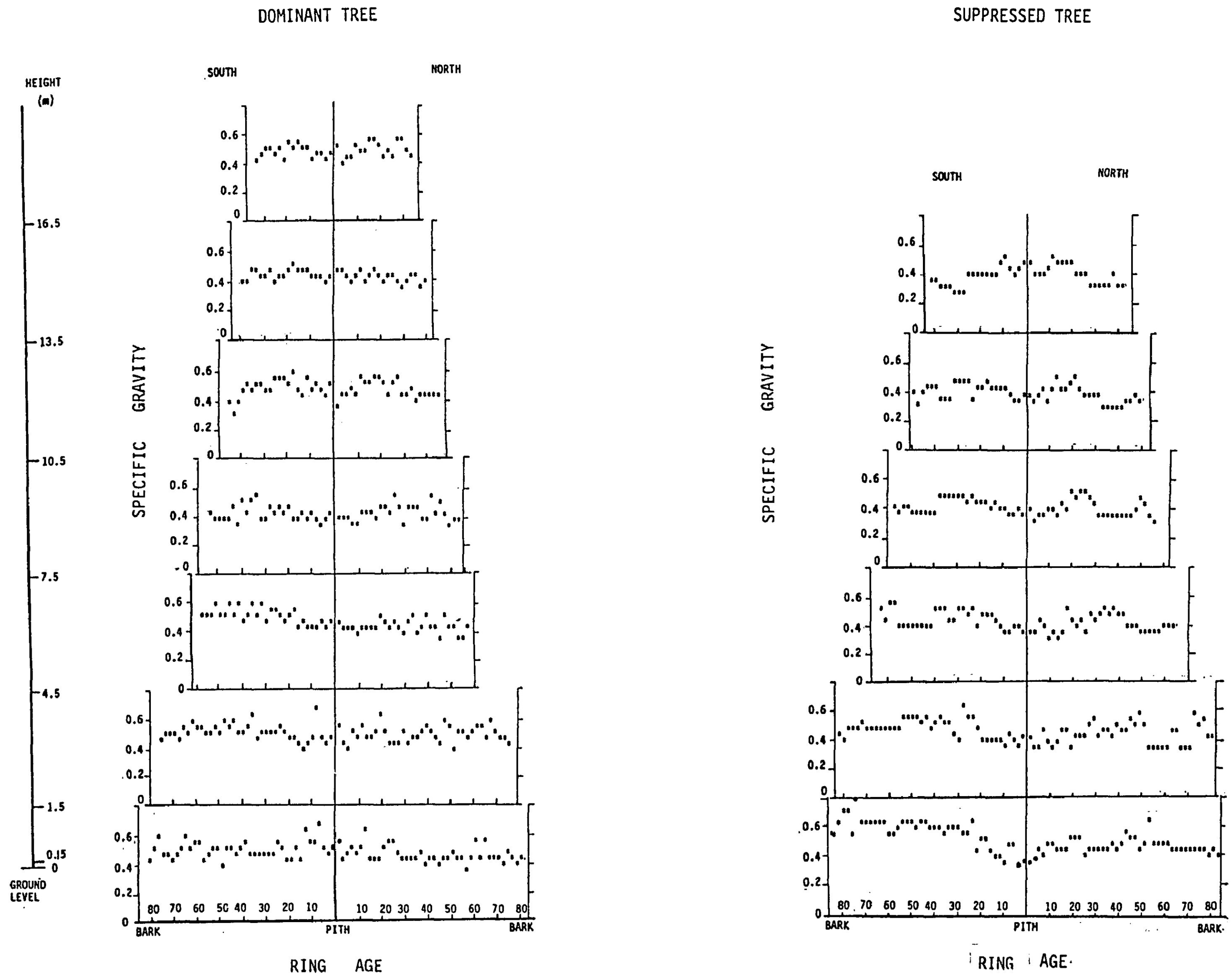

Figure 9. Variation of specific gravity with ring age at successive heights of the south and north aspects of the dominant and suppressed trees.

Table 5. Linear equations $\hat{Y}=A+BX$ expressing the variation of specific gravity with ring age in juvenile wood, mean specific gravity of mature wood for each of the heights for the south and north aspects in the dominant and suppressed trees.

Height	South			North		
(m)	A + BX	r	$\overline{Y}_M$	A + BX	r	$\overline{Y}_M$
			Dominant			
16.5		ns	0.50		ns	0.51
13.5	0.41+0.0056X	0.77*	0.45	0.48-0.0043X	0.54 (α=0.09)	0.42
10.5		ns	0.48	0.35+0.016X	0.83*	0.49
7.5	0.40+0.0022X	0.50*	0.45		ns	0.45
4.5	0.44+0.0031X	0.59*	0.55		ns	0.44
1.5	0.47+0.0018X	0.35 (α=0.06)	0.55		ns	0.51
0.15	0.54-0.0012X	0.31 (α=0.07)	0.51	0.52-0.0018X	0.51**	0.45
			Suppressed			
13.5		ns	0.36		ns	0.37
10.5	0.37+0.0058X	0.62 (α=0.09)	0.42	0.35+0.0099X	0.70*	0.39
7.5		ns	0.42	0.34+0.0050X	0.59 (α=0.06)	0.41
4.5	0.34+0.0058X	0.78**	0.47		ns	0.43
1.5	0.38+0.0043X	0.65**	0.50	0.38+0.0038X	0.61**	0.46
0.15	0.41+0.0059X	0.86**	0.63	0.43+0.0018X	0.39 (α=0.06)	0.47

A = the intercept, B = the slope; r = correlation coefficient of the regression;
* significant at $\alpha<0.05$, ** significant at $\alpha<0.01$,
ns not significant; $\overline{Y}_M$ = mean specific gravity of mature wood.

Axial Variation

In the suppressed tree, specific gravity of the mature wood decreased progressively from the base to the top. In contrast, specific gravity of the juvenile wood decreased first from the base up to the 7.5 m height and then increased to the top. In the dominant tree, however, specific gravity did not show the definite variation pattern as found in the suppressed tree. Figure 10 shows the axial variation of specific gravity with height for the two trees. In the dominant tree, the highest specific gravity occurred at the 1.5 m height and the lowest at the 7.5 height for both juvenile and mature wood (Figure 10). The means of the specific gravity of

Table 6. Multiple comparisons of the means of specific gravity at various heights for testing the axial variation in juvenile and mature wood of the dominant and suppressed trees.

Height (m)	Dominant									Suppressed									
	Mature				Juvenile					Mature						Juvenile			
	Mean	A	B	C	Mean	a	b	c	d	Mean	A	B	C	D	E	Mean	a	b	c
16.5	0.50		B	C	0.46	a	b	c	d										
13.5	0.44	A	.		0.45	a	b			0.37	A					0.46		b	c
10.5	0.48		B		0.48		b	c	d	0.41		B				0.41	a	b	
7.5	0.45	A			0.42	a				0.42		B				0.38	a		
4.5	0.50		B	C	0.46	a	b	c		0.45			C			0.40	a	b	
1.5	0.53			C	0.50				d	0.48				D		0.45		b	
0.15	0.48		B		0.49			c	d	0.54					E	0.49			c

Mean = mean specific gravity of height of the two aspects; subgroup A, B, ... (for mature wood) and subgroup a, b, ... (for juvenile wood) = denote subgroups significantly different from each other, the height means within the subgroups were not significantly different.

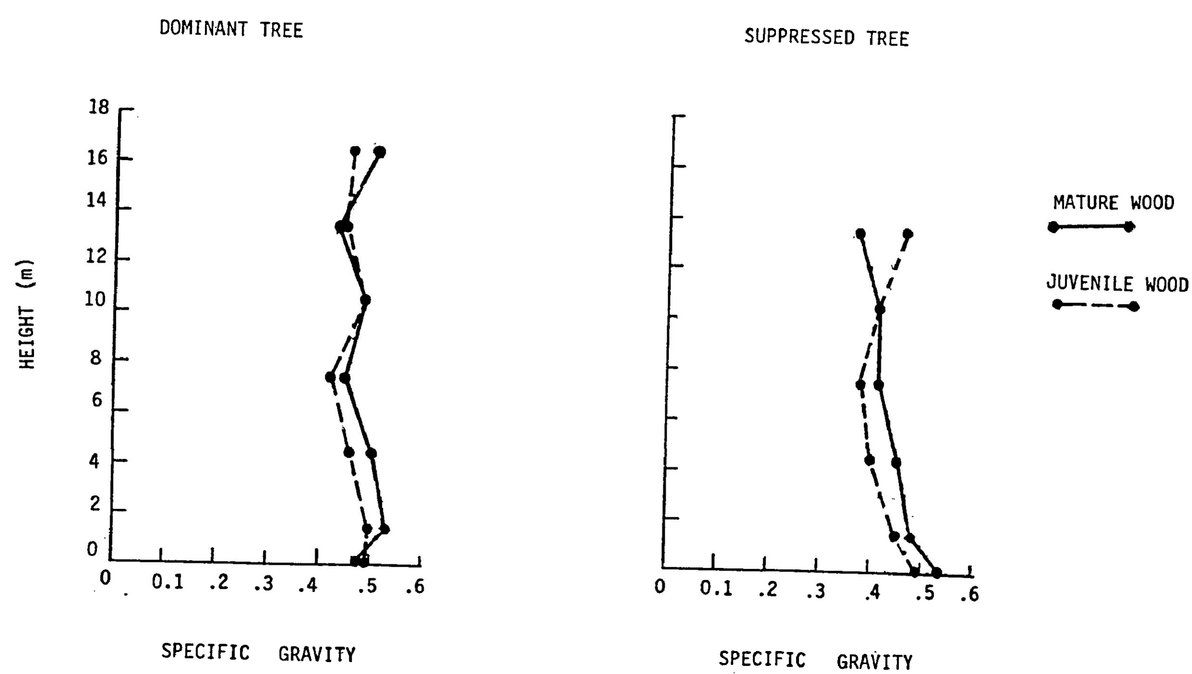

Figure 10. Variation of specific gravity with height in juvenile and mature wood of the dominant and suppressed trees.

mature wood at the 1.5, 4.5 and 16.5 m heights were in the subgroup of the highest value, and that of the 7.5 and 13.5 m heights were in the subgroup of the lowest value (Table 6). In the suppressed tree, specific gravity of mature wood decreased progressively from the base to the top, each mean was significantly smaller than the one below, except for the 7.5 m and 10.5 m heights. Specific gravity of the juvenile wood followed the same trend as that of the mature wood below the 7.5 m height, then it increased in the remaining height in juvenile wood. In the suppressed tree, the specific gravity of juvenile wood at the 13.5 m height was not significantly different from that at the stem base (0.15 m); the two values were in the subgroup of the highest means of juvenile wood of the suppressed tree (Table 6).

Difference Between Two Aspects

The mean specific gravity of the south aspect was significantly greater than that of the north aspect in both juvenile and mature wood and the dominant and suppressed trees (Table 7). In the mature wood, the mean specific gravity of the south aspect was 0.03 - 0.04, 6 - 9% greater than that of the north aspect for the two trees. In the juvenile wood, the mean specific gravity of the south aspect was 0.02 - 0.04, 4 - 10% greater than that of the north aspect for the two trees. This difference occurred mostly at the heights below 4.5 m in both juvenile and mature wood.

Difference Between Two Trees

The overall mean of specific gravity of the mature wood in the dominant tree was 0.03 higher than that of the suppressed tree (Table 7). Except at the stem base, the mean specific gravity in the dominant tree was greater than that of the suppressed tree for every height, in both juvenile and mature wood (Table 6).

Table 7. T tests on the differences in specific gravity between the south and north aspects within the dominant and suppressed trees, and between the two trees.

	Mature				Juvenile			
	n	Mean	s	t	n	Mean	s	t
				Dominant				
South	105	0.50	0.063	4.13**	90	0.49	0.057	2.37*
North	104	0.47	0.061		91	0.47	0.053	
				Suppressed				
South	116	0.47	0.097	3.71**	74	0.46	0.088	3.22**
North	121	0.43	0.072		68	0.42	0.056	
				Between Trees				
Dominant	209	0.48	0.064	4.98**	181	0.48	0.056	4.24**
Suppressed	287	0.45	0.088		142	0.44	0.077	

n = number of measurements; Mean = mean specific gravity; s = standard deviation; t = calculated t value for testing the difference between the two means; * significant at $\alpha<5\%$, ** significant at $\alpha<1\%$.

RING WIDTH

Radial Variation

Ring width generally decreased from the pith outward in the juvenile wood, and fluctuated or, leveled off in the mature wood (Figure 11). at the 4.5 m height and above, ring width followed the general pattern stated above, with width range from 2 to 4 mm near the pith. Below the 4.5 m height ring width was about 1 mm for the growth rings near the pith, and increased outward. Ring width reached the widest at ring 25, it then decreased outward, and followed by the leveling off. Both dominant and suppressed tree were suppressed for the first 20 to 25 years. This was especially obvious in the dominant tree. In the mature wood of

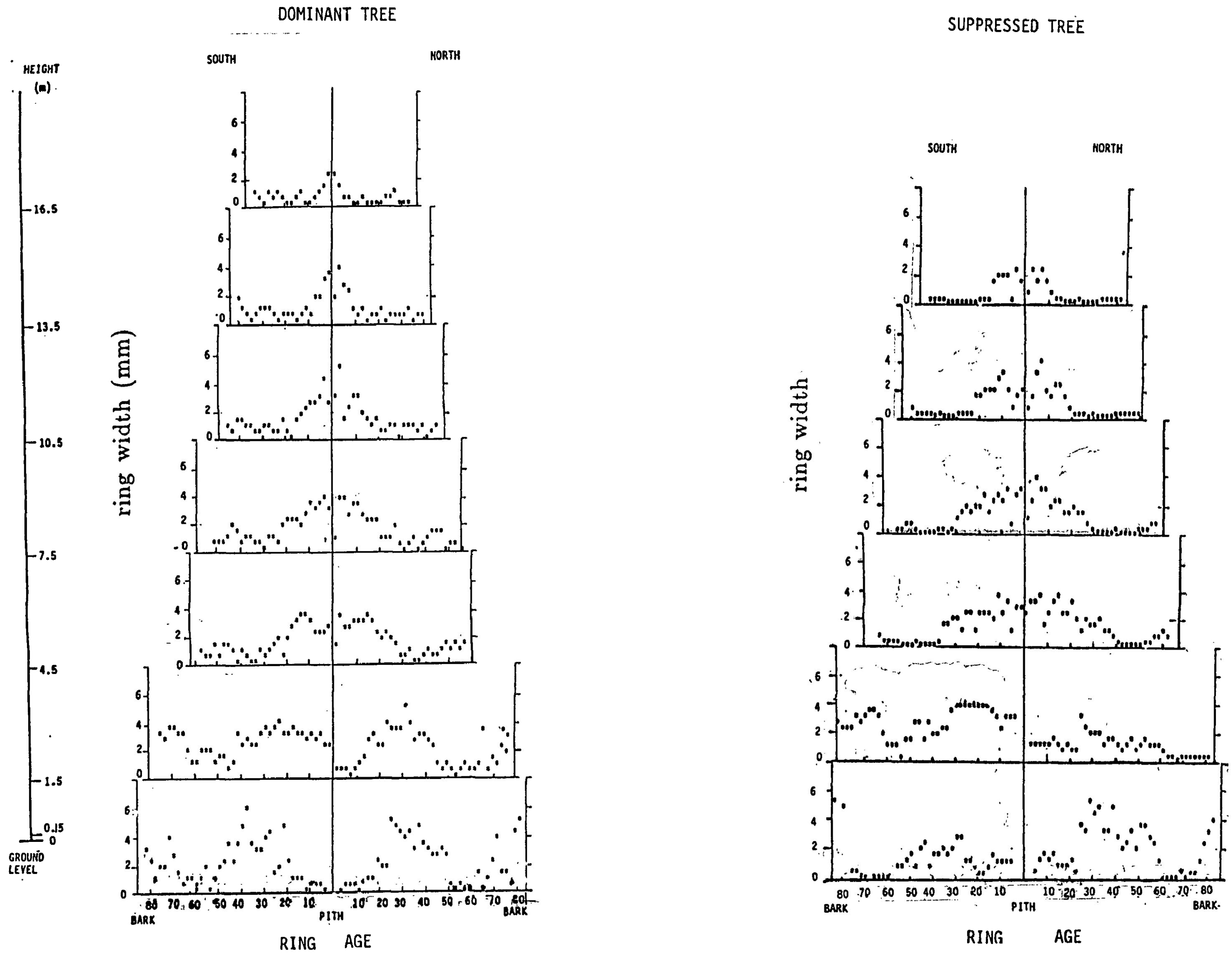

Figure 11. Variation of ring width with ring age at successive heights of the south and north aspects of the dominant and suppressed trees.

the suppressed tree, there was a narrow ring zone containing about 30 growth rings counted from the bark at all heights. The ring width in these zones were less than 1 mm (Figures 6 and 11). This was the wood formed in the later suppression in the suppressed tree. The mean ring width of the mature wood of this tree ranged from 0.25 mm (at the 13.5 m height) to 1.61 mm (at the 0.15 m height).

Table 8 lists linear equations expressing the variation of ring width with ring age. The slope of the equations for the 0.15 m and 1.5 m heights were positive, representing the increase

Table 8. Linear equations $\hat{Y}=A+BX$ expressing the variation of ring width with ring age in juvenile wood for each of the heights of the south and north aspects in the dominant and suppressed trees.

Height	South			North		
(m)	A + BX	r	Y_M (mm)	A + BX	r	Y_M (mm)
			Dominant			
16.5	2.57-0.25X	0.97**	0.79	2.16-0.18X	0.95**	0.57
13.5	3.57-0.24X	0.92**	0.86	3.41-0.20X	0.78*	0.79
10.5	3.99-0.16X	0.81**	1.13		ns	1.07
7.5		ns	0.99		ns	1.15
4.5		ns	0.96	3.15-0.031X	0.39 (α=0.08)	0.96
1.5	1.16+0.029X	0.41*	0.86	0.84+0.073X	0.73**	1.32
0.15	0.63+0.085X	0.75**	1.72	1.00+0.062X	0.60**	1.77
			Suppressed			
13.5		ns	0.25		ns	0.25
10.5		ns	0.64		ns	0.61
7.5		ns	0.86		ns	0.70
4.5		ns	0.65		ns	0.88
1.5	0.75+0.060X	0.59**	0.98	1.19+0.015X	0.33 (α=0.07)	0.74
0.15	0.86+0.030X	0.45*	1.61	0.93+0.067X	0.64**	1.57

A = the intercept, B = the slope, r = correlation coefficient of the regression;
* significant at $\alpha<0.05$, ** significant at $\alpha<0.01$,
ns not significant; Y_M = mean ring width of mature wood.

in ring width with ring age in the juvenile wood. The slopes of the heights of 4.5 m and above were negative, representing the decrease. The regressions for the equations of the 4.5 m height and above in the suppressed tree were not significant.

Axial Variation

Figure 12 shows the axial variation patterns of ring width in juvenile and mature wood of the dominant and suppressed trees. In both juvenile and for mature wood and the two trees, ring width decreased from the 0.15 m up to 1.5 m heights. Above the 1.5 m height ring width of the mature wood varied relatively little. Ring width of juvenile wood increased from the 1.5 m up to the 4.5 m height, and then decreased further up to the top. The relatively narrow ring width in the juvenile wood at the 1.5 m height was attributable to the early suppression of the tree growth in the first 20 years (Figure 6). The widest rings in the two tree stems located in the juvenile wood between 4.5 and 10.5 m heights in the dominant tree, and the 4.5 m and 7.5 m heights in the suppressed tree (Figure 12). In both trees, the mean ring width of mature wood at the 0.15 m height was significantly greater than that above (Table 9). This wide ring width corresponded to the butt swell at the stem base (the 0.15 m height in Figures 6 and 11). In the juvenile wood, there were two subgroups of the height means in each tree, height means at 13.5 m and 16.5 m were significantly greater than those below in the dominant tree, and height means at 4.5 m and 7.5 m were significantly greater than the others in the suppressed tree (Table 9).

Difference Between Two Aspects

In the dominant tree, the ring width was not found to be significantly different for the south and north aspects in both juvenile and mature wood (Table 10). In the suppressed tree, ring width was greater in the south than in the north aspect in the juvenile wood, while it was not significantly different between the two aspects in the mature wood.

Table 9. Multiple comparisons of the means of ring width (mm) at various heights for testing the axial variation in juvenile and mature wood of the dominant and suppressed trees.

Height (m)	Dominant						Suppressed						
	Mature			Juvenile			Mature				Juvenile		
	Mean	A	B	Mean	a	b	Mean	A	B	C	Mean	a	b
16.5	0.68	A		1.17	a								
13.5	0.83	A		1.87	a	b	0.25	A			1.69	a	b
10.5	1.09	A		2.76		b	0.63	A	B		2.11	a	b
7.5	1.08	A		2.79		b	0.78	A	B		2.53		b
4.5	0.96	A		2.67		b	0.77	A	B		2.56		b
1.5	1.09	A		2.13		b	0.87		B		1.53	a	
0.15	1.74		B	2.50		b	1.59			C	1.85	a	

Mean = mean ring width (mm) of height of two aspects; subgroup A, B, ... (for mature wood) and subgroup a, b, ... (for juvenile wood) = denote subgroups significantly different from each other, the height means within the subgroups were not significantly different.

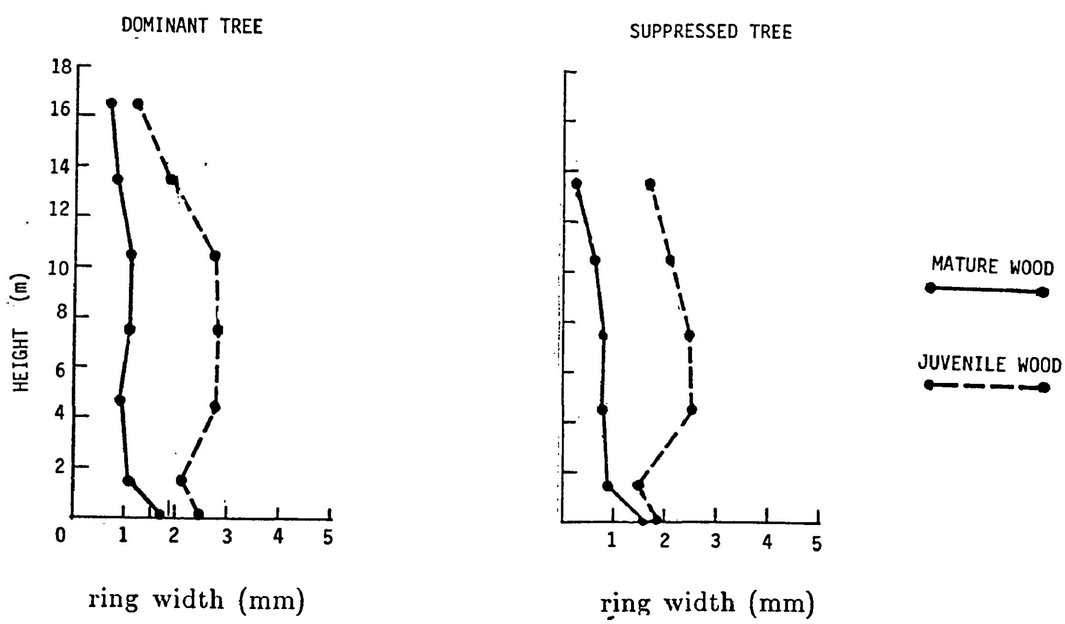

Figure 12. Variation of ring width with height in juvenile and mature wood of the dominant and suppressed trees.

Table 10. T tests on the differences in ring width between the south and north aspects within the dominant and suppressed trees, and between the two trees.

	Mature				Juvenile			
	n	Mean (mm)	s (mm)	t	n	Mean (mm)	s (mm)	t
				Dominant				
South	105	1.06	0.59	ns	90	2.27	1.19	ns
North	104	1.12	0.81		91	2.45	1.30	
				Suppressed				
South	121	0.91	1.15	ns	68	1.80	0.85	1.97*
South	116	0.80	0.86		74	2.12	1.10	
				Between Trees				
Dominant	209	1.09	0.71	2.90**	181	2.36	1.24	3.13**
Suppressed	237	0.85	1.02		142	1.97	1.00	

n = number of measurements; Mean = mean ring width; s = standard deviation; t = calculated t value; * significant at $\alpha<0.05$, ** significant at $\alpha<0.01$, ns not significant.

Difference Between Two Trees

The overall mean ring width of the dominant tree was greater than that of the suppressed tree for both juvenile and mature wood. The overall means of ring width were 1.09 and 0.85 mm for the mature wood, and 2.36 and 1.97 mm for the juvenile wood in the dominant and suppressed tree respectively. It was consistent for all the corresponding heights that the ring width of the dominant tree was greater than that of the suppressed tree for both juvenile and mature wood (Table 9).

LATEWOOD PERCENTAGE

Radial Variation

Latewood percentage generally increased from the pith outward in the juvenile wood, and fluctuated in the mature wood (Figure 13). Latewood percentage was as low as 10% near the pith, and increased to as as high as 50% further outward, such as in between ring age 40 - 60 at height 1.5 m, 10 - 20 at height 10.5 m and 13.5 m in the dominant tree, and ring age 20 - 40 at height 4.5 m in the suppressed tree.

Table 11 shows the linear equations expressing the radial variation of latewood percentage with ring age in the juvenile wood. The slopes of the equations were positive for all the heights and aspects in the two trees, except the 0.15 m height on the north aspect of the dominant tree. The slope of the equations at the greater heights tended to be steeper than those at the lower heights, as the pattern shown in the tracheid length. The greatest slopes appeared at the 10.5 m height in both trees. For several heights, the regressions were not significant.

At the 0.15 m height south of the suppressed tree, the latewood wood percentage measured up to 70%. This portion of wood showed compression wood features, with wide rings and high specific gravity (Figures 6, 9, 13).

Axial Variation

In both juvenile and mature wood, the latewood percentage decreased with increasing height in the suppressed tree, while it did not vary consistently in the dominant tree (Figure 14). Table 12 shows the results of the multiple comparison. In the dominant tree, there were two subgroups significantly different from each other in both juvenile and mature wood; the height means of latewood percentage in some middle heights were significantly lower than those below and above. In the suppressed tree, there were four subgroups in the mature wood

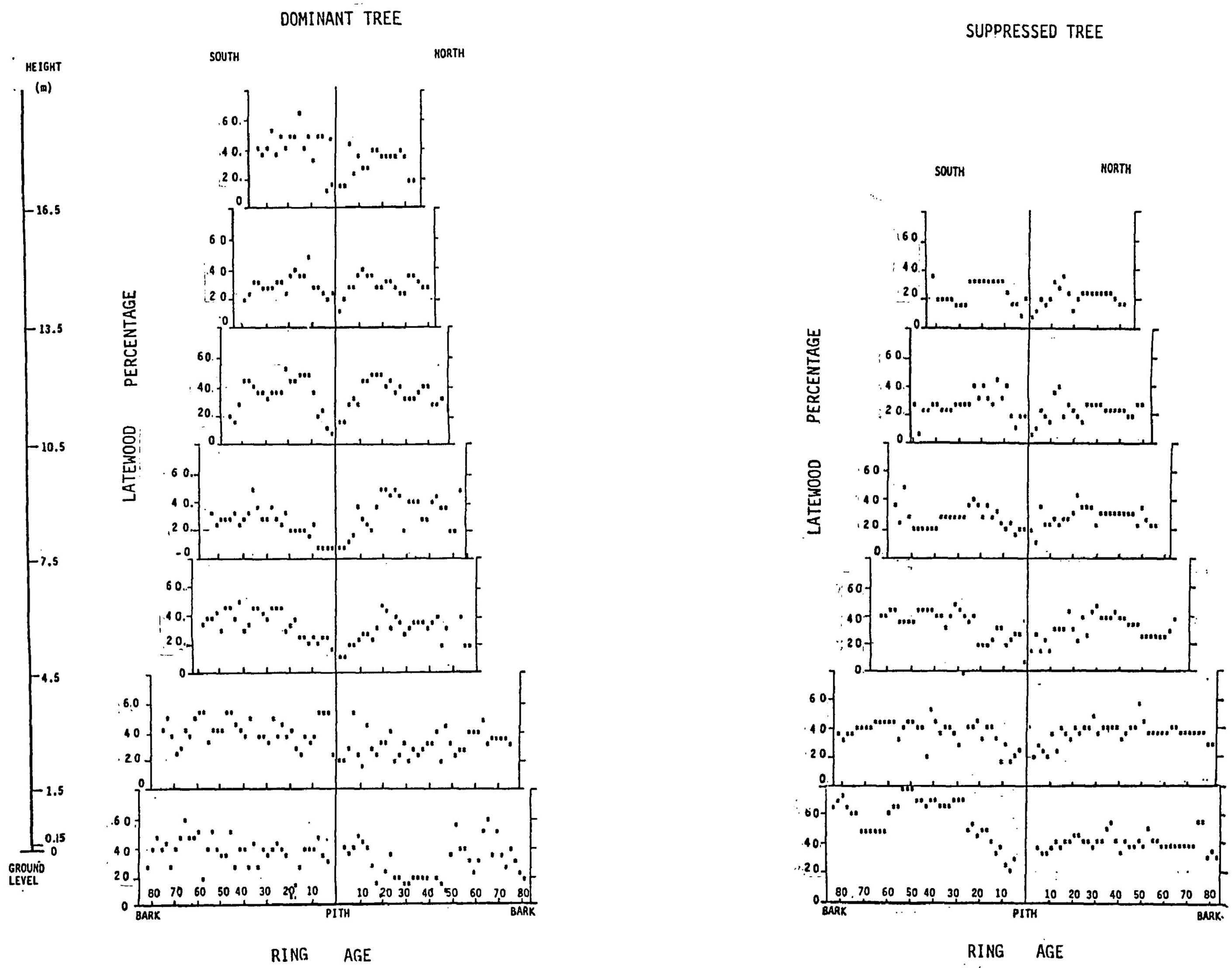

Figure 13. Variation of latewood percentage with ring age at successive heights of the south and north aspects of the dominant and suppressed trees.

Table 11. Linear equations $\hat{Y}=A+BX$ expressing the variation of latewood percentage with ring age in juvenile wood, mean latewood percentage of mature wood for each of the heights of the south and north aspects of the dominant and suppressed trees.

Height (m)	South A + BX	South r	South $\bar{Y}_M$ (%)	North A + BX	North r	North $\bar{Y}_M$ (%)
			Dominant			
16.5		ns	45.9		ns	33.7
13.5	18.0+1.78X	0.77*	30.7	16.1+1.70X	0.87**	29.7
10.5	7.10+2.77X	0.92**	36.0	12.4+2.62X	0.92**	38.4
7.5	8.39+0.80X	0.84**	30.8	8.21+1.48X	0.77**	38.0
4.5	15.6+0.89X	0.82**	39.0	13.5+1.11X	0.84**	33.8
1.5		ns	41.5		ns	35.1
0.15		ns	41.8	33.6-0.28X	0.34*	36.1
			Suppressed			
13.5		ns	26.0	8.18+1.61X	0.90**	22.2
10.5	13.7+1.67X	0.63 (α=0.09)	28.2	5.51+2.46X	0.88**	24.9
7.5	15.8+1.00X	0.73*	29.2		ns	31.4
4.5		ns	41.0	19.5+0.66X	0.60*	36.9
1.5	23.0+0.67X	0.63*	38.5	23.1+0.69X	0.78**	38.0
0.15	30.5+1.08X	0.90**	61.4	35.8+0.21X	0.52*	38.7

A = the intercept, B = the slope; r = correlation coefficient of the regression, * significant at $\alpha<0.05$, ** significant at $\alpha<0.01$, ns not significant; $\bar{Y}_M$ = mean latewood percentage of mature wood.

Table 12. Multiple comparisons of the means of latewood percentage at various heights for testing the axial variation in juvenile and mature wood of the dominant and suppressed trees.

Height (m)	Dominant						Suppressed								
	Mature			Juvenile			Mature					Juvenile			
	Mean	A	B	Mean	a	b	Mean	A	B	C	D	Mean	a	b	c
16.5	40.1		B	29.4		b									
13.5	30.2	A	B	30.0		b	24.2	A				18.6	a		
10.5	37.3	A		30.5		b	26.6	A				23.2	a		
7.5	34.8	A	B	19.5	a		30.3		B			23.8	a		
4.5	36.6		B	27.9		b	38.6			C		26.3	a		
1.5	38.4		b	34.0		b	38.2			C		34.4		b	
0.15	39.1		B	30.9		b	48.2				D	46.6			c

Mean = mean latewood percentage (%) of height of two aspects; subgroup A, B, ... (for mature wood) and subgroup a, b, ... (for juvenile wood) = denote subgroups significantly different from each other, the height means within the subgroups were not significantly different.

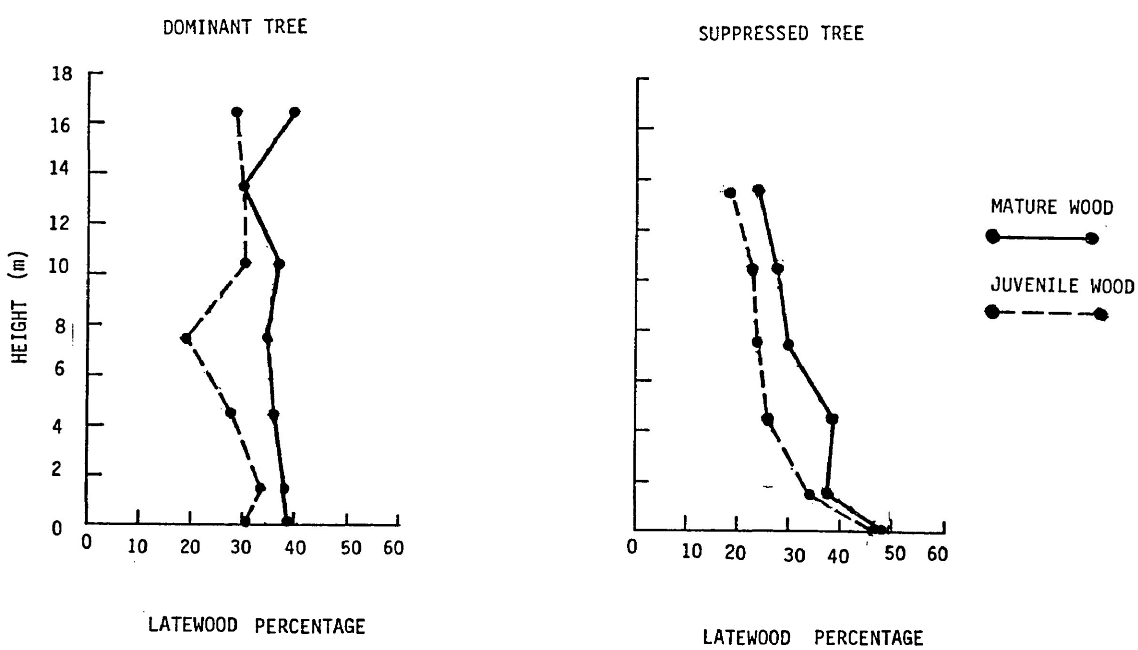

Figure 14. Variation of latewood percentage with height in juvenile and mature wood of the dominant and suppressed trees.

Table 13. T tests on the differences in latewood percentage between the south and north aspects within the dominant and suppressed trees, and between the two trees.

	Mature				Juvenile			
	n	Mean (%)	s (%)	t	n	Mean (%)	s (%)	t
				Dominant				
South	105	38.1	9.3	2.21*	90	31.8	12.1	2.48*
North	104	35.3	8.4		91	27.6	10.8	
				Suppressed				
South	116	37.3	13.5	3.01**	74	36.0	17.7	2.53*
North	121	32.9	8.00		68	29.9	9.8	
				Between Trees				
Dominant	209	36.7	9.00	1.67	181	29.7	11.7	2.25*
Suppressed	237	35.1	11.3	(α=0.10)	142	33.1	14.7	

n = number of measurements; Mean = mean tracheid length; s = standard deviation; t = calculated t value; * significant at $\alpha<0.05$, ** significant at $\alpha<0.01$;

and three in the juvenile wood, which showed a gradual decrease of latewood percentage from the base upward. Latewood percentage ranged from 40% to 50% at the stem base, and 30% to 40% at the heights above for the juvenile and mature wood of the two trees. Latewood percentages of juvenile wood were lower than that of mature wood at all height (Figure 14). Note that at the 13.5 m height in the juvenile wood of the suppressed tree, latewood percentage was low, but the specific gravity was high (Figure 10).

Difference Between Two Aspects

The mean latewood percentage for the south aspect was significantly greater than that of the north aspect (Table 13). The differences between the means of the south and north aspect in the juvenile wood were 4.2% (the dominant) and 6.1% (the suppressed), whereas the differences in the mature wood were 2.8% (the dominant) and 5.4% (the suppressed).

Difference Between Two Trees

In the mature wood, latewood percentages between the dominant and suppressed trees were not significantly different (Table 13). In the juvenile wood, however, latewood percentages were greater in the suppressed tree than in the dominant tree.

CORRELATIONS OF THE VARIABLES

Table 14 shows the correlations of ring age, ring width, latewood percentage, specific gravity, and tracheid length on the whole tree basis.

In the juvenile wood of both trees, tracheid length, specific gravity, ring width, and latewood percentage were positively correlated with ring age. The correlation coefficients were (in the order of strength) 0.65** for tracheid length, 0.35** for ring width, 0.22** for latewood percentage, and 0.17** for specific gravity in the dominant tree; 0.73** for latewood percentage, 0.69** for tracheid length, 0.68** for specific gravity, and 0.27** for ring width in the suppressed tree. In the mature wood, the four variables were not correlated with ring age, except for latewood percentage ($r=0.36^{**}$) and specific gravity ($r=0.25^{**}$) in the suppressed tree.

In the juvenile wood, tracheid length and ring width were positively correlated in the two trees. The correlations were weak, with $r = 0.19^{**}$ for the dominant tree, and $r = 0.16$ ($\alpha = 0.07$) for the suppressed tree. In the juvenile wood, tracheid length and latewood percentage were positively correlated in both trees. Tracheid length and specific gravity were positively correlated in the suppressed tree, but not in the dominant tree. In mature wood of both trees, tracheid length was not correlated with any other variables.

Table 14. Correlation coefficients (r) of ring age (AG), tracheid length (TL), specific gravity (SG), ring width (RW), latewood percentage (LP) in juvenile wood (top right of the diagonal), and mature wood (bottom left of the diagonal) of the dominant and suppressed trees.

Dominant Tree	Juvenile Wood (n=181 for all variables)				
	AG	RW	LP	SG	TL
AG		0.35**	0.22**	0.17*	0.65**
RW	ns		-0.38**	-0.27**	0.19**
LP	ns	ns		0.50**	0.32**
SG	ns	ns	0.63**		ns
TL	ns	ns	ns	ns	
	Mature Wood (n=209 for all variables)				

Suppressed Tree	Juvenile Wood (n=142 for all variables)				
	AG	RW	LP	SG	TL
AG		0.27**	0.73**	0.68**	0.69**
RW	ns		0.16*	0.16*	0.16 (α=0.07)
LP	0.36**	0.42**		0.76**	0.40**
SG	0.25**	0.37**	0.73**		0.38**
TL	ns	0.11 (α=0.08)	ns	0.12 (α=0.07)	
	Mature Wood (n=237 for all variables)				

* significant at $\alpha<0.05$, ** significant at $\alpha<0.01$; n = number of measurements.

In the juvenile wood, specific gravity and the ring width were negatively correlated with r=-0.27** for the dominant tree, and r=0.16* for the suppressed tree. In the mature wood, specific gravity and ring width were correlated in the suppressed tree (r=0.37**), but not in the dominant tree.

In both juvenile and mature wood, specific gravity and latewood percentage were positively correlated in both trees. The correlation values (r) ranged from 0.50 to 0.76. This indicates that 25 - 61% of the total variation of specific gravity can be attributed to the variation of latewood percentage.

In the juvenile wood, latewood percentage and ring width were negatively correlated in the dominant tree (r=-0.38**), and positively in the suppressed tree (r=0.16*). In the mature wood, latewood percentage and ring width were positively correlated in the suppressed tree (r=0.42**), but not in the dominant tree.

DISCUSSION

TRACHEID LENGTH

Radial Variation

The variation pattern of tracheid length observed in this study agrees with the first pattern generalized by Panshin and De Zeeuw (1980), that it increased progressively from the pith outward, and after a certain ring age, it remained basically constant with some fluctuation. This variation pattern has been reported by Liang (1948) in *Larix*, Anderson (1951) in *Abies*, Elliott (1960) and Dinwoodie (1963) in *Picea sitchensis*, and Megraw (1985) in *Pinus taeda*.

The variation pattern of the slope (the rate of increase in tracheid length of the juvenile wood) with height found in this study supports the observation of Megraw (1985). He reported that in *Pinus taeda* the rate of increase in tracheid length was slow at the stem base, The rate of increase became greater with increasing height, and stabalized further up. Similar results were found by Kribs (1928) in *Pinus banksiana*, Chalk (1930) and Elliott (1960) in *Picea sitchensis*, Wellwood (1960) in *Tsuga heterophylla*, and Taylor, et al. (1982) in *Picea glauca*.

While the radial variation patterns of other variables were inconsistent at different heights of the two trees, the radial variation patterns of tracheid length were relatively consistent at all heights of the two trees. For determining the juvenile and mature wood boundary in the tree stem, tracheid length is relatively suitable.

Latewood and Earlywood

This study indicated that latewood had longer tracheids than earlywood in both juvenile and mature wood. This finding agrees with that by Bisset and Dadswell (1950) in *Abies grandis, Larix laricina, Picea sitchensis, Pinus sulvestris, P. radiata,* and *Psedotsuga taxifolia,* Ahmad (1969) in *Picea smithiana,* and Megraw (1985) in *Pinus taeda.* In their studies, Megraw (1985) and Ahmad (1969) pointed out that the difference was more pronounced in juvenile wood than in mature wood. This was not observed in the two tamarack trees of this study.

Axial Variation

In both juvenile and mature wood of the two trees studied, tracheid length increased from the stem base upward, reached a maximum at a certain height, and then decreased up to the top. This variation pattern was similar to that reported by Kribs (1928) in *Pinus banksiana,* Ahmad (1969) in *Picea smithiana,* and France and Mexal (1980) in *Picea engelmanii* and *Pinus contorta.* It has been reported that the height effect on tracheid length reflects the effect of ring width distribution, the growth of the tree height (Bannan, 1967), and the cambial initial age (Yang, et al. 1986). In the two trees studied, the longest or the shortest tracheids occurred at the same heights in both juvenile and mature wood. Tracheids at the same heights were derived from the initials of the same cambium initial age (cambial initial age was defined as the number of years between the formation of the cambium initial and the seed germination (Yang, et al. 1986)). It is possible that the cambium initial age influences the tracheid length (probably ring width also) from the pith to bark at any given height. This topic deserves further study.

Variation with Aspect

The differences in tracheid lengths of the south and north aspects were relatively small. The difference was 0.09 mm in the suppressed tree, and not significant different in the dominant tree. A similar result has been reported in *Eucalytus regran* (Bisset and Dadswell, 1949), *Pinus radiata* (Nicholls and Dadswell, 1962), and *P. wallichiana* (Jain and Seth, 1979). The aspect effect, if any, may reflect the extent of the sun exposure, wind load on the tree stem, and eccentric growth in the crown and stem. For example, Liese and Dadswell (1959) considered that more sun exposure could cause more frequent anticlinal divisions of the fusiform initials in the cambium in the south aspect, which resulted in shorter tracheid length on average.

SPECIFIC GRAVITY

Radial and Axial Variations

In species which have relatively distinct latewood in the growth rings, specific gravity generally increases from pith outward, and decreases from the base to top (Elliott, 1970; Okkonen, et al. 1972). Wood of tamarack normally has distinct latewood. Its specific gravity would be expected to vary in the pattern mentioned above.

In the dominant tree studied, however, the variation pattern was not consistent with the general trend. At the lower two heights (0.15 and 1.5 m), specific gravity of the wood near the pith was as high as in the growth rings further outward. The dominant tree was suppressed in the first 20 years. The wood formed in that period had extremely narrow growth rings, and had relatively high latewood percentage. The growth conditions of the tree in that period hastened the formation of the dense latewood earlier in the season, which resulted in higher specific gravity. At the upper levels of of the stem of the dominant tree within the crown, specific gravity varied irregularly with increasing height. It is possible that the wood at those heights with abrupt increase in specific gravity was close to and under the influence of knots of the branches, where the wood was much denser (Paul, 1939; Larson, 1957).

In the suppressed tree, specific gravity basically followed the general trend as outlined by Elliott (1970). The exception is at the top levels in juvenile wood where, specific gravity was higher near the pith and decreased outward. This shows the feature of the earlywood variation pattern of specific gravity in *Pinus spp.* (Paul, 1939; Koch, 1972; Megraw, 1985), where specific gravity of earlywood was high near the pith, and decreased outward in that species. At the 13.5 m height, the proportion of earlywood was high (and latewood percentage was low), and the variation pattern at that level was closer to that of earlywood which, decreased from the pith outward. The above stated pattern explains the increase in specific gravity of juvenile wood from the 10.5 m to 13.5 m heights in the suppressed tree (Figure 10). From the 0.5 m to 13.5 m height, specific gravity increased whereas latewood percentage decreased. In other words, specific gravity and the proportion of earlywood both increased upward between the 10.5 m and 13.5 m height.

Variation with Aspect

In the two trees studied, specific gravity in the south aspect was higher than in the north at all heights except the upper levels. Ward and Gardiner (1976) reported that specific gravity was higher in the west than in the east throughout the stem in a single tree of *Picea sitchensis*. Taras (1965) reported that the difference in four aspects at a 90^0 angle was significant in most heights sampled in *Pinus palustris* and *P. elliottii.* However, many reports indicated that effect of aspect on specific gravity was not significant in *Larix kaempferi* (Hirai, 1949), *Pinus taeda* (Zobel and Rhodes, 1955), *Pinus elliottii* (Sellers, 1962), and *Picea rubens* (Perng, 1983). The effect of aspect on specific gravity could be results of differences in local growth conditions, rather than having a general tendency. For instance, a difference in long term wind effect, or unbalanced crown weight favouring one aspect of the tree, would induce the formation of wood with higher specific gravity in one aspect of the stem than others.

RING WIDTH

Apart from genetic influence, ring width depends on how fast and how long the wood is produced in the cambium in a growth season. The variation of ring width reflects more directly the change in the growth environment of the tree (or any other factors). In the two trees studied, ring width varied considerably with ring age, such as that before ring age 20 in both trees, and after ring age 50 in the suppressed tree.

Radial Variation

The radial variation pattern of ring width in the two trees basically agreed with that found by Taras (1965) in *Pinus elliottii*, and Perng (1983) in *Picea rubens*, as ring width decreased from the pith outward, and leveled off at certain ring age. The exception of this pattern was found at the lower two levels (0.15 and 1.5 m height) of both trees. The ring width was narrower near the pith and increased outward in the first 20 growth rings. At that time the trees were growing under suppression, and then gradually released from the suppression. The ring width varied considerably in that period, ranging from less than 1 mm up to 4 mm. This indicated that the ring width was more directly affected by the changing environment.

Axial Variation

The ring width in the trees studied increased from the top levels down, similar to the tendency described by Kozlowski (1971), and reached the maximum (in height average) between the 4.5 m and 10.5 m heights for both juvenile and mature wood. Denne (1979) reported that the maximum ring width occurred below the height where the leaf volume is maximum. Comparing ring width with tracheid length, the wide rings and long tracheids average occurred in the same portion of the stem (4.5 - 10.5 m height in the dominant tree, 4.5

- 7.5 m height in the suppressed tree). In other words, these portions of the tree stem produced wider rings and longer tracheids than other portions. Below the 1.5 m height, the ring width increased from the 1.5 m height height down, while tracheid length decreased. This has been discussed by Megraw (1985) relating to the effect of butt swell at the stem base.

LATEWOOD PERCENTAGE

One of the major factors which influence the variation of latewood percentage in the stem is considered to be the distance from the tree crown. Latewood percentage increases radially from the pith outward, and decreases axially from the base up to the top (Larson, 1957; Taras, 1965; Koch, 1972; Megraw, 1985). The variation of latewood percentage in the suppressed tree generally followed the pattern stated above. In the dominant tree, however, the variation patterns were not consistent with the expected pattern. Explanations would be similar to that for specific gravity.

Megraw (1985) reported that latewood percentage increased faster from the pith outward at the lower height levels than at the higher levels, opposite to the variation pattern of tracheid length. The results from this study did not support Megraw's finding. The radial variation patterns of latewood percentage at different heights were not consistent. This may either be because of the great variation in the formation of latewood in the trees studied, or the lack of accuracy in determination of the latewood percentage.

In both trees, the axial variation patterns of latewood percentage were similar to that of specific gravity except the upper two heights in the juvenile wood of both trees. At these levels, specific gravity of juvenile wood decreased upward, whereas latewood percentage increased. This has been explained in a previous section dealing with specific gravity.

Latewood percentage was higher in the south aspect than in the north.

RELATIONSHIPS BETWEEN/AMONG THE VARIABLES

Ring Age and the Four Variables

In the juvenile wood, tracheid length, specific gravity, ring width, and latewood percentage were positively correlated with ring age on the whole stem basis. This is one more evidence supporting the concept that the above wood property variables increase with ring age in the juvenile wood except for ring width. Ring width decreased with increasing ring age at heights above 1.5 m height, while it increased with ring age at the 1.5 m and 0.15 m heights. The correlations for the whole tree were influenced by the data of all the heights. The influence was stronger for data below the 4.5 m height .

In the mature wood, the four variables were not significantly correlated with ring age. This indicates that the four variables of wood property became stablized in the mature wood. As an exception, specific gravity and latewood percentage in the mature wood of the suppressed tree were correlated with ring age. However, the correlations were weak, accounting only for about 10% of total variation in the tree.

Tracheid Length and Ring Width

Many authors have reported that tracheid length is negatively correlated with ring width, especially in mature wood (Hale and Fensom, 1931; Trendelenburg, 1935; Elliott, 1960; Ahmad, 1970; Ward and Gardiner, 1976; Megraw, 1985). In this study, however, the correlation was not significant in the mature wood, where the ring width (height averages excluding that of the 0.15 m height) was 0.68 - 1.09 mm in the dominant tree, and 0.25 - 0.87 mm in the suppressed tree. Bannan (1967) emphasized that the negative relationship, as mostly observed, did not apply for the entire range of ring width. In *Pinus strobus,* it was operative only in the growth rings where ring width exceeded 1.5 mm. Tracheid length tended to reduce in growth rings narrower than 0.5 mm, and the negative correlation between them became weaker. This may explain why the correlation was not significant in the two trees studied.

In the juvenile wood, tracheid length and ring width were positively (but weakly) correlated for the whole stem. This result implies that both tracheid length and ring width varied with the same trend. However, this was true only below the 1.5 m height where both tracheid length and ring width increased from the pith outward in the juvenile wood. Above the 1.5 m height, tracheid length increased outward, whereas the ring width decreased. The correlation for the whole tree were jointly influenced by the data of all the heights. The influence of data below the 1.5 m height was stronger.

Tracheid Length and Latewood Percentage

In both juvenile and mature wood, tracheid length was positively correlated with latewood percentage in this study. One of the reasons is that tracheid length was calculated from the weighted average of tracheid length of latewood and earlywood, based on the latewood percentage. Latewood tracheids have been found to be consistently longer than those of earlywood (Table 2). Consequently the growth rings with greater latewood percentage were associated with longer tracheids, and the correlation between tracheid length and latewood percentage were positive.

Specific Gravity and Ring Width

Yao (1970) reported that specific gravity of mature wood was correlated with ring width that was wider than 3 mm, and it was not correlated with ring width that was narrower than 3 mm. In the dominant tree studied, specific gravity was negatively, but weakly correlated with ring width in the juvenile wood. The correlation was not significant in the mature wood. The weak correlation may be due to the effect of ring age on both ring width and specific gravity as suggested by Elliott (1970), which causes the indirect correlation between ring width and specific gravity. In the mature wood where there was less influence of ring age on specific gravity, the correlation was not significant. This subject has been discussed by Rendle and Phillips (1958), Elliott (1970), and Bendtsen (1978). In the suppressed tree, however, there was a different tendency. Specific gravity (also latewood percentage) was positively correlated with ring width in both juvenile and mature wood. Similar to the case of tracheid length, it implies that in the suppressed tree with narrow rings, higher specific gravity was associated with wider ring width. The above result supports Megraw's (1985) opinion. He considered that the correlation between specific gravity and ring width may be positive, negative, or nonexistent, depending on particular circumstances of the growth environment.

Specific Gravity and Latewood Percentage

For the whole tree, latewood percentage is positively correlated with specific gravity, accounting for about 25% to 60% of the total variation of specific gravity. Similar results have been found in *Pseudotsga menziessii* (Smith, 1956), and *Pinus elliottii* (Larson, 1957; Taras, 1965). This was expected because the latewood is denser than earlywood for it has thicker cell walls and smaller cell diameter.

DIFFERENCE BETWEEN THE TWO TREES

The ring width variation pattern in Figure 6 showed the growth rate of the two trees. In the first 20 years, both trees were growing under suppression. Then they were released from the suppression and grew relatively rapidly afterwards. The growth gradually slowed down in the 40th to 50th years. The growth rate of the dominant tree became relatively stabalized thereafter. The suppressed tree was suppressed by the dominant tree after the 50th year.

The difference in wood properties between the two trees, existed mainly in the growth rings in the last 30 growth rings formed, that is, in the mature wood. In that period in the suppressed tree, the growth in both diameter and height was slower than that of the dominant tree. The growth rings formed in that time were narrower than 0.5 mm which, was much narrower than the optimum width as outlined by Bannan (1967).

The average tracheid length in the suppressed tree was significantly shorter than in the dominant tree in the wood formed in the same years. Note that the t test on tracheid length between the two trees was significant in the mature wood, but not in the juvenile wood (Table 4). This indicated that the tracheid length did not become different between the two trees until later, when the mature wood was formed and one of the trees was suppressed.

Specific gravity and latewood percentage of the suppressed tree were also reduced in that period. It has been reported that the properties of wood formed under suppression are inferior to that formed under normal growth condition (Klem, 1968; Denne, 1979). The suppression in the tree growth may not only reduce the amount of latewood formed, but also reduce the specific gravity of the latewood (Megraw, 1985).

SUMMARY

Radial and axial variations of four variables of wood property in the juvenile and mature wood of a dominant and a suppressed tamarack tree stems were studied. The results are summarized as follows.

(1) At all heights sampled in the two trees, tracheid length increased radially from the pith outward and leveled off at a certain ring age towards the bark.

(2) The ring ages at which tracheid length started to level off were used as the boundary of the juvenile and mature wood. The ring age of the boundary decreased with increasing height.

(3) The rate of increase in tracheid length with ring age, became greater with increasing height.

(4) Average tracheid length increased from the stem base upward, and reached maximum at 4.5 m height, remained the same length up to about 10 m, then decreased for the remaining heights. This trend applied to both juvenile and mature wood.

(5) Tracheid length of latewood was consistently longer than that of earlywood in the same growth rings in both juvenile and mature wood.

(6) Tracheid length of the south aspect was not significantly different from that of the north aspect in both juvenile and mature wood of the two trees.

(7) In the juvenile wood, tracheid length of the dominant tree was not significantly different from that of the suppressed tree. In the mature wood, tracheid length of the dominant tree was significantly longer than that of the suppressed tree.

(8) Specific gravity generally decreased with height, and increased with ring age from pith outward in the juvenile wood, followed by a fluctuation in the mature wood. The variation pattern became inconsistent in extremely narrow growth rings.

(9) In both juvenile and mature wood, specific gravity varied axially without a definite pattern in the dominant tree, while it decreased upward in the suppressed tree.

(10) Specific gravity was significantly higher in the south aspect than in the north aspect in both juvenile and mature wood of the two trees.

(11) Specific gravity of both juvenile and mature wood was significantly higher in the dominant tree than in the suppressed tree.

(12) Ring width generally decreased from the pith outward in the juvenile wood, and became more stable in the mature wood. It was extremely narrow in the first 20 years of growth in both trees, and in the last 30 years in the suppressed tree.

(13) Ring width decreased with increasing height slightly in the mature wood. Ring width increased in the juvenile wood with height upward from the 1.5 m height and reached maximum at heights 4.5 m to 7.5 m, and then decreased to the top. The widest rings were located in the juvenile wood between height 4.5 m to 7.5 m.

(14) Ring width of the south aspect was not significantly different from that of the north aspect in both juvenile and mature wood in the dominant tree. In the suppressed tree, ring width was greater for the south aspect than the north aspect in the juvenile wood, it was not significantly different between the two aspects in the mature wood.

(15) Ring width of the dominant tree was greater than that of the suppressed tree in both juvenile and mature wood.

(16) Latewood percentage generally increased with ring age from pith outward in the juvenile wood, followed by a fluctuation in the mature wood. The variation pattern became inconsistent in extremely narrow growth rings.

(17) Latewood percentage varied axially without a definite pattern in the dominant tree, it decreased upward in the suppressed tree.

(18) Latewood percentage was significantly higher in the south aspect than in the north aspect in both juvenile and mature wood of the two trees.

(19) In the juvenile wood, latewood percentage of the suppressed tree was significantly higher than that of the dominant tree. For the mature wood, the difference was not significant.

(20) In the juvenile wood, ring age was positively correlated with tracheid length, specific gravity, ring width, and latewood percentage in both trees. In the mature wood, ring width was not correlated with any of the four variables except with specific gravity and latewood percentage in the suppressed tree.

(21) Tracheid length was positively correlated with ring width, and latewood percentage in the juvenile wood; it was not correlated with any of them in the mature wood.

(22) In the dominant tree, specific gravity was negatively correlated with ring width in the juvenile wood. In the suppressed tree, it was positively correlated with ring width in both juvenile and mature wood. Specific gravity was strongly correlated with latewood percentage.

(23) In the dominant tree, latewood percentage and ring width were negatively correlated in the juvenile wood, and were not significantly correlated in the mature wood. In the suppressed tree, the latewood percentage and ring width were positively correlated in both juvenile and mature wood.

LITERATURE CITED

Ahmad, S.S. 1969. Variation of tracheid dimension within a single stem of spruce. Pakistan J. For. 19(1): 113-128.

Ahmad, S.S. 1970. Variation in tracheid dimensions within a single stem of fir. Pakistan J. of For. 20(1): 89-109.

Anderson, E.A. 1951. Tracheid length variation in conifers as related to distance from the pith. J. For. 49(1): 38-42.

Bannan, M.W. 1966. Cell length and rate of anticlinal division in the cambium of the sequoias. Can. J. Bot. 44: 209-218.

Bannan, M.W. 1967. Anticlinal division and cell length in conifer cambium. For. Prod. J. 17(6): 63-69.

Bendtsen, B.A. 1978. Properties of wood from improved and intensively managed trees. For. Prod. J. 28(10): 61-72.

Bisset, I.J.W. and J.E. Dadswell. 1949. The variation of fiber length within one tree of *Eucalytus regrans*. Aust. For. 13(2): 86-96.

Bisset I.J.W. and H.E. Dadswell. 1950. The variation in cell length within one growth ring of certain angiosperms and gymnosperms. Aust. For. 14(1): 17-29.

Chalk, L. 1930. Tracheid length with special reference to Sitka spruce. Forestry 4: 7-14.

Clarke, F.R. and H.G. Murchison. 1987. Evaluation of Holman-digimicrometer. For. Chr. 63(2): 80-83.

Cown, D.J. 1975. Variation in tracheid dimensions in the stem of a 26-year-old Radiata pine tree. Appita 28(4): 237-245.

Denne, M.P. 1979. Wood structure and production within the trunk and branches of *Picea sitchensis* in relation to canopy formation. Can. J. For. Res. 9: 406-427.

Dinwoodie, J.M. 1961. Tracheid and fiber length in timber, a review of literature. Forestry 34(2): 125-155.

Dinwoodie, J.M. 1963. Variation in tracheid length in *Picea sitchensis* (Carr.). Special Rep. For. Prod. Res. Lond. No. 16. 55pp.

Einspahr, D.W., G.W. Wyckoff and M. Fiscus. 1984. Larch - A fast growing fiber source for the Lake States and Northeast. J. For. 82(2): 104-106.

Elliott, G.K. 1960. The distribution of tracheid length in a single stem of Sitka spruce. J. Inst. Wood Sci. 5: 38-47.

Elliott, G.K. 1970. Wood density in conifers. Commonwealth For. Bur. Oxford, Engl., Tech. Comm. No.8, 44pp.

France, R.C. and J. G. Mexal. 1980. Morphological variation of tracheid in bole wood of mature Picea engelmanii and Pinus contorta. Can. J. For. Res. 10(80): 573-578.

Franklin, G.L. 1945. Preparation thin sections of synthetic resins and wood-resin composites, and a new maceration method for wood. Nature 155: 51.

Greene, J.T. 1966. Selection for tracheid length in loblolly pine. Geogia For. Res. Coun. Rep. 18. GA, USA. 30pp.

Hale, J.B. and K.G. Fensom. 1931. The rate of growth and density of the wood of white spruce. Can. Dept. Interior, For. Serv. Circ. 30. 19pp.

Hansmann, A. and E.A.N. Sugden. 1983. The chemistry and kraft pulping of larch. In larch symposium - potential for the future. Sponsored by the Ont. Min. Nat. Res. and Fac. For. Univ. Toronto, Toronto, Ont. Nov. 9, 1982. pp. 115-136.

Haygreen, J.C. and J.L. Bowyer. 1982. Forest products and wood science: an introduction. The Iowa St. Univ. Press. Ames, Iowa, USA. 495pp.

Hirai, S. 1949. Studies on the variation in density of woods in the green stem of Japanese larch. Hokkaido Univ. Expt. For Res. Bull. 14: 124-154.

Holder, D.A. 1983. The potential of larch for the kraft and refiner mechanical pulping process. In Larch Sympodium - Potential for the future. Sponsored by the Ont. Min. Nat. Res. and Fac. For. Univ. Toronto, Toronto, Ont. Nov. 9, 1982. pp. 137-152

Isebrands, J.G., D.W. Einspahr, J.E. Phelps and J.B. Crist. 1982. Kraft pulp and paper properties of juvenile hybrid larch grown under intensive culture. Tappi 65(9): 122-126.

Jackson, L.W.R. 1959. Loblolly pine tracheid length in relation to position in tree. J. For. 57(5): 366-367.

Jain, K.K. and M.K. Seth. 1979. Intra-increment circumferential variation in tracheid length at breast height ads a basis for sampling in straight trees of blue pine. Silvae Genetica 28(2/3): 79-83.

Kandeel, E.S.A. 1971. Polynomial model to study and present within-tree variation of wood properties. Wood and Fiber. 3(2): 106-111.

Kikuchi, F. and Kayama. 1975. Kraft pulping of thinnings of larch. Bull. of Cov. For. Expt. Stat. Meguro 273: 95-100.

Klem, G.S. 1968. Quality of wood from fertilized forests. Tappi 5(1): 99A-103A.

Koch, P. 1972. Utilization of the southern pines. Vol. I---The raw material. Agr. Handbook No. 420, For. Serv. USDA. 1663pp.

Kozlowski, T.T. 1971. Growth and Development of Trees. Vol. II. Academic Press, NY, USA. p77.

Krahmer, R.L. 1966. Variation of specific gravity in western hemlock trees. Tappi 49(5): 227-229.

Kribs, D.A. 1928. Length of tracheid in jack pine in relation to their position in the vertical and tangential axes of the tree. Tech. Bull. 54, 14pp.

Larson, P.R. 1957. Effect of environment on the percentage of summerwood and specific gravity of slash pine. Bull. Yale Univ. Sch. For. No. 63, 80pp.

Larson, P.R. 1969. Wood formation and the concept of wood quality. Bull. Yale Univ. Sch. For. No. 74, 54pp.

Liang, S.C. 1948. Variation in tracheid length from the pith outwards in the wood of the genus *Larix* , with a note on variations in other anatomical features. Forestry 22(2): 222-237.

Liese, W. and H.E. Dadswell. 1959. Ueber den Einfluss der Himmelsrichtung auf die Lange von Holzfasern und Tracheiden. Holz alz Roh. und Werkstoff 17: 421-427.

Megraw, R.A. 1985. Wood quality factors in loblolly pine. The influence of tree age, position in tree, and cultural practice on wood specific gravity, fiber length, and fibril angle. Tappi Press, Atlanta, GA, USA. 88pp.

Nicholls, J.W.P. and H.E. Dadswell. 1962. Tracheid length in *Pinus radiata* D. Don. Div. For. Prod. Tech. Paper No. 24. C.W. Sci. and Ind. Res. Org., Aust. 19pp.

Norusis, M.J. 1982. SPSS introductory guide: basic statistics and operations. McGraw-Hill Book Co. NY, USA. 173pp.

Okkonen, E.A., H.E. Wahlgren and R.R. Maeglin. 1972. Relationship of specific gravity to tree height in commercially important species. For. Prod. J. 22(7): 37-41.

Panshin, A.J. and C. de Zeeuw. 1980. Textbook of wood technology. 4rd ed. McGraw-Hill Book Co. NY, USA. 722pp.

Paul, B.H. 1939. Variation in specific gravity of the springwood and summerwood of four species of southern pines. J. For. 37: 478-482.

Pearson, R.C. and B.E. Ross. 1984. Growth rate and bending property of selected loblolly pines. Wood and Fiber Sci. 16(1): 37-47.

Perng, W.R. 1983. Variation of specific gravity, ring width, and porosity within a red spruce tree. Quart. J. Chinese For. 16(1): 61-68.

Rendle, B.J. and E.W.J. Phillips. 1958. The effect of rate of growth on the density of softwood. Forestry 31(2): 113-120.

Rendle, B.J. 1960. Juvenile wood and adult wood. J. Inst. Wood Sci. 5: 58-61.

Roe, E.I. 1957. Silvical characteristics of tamarack. USDA For. Serv., Lake St. For. Expt. Stn. Stn. Pap. No. 52, 22pp.

Schultze-Dewitz, G. 1958. Influence of position in the stand on the annual ring structure and on the wood elements in Scotch pine, Mugo pine, and larch. Holz-Aentr 84: 849-851.

Schultze-Dewitz, G. 1965. Variation und Haufigkeit der Faserlange der Kiefer. Holz alz Roh. und Werkstoff 23: 81-86.

Sellers, J.T. 1962. Factors influencing the wood quality of plantation grown slash pine. For. Prod. J. 12(9): 443-446.

Seth, M.K. 1981. Variation in tracheid length in blue pine (*Pinus wallichiana* A.B. Jackson). Part 2. Radial pattern of variation in tracheid in the first formed earlywood from the pith to bark. Wood Sci. Technol. 15(4): 275-286.

Singh, T. 1984. Variation in the ovendry wood density of ten prairie tree species. For. Chr. August, p217-221.

Smith, D.M. 1954. Maximum moisture content method for determining specific gravity of small wood samples. USDA For. Serv. For. Prod. Lab. Rep. 2014, 8pp.

Smith, D.M. 1956. Effect of growth zone on specific gravity and percentage of summerwood in wide-ringed Douglas-fir. USDA For. Serv., For. Prod. Lab., Rep. No. 2057.

Spurr, S.H. and W.Y. Hsiung. 1954. Growth rate and specific gravity in conifers. J. For. 52(3): 191-200.

Spurr, S.H. and M.J. Hyvarinen. 1954. Wood fiber length as related to position in tree and growth. Bot. Rev. 20(9): 561-575.

Steel, R.G.D. and J.H. Torrie. 1980. Principles and procedures of statistics. 2nd ed. McGraw-Hill Book Company, NY, USA. 633pp

Taras and Wahlgren 1963. A comparison of increment core sampling methods for estimating tree specific gravity. U.S. For. Ser. Res. Pap. SE-7. Stheast. For. Exp. Stn. Ashevelle, NC, USA. 16pp.

Taras, M.A. 1965. Some wood properties of slash pine and their relationship to age and height within the stem. Ph.D. thesis, N.C. Sta. Univ. Sch. For. Raleigh, NC, USA.

Taylor, F.W. 1975. Fiber length measurement---an accurate, inexpensive technique. Tappi 58(12): 125-127.

Taylor, F.W. and Moore, J.S. 1981. A comparison of earlywood and latewood tracheid length of loblolly pine. Wood and Fiber 13(3): 159-161.

Taylor, F.W. 1982. Growth ring characteristics, specific gravity, and tracheid length of rapidly grown loblolly pine. Wood and Fiber 14(13): 204-210.

Taylor, F.W., E.I.C. Wang, A. Yanchuk and M.M. Micko. 1982. Specific gravity and tracheid length variation of white spruce in Alberta. Can J. For. Res. 12(3): 561-566.

Trendelenburg, R. 1935. Variation in the density of important coniferous timbers, due to locality, habitant differences in individual trees. Z. Ver. deut. Ingr. 79: 85-89.

Tsoumis, G. and N. Panagiotidis. 1980. Effect of growth conditions on wood quality characteristics of black pine. Dep. For. Aristotelian Univ., Thessaloniki, Greece. Wood Sci. and Technol. 14(4): 301-310.

Voorhies, C. and D.A. Jameson. 1969. Tracheid length in young-growth ponderosa pine. For. Prod. J. 19(5): 52-55.

Ward, D. and J.J. Gardiner. 1976. The influence of spacing on tracheid length and density in Sitka spruce. Irish For. 33(1): 39-56.

Wellwood, R.W. 1960. Specific gravity and tracheid length variations in second-growth western hemlock. J. For. 58(5): 361-368.

Yang, K.C., C.A. Benson, J.K. Wong. 1986. Distribution of juvenile wood in two stems of *Larix laricina* [(Du Roi) K. Koch]. Can. J. For. Res. 16: 1041-1049.

Yao, J. 1970. Influence of growth rate on specific gravity and other selected properties of loblolly pine. Wood Sci. Tech. 4(3):163-173.

Zobel, B.J. and R.R. Rhodes. 1955. Relationship of wood specific gravity in loblolly pine to growth and environmental factors. Texas For. Serv. Rep. II. 32pp.

APPENDICES

APPENDIX I

FIELD DATA OF THE SAMPLED STAND

Date	May 15, 1984
Location	Longitude $89^0 22'$ Latitude $48^0 39'$
Elevation	536 m (Above Sea Level)
Stand	Jack Haggerty Forest, Lakehead University Stand No. 4
Age	1983 - 1890 = 93 Years
Species Composition	Black spruce 40% White Birch 30% Balsam fir 20% Other 10%
Height	(Average) 16 m
Stocking	0.7
Site Index	11

APPENDIX II

DETERMINATION OF NUMBER OF TRACHEIDS TO BE MEASURED FOR ESTIMATING THE AVERAGE TRACHEID LENGTH IN THE LATEWOOD AND EARLYWOOD OF A GROWTH RING

Ring Age	Mean Length ($\bar{X}$)		CV (100 s/$\bar{X}$) (%)	Calculated (n)
		Latewood		
5	1.28	0.207	16.2	13
13	2.43	0.392	16.1	13
68	3.38	0.463	13.7	10
		Earlywood		
5	1.02	0.183	17.9	15
20	2.07	0.249	12.0	8
68	3.16	0.598	18.9	17

The formula for the calculation of the sample size n (Steel and Torrie, 1980):

$$n = \left(\frac{t_{0.05,n'} \, s}{10\% \bar{X}} \right)^2$$

Where, n = number of tracheids to be measured for estimating the average tracheid length in the latewood and earlywood of a growth ring; $t_{0.05,n'}$ = tabulated student t value at 0.05 significant level (two-tailed) and degree of freedom n'; s and $\bar{X}$ = standard deviation and mean of the samples respectively, and $10\%\bar{X}$ = selected confidence interval at 10% of the sample mean.

APPENDIX III

DATA SUMMARIES OF THE FOUR VARIABLES WITH RESPECT TO JUVENILE AND MATURE WOOD, HEIGHT, ASPECT, AND TREE.

A. Average tracheid length (mm) of the successive heights in the juvenile (J) and mature (M) wood of the south (Sth) and north (Nth) aspect of the dominant and suppressed trees.

Height	South		North		(Sth+Nth)/2		Sth-Nth		Overall
(m)	M	J	M	J	M	J	M	J	Mean
					Dominant				
16.5	2.38	1.67	2.43	1.56	2.40	1.61	-0.05	0.11	2.15
13.5	3.94	1.93	2.90	1.82	2.92	1.87	0.04	0.11	2.52
10.5	3.47	2.32	3.36	2.23	3.41	2.28	0.11	0.09	3.05
7.5	3.62	2.31	3.33	2.12	3.46	2.23	0.09	0.09	2.98
4.5	3.66	2.38	3.58	2.49	3.63	2.44	0.08	-0.11	3.09
1.5	3.14	2.15	3.28	2.22	3.21	2.19	-0.14	-0.07	2.63
0.15	2.76	1.91	2.84	1.98	2.80	1.95	-0.08	-0.07	2.28
Mean	3.16	2.11	3.15	2.10	3.16	2.11	0.01	0.01	2.67
					Suppressed				
13.5	2.49	1.68	2.60	1.67	2.54	1.67	-0.11	0.01	2.29
10.5	2.94	2.02	2.93	1.78	2.93	1.89	0.01	0.24	2.66
7.5	2.94	2.19	3.14	2.13	3.03	2.16	-0.20	-0.06	2.80
4.5	3.17	2.27	3.26	2.12	3.21	2.19	-0.09	-0.15	2.83
1.5	3.21	2.25	3.16	2.17	3.18	2.21	0.05	-0.08	2.74
0.15	2.61	2.01	2.82	2.31	2.74	2.13	-0.21	-0.30	2.44
Mean	2.91	2.11	3.00	2.10	2.96	2.11	0.04	0.01	2.64

B. Average specific gravity of the successive heights in the juvenile (J) and mature (M) wood of the south (Sth) and north (Nth) aspect of the dominant and suppressed trees.

Height	South		North		(Sth+Nth)/2		Sth-Nth		Overall
(m)	M	J	M	J	M	J	M	J	Mean
					Dominant				
16.5	0.504	0.463	0.505	0.465	0.504	0.464	-0.001	-0.002	0.491
13.5	.452	.445	.418	.446	.436	.445	.034	- .001	.440
10.5	.484	.508	.485	.449	.484	.840	- .001	.059	.484
7.5	.447	.427	.450	.406	.449	.418	- .003	.013	.437
4.5	.547	.428	.444	.452	.499	.464	.103	- .024	.483
1.5	.547	.505	.512	.499	.530	.502	.035	.006	.514
0.15	.506	.511	.446	.479	.478	.495	.060	.032	.488
Mean	.501	.486	.466	.467	.484	.476	.035	.019	.480
					Suppressed				
13.5	.360	.463	.373	.453	.366	.457	- .013	.010	.392
10.5	.423	.404	.392	.416	.408	.410	.031	- .028	.409
7.5	.422	.386	.407	.379	.415	.382	.015	.007	.406
4.5	.467	.408	.428	.392	.449	.400	.039	.006	.483
1.5	.504	.463	.460	.434	.480	.450	.036	.029	.466
0.15	.634	.525	.465	.448	.536	.493	.169	.077	.515
Mean	.469	.463	.427	.423	.448	.444	.042	.040	.446

C. Average ring width (mm) of the successive heights in the juvenile (J) and mature (M) wood of the south (Sth) and north (Nth) aspect of the dominant and suppressed trees.

Height	South		North		(Sth+Nth)/2		Sth-Nth		Overall
(m)	M	J	M	J	M	J	M	J	Mean
					Dominant				
16.5	0.57	1.06	0.79	1.31	0.68	1.17	-0.22	-0.27	0.84
13.5	0.79	1.83	0.86	1.93	0.83	1.88	-0.07	-0.10	1.22
10.5	1.07	3.08	1.13	2.55	1.0o	2.76	-0.06	0.53	1.64
7.5	1.15	2.93	0.99	2.69	1.08	2.80	0.16	0.26	1.75
4.5	0.96	2.72	0.96	2.62	0.96	2.67	0.00	0.10	1.73
1.5	1.32	2.46	0.86	1.78	1.09	2.13	0.48	0.68	1.67
0.15	1.77	2.49	1.72	2.51	1.74	2.50	0.05	-0.02	2.20
Mean	1.12	2.45	1.06	2.27	1.09	2.36	0.06	0.18	1.68
					Suppressed				
13.5	0.25	1.66	0.25	1.72	0.25	1.69	-0.00	-0.06	0.66
10.5	0.64	2.02	0.61	2.22	0.63	2.11	-0.03	-0.20	1.01
7.5	0.86	2.40	0.70	2.67	0.78	2.53	-0.16	-0.27	1.24
4.5	0.65	2.36	0.88	2.80	0.77	2.56	-0.23	-0.44	1.44
1.5	0.98	1.59	0.74	1.49	0.87	1.53	0.24	0.10	1.17
0.15	1.61	1.26	1.57	2.28	1.59	1.85	0.04	0.02	1.72
Mean	0.91	1.80	0.79	2.12	0.85	1.97	0.12	-0.32	1.27

D. Average latewood percentage (%) of the successive heights in the juvenile (J) and mature (M) wood of the south (Sth) and north (Nth) aspect of the dominant and suppressed trees.

Height	South		North		(Sth+Nth)/2		Sth-Nth		Overall
(m)	M	J	M	J	M	J	M	J	Mean
					Dominant				
16.5	45.9	31.7	33.7	27.5	40.1	29.4	12.2	4.2	36.6
13.5	30.7	30.4	29.7	29.6	30.2	30.0	1.0	0.8	30.1
10.5	36.0	32.0	38.4	28.1	37.3	30.5	-2.4	3.9	35.1
7.5	30.8	18.0	38.0	21.5	34.8	19.5	-7.2	-2.5	28.8
4.5	39.0	26.4	38.0	29.1	36.6	27.9	1.0	-2.7	32.7
1.5	41.5	39.2	35.1	29.1	38.4	34.0	6.4	10.1	35.9
0.15	41.8	35.4	36.1	26.8	39.1	30.9	5.7	8.6	34.1
Mean	38.1	31.8	35.3	27.6	36.7	29.7	2.8	4.2	33.5
					Suppressed				
13.5	26.0	17.5	22.2	19.4	24.2	18.6	3.8	-1.9	22.6
10.5	28.2	23.7	24.9	22.7	26.6	23.2	3.3	1.0	25.7
7.5	29.2	22.8	31.4	24.7	30.3	23.8	-2.2	-1.9	28.6
4.5	41.0	24.2	35.9	28.0	38.6	26.3	5.9	-3.8	34.0
1.5	38.5	35.6	38.0	32.8	38.2	34.4	0.5	2.8	36.5
0.15	61.4	52.4	38.7	38.5	48.2	46.6	22.7	13.9	47.4
Mean	37.3	36.0	32.9	29.9	35.1	33.1	4.4	6.1	34.3