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GENETIC VARIATION OF WOOD PROPERTIES IN TAMARACK *(Larix laricina* (Du Roi) K. Koch)

by

Yusheng Dong ©

A Graduate Thesis
Submitted in Partial Fulfillment of the Requirements
for the Degree of Master of Science in Forestry

Faculty of Forestry
Lakehead University
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ABSTRACT

Dong, Y. 1996. Genetic variation of wood properties in tamarack (*Larix laricina*). 93pp. Advisor: Dr. R. E. Farmer.

Key Words: *Larix laricina*, Broad-sense heritability, genetic correlation, genetic variation, height growth, latewood percentage, ring width, wood specific gravity, tracheid length.

Genetic variation of tracheid length, specific gravity, latewood percentage, height growth, and ring width among and within four provenances of tamarack (*Larix laricina* (Du Roi) K. Koch) was investigated in a ten-year-old provenance test that was planted in Thunder Bay, Ontario. Significant genetic variation of tracheid length, height growth, and ring width was found among provenances and among clones within provenances. A south-north trend of decreasing provenance means with increasing latitude was found for tracheid length, height growth, and ring width. Fast-growing provenances generally had longer tracheids than slow-growing provenances. Variation of specific gravity and latewood percentage was not significant among provenances or among clones within provenances. Variance components and broad-sense heritabilities of wood properties due to clones within provenances were larger than those due to provenances. However, variance components and broad-sense heritabilities of growth characteristics due to clones within provenances were smaller than those due to provenances. Positive genetic correlations ($r=0.03$ to 0.88) between wood properties and growth characteristics were detected, and the possibility of improvement of both wood properties and wood volume in tamarack was discussed.

TABLE OF CONTENTS

Page

LIST OF TABLES

Page

LIST OF FIGURES

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Y. Dong

INTRODUCTION

Tamarack (*Larix laricina (Du Roi) K. Koch*) is one of the few native North American conifers that have a transcontinental distribution. Its main range extends from the Atlantic coast of Maine, Nova Scotia and Newfoundland through the Lake States and central Canada to the Mackenzie River drainage (Johnston 1990). Northwest Ontario is in the center of tamarack's natural range. Tamarack grows under a wide variety of environmental conditions and exhibits rapid juvenile growth on well-drained sites (Fowells 1965).

The most common commercial use of tamarack in the United States and Canada is for making pulp products (Johnston 1990), and many study results have shown that tamarack wood chips not only can be pulped successfully, but its paper making characteristics are comparable or even superior to that of *Picea mariana* (Isebrands *et al.* 1982; Einspahr *et al.* 1983; Hansmann and Sugden 1983; Holder 1983). Also, tamarack timbers can be used as lumber, railway ties and mine timbers and other wood products (MacGillivray 1969; Johnston 1990).

Studies on tamarack in Canada and the United States have revealed a variety of patterns in phenotypic and genetic variation in height growth, radial growth, leaf, cone and seed morphology, syllepsis, rooting, allozyme and spatial genetic structure (Farmer and Reinholt 1986; Farmer *et al.* 1986; Park and Fowler 1987; Dickinson *et al.* 1988; Parker and Dickinson 1990; Peggy *et al.* 1991; Liu and Knowles. 1991; Ying and Morgenstern 1991; Farmer *et al.* 1992; Farmer *et al.* 1993). Field tests in the Lake States and northwest Ontario have shown that provenances from the south have better height and radial growth rate than northern provenances (Rehfeldt 1970; Riemenschneider and Jeffers 1980; Farmer *et al.* 1993). However, wood quality characteristics (e.g., specific gravity, tracheid length) generally are not included in the objectives of the many tree improvement programs, and few studies have been done of genetic variation in wood properties of tamarack.

Although the primary goal of most tree breeding programs is to obtain faster-growing, better-formed, well-adapted, and pest-resistant trees, wood properties may also be improved from the same tree improvement programs (Zobel and van Buijtenen 1989). Research on conifers has shown that selection can improve not only growth characteristics, but can also wood quality characteristics. Wood properties affect the quality and yield of wood products, and are inherited strongly enough to obtain rapid, economically important gains through genetic manipulation (Artuz-Siegel *et al.* 1968; Higgins *et al.* 1973; Barker 1974; Zobel *et al.* 1983; Megraw 1985). Generally, the wood quality characteristics in forest trees are more highly inherited and less influenced by the environment than growth characteristics (Zobel and Talbert 1984). Therefore genetic variation of wood properties should be considered in tree improvement programs.

In this study, I investigated genetic variation in growth and wood property characteristics of juvenile tamarack (10 years) using 32 clones from four provenances in northwest Ontario. The objectives of this study were to explore phenotypic and genetic variation in specific gravity, tracheid length, height growth rate, radial growth rate and latewood percentage, among provenances and clones within provenances. Heritability of each trait was estimated as a guide to the breeding value. Phenotypic and genetic correlations among specific gravity, tracheid length, latewood percentage and growth rate were also evaluated.

LITERATURE REVIEW

WOOD PROPERTY VARIATION

Wood is the most important forest product. Wood properties, the cause of wood property variation, and how best to modify wood properties for desired products must be understood by the tree breeder. There are many wood properties, but generally specific gravity and tracheid length are two of the most important characteristics. Paper properties are in some degree dependent on specific gravity and tracheid length (Zobel and van Buijtenen 1989; Panshin and de Zeeuw 1980). Many other wood property characteristics, such as wall thickness, lumen diameter, cell diameter, length-width ratio of the cells, fibril angle are generally strongly correlated with specific gravity and tracheid length, and much less important in a juvenile wood study (Dinwoodie 1965; Barefoot *et al.* 1966; Zobel and van Buijtenen 1989). Latewood percentage is related to both specific gravity and tree growth rate, so normally it is included in wood property studies (Panshin and de Zeeuw 1980).

Specific Gravity Variation

Specific gravity (relative density) is the amount of wood substance present in a given volume of wood. Although there are many different definitions, wood specific gravity is usually defined as the ratio of the weight of a given volume of wood to the weight of an equal volume of water at 4 °C (grams of wood /grams of cubic centimeter of water) (Zobel and van Buijtenen 1989). It is one of the most important characteristics to tree improvement, because it not only has a major effect on both yield and quality of the final product (Dinwoodie 1965; Barefoot *et al.* 1966), but also it is strongly inherited (Zobel 1961; van Buijtenen 1962; Smith 1967; Matziris and Zobel 1973; Nicholls *et al.* 1980).

In most situations, specific gravity is one of the most significant properties affecting the end use of wood. Specific gravity affects the yield and quality of pulp and paper products. It is considered as the best index for predicting the strength properties of wood (Panshin and de Zeeuw 1980). Most wood product characteristics (e.g., pulp and paper flexibility, tensile strength, tear, burst, printability, bendability, and many mechanical properties of wood) are strongly controlled by wood specific gravity (Panshin and de Zeeuw 1980; Zobel and van Buijtenen 1989).

Variation of specific gravity within a species is divided into geographic variation (provenance variation), variation among individual trees and variation within individual trees (Zobel and van Buijtenen 1989). Although results on many provenance and specific gravity studies are controversial, the idea that geographic variation is controlled by both environment and genetic factors is widely accepted. Provenance variation is normally considered to be result of evolutionary selection related to different environments, especially the temperature and photoperiod (Callaham 1964; Aastveit 1983; Heide 1983). Many studies indicate that provenance variation exists widely in tree species. For example, tamarack grown in natural stands in northwest Ontario exhibits significant specific gravity differences among provenances, and has a weak trend of increasing specific gravity with increasing latitude (Yang and Hazenberg 1987). Holst (1960) found large differences in specific gravity among *Picea glauca* sources in Canada. Taylor *et al.* (1982) reported wide specific gravity variation among *Picea glauca* sources in Alberta. Harris (1965) reported that specific gravity of *Pinus radiata* in New Zealand decreases about 0.1 with each increase in degree of latitude, and increases by about 0.01 with each 100 m increase in altitude. *Populus balsamifera* grown in the north generally have a little higher specific gravity than those growth in south, and southern provenances normally have longer fibers than northern provenances in Ontario (Balatinecz and Peng 1984). Effects of provenance upon wood properties of trees in plantations are different. In some studies, the provenance has an effect on the wood of a plantation (Echols and Conkle 1971; Kennedy 1971), but in many others the environment in which the plantation has been established exerts a very strong effect, and provenance differences tend to be masked (Gilmore *et al.* 1966). *Populus balsamifera* provenance tests in northwest Ontario indicated that specific gravity variation among provenances was not significant (Ivkovich 1995). However, a test on 29 sources of *Pinus banksiana* showed that a number of phenological and xylem characteristics had significant variation and strong relationships with provenance (Kennedy 1971).

Generally, tree-to-tree variation in wood properties within a provenance is large. Yang *et al.* (1987) found that tamarack juvenile wood specific gravity, tracheid length, and latewood percentage varied significantly among individual trees. Similar variation of specific gravity in tamarack was found by Alemdag (1984). Variation in specific gravity between dominant and suppressed tamarack trees was reported by Wong (1987). He stated that dominant trees have a higher specific gravity than suppressed trees. Isebrands and Hunt (1975) and Loo *et al.* (1982) demonstrated that there were large specific gravity differences among trees of *Larix leptolepis*. In many other conifers specific gravity variation among trees is significant (Grigal and Sucoff 1966; Taylor *et al.* 1982; Roddy 1983). However, specific gravity variation within a clone is much smaller than the variation between clones (Kennedy 1966) in *Picea abies*, and specific gravity variation was not significant within clones in a *Populus balsamifera* provenance test (Ivkovich 1995).

The variation of specific gravity within a tree can be subdivided into radial variation (variation within a ring, variation from the pith to the bark), and axial variation (variation associated with different heights in a tree) (Panshin and de Zeeuw 1980; Zobel and van Buijtenen 1989). Generally, earlywood specific gravity in conifers is much lower than that of latewood (Lutz 1964; Echols and Conkle 1971; Megraw 1985). Specific gravity in larch and many other species increases from the pith outward, then becomes basically constant after a certain ring age (when the tree is mature) (Panshin and de Zeeuw 1980; Yang *et al.* 1986). Specific gravity either decreases or increases from the stem base upward to the crown depending on species. There is a clear decrease in specific gravity with increasing height in larch and most conifers (Panshin and de Zeeuw 1980; Yang *et al.* 1986; Wong 1987; Zobel and van Buijtenen 1989).

Tracheid Length Variation

Tracheid length is determined primarily by the length of the cambial initials, and secondly by cell elongation after the division (Bannan 1964, 1965). Coniferous tracheid length exhibits great variability and is strongly inheritable (Wheeler *et al.* 1965; Smith 1967). Tracheid length sometimes has a marked effect on product quality and the use of wood. There are positive relationships between the pulp and paper quality and the tracheid length, and tracheid length is usually used as one of the criterions to determine the final paper product value (Zobel and van Buijtenen 1989). Studies have shown that tracheids shorter than 2 mm are responsible for deficiencies in certain paper properties and other wood products (Panshin and de Zeeuw 1980). It is generally assumed that tensile strength (break length) and burst strength of paper are determined primarily by tracheid length or fiber length (Horn 1978). Usually short fiber wood (e.g., hardwood and juvenile wood in conifers) is not good enough to produce paper, unless some long tracheids or fibers are added to increase its strength. In this situation, tree improvement methods used to increase tracheid length in certain long fiber hardwoods and in juvenile conifer wood become important and valuable (Panshin and de Zeeuw 1980; Zobel and Buijtenen 1989).

Previous studies indicted that tracheid length varied greatly both within and among trees and was under strong genetic control (Wheeler *et al.* 1965; Zobel and van Buijtenen 1989). Correlations of tracheid length with latitude in conifers are reported by Zobel *et al.* (1960), Taylor *et al.* (1982), Megraw (1985), and Yang and Hazenberg (1987), however, the results are controversial. In tamarack, a weak increasing trend of tracheid length with increasing latitude from 46 to 54 °N was found; and tracheid lengths are significantly different among trees, stands and locations in northwest Ontario (Yang and Hazenberg 1987). *Pinus taeda* studies in the United States showed that inland and northern sources had shorter tracheids than southern and coastal sources (Zobel *et al.* 1960; Jackson and Strickland 1962). Echols (1973) reported that *Pinus ponderosa* at high elevations, near the timberline, produced wood with short fiber and low specific gravity as a result of short growing season, little summer rain, and cool springs and summers. He generalized that the relationship of thin cell walls with higher elevation or higher latitude is common to forest trees. A provenance test on *Populus balsamifera* demonstrated that fiber length variation among provenances was significant at 0.05 level of probability. Fibers are longer in *Populus balsamifera* originally from south than those from north (Ivkovich 1995).

Tree-to-tree variation in tracheid length or fiber length is normally large. Yang and Hazenberg (1987) found that tamarack tracheid lengths were significantly different among trees within a stand. Difference in tracheid length between tamarack mature wood of dominant trees and suppressed trees is significantly different (Yang *et al.* 1986; Wong 1987). Ledig *et al.* (1975) found that 28-71% of the total variation of specific gravity and tracheid length in *Pinus caribaea* was due to trees within stands. The large tree-to-tree differences in fiber length accounted for 49% of the variation at 11 years and 90% at 31 years in *Liriodendron tulipifera* (Thorbjornsen 1961). Vegetative propagation can produce trees with similar tracheid length within clones, but clonal differences are very large(Kennedy 1966; Ivkovich 1995).

There are several variation patterns for tracheid length within trees. The first is radial variation (within-ring variation, and the variation from the pith of the tree to the bark), and the second is axial variation (the differences associated with different heights in the tree) (Panshin and de Zeeuw 1980). In most conifer species, including larch, earlywood tracheid length is shorter than latewood tracheid length. Tracheid length of tamarack juvenile wood is normally much shorter than the tracheid length of mature wood. From the pith to the bark tracheid length normally increases (Yang *et al.* 1986). There is complex variation with changing height. However, in most conifers including larch, tracheid length decreases from the bottom to the top of the tree (Spurr and Hyvarinen 1954; Wellwood 1960; Dinwoodie 1961; Yang *et al.* 1986).

Latewood Percentage Variation

Latewood percentage is defined as latewood width divided by the whole ring width (Panshin and de Zeeuw 1980). Generally earlywood is formed in spring and early summer, and latewood is formed in late summer and fall after height growth has stopped (Zobel and van Buijtenen 1989). Latewood has longer tracheid (fiber) lengths, thicker cell walls and higher specific gravity than earlywood (Panshin and de Zeeuw 1980). The formation of latewood is influenced by environmental factors (such as temperature, rain), fertilization and cultivation. Some studies show that latewood percent in some species appears to under fairly strong genetic control (Rees and Brown 1954; Kennedy 1971; Worrall 1975). Many studies indicate that latewood percentage is strongly correlated with specific gravity, but literature on assessments of the inheritance of the latewood percentage is rare (Zobel and Talbert 1984). Variation of specific gravity within rings is mainly due to the variation in the latewood percentage. A higher latewood percentage generally results in higher specific gravity because latewood has a higher specific gravity than earlywood (Goggans 1964; Kennedy 1966; Zobel and van Buijtenen 1989). Earlywood and latewood have quite different wood properties. Biblis (1969) found that specific stress and specific stiffness of latewood are more than 50 and 60% higher than corresponding values for earlywood. In most cases, latewood has a major influence on the quality of finished wood products. Paul and Smith (1950), and Wilson (1964) indicated that earlywood and latewood gave great differences in pulp quality. Gladstone *et al.* (1970) found that *Pinus taeda* had higher holocellulose, alpha-cellulose, and glucan contents in latewood than in earlywood, and latewood had 2-7% higher pulp yield from a given weight of dry wood than earlywood. Brazier (1983) found that earlywood and latewood zones showed a different coarse texture in both softwood and hardwood. This leads to the deflection of nails, splitting, and distortion on drying, and earlywood makes wood difficult to finish.

The latewood percentage of tamarack is significantly different among locations (provenances), and a weak trend of increasing tamarack wood specific gravity and latewood percentage with increasing latitude was found in northwest Ontario by Yang and Hazenberg (1987). Some researchers found that latewood percentage was negatively related to the growth rate in *Pinus banksiana* (Kennedy 1971) and in *Pinus radiata* (Nicholls *et al.* 1980). The *Pinus taeda* latewood percent increased from southern sources to northern sources (Rees and Brown 1954). However, many studies indicate that differences in the earlywood-latewood percentage among seed sources, when trees are planted in the same location, appear to be slight (Rees and Brown 1954; Saucier and Taras 1967; Kennedy 1971; Worrall 1975). Results of a *Pinus banksiana* provenance test demonstrated that there was no systematic trend in the latewood percentage related to provenance (Kennedy 1971), and most of the variation was considered to result from an interaction between the test location and the provenance. He explained that some provenances developed significantly higher latewood percentage largely because their earlywood formation was retarded and caused most of the wood to be formed during the summer or early fall.

Latewood percentage variation among trees was significant within natural stands of tamarack in northwest Ontario (Yang and Hazenberg 1987). Wong (1987) noted that in tamarack juvenile wood, latewood percentage in suppressed trees was significantly higher than that in dominant trees, but the difference was not significant in mature wood. No literature is available about clonal latewood variation in tamarack clones. Results from a *Picea abies* clonal test reported by Kennedy (1966) and Worrall (1975) showed that variation in latewood percentage within clones was not significant, although variation among clones was highly significant.

Within a tamarack tree latewood percentage generally increases with ring age from the pith outward in juvenile wood, and becomes more uniform in mature wood (Yang *et al.* 1986; Wong 1987). Latewood percentage decreases with height in both juvenile and mature wood in most conifers and larch (Larson 1957; Koch 1972; Megraw 1985; Yang *et al.* 1986; Wong 1987). Megraw (1985) reported that latewood percentage increased faster with ring age at the lower height levels than it did at higher levels. He found that within the same rings, latewood percentage was normally greater at stem base than at the upper levels of the same stem.

VARIATION IN GROWTH RATE AND OTHER CHARACTERISTICS

Most tree improvement programs focus on characteristics that directly affect forest productivity, such as improved volume growth. The most common traits considered in forest tree improvement studies are tree radial growth rate and tree height growth rate, because there is substantial genetic variation in those traits (Wright 1976). Variation among diameter and height growth rates has been studied in tamarack by a few researchers.

A study on 24 tamarack seed sources in northern Wisconsin demonstrated significant differences in height growth among provenances (Jeffers 1975; Cech *et al.* 1977). Riemenschneider and Jeffers (1980) demonstrated that variation in both height growth and radial growth were significant in a tamarack seed source test in northern Wisconsin. A significant negative correlation of height and radial growth with latitude and longitude of the source origins was found. The study on genecology of tamarack by Rehfeldt (1970) demonstrated clinal patterns of variation for 2-year height, date of bud set, and patterns of root development. He explained that clinal variation in these variables was due to the significant correlation between the date of bud set and frost-free period of the seed origin. Results on a tamarack provenance test in northwest Ontario showed that variation in height growth among provenances and among clones within provenance was significant, and height growth was negatively correlated with latitude (Farmer *et al.* 1993). The authors interpreted the effect of latitude as a photoperiod controlled adaptation to environmental gradients.

Photoperiod is a stable environmental factor. It is generally considered as the most important factor in controlling forest trees' height growth cessation, winter bud formation, leaf abscission and, in some situations, bud break, flower initiation and seed germination (Ekberg *et al.* 1976). Height growth cessation or bud set in response to photoperiod allows trees to enter the dormant stage before the occurrence of the first autumn frost (Heide 1983). In higher latitude areas the first frost occurs earlier than in lower latitude areas. Thus, provenances in high latitudes normally cease height growth or set buds earlier than southern provenances (Pollard and Logan 1976). On the other hand, daylength in high latitude areas is longer, and night is shorter than low latitude areas in summer and early autumn. Thus the northern provenances have longer critical photoperiods for apical growth cessation and winter bud formation than southern provenances (Heide 1983). When the northern provenances are planted in south, they may stop growth very early, when the photoperiods are same as those in their original areas. Sylven (1940) found when the northern provenances of *Populus tremula* were planted at a southern location, they stopped growing in height earlier than those planted in the north. In contrast to the reduction or cessation of growth induced by short photoperiods at low latitudes, growth was prolonged by planting southern provenances at higher latitudes with longer photoperiods. When southern provenances were planted at a northern location, they had a longer growth period than northern provenances and also longer than when planted in their original areas. Sylven (1940) also found that when southern provenances were planted in the far north, they were damaged by autumn frost. However, hybrids from crosses between parents from northern and southern provenances demonstrated fast growth and great frost resistance. These results demonstrated the strong inheritance of the photoperiodic response in the forest trees.

Variation in tamarack populations has been detected through allozyme variation analysis. Park and Fowler (1987) showed that genetic variation due to clones within families was large for both height growth and survival. Variation in allozymes of western larch (*Larix occidentalis Nutt.*) was reported within rather than between the populations groups (Fins and Seed 1986). However, in a study of allozyme variation in populations of eastern tamarack across northwest Ontario, Knowles and Perry (1987) did not found obvious heterogeneity among the populations.

Phenotypic and genetic variation has also been found in other characteristics. In a test of tamarack population structure and genetic diversity, Cheliak *et al.* (1988) reported that clonal variation in isozymes was large. Considerable phenotypic variation in stem form and branch habit was also reported by Fowler (1986). Significant provenance variation in syllepsis was noted by Farmer *et al.* (1993). Phenotypic variation in cone and seed characters of tamarack is significant among stands and trees within stands, but not significant among provenances in northwest Ontario (O'Reilly and Farmer 1991). A range-wide study on morphological and anatomical phenotypic variation in tamarack cones and needles shows that provenance variation has a weak geographic trend; the greatest variance components existed among trees within stands and within trees (Parker and Dickinson 1990).

CORRELATION AMONG TRAITS

A tree improvement program is generally designed to improve several traits at the same time. Thus, relationships among traits should be considered.

Genetic correlation measures the genetic similarity between two characteristics. It is expressed as the ratio of the two characters' genetic covariance to the product of the two characters' genetic standard deviations (Falconer 1981). Pleiotropic effects are the main reason for genetic correlation. However, pleiotropy does not always cause a detectable correlation, because some genes may increase both characters, while others may increase one and reduce the other. The former tends to cause a positive correlation, and the latter causes a negative correlation (Namkoong *et al.* 1988; Falconer 1981). Thus, even if we cannot find phenotypic correlation between two traits, genetic correlation between them may be estimated.

Correlation among wood properties has been widely studied. However, most of studies only report the phenotypic correlation between the traits. Results on some species demonstrated that wood properties, especially specific gravity and tracheid length, are only slightly correlated phenotypically and are sometimes genetically independent from one another. For example, Zobel *et al.* (1960) found that specific gravity was slightly correlated with tracheid length (r = -0.16). However, many studies show significant phenotypic and genetic correlations between tracheid length and fibril angle, between specific gravity and cell wall thickness, specific gravity and moisture content, latewood percentage and specific gravity (Zobel *et al.* 1960; Bunn 1981; Megraw 1985; Ivkovich 1995). A provenance test in

Populus balsamifera indicated that both phenotypic and genetic correlations between fiber length and specific gravity were significant (Ivkovick 1995).

Correlation of growth rate with wood properties has been widely investigated. Because many complex factors influence the tree growth rate, results of the studies are controversial. Paul (1932) demonstrated that fast grown southern pines could produce wood that has characteristics unsuitable for high quality products. Many studies have shown that there is an increase in the proportion of juvenile wood and earlywood percent in rapidly grown trees, and that properties of wide-ring wood are poor in comparison with the slow-growing trees (Bendsten 1978; Zobel 1981; Zobel and Talbert 1984; Megraw 1985). However, Allen (1977) reported a positive correlation of height and radial growth with specific gravity in *Pinus elliottii*: Smith *et al.* (1966) demonstrated that in *Pseudotsuga menziesii* specific gravity was negatively correlated with growth rate. Zobel (1964) found that fast growth did not affect the wood density on the several Mexican pines he tested, and a similar result was reported by Smith (1962) for *Pinus menziesii*. In a *Populus balsamifera* provenance test in Thunder Bay, Ontario, a slight negative correlation between radial growth rate and relative density was found by Ivkovich (1995).

A strong phenotypic correlation between height and radial growth (0.93 to 0.98) was found by Riemenschneider and Jeffers (1980) in a tamarack provenance test. Genetic correlations among growth traits are similar to phenotypic correlations in tamarack, and a strong correlation between the number of syllepsis and height growth was found by Deng (1990) and Farmer *et al.* (1993). Correlation between clonal means for rooting per cent and clonal means for the number of roots per cutting was moderate to strong in a tamarack rooting test (Farmer *et al.* 1992).

Some studies have examined genetic correlations at different ages to determine the possibility of trait selection in juvenile trees. Wakeley (1971) found that in *Pinus palustris* juvenile growth (before age 15) was not strongly correlated with the same trait at age 30. However, juvenile-mature correlations in Pinaceae exist, and early selection in Pinaceae of superior progenies appears to feasible (Lambeth 1980). A similar conclusion was reported by Ying and Morgenstern (1979) in *Picea glauca*. Juvenile and mature wood specific gravity and tracheid length are generally very well correlated with each other in *Pinus taeda* (Stonecypher and Zobel 1966; Zobel 1970). Patterns of change in tamarack tracheid length, specific gravity, and latewood percentage (Yang *et al.* 1986; Yang and Hazenberg 1987; Wong 1987), suggested that this juvenile-mature relationship exists.

HERITABILITY

Heritability is the proportion of the phenotypic variation in a population that is due to the average effects of genes. It is a ratio indicating the probability with which parent trees transmit their characteristics to their offspring (Falconer 1981; Zobel and Talbert 1984). Heritability also indicates the reliability of the total phenotypic values as a guide to the breeding value. However, its value will change for certain characteristics of given species, because heritability is the ratio between genetic variances and phenotypic variances. Furthermore, estimates of heritability always have errors. Thus, heritability should only be considered as the estimated value that gives a general idea about the ability of inheritance. They change with age, environment, trait, and even test design and plantation (Zobel and Talbert 1984).

There are two types of heritability normally used in a tree improvement program. The first is broad-sense heritability (H^2). It is defined as the ratio of total genetic variation in a population to phenotypic variation. The second is narrow-sense heritability (h^2). It is defined as the ratio of additive genetic variance to total variance (Falconer 1981). Broad-sense heritability is normally greater or equal to the narrow-sense heritability. This is because total genetic variation includes both additive and non-additive variation. In special conditions when non-additive genetic variation is zero, broad-sense heritability is equal to narrow-sense heritability. Forest tree improvement programs are generally aimed at improving combining ability and only the additive genetic variation will be used. Therefore, narrow-sense heritability is more widely used than broad-sense heritability in tree improvement (Zobel 1984; Falconer 1981; Namkoong *et al.* 1988). It is assumed that in clonal tests both the additive and non-additive variance can be transferred from parent to offspring, it is impossible to separate non-additive variance and additive variance. So clonal tests can only estimate broad-sense heritability (Wright 1976; Falconer 1981; Zobel and Talbert 1984).

Different characteristics have quite different heritabilities. Wood specific gravity and tracheid length are considered as two ideal characteristics to manipulate genetically. This is because they have large tree-to-tree variation, strong heritability, low genetic and environment interaction, and these characteristics are important characteristics affecting wood yield and wood quality (Zobel and van Buijtenen 1989). Previous studies indicated that both in softwoods and hardwoods, heritability of specific gravity is high, normally in a range of $h^2 =$ 0.3 to 0.7 (Stonecypher and Zobel 1966; Einspahr *et al.* 1967; McKinnery and Nicholas 1971; Nicholls *et al.* 1980; Land and Lee 1981). Research has demonstrated that there is good potential for wood property improvement in *Larix leptolepsis* (Isebrands and Hunt 1975). Heritability of latewood-earlywood ratio varies greatly (Goggans 1964; Kennedy 1966), but differences in the latewood percentage among seed sources, when planted in the same location, appear to be slight (Rees and Brown 1954; Saucier and Taras 1967; Kennedy 1971; Worrall 1975). Broad-sense heritability of tamarack height growth rate was investigated by Farmer *et al.*(1993). The value varied from 0.11 to 0.23. However, heritability (0.47) in sylleptic branching is much higher than that for height growth rate. Park and Fowler (1987) found that tamarack clonal heritability for height growth rate of different populations range from 0.04 to 0.18, slightly larger than heritability for survival. Heritability of *Picea glauca* varies greatly from age to age for the same traits had been reported by Ying and Morgenstern (1979).

MATERIALS AND METHODS

MATERIALS

Materials from four provenances (Thunder Bay, North Bay, Kenogami River, and Sandy Lake, Figure 1.), two stands within each provenance, 4 clones within each stand and four ramets within each clone were included in this study. All were sampled from a provenance test established in Thunder Bay by Lakehead University. Provenance selection for this study was according to the latitude and longitude distribution. Some provenances in the test were not considered in this selection because of their low growth rate and survival rate. Materials from four blocks and eight randomly selected clones in each provenance were used in this study. A total of 128(4×4×2×4×1) trees were sampled from the four blocks.

The provenance test has a three level nested design with a fixed block arrangement. Each block includes all of the provenances, and the provenances were randomly arranged in the blocks. Each provenance has a plot, and the 20 clones within each provenance were randomly arranged within provenance plots. Each clone has three ramets in each plot (Deng 1990).

The test plantation was established between fall 1984 and spring 1985 using uniform age ramets. In total, eleven provenances were included in the test, all of which were collected from northwest Ontario within Longitude 80° to 95° and Latitude 46° to 54°. There are two stands in each provenance, and each stand is presented by ten clones. The ortets were sampled from wildings with ages ranging from 3 to 10, and the ramets were cut from them and rooted in Spencer-Lemaire containers (750 ml). Ramet rooting and plantation establishment have been described by Farmer *et al.* (1986) and Deng (1990).

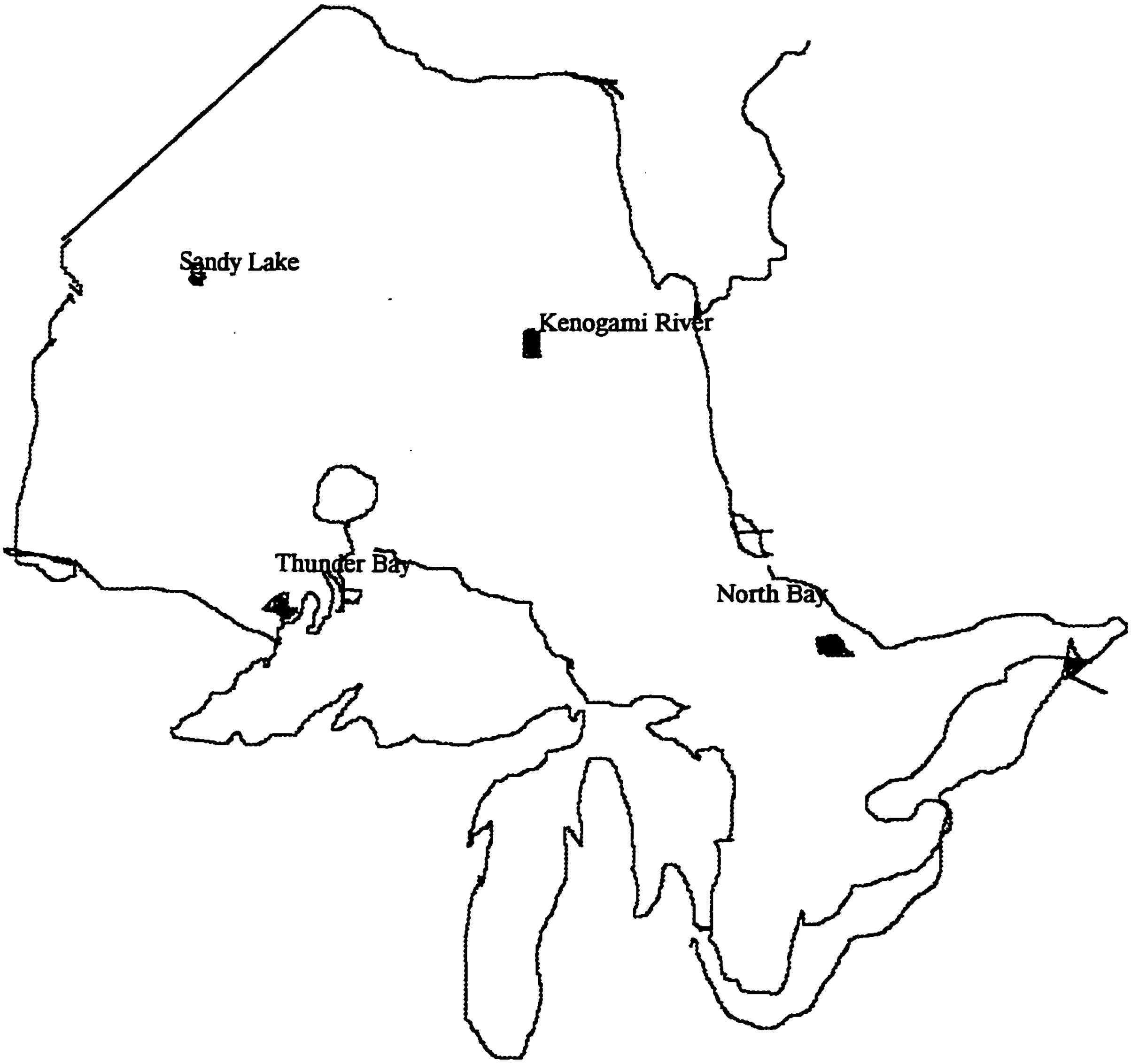

Figure 1. The locations in Ontario of the four tamarack provenances used in the study

The test includes four blocks. They have similar topography, but different soil conditions. Blocks 1 and 2 have a deep, sandy loam soil; the soil of blocks 3 and 4 is a stony, sandy loam relatively shallow and with occasional boulder outcrops (Farmer *et al.* 1993). Block 3 and block 4 are better drained than block 1 and block 2.

METHODS

DATA COLLECTION

Three wood properties (tracheid length, specific gravity and latewood percentage), two growth traits (annual height growth, annual radial growth) were included in this study. Only 1991 and 1994 were sampled and evaluated because of the limited time and other resources. Trees that were damaged, forked or dead were not used. Before the trees were cut down, the south side of the stems were marked. The field sampling began on September 21, 1995 after the tree height growth stopped, and ended on October 20, 1994. The laboratory work was finished within three months after the field work.

Height Growth Rate Measurement and Disks Collection

After trees were cut, height increment for 1991 and 1994 was measured using a tape in the field. This investigation was done in a young plantation where many live branches occur below the DBH. In order to avoid branch knots influence measurement, a

3 cm thick disk was cut from each tree at the base, 10 cm above the ground, where the bole was clear. Before cutting the disk, North-South directions were marked on the disk, and the tree identification number was marked on the reverse side of the disk. Disks were placed in a plastic bag and sealed. All the disks were brought to the laboratory within 24 hours and kept in a refrigerator at about 5 ^{o}C until examined. The average of North - South and East - West specimens were used for each measurement.

Radial Growth Rate (Ring Width) Measurement

Radial growth rate is expressed as the width (cm) of a growth ring. Before the disk was used to measure ring width, the cross-section was smoothed by fine sandpaper. Growth ring width was determined by a TRIM(Tree Ring Increment Measurer) provided by the Ontario Ministry of Natural Resources. The average of the North - South ring width and East -West ring width in a year was considered the disk's "ring width". The accuracy of the TRIM is around 0.001 cm. The measurement of ring width starts from the cambium towards to the pith, and the earlywood and latewood were measured separately. The sum of earlywood width and latewood width comprised the whole ring width.

Latewood Percentage Measurement

Latewood percentage is defined as the ratio of the width of the latewood zone to total width of the growth ring. The measurement of latewood percentage was finished using TRIM during measurement of ring width. Latewood and earlywood were determined based on wood color within the ring and smoothness of the wood surface. Earlywood color is usually lighter than latewood , and latewood surface is smoother than earlywood surface.

Specific Gravity Measurement

Specific gravity was determined by the maximum moisture content method (Smith 1954). Wood specific gravity can be categorized as extracted specific gravity and unextracted specific gravity. Specific gravity after extraction is the specific gravity after the resinous and phenolic deposits and sugars in wood have been extracted with alcohol - benzene and with hot or cold water. The difference between extracted and unextracted specific gravity of most resin-rich pine and fir is substantial, especially for heartwood and reaction wood, if the trees are old enough (generally older than 25-year-old) (Posey *et al.* 1970; Panshin and Zeeuw 1980). In juvenile wood the differences between extracted and unextracted wood specific gravity are very small; there is no significant effect on the specific gravity of alcohol-benzene extraction (Posey *et al.* 1970; Megraw 1985). In this study only unextracted specific gravity is measured. There are two reasons. First, the trees are only 10 years old, so amount of the extraction will not significantly change wood specific gravity. Second, unextracted specific gravity will be a little higher than the extracted specific gravity, but all the specimen values are inflated by about the same rate.

After measuring ring width and latewood percentage, the core was divided into individual rings which were numbered from the cambium towards the pith. Then the small ring chips were placed into a test tube with distilled water. To ensure that these chips reached the point of maximum moisture content; they were submerged until the last two measurements of moisture content weight were constant. The agreement between the last two weightings was within 0.5%. Usually, it took 2 to 3 weeks to reach maximum moisture content after complete submersion of the specimen. In order that maximum moisture could be reached faster, a vacuum was used in this study, and the actual time used to reach the maximum moisture was about two weeks.

After reaching maximum moisture content, the specimen was taken out, and weighted after its surface water was removed by paper. The specimens were replaced in water after weighing, and when all specimens were weighed once, the whole procedure was repeated for a second weighing after two days. According to previous experience, the agreement between the two weighings should be within 0.5%. The average weight of the specimen was the maximum moisture content weight (Wm). After weighing, the specimens were dried in an oven at 105^{o} C for about 24 hours, and the oven dry weight was determined (Wo). The saturated and oven dry weights were recorded to the nearest milligram. The following equation was used to calculate specific gravity:

$$\text{Specific gravity} = \frac{1}{\dfrac{Wm - Wo}{Wo} + \dfrac{1}{Go}}$$

where:

Wm = specimen weight at maximum moisture content

Wo = oven dry weight

Go = the density of wood substance = 1.53

Tracheid Length Measurement

After specific gravity determination, each individual ring chip was further split into earlywood and latewood splints for measurement of tracheid length (in this study refers earlywood tracheid length). Only earlywood tracheid was used to measure tracheid length in this study. Individual earlywood splints were macerated according to Franklin's (1945) method. Each of the early wood chips was soaked in a 1:1 mixture of glacial acetic acid and hydrogen peroxide(30%) in a test tube. The test tubes were kept at 80^{o} C for about 24 hours until the wood chips' color turned to white. Then distilled water was used to wash the chips three times. The tubes were then shaken until the chips disintegrated into individual tracheids. The tracheids were finally used to make a microscopic slide, and covered with a cover slip. The edge of the cover slip was sealed with cover bound. Each slide contained at least 100 tracheids. According to previous experience, at least 25 tracheids were randomly selected and their lengths were measured(Yang *et al.* 1987). The least number of tracheids that must be measured was determined according to the empirical formula:

$$N = t^2 \times s^2 / E^2$$

Where:

t - student's t value at the probability level (here 0.05)

s^2- the variance of preliminary samples

E - the allowable error set at 10% of the mean tracheid length

Finally, the image of a tracheid magnified 100× was projected through a microscope onto a HIPAD digitizer connected to an Apple IIe microcomputer. The mean length of 25 tracheids from earlywood was used as the tracheid length for each individual growth ring.

DATA ANALYSIS

There are four sources of variance in this study: block, provenance, stand, and clone. Each tree trait was analyzed through all the following steps. Differences were considered to statistically significant if the probability of rejecting the null hypothesis of no difference was 0.05 or less. Analysis of variance of each individual provenance was used in this study for further analysis of variation.

Analysis of Variance

The linear model in this study was expressed as :

$Y_{ijklm} = \mu + B_i + \delta_{(i)} + P_j + BP_{ij} + \omega_{(ij)} + S_{(j)k} + BS_{i(j)k} + C_{(jk)l} + BC_{i(jk)l} + E_{(ijkl)m}$...........[1]

Where:

Y_{ijklm} = the *mth* response within (tracheid length, specific gravity, annual height growth, ring width, and latewood percentage) the *lth* clone within *kth* stand within *jth* provenance in *ith* block

μ = overall mean;

B_i = fixed *ith* block effects, i = 1,2,3,4;

$\delta_{(i)}$ = the first restriction due to blocking ;

P_j = the *jth* provenance random effect, j = 1,2,3,4;

BP_{ij}= block and provenance interaction effect (random);

$\omega_{(ij)}$= second restriction error due to provenances within blocks;

$S_{(j)k}$ = the random effect of *kth* stand within the *jth* provenance region, k= 1, 2;

$BS_{i(j)k}$= the interaction of *ith* block with *kth* stand within *jth* provenance;

$C_{(jk)l}$ = the random effect of the *lth* clone within *kth* stand within *jth* provenance, l=1,2,3,4;

BCi(jk)l = the random effect of the *lth* within *kth* stand within *jth* provenance in *ith* block;

$E_{(ijkl)m}$ = the random effect error, m = 1;

(all the random effects are assume to fit IID $N(0, \sigma^2)$).

The Expected Mean Square (EMS) table and test of the hypotheses are listed in Table 1, and Table 2, respectively.

Table 1. Expected mean square associated with the linear model [1]

Source	DF	Expected Mean Square
B_i	3	$\sigma^2 + \sigma^2_{BC} + 4\sigma^2_{BS} + 8\sigma^2_{\omega} + 8\sigma^2_{BP} + 32\sigma^2_{\delta} + 32\phi_{(B)}$
$\delta(I)$	0	$\sigma^2 + \sigma^2_{BC} + 4\sigma^2_{BS} + 8\sigma^2_{\omega} + 8\sigma^2_{BP} + 32\sigma^2_{\delta}$
P_j	3	$\sigma^2 + 4\sigma^2_{C} + 16\sigma^2_{S} + 8\sigma^2_{\omega} + 32\sigma^2_{P}$
BP_{ij}	9	$\sigma^2 + \sigma^2_{BC} + 4\sigma^2_{BS} + 8\sigma^2_{\omega} + 8\sigma^2_{BP}$
$\omega(ij)$	0	$\sigma^2 + \sigma^2_{BC} + 4\sigma^2_{BS} + 8\sigma^2_{\omega}$
$S_{(j)k}$	4	$\sigma^2 + 4\sigma^2_{C} + 16\sigma^2_{S}$
$BS_{i(j)k}$	12	$\sigma^2 + \sigma^2_{BC} + 4\sigma^2_{BS}$
$C_{(jk)l}$	24	$\sigma^2 + 4\sigma^2_{C}$
$BC_{i(jk)l}$	72	$\sigma^2 + \sigma^2_{BC}$
$E_{(ijkl)m}$	0	σ^2
Total	127	

In this study I use MS(P)/MS(S) to test the null hypotheses of $\sigma^2_P = 0$. Table 1 shows that this is the correct test so long as $\sigma^2_{\omega} = 0$. In order to discover whether H_{01}: $\sigma^2_{\omega} = 0$ is true. I first test H_{02}: $\sigma^2_{\omega} + \sigma^2_{BP} = 0$ using MS(BP)/MS(BS). If H_{02} is accepted at $\alpha = 0.25$, then I know that both $\sigma^2_{\omega} = 0$ and $\sigma^2_{BP} = 0$ and I can proceed to test H_{01} as outlined above. In this study, H_{02} was accepted for most traits. The exceptions were diameter growth in 1991, 1994; latewood percentage in 1991; and height growth in 1991 (Appendix III). So, for those characteristics, apparent provenance effects may actually reflect, in whole or part, the restriction error effect.

Table 2. Tests for the null hypotheses associated with the linear model [1]

Hypotheses	Test Statistic	Reference Distribution
$\phi_B = 0$	no test	
$\sigma^2_\delta = 0$	no test	
$\sigma^2_P = 0$	No test, see the explanation of preliminary test procedures below.	
$\sigma^2_{BP} = 0$	no test	
$\sigma^2_\omega = 0$	no test	
$\sigma^2_S = 0$	MS(S)/MS(C)	F(4, 24)
$\sigma^2_{BS} = 0$	MS(BS)/MS(BC)	F(12, 72)
$\sigma^2_C = 0$	MS(C)/MS(BC)*	F(24, 72)
$\sigma^2_{BC} = 0$	no test	

* This is a "consevative test" based on the assumption that $\sigma^2_{BC} = 0$.

The Duncan's new multiple range method (Milliken and Johnson 1984) was used in this study to compare each pair of provenance means.

In this study, each provenance was considered as a randomized complete block design and individual provenances were analyzed separately using the following model:

$$Y_{ijk} = \mu + B_i + \delta_{(i)} + C_j + BC_{ij} + E_{(ij)k} \ldots\ldots [2]$$

The EMS Table associated with this model was in Table 3.

Table 3. Expected mean square table associated with the linear model [2]

Source	DF	Expected Mean Square
B_i	3	$\sigma^2 + \sigma^2_{BC} + 8\sigma^2_{\delta} + 8\phi_{(B)}$
$\delta(i)$	0	$\sigma^2 + \sigma^2_{BC} + 8\sigma^2_{\delta}$
C_j	7	$\sigma^2 + 4\sigma^2_C$
BC_{ij}*	21	$\sigma^2 + \sigma^2_{BC}$
$E_{(ij)k}$	0	σ^2

* σ^2_{BC} is assumed to equal to zero.

Since only one ramet in each block was used in this study, the degrees of freedom for error is zero. Thus we could not estimate the mean square for error. In this study it is assumed that $\sigma^2_{BC} = 0$ and use $SS_{BC}/72(\sigma^2_e)$ as the error to test clone effects. Furthermore, there are sampling errors included in the $E_{(ijkl)m}$. So, some effects that really exist may not be found (Brown 1994).

Heritability Measurement

Broad-sense heritability is defined as the ratio of total genetic variation in a population to the phenotypic variation (Falconer 1981), or

$$H^2 = \frac{\sigma^2_G}{\sigma^2_P} = \frac{\sigma^2_A + \sigma^2_{NA}}{\sigma^2_A + \sigma^2_{NA} + \sigma^2_e}$$

In this study broad-sense heritability of provenances and clones is expressed respectively as:

$$H^2_P = \sigma^2_P / (\sigma^2_P + \sigma^2_C + \sigma^2_{BS} + \sigma^2_S + \sigma^2_{BP} + \sigma^2_e)$$

$$H^2_C = \sigma^2_C / (\sigma^2_C + \sigma^2_e)$$

Table 4. Analysis of variance, variance components and heritability

Source of variance	Sum of square	DF	MS	Variance components	Heritability
B_i	SS_B	3	$SS_B/3$	$SS_B/96 - SS_{BP}/288(\sigma^2_B)$	
P_j	SS_P	3	$SS_P/3$	$SS_P/96 - SS_S/128(\sigma^2_P)$	$\sigma^2_P/(\sigma^2_P+\sigma^2_{BP}+\sigma^2_S+\sigma^2_{BS}+\sigma^2_C+\sigma^2_e)$
BP_{ij}	SS_{BP}	9	$SS_{BP}/9$	$SS_{BP}/72 - SS_{BS}/96(\sigma^2_{BP})$	
$S_{(j)k}$	SS_S	4	$SS_S/4$	$SS_S/64 - SS_C/384(\sigma^2_S)$	
$BS_{i(j)k}$	SS_{BS}	12	$SS_{BS}/12$	$SS_{BS}/48 - SS_{BC}/288(\sigma^2_{BS})$	
$C_{(jk)l}$	SS_C	24	$SS_C/24$	$SS_C/96 - SS_E/288(\sigma^2_C)$	$\sigma^2_C/(\sigma^2_C+\sigma^2_e)$
$BC_{i(jk)l}$	SS_{BC}	72	$SS_{BC}/72$	$SS_{BC}/72(\sigma^2_e)$	
$E_{(ijkl)m}$	SS_E	0			
Total		127			

Table 5. Calculation of clonal variance components and heritability of individual provenance

Source of variance	Sum of square	DF	Variance components	Heritability
B_i	SS_{Bi}	1	$SS_{Bi}/24 - SS_{E(ij)k}/168$	
C_j	SS_{Cj}	7	$Ss_{Cj}/28 - SS_{E(ij)k}/84$	$\sigma^2_C/(\sigma^2_C+\sigma^2_e)$
$E_{(ij)k}$	$SS_{E(ij)k}$	21	$SS_{E(ij)k}/21$	

Variance components and heritability were derived from the overall ANOVA and the ANOVA of individual provenances. Methods of calculation for heritabilities of provenance and clones and heritabilities of clones based on individual provenance ANOVA are presented in Table 4 and Table 5, respectively.

Phenotypic and Genetic Correlation

Genetic correlation measures how strongly two characteristics (X and Y) are correlated genetically. It is defined as the ratio of the genetic covariance to the product of the two genetic standard deviations and is commonly used in determining the degree to which selection for one trait will be successful in improving another trait (Falconer 1981). It can be expressed as:

$$r_{XY} = \mathrm{COV(XY)}/\sqrt{\mathrm{VAR(XX)} \times \mathrm{VAR(YY)}}$$

Where:

COV(XY)= Provenance or clonal genetic covariance for trait X and Y

V(XX)= Provenance or clonal variance of trait X

V(YY)= Provenance or clonal variance of trait Y

Covariance components analysis used in above formula were obtained by methods similar to those used to estimate variances (Becker 1984); and the procedures of calculation are presented in Table 4. Because the degrees of freedom for error is zero, tests were based on the assumption that $\sigma^2_{BC} = 0$.

Table 6. Calculation of covariance components

Source of covariance	sums of covariance	DF	MSCP	Covariance components
B_i	SCP_B	3	$SCP_B/3$	$SCP_B/96 - SCP_{BP}/288$
P_j	SCP_P	3	$SCP_P/3$	$SCP_P/96 - SCP_S/128$
BP_{ij}	SCP_{BP}	9	$SCP_{BP}/9$	$SCP_{BP}/72 - SCP_{BS}/96$
$S_{(j)k}$	SCP_S	4	$SCP_S/4$	$SCP_S/64 - SCP_C/384$
$BS_{i(j)k}$	SCP_{BS}	12	$SCP_{BS}/12$	$SCP_{BS}/48 - SCP_{BC}/288$
$C_{(jk)l}$	SCP_C	24	$SCP_C/24$	$SCP_C/96 - SCP_{BC}/288$
$BC_{i(jk)l}$	SCP_{BC}	72	$SCP_{BC}/72$	$SCP_{BC}/72$
$E_{(ijkl)m}$	SCP_E	0		
Total		127		

Both phenotypic and genetic correlation between following pairs of traits were estimated:

1. Tracheid length vs specific gravity, height growth rate, ring width and latewood percentage.
2. Specific gravity vs height growth rate, ring width and latewood percentage.
3. Height growth rate vs ring width and latewood percentage.
4. Ring width vs latewood percentage.

RESULTS

Height growth

Height growth in 1991 differed considerably among provenances. Analysis of variance indicated that variation among provenances is significant (Table 7). The two southern provenances exhibited significantly higher height growth than the two northern provenances. However, differences between the two northern provenances and between the two southern provenances were not significant. The North Bay provenance had the highest annual height growth (0.74 m), and the Kenogami River provenance was the slowest (0.56 m) (Table 9).

In 1994, the two southern provenances again had a much higher height growth rate than the two northern provenances, and variation among provenances was significant (Table 8). Height growth differences between the two southern provenances (Thunder Bay 0.82 m and North Bay 0.81m) and between the two northern provenances (0.64m and 0.66m) were also not significant. The highest annual growth was found in the Thunder Bay provenance, the slowest growing provenance was from the Kenogami River in 1994 (Table 10.).

Clonal variation in height growth was not statistically significant in 1991(Table 7), but the variation was significant in 1994 (Table 8). In 1991, the highest height growth for a clone was in the North Bay provenance, and the lowest was in the Kenogami River provenance (Table 9). However, in 1994, the highest height growth for a clone was in the Thunder Bay provenance, and the lowest clone mean was in the Sandy Lake provenance (Table 10). Analyses of variance for individual provenances showed that significant clonal variation in 1991 and 1994 existed only in the Kenogami River and the Sandy Lake provenances respectively (Table 9, 10). Variation of stands within provenance was not significant in either 1991 or 1994 (Table 7, 8).

The variance components of height growth due to provenances were larger than those for clones within provenances. From 1991 to 1994, the Percentage of the variance for height growth increased for both provenances (from 16% to 29%) and clones (from 0% to 7%)(Table 11). Both provenance and clonal annual height growth were increased from 1991 to 1994 (Table 9, 10).

Table 7. Analysis of variance for wood property and growth traits, 1991(1)

		Mean Square				
Source	df	Tracheid Length	Specific Gravity	Height Growth	Ring Width	Latewood Percentage
BI	3	0.009ns (2)	0.003ns	0.214*	0.027ns	0.006ns
PJ	3	0.010ns	0.006ns	0.229*	0.577**	0.002ns
BIPJ	9	0.006ns	0.002ns	0.051ns	0.116**	0.017*
Std	4	0.006ns	0.002ns	0.026ns	0.017ns	0.0021ns
BIStd	12	0.005ns	0.001ns	0.024ns	0.009ns	0.005ns
Cln	24	0.018**	0.006**	0.021ns	0.049ns	0.006ns
Error	72	0.006	0.002	0.024	0.033	0.007

(1) Separate ANOVA Tables are presented in Appendix III
(2) * and ** : significant at 5% and 1% levels of probability respectively; ns: not significant at $\alpha \leq 0.05$.

Table 8. Analysis of variance for wood property and growth traits, 1994[1]

		Mean Square				
Source	df	Tracheid Length	Specific Gravity	Height Growth	Ring Width	Latewood Percentage
BI	3	0.007 ns[2]	0.004*	0.208**	1.332**	0.044ns
PJ	3	0.219 **	0.002ns	0.289**	0.695*	0.004ns
BIPJ	9	0.011 ns	0.001ns	0.026ns	0.075ns	0.012ns
Std	4	0.008 ns	0.002ns	0.014ns	0.059ns	0.011ns
BIStd	12	0.014 ns	0.001ns	0.018ns	0.048ns	0.008ns
Cln	24	0.025 **	0.004**	0.019*	0.086**	0.008ns
Error	72	0.012	0.001	0.010	0.041	0.005

(1) Separate ANOVA Tables are presented in Appendix III

(2) * and ** : significant at 5% and 1% levels of probability respectively; ns: not significant at $\alpha \leq 0.05$.

Radial growth rate (Ring Width)

In 1991, significant ring width variation was found among the provenances (Table 7.). The North Bay provenance was significantly different from all other provenances, and the Thunder Bay provenance was significantly different from the Kenogami River provenance. Variation between the Thunder Bay provenance and the Sandy Lake provenance, and between Kenogami River provenance and the Sandy Lake provenance was not significant (Table 9.). Clonal effects within the Thunder Bay provenance were significantly different, but no significant clonal variation was found within other provenances(Table 9.).

Table 9. Provenance means(M), clone means, the range of clone means (underline), and the Duncan's new multiple range test of the provenance means for 1991 growth and wood property traits

Provenances	Tracheid Length	Specific Gravity	Height Growth	Ring width	Latewood Percentage
Clones No.	mm		m	cm/ring	%
North Bay(M)	**1.14 a** (1)	**0.45a**	**0.74 a**	**0.97a**	**0.28a**
10121	1.21	0.48	0.59	0.78	0.26
10132	1.14	0.48	0.69	1.07	0.29
10134	1.15	0.41	0.76	0.98	0.26
10137	1.07	0.47	0.77	1.10	0.30
10225	1.10	0.43	0.81	0.96	0.23
10229	1.12	0.50	0.72	0.92	0.26
10232	1.22	0.41	0.68	1.00	0.37
10235	1.08	0.43	0.86	0.97	0.26
Thunder Bay(M)	**1.14 a *** (2)	**0.43ab ***	**0.68a**	**0.84b ***	**0.26a**
50127	1.19	0.45	0.68	0.94	0.27
50128	1.15	0.42	0.73	1.06	0.25
50131	1.12	0.47	0.61	0.73	0.21
50133	1.13	0.44	0.64	0.74	0.26
50226	1.10	0.38	0.58	0.75	0.27
50229	1.18	0.46	0.67	0.99	0.27
50232	1.23	0.42	0.77	0.87	0.25
50233	1.05	0.43	0.74	0.62	0.27
Kenogami River(M)	**1.11a ***	**0.43ab ***	**0.56 b***	**0.65c**	**0.26a**
90125	1.15	0.39	0.60	0.75	0.32
90128	1.16	0.52	0.45	0.65	0.25
90140	1.09	0.38	0.63	0.77	0.25
90141	0.92	0.41	0.43	0.58	0.22
90231	1.19	0.45	0.64	0.58	0.20
90236	1.19	0.49	0.60	0.56	0.28
90240	1.08	0.39	0.55	0.65	0.28
90241	1.06	0.42	0.61	0.69	0.31
Sandy Lake (M)	**1.12 a ***	**0.42b ***	**0.57b**	**0.75 b**	**0.27a**
130121	1.08	0.46	0.70	0.84	0.27
130123	1.20	0.42	0.59	0.71	0.32
130129	1.10	0.38	0.53	0.74	0.31
130134	1.07	0.41	0.56	0.74	0.23
130221	1.10	0.43	0.62	0.65	0.23
130225	1.19	0.42	0.52	0.71	0.26
130227	1.10	0.41	0.52	0.79	0.24
130228	1.10	0.41	0.51	0.85	0.30

(1) Provenance means in a same column, with different letters are significantly different at the 0.05 level of probability. (2) *: Clonal variation within the provenance is significant at the 0.05 levlel of probability. Individual provenances' ANOVA tables are listed on appendix V.

Table 10. Provenance means(M), clone means, the range of clone means (underline), and the Duncan's new multiple range test of the provenance means for 1994 growth and wood property traits

Provenances Clones No.	Tracheid Length mm	Specific Gravity	Height Growth m	Ring width cm/ring	Latewood Percentage %
North Bay (M)	**1.45a** (1)	**0.45a** *(2)	**0.81a**	**1.21a** *	**0.30a** *
10121	1.48	0.47	0.86	0.91	0.27
10132	1.40	0.44	0.79	1.27	0.40
10134	1.34	0.40	0.84	1.65	0.34
10137	1.57	0.49	0.79	1.25	0.30
10225	1.46	0.45	0.83	1.04	0.28
10229	1.49	0.47	0.75	1.08	0.26
10232	1.51	0.41	0.70	1.22	0.25
10235	1.34	0.43	0.89	1.24	0.29
Thunder Bay (M)	**1.41a**	**0.43 a**	**0.82a**	**1.13a**	**0.30a**
50127	1.47	0.41	0.75	1.18	0.31
50128	1.30	0.43	0.92	1.20	0.25
50131	1.41	0.46	0.76	1.02	0.31
50133	1.43	0.47	0.88	1.10	0.27
50226	1.40	0.40	0.75	1.27	0.39
50229	1.40	0.46	0.71	0.93	0.26
50232	1.52	0.42	0.87	1.22	0.37
50233	1.35	0.42	0.85	1.13	0.27
Kenogami (M)	**1.28 b***	**0.44a**	**0.64 b**	**0.90b**	**0.29a**
90125	1.27	0.42	0.69	0.91	0.25
90128	1.36	0.48	0.60	0.96	0.34
90140	1.34	0.41	0.66	1.06	0.29
90141	1.20	0.42	0.66	0.74	0.25
90231	1.26	0.45	0.57	0.88	0.25
90236	1.37	0.48	0.67	0.72	0.34
90240	1.30	0.42	0.62	0.98	0.32
90241	1.16	0.45	0.62	0.94	0.28
Sandy Lake (M)	**1.30b**	**0.43a** *	**0.66b** *	**0.95b**	**0.28a**
130121	1.21	0.47	0.80	0.92	0.28
130123	1.40	0.44	0.56	0.84	0.29
130129	1.28	0.37	0.62	0.97	0.28
130134	1.18	0.42	0.53	0.84	0.23
130221	1.36	0.48	0.70	0.93	0.26
130225	1.35	0.42	0.71	0.95	0.23
130227	1.32	0.40	0.71	1.12	0.34
130228	1.27	0.42	0.68	1.01	0.33

(1) Provenance means in a same column, with different letters are significantly different at the 0.05 level of probability. (2) * : Clonal variation within the provenance is significant at the 0.05 levlel of probability. Individual provenances' ANOVA tables are listed on appendix V.

Variation in 1994 ring width was also significant among provenances (Table 8.). Southern provenances (North Bay, Thunder Bay) were significantly different from northern provenances (Kenogami River, Sandy Lake); but provenance differences within these two regions were not significant. Clonal effects were significant within the North Bay provenance, but not significant within others (Table 10).

In both 1991 and 1994 southern provenances had wider rings than northern provenances. Ring width increased from 1991 to 1994 for all the provenances and clones (Table 9, 10). The widest rings in both 1991 and 1994 were observed in the North Bay provenance, and the narrowest rings were found in the Kenogami River provenance (Table 9, 10). No significant stand effects within provenances were detected in either 1991 or 1994 (Table 7, 8).

Variance components for provenance were larger than those for clones within provenance for ring width in both 1991 and 1994. From 1991 to 1994, variance components of clones increased from 5.9% to 9.8%, but variance components for provenances decreased from 25.9% to 17.0% (Table 11).

Latewood percentage

Provenance variation in latewood percentage was not significant at the 0.05 level of probability in either 1991 or 1994 (Table 7, 8). Changes in all the latewood percentages of provenance were irregular and showed slight increase from 1991 to 1994. Clonal variation was also not significant (Table 7, 8). Latewood percentage means for clones were very similar among provenances and showed a slight increase from 1991 to 1994. No significant stand variation was found in eithor 1991 or 1994 (Table 9, 10).

Table 11. Variance components and per cent of variance components(in parentheses) for wood property and growth traits *

	Source of variation						
Trait	**Bi**	**Pj**	**BiPj**	**Std**	**BiStd**	**Cln**	**Error**
				1991			
Tracheid Length	.000103	.000147	.000067	0	0	.002993	.006185
	(1.09)	(1.55)	(.71)	(0)	(0)	(31.52)	(65.13)
Specific Gravity	.000034	.000127	.000028	0	0	.000997	.001765
	(1.17)	(4.30)	(.96)	(0)	(0)	(33.78)	(59.78)
Height Growth	.005075	.006359	.003400	.000305	.000006	0	.024195
	(12.90)	(16.17)	(8.64)	(.77)	(.01)	(0)	(61.50)
Ring Width	0	.017493	.013369	0	0	.003984	.032736
	(0)	(25.88)	(19.78)	(0)	(0)	(5.89)	(48.43)
Latewood percent	0	.000015	.001538	0	0	0	.006627
	(0)	(.19)	(18.80)	(0)	(0)	(0)	(81.01)
				1994			
Tracheid Length	0	.006606	0	0	.000458	.003200	.012306
	(0)	(29.27)	(0)	(0)	(2.03)	(14.18)	(54.52)
Specific Gravity	.000098	.000005	0	0	(0)	.000589	.001490
	(4.50)	(.21)	(0)	(0)	(0)	(27.00)	(68.29)
Height Growth	.005687	.008604	.000910	0	.002077	.002205	.010130
	(19.20)	(29.05)	(3.07)	(0)	(7.01)	(7.45)	(34.21)
Ring Width	.039274	.019874	.003441	0	.001790	.011457	.040613
	(33.73)	(17.07)	(2.95)	(0)	(1.54)	(9.84)	(34.88)
Latewood percent	.000993	0	.000512	.000166	.000673	.000646	.005405
	(11.83)	(0)	(6.09)	(1.98)	(8.01)	(7.69)	(64.39)

* "0" refers to the component value is zero or negative.

Variance components for latewood percentage were extremely small in comparison with other traits. Variance components of latewood percentage for provenances were almost zero in both years. From 1991 to 1994, variance components of latewood percentage for clones increased from 0% to 7.7% (Table 11.).

Specific Gravity

Provenance variation was not significant in either 1991 or 1994 for specific gravity (Table 7, 8). There was no major change in provenance means from 1991 to 1994 (Table 9, 10). However, highly significant differences were found among clones in both years (Table 7, 8). Analyses of variance for individual provenances indicated that clonal variation was significant within the Sandy Lake provenance in both 1991 and 1994, within the Thunder Bay provenance and the Kenogami River provenance in 1991, and within the North Bay provenance in 1994 (Table 9, 10). In 1991, both the lowest and highest clonal means were in the Kenogami River provenance (0.38 to 0.52). In 1994, a clone of the Sandy Lake provenance had the lowest specific gravity (0.37), and one from the North Bay provenance had the highest specific gravity (0.49) . No regular trends were found from south to north , and from pith to bark. No significant stand variation was found in either 1991 or 1994 (Table7, 8).

The variance components due to provenances were much smaller than those due to clones in both two years. Variance components Percentage due to provenances changed from 1991 (4.3%) to 1994 (0.2%). However, variance components due to clones were relatively constant from 1991 (33.8%) to 1994 (27%) (Table 11.).

Tracheid Length

In 1991, provenance variation of tracheid length was not significant (Table 7). However, in 1994, the variation was significant (Table 8). Tracheid length was significantly different between the northern and southern provenances, but the differences were not significant within the northern and within the southern region (Table 9, 10). The North Bay provenance had the longest tracheid length (1.45 mm), which decreased north and west to the Thunder Bay provenance (1.44 mm), the Kenogami River provenance (1.28 mm), and the Sandy Lake provenance (1.30 mm) (Table 10). From 1991 to 1994 tracheid length of the two southern provenances increased more than that for two northern provenances.

Clonal variation was significant in both 1991 and 1994 (Table 7, 8). Analysis of variance based on individual provenance indicated that clonal differences within the Thunder Bay, the Kenogami River and the Sandy Lake provenances were significant in 1991, but only clones within the Kenogami River provenance exhibited significant variation in 1994. In both years, the shortest tracheid was in a clone from the Kenogami River provenance and the longest tracheid clone was in the Thunder Bay provenance. Two southern provenances had longer tracheids than two northern provenances in 1994, but their trachied length was similar to that in 1991 (Table 9, 10). Stand variation was not significant in either 1991 or 1994 (Table 7, 8).

Variance components for provenance increased from 1991 (1.5%) to 1994 (29.3%). However, variance components for clones decreased from 1991 (31.5%) to 1994 (14.2%) (Table 11).

Heritability

Broad-sense heritabilities based on variance components for provenances and clones within provenance are presented for each attribute in Table 12. Broad-sense heritabilities of tracheid length and specific gravity were much higher based on clonal variances than based on provenance variances. However, broad-sense heritabilities of diameter and height growth based on clonal variances were smaller than those based on provenance variances. In all the traits, latewood percentage had the lowest broad-sense heritabilities for both provenance and clone.

From 1991 to 1994, provenance broad-sense heritabilities of tracheid length, height growth , and ring width increased significantly, but there were no obvious changes in heritabilities of latewood percentage and specific gravity. Clonal broad-sense heritabilities of tracheid length and specific gravity showed a slight decrease from 1991 to 1994, but broad-sense heritabilities for all other traits increased.

Clonal broad-sense heritabilities estimated for individual provenances are listed in Table 13. They ranged widely for all the traits in both 1991 and 1994. The Kenogami

River provenance exhibited the highest clonal broad-sense heritabilities of tracheid length in both 1991 and 1994, and for specific gravity and height growth in 1991. The North Bay provenance showed the highest clonal broad-sense heritabilities for latewood percentage in both 1991 and 1994, and specific gravity and ring width in 1994. The Thunder Bay provenance had the highest broad-sense heritabilities for ring width in 1991, and the Sandy Lake provenance had the highest heritability for height growth in 1994. Except for 1991 specific gravity, they are larger than the clonal broad-sense heritabilities estimated using all provenances. Those traits that had higher clonal broad-sense heritabilities estimated using all the provenances also had higher clonal broad-sense heritabilities estimated using individual provenance analysis of variance.

Table 12. Broad-sense heritabilities based on provenance and clonal variance and their standard errors (in parentheses)

Traits	Heritability	
	provenance	clone
Tracheid Length, 1991	0.02(±0.04)	0.33(±0.10)
Tracheid Length, 1994	0.29(±0.18)	0.21(±0.09)
Specific Gravity, 1991	0.04(±0.06)	0.36(±0.10)
Specific Gravity, 1994	0.00(±0.03)	0.28(±0.10)
Height Growth Rate, 1991	0.19(±0.14)	0.00*(±0.07)
Height Growth Rate, 1994	0.36(±0.20)	0.18(±0.09)
Ringwidth Growth, 1991	0.26(±0.17)	0.11(±0.09)
Ringwidth Growth, 1994	0.26(±0.17)	0.22(±0.09)
Latewood percentage, 1991	0.00(±0.03)	0.00(±0.07)
Latewood percentage, 1994	0.00(±0.03)	0.11(±0.09)

* Heritability is zero or negative

Table 13. Broad-sense heritability and their standard errors (in parentheses)* based on clonal variance from analyses of variance for individual provenances

provenance	North Bay	Thunder Bay	Kenogami	Sandy Lake
		1994		
Tracheid Length	0.15 (±0.09)	0.18 (±0.09)	0.25 (±0.10)	0.11 (±0.09)
Specific Gravity	0.45 (±0.09)	0.15 (±0.09)	0.15 (±0.09)	0.31 (±0.10)
Height Growth	0.12 (±0.09)	0.10 (±0.09)	0 (±0.07)	0.39 (±0.10)
Ring Width	0.60 (±0.08)	0 (±0.07)	0.12 (±0.09)	0 (±0.07)
Latewood percentage	0.31 (±0.10)	0. 15 (±0.09)	0.04 (±0.08)	0 (±0.07)
		1991		
Tracheid Length	0.11 (±0.09)	0.29 (±0.10)	0.43 (±0.10)	0.30 (±0.10)
Specific Gravity	0.09 (±0.08)	0.33 (±0.10)	0.55 (±0.09)	0.10 (±0.08)
Height Growth	0.13 (±0.09)	0 (±0.07)	0.28 (±0.10)	0.03 (±0.08)
Ring Width	0.04 (±0.08)	0.28 (±0.10)	0.07 (±0.08)	0 (±0.07)
Latewood percentage	0.02 (±0.08)	0 (±0.07)	0 (±0.07)	0 (±0.07)

*** Clonal broad-sense heritability estimates for individual provenance's were based on individual provenance ANOVA that were presented in Appendix V.**

Correlations

Pearson product-moment correlation coefficients (phenotypic correlation) based on individual tree data for all traits in both 1991 and 1994 are presented in Tables 14 and Table 15.

The phenotypic correlations are very small, and in most situations, they are not significant except correlations of height growth with ring width, and latewood percentage with ring width. An negative correlation of latewood percentage with specific gravity was found. Most of the phenotypic correlations increased in variable degrees from 1991 to 1994.

Genetic correlations were calculated for all pairs of traits in the same year at the clonal level. Some genetic correlation are not available for 1991, because the variation components were zero or negative. Most genetic correlations estimated from clonal components are higher than phenotypic correlations, especially correlations of tracheid length with specific gravity, and ring width with latewood percentage. However genetic correlations of ring width with height growth and latewood percentage with height growth were lower than phenotypic correlations. Genetic correlations of ring width with latewood percentage, height growth with latewood percentage and height growth with ring width are similar to phenotypic correlations.

Table 14. Phenotypic and Genetic Correlation (in Parentheses) Among Wood Property and Growth Traits in 1991.

	Tracheid Length	Specific Gravity	Height Growth	Ring Width
Specific Gravity	-0.04(0.80)			
Height Growth	0.02na*	0.02na		
Ring Width	0.08(0.61)	0.06(0.25)	0.38na	
Latewood percentage	0.09na	-0.11 na	0.04na	0.07na

* Genetic correlations are not available because variation components are zero or negative

Table 15. Phenotypic and Genetic Correlation (in Parentheses) Among Wood Property and Growth Traits in 1994

	Tracheid Length	Specific Gravity	Height Growth	Ring Width
Specific Gravity	0.04(0.88)			
Height Growth	0.16(0.24)	0.06(0.58)		
Ring Width	0.07(0.52)	-0.24(0.03)	0.49(0.48)	
Latewood percentage	0.05(0.79)	-0.05(0.30)	0.24(0.19)	0.60(0.61)

DISCUSSION

Growth Characteristics

The significant variation in growth between northern and southern provenances demonstrated that tamarack growth characteristics in this test continue to follow a clinal pattern associated with environmental gradients of latitude and the length of the growing season (Deng 1990; Farmer *et al.* 1993). Similar observations on tamarack growth patterns have been reported by Jeffers (1975), Cech *et al.* (1977), Riemenschneider *et al.* (1980). They concluded that the reason for the clinal pattern is the photoperiodic response. Aastveit (1983) and Heide (1983) explained this photoperiodic response in forest trees as the result of eons of adaptation to given environments. The northern provenances adapt to short growth periods and develop hardiness in late summer. The southern provenances, from regions with longer growing seasons, adapt to display a higher growth potential than northern provenances.

The clonal variation for growth characteristics was much smaller than provenance variation. However, the clonal variance increased substantially from 1991 to 1994 (Table 11). Analysis of variance showed that clonal height growth and diameter growth did not vary significantly in 1991. But clonal variance was significant in 1994 for both height and diameter growth and contributed a substantial percent of variance. However, analysis of variance for individual provenance showed that clonal variation is unstable from provenance to provenance and from year to year. This result is in agreement with the results of Deng (1990), and Farmer *et al.* (1993). They interpreted this to (1) the relatively small samples, (2) some provenances (normally the northern provenances) may more sensitive to photoperiodic response than others, and (3) clones within those provenances may have more widely different shoot elongation periods. Competition among clones may also contribute to the clonal variance, and the clonal variation may increase with the age increasing. St.Clair (1993) noted that Douglas-fir height growth and diameter are distinct traits in reaction to competition. He concluded that "As the stand developed, larger trees appeared to allocate more stem biomass to diameter growth than to height growth, whereas smaller trees attempted to avoid suppression by allocating stem biomass to height growth at the expense of diameter." This may be the reason why the significant clonal height growth variation existed in the Kenogami River and the Sandy Lake provenances, and the significant clonal diameter growth variation only existed in the North Bay and the Thunder Bay provenances (Table 9, 10).

Wood Properties

The pattern of tracheid length variation is similar to that of growth characteristics variation in the two years (7 and 10) studied. Differences among provenances and clones increased from 1991 to 1994. In 1994 variation was significantly different among provenances. The radical change of the tracheid length from 1991 to 1994 demonstrated that the transition from juvenile growth to mature growth in the North Bay and the Thunder Bay provenances may take place earlier than in the Kenogami River and the Sandy Lake provenances. It also suggested that the North Bay and the Thunder Bay provenances may have a shorter juvenile growth period than the Kenogami River and the Sandy Lake provenances. Negative correlation between tracheid length and latitude was found in this study. However, Yang and Hazenberg (1987) found a weak positive correlation between tracheid length and latitude in tamarack, although they noted that it was not statistically significant. Zobel *et al.*. (1960) and Whitesell *et al.*. (1966) demonstrated that in *Pinus taeda* tracheid lengths increased significantly with decreasing latitude. Dinwoodie and Richardson (1961), in their study on *Picea sitchensis*, found a highly significant positive linear relationship between tracheid length and height increment and they noted that tracheid length decreased with increasing latitude of origins. The south-north trend existing in tracheid length had been explained by Larson (1963) and Irgens-Moller (1958) as the result of heritable differences in growing periods and the resulting physiological processes directly influencing cambial initial and tracheid elongation.

Clonal variation in tracheid length was significantly different in both 1991 and 1994 (Table7, 8). Clonal variance contributed most of the total genetic variance. This is similar to the results reported by Yang and Hanzenberg (1987), i.e. that individual tamarack trees within natural stands exhibit significant tracheid length variation. The observation is also in agreement with those of clonal variation in tracheid length in *Picea abies* (Kennedy 1966) and *Populus balsamifera* (Ivkovich 1995).

Provenance variation in specific gravity was not significant in either 1991 or 1994(Table7, 8). The faster growing provenances had a slightly higher specific gravity than slower growing provenances. This result is at odds with some observations that faster growth will produce lower specific gravity wood (Bendsten 1978; Zobel 1981; Megraw 1985). It is also different from the results reported by Yang and Hazenberg (1987), that tamarack specific gravity of natural stands increased slightly with increasing latitudes and the relationship between them is significant. It is in agreement with the results reported by Loo *et al.*. (1982) for *Larix leptolepis* , and the *Pinus taeda* provenance tests reported by Zobel and McElwee (1958), Zobel *et al.* (1960), Mitchell (1964), and Ledig *et al.* (1975) showing that specific gravity increases slightly with decreasing latitude.

The clonal variation in specific gravity contributed about one third of the total variance, and thus demonstrated that specific gravity was under strong genetic control. No data are available on tamarack clonal specific gravity for comparison. However results from studies on phenotypic variation reported by Isebrands and Hunt (1975), and Yang and Hazenberg (1987) in natural stands of tamarack showed that variation among individual trees within stands was significantly different. My findings are also in agreement with the results of a *Picea abies* clonal test reported by Kennedy (1966) and a *Populus balsamifera* clonal test reported by Ivkovich (1995).

Increase in specific gravity with age was small and not statistically significant. Yang *et al.*. (1986) and Wong (1987) noted that specific gravity increased with age in tamarack juvenile wood. This increase in specific gravity with age has also been reported by Szymanski and Tauer (1991) in *Pinus taeda*. They noted that specific gravity and percent of summerwood had negative correlations with juvenile-mature transition age. Southern provenances make the transition from juvenile growth to mature growth earlier than northern provenances (Zobel and Talbert 1984). We may expect that southern provenances have higher whole tree specific gravity than northern provenances when they are planted under the same environmental conditions on southern sites. This has been suggested by Szymanski and Tauer (1991) as a way to breed trees with a small percent of juvenile wood and high whole tree specific gravity. However, the complex internal and external effects on specific gravity, the lack of information on the genotypic variation in tamarack, and the irregular trend in this study suggest that more research is required prior to making such a recommendation for tamarack.

Although significant phenotypic variation in latewood percent was found among locations by Yang and Hazenberg (1987) in tamarack, in this study variation in latewood percentage is not significant among provenances or clones within provenances (Table 7, 8). The provenance and clonal contributions to the total variance are small and negligible (Table 11). Larson (1963) stated that when northern provenances are planted south of origin, their earlywood growth can be prolonged by favorable environmental conditions. This result suggests that latewood percentage could be influenced more by environmental factors than by the genetic composition of the provenances or clones. Zahner (1962) found that the transition from earlywood to latewood begins after the trees are under severe water deficit and may occur very early in summer. Larson (1963) noted that the drought caused transition from earlywood to latewood by limiting auxin supply. Water stress also operates indirectly by reducing photosynthesis and growth. This results in a decrease in the synthesis of auxin and the induction of the transition from earlywood to latewood change. Many other environmental factors, such as temperature, soil, light, affect the formation of latewood (Zobel and van Buijtenen 1989). Kennedy(1971) reported a similar variation in latewood percent in *Pinus banksinana*. However, a significant increase in provenance and clonal variance components percent (Table 11) from 1991 to 1994 indicated that age is a factor influencing formation of latewood, and genetic selection for latewood percentage may still be possible with increasing age. Larson (1957), Megraw (1985), Yang *et al.* (1986) and Wong (1987) found that with increasing age, the variation of latewood percentage increased in tamarack and other species. However, because many and complex factors influence the formation of latewood, the reliability of those selections is low (Zobel and van Buijtenen 1989). Studies are therefore needed to further understand latewood percentage variation in tamarack provenances, clones, different ages and different plantations.

Phenotypic and Genetic Correlation

The strong phenotypic and genetic correlations between height growth and diameter growth indicate that tamarack diameter growth and height growth represent each other reliably, and selection for one will have high probability of success in the other. A similar correlation between diameter and height growth has been reported in tamarack provenances by Riemenschneider (1980).

Phenotypic correlations among wood properties are low (Table 14, 15). This agrees with observations reported by Yang and Hanzenberg (1987) for tamarack natural stands study in northwest Ontario. It is also in agreement with results reported by Tayor and Burton (1982) for *Pinus taeda*. The genetic correlations among wood properties are positive and high (Table 14, 15). They are larger than phenotypic correlations. Similar correlations (0.44 to 0.67) between specific gravity and latewood percentage were reported in *Pinus radiata* by Nicholls *et al.* (1980), and in *Pinus taeda* by Goggans (1964). However, the strong genetic correlation between tracheid length and specific gravity in this study is in contrast with the lack of correlation among these characters reported by Harris *et al.* (1975) in *Pinus radiata*, Zobel (1960) and Megraw (1985) in *Pinus taeda*. They concluded that the genetic correlation between tracheid length and specific gravity is either weak or genetically independent.

Correlations between growth rate and wood properties are complex. Tracheid length has a slight phenotypic correlation with height growth and diameter growth. This is similar to results reported by Yang and Hanzenberg (1987), but different from those of Petrik (1968) in tamarack. The genetic correlations between tracheid length and growth rate are moderate and positive. These correlations are similar with results reported by Echols (1958) in *Pinus sylvestris*, Matziris and Zobel (1973) in *Pinus taeda*, and Ivkovich (1995) in *Populus balsamifera*. Other researchers (Dorn 1969; Echols 1973; Goggans 1964) noted those correlations may not exist or are low. Some papers reported negative correlations, e.g. Megraw (1985) in *Pinus taeda*, and Echols and Conkle (1971) in *Pinus ponderosa*. The phenotypic correlations between specific gravity and growth rate are low or negative. This is in agreement with the observation of Yang and Hazenberg (1987). It is also similar with the result reported by Zhang (1991) that growth rate shows little effect on specific gravity of *Quercus liaotungensis* juvenile wood. The low genetic correlation between diameter growth and specific gravity indicate these traits are genetically independent in this species. However, a high and positive correlation between height growth and specific gravity was found. These correlations between growth rate and wood properties demonstrate that fast growing tamarack provenances may also produce high quality wood. No study of the genetic relationship between the growth rate and specific gravity in tamarack was reported. Many studies had been done on the genetic relation between growth rate with specific gravity in other species, but the results are varied and confused. However, it is generally agreed that an inherent tendency for fast growth does not necessarily result in lower specific gravity wood (Megraw 1985). Zobel (1970) concluded " it is possible to breed for rapid growth and still retain high wood specific gravity if simultaneous selections are made for both growth and wood density."

Heritability

Provenance and clonal heritability varied from trait to trait, and year to year. Similar patterns have been reported by Zobel (1961, 1965) for *Pinus taeda* and Farmer *et al.*(1993) for tamarack. Larson (1963) indicated that the heritability changes from year to year partly due to the environment influences on tree growth and cell development. However, Nicholls (1967) stated that heritability changes with age is caused by the inherent age factor. He explained that different genes played a different role at different times, and the dominance relations of the same genes at different growth period are different.

The provenance heritability of growth characteristics is higher than clonal heritability. The genetic variation among provenances is mainly due to the different photoperiod response. Similar results have been reported by Deng (1990) and Farmer *et al.* (1993) for this tamarack provenance test. Although the clonal variation is significant in both 1991 and 1994, the percent of the clonal variance component and the clonal broad-sense heritability for growth characteristics are extremely low. So, this clonal variation may partly due to the environmental effects or error, because the estimates of clonal heritabilities were only based on the 8 genotypes sampled from each of four provenances (Deng 1990). The large differences in clonal variances may also due to the result of the interaction between genotype and environment. Competition among clones possibly contributed to clonal heritability increasing from 1991 to 1994. The irregular clonal broad-sense heritability estimated from the clonal variance for individual provenances, indicated that the reliability of clonal heritabilities for growth characteristics is low.

In contrast to growth characteristics, provenance broad-sense heirtabilities for tracheid length and specific gravity are much lower than clonal broad-sense heritabilities

(Table 12). This suggests that growth rate and length of growing season will not significantly influence the specific gravity. The heritabilities for specific gravity and tracheid length were relatively constant over age. The similar results have been reported before for *Pinus taeda* (Stonecypher and Zobel 1966), *Populus tremuloides* (Einspahr *et al.* 1977), *Pinus radiata* (Nicholls *et al.* 1980). The significant increase of provenance heritabilities for tracheid length may be the result that heritable factors influence the initial and elongation of tracheid (Bannan 1964). These results suggested that the provenance broad-sense heritability for tracheid length may increase with age. These results also suggest that it is essential to measure tracheid and other wood properties as long as possible over tree growth period (Zobel and van Buijtenen 1989).

Stand heritabilities for both growth characteristics and wood property characteristics are extremely low, and genetic gain in juvenile growth and wood property from stand selection is impossible. The similar results have been reported by Deng (1990) and Farmer *et al.* (1993) in tamarack.

CONCLUSIONS

(1) There is significant variation among provenances. Southern provenances have higher height growth, diameter growth, and longer tracheid length than northern provenances. Variation among provenances is not significant for either specific gravity or latewood percentage.

(2) Clonal variance contributes a significant portion of the total variance. Clonal variance in wood properties is large and relatively constant. However, growth characteristics variances are smaller compared with provenance variances, and are easier influenced by environmental factors than wood properties.

(3) Growth characteristics have higher provenance and lower clonal heritabilities than wood property characteristics. Heritabilities change with age, but heritabilities of wood properties are more constant than those of growth characteristics. Heritabilities of latewood percentage varied irregularly and are unreliable.

(4) The positive genetic correlations between growth characteristics and wood properties indicate that it is possible to improve both wood volume and wood properties in tamarack at same time.

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APPENDICES

APPENDIX I

TRACHEID LENGTH, SPECIFIC GRAVITY, HEIGHT GROWTH, DIAMETER GROWTH, AND LATEWOOD PERCENTAGE OF INDIVIDUAL TREES

(1991)

Tree Number	Tracheid Length mm	Specific Gravity	Annual Height Growth m	Diameter Growth (Ring Width) cm/ring	Latewood Percentage %
101211	1.15	0.50	0.63	0.57	0.26
101323	1.09	0.54	0.77	1.16	0.39
101343	1.11	0.42	1.01	0.81	0.31
101372	1.11	0.45	0.99	1.22	0.50
102253	1.12	0.46	0.85	0.87	0.21
102291	1.22	0.45	0.87	0.74	0.20
102323	1.20	0.40	0.78	1.20	0.40
102351	0.95	0.43	1.07	0.87	0.29
.	.	.	.	.	.
101211	1.23	0.59	0.68	0.98	0.23
101321	1.07	0.53	0.61	1.08	0.20
101342	1.28	0.37	0.83	1.04	0.33
101372	1.05	0.50	0.96	0.86	0.24
102251	1.04	0.41	0.98	1.03	0.27
102292	1.02	0.55	0.96	1.21	0.45
102321	1.31	0.38	0.83	0.83	0.35
102351	1.04	0.44	1.00	1.07	0.31
.	.	.	.	.	.
101211	1.22	0.42	0.40	1.00	0.23
101323	1.20	0.37	0.81	1.33	0.19
101342	1.10	0.47	0.42	1.09	0.23
101372	0.98	0.49	0.62	1.29	0.26
102252	1.10	0.46	0.65	1.13	0.16
102293	1.19	0.42	0.46	0.92	0.17
102321	1.06	0.47	0.68	0.91	0.30
102351	1.13	0.45	0.60	1.32	0.13
.	.	.	.	.	.
101213	1.22	0.41	0.66	0.56	0.32
101323	1.18	0.47	0.58	0.71	0.37
101341	1.11	0.38	0.78	0.97	0.19
101371	1.14	0.45	0.50	1.01	0.21
102252	1.14	0.41	0.75	0.79	0.26
102293	1.04	0.59	0.60	0.82	0.20
102323	1.30	0.38	0.44	1.07	0.44
102351	1.22	0.40	0.78	0.60	0.32
.	.	.	.	.	.
501272	1.16	0.45	0.98	1.19	0.21
501282	1.08	0.43	0.88	1.04	0.17
501311	1.17	0.45	1.03	0.91	0.22
501333	1.11	0.44	0.68	0.90	0.34
502261	1.05	0.38	0.73	0.83	0.38
502291	1.21	0.47	0.30	1.05	0.33
502322	1.14	0.45	0.99	1.10	0.28
502332	1.12	0.43	0.93	0.79	0.26

Appendix I Continued.

501272	1.32	0.47	0.75	0.45	0.31
501283	1.20	0.43	0.70	1.21	0.26
501313	1.15	0.50	0.53	0.87	0.29
501332	1.12	0.43	0.70	0.80	0.20
502261	1.18	0.38	0.47	1.01	0.33
502291	1.25	0.39	0.62	0.72	0.16
502322	1.23	0.41	0.83	0.73	0.19
502333	1.01	0.41	0.46	0.57	0.27
.	.	.	.	.	.
501272	1.05	0.41	0.68	1.11	0.23
501281	1.15	0.42	0.40	0.95	0.33
501313	1.12	0.46	0.25	0.49	0.17
501331	1.22	0.38	0.60	0.60	0.23
502261	1.12	0.37	0.57	0.73	0.17
502293	1.10	0.40	1.12	1.14	0.26
502322	1.22	0.42	0.51	0.81	0.27
502333	0.98	0.44	0.69	0.49	0.39
.	.	.	.	.	.
501273	1.23	0.45	0.30	1.02	0.34
501282	1.19	0.41	0.93	1.05	0.25
501313	1.06	0.48	0.64	0.64	0.17
501331	1.07	0.50	0.58	0.65	0.28
502261	1.04	0.39	0.56	0.41	0.20
502292	1.17	0.56	0.65	1.04	0.34
502323	1.34	0.43	0.75	0.85	0.26
502331	1.09	0.42	0.86	0.66	0.16
.	.	.	.	.	.
901251	1.20	0.41	0.69	0.76	0.25
901281	1.14	0.58	0.33	0.52	0.26
901403	1.07	0.37	0.71	0.75	0.29
901412	0.91	0.38	0.49	0.66	0.31
902312	1.08	0.45	0.55	0.37	0.27
902363	0.97	0.44	0.61	0.44	0.23
902403	0.99	0.39	0.65	0.72	0.39
902412	1.11	0.42	0.47	0.40	0.30
.	.	.	.	.	.
901253	1.17	0.38	0.60	0.91	0.23
901281	1.14	0.54	0.57	0.93	0.22
901403	1.14	0.39	0.62	0.93	0.30
901413	0.99	0.38	0.45	0.57	0.28
902313	1.18	0.44	0.69	0.64	0.16
902361	1.36	0.42	0.83	0.84	0.32
902401	1.13	0.39	0.65	0.65	0.20
902411	1.06	0.39	0.83	1.07	0.21
.	.	.	.	.	.
901253	1.17	0.40	0.48	0.63	0.37
901282	1.22	0.47	0.47	0.45	0.28
901401	1.11	0.35	0.61	0.71	0.22
901413	0.96	0.41	0.40	0.61	0.18
902313	1.23	0.46	0.62	0.63	0.20
902363	1.29	0.46	0.42	0.64	0.39
902403	1.02	0.40	0.34	0.60	0.24
902413	0.98	0.41	0.43	0.55	0.34

Appendix I Continued.

901252	1.04	0.38	0.61	0.70	0.42
901282	1.14	0.50	0.42	0.69	0.23
901402	1.04	0.39	0.58	0.71	0.21
901413	0.83	0.46	0.40	0.49	0.13
902313	1.26	0.44	0.68	0.68	0.16
902361	1.12	0.64	0.54	0.30	0.19
902402	1.19	0.37	0.57	0.61	0.30
902411	1.11	0.44	0.72	0.76	0.38
1301213	1.14	0.48	0.75	0.85	0.15
1301233	1.17	0.45	0.45	0.73	0.23
1301291	1.13	0.36	0.64	0.61	0.23
1301342	0.96	0.43	0.59	1.00	0.16
1302213	1.11	0.45	0.73	0.71	0.17
1302253	1.27	0.44	0.50	0.83	0.28
1302273	1.14	0.42	0.32	1.07	0.18
1302283	1.07	0.43	0.73	0.91	0.11
1301212	1.05	0.43	0.71	0.78	0.22
1301233	1.25	0.43	0.68	0.70	0.37
1301292	1.11	0.40	0.41	0.44	0.41
1301342	1.14	0.41	0.52	0.70	0.17
1302211	1.14	0.43	0.54	0.61	0.26
1302252	1.18	0.43	0.72	0.63	0.24
1302272	1.12	0.40	0.56	0.59	0.30
1302283	1.07	0.43	0.48	0.74	0.19
1301212	1.04	0.49	0.49	0.77	0.26
1301231	1.28	0.36	0.49	0.50	0.40
1301293	1.11	0.38	0.48	0.92	0.20
1301342	1.10	0.39	0.45	0.68	0.28
1302211	1.06	0.41	0.43	0.56	0.25
1302253	1.25	0.41	0.40	0.79	0.16
1302272	1.08	0.40	0.41	0.45	0.19
1302281	1.06	0.39	0.36	0.90	0.44
1301212	1.09	0.44	0.83	0.96	0.46
1301231	1.10	0.46	0.75	0.90	0.28
1301292	1.06	0.39	0.59	0.98	0.40
1301342	1.08	0.41	0.67	0.58	0.31
1302212	1.10	0.43	0.77	0.72	0.23
1302251	1.07	0.41	0.47	0.59	0.37
1302271	1.06	0.42	0.80	1.07	0.29
1302282	1.16	0.38	0.47	0.87	0.45

APPENDIX II

TRACHEID LENGTH, SPECIFIC GRAVITY, HEIGHT GROWTH, DIAMETER GROWTH, AND LATEWOOD PERCENTAGE OF INDIVIDUAL TREES

(1994)

Tree Number	Tracheid Length mm	Specific Gravity	Annual Height Growth m	Diameter growth (Ring Width) cm/ring	Latewood Percentage %
101211	1.50	0.56	0.83	0.79	0.28
101323	1.50	0.50	0.73	0.94	0.32
101343	1.24	0.42	0.93	1.58	0.30
101372	1.80	0.50	0.75	0.78	0.29
102253	1.45	0.46	0.74	0.79	0.22
102291	1.58	0.48	0.60	0.65	0.22
102323	1.42	0.42	0.52	0.75	0.22
102351	1.13	0.42	0.85	0.97	0.39
101211	1.46	0.49	1.01	0.95	0.31
101321	1.50	0.47	0.86	1.47	0.53
101342	1.43	0.39	0.75	1.66	0.35
101372	1.50	0.49	0.75	1.08	0.25
102251	1.44	0.44	0.84	1.27	0.28
102292	1.58	0.48	0.80	1.22	0.27
102321	1.39	0.41	0.65	1.39	0.25
102351	1.39	0.47	0.88	1.45	0.33
101211	1.60	0.40	0.74	0.94	0.22
101323	1.31	0.38	0.92	1.49	0.40
101342	1.33	0.42	0.89	1.72	0.38
101372	1.53	0.48	0.76	1.71	0.35
102252	1.40	0.46	0.91	1.04	0.28
102293	1.42	0.44	0.94	1.33	0.29
102321	1.67	0.43	0.91	1.33	0.32
102351	1.44	0.42	0.98	1.45	0.28
101213	1.35	0.45	0.87	0.96	0.26
101323	1.30	0.42	0.63	1.18	0.36
101341	1.36	0.39	0.80	1.64	0.34
101371	1.44	0.49	0.89	1.45	0.30
102252	1.56	0.45	0.81	1.08	0.34
102293	1.39	0.46	0.65	1.13	0.25
102323	1.55	0.36	0.72	1.41	0.23
102351	1.43	0.43	0.86	1.08	0.14
501272	1.61	0.43	0.65	1.25	0.33
501282	1.32	0.45	0.82	1.08	0.20
501311	1.45	0.48	0.50	0.74	0.19
501333	1.52	0.43	0.78	1.05	0.29
502261	1.29	0.39	0.68	1.07	0.22
502291	1.46	0.45	0.98	0.51	0.17
502322	1.49	0.41	0.76	0.83	0.23
502332	1.55	0.42	0.83	0.80	0.23

Appendix II Continued.

		.	.	.	
501272	1.53	0.40	0.57	0.43	0.25
501283	1.24	0.44	0.82	0.93	0.19
501313	1.38	0.47	0.71	1.08	0.27
501332	1.31	0.47	0.87	1.35	0.28
502261	1.49	0.44	0.69	1.49	0.53
502291	1.40	0.42	0.77	0.93	0.28
502322	1.43	0.44	0.83	1.24	0.42
502333	1.23	0.42	0.65	1.10	0.33
.	.	.	.	.	.
501272	1.44	0.44	0.87	1.71	0.35
501281	1.29	0.44	1.04	1.41	0.25
501313	1.46	0.44	0.83	1.22	0.38
501331	1.54	0.44	0.97	0.95	0.24
502261	1.36	0.39	0.78	1.68	0.54
502293	1.39	0.40	0.54	1.28	0.32
502322	1.68	0.44	0.93	1.55	0.46
502333	1.24	0.43	0.90	1.46	0.28
.	.	.	.	.	.
501273	1.31	0.39	0.90	1.34	0.32
501282	1.37	0.40	0.99	1.38	0.35
501313	1.35	0.44	0.95	1.03	0.41
501331	1.36	0.53	0.91	1.04	0.27
502261	1.47	0.37	0.85	0.85	0.26
502292	1.34	0.56	0.95	0.99	0.28
502323	1.48	0.41	0.95	1.27	0.36
502331	1.38	0.41	1.00	1.18	0.26
.	.	.	.	.	.
901251	1.42	0.42	0.65	0.73	0.21
901281	1.42	0.47	0.41	0.77	0.27
901403	1.28	0.40	0.62	1.03	0.32
901412	1.15	0.43	0.46	0.52	0.21
902312	1.19	0.53	0.50	0.39	0.19
902363	1.31	0.50	0.46	0.38	0.21
902403	1.28	0.44	0.49	1.10	0.37
902412	1.16	0.46	0.51	0.63	0.20
.	.	.	.	.	.
901253	1.18	0.46	0.53	0.77	0.24
901281	1.22	0.53	0.58	1.04	0.40
901403	1.39	0.42	0.66	0.84	0.21
901413	1.20	0.32	0.53	0.68	0.24
902313	1.26	0.44	0.56	0.89	0.26
902361	1.61	0.45	0.40	0.58	0.24
902401	1.25	0.43	0.52	0.77	0.23
902411	1.15	0.47	0.48	0.86	0.31
.	.	.	.	.	.
901253	1.26	0.41	0.80	1.11	0.28
901282	1.48	0.46	0.63	0.93	0.36
901401	1.35	0.39	0.46	1.33	0.42
901413	1.23	0.46	0.79	0.72	0.25
902313	1.26	0.42	0.56	1.22	0.24
902363	1.46	0.43	0.98	1.22	0.55
902403	1.33	0.42	0.76	1.09	0.35
902413	1.15	0.44	0.81	0.94	0.34

Appendix II Continued

901252	1.22	0.40	0.78	1.05	0.28
901282	1.33	0.45	0.76	1.10	0.33
901402	1.35	0.42	0.89	1.04	0.20
901413	1.22	0.47	0.86	1.03	0.33
902313	1.33	0.39	0.65	1.01	0.31
902361	1.11	0.56	0.85	0.71	0.37
902402	1.32	0.39	0.72	0.94	0.35
902411	1.17	0.42	0.68	1.32	0.26
.	.	.	.	.	.
1301213	1.33	0.45	0.65	0.37	0.16
1301233	1.55	0.43	0.31	0.62	0.21
1301291	1.37	0.38	0.56	0.38	0.13
1301342	1.22	0.43	0.45	0.63	0.12
1302213	1.29	0.53	0.59	0.52	0.24
1302253	1.34	0.44	0.65	0.61	0.13
1302273	1.25	0.41	0.79	1.09	0.46
1302283	1.21	0.41	0.65	0.65	0.19
.	.	.	.	.	.
1301212	1.08	0.48	0.81	0.75	0.22
1301233	1.24	0.50	0.51	0.80	0.36
1301292	1.46	0.39	0.59	0.71	0.20
1301342	1.29	0.47	0.59	0.64	0.23
1302211	1.58	0.44	0.56	0.92	0.30
1302252	1.31	0.43	0.64	0.98	0.26
1302272	1.49	0.31	0.66	0.96	0.27
1302283	1.27	0.46	0.65	0.91	0.22
.	.	.	.	.	.
1301212	1.16	0.46	0.98	1.14	0.20
1301231	1.52	0.40	0.78	0.84	0.27
1301293	1.11	0.36	0.68	1.34	0.26
1301342	1.08	0.36	0.52	1.13	0.25
1302211	1.24	0.41	0.83	1.21	0.28
1302253	1.30	0.39	0.77	1.35	0.24
1302272	1.29	0.45	0.63	1.09	0.28
1302281	1.14	0.42	0.81	1.15	0.41
.	.	.	.	.	.
1301212	1.29	0.48	0.77	1.41	0.52
1301231	1.29	0.45	0.65	1.09	0.30
1301292	1.20	0.36	0.66	1.47	0.51
1301342	1.12	0.43	0.55	0.96	0.31
1302212	1.35	0.53	0.84	1.07	0.23
1302251	1.46	0.42	0.78	0.88	0.27
1302271	1.25	0.43	0.75	1.36	0.37
1302282	1.44	0.41	0.61	1.31	0.49

Appendix III

ANALYSIS OF VARIANCE, VARIANCE COMPONENTS CALCULATIONS FOR WOOD PROPERTY AND GROWTH TRAITS

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1. Analysis of Variance For 1991 Tracheid Length

Source	df	Sums of Squares	Mean Square	F-ratio	Prob	Variance Components
bi	3	0.0266	0.0089	1.59	0.26	0.00010
pj	3	0.0309	0.0103	1.84	0.28	0.00015
bi*pj	9	0.0501	0.0056	1.11	0.43	0.00007
sjk	4	0.0224	0.0056	0.31	0.87	0.00000
bi*sjk	12	0.0603	0.0050	0.81	0.64	0.00000
cjl	24	0.4358	0.0182	2.94	0.00	0.00299
Error	72	0.4453	0.0062			0.00619
Total	127	1.0714				

2. Analysis of Variance For 1991 Specific Gravity

Source	df	Sums of Squares	Mean Square	F-ratio	Prob	Variance Components
bi	3	0.0084	0.0028	1.65	0.25	0.000034
pj	3	0.0178	0.0059	3.18	0.15	0.000127
bi*pj	9	0.0154	0.0017	1.15	0.40	0.000028
sjk	4	0.0074	0.0019	0.32	0.86	0.000000
bi*sjk	12	0.0177	0.0015	0.84	0.61	0.000000
cjl	24	0.1381	0.0058	3.26	0.00	0.000997
Error	72	0.1271	0.0018			0.001765
Total	127	0.3319				

3. Analysis of Variance For 1991 Diameter Growth

Source	df	Sums of Squares	Mean Square	F-ratio	Prob	Variance Components
bi	3	0.0823	0.0274	0.24	0.87	0.00000
pj	3	1.7316	0.5772	33.09	0.00	0.01749
bi*pj	9	1.0399	0.1155	13.46	0.00	0.01337
sjk	4	0.0698	0.0174	0.36	0.84	0.00000
bi*sjk	12	0.1030	0.0086	0.26	0.99	0.00000
cjl	24	1.1681	0.0487	1.49	0.10	0.00398
Error	72	2.3570	0.0327			0.03274
Total	127	6.5516				

4. Analysis of Variance For 1991 Latewood Percentage

Source	df	Sums of Squares	Mean Square	F-ratio	Prob	Variance Components
bi	3	0.0169	0.0056	0.33	0.81	0.00000
pj	3	0.0074	0.0025	1.25	0.40	0.00002
bi*pj	9	0.1558	0.0173	3.45	0.02	0.00154
sjk	4	0.0079	0.0020	0.34	0.85	0.00000
bi*sjk	12	0.0601	0.0050	0.76	0.69	0.00000
cjl	24	0.1406	0.0059	0.88	0.62	0.00000
Error	72	0.4772	0.0066			0.00663
Total	127	0.8660				

5. Analysis of Variance For 1991 Height Growth

Source	df	Sums of Squares	Mean Square	F-ratio	Prob	Variance Components
bi	3	0.6415	0.2138	4.16	0.04	0.00508
pj	3	0.6873	0.2291	8.95	0.03	0.00636
bi*pj	9	0.4627	0.0514	2.12	0.11	0.00334
sjk	4	0.1024	0.0256	1.24	0.32	0.00031
bi*sjk	12	0.2906	0.0242	1.00	0.46	0.00001
cjl	24	0.4975	0.0207	0.86	0.66	0.00000
Error	72	1.7420	0.0242			0.02420
Total	127	4.4239				

6. Analysis of Variance For 1994 Tracheid Length

Source	df	Sums of Squares	Mean Square	F-ratio	Prob	Variance Components
bi	3	0.0229	0.0076	0.72	0.56	0.00000
pj	3	0.6584	0.2195	27.17	0.00	0.00661
bi*pj	9	0.0949	0.0105	0.75	0.67	0.00000
sjk	4	0.0323	0.0081	0.32	0.86	0.00000
bi*sjk	12	0.1697	0.0141	1.15	0.34	0.00046
cjl	24	0.6025	0.0251	2.04	0.01	0.00320
Error	72	0.8860	0.0123			0.01231
Total	127	2.4667				

7. Analysis of Variance For 1994 Specific Gravity

Source	df	Sums of Squares	Mean Square	F-ratio	Prob	Variance Components
bi	3	0.0117	0.0039	5.22	0.02	0.000098
pj	3	0.0054	0.0018	1.09	0.45	0.000005
bi*pj	9	0.0067	0.0007	0.52	0.84	0.000000
sjk	4	0.0066	0.0016	0.43	0.79	0.000000
bi*sjk	12	0.0173	0.0014	0.97	0.49	0.000000
cjl	24	0.0923	0.0038	2.58	0.00	0.000589
Error	72	0.1072	0.0015			0.001496
Total	127	0.2471				

8. Analysis of Variance For 1994 Height Growth

Source	df	Sums of Squares	Mean Square	F-ratio	Prob	Variance Components
bi	3	0.6231	0.2077	8.08	0.01	0.00569
pj	3	0.8673	0.2891	20.98	0.01	0.00860
bi*pj	9	0.2314	0.0257	1.39	0.29	0.00091
sjk	4	0.0551	0.0137	0.73	0.58	0.00000
bi*sjk	12	0.2213	0.0184	1.82	0.06	0.00208
cjl	24	0.4548	0.0190	1.87	0.02	0.00221
Error	72	0.7294	0.0101			0.01013
Total	127	3.1824				

9. Analysis of Variance For 1994 Diameter Growth

Source	df	Sums of Squares	Mean Square	F-ratio	Prob	Variance Components
bi	3	3.9963	1.3321	17.69	0.00	0.03927
pj	3	2.0847	0.6949	11.79	0.02	0.01987
bi*pj	9	0.6777	0.0753	1.58	0.23	0.00344
sjk	4	0.2358	0.0589	0.68	0.61	0.00000
bi*sjk	12	0.5733	0.0478	1.18	0.32	0.00179
cjl	24	2.0746	0.0864	2.13	0.01	0.01146
Error	72	2.9241	0.0406			0.04061
Total	127	12.5664				

10. Analysis of Variance For 1994 Latewood Percentage

Source	df	Sums of Squares	Mean Square	F-ratio	Prob	Variance Components
bi	3	0.1319	0.0440	3.61	0.06	0.00099
pj	3	0.0123	0.0041	0.38	0.77	0.00000
bi*pj	9	0.1097	0.0122	1.51	0.25	0.00051
sjk	4	0.0426	0.0107	1.33	0.29	0.00017
bi*sjk	12	0.0972	0.0081	1.50	0.15	0.00067
cjl	24	0.1917	0.0080	1.48	0.10	0.00065
Error	72	0.3892	0.0054			0.00541
Total	127	0.9745				

APPENDIX IV

CALCULATIONS OF COVARIANCE COMPONENTS

1. Tracheid Length vs Specific Gravity of 1991

Source	df	Sums of Squares	Mean Square	F-ratio	Prob	Covariance Components
bi	3	0.0070	0.0023	2.22	0.16	0.00004
pj	3	0.0188	0.0063	2.27	0.22	0.00011
bi*pj	9	0.0094	0.0010	0.53	0.83	-0.00012
sjk	4	0.0110	0.0028	0.43	0.79	-0.00023
bi*sjk	12	0.0238	0.0020	2.14	0.02	0.00026
cjl	24	0.1554	0.0065	6.98	0.00	0.00139
Error	72	0.0668	0.0009			0.00093
Total	127	0.2921				

2. Tracheid Length vs Height Growth Rate of 1991

Source	df	Sums of Squares	Mean Square	F-ratio	Prob	Covariance Components
bi	3	0.3006	0.1002	5.84	0.02	0.00260
pj	3	0.3337	0.1112	7.64	0.04	0.00302
bi*pj	9	0.1544	0.0172	1.32	0.32	0.00052
sjk	4	0.0583	0.0146	1.23	0.32	0.00017
bi*sjk	12	0.1561	0.0130	1.10	0.37	0.00030
cjl	24	0.2836	0.0118	1.00	0.48	0.00001
Error	72	0.8495	0.0118			0.01180
Total	127	2.1362				

3. Tracheid Length vs Riong Width of 1991

Source	df	Sums of Squares	Mean Square	F-ratio	Prob	Covariance Components
bi	3	0.0301	0.0100	0.24	0.86	-0.00097
pj	3	0.6908	0.2303	50.96	0.00	0.00706
bi*pj	9	0.3709	0.0412	8.14	0.00	0.00452
sjk	4	0.0181	0.0045	0.21	0.93	-0.00107
bi*sjk	12	0.0607	0.0051	0.38	0.96	-0.00202
cjl	24	0.5178	0.0216	1.64	0.06	0.00211
Error	72	0.9473	0.0132			0.01316
Total	127	2.6358				

4. Tracheid Length vs Latewood Percentage of 1991

Source	df	Sums of Squares	Mean Square	F-ratio	Prob	Covariance Components
bi	3	0.0201	0.0067	0.40	0.76	-0.00032
pj	3	0.0076	0.0025	1.13	0.44	0.00001
bi*pj	9	0.1519	0.0169	3.49	0.02	0.00151
sjk	4	0.0089	0.0022	0.26	0.90	-0.00039
bi*sjk	12	0.0580	0.0048	0.64	0.80	-0.00067
cjl	24	0.2041	0.0085	1.13	0.33	0.00025
Error	72	0.5414	0.0075			0.00752
Total	127	0.9919				

5. Specific Gravity vs Height Growth of 1991

Source	df	Sums of Squares	Mean Square	F-ratio	Prob	Covariance Components
bi	3	0.1449	0.0483	5.22	0.02	0.00122
pj	3	0.1605	0.0535	10.96	0.02	0.00152
bi*pj	9	0.0833	0.0093	1.89	0.15	0.00055
sjk	4	0.0195	0.0049	1.01	0.42	0.00000
bi*sjk	12	0.0587	0.0049	1.18	0.32	0.00018
cjl	24	0.1157	0.0048	1.16	0.31	0.00017
Error	72	0.2990	0.0042			0.00415
Total	127	0.8815				

6. Specific Gravity vs Ring Width of 1991

Source	df	Sums of Squares	Mean Square	F-ratio	Prob	Covariance Components
bi	3	0.0164	0.0055	0.30	0.82	-0.00040
pj	3	0.3171	0.1057	24.86	0.00	0.00317
bi*pj	9	0.1643	0.0183	9.23	0.00	-0.00019
sjk	4	0.0170	0.0043	0.57	0.69	-0.00020
bi*sjk	12	0.0237	0.0020	0.36	0.97	0.00357
cjl	24	0.1790	0.0075	1.36	0.16	0.00049
Error	72	0.3951	0.0055			0.00549
Total	127	1.1127				

7. Specific Gravity vs Latewood Percentage of 1991

Source	df	Sums of Squares	Mean Square	F-ratio	Prob	Covariance Components
bi	3	0.0109	0.0036	0.54	0.66	-0.00010
pj	3	0.0076	0.0025	2.90	0.17	0.00005
bi*pj	9	0.0602	0.0067	2.70	0.06	0.00053
sjk	4	0.0035	0.0009	0.38	0.82	-0.00009
bi*sjk	12	0.0297	0.0025	0.93	0.52	-0.00005
cjl	24	0.0551	0.0023	0.86	0.65	-0.00009
Error	72	0.1914	0.0027			0.00266
Total	127	0.3584				

8. Height Growth vs Ring Width of 1991

Source	df	Sums of Squares	Mean Square	F-ratio	Prob	Covariance Components
bi	3	0.2752	0.0917	1.59	0.26	0.00106
pj	3	1.0059	0.3353	68.19	0.00	0.01032
bi*pj	9	0.5196	0.0577	4.57	0.01	0.00564
sjk	4	0.0197	0.0049	0.22	0.92	-0.00108
bi*sjk	12	0.1515	0.0126	0.72	0.73	-0.00125
cjl	24	0.5325	0.0222	1.26	0.22	0.00114
Error	72	1.2685	0.0176			0.01762
Total	127	3.7728				

9. Height Growth vs Latewood Percentage of 1991

Source	df	Sums of Squares	Mean Square	F-ratio	Prob	Covariance Components
bi	3	0.1007	0.0336	1.46	0.29	0.00033
pj	3	0.0912	0.0304	5.11	0.07	0.00076
bi*pj	9	0.2066	0.0230	3.92	0.02	0.00214
sjk	4	0.0238	0.0059	1.28	0.30	0.00008
bi*sjk	12	0.0703	0.0059	1.06	0.41	0.00008
cjl	24	0.1113	0.0046	0.84	0.68	-0.00022
Error	72	0.3978	0.0055			0.00552
Total	127	1.0017				

10. Ring Width vs Latewood Percentage of 1991

Source	df	Sums of Squares	Mean Square	F-ratio	Prob	Covariance Components
bi	3	0.0138	0.0046	0.26	0.86	-0.00042
pj	3	0.1724	0.0575	32.47	0.00	0.00174
bi*pj	9	0.1620	0.0180	2.88	0.05	0.00147
sjk	4	0.0071	0.0018	0.16	0.95	-0.00056
bi*sjk	12	0.0749	0.0062	0.75	0.70	-0.00051
cjl	24	0.2579	0.0107	1.30	0.20	0.00061
Error	72	0.5973	0.0083			0.00830
Total	127	1.2853				

11. Tracheid Length vs Specific Gravity of 1994

Source	df	Sums of Squares	Mean Square	F-ratio	Prob	Covariance Components
bi	3	0.0148	0.0049	3.10	0.08	0.00011
pj	3	0.0728	0.0243	17.56	0.01	0.00072
bi*pj	9	0.0144	0.0016	0.77	0.65	-0.00006
sjk	4	0.0055	0.0014	0.22	0.93	-0.00031
bi*sjk	12	0.0250	0.0021	1.31	0.23	0.00012
cjl	24	0.1538	0.0064	4.03	0.00	0.00121
Error	72	0.1145	0.0016			0.00159
Total	127	0.4009				

12. Tracheid Length vs Height Growth Rate of 1994

Source	df	Sums of Squares	Mean Square	F-ratio	Prob	Covariance Components
bi	3	0.2592	0.0864	6.05	0.02	0.00225
pj	3	0.8843	0.2948	20.25	0.01	0.00876
bi*pj	9	0.1286	0.0143	1.36	0.30	0.00047
sjk	4	0.0582	0.0146	1.67	0.19	0.00037
bi*sjk	12	0.1261	0.0105	1.69	0.09	0.00107
cjl	24	0.2092	0.0087	1.40	0.14	0.00062
Error	72	0.4481	0.0062			0.00622
Total	127	2.1137				

13. Tracheid Length vs Ring width of 1994

Source	df	Sums of Squares	Mean Square	F-ratio	Prob	Covariance Components
bi	3	1.3512	0.4504	15.36	0.00	0.01316
pj	3	1.3933	0.4644	14.36	0.01	0.01350
bi*pj	9	0.2639	0.0293	1.45	0.27	0.00114
sjk	4	0.1293	0.0323	1.20	0.34	0.00034
bi*sjk	12	0.2421	0.0202	1.40	0.19	0.00143
cjl	24	0.6471	0.0270	1.87	0.02	0.00313
Error	72	1.0409	0.0145			0.01446
Total	127	5.0679				

14. Tracheid Length vs Latewood Percentage of 1994

Source	df	Sums of Squares	Mean Square	F-ratio	Prob	Covariance Components
bi	3	0.1443	0.0481	3.26	0.07	0.00104
pj	3	0.0930	0.0310	2.14	0.24	0.00052
bi*pj	9	0.1322	0.0147	2.07	0.12	0.00095
sjk	4	0.0578	0.0145	1.31	0.29	0.00021
bi*sjk	12	0.0851	0.0071	1.10	0.38	0.00016
cjl	24	0.2646	0.0110	1.70	0.04	0.00114
Error	72	0.4656	0.0065			0.00647
Total	127	1.2425				

15. Specific Gravity vs Height Growth Rate of 1994

Source	df	Sums of Squares	Mean Square	F-ratio	Prob	Covariance Components
bi	3	0.0789	0.0230	4.49	0.03	0.00056
pj	3	0.1481	0.0494	15.18	0.01	0.00144
bi*pj	9	0.0460	0.0051	1.18	0.39	0.00010
sjk	4	0.0130	0.0033	0.63	0.65	-0.00012
bi*sjk	12	0.0522	0.0043	1.70	0.08	0.00045
cjl	24	0.1244	0.0052	2.03	0.01	0.00066
Error	72	0.1842	0.0026			0.00256
Total	127	0.6368				

16. Specific Gravity vs Ring Width of 1994

Source	df	Sums of Squares	Mean Square	F-ratio	Prob	Covariance Components
bi	3	1.6918	0.5639	23.88	0.00	0.00366
pj	3	1.3102	0.4367	15.02	0.01	0.00235
bi*pj	9	0.2126	0.0236	1.64	0.21	0.00053
sjk	4	0.1163	0.0291	1.30	0.30	0.00015
bi*sjk	12	0.1726	0.0144	1.14	0.34	0.00003
cjl	24	0.5360	0.0223	1.77	0.03	0.00007
Error	72	0.9073	0.0126			0.00542
Total	127	4.9468				

17. Specific Gravity vs Latewood Percentage of 1994

Source	df	Sums of Squares	Mean Square	F-ratio	Prob	Covariance Components
bi	3	0.0385	0.0128	2.42	0.13	0.00024
pj	3	0.0098	0.0033	0.74	0.58	-0.00004
bi*pj	9	0.0478	0.0053	1.85	0.16	0.00031
sjk	4	0.0177	0.0044	1.54	0.22	0.00008
bi*sjk	12	0.0345	0.0029	1.36	0.21	0.00019
cjl	24	0.0688	0.0029	1.35	0.16	0.00019
Error	72	0.1526	0.0021			0.00212
Total	127	0.3697				

18. Height Growth Rate vs Ring Width 1994

Source	df	Sums of Squares	Mean Square	F-ratio	Prob	Covariance Components
bi	3	1.6918	0.5639	23.88	0.00	0.01689
pj	3	1.3102	0.4367	15.02	0.01	0.01274
bi*pj	9	0.2126	0.0236	1.64	0.21	0.00115
sjk	4	0.1163	0.0291	1.30	0.30	0.00042
bi*sjk	12	0.1726	0.0144	1.14	0.34	0.00045
cjl	24	0.5360	0.0223	1.77	0.03	0.00243
Error	72	0.9073	0.0126			0.01260
Total	127	4.9468				

19. Height Growth Rate vs Latewood Percentage 1994

Source	df	Sums of Squares	Mean Square	F-ratio	Prob	Covariance Components
bi	3	0.2710	0.0903	8.39	0.01	0.00249
pj	3	0.1390	0.0463	4.19	0.10	0.00110
bi*pj	9	0.0969	0.0108	1.73	0.19	0.00057
sjk	4	0.0442	0.0111	1.96	0.13	0.00034
bi*sjk	12	0.0748	0.0062	1.31	0.23	0.00037
cjl	24	0.1356	0.0057	1.19	0.28	0.00023
Error	72	0.3421	0.0048			0.00475
Total	127	1.1036				

20. Ring Width vs Latewood Percentage 1994

Source	df	Sums of Squares	Mean Square	F-ratio	Prob	Covariance Components
bi	3	0.7439	0.2480	9.72	0.00	0.00695
pj	3	0.2125	0.0708	2.89	0.17	0.00145
bi*pj	9	0.2297	0.0255	1.40	0.29	0.00092
sjk	4	0.0980	0.0245	1.34	0.28	0.00039
bi*sjk	12	0.2180	0.0182	1.56	0.12	0.00163
cjl	24	0.4385	0.0183	1.57	0.07	0.00165
Error	72	0.8398	0.0117			0.01166
Total	127	2.7804				

APPENDIX V

ANALYSIS OF VARIANCE OF INDIVIDUAL PROVENANCES FOR WOOD PROPERTY AND GROWTH TRAITS

TRACHEID LENGTH

(1). 1991

provenance	Source	df	Sums of Squares	Mean Square	F-ratio	Prob
North Bay	bi	3	0.0147	0.0049	0.64	0.60
	cj	7	0.0811	0.0116	1.51	0.22
	Error	21	0.1611	0.0078		
	Total	31	0.2569			
Thunder Bay	bi	3	0.0188	0.0063	1.20	0.33
	cj	7	0.0958	0.0137	2.62	0.04
	Error	21	0.1096	0.0052		
	Total	31	0.2242			
Kenogami River	bi	3	0.0352	0.0117	1.55	0.23
	cj	7	0.2124	0.0303	4.01	0.01
	Error	21	0.1590	0.0076		
	Total	31	0.4066			
Sandy Lake	bi	3	0.0080	0.0027	0.74	0.54
	cj	7	0.0689	0.0098	2.72	0.04
	Error	21	0.0760	0.0036		
	Total	31	0.1529			

(2). 1994

provenance	Source	df	Sums of Squares	Mean Square	F-ratio	Prob
North Bay	bi	3	0.0077	0.0026	0.17	0.91
	cj	7	0.1784	0.0256	1.71	0.16
	Error	21	0.3138	0.0149		
	Total	31	0.5000			
Thunder Bay	bi	3	0.0390	0.0130	1.36	0.28
	cj	7	0.1270	0.0181	1.89	0.12
	Error	21	0.2012	0.0096		
	Total	31	0.3672			
Kenogami River	bi	3	0.0143	0.0048	0.47	0.71
	cj	7	0.1668	0.0238	2.34	0.06
	Error	21	0.2135	0.0102		
	Total	31	0.3946			
Sandy Lake	bi	3	0.0567	0.0189	1.21	0.33
	cj	7	0.1626	0.0232	1.49	0.22
	Error	21	0.3272	0.0156		
	Total	31	0.5466			

Appendix V Continued

SPECIFIC GRAVITY

(1). 1991

provenance	Source	df	Sums of Squares	Mean Square	F-ratio	Prob
	bi	3	0.0062	0.0021	0.60	0.62
North Bay	cj	7	0.0334	0.0048	1.40	0.26
	Error	21	0.0719	0.0034		
	Total	31	0.1116			
	bi	3	0.0072	0.0024	2.15	0.12
Thunder Bay	cj	7	0.0229	0.0033	2.94	0.03
	Error	21	0.0234	0.0011		
	Total	31	0.0534			
	bi	3	0.0065	0.0022	1.16	0.35
Kenogami River	cj	7	0.0756	0.0108	5.80	0.00
	Error	21	0.0391	0.0019		
	Total	31	0.1212			
	bi	3	0.0040	0.0013	2.65	0.08
Sandy Lake	cj	7	0.0136	0.0019	3.89	0.01
	Error	21	0.0105	0.0005		
	Total	31	0.0280			

(2). 1994

provenance	Source	df	Sums of Squares	Mean Square	F-ratio	Prob
	bi	3	0.0088	0.0029	3.24	0.04
North Bay	cj	7	0.0268	0.0038	4.23	0.00
	Error	21	0.0190	0.0009		
	Total	31	0.0547			
	bi	3	0.0008	0.0003	0.19	0.90
Thunder Bay	cj	7	0.0173	0.0025	1.69	0.17
	Error	21	0.0306	0.0015		
	Total	31	0.0487			
Kenogami River	bi	3	0.0032	0.0011	0.56	0.65
	cj	7	0.0229	0.0033	1.70	0.16
	Error	21	0.0406	0.0019		
	Total	31	0.0668			
	bi	3	0.0055	0.0018	1.12	0.36
Sandy Lake	cj	7	0.0318	0.0045	2.78	0.03
	Error	21	0.0343	0.0016		
	Total	31	0.0716			

Appendix V Continued

ANNUAL HEIGHT GROWTH

(1). 1991

provenance	Source	df	Sums of Squares	Mean Square	F-ratio	Prob
North Bay	bi	3	0.5363	0.1788	10.25	0.00
	cj	7	0.1928	0.0276	1.58	0.20
	Error	21	0.3664	0.0174		
	Total	31	1.0956			
Thunder Bay	bi	3	0.2153	0.0718	1.31	0.30
	cj	7	0.1162	0.0166	0.30	0.94
	Error	21	1.1486	0.0547		
	Total	31	1.4801			
Kenogami River	bi	3	0.1336	0.0445	4.44	0.01
	cj	7	0.1779	0.0254	2.53	0.05
	Error	21	0.2107	0.0100		
	Total	31	0.5222			
Sandy Lake	bi	3	0.2190	0.0730	5.00	0.01
	cj	7	0.1129	0.0161	1.10	0.40
	Error	21	0.3069	0.0146		
	Total	31	0.6388			

(2). 1994

provenance	Source	df	Sums of Squares	Mean Square	F-ratio	Prob
North Bay	bi	3	0.0833	0.0278	2.70	0.07
	cj	7	0.1112	0.0159	1.55	0.21
	Error	21	0.2159	0.0103		
	Total	31	0.4104			
Thunder Bay	bi	3	0.2137	0.0712	5.63	0.01
	cj	7	0.1272	0.0182	1.44	0.24
	Error	21	0.2658	0.0127		
	Total	31	0.6067			
Kenogami River	bi	3	0.4211	0.1404	10.44	0.00
	cj	7	0.0484	0.0069	0.51	0.81
	Error	21	0.2823	0.0134		
	Total	31	0.7518			
Sandy Lake	bi	3	0.1364	0.0455	5.12	0.01
	cj	7	0.2231	0.0319	3.59	0.01
	Error	21	0.1866	0.0089		
	Total	31	0.5462			

Appendix V Continued

RING WIDTH

(1). 1991

provenance	Source	df	Sums of Squares	Mean Square	F-ratio	Prob
North Bay	bi	3	0.4017	0.1339	4.01	0.02
	cj	7	0.2682	0.0383	1.15	0.37
	Error	21	0.7007	0.0334		
	Total	31	1.3705			
Thunder Bay	bi	3	0.2099	0.0700	1.92	0.16
	cj	7	0.6479	0.0926	2.54	0.05
	Error	21	0.7640	0.0364		
	Total	31	1.6219			
Kenogami River	bi	3	0.2912	0.0971	4.78	0.01
	cj	7	0.1840	0.0263	1.29	0.30
	Error	21	0.4263	0.0203		
	Total	31	0.9015			
Sandy Lake	bi	3	0.2193	0.0731	2.70	0.07
	cj	7	0.1378	0.0197	0.73	0.65
	Error	21	0.5691	0.0271		
	Total	31	0.9262			
			(2). 1994			
North Bay	bi	3	1.0376	0.3459	12.96	0.00
	cj	7	1.3303	0.1900	7.12	0.00
	Error	21	0.5607	0.0267		
	Total	31	2.9286			
Thunder Bay	bi	3	1.0158	0.3386	4.90	0.01
	cj	7	0.3608	0.0515	0.75	0.64
	Error	21	1.4519	0.0691		
	Total	31	2.8284			
Kenogami River	bi	3	0.7739	0.2580	7.25	0.00
	cj	7	0.3804	0.0543	1.53	0.21
	Error	21	0.7471	0.0356		
	Total	31	1.9014			
Sandy Lake	bi	3	1.8466	0.6155	17.52	0.00
	cj	7	0.2389	0.0341	0.97	0.48
	Error	21	0.7377	0.0351		
	Total	31	2.8232			

Appendix V Continued

LATEWOOD PERCENTAGE

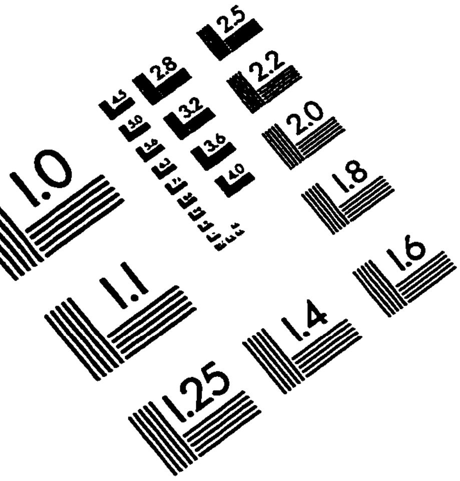
(1). 1991

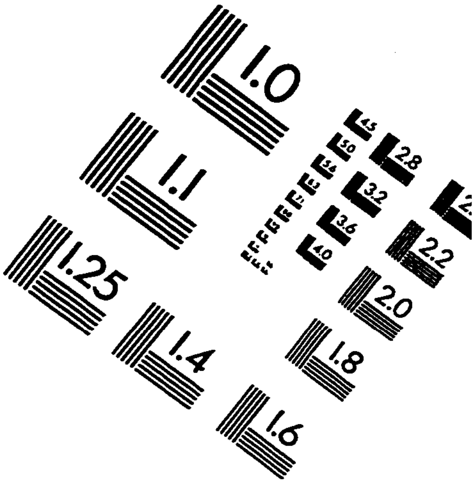
provenance	Source	df	Sums of Squares	Mean Square	F-ratio	Prob
North Bay	bi	3	0.0567	0.0189	2.76	0.07
	cj	7	0.0528	0.0075	1.10	0.40
	Error	21	0.1438	0.0068		
	Total	31	0.2533			
Thunder Bay	bi	3	0.0027	0.0009	0.16	0.92
	cj	7	0.0115	0.0016	0.28	0.95
	Error	21	0.1223	0.0058		
	Total	31	0.1366			
Kenogami River	bi	3	0.0142	0.0047	0.52	0.68
	cj	7	0.0336	0.0048	0.52	0.81
	Error	21	0.1930	0.0092		
	Total	31	0.2409			
Sandy Lake	bi	3	0.1023	0.0341	4.62	0.01
	cj	7	0.0379	0.0054	0.73	0.65
	Error	21	0.1551	0.0074		
	Total	31	0.2953			

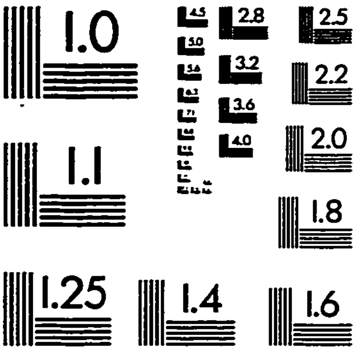
(2). 1994

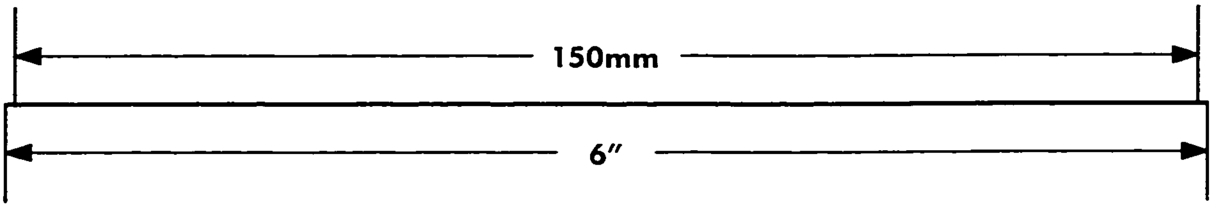
provenance	Source	df	Sums of Squares	Mean Square	F-ratio	Prob
North Bay	bi	3	0.0124	0.0041	1.16	0.35
	cj	7	0.0697	0.0100	2.79	0.03
	Error	21	0.0750	0.0036		
	Total	31	0.1571			
Thunder Bay	bi	3	0.0607	0.0202	3.29	0.04
	cj	7	0.0728	0.0104	1.69	0.17
	Error	21	0.1292	0.0062		
	Total	31	0.2627			
Kenogami River	bi	3	0.0490	0.0163	3.21	0.04
	cj	7	0.0415	0.0059	1.17	0.36
	Error	21	0.1068	0.0051		
	Total	31	0.1973			
Sandy Lake	bi	3	0.1195	0.0398	4.77	0.01
	cj	7	0.0503	0.0072	0.86	0.55
	Error	21	0.1753	0.0083		
	Total	31	0.3451			

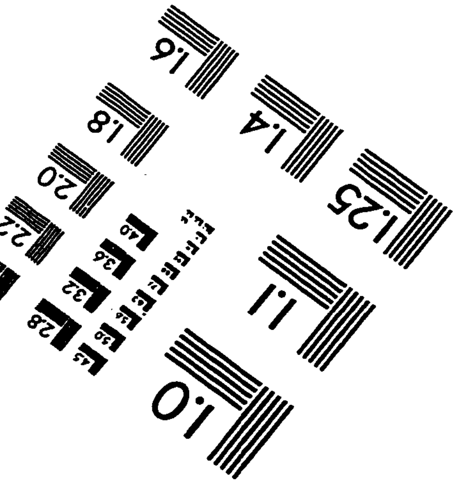
IMAGE EVALUATION TEST TARGET (QA-3)

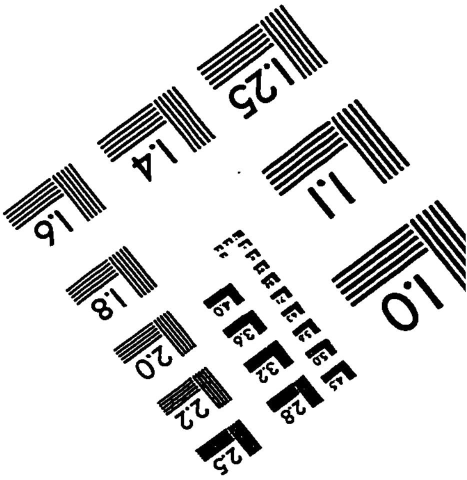












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