

GENETIC VARIATION IN HEIGHT AND DIAMETER OF TAMARACK (*Larix Laricina*)  
AND THEIR CORRELATION WITH SYLLEPSIS

by

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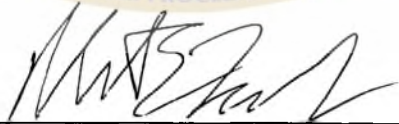
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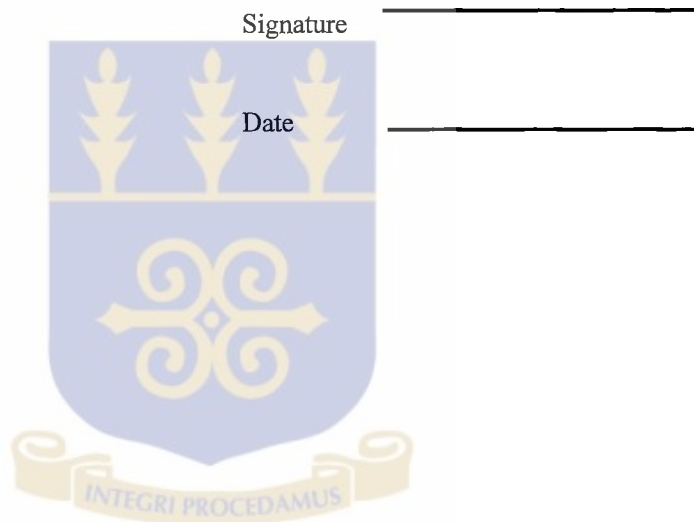
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## ABSTRACT

Bayor, H. 1996. Genetic variation in height and diameter of tamarack (*Larix laricina* (Du Roi) K. Koch) and their correlation with syllepsis. 62pp . Advisor. Dr. R. E. Farmer.

Key words: Broad sense heritability, genetic correlation, age-age correlation, tamarack, *Larix Laricina* (Du Roi) K. Koch, syllepsis.

The broad sense heritability of total height, annual height increment, diameter, volume index and syllepsis of 11 provenances of tamarack in northwestern Ontario were examined. Genetic and Pearson Product Moment correlations among these characters were also examined. Broad sense heritability ranged from 0.13 at age three to 0.36 at age 11 for total height among provenances. Broad sense heritability within individual provenances generally increased from age three to age 11 but showed no geographic trend. Genetic age-age correlation between total height at ages three and 11 was 0.61. Number of sylleptic long shoots at age three and four correlated better with height at age 11 than height at the early ages. Good correlation between height and diameter suggests that both height and diameter could be improved by selecting for total height.



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## 1. INTRODUCTION

Tamarack is one of the most widely distributed North American conifers (Johston, 1990; Roe, 1957). It grows under a wide range of climatic conditions and site characteristics and is one of the fastest growing boreal conifers on well drained sites (Riemenschneider and Jeffers, 1980). However, tamarack has, until recently, been relegated to the background of forestry. MacGillivray, (1969) described tamarack as an almost forgotten species. The use of tamarack in forestry is also limited due to several inherent disadvantages (Stiell 1986) some of which include: erratic seed supply, devastating attacks by the larch sawfly (*Pristiphora erichsonii* Hgt) (Johston, 1990; Stiell, 1986), and low available wood volume over much of its natural range (MacGillivray, 1969; Roe, 1957).

Despite these shortcomings interest in reforestation planting using tamarack is growing particularly in eastern and central Canada and northeastern United States (Carter and Simpson 1985; Stiell, 1986). This is due to its extremely rapid juvenile height growth (Stiell, 1986). Tamarack has many uses. For example, before the sawfly destroyed matured trees, tamarack was used for lumber, railroad ties, and mine timbers (MacGillivray, 1969). Pulp, poles, pilings and veneer could also be obtained from tamarack if supplies could be sustained (MacGillivray, 1969; Cunningham and Findell, 1953).

The potential of tamarack and other larch species for reforestation on short rotations was pointed out by MacGillivray (1969) who also noted that this rapid juvenile growth coupled with early flowering and the wide spectrum of adaptability could be utilized

through research and tree improvement to maximize wood production. Seed orchards of tamarack and other *Larix* species have already been established in several locations in Canada and the United States (Carter and Simpson, 1985). With this growing interest in tamarack also comes the need for more detailed information on its genetic variation over the whole of its natural range. This information, however, is still limited (Boyle *et al.*, 1989). The experimental material examined in this thesis was established to provide genetic information of tamarack in northwestern Ontario.

Earlier assessment of the experimental material examined in this thesis has indicated that genetic variation of height and syllepsis among populations and within populations were both significant. The use of clones to establish productive plantations is a way of capturing a greater proportion of the genetic variation than is possible with the seed orchard approach and it can be incorporated into long-term breeding programs. Using clones particularly calls for early selections. This is because maturation of ortets constitutes a major biological obstacle in clonal forestry (Jiang, 1985). This might be due primarily to the fact that for many tree species cuttings from young individuals root more successfully than cuttings from older individuals (Morgenstern *et al.*, 1984). Secondly, even if rooted, cuttings taken from old ortets may show abnormal form (Jiang, 1982), which makes them less useful for productive purposes. Until methods for rejuvenation or retarding maturation have been fully developed clonal selection will depend heavily on early selection (Rauter, 1985). Also due to the long economic rotation of forest trees (estimated by Castonguay, 1979 for tamarack to be 51-55 years) it is often necessary to make selections long before the rotation age is reached. To do this, ways of predicting performance at rotation age from

juvenile trees has received substantial research attention. Two basic approaches have been used: (i) the development of predictive functions relating juvenile characteristics to mature performance (e.g. Hühn and Kleinschmit, 1993; Lambeth, 1980; Magnussen, 1988, 1989a, 1989b, 1991) and (ii) the search for juvenile characteristics (physiological, morphological or biological) which are indicative of mature performance (e.g. Bridgwater and Williams, 1987; Greenwood and Volkaert, 1992; Jiang *et al.*, 1989; Li *et al.*, 1989). Both of these approaches have been widely used and are often complementary. In either of the above situations, one of two options are available: (a) age-age correlation studies within adult trees existing field trial data are used to relate growth statistically at different ages, and (b) juvenile performance studies in which early selections are made and the tests established are then followed for several years of observation to determine the effectiveness of the screening procedure.

Earlier reports on tamarack suggested that juvenile syllepsis seems to correlate positively with height growth (Remphrey and Powell, 1984, 1985; Farmer *et al.*, 1993). A strong genetic correlation between juvenile syllepsis and later growth suggests it may be a useful character in early selection (Farmer *et al.*, 1993). Nienstaedt (1984) found that early selection of black spruce was not effective at the early age of three years because the correlation with subsequent field performance was not high. Corriveau (1982) also found that correlations between juvenile growth and ten-year height of black spruce were not sufficiently large to make early selection effective. Though these results were not reported for tamarack, the need for comprehensive series of provenance trials and continued assessment of these tests is evident since juvenile growth characteristics in general do not

consistently reflect later performance (Zobel and Talbert, 1984). Hence the aims of this thesis are to present the test performance data and determine:

1. the trends of variance components and heritability over time
2. the genetic (clonal) age-age correlation of total height (FHT) and annual height increment (AHI) to age 11
3. the genetic correlation of four years of syllepsis with total height, annual height increment and volume index at age 11
4. genetic correlation of diameter with syllepsis, total height and annual height increment at age 11.





## 2. LITERATURE REVIEW

### 2.1 HEIGHT, DIAMETER AND SYLLEPSIS

Increase in wood volume is the objective of many forest tree improvement programs. However, height and diameter are often used as criteria for selection to improve wood volume. Apart from height and diameter, attempts have also been made to use other morphological and physiological features of trees as indicators of wood producing capacity and potential yield. Of particular interest are features associated with the size of the photosynthetic tissue. Genetic differences in yield of deciduous trees were linked to differences in size, structure and duration of the canopy (Farmer, 1976). Shoot growth patterns (Greenwood and Volkaert, 1992), photoperiodic responses (Ekberg *et al.*, 1976), carbon dioxide exchange (Ledig, 1976) and many other features have also been investigated with the hope of linking them to growth rate. Syllepsis and a closely related term prolepsis are used to describe patterns of free (von Wühlisch and Muhs, 1986) growth of the leading shoot. Two forms of shoot growth are generally recognized (i) predetermined or fixed growth occurs when needle primordia develop in the preceding growth period, overwinter in the bud and elongate in the following spring and (ii) free growth occurs when needle primordia develop and elongate in the same growth period (von Wühlisch and Muhs, 1986). In some tree species both types of growth occur in one growing period and free growth follows predetermined. When free growth precedes predetermined growth after a pause in shoot elongation during which a temporary bud is set, this is termed prolepsis (von Wühlisch and

Muhs, 1986) but when no interruption occurs, this is termed syllepsis. The terms syllepsis and prolepsis in their original usage seem to refer to growth of buds on both terminal and lateral leading shoots (von Wühlisch and Muhs, 1986). More recent usage of these terms, however, refers specifically to lateral shoots (Jablanczy, 1971). Also the term “proleptic shoot” now seems to encompass all growth from rested buds, predetermined or free (Powell and Vescio, 1986; Tomlinson and Gill, 1973; Hallé *et al.*, 1978), though its original use by Berdan (Marcet, 1975) referred to only free growth. In this thesis syllepsis refers specifically to growth of lateral shoots without an intermediate resting stage. Syllepsis, defined as a lateral branch that develops simultaneously with its parent shoot without an intervening period of dormancy after bud formation, is one such character that seems to be useful as an indicator of height growth in tamarack (Powell and Vescio, 1986; Remphrey and Powell, 1984, 1985).

## 2.2 SILVICS AND ECOLOGY OF TAMARACK

The geographic range of tamarack is regarded as the widest for any native north American conifer. It stretches from Newfoundland and Labrador along the northern limits of tree growth across Canada to Alaska where several disjunct populations occur (Johston, 1990; Roe, 1957). The southern limits cuts across northeastern British Columbia through several northern states in the United States to Maine (Johston, 1990; Roe, 1957).

Tamarack tolerates low soil temperature, high acidity, high soil moisture and moderate drought, and occurs on a wide range of site characteristics (Johston, 1990) but is highly shade intolerant. Therefore, tamarack cannot regenerate under its own shade and is

successionally replaced by black spruce and other more tolerant species (Roe, 1957). In ecologically more advanced forest types tamarack is found as a dominant or a co-dominant tree (Roe, 1957).

Reproduction in tamarack, like most conifers, is mainly by wind pollinated and wind dispersed seed. Notorious for its low, infrequent seed production and low quality of seeds, tamarack flowers as early as four years in plantations (Johston, 1990), but does not produce seed in large quantities in natural forest until 40 or 50 years old. Large seed crops then occur at four to six year intervals. Germination of up to 86% have been obtained (O'Reilly and Farmer, 1988) but erratic seed germination in nurseries and even in greenhouses have occurred (Johston, 1990). At the northern limits of tree growth tamarack mainly regenerates by layering (Johston, 1990). Tamarack can be propagated vegetatively by rooted cuttings (Farmer *et al.*, 1986).

Described as a small to medium sized tree with relatively few enemies, tamarack is a pioneer species in bogs, swamps and at the northern limits of the tree line (Johston, 1990; Roe, 1957). Tamarack may be regarded as being relatively free from insects and diseases. The larch saw fly, however, periodically reaches epidemic proportions and causes heavy mortality to tamarack. Although not as serious a pest as the larch saw fly, the larch case bearer (*Coleophora laricella*) can also cause mortality to tamarack. Root infecting fungal diseases of tamarack include heartrot (caused by *Fomes pini*) and butt rot (caused by *Armillaria sp.*) (Ip, 1991, Roe, 1957).

The main uses of tamarack include pulp making, rough lumber, poles, pilings and railroad sleepers (MacGillivray, 1965; Cunningham and Findell, 1953).

### 2.3 GENETICS OF TAMARACK

Literature on the genetic variation of tamarack is limited (Boyle *et al.*, 1989). MacGillivray (1969) inferred from the wide distribution of tamarack that much geographic variation might exist within this species. A relatively high level of variation among provenances is now known to exist in this species (Cheliak *et al.*, 1988). Significant levels of inter-provenance variation in survival, height growth and tree form have been reported (Jeffers, 1975; Cech *et al.*, 1977; Riemenschneider and Jeffers, 1980; Fowler *et al.*, 1995). Rehfeldt (1970) reported from a study of tamarack populations in northern Wisconsin that variation in height, date of bud set and pattern of root development were clinal. Genetic variation across the species' wide geographic range is now thought to also be clinal (Rauter and Graham, 1983). This pattern is found in many other conifers with extensive ranges (e.g. Nienstaedt and Teich, 1972; Morgenstern, 1978; Rudolph and Yeatman, 1981). Joyce (1987) found that variation in fall cold hardiness was clinal and correlated with both the latitude and altitude of the origin of material. Tamarack in Alaska was, however, thought to be a different variety and designated *L. laricina* var. *alaskensis* (Hosie, 1969) or even a separate species and called *Larix alaskensis* (Wright, 1908). Viereck and Little (1972) considered both *L. alaskensis* and *L. laricina* var. *alaskensis* as synonymous with *Larix laricina*. Parker and Dickinson (1990) investigated this further and concluded that "while Alaska provenances were distinguished from other provenances based on canonical variates analysis of needle data, but not of cone data, this distinction is insufficient to recognize Alaska tamarack separately at either the species or variety level." Neither photoperiodic ecotypes, which were thought to exist in tamarack (Vaartaja, 1959), nor races are currently recognized (Johston,

1990). Tamarack populations are therefore thought to have a highly variable but unsegmented gene pool.

Within-provenance variation of tamarack is high (Park and Fowler, 1982; Cheliak *et al.*, 1988; Ying and Morgenstern, 1991). Park and Fowler (1982) reported significant differences in growth traits among stands within provenances in New Brunswick populations. In contrast Farmer *et al.* (1993) found no significant difference in height and sylleptic traits among stands within provenances in northwestern Ontario populations. Significant family differences in height growth have also been observed in tamarack (Park and Fowler, 1987; Farmer *et al.* 1993). High levels of variation among clones within provenances in survival, height growth, syllepsis and rooting ability have been reported in tamarack (Farmer *et al.*, 1993; Farmer *et al.*, 1992; Park and Fowler, 1987; Morgenstern *et al.*, 1984).

Isozyme study of the breeding pattern of tamarack suggests a high level of self-fertilization among populations in Northwestern Ontario (Knowles *et al.*, 1987). Park and Fowler (1982) also showed that trees growing close together were often related. In comparison to other conifers, however, tamarack is below average in self-fertility but above average in lethal equivalents. Park and Fowler (1987) found that tamarack also exhibits a high level of specific combining ability for five year height growth and suggested that clonal forestry might be useful in this species.

#### 2.4 JUVENILE-MATURE CORRELATIONS

The purpose of studying juvenile mature correlation is to maximize gain per unit time (Squillace and Gansel, 1974). From a theoretical point of view early selection is superior to



selection at maturity (rotation age or any age that the selection is done) if :

- the juvenile-mature correlations are high
- the selection intensity that can be achieved at the early stage is higher than that at the later stage
- the early trait has higher heritability than the mature trait

The selection intensity at the juvenile stage ( $i_j$ ) could possibly be larger than the intensity of selection at the mature stage because in early test environments it is easy to evaluate a much larger number of genotypes (Nanson, 1976; Lambeth, 1980). But as pointed out by Lambeth (1980), restrictions on the number of genetic entries could limit the value of  $i_j$ . Heritability does not seem to have a consistent pattern of change in the literature. However, it has been suggested that in early selections test size and environmental variance can be reduced so that juvenile heritability is manipulated to be higher than is possible in older tests (Lambeth, 1980). If this were the case, the only uncertain factor then would be the juvenile-mature correlation. However, the correlations need not be very high to maximize genetic gain per unit time if the generation interval should be substantially shortened (Ledig, 1975; Jiang, 1985).

Some experimental results, notably with *Pseudotsuga menziesii* (Namkoong *et al.*, 1972) *Pinus ponderosa*, (Namkoong and Conkle, 1976) and *Pinus taeda* (Franklin, 1979), have shown poor correlations for juvenile height and volume with mature height and volume. Franklin (1979) therefore suggested that for conifers selection should be postponed until half the rotation age has elapsed. Bentzer *et al.*, (1989) found high enough correlations to make selection at age four for 10-year height and volume efficient for a Norway spruce clonal test.

Other workers such as Ying and Morgenstern (1979), Williams *et al.* (1987), and Matheson *et al.* (1994) found for the conifers studied that the greatest gain per unit time will be achieved if selection is done between 5 and 10 years. For tamarack Simpson (1983) suggested 10 years for selection among families while Paques and Perinot (1994) indicated that selection for 25-year height and volume was efficient as early as seven years using total height.

## 2.5 HERITABILITY

Heritability is described as a parameter measuring the strength of inheritance. Two types of heritability are often calculated. Narrow sense heritability ( $h^2$ ) is the ratio of the additive genetic variance ( $V_a$ ) to the phenotypic variance ( $V_p$ ). The formula is:

$$h^2 = \frac{V_a}{V_p}$$

Broad sense (gross) heritability is the ratio of the total genetic variance to the phenotypic variance, i.e.,

$$H^2 = \frac{V_g}{V_p}$$

where:

$h^2$  and  $H^2$  are narrow and broad sense heritabilities respectively.

$V_a$  = additive genetic variance

$V_g$  = genetic variance (including additive, dominance and epistatic variances)

$V_p$  = phenotypic variance

Heritabilities should be interpreted carefully. Each heritability estimate is specific to the population, trait, field design, time of evaluation and the environment in which the estimate is based (Fins *et al.*, 1992; Falconer, 1989; Zobel and Talbert, 1984). A given species does not have fixed heritabilities over all environments. Factors that change the proportions of the variance components can also change heritability and include change of micro environmental effects between planting and crown closure (Namkoong *et al.*, 1972). Competition among trees also influences variance components and is commonly used as an explanation of time trends in variance with age (Balocchi *et al.*, 1993; Cotterill and Dean, 1988; Foster, 1986; Namkoong and Conkle, 1976). Heritability can be increased by reducing environmental variance in an experimental design (Falconer, 1989).

The narrow sense heritability is more appropriate for seed orchards and seed production areas, i.e., for species and programs in which sexual recombination occurs and additive effects are important. Broad-sense heritability, on the other hand, which includes all genetic variation, is particularly appropriate for vegetatively propagated material. Vegetative propagation offers an opportunity to obtain higher gains in tree improvement than sexual reproduction because both additive and non-additive gene effects can be recovered.

Heritability is used to predict gain and correlated gain. The changes in the numerical value of heritability in a test plantation as the test becomes older is important for decisions concerning optimum age of selection and selection efficiency. Many authors have studied time trends in genetic parameters (e.g. Balocchi *et al.*, 1993; Bouvet and Vigneron, 1995; Franklin, 1979; Namkoong and Conkle, 1976; Sato, 1995; Squillace and Gansel, 1974). There is some evidence from conifer studies that heritability for growth may increase as

genetic test plantations become older and that heritability may culminate at about half the midlife of the stand (Balocchi *et al.*, 1993; Franklin, 1979; Namkoong *et al.*, 1972; Namkoong and Conkle, 1976; Zobel and Talbert, 1984). However, Sato (1995) reported for a 21-year old *Abies sachalinensis* that the heritability for height growth was highest at the youngest age and showed the tendency to decrease with stand development. Bentzer *et al.* (1989) also found a similar situation for Norway spruce clonal tests in Sweden.

Franklin (1979) suggested three phase changes in variance and heritability with stand development. In the first, the juvenile genotypic phase, the additive variance remains constant or increases slightly and heritability diminishes over time. This phase corresponds to the micro environment capture after planting and to the progressive increase of competition until crown closure. Its duration is very short. In the second, the mature genotypic phase, inter tree competition intensifies. Additive variance increases strongly as does the heritability which then reaches a maximum. In the third phase the codominance suppression phase, which generally occurs after harvesting age, estimates of genetic additive variance decrease upon degeneration of the stand.

## 2.6 COVARIANCE AND CORRELATION OF CHARACTERS

The term covariance is used to describe the simultaneous variation among multiple traits. The covariance between two traits can be partitioned into its component parts.

The phenotypic covariance,  $\text{cov}(y_{1p}, y_{2p})$ , is the average cross product between the phenotypic values of trait  $y_1$  and trait  $y_2$  for each individual. When this is divided by the phenotypic standard deviations, it expresses the phenotypic correlation ( $r_{y_1y_2p}$ ).



The genetic correlations among traits are useful and of interest to the tree improvers because they indicate the degree to which one trait changes as a result of change in another trait (Zobel and Talbert, 1984). They play a role in determining the degree to which selection for one trait in the hope of improving another trait will be successful. Genetic correlation ( $r_G$ ) is calculated by dividing the genetic covariance by the product of the genetic standard deviations for the two characters. The formula is:

$$r_G = \frac{c\hat{v}(y_1 y_2)}{\sqrt{\hat{\sigma}_{y_1}^2 * \hat{\sigma}_{y_2}^2}}$$

where:

$c\hat{v}(y_1, y_2)$  = the genetic covariance component between trait  $y_1$  and trait  $y_2$

$\hat{\sigma}_{y_1}^2$  and  $\hat{\sigma}_{y_2}^2$  = the genetic variance components of traits  $y_1$  and  $y_2$  respectively.

Genetic correlations have also been used to study genotype-environment interactions (Burdon, 1977). In this case measurements on different individuals within a genetic group located in the two environments are used to calculate the genetic correlation coefficient often called type B correlation. A type B correlation equal to one indicates there is no genotype-environment interaction between a trait expressed in the two environments. Whenever the type B correlation coefficient is less than one it means there is genotype-environment interaction and the relative amount of the genotype-environment interaction increases as the type B correlations decreases.

The genetic causes of correlation are due to pleiotropy, linkage or both (Falconer, 1989; von Weissenberg, 1976). Pleiotropy is the property of a gene whereby it affects two

or more characters, so that if the gene is segregating it causes simultaneous variation in the characters it affects (Falconer, 1989). Linkage occurs when the two different genes controlling the traits are located close together on the same chromosome. Genetic correlation due to linkage, assuming no epistasis, between the genes will decrease by repeated cycles of selection due to breaking up of the linkage block during the breeding process (von Weissenberg, 1976). The genetic correlation due to pleiotropy, however, will remain unchanged over several cycles of selection (von Weissenberg, 1976).

Estimates of genetic correlations are subject to large sampling errors and are therefore not very precise. Also, genetic correlations are strongly influenced by gene frequencies and may differ markedly between populations (Falconer, 1989; Namkoong *et al.*, 1988). Estimates of genetic correlations, therefore, give general impressions about how strongly two characters are correlated.



### 3. MATERIALS AND METHODS

#### 3.1. MATERIALS

##### 3.1.1 Study Area

The study was carried out in a clonal test of tamarack established by Lakehead University on two hectares of an old field site near the university in Thunder Bay, Latitude  $48^{\circ} 25' 34''$  W and Longitude  $89^{\circ} 16' 3''$  N.

##### 3.1.2 Source of Plant Material and Sampling Procedure

Eleven provenances were sampled from an area bounded by Longitude  $80^{\circ}$  and  $95^{\circ}$ W and Latitude  $45^{\circ}$  and  $54^{\circ}$ N (Table 3.1). The location of the provenances are shown in Figure 3.1. Two stands were sampled from each provenance and ten wildlings were collected from each stand (240 wildlings in all). Sampling was random with the restriction that stands were at least 10 km apart and wildlings 100 m apart. In a greenhouse sufficient ramets were successfully developed from these wildlings using the methods described by Farmer *et al.* 1986. Rooting of cuttings were completed in the summer of 1984. The (240) clones were overwintered in a lathhouse in 750 ml Spencer-Lamaire containers and planted into the experiment in August 1985 (two replications) and May-June 1986 (two replications).

##### 3.1.3 Soil and Site Preparation

The soil was deep sandy loam in one hectare. The other also has a sandy loam soil but with occasional boulder outcrops. Preparing the site involved removing the brush and

spraying with glyphosate (4l/ha) in June 1985. Glyphosate was applied again in the summer of 1986 after the trees were planted. Since then weeding was done entirely by annual mowing until the summer of 1990. Some replacement planting was done in the first growing season.

Table 3.1 Number designations of provenances in the study

Latitude	Longitude			
	80-83 <sup>o</sup>	84-89 <sup>o</sup>	90-92 <sup>o</sup>	93-94 <sup>o</sup>
46-47 <sup>o</sup>	1	4		-
48-49 <sup>o</sup>	2	5	8	-
50-51 <sup>o</sup>	3	6	9	
53-54 <sup>o</sup>	-	7	10	11



#### 3.1.4 Field Design of Experiment and Planting

The eleven provenances were randomized within each of the four replications (blocks). This was done to prevent inter-provenance competition. Within each provenance the 60 ramets (2 stands x 10 clones x 3 ramets per clone) were randomized and arranged in a non-contiguous (Libby and Cockerham, 1981) layout at a spacing of 1.5 m x 1.5 m. Three ramets from each clone were included in each provenance block. This allows for the evaluation of within clone error variation. When analysing the experiment as a whole, there are two restrictions on randomization- blocking over locations (replications) and blocking over provenances. Therefore, there are no direct F-tests for blocks and provenances (Table 3.2). Provenance effects can, however, be estimated with the assumption that the restriction error on the randomization of provenances is negligible. Each provenance can also be

analysed separately as a randomized complete block design (Table 3.3). The linear models for the analysis of this design are:

(1) Entire test

$$Y_{ijklm} = \mu + B_i + \delta_{(i)} + P_j + PB_{ij} + \omega_{(ij)} + S_{(j)k} + BS_{i(j)k} + C_{(j)l} + BC_{i(j)l} + \epsilon_{(ijkl)m} \cdot$$

[eq 1.0]

where:

- $Y_{ijklm}$  = the  $m^{\text{th}}$  observation on the  $l^{\text{th}}$  clone of the  $k^{\text{th}}$  stand of the  $j^{\text{th}}$  provenance in the  $i^{\text{th}}$  block
- $\mu$  = the overall mean
- $B_i$  = block effects (fixed),  $i = 1, 2, 3, 4$
- $\delta_{(i)}$  = first restriction error due to blocking assumed IID  $N(0, \sigma_\delta^2)$ .
- $P_j$  = provenance effects (random),  $j = 1, 2, \dots, 11$
- $BP_{ij}$  = the mixed interaction effect of the  $i^{\text{th}}$  block with the  $j^{\text{th}}$  provenance
- $\omega_{(ij)}$  = the second restriction error due to the restriction of the randomization of the ramets to within provenances. The  $\omega_{(ij)}$ 's are assumed IID  $N(0, \sigma_\omega^2)$ .
- $S_{(j)k}$  = the random effect of the  $k^{\text{th}}$  stand within the  $j^{\text{th}}$  provenance,  $k = 1, 2$ .
- $BS_{i(j)k}$  = the mixed interaction effect of  $i^{\text{th}}$  block with the  $k^{\text{th}}$  stand within the  $j^{\text{th}}$  provenance
- $C_{(j)l}$  = the random effect of the  $l^{\text{th}}$  clone,  $l = 1, 2, \dots, 10$  (maximum);
- $BC_{i(j)l}$  = the interaction effect of the  $i^{\text{th}}$  block with the  $l^{\text{th}}$  clone within the  $k^{\text{th}}$  stand within the  $j^{\text{th}}$  provenance

$\epsilon_{(ijkl)m}$  = the random effect of the  $m^{\text{th}}$  ramet of the  $l^{\text{th}}$  clone in the  $k^{\text{th}}$  stand in the  $j^{\text{th}}$  provenance in the  $i^{\text{th}}$  block,  $m = 1, 2, 3$  (maximum). The  $\epsilon_{(ijkl)m}$ 's are assumed IID  $N(0 \sigma_{\epsilon}^2)$ .

(2). Individual provenances

$$Y_{ijk} = \mu + B_i + \delta_{(i)} + C_j + BC_{ij} + \epsilon_{(ij)k} \quad [eq2.0]$$

where:

- $Y_{ijk}$  = the  $k^{\text{th}}$  ramet of the  $j^{\text{th}}$  clone in the  $i^{\text{th}}$  block
- $\mu$  = the overall mean
- $B_i$  = the fixed block effects,  $i = 1, 2, 3, 4$ .
- $\delta_{(i)}$  = the restriction error due to blocking assumed IID  $N(0 \sigma_{\delta}^2)$ .
- $C_j$  = the random effect of the  $j^{\text{th}}$  clone,  $j = 1, 2, 3, \dots, 20$  (maximum)
- $BC_{ij}$  = the mixed effect of the  $i^{\text{th}}$  block and the  $j^{\text{th}}$  clone interaction
- $\epsilon_{(ij)k}$  = the random effect of the  $k^{\text{th}}$  ramet of the  $j^{\text{th}}$  clone in the  $i^{\text{th}}$  block,  $k = 1, 2, 3$  (maximum). The  $\epsilon_{(ij)k}$ 's are assumed IID  $N(0 \sigma_{\epsilon}^2)$ .





Figure 3.1. Location of tamarack collections.

Table 3.2: Expected mean squares of the entire experimental design

Source of Variation	Degree of Freedom	Expected Mean Square
<sup>1</sup> Block (B <sub>i</sub> )	3	$\sigma^2 + 3\sigma_{BC}^2 + 30\sigma_{BS}^2 + 60\sigma_{\omega}^2 + 60\sigma_{BP}^2 + 660\sigma_{\delta}^2 + 660\phi_B$
$\delta_{(i)}$ (1st restriction error)	0	$\sigma^2 + 3\sigma_{BC}^2 + 30\sigma_{BS}^2 + 60\sigma_{\omega}^2 + 60\sigma_{BP}^2 + 660\sigma_{\delta}^2$
Provenance (P <sub>j</sub> )	10	$\sigma^2 + 12\sigma_C^2 + 120\sigma_S^2 + 60\sigma_{\omega}^2 + 240\sigma_P^2$
BP <sub>ij</sub>	30	$\sigma^2 + 3\sigma_{BC}^2 + 30\sigma_{BS}^2 + 60\sigma_{\omega}^2 + 60\sigma_{BP}^2$
2 <sup>nd</sup> restriction error ( $\omega_{(ij)}$ )	0	$\sigma^2 + 3\sigma_{BC}^2 + 30\sigma_{BS}^2 + 60\sigma_{\omega}^2$
Stand (S <sub>(j)k</sub> )	11	$\sigma^2 + 12\sigma_C^2 + 120\sigma_S^2$
BS <sub>i(j)k</sub>	33	$\sigma^2 + 3\sigma_{BC}^2 + 30\sigma_{BS}^2$
Clone (C <sub>(jkl)</sub> )	198	$\sigma^2 + 12\sigma_C^2$
Bc <sub>i(jkl)</sub>	594	$\sigma^2 + 3\sigma_{BC}^2$
Error ( $\epsilon_{(ijkl)m}$ )	1760	$\sigma^2$
Total	2639	

<sup>1</sup> Symbols are defined as in the linear model



## 3.2 DATA COLLECTION AND ANALYSIS

### 3.2.1 Field Measurements

Early in the spring of 1995, before the trees commenced growth, the 1994 total height was measured and the number of sylleptic long shoots on the 1994 growth counted. In late August of 1995, after the trees ceased growth the 1995 total height was measured and the sylleptic long shoots on the 1995 growth was counted. The 1995 height growth was obtained as the difference between the 1995 total height and the 1994 total height. Diameter at 0.5m above ground was also measured.

### 3.2.2 Data Retrieved from Storage

Total heights for 1987, 1988, 1989, 1990 and 1992 as well as the number of sylleptic long shoots on the growth of 1988, and 1989 were also available. Annual height increment data were obtained as differences between total heights of successive years.

Table 3.3. Design for the analysis of individual provenances

Source of variation <sup>1</sup>	Degrees of freedom	Expected mean squares
B <sub>i</sub> (Block)	3	$\sigma^2 + 3\sigma^2_{BC} + 60\sigma^2_{\delta} + 60\phi_B$
$\delta_{(i)}$ (restriction error)	0	$\sigma^2 + 3\sigma^2_{BC} + 60\sigma^2_{\delta}$
C <sub>j</sub> (Clone)	19	$\sigma^2 + 12\sigma^2$
BC <sub>ij</sub>	57	$\sigma^2 + 3\sigma^2$
Error	160	$\sigma^2$
Total	239	

<sup>1</sup> For this experiment, stands were not a significant source of variation.

### 3.2.3 Data Preparation

Ramets for which the data were missing in some years were deleted across all years. This ensured that the degrees of freedom and the adjusted coefficients of expected mean squares (EMS) and expected mean cross-products (EMCP) were the same for all ANOVA's and ANCOVA's. Also the ANCOVA calculations were much simplified. Twelve clones were dropped from the analysis because of mortality.

### 3.2.4 ANOVA and ANCOVA Calculation

The ANOVA and ANCOVA calculations were done using eqs. 1.0 and 2.0. From the ANOVA and ANCOVA analysis, variance components and covariance components were estimated. The coefficients of variance components were adjusted for missing data (Appendix I) using the methods described by Snedecor and Cochran (1980).

### 3.2.5 Volume Index (VI10) Calculation

The index was calculated as:

$$VI10 = d_{0.5}^2 H_{10}$$

where:

VI10 = the volume index in 1995

$d_{0.5}$  = the diameter at 0.5 m above ground

$H_{10}$  = the 1995 total height

### 3.2.6 Calculation of Broad Sense Heritability

The broad sense heritability based on individual ramets for all provenances combined, which indicates the general degree of genetic control, was calculated using the same formula that was used by Farmer *et al.* (1993):

$$H^2 = \frac{\hat{\sigma}_C^2}{\hat{\sigma}_C^2 + \hat{\sigma}_{BC}^2 + \hat{\sigma}_e^2}$$

where:

$H^2$  = the broad sense heritability of individual trees

$\sigma_c^2$  = the clonal variance component of individual trees

$\sigma_{BC}^2$  = the variance component of clone by block interaction

$\sigma_e^2$  = the within clone variance component

The standard error of the heritability was calculated by (Becker, 1984) as:

$$SE(H^2) = \sqrt{\frac{2(1-H^2)^2[1+(n-1)H^2]^2}{n(n-1)(c-1)}}$$

where:

$SE(H^2)$  = standard error of the heritability

$H^2$  = intraclass correlation coefficient (= broad sense heritability)

$c$  = number of clones included in the analysis

$n$  = adjusted number of trees per plot which is calculated using the formula  
(Becker, 1984)

$$n = \frac{1}{c-1} \left( \sum n_i - \frac{\sum n_i^2}{\sum n_i} \right)$$

and  $n_i$  = the number of ramets per clone within each provenance block.

A single estimate of the combined heritability is of little value for the purposes of selection so heritabilities were calculated for the individual provenances.



### 3.2.7 Calculation of Genetic Correlation

The genetic correlation coefficient for two characters  $y_1$  and  $y_2$  were calculated as given by Becker (1984) in the formula:

$$r_G = \frac{c\hat{\sigma}_{y_1y_2}}{\sqrt{\hat{\sigma}_{y_1}^2 * \hat{\sigma}_{y_2}^2}}$$

where:

$r_G$  = the genetic (clonal) correlation coefficient

$c\hat{\sigma}_{y_1y_2}$  = estimated 'cross-covariance' component between character  $y_1$  and character  $y_2$

$\hat{\sigma}_{y_1}^2$  = the estimated genetic (clonal) variance component of trait  $y_1$

$\hat{\sigma}_{y_2}^2$  = the estimated genetic (clonal) variance component of trait  $y_2$ .

The standard deviations of the genetic correlation coefficients were calculated as (Robertson, 1959):

$$\sigma_{r_G} = \sqrt{\frac{(1 - r_G^2)^2}{2H_{y_1}^2 H_{y_2}^2} \sigma_{(H_{y_1}^2)} \sigma_{(H_{y_2}^2)}}$$

where:

$\sigma_{r_G}$  = the standard error of the genetic correlation coefficient

$\sigma_{H_{y_1}^2}$   $\sigma_{H_{y_2}^2}$  = the standard deviations for the heritabilities of trait  $y_1$  and trait  $y_2$  respectively

$r_G$  = genetic correlation coefficient



$H_{y_1}^2 H_{y_2}^2$  = the heritabilities of traits  $y_1$  and  $y_2$

Pearson Product-moment correlations were used to calculate phenotypic correlation coefficients.

### 3.2.8 Fitting Models to Age-age Correlations

Two models were fitted to the age-age correlations of total height. Although it is unusual to fit models to age-age correlations in provenance tests, it was permissible in this test since the provenances maintained their ranking up to age 11.

Lambeth's (1980) formula was fitted to the age-age correlations for total height. The equation fitted to the data is of the form:

$$r_{\text{age1, age2}} = A + B * \log_e (\text{age1} / \text{age2}).$$

where:

A and B are constants

age 1 = younger age

age 2 = a later age.

This model assumes that the age-age correlation coefficients are linearly dependent on natural logarithm of the age-ratio. Age 1 was equal to two years from planting in the field.

Hühn and Kleinschmit (1993) proposed a formula that assumes that the correlation coefficient between the height at age 2 with older ages was asymptotic. The formula fitted to this data is of the form:

$$r_G = c_1 \cdot \frac{1 + c_2 \cdot x_i}{1 + c_3 \cdot x_i}$$

$r_G$  = the genetic correlation between total height at age two and total height at a later age

$x_i$  = the later age of the test plantation ,

$c_1$ ,  $c_2$ , and  $c_3$  = constants to be determined from the data (see Appendix II for detail derivation).

## 4. RESULTS

### 4.1 ANNUAL HEIGHT INCREMENT

The provenance mean annual height increment at age 11 (1995) ranged from 59 cm to 72 cm with a test mean of 67 cm (Table 4.1). Although ANOVA (Appendix III) indicated significant difference among provenances in 1995, there was an obvious reduction in the variation compared to previous observations. The phenotypic coefficient of variation decreased from 20.4 in 1988 to 6.0 in 1995 (Table 4.1). Duncan's multiple range test indicated only three distinct groups among the provenances compared with five in most previous observations (Table 4.1). The north-south trend of increasing shoot length was still apparent in 1995. However, the North Bay provenance which always produced the longest shoot growth fell to the second place in 1995, being outgrown by the local Thunder Bay provenance. From 1988 to 1990 the annual height increment increased from year to year in all provenances. The means of the two-year measurements (i.e., 1991-1992 and 1993-1994) also seemed to follow this pattern with the mean increment for 1993-1994 being longer than the mean increment in 1991-1992 in all provenances. Comparing the means for the 1993-1994 height increment with the 1995 height increment, however, showed that the 1995 height increment was longer than the mean of the 1993-1994 increment only in provenances from northern locations (Lat. 50°-54°). For provenances from more southern locations (Lat 46°-50°) (with the exception of Wawa (Lat 46°-47°)) the mean for the 1995 increment was shorter than the mean for the 1993 and 1994 increment in all provenances (Table 4.1).

Table 4.1. Provenance means of annual height increment (cm) with range of clone means in parenthesis. Numbers followed by two different letters are significantly different at the 5% level of probability<sup>1</sup>.

Provenance	Year					
	1988	1989	1990	mean 1991-92	mean 1993-94	1995
8. Pickle Lake	20 (10-31)	35 (22-47)	42 (20-52)	49 (35-83)	57a (24-785)	59a (29-75)
10. Moosonee	23 (14-28)	36 (17-47)	45 (20-54)	53 (39-53)	56a (20-69)	64a (36-81)
11. Sandy Lake	28 (8-36)	47 (18-59)	57 (34-76)	59 (36-69)	67b (31-86)	64a (42-73)
9. Kenongami	24 (10-34)	44 (17-65)	53 (20-71)	54 (39-697)	61b (20-75)	67ab (36-79)
7. Red Lake	23 (12-36)	44 (22-66)	59 (31-84)	52 (33-68)	68bc (36-91)	67ab (42-79)
6. Fort Frances	37 (20-39)	57 (44-70)	67 (50-82)	68 (47-74)	71bc (48-88)	68b (54-81)
2. Sault Ste Marie	29 (19-35)	55 (37-71)	71 (54-89)	54 (40-67)	78e (67-95)	69bc (61-80)
3. Timmins	25 (16-38)	52 (42-73)	65 (51-79)	54 (42-67)	75de (51-92)	70bc (63-82)
4. Wawa	29 (18-32)	51 (36-58)	62 (45-71)	58 (46-64)	70bc (61-80)	70bc (63-80)
1. North Bay	38 (22-42)	69 (53-99)	77 (61-98)	64 (48-80)	78e (56-92)	71bc (54-88)
5. Thunder Bay	31 (16-39)	54 (30-70)	64 (36-82)	63 (46-74)	72cd (39-88)	72c (46-81)
Test Mean	28 (20-38)	49 (35-69)	61 (42-77)	57 (49-65)	69 (20-95)	67 (59-72)
CVP%	20.4	20.0	17.1	9.6	11.0	6.0

1. Provenances are ranked by the 1995 mean annual height increment

## 4.2 TOTAL HEIGHT

The mean heights, diameter and volume index of provenances at year 10 and 11 with range of clone means in parenthesis are shown in Table 4.2. The provenance means at year 11 ranged from 404 cm to 599 cm with a test mean of 500 cm. The North Bay (southern most) provenance was the tallest provenance and was 19.8% taller than the overall population mean while the Pickle Lake provenance, the shortest, was 19.2% shorter than the population mean in 1995. All the provenances seemed to be stable and consistent, maintaining their ranking at this site up to age 11. There were significant differences among provenances and clones within stands within provenances as indicated by the analysis of variance (Appendix III). Stand effects were negligible in all years analysed. Duncan's multiple range test suggested that there were five different height groups among the provenances planted in this test (Table 4.2) which followed a north-south trend of increasing height. The North Bay provenance was significantly different from all other provenances.

## 4.3 DIAMETER

Provenance means of diameter are also presented in Table 4.2. The means ranged from 4.9 cm to 7.1 cm with a test mean of 6.1 cm. Generally, taller trees also had bigger diameters. However, the provenance from Sault Ste Marie (ranking fourth by 1995 total height) had the largest mean diameter, but this was not statistically different from the mean of the North Bay provenance (Table 4.2). Moreover, the biggest diameter recorded was 12.0 cm found in the North Bay provenance. The Moosonee provenance had the smallest mean

diameter. Five groups of diameter classes were also suggested by the Duncan's multiple range test.

Table 4.2. Means of height, diameter and volume index of year 10 and 11 of 11 provenances of tamarack in northwestern Ontario with range of clone means in parenthesis<sup>1</sup>.

Provenance	Total Height <sup>2</sup> (cm)		Diameter (cm)	Volume Index (dm <sup>3</sup> )
	Year 10	Year 11	Year 11	Year 11
8. Pickle Lake	346 (209-401)	404a (238-470)	4.9a (1.2-7.4)	11.8a (1.5-18.3)
10. Moosonee	365 (278-441)	418a (329-515)	4.8a (1.1-8.5)	13.4a (4.6-27.2)
9. Kenogami River	396 (170-468)	460b (206-538)	5.8b (1.5-8.8)	18.3b (0.8-31.7)
7. Red Lake	405 (277-530)	471b (334-605)	5.9b (2.5-9.1)	19.6b (4.0-40.3)
11. Sandy Lake	412 (216-478)	475b (258-536)	5.8b (1.8-8.7)	18.5c (0.9-28.8)
3. Timmins	450 (365-536)	518c (435-599)	6.4c (3.3-9.4)	25.0c (14.0-40.7)
4. Wawa	449 (392-490)	520c (464-567)	6.6c (3.7-9.0)	25.2d (13.1-40.4)
2. Sault Ste. Marie	472 (380-538)	539d (446-613)	7.1de (4.7-9.8)	29.3cd (16.5-37.3)
5. Thunder Bay	475 (297-550)	547d (343-632)	6.7c (2.5-10.7)	28.0cd (4.7-39.9)
6. Fort Frances	481 (412-558)	549d (549-469)	6.6c (3.8-10.5)	26.9d (15.9-55.9)
1. North Bay	528 (431-628)	599e (488-706)	7.0cd (3.8-10.4)	33.7e (16.5-64.0)
Test mean	432 (170-628)	500 (206-706)	6.8 (1.1-10.7)	23.7 (0.8-64)



1. Provenance means followed by different letters are significantly different at 5% level of probability
2. Provenances are ranked by year 11 total height.

#### 4.4 VOLUME INDEX (VI10)

The provenance means ranged from 11.8 to 33.7 dm<sup>3</sup> with a test mean of 23.7 dm<sup>3</sup> (Table.4.2). Duncan's multiple range test indicated five distinct categories of volume index. The highest individual (ramet number 10235-2 in the North Bay provenance) volume index was 110.6 dm<sup>3</sup>; more than 350% above the test mean. The mean of the North Bay provenance, the highest in the test was 42.2% above the test mean while the Pickle Lake provenance, the lowest, was 50.2% below the test mean. The local Thunder Bay provenance ranked third and was 18.1% above the test mean.

#### 4.5 SYLLEPSIS

The syllepsis data is presented in Table 4.3. In 1994 the percentage of clones with syllepsis ranged from 60 to 100 with a mean of 84.5. This increased in 1995 to range from 70 to 100 with a mean of 94.5. The percentage of trees with syllepsis was much smaller than the percentage of clones. In 1994, the mean number of trees with syllepsis was 51.6 with a range from 22.8 to 79.6. This increased to 70.2 in 1995 with a range from 52.0 to 84.3.

Table 4.3. Percent of clones with syllepsis, percent of trees with syllepsis and mean number of sylleptic shoots per tree (clone means in parenthesis) in each provenance.

Provenance	Percent of clones with syllepsis		Percent of trees with syllepsis		Mean number of sylleptic shoots per tree	
	Year					
	1994	1995	1994	1995	1994	1995
1. North Bay	95	100	72.7	84.3	6.0 (0-20.6)	7.2 (2.9-16.6)
2. Sault Ste Marie	100	100	79.6	74.6	5.1 (0-13.5)	5.8 (1.6-10.3)
3. Timmins	90	95	58.7	68.2	4.1 (0-15)	4.9 (0-13.0)
4. Wawa	90	100	41.9	66.2	2.9 (0-26.2)	3.4 (0-9.2)
5. Thunder Bay	95	100	71.2	82.9	5.0 (0-13.3)	7.4 (2.6-12.9)
6. Fort Frances	95	95	72.3	85.1	6.4 (0-8.5)	6.3 (0-12.0)
7. Red Lake	90	100	57.1	75.3	4.5 (0-8.5)	7.8 (0.2-17.6)
8. Pickle Lake	60	70	28.4	52.0	1.3 (0-7.4)	3.6 (0-11)
9. Kenogami	65	95	32.5	57.0	1.6 (0-4.2)	4.0 (0-9.6)
10. Moosonee	60	90	22.8	59.7	0.8 (0-4.5)	3.4 (0-7.0)
11. Sandy Lake	70	95	29.6	67.2	1.4 (0-4.8)	4.1 (0-11.5)



## 4.6 TRENDS OF VARIANCE COMPONENTS AND HERITABILITY

### 4.6.1 Total height

For total height, the proportion of variance for provenances and clones increased over the years as the stand developed. The provenance portion of the variation accounted for between 12.8% in 1987 and 27.2% in 1995. The clonal portion ranged from 9.6% to 21.5% within the same period. The provenance portion was always larger than the clonal portion in any given year (Figure 4.1). The pattern of increase also seemed to be different in these two sources of variation. From 1987 to 1990 and from 1990 to 1995 the proportion of the provenance variance component increased by 9.9% and 4.7% respectively while during the same period the clonal variance component increased by 3.3% and 8.6%. It therefore appeared that the proportion of provenance variance components increased faster than the clonal variance components in the first five years while in the next five years the clonal component increased faster in this test. The experimental error was the largest source of variation and accounted for 55% of the variation in 1988 and 39% in 1995. There was a slight increase from 54% in 1987 to 55% in 1988.

For the combined analysis the pattern of change of broad sense heritability with time is shown in Figure 4.1. The clone broad sense heritability started from 0.13 in 1987 and increased gradually to 0.36 in 1995. The heritabilities for clones seemed unstable but a consistent pattern of increase was observed.



#### 4.6.2 Annual Height Increment

The within clone variance was again much higher than all the other sources of variation and constituted between 57.2 and 77.4% of the total variation (Appendix IIB). The variation due to provenances accounted for 9.7% in 1987, rose to a peak in 1989 when it accounted for 17.3% of the variation, and then declined to 5.6% in 1992, rose again slightly in 1994 and fell to its lowest value of 2.5% in 1995. This probably supports the observation made earlier that there was a reduction in variation among provenances. Clonal source of variation explained between 2.3% in 1988 and 11.7% in 1994. It is noted that the clonal source of variation was higher than the provenance source of variation for 1994 and 1995.

The trends of heritability for annual height increment are shown on Figure 4.2 and the values are shown on the diagonal of Table 4.5. Apart from 1988 and the 1991-1992 height increments for which the heritabilities were extremely low (0.03 and 0.06 respectively) values for all other years were in the narrow range of 0.11 to 0.15. The broad sense heritability for 1995 was 0.11 which was lower than that for 1994 (0.14).

Figure 4.1 Trends of variance components and heritability for total height

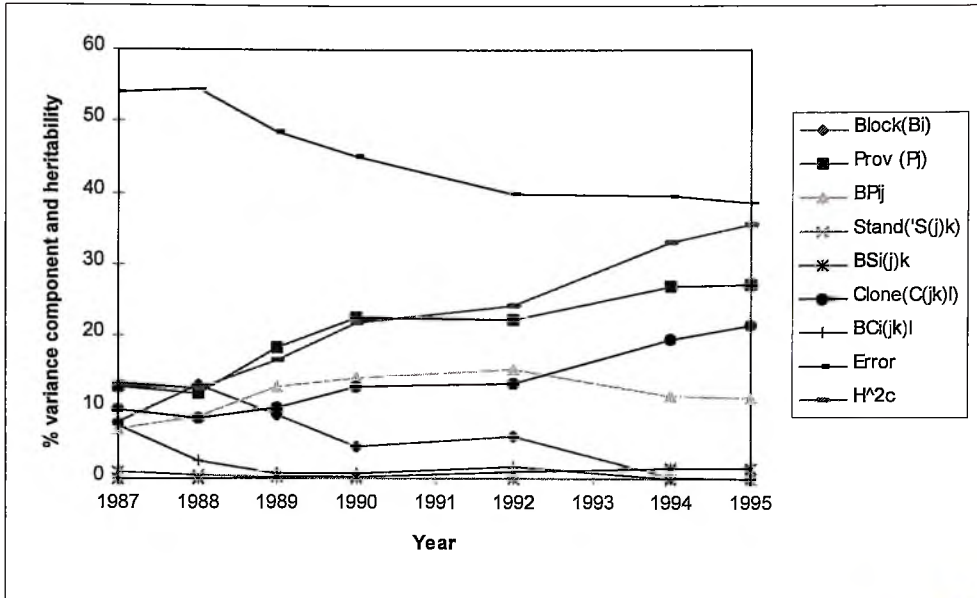
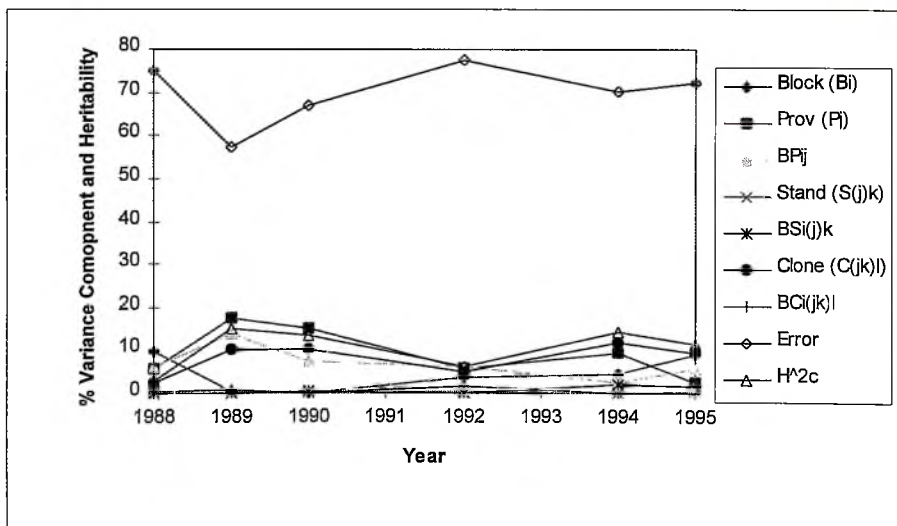


Figure 4.2 Trends of variance components and heritability for annual height increment



#### 4.6.3 4.6.3 Synthesis

The proportion of variance components for provenances ranged from 2.1% in 1988 to 9.0% in 1995 (Appendix III). After this initial sharp increase, there was a decline to 8.0% in 1994 and a further decline to 6.6% in 1995. The clonal component of variance explained from 11.8% (1988) to 37.3% (1995) of the total variation.

The clonal heritability was therefore highest at 0.42 in 1995, having risen from a value of 0.13 in 1988.

#### 4.7 AGE-AGE CORRELATIONS

The genetic and phenotypic age-age correlation coefficients of total height were all positive and significant at the five percent level of probability (Table 4.4). The genetic correlation coefficients were generally higher than their corresponding phenotypic values. The genetic correlation coefficients generally improved the closer the years were. The coefficients for correlation of 1995 total height with earlier years varied from 0.61 (1988) to 1.00 (1994). The correlation coefficients for 1987 total height and later years varied from 0.61 to 1.02.

Table 4.4 Heritability (diagonal), phenotypic (above diagonal), and genetic (below diagonal) correlation coefficients for total height and diameter at 0.5 m above ground.

	FHT 87	FHT 88	FHT 89	FHT 90	FHT 92	FHT 94	FHT 95	DIA95
FHT87	<b>0.13</b> (0.02)	0.90**	0.81**	0.76**	0.68**	0.65**	0.63**	0.61**
FHT88	1.02 (0.01)	<b>0.13</b> (0.02)	0.93**	0.85**	0.77**	0.71**	0.69**	0.64**
FHT89	0.83 (0.02)	0.97 (0.01)	<b>0.17</b> (0.02)	0.94**	0.86**	0.82**	0.79**	0.73**
FHT90	0.71 (0.03)	0.90 (0.01)	1.01 (0.01)	<b>0.22</b> (0.02)	0.91**	0.88**	0.86**	0.79**
FHT92	0.70 (0.02)	0.86 (0.01)	1.00 (0.01)	1.00 (0.01)	<b>0.24</b> (0.02)	0.91**	0.89**	0.78**
FHT94	0.62 (0.03)	0.78 (0.02)	0.91 (0.01)	0.94 (0.01)	0.96 (0.01)	<b>0.33</b> (0.03)	0.98**	0.81**
FHT95	0.61 (0.03)	0.77 (0.02)	0.90 (0.01)	0.92 (0.01)	0.95 (0.01)	1.00 (0.01)	<b>0.36</b> (0.03)	0.81**
DIA95	0.58 (0.03)	0.77 (0.02)	0.89 (0.01)	0.87 (0.01)	0.86 (0.01)	0.84 (0.01)	0.83 (0.01)	<b>0.33</b> (0.03)

\*\* - significant at  $P < 0.01$

Standard error of genetic correlations and heritability in parenthesis

#### 4.7.1 Lambeth' Formula

The equation obtained by fitting Lambeth's formula is:

$$r_G = 1.08 + 0.31 * \log_e(\text{age 1}/\text{age 2}). \quad R^2 = 0.88$$

age1 =2; age 2 varied from 3 to 10.

The similarity between the constants  $A = 1.08$  and  $B = 0.31$  obtained from this data and those obtained by Lambeth ( $A = 1.02$ ,  $B = 0.308$ ) is obvious. But the coefficient of

determination was much lower ( $R^2 = 0.88$  vs  $0.93$ ). The estimated genetic correlations are shown in Table 4.5 for comparison with those estimated from the data.

#### 4.7.2 Hühn and Kleinschmit's Formula:

The formula obtained by fitting Hühn and Kleinschmit's formula is:

$$r_G = -0.107 \times \frac{1 + 3.63 \times \text{Age}}{1 - 0.75 \times \text{Age}}$$

$r_G$  = the genetic correlation between age 2 and any later age designated as Age in the formula. The estimates from this formula corresponds well with values calculated from the data (Table 4.5). But the constants  $c_1$ ,  $c_2$  and  $c_3$  are completely different from those obtained by Hühn and Kleinschmit (1993).

Table 4.5 Genetic covariance, standard deviation and age-age correlation of 1987 total height and later years estimated by different methods.

Year	Age <sup>a</sup>	Genetic covariance	$\sigma_e^2$ calculated from data	$r_G$ Estimated from data	$r_G$ Estimated by Lambeth's formula	$r_G$ Estimated by Hühn and Kleinschmit's formula
1987	2		6.20			
1988	3	55.94	8.8	1.02	0.95	1.02
1989	4	72.50	14.0	0.83	0.86	0.83
1990	5	91.97	21.0	0.71	0.79	0.74
1992	7	125.28	28.72	0.70	0.69	0.66
1994	9	160.67	42.06	0.62	0.61	0.62
1995	10	175.91	46.16	0.61	0.58	0.61

a Note that age = plantation age. Plantation was one year old in 1986.

#### 4.7.3 Annual Height Increment

The coefficients of the age-age phenotypic correlations of annual height increment were all positive except the correlation between the annual height increment of 1990-1992 and 1993-1994 which was negative and nonsignificant at the 5% level of probability (Table 4.6). The phenotypic correlation coefficients were generally low. The 1995 annual height increment correlates poorly with the 1995 total height (0.36). Also the annual height increment in 1988 correlates poorly with the 1995 annual height increment (0.15) but slightly better with the 1995 total height (0.47).

The genetic correlations were much higher than their corresponding phenotypic values and many of them exceeded their theoretical limits indicating overestimation. The correlation of the 1988 annual height increment with the 1995 annual height increment was not high (0.36) but the correlation with the 1995 total height was moderately high 0.83.

Table 4.6. Phenotypic (above diagonal) and genetic (below diagonal) correlation coefficients of annual height increment, and with total height and diameter.

	AHI 88	AHI 89	AHI 90	AHI 91-92	AHI 93-94	AHI 95	FHT 95	DIA 95
AHI88	<b>a0.03</b> <b>b(0.01)</b>	0.45**	0.25**	0.25**	0.07**	0.15**	0.47**	0.39**
AHI89	1.16 (0.02)	<b>0.15</b> <b>(0.02)</b>	0.58**	0.23**	0.27**	0.15**	0.74**	0.66**
AHI90	1.21 (0.03)	1.09 (0.01)	<b>0.13</b> <b>(0.02)</b>	0.28**	0.30**	0.10**	0.65**	0.58**
AHI 91-92	1.00 (0.01)	1.17 (0.02)	1.30 (0.04)	<b>0.06</b> <b>(0.01)</b>	-0.04ns	0.07**	0.48**	0.37**
AHI 93-94	0.93 (0.01)	0.85 (0.01)	1.06 (0.01)	1.22 (0.03)	<b>0.14</b> <b>(0.02)</b>	0.14**	0.48**	0.37**
AHI95	0.36 (0.10)	0.63 (0.04)	0.54 (0.05)	0.63 (0.05)	0.81 (0.02)	<b>0.11</b> <b>(0.02)</b>	0.36**	0.24**
FHT95	0.83 (0.02)	0.79 (0.01)	0.89 (0.02)	0.85 (0.01)	0.89 (0.01)	0.76 (0.02)	<b>0.36</b> <b>(0.03)</b>	0.81**
DIA95	0.91 (0.01)	0.82 (0.01)	0.77 (0.02)	0.72 (0.03)	0.69 (0.02)	0.59 (0.02)	0.83 (0.03)	<b>0.33</b> <b>(0.03)</b>

a Heritability on diagonal

b Standard error in parenthesis

ns not significant at 5% level of probability

#### 4.8. CORRELATION AMONG CHARACTERS

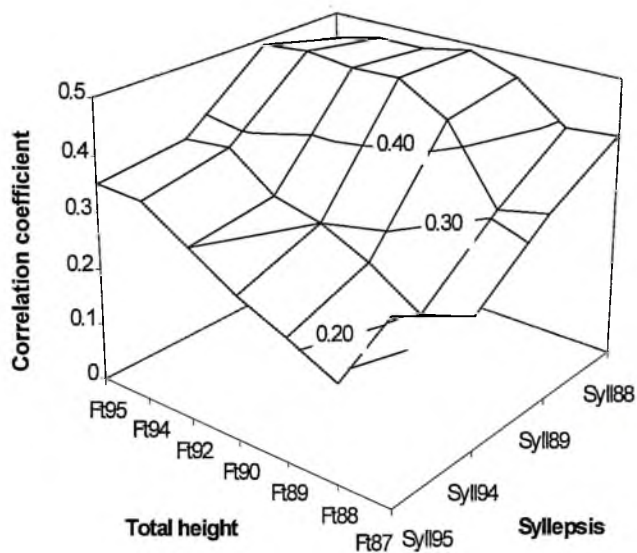
Phenotypic and genetic correlation coefficients of syllepsis with total height, annual height increment, diameter and volume index are shown in Table 4.7.

##### 4.8.1 Syllepsis and Total Height

The phenotypic correlation coefficients were all positive and significant at the 1% level of probability. However they were all generally low or moderate with none exceeding 0.44 (Table 4.7). The genetic correlation coefficients were in most cases slightly higher than



Figure 4.3 Correlation surface of syllepsis and total height.



their corresponding phenotypic values. However, they were also generally low. Some trends in correlation coefficients can be observed. For syllepsis in any given year, the correlation with total height improves with age. For total height in any given year, the correlation coefficients are better with syllepsis at the younger ages than syllepsis at the older ages (Figure 4.3).

Table 4.7. Phenotypic and genetic correlations of total height, annual height increment, diameter and volume index with four years of syllepsis.

	SYL88	SYL89	SYL94	SYL95	VI10
FHT87	a0.20 ** b0.40 (0.06)	0.22** 0.33 (0.05)	0.12** 0.23 (0.06)	0.10** 0.31 (0.05)	0.65** 0.51 (0.04)
FHT88	0.30** 0.39 (0.06)	0.24** 0.31(0.05)	0.09** 0.20 (0.06)	0.12** 0.17 (0.06)	0.71** 0.75 (0.02)
FHT89	0.31** 0.46 (0.05)	0.40** 0.44 (0.04)	0.13** 0.26 (0.05)	0.16** 0.21 (0.05)	0.78** 0.87 (0.01)
FHT90	0.29** 0.49 (0.04)	0.44** 0.49 (0.03)	0.16** 0.30 (0.04)	0.19** 0.25 (0.04)	0.82** 0.86 (0.01)
FHT92	0.31** 0.47 (0.04)	0.40** 0.49 (0.03)	0.14** 0.32 (0.04)	0.19** 0.30 (0.04)	0.79** 0.86 (0.01)
FHT94	0.27** 0.47 (0.04)	0.42** 0.50 (0.03)	0.22** 0.38 (0.03)	0.25** 0.35 (0.03)	0.83** 0.83 (0.01)
FHT95	0.25** 0.45 (0.04)	0.42** 0.49 (0.03)	0.24** 0.37 (0.03)	0.29** 0.35 (0.03)	0.83** 0.82 (0.01)
AHI88	0.29** 0.66 (0.17)	0.17** 0.67 (0.04)	0.03ns 0.29 (0.08)	0.10** 0.27 (0.08)	0.45** 0.97 (0.01)
AHI89	0.24** 0.41 (0.19)	0.53** 0.56 (0.03)	0.15** 0.15 (0.06)	0.18** 0.30 (0.05)	0.69** 0.82 (0.01)
AHI90	0.17** 0.57 (0.14)	0.35** 0.61 (0.03)	0.17** 0.42 (0.04)	0.16** 0.40 (0.04)	0.58 ** 0.80 (0.02)
AHI 91-92	0.20** 0.51 (0.21)	0.16** 0.48 (0.05)	0.03ns 0.36 (0.06)	0.12** 0.45 (0.05)	0.41** 0.74 (0.03)
AHI 93-94	0.01ns 0.43 (0.18)	0.20** 0.44 (0.04)	0.23** 0.42 (0.04)	0.17** 0.41 (0.04)	0.36 ** 0.65 (0.03)
AHI95	-0.04ns 0.13 (0.30)	0.11** 0.24 (0.05)	0.14** 0.16 (0.07)	0.25** 0.21 (0.06)	0.21** 0.55 (0.03)
DIA95	0.19** 0.41 (0.04)	0.40** 0.46 (0.03)	0.17** 0.25 (0.04)	0.23** 0.25 (0.04)	0.94** 0.96 (0.01)
VI10	0.25** 0.48 (0.05)	0.47 ** 0.56 (0.03)	0.18** 0.31 (0.04)	0.23** 0.27 (0.04)	<b>c0.31 (0.03)</b>

\*\* significant at  $P < 0.01$ 

a phenotypic

b genetic (clonal) with standard error in parenthesis

c. Heritability of volume index with standard error in parenthesis

ns non-significant at  $P = 0.05$ 

#### 4.8.2. Syllepsis and annual height increment

Phenotypic correlations between syllepsis and annual height increment were lower than those observed for syllepsis and total height. A single negative value was observed although this was not significant at the 5% level of probability (Table 4.7). The genetic correlation coefficients, which ranged from 0.12 to 0.67 were all positive and higher than their corresponding values observed between syllepsis and total height. The pattern of change over time was, however, less distinct though it was still clear that syllepsis at the two younger ages (year 4 and year 5) correlated better with all ages of height increment than syllepsis at the two older ages. The strongest correlation coefficients between the syllepsis in any given year tended to occur with the annual height increment within the same year or the year immediately after (Table 4.7).

#### 4.8.3. Syllepsis and diameter at 0.5 m above ground

The phenotypic and genetic correlation coefficients ranged from 0.19 to 0.40 and 0.25 to 0.46 respectively (Table 4.7). For the four years of sylleptic traits, the 1989 sylleptic branching trait has the highest phenotypic (0.40) and genetic (0.46) correlation with diameter.

#### 4.8.4. Syllepsis and volume index

The last two rows of Table 4.7 show the correlation coefficients of the four years of syllepsis and volume index. The 1989 syllepsis again showed the highest phenotypic and genetic correlation with volume index.



#### 4.8.5 Volume index and total height

Both phenotypic and genetic correlation coefficients of total height with volume index are moderately high ranging from 0.65 to 0.83 for phenotypic values and 0.51 to 0.86 for genetic values (Table 4.7).

#### 4.8.6. Volume index and annual height increment

While the phenotypic correlation between volume index and annual height increment is not high (0.21 to 0.69) the genetic coefficients are much higher (0.55 to 0.97) (Table 4.7). With the exception of the phenotypic correlation with height increment in 1988, a general decrease in correlation coefficient was observed as the test plantation got older.

### 4.9 BROAD SENSE HERITABILITY OF TOTAL HEIGHT FOR THE INDIVIDUAL PROVENANCES

The broad sense heritability for the individual provenances is shown in Appendix IV. The general pattern of change over time is similar to that of the entire analysis viz. low heritability in the early stages and a gradual increase over time. Although the heritabilities fluctuated from year to year within the same provenances in the early stages, these fluctuations decreased over time. However no geographic trends could be found in broad sense heritabilities even at age 11. For example the Wawa (southern) provenance showed consistently low heritability (0.06 to 0.09) while the Red Lake provenance (northern) showed high heritabilities (0.26 to 0.60).

## 5. DISCUSSION

### 5.1. TOTAL HEIGHT AND ANNUAL HEIGHT INCREMENT

The height performance of this clonal test is remarkable. At age 11, the provenance means of total height which range from 404 to 599 cm are comparable to 14 year height (516 to 636 cm) of tamarack from seed planted in Wisconsin (Riemenschneider and Jeffers, 1981). Clonal forestry in tamarack might be useful in tamarack since high specific combining ability has been noted in this species (Park and Fowler, 1982). The north-south trend of gradual increase in height observed in earlier studies of this experiment (Farmer *et al.*, 1993) have been maintained to age 11. This, therefore, probably suggests that height variation within the sampled region might be clinal (Deng, 1990; Farmer *et al.*, 1993). It also adds some evidence to the suggestion that height variation in tamarack might be clinal over its entire range (Rauter and Graham, 1983). North-south trends of increasing height have also been observed in several other studies of tamarack (e.g. Jeffers, 1975; Riemenschneider and Jeffers, 1980; Cech *et al.*, 1977).

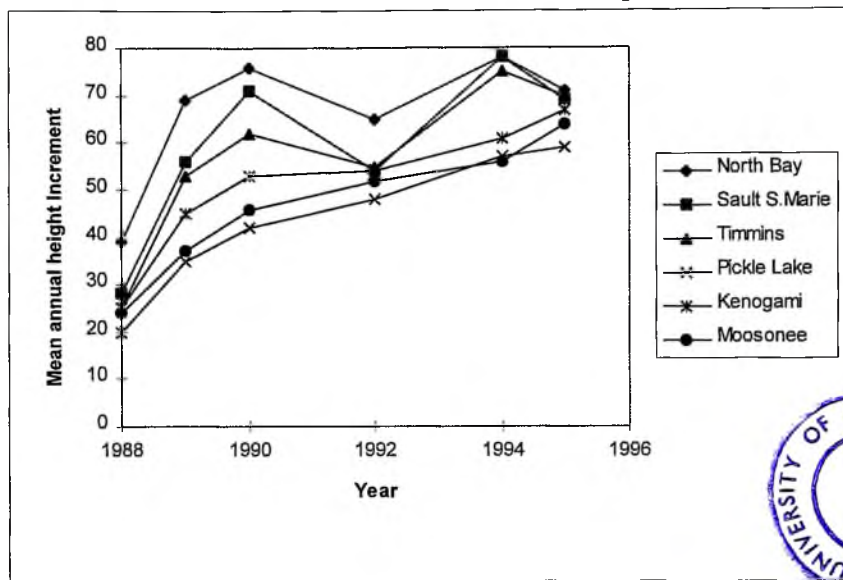
In a detailed study of shoot growth pattern Deng (1990) and Farmer *et al.* (1993) found that the differences in annual height increment were due to late summer growth rather than midsummer growth with southern provenances growing later into summer than northern provenances. It is also known that free growth forms a considerable portion of tamarack shoot extension (Remphrey and Powell, 1984). Shorter than usual photoperiod affects the length of both the fixed and free growth extension of shoots, (Pollard and Logan, 1974;

Wühlisch and Muhs, 1986) but differently. Free growth is more drastically reduced than fixed growth (von Wühlisch and Muhs, 1986). For example, whereas a short day treatment at the start of bud break did not stop fixed growth until all preformed stem and needle primordia had elongated, it immediately stopped the elongation of stem and needle primordia in free growth (Dormling, *et al.* 1968). Therefore, as noted by Deng (1990), the differences in height increment might be strongly influenced by differences in free growth, with the provenances from more southern locations exhibiting a greater amount of free growth than provenances from northern locations.

The reduction in variation among the provenances as observed in the present study was mainly due to provenances from southern locations tending to grow less than before (have shorter shoot elongation) while provenances from more northern locations maintaining their annual height increments or even growing taller. Figure 5.1 shows the provenance mean annual height increments of three provenances from southern locations (North Bay, Timmins and Sault Ste Marie) and three provenances from more northern locations (Pickle Lake, Kenogami and Moosonee) plotted on the same axes. The points plotted for 1992 and 1994 represent means for the two year periods 1991-1992 and 1992-1994 respectively. The reduction in height growth and wide fluctuations in annual height increment among the three southern provenances is obvious. The northern provenances tend to have less fluctuations and showed continued increase over the 10-year period. Reduction in the annual height increment among the southern provenances observed in this study is probably due to a decrease in the proportion of free growth as the trees become older in these provenances. Free growth decreases with age while fixed growth is more stable over age (Jablanczy, 1971;

Pollard and Logan, 1976). Free growth was found to be generally absent in 12 year old *Picea mariana* (Pollard *et al.*, 1975).

Figure 5.1. Mean annual height increment of three provenances from the northern and southern locations of the sampled area.



The fluctuations associated with the annual height increment of the more southern provenances in 1992 might reflect adverse weather conditions in that year. This may be partly due to northern provenances being better adapted to severe environmental conditions and are less affected by adverse changes in weather conditions. An exception in this pattern is observed in the Sandy Lake provenance (the northern most) which has generally grown faster than many provenances located to the south of it. Its pattern of annual height increment also tends to be more like the fast growing southern provenances with a marked depression in 1992. Another observation worth commenting on is that the local Thunder bay provenance



did not show any such depression. This might be due to a better adaptation to the local prevailing conditions than provenances moved north.

Northern provenances might exhibit less free growth because of adaptation to environment (natural selection would favour less free growth and earlier growth cessation in order to escape late season frost). In black spruce, fixed growth was found to vary little among provenances over a wide area while free growth showed a clinal variation from north to south (Pollard and Logan, 1974, 1976).

Although the provenances from the more southern location showed a reduction in height growth over time, their annual height increments were on average greater than the provenances from the more northern locations (Figure 5.1). Therefore, while there seems to be a catching up in the annual height increment between the northern and southern provenances, the difference between their total heights are still increasing. Therefore, either a substantial amount of free growth still occurs in these trees, particularly in those trees from southern locations, or the differences in height growth were not due solely to the differences in the amount of free growth. Number of stem units per shoot and the length attained by each stem unit could also influence height growth differences.

The proportion of variance for total height among provenances remained constant at 27% in 1994 and 1995. This probably signifies a stabilization of the variation and suggests that improvements in height may be made by moving southern provenances slightly north since no frost damage was observed. This is, however, not a recommendation and further testing is required. The clonal variance component showed a consistent pattern of gradual increase with age until 1995. This might be because the populations represent an unselected

group from a wide variety of environmental and climatic conditions which have different developmental patterns. The analysis of individual provenances also showed this pattern of continued increase in clonal variance in many of the provenances although a few provenances showed a more or less stable effect (Appendix IV). For the combined analysis, decrease in the within clone error could have contributed to the gradual increase in the percent of variation among provenances and clones. The broad sense heritability for the combined analysis increased continuously until 1995. This sort of pattern has been observed in other conifer studies, e.g. *Pinus taeda* (Foster, 1986), *Pinus eliottii* (Hodge and White, 1992) and *Pinus pinaster* (Costa and Durel, 1996). Similar data for tamarack could not be found for comparison.

## 5.2 DIAMETER AND VOLUME INDEX

The variation in diameter is also clinal probably because height is strongly correlated with diameter and taller trees tend to have bigger diameters. This was the case found in Wisconsin (Riemenschneider and Jeffers 1981). However, in this experiment, the provenance from Sault Ste Marie, which ranked fourth in the 1995 total height had the largest mean diameter probably suggesting that the tallest source is not necessarily the largest diameter source. The strong height-diameter genetic correlations (0.81 between 1995 total height and 1995 diameter) suggest that both diameter and height can be improved simultaneously by selecting for total height. Moreover the North Bay provenance which has the tallest trees also has some of the largest diameters recorded in the test (Appendix IV). The North Bay provenance is also by far the most superior with regard to the volume index observed in this

experiment. Some of the best clones are found in this provenance (Appendix IV). However because diameter was measured at 0.5 m above ground, the volume index values might be bigger than the real volume. Since volume is related to both diameter and height, the ranking of provenances using volume index might be more accurate than using either height or diameter singly if differences in form factor among provenances is neglected.

### 5.3 SYLLEPSIS

The increase in sylleptic long shoots from 1994 to 1995 among all provenances is surprising. Syllepsis is a juvenile character that is seldom observed in trees older than 25 years (Remphrey and Powell, 1985). The amount of syllepsis is often correlated with growth rate of the terminal leader (Remphrey and Powell, 1985; Powell and Vescio, 1986). Powell and Vescio also observed that the amount of syllepsis becomes more erratic and highly correlated with the environmental conditions as the trees grow older. It is therefore possible that the higher amount of syllepsis observed in 1995 was due to a more favourable environmental conditions in 1995 than in 1994.

### 5.4 CORRELATIONS

#### 5.4.1 Age-age Correlation of Total Height

The clonal correlation of the 1987 total height with that of subsequent years declined as the plantation age increased but was still moderate at age 11 (0.61). Both Lambeth's (1980) formula and Hühn and Kleinschmit's (1993) formula gave relatively good estimates of observed correlation coefficients. Due to the limited number of data points (seven points

spanning 10 years) used in the estimation of these formulae they probably only serve to illustrate the trends of correlation up to age 11 and further extrapolation might be risky. Using the formula obtained by the method of Hühn and Kleinschmit (1993), the correlation coefficient is estimated to fall to 0.52 as the plantation ages. This suggests that height at age three might be a good indicator of 11 year total height and possibly of later height in this test. However, it should be kept in mind that these calculations were done in a provenance test located only at one test site (not a progeny test), therefore the results cannot be used for breeding tamarack other than give a general impression of age-age correlations in tamarack. Moreover, calculations were based on measurements made on the same individuals at different periods in time. Common environmental effects are, therefore, confounded with genetic effects and might have a biasing influence on the correlation coefficients (Namkoong *et al.*, 1988). High age-age correlations have, however, been reported in tamarack. Eight provenances planted at three sites in France showed little genotype by environment interaction and age-age correlations in were found to be high enough to make selection at age seven for 25 year height efficient (Paques and Perinot, 1994).

### 5.3.2. Correlation Among Characters

The observations made in this test indicate that syllepsis correlates positively with the leader length of the current growth. Many studies support this view (e.g. Remphrey and Powell 1984, 1985; Powell and Vescio, 1986; Deng, 1990; Farmer *et al.*, 1993). In this test juvenile syllepsis correlated poorly with later height increment maybe because both syllepsis and height increment vary considerably between years depending on weather conditions and

age of the test plantation.

The correlation between juvenile syllepsis and total height of the current year was low but improved with age. This might be expected from the observations that (1) syllepsis in early stages of the test (year 4) correlated positively with the leader length and shoot vigour, (2) trees which produced sylleptic shoots in one year tended to be even more sylleptic the next year (Powell and Vescio, 1986) and (3) an advantage of a larger photosynthetic surface is conferred on trees which produced sylleptic long shoots early. Total height is an accumulation of successive annual height increments and tends to average out the fluctuations in individual years. Therefore, early syllepsis tends to correlate better with total height at the later stages. This probably agrees with Remphrey and Powell (1985) who suggested that syllepsis is part of an adaptive and exploitative mechanism that permits *Larix laricina* to display as large a photosynthesizing surface as possible within the limits of an excurrent crown form.

Although both phenotypic and genetic correlations of syllepsis with total height were only moderate (Table 4.7), the fact that the correlation coefficients improve with age is good reason to consider syllepsis seriously in selecting for total height. This has already been advocated by Powell (1987).

Both diameter and volume index correlated best with the 1989 syllepsis, suggesting that juvenile syllepsis is a better indicator of both diameter at year 11 and volume index at year 11.

## 6. CONCLUSIONS

1. The southern provenances in this clonal test plantation has performed well both in survival and height growth. Vegetative propagation in tamarack from cuttings might be useful for both clonal replication in tests as well as plantation establishment.

2. In this test the best provenances at age 11 could be identified as early as age 4. However the best individuals are more difficult to identify since the broad sense heritability increases continuously to age 11.

3. Height and diameter are strongly correlated in this test suggesting it might be possible to improve both height and diameter by selecting for total height.

4. There is positive correlation between juvenile syllepsis and annual height increment. The correlation coefficient varies from year to year.

5. The correlation between juvenile syllepsis and total height improves as the plantation becomes older. Juvenile syllepsis, is therefore, a better indicator of 11 year height than syllepsis at the later stages.



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## **APPENDICES**

APPENDIX I  
ADJUSTED COEFFICIENTS OF THE EXPECTED MEAN SQUARES

Source of Variation	Degree of Freedom	Expected Mean Square
Bi (Block)	3	$\sigma^2 + 2.49\sigma_{BC}^2 + 24.86\sigma_{BS}^2 + 49.71\sigma_{\omega}^2 + 49.71\sigma_{BP}^2 + 547.8\sigma_{\delta}^2 + 547.8\phi_B$
$\delta(I)$ (1 <sup>st</sup> restriction error)	0	$\sigma^2 + 2.49\sigma_{BC}^2 + 24.86\sigma_{BS}^2 + 49.71\sigma_{\omega}^2 + 49.71\sigma_{BP}^2 + 547.8\sigma_{\delta}^2$
Pj (Provenance)	10	$\sigma^2 + 9.94\sigma_C^2 + 99.42\sigma_S^2 + 49.71\sigma_{\omega}^2 + 198.84\sigma_P^2$
BPij (Block x Provenance)	30	$\sigma^2 + 2.49\sigma_{BC}^2 + 24.86\sigma_{BS}^2 + 49.71\sigma_{\omega}^2 + 49.71\sigma_{BP}^2$
$\omega(ij)$ (2 <sup>nd</sup> restriction error)	0	$\sigma^2 + 2.49\sigma_{BC}^2 + 24.86\sigma_{BS}^2 + 99.42\sigma_{\omega}^2$
S(I)j (Stand/Provenance)	11	$\sigma^2 + 9.94\sigma_C^2 + 99.42\sigma_S^2$
BSi(j)k (Blk x St./Prov)	33	$\sigma^2 + 2.49\sigma_{BC}^2 + 24.86\sigma_{BS}^2$
C(jk)l (Clone/St./Prov)	198	$\sigma^2 + 9.94\sigma_C^2$
BCi(jk)l (Blk x C/St/Prov)	594	$\sigma^2 + 2.49\sigma_{BC}^2$
E(ijkl)m (Error)	1760	$\sigma^2$
Total	2639	

## APPENDIX II

## DERIVATION OF HÜHN AND KLEINSCHMIT'S FORMULA AGE-AGE

## CORRELATION

Hühn and Kleinschmit's (1993) formula was derived as follows:

$$\text{cov}(y_1, y_2) = k_1 + k_2 x_i$$

$$\sigma_y = k_3 + k_4 x_i$$

Where

$\text{cov}(y_1, y_2)$  = covariance of traits  $y_1$  and  $y_2$  at age  $x_i$

$\sigma_y$  = the clonal standard deviation

$k_1$  = a constant (intercept of the linear regression equation on the covariance axis)

$k_2$  = the coefficient of the linear regression equation of covariance on age

$k_3$  = a constant (intercept of the linear regression equation on the  $\sigma_y$  -axis)

$k_4$  = the coefficient of the linear regression of the clonal standard deviation on age

$x_i$  = age of the plantation in years from date of planting

Based on the definition of the correlation coefficient, and using these two linear dependencies, Hühn and Kleinschmit (1993) proposed a formula for juvenile-mature (age-age) correlation coefficient

as:

$$r_G = \frac{c_1 \cdot x_i + c_2}{c_3 \cdot x_i + c_4}$$

where

$r_G$  = the juvenile mature correlation coefficient

$c_1, c_2, c_3$  and  $c_4$  = constants to be derived from the data.

Factoring out  $c_2$  and  $c_4$  and letting  $c_5 = c_2/c_4$ ,  $c_6 = c_1/c_2$ , and  $c_7 = c_3/c_4$  then, the formula can be expressed as :

$$r_G = c_5 \cdot \frac{1 + c_6 \cdot x_i}{1 + c_7 \cdot x_i}$$



APPENDIX III  
ANOVA'S FOR TOTAL HEIGHT, HEIGHT GROWTH, DIAMETER AND  
SYLLEPSIS (ALL PROVENANCES COMBINED)

Source of variation	Degrees of freedom	Sum of squares	Mean square	Variance Component	% of total variance
1987 total height					
Block (B)	3	56615.50	18871.90	32.25	8.71
Provenance (P)	10	109927.30	10992.70	51.41	13.88
B X P	30	49171.60	1639.10	28.68	7.50
Stand (S/P)	11	11044.70	1004.10	7.66	2.07
B X S	33	8123.60	246.20	-1.78	0.00
Clone(C/S/P)	186	109919.00	260.00	4.43	1.20
B X C/S/P	521	150832.70	289.51	29.85	8.06
Error	1136	246550.20	217.00	217.00	58.59
1988 total height					
Block (B)	3	209819.40	69939.80	122.45	13.21
Provenance (P)	10	231827.60	23182.76	110.07	11.88
B X P	30	135491.72	4516.39	83.54	8.78
Stand (S/P)	11	19766.00	1796.91	5.55	0.60
B X S	33	15139.50	458.77	-4.33	0.00
Clone(C/S/P)	186	234024.60	1258.20	77.45	8.36
B X C/S/P	521	293830.90	563.97	23.97	2.59
Error	1136	574550.30	505.77	505.77	54.58

## APPENDIX III CONTINUED

Source of variation	Degrees of freedom	Sum of squares	Mean square	Variance Component	% of total variance
1989 total height					
Block (B)	3	325230.40	108410.13	177.82	8.97
Provenance (P)	10	745445.50	74544.55	365.70	18.45
B X P	30	401928.40	13397.61	252.98	12.76
Stand (S/P)	11	38400.70	3490.97	6.38	0.32
B X S	33	36615.20	1109.55	4.62	0.23
Clone(C/S/P)	186	534009.50	2871.02	196.10	9.89
B X C/S/P	521	519601.80	997.32	12.90	0.65
Error	1136	1097358.70	965.98	965.99	48.73
1990 total height					
Block (B)	3	319887.80	106629.27	152.49	4.45
Provenance (P)	10	1573531.00	157353.10	782.04	22.74
B X P	30	754545.10	25151.50	478.38	13.95
Stand (S/P)	11	59469.50	5406.32	-4.29	0.00
B X S	33	63187.80	1914.78	13.01	0.38
Clone(C/S/P)	186	1083091.30	5823.07	440.84	12.86
B X C/S/P	521	833031.70	1598.91	24.06	0.70
Error	1136	1749981.60	1540.48	1540.48	44.92

## APPENDIX III CONTINUED

Source of variation	Degrees of freedom	Sum of squares	Mean square	Variance Component	% of total variance
1992 total height					
Block (B)	3	738703.80	246234.60	369.03	2.92
Provenance (P)	10	2779115.50	277911.55	1429.87	10.91
B X P	30	1471854.10	49061.80	920.71	6.37
Stand (S/P)	11	1059.20	96.29	-106.85	0.00
B X S	33	143215.90	4339.88	-42.66	0.00
Clone(C/S/P)	186	1948633.00	10476.52	46.69	0.37
B X C/S/P	521	2800906.40	5376.02	-1913.40	0.00
Error	1136	11385961.50	10022.85	10022.90	79.43
1994 total height					
Block (B)	3	225327.20	75109.07	37.74	0.42
Provenance (P)	10	4933953.80	493395.38	2456.82	27.23
B X P	30	1648436.80	54947.89	988.52	11.07
Stand (S/P)	11	176551.30	16050.12	-48.44	0.00
B X S	33	228756.90	6932.03	141.78	1.55
Clone(C/S/P)	186	3860565.30	20755.73	1769.45	19.81
B X C/S/P	521	1817515.70	3488.51	-31.94	0.00
Error	1136	4051061.30	3566.08	3566.08	39.92



## APPENDIX III CONTINUED

Source of variation	Degrees of freedom	Sum of squares	Mean square	Variance Component	% of total variance
1995 total height					
Block (B)	3	93761.00	31253.67	-51.41	0.00
Provenance (P)	10	5500998.10	550099.81	2719.49	23.37
B X P	30	1761799.10	58726.64	1061.99	8.96
Stand (S/P)	11	238910.30	21719.12	-28.98	0.00
B X S	33	235673.10	7141.61	-50.37	0.00
Clone(C/S/P)	186	4563379.10	24534.30	2130.57	18.41
B X C/S/P	521	4358190.30	8365.05	1864.70	16.11
Error	1136	4358190.30	3836.44	3836.44	33.15
1995 Diameter					
Block (B)	3	28.80	9.60	0.00	0.00
Provenance (P)	10	820.30	82.03	0.37	12.12
B X P	30	359.90	12.00	0.20	6.38
Stand (S/P)	11	106.30	9.66	0.00	0.00
B X S	33	81.70	2.48	0.03	1.09
Clone(C/S/P)	186	1797.06	9.66	0.83	26.90
B X C/S/P	521	867.40	1.66	0.01	0.47
Error	1136	1851.70	1.63	1.63	53.04

## APPENDIX III CONTINUED

Source of variation	Degrees of freedom	Sum of squares	Mean square	Variance Component	% of total variance
1988 Annual Height Increment					
Block (B)	3	88601.40	29533.80	51.50	14.47
Provenance (P)	10	65319.20	6531.92	30.08	8.45
B X P	30	60588.20	2019.61	36.92	9.34
Stand (S/P)	11	7569.50	688.14	1.77	0.50
B X S	33	7464.30	226.19	-7.36	0.00
Clone(C/S/P)	186	96054.20	516.42	49.06	13.79
B X C/S/P	521	210932.00	404.86	150.33	42.26
Error	1136	45232.70	39.82	39.80	11.19
1989 Annual Height Increment					
Block (B)	3	14529.00	4843.00	8.43	2.08
Provenance (P)	10	163227.60	16322.76	81.51	19.80
B X P	30	10228.70	340.96	2.07	0.35
Stand (S/P)	11	5343.70	485.79	-2.46	0.00
B X S	33	7931.80	240.36	-1.33	0.00
Clone(C/S/P)	186	134837.40	724.93	47.36	11.68
B X C/S/P	521	142025.70	272.60	3.18	0.78
Error	1136	300894.60	264.87	264.87	65.32

## APPENDIX III CONTINUED

Source of variation	Degrees of freedom	Sum of squares	Mean square	Variance Component	% of total variance
1990 Annual Height Increment					
Block (B)	3	4278.00	1426.00	-1.58	0.00
Provenance (P)	10	164412.20	16441.22	80.13	15.12
B X P	30	68073.50	2269.12	38.68	7.30
Stand (S/P)	11	9588.10	871.65	-0.14	0.00
B X S	33	12876.20	390.19	3.06	0.27
Clone(C/S/P)	186	164597.20	884.93	54.56	10.30
B X C/S/P	521	164624.30	315.98	-16.04	0.00
Error	1136	403193.60	354.92	354.92	67.01
1992 Annual Height Increment					
Block (B)	3	112273.70	37424.57	59.04	3.79
Provenance (P)	10	192925.10	19292.51	87.33	5.61
B X P	30	176379.10	5879.30	98.58	6.09
Stand (S/P)	11	25565.40	2324.13	3.73	0.24
B X S	33	36001.60	1090.96	-7.51	0.00
Clone(C/S/P)	186	364852.90	1961.57	77.90	5.01
B X C/S/P	521	663455.90	1273.43	28.25	1.82
Error	1136	1368685.50	1204.83	1204.83	77.44



## APPENDIX III CONTINUED

Source of variation	Degrees of freedom	Sum of squares	Mean square	Variance Component	% of total variance
1994 Annual Height Increment					
Block (B)	3	169561.30	56520.43	98.27	2.52
Provenance (P)	10	419991.80	41999.18	201.31	5.02
B X P	30	120426.30	4014.21	30.63	0.24
Stand (S/P)	11	31738.30	2885.30	-10.65	0.00
B X S	33	83376.70	2526.57	42.10	0.00
Clone(C/S/P)	186	729171.40	3920.28	37.00	0.95
B X C/S/P	521	783641.80	1504.11	-846.88	0.00
Error	1136	4045105.10	3560.83	3560.83	91.27
1995 Annual Height Increment					
Block (B)	3	49408.40	16469.47	28.76	9.14
Provenance (P)	10	21909.50	2190.95	7.88	2.50
B X P	30	33031.50	1101.05	15.48	4.92
Stand (S/P)	11	7267.70	660.70	1.58	0.50
B X S	33	11515.46	348.95	5.32	1.60
Clone(C/S/P)	186	94417.90	507.62	28.88	9.18
B X C/S/P	521	114532.60	219.83	-2.98	0.00
Error	1136	257937.70	227.06	227.06	72.16

## APPENDIX III CONTINUED

Source of variation	Degrees of freedom	Sum of squares	Mean square	Variance Component	% of total variance
1988 Syllepsis					
Block (B)	3	179.50	59.83	0.09	2.76
Provenance (P)	10	201.10	20.11	0.07	2.09
B X P	30	282.30	9.41	0.11	3.32
Stand (S/P)	11	68.20	6.20	0.00	0.07
B X S	33	128.70	3.90	0.01	0.29
Clone(C/S/P)	186	1112.40	5.98	0.40	11.78
B X C/S/P	521	1906.70	3.66	0.66	19.18
Error	1136	2349.30	2.07	2.07	60.51
1989 Syllepsis					
Block (B)	3	567.20	189.07	0.14	0.44
Provenance (P)	10	6954.70	695.47	2.92	9.02
B X P	30	3376.20	112.54	2.06	5.82
Stand (S/P)	11	1415.20	128.65	0.19	0.60
B X S	33	410.50	12.44	-0.35	0.00
Clone(C/S/P)	186	20431.00	109.84	9.77	30.18
B X C/S/P	521	10956.90	21.03	2.50	7.73
Error	1136	16985.00	14.95	14.95	46.20

## APPENDIX III CONTINUED

Source of variation	Degrees of freedom	Sum of squares	Mean square	Variance Component	% of total variance
1994 Syllepsis					
Block (B)	3	2676.80	892.27	1.62	5.65
Provenance (P)	10	5567.50	556.75	2.31	8.05
B X P	30	790.30	26.34	0.05	0.18
Stand (S/P)	11	1188.20	108.02	0.13	0.44
B X S	33	786.60	23.84	0.10	0.34
Clone(C/S/P)	186	17802.52	95.71	8.62	30.02
B X C/S/P	521	11178.78	21.46	3.90	13.59
Error	1136	13609.50	11.98	11.98	41.73
1995 Syllepsis					
Block (B)	3	891.52	297.17	0.42	1.32
Provenance (P)	10	5488.10	548.81	2.36	6.64
B X P	30	2111.80	70.39	0.94	2.92
Stand (S/P)	11	986.80	89.71	-0.44	0.00
B X S	33	810.90	24.57	0.25	0.78
Clone(C/S/P)	186	24627.40	132.41	12.08	37.44
B X C/S/P	521	9615.00	18.45	1.42	4.39
Error	1136	17053.00	15.01	15.01	46.51



APPENDIX IV  
BROAD SENSE HERIABILITIES OF TOTAL HEIGHT FOR THE INDIVIDUAL  
PROVENANCES.

Provenance		Height						Dia- meter	
		Year							
		1987	1988	1989	1990	1992	1994	1995	1995
North Bay	H <sup>2</sup>	0.09	0.09	0.16	0.23	0.39	0.44	0.46	0.41
	SE(H <sup>2</sup> )	0.06	0.06	0.07	0.08	0.09	0.09	0.09	0.09
Sault Ste.	H <sup>2</sup>	0.14	0.10	0.09	0.09	0.12	0.15	0.14	0.09
Marie	SE(H <sup>2</sup> )	0.07	0.06	0.06	0.06	0.06	0.07	0.07	0.06
Timmins	H <sup>2</sup>	0.09	0.04	0.11	0.13	0.08	0.22	0.22	0.15
	SE(H <sup>2</sup> )	0.06	0.05	0.06	0.07	0.06	0.08	0.08	0.07
Wawa	H <sup>2</sup>	0.09	0.06	0.06	0.08	0.07	0.06	0.07	0.14
	SE(H <sup>2</sup> )	0.06	0.05	0.05	0.05	0.05	0.05	0.05	0.07
Thunder	H <sup>2</sup>	0.17	0.16	0.17	0.23	0.23	0.34	0.41	0.36
Bay	SE(H <sup>2</sup> )	0.07	0.07	0.07	0.08	0.08	0.09	0.10	0.10
Fort	H <sup>2</sup>	0.14	0.14	0.18	0.15	0.16	0.23	0.28	0.36
Frances	SE(H <sup>2</sup> )	0.07	0.07	0.08	0.07	0.07	0.08	0.09	0.09
Red Lake	H <sup>2</sup>	0.26	0.38	0.44	0.46	0.44	0.58	0.60	0.55
	SE(H)	0.09	0.10	0.10	0.10	0.10	0.09	0.09	0.09
Pickle Lake	H <sup>2</sup>	0.12	0.16	0.07	0.16	0.16	0.44	0.48	0.46
	SE(H <sup>2</sup> )	0.08	0.09	0.07	0.07	0.09	0.11	0.11	0.11
Kenogami River	H <sup>2</sup>	0.19	0.21	0.29	0.33	0.35	0.47	0.50	0.45
	SE(H <sup>2</sup> )	0.08	0.08	0.09	0.09	0.10	0.11	0.10	0.10
Moosonee	H <sup>2</sup>	0.19	0.25	0.21	0.21	0.20	0.33	0.35	0.30
	SE(H <sup>2</sup> )	0.09	0.10	0.09	0.09	0.09	0.10	0.11	0.10
Big Trout Lake	H <sup>2</sup>	0.09	0.02	0.03	0.22	0.25	0.28	0.28	0.35
	SE(H <sup>2</sup> )	0.06	0.04	0.05	0.08	0.09	0.09	0.09	0.10

APPENDIX V  
CLONE MEANS OF TOTAL HEIGHT

CLONE#	HT87	HT88	HT89	HT90	HT92	HT94	HT95
010121	68.08	102.00	173.00	234.00	359.75	522.08	596.42
010122	68.06	95.19	167.08	238.08	371.93	502.50	567.00
010123	64.24	92.61	148.63	226.25	362.04	495.25	555.92
010129	72.42	103.29	155.57	217.86	312.68	484.69	545.44
010131	72.43	90.61	149.01	217.38	344.83	485.94	556.28
010132	89.42	129.54	204.38	289.13	414.25	560.67	625.75
010133	62.96	88.04	162.47	226.88	345.92	496.92	564.58
010134	73.61	121.00	201.25	287.75	422.25	579.42	652.42
010136	67.51	96.40	173.13	240.93	351.92	494.61	564.17
010137	78.75	108.75	188.38	272.63	412.13	567.42	644.00
010222	66.78	109.75	186.83	267.36	414.81	566.64	640.14
010225	69.44	100.63	166.13	250.67	380.88	548.75	620.42
010226	72.58	114.74	190.69	288.51	448.36	626.11	703.83
010227	57.22	94.49	160.35	221.74	328.18	492.50	568.28
010229	54.72	82.67	147.21	228.75	372.42	534.83	602.92
010232	82.15	114.69	180.86	256.33	392.51	554.44	636.89
010233	55.47	83.82	140.43	199.82	337.64	475.22	550.42
010234	67.51	90.22	148.78	210.00	339.72	470.58	545.22
010235	63.06	98.93	187.75	286.06	441.03	628.36	708.81
010238	56.85	85.65	139.14	200.61	316.38	427.86	484.31
020121	64.53	85.64	144.53	234.85	356.36	539.44	614.64
020124	65.53	93.06	155.06	220.25	341.93	500.50	572.25

## APPENDIX V CONTINUED

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020126	55.29	81.10	137.07	211.60	330.90	503.56	574.42
020127	85.75	106.33	161.17	238.22	331.33	492.78	576.56
020128	62.71	90.25	148.00	226.17	328.25	478.42	548.00
020130	66.39	102.47	163.33	224.47	323.42	469.72	532.94
020132	49.04	67.33	106.06	166.50	237.08	365.22	432.94
020133	51.17	69.88	125.35	201.46	310.51	498.50	566.94
020136	60.29	82.60	134.04	204.83	319.07	452.33	517.11
020137	56.13	79.63	140.33	209.08	328.13	486.25	563.17
020221	61.43	92.97	142.39	207.06	339.44	481.14	546.25
020223	63.07	91.68	134.40	200.61	300.83	442.89	509.03
020225	55.46	74.71	123.74	183.82	278.33	426.94	490.39
020226	42.78	67.00	121.50	191.94	293.50	432.22	496.00
020227	67.36	91.75	142.75	215.31	324.17	475.67	545.50
020230	67.22	92.56	140.31	209.61	314.64	474.50	539.28
020232	61.83	87.92	145.46	204.63	314.96	471.50	534.08
020233	63.44	86.74	140.21	193.61	282.42	429.28	507.25
020235	61.28	81.75	133.79	212.21	294.50	446.83	517.25
020236	68.47	90.44	150.56	234.06	364.89	522.89	580.33
030125	41.60	64.08	117.08	167.22	263.82	365.47	437.75
030126	63.38	99.17	169.92	247.96	348.71	536.17	598.92
030127	52.81	79.15	122.63	175.08	295.00	426.22	488.28
030128	54.29	77.24	130.18	199.04	302.51	467.47	537.33
030129	60.07	83.40	138.54	217.35	331.22	507.47	580.58
030130	62.00	85.10	140.83	202.26	303.01	457.58	530.97
030133	60.36	82.03	146.36	216.67	312.42	475.11	547.06

## APPENDIX V CONTINUED

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030134	44.43	74.90	127.88	190.01	291.07	448.22	521.31
030135	49.17	81.39	150.33	219.01	321.36	415.86	479.17
030221	49.13	67.39	120.36	192.86	292.06	437.94	503.14
030222	59.43	75.89	118.75	188.78	271.82	398.64	461.97
030226	49.21	71.17	126.42	195.13	326.88	488.08	555.67
030228	50.44	67.47	113.31	175.25	292.75	437.22	510.56
030229	46.33	79.35	131.76	196.22	314.42	453.11	524.81
030230	50.86	74.17	110.44	170.28	319.67	408.00	479.22
030232	59.92	86.60	136.76	202.54	336.29	479.17	543.53
030234	51.96	75.96	126.67	185.63	300.25	457.08	529.00
030235	62.33	88.96	140.79	198.92	305.00	450.08	533.92
030236	56.83	76.31	125.42	189.13	322.79	473.75	549.03
040122	52.33	71.71	120.88	180.46	298.46	455.58	535.50
040124	45.22	65.35	107.28	150.92	241.85	387.67	460.08
040126	55.63	75.44	124.94	185.17	308.97	430.50	503.72
040128	55.75	85.06	138.11	192.64	299.68	433.11	506.28
040129	69.19	96.83	146.83	207.13	316.07	450.72	515.44
040130	65.81	95.47	150.99	217.82	331.85	482.97	549.69
040131	61.08	87.25	140.33	211.19	334.50	481.75	548.83
040133	57.25	92.08	141.83	200.58	330.17	467.00	545.08
040134	57.83	82.33	126.83	187.63	286.71	429.25	498.08
040136	53.08	77.14	121.14	180.82	293.69	416.14	481.47
040223	69.13	100.74	153.81	215.31	342.74	481.14	554.86
040224	46.33	71.83	130.00	193.42	309.58	460.33	534.17
040225	64.04	93.42	149.97	213.35	324.17	475.17	543.86

## APPENDIX V CONTINUED

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040226	57.47	89.13	148.83	217.63	327.47	460.67	529.83
040227	60.44	88.10	142.17	213.18	340.74	493.11	570.39
040228	53.92	77.13	130.53	196.04	311.75	442.44	518.06
040230	42.61	72.33	108.06	166.83	273.28	406.11	477.78
040234	53.19	83.29	130.54	181.58	302.75	442.00	508.50
040235	58.40	85.21	134.96	190.54	304.25	455.67	518.00
050122	76.14	104.63	158.33	227.10	365.64	516.14	601.97
050125	54.19	77.17	128.75	189.64	334.89	469.22	539.78
050126	69.78	104.89	159.65	217.06	354.88	471.25	544.78
050127	71.21	101.38	164.17	233.71	351.92	506.33	572.33
050128	54.71	86.68	150.38	214.99	344.08	520.69	597.17
050129	64.22	104.33	166.19	226.22	348.64	493.36	558.58
050131	51.26	80.31	130.35	186.74	301.75	450.69	531.00
050133	52.90	75.06	136.63	208.31	340.78	504.94	579.39
050134	45.61	66.64	106.86	144.42	257.67	356.11	411.11
050221	52.42	75.17	108.17	156.83	272.92	391.50	454.67
050223	69.44	100.72	151.22	203.50	332.17	466.28	529.83
050226	59.03	82.65	137.17	209.60	316.93	467.31	539.75
050227	69.89	100.58	155.03	215.11	355.83	492.17	562.50
050228	65.33	88.50	123.89	173.03	296.08	423.61	504.78
050229	71.64	103.10	176.32	252.96	393.61	551.33	632.08
050231	43.42	59.67	98.92	126.08	223.33	298.50	347.00
050232	74.29	106.01	165.11	236.10	367.31	535.22	606.89
050233	62.44	82.50	129.50	187.06	320.67	474.11	549.78
050234	47.25	78.14	135.86	197.33	310.22	432.11	507.28

## APPENDIX V CONTINUED

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060121	55.71	83.83	134.75	202.29	321.38	482.67	545.42
060124	54.08	82.99	128.96	190.53	328.63	475.64	549.19
060125	64.75	96.08	146.79	199.08	334.21	457.42	530.67
060126	57.89	98.46	188.46	229.33	352.21	508.67	584.17
060129	52.75	91.61	149.28	206.44	335.50	428.00	483.11
060130	67.06	99.97	168.82	245.22	385.17	526.17	597.17
060132	67.22	101.69	160.51	227.06	342.79	470.39	543.14
060133	57.38	77.01	125.63	187.57	303.17	443.83	515.94
060134	69.85	121.08	186.88	267.88	399.04	557.83	636.00
060135	78.08	107.36	166.42	228.65	374.36	511.08	579.11
060222	50.29	87.47	142.71	201.96	317.68	445.31	500.03
060224	48.01	75.03	131.85	199.22	328.28	466.31	531.58
060225	55.42	88.26	148.31	205.64	343.14	492.64	561.17
060229	43.65	66.07	123.10	200.63	342.28	487.50	560.06
060230	64.36	96.88	173.85	230.33	324.06	495.89	568.14
060232	55.44	76.83	121.03	183.85	311.82	445.83	510.86
060233	70.83	110.67	177.81	252.65	399.67	545.28	624.31
060235	48.94	72.68	123.67	188.40	282.19	445.83	500.67
060236	52.28	85.71	143.03	221.57	361.94	501.22	571.25
060237	52.67	80.97	134.46	188.68	303.44	412.64	468.92
070121	64.54	99.60	157.76	232.28	353.46	525.75	600.69
070122	46.78	67.89	108.72	177.39	287.78	410.67	477.11
070124	45.00	72.58	104.83	166.92	275.58	397.83	473.50
070126	44.42	56.42	92.08	139.42	231.67	312.33	353.83
070128	45.67	60.46	99.79	144.11	234.50	343.81	408.19

## APPENDIX V CONTINUED

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070132	55.00	82.39	127.17	185.39	270.64	396.22	475.78
070133	38.65	57.56	94.39	140.22	230.01	355.50	414.69
070134	52.14	68.36	107.31	156.10	249.53	395.33	466.81
070137	46.67	51.39	83.28	123.33	228.86	340.56	412.78
070138	45.57	66.83	125.17	172.75	286.19	439.06	514.72
070224	24.44	37.28	63.67	96.67	156.61	263.11	325.22
070225	51.00	87.88	156.17	230.21	346.04	483.08	549.67
070226	61.25	92.11	149.89	227.67	353.61	530.11	604.78
070227	46.50	61.83	mis	135.08	238.00	398.25	469.67
070228	61.00	87.56	141.11	205.94	305.94	456.78	517.56
070231	41.83	60.25	110.39	176.96	291.33	447.67	523.67
070232	34.25	53.42	91.75	138.83	234.00	343.67	407.67
070233	35.22	47.50	69.72	99.17	178.89	283.67	333.78
070235	44.17	66.06	110.17	168.33	282.56	391.89	457.56
070238	51.92	79.86	129.64	195.53	306.36	453.00	516.86
080122	34.42	53.67	88.17	127.58	216.75	328.83	396.67
080123	39.39	58.06	98.22	143.94	231.56	334.33	397.28
080124	49.67	74.33	95.83	128.67	223.50	378.00	420.33
080125	31.00	47.25	93.50	113.13	297.75	342.50	419.75
080126	47.06	65.42	107.47	158.53	254.44	384.17	456.00
080128	42.25	55.29	90.54	135.54	213.25	299.92	344.50
080130	25.50	39.38	60.88	80.88	151.50	208.50	237.50
080131	48.29	78.63	122.54	175.50	270.88	397.33	459.42
080132	36.94	57.90	94.44	129.65	226.94	347.61	416.64
080136	58.56	72.83	107.28	158.11	255.78	398.89	462.22



## APPENDIX V CONTINUED

080221	44.06	59.17	96.72	140.42	243.00	384.50	458.72
080224	43.81	68.25	101.14	141.50	237.03	331.28	387.89
080227	35.42	45.08	73.75	100.83	197.42	254.33	293.33
080229	43.29	64.13	93.29	141.18	249.24	344.00	402.25
080232	51.72	79.67	115.86	162.11	283.03	405.94	470.11
080233	38.04	55.58	85.04	127.50	207.46	300.25	351.17
080235	41.56	61.78	99.94	139.39	228.28	341.89	402.17
080236	51.60	72.01	99.04	138.19	246.19	374.78	434.47
090121	45.81	68.83	113.56	162.00	285.11	391.56	467.28
090122	44.86	65.94	101.33	151.44	270.75	379.50	435.14
090124	52.25	77.97	127.72	178.92	309.81	433.00	504.72
090125	59.07	87.49	132.85	190.85	293.56	433.83	501.06
090128	56.25	78.60	120.04	168.18	261.94	376.53	438.47
090131	54.00	77.08	113.13	160.33	265.96	387.33	455.83
090134	63.74	97.03	149.56	209.60	298.36	446.08	518.25
090137	52.21	81.71	148.49	220.88	341.47	473.64	544.36
090140	45.57	69.10	120.71	177.26	296.61	425.19	496.00
090141	52.61	72.47	105.39	152.04	255.26	378.22	457.08
090223	38.07	60.39	106.33	157.74	291.17	405.53	478.75
090231	41.00	67.44	110.36	166.24	293.21	407.72	473.72
090232	47.25	67.53	105.75	151.86	263.86	338.50	395.22
090233	21.00	29.38	41.75	60.13	147.50	157.50	189.50
090234	37.13	53.50	83.79	123.58	199.96	302.75	351.75
090235	31.81	55.83	95.25	142.13	238.04	347.58	411.33
090236	45.26	68.01	120.07	182.26	288.35	421.61	481.00

## APPENDIX V CONTINUED

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090240	52.06	66.07	111.17	165.93	255.04	389.17	467.25
090241	54.54	81.32	133.78	189.19	313.13	425.44	490.42
100122	47.83	60.94	90.56	137.94	231.11	346.28	422.78
100123	48.94	74.17	119.78	169.17	286.72	407.28	474.00
100128	35.58	54.25	81.67	125.08	199.50	285.17	333.17
100130	63.33	89.76	129.60	182.81	286.61	411.86	477.78
100133	35.25	54.92	86.83	121.50	209.67	281.83	333.83
100135	43.33	64.51	103.90	150.69	255.63	372.00	440.39
100136	53.29	82.21	112.54	154.75	239.93	358.81	418.31
100222	50.50	75.51	115.74	165.11	282.53	413.83	484.44
100223	35.53	52.07	74.39	111.21	220.04	286.92	338.19
100224	39.18	57.97	93.56	135.86	219.89	314.53	370.44
100225	54.90	81.72	116.68	161.31	264.72	388.44	442.50
100229	40.56	57.89	95.28	138.78	220.67	318.00	389.00
100230	47.17	69.58	111.25	159.50	274.33	381.50	460.00
100234	40.42	61.64	94.47	130.11	210.56	315.83	370.56
100235	58.54	86.42	133.25	180.00	302.50	423.42	491.08
100236	50.56	81.40	128.19	182.96	308.32	441.39	515.44
130121	55.03	80.06	128.78	208.06	341.44	476.61	535.64
130123	39.79	65.08	109.11	170.19	293.61	409.64	481.31
130124	43.83	71.28	109.94	139.28	252.83	380.28	449.53
130127	40.28	67.69	110.86	147.89	257.89	356.56	414.56
130128	22.00	30.00	48.00	81.50	153.50	216.00	258.00
130129	39.43	66.38	111.54	164.19	273.97	403.25	460.75
130130	38.08	60.11	122.72	154.33	260.92	363.72	416.44

## APPENDIX V CONTINUED

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130131	49.78	68.00	113.06	182.61	301.39	456.67	525.78
130132	45.06	64.61	101.28	147.17	251.61	366.56	425.33
130134	49.50	81.46	132.57	195.13	302.93	424.28	479.97
130221	44.06	75.17	126.67	189.33	318.44	449.06	505.25
130223	46.17	82.31	124.22	166.56	260.81	380.56	450.50
130224	44.51	77.10	133.44	193.67	309.61	419.78	492.78
130225	51.38	73.25	123.00	181.58	306.26	422.67	488.92
130227	43.83	66.54	117.38	191.38	325.13	464.58	532.75
130228	56.83	83.28	128.29	204.00	322.13	442.25	502.08
130229	53.25	50.83	108.42	208.46	325.00	427.92	502.75
130230	38.76	61.78	105.43	153.86	257.50	396.69	469.86

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APPENDIX VB  
CLONE MEAN OF ANNUAL HEIGHT INCREMENT (AHI)

CLONE#	HTG88	HTG89	HTG90	HTG 91-92	HTG 93-94	HTG95	DIA95
010121	162.33	44.54	71.00	61.00	125.75	74.33	6.61
010122	130.57	27.14	71.89	71.00	133.85	64.50	7.19
010123	162.00	26.08	62.83	77.63	107.00	60.67	6.20
010129	172.01	30.88	52.28	62.29	94.82	60.75	6.56
010131	168.29	25.32	53.29	63.36	117.36	70.33	5.53
010132	146.42	40.13	74.83	84.75	125.13	65.08	8.08
010133	151.00	25.08	58.17	80.67	119.04	67.67	5.43
010134	157.17	65.79	80.25	86.50	134.50	73.00	9.83
010136	142.69	28.89	76.72	67.81	110.99	69.56	6.70
010137	155.29	42.71	79.63	84.25	139.50	76.58	8.59
010222	151.83	48.76	77.08	80.53	147.44	73.50	7.83
010225	167.88	48.54	65.50	84.54	130.21	71.67	7.12
010226	177.75	42.15	75.96	97.82	159.85	77.72	8.34
010227	164.32	41.65	65.86	61.39	106.44	75.78	6.66
010229	162.42	46.54	64.54	81.54	143.67	68.08	5.97
010232	161.93	32.54	66.17	75.47	136.18	82.44	7.38
010233	137.58	28.35	56.61	59.39	137.82	75.19	5.41
010234	130.86	35.82	58.56	61.22	129.72	74.64	5.82
010235	187.33	43.72	95.76	98.31	154.97	80.44	8.90
010238	111.49	28.81	53.49	61.47	115.76	56.44	5.36
020121	183.08	26.83	58.89	90.32	121.51	75.19	6.76

## APPENDIX VB CONTINUED

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020124	158.57	19.97	69.56	65.19	121.68	71.75	7.95
020126	172.65	25.81	55.97	74.53	119.31	70.86	7.48
020127	161.44	29.17	54.83	77.06	93.11	83.78	6.40
020128	150.17	37.42	57.75	78.17	102.08	69.58	7.49
020130	146.31	36.08	60.86	61.14	98.94	63.22	6.66
020132	128.14	34.64	38.72	60.44	70.58	67.72	5.43
020133	187.99	18.71	55.47	76.11	109.06	68.44	7.61
020136	133.26	22.31	51.44	70.79	114.24	64.78	6.69
020137	158.13	23.50	60.71	68.75	119.04	76.92	6.88
020221	141.69	31.54	49.42	64.67	132.39	65.11	7.06
020223	142.06	28.61	42.72	66.21	100.22	66.14	6.63
020225	148.61	19.25	49.03	60.08	94.51	63.44	6.90
020226	138.72	24.22	54.50	70.44	101.56	63.78	6.68
020227	151.50	30.78	51.00	72.56	108.86	69.83	7.86
020230	159.86	22.50	59.53	69.31	105.03	64.78	7.34
020232	156.54	26.08	57.54	59.17	110.33	62.58	7.56
020233	146.86	23.73	63.22	53.40	88.81	77.97	8.13
020235	152.33	25.92	52.04	60.25	100.46	70.42	6.47
020236	158.00	31.11	60.11	83.50	130.83	57.44	7.57
030125	101.65	22.49	53.00	50.14	96.60	72.28	5.59
030126	187.46	35.79	70.75	78.04	100.75	62.75	7.96
030127	131.22	26.35	43.47	52.46	119.92	62.06	6.49
030128	164.96	22.94	52.94	68.86	103.47	69.86	6.49
030129	176.25	23.33	55.14	78.81	113.88	73.11	7.68
030130	154.57	23.10	55.74	61.43	100.75	73.39	6.37



## APPENDIX VB CONTINUED

030133	162.69	26.97	64.33	70.31	95.75	71.94	7.42
030134	181.15	30.47	52.97	62.14	77.06	73.08	6.40
030135	131.42	35.89	50.61	60.96	91.49	63.31	6.76
030221	145.89	18.26	52.97	72.50	99.19	65.19	6.56
030222	126.82	16.46	42.86	70.03	83.04	63.33	5.46
030226	161.21	21.96	55.25	68.71	131.75	67.58	7.06
030228	144.47	17.03	45.83	61.94	117.50	73.33	5.59
030229	138.69	33.01	52.42	64.46	118.19	71.69	6.31
030230	147.75	24.29	44.44	59.83	89.97	71.22	5.52
030232	142.88	26.68	50.17	65.78	133.75	64.36	6.36
030234	156.83	24.00	50.71	58.96	114.63	71.92	6.74
030235	145.08	26.63	51.83	58.13	106.08	83.83	7.34
030236	150.96	19.47	49.11	63.71	133.67	75.28	7.15
040122	157.13	19.38	49.17	59.58	118.00	79.92	5.96
040124	145.82	20.13	41.93	43.64	90.93	72.42	5.28
040126	121.53	19.82	49.50	60.22	123.81	73.22	5.99
040128	133.43	33.64	48.11	67.31	107.04	73.17	6.34
040129	134.65	27.64	50.00	60.29	108.94	64.72	7.52
040130	151.13	34.86	55.51	66.83	114.03	66.72	7.72
040131	147.25	31.00	53.08	70.86	123.31	67.08	7.28
040133	136.83	34.83	49.75	58.75	129.58	78.08	5.84
040134	142.54	24.50	44.50	60.79	99.08	68.83	5.78
040136	122.44	24.06	44.00	59.68	112.88	65.33	6.58
040223	138.40	38.31	53.07	61.50	127.43	73.72	8.24
040224	150.75	25.50	58.17	63.42	116.17	73.83	5.60

## APPENDIX VB CONTINUED

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040225	151.00	29.38	56.56	63.38	110.82	68.69	6.76
040226	133.20	35.67	59.71	68.79	109.84	69.17	7.34
040227	152.38	27.65	54.07	71.01	127.56	77.28	6.58
040228	130.69	23.21	53.40	65.51	115.71	75.61	6.84
040230	132.83	29.72	35.72	58.78	106.44	71.67	5.14
040234	139.25	27.96	43.17	61.67	121.17	66.50	7.01
040235	151.42	32.00	49.75	55.58	113.71	62.33	6.50
050122	150.50	28.49	53.71	68.76	138.54	85.83	7.30
050125	134.33	29.19	51.58	60.89	145.25	70.56	5.32
050126	116.38	35.11	54.76	57.40	137.82	73.53	7.36
050127	154.42	30.17	62.79	69.54	118.21	66.00	7.85
050128	211.11	36.54	63.69	64.61	94.60	76.47	8.06
050129	144.72	40.11	61.86	60.03	122.42	65.22	7.69
050131	148.94	33.89	50.04	56.39	115.01	80.31	6.39
050133	164.17	25.88	61.57	71.68	132.47	74.44	7.23
050134	98.44	21.03	40.22	37.56	113.25	55.00	4.52
050221	118.58	22.75	33.00	48.67	116.08	63.17	4.70
050223	134.11	31.28	35.28	67.50	128.67	63.56	6.46
050226	150.38	23.63	54.51	72.43	107.33	72.44	7.15
050227	136.33	30.69	54.44	60.08	140.72	70.33	6.56
050228	127.53	23.17	35.39	49.14	123.06	81.17	6.34
050229	157.72	40.46	73.22	76.64	140.65	80.75	7.15
050231	75.17	16.25	17.17	49.25	97.25	48.50	3.20
050232	167.92	47.51	59.10	70.99	131.21	71.67	7.67
050233	153.44	26.50	47.00	57.56	133.61	75.67	6.48

## APPENDIX VB CONTINUED

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050234	121.89	30.89	57.72	61.47	112.89	75.17	6.09
060121	161.29	42.29	50.92	67.54	119.08	62.75	5.68
060124	147.01	32.35	45.97	61.57	138.10	73.56	6.97
060125	123.21	31.33	50.71	52.29	135.13	73.25	6.64
060126	156.46	54.13	53.50	77.38	122.88	75.50	6.20
060129	92.50	51.11	57.67	57.17	129.06	55.11	5.67
060130	141.00	38.35	68.85	76.40	139.94	71.00	7.63
060132	127.60	39.81	58.82	66.54	115.74	72.75	6.36
060133	140.67	19.64	48.61	61.94	115.60	72.11	6.44
060134	158.79	56.17	65.79	81.00	131.17	78.17	9.09
060135	136.72	29.28	59.06	62.24	145.71	68.03	7.06
060222	127.63	41.99	55.24	59.25	115.72	54.72	5.73
060224	138.03	27.01	56.82	67.38	129.06	65.28	6.13
060225	149.50	32.85	60.04	57.33	137.50	68.53	7.34
060229	145.22	22.42	57.03	77.53	141.65	72.56	6.05
060230	171.83	32.51	52.39	81.07	93.72	72.25	6.18
060232	134.01	21.39	44.19	62.82	127.97	65.03	5.53
060233	145.61	44.79	67.14	74.85	147.01	79.03	8.46
060235	197.39	23.74	50.99	64.74	131.19	54.83	5.10
060236	139.28	39.10	57.32	78.54	140.38	70.03	6.51
060237	109.19	31.92	53.49	54.22	114.76	56.28	6.66
070121	172.29	35.06	58.17	74.51	121.18	74.94	7.73
070122	122.89	21.11	40.83	68.67	110.39	66.44	5.84
070124	122.25	15.25	44.58	62.08	108.67	75.67	5.80
070126	80.67	12.00	35.67	47.33	92.25	41.50	5.48

## APPENDIX VB CONTINUED

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070128	109.31	18.50	39.33	44.32	90.39	64.39	4.52
070132	125.58	27.39	44.78	58.22	85.25	79.56	6.20
070133	125.49	18.90	36.83	45.83	89.79	59.19	5.01
070134	145.81	16.22	38.94	48.79	93.43	71.47	5.13
070137	111.69	11.33	31.89	40.06	105.53	72.22	3.86
070138	152.86	21.26	42.56	63.36	113.44	75.67	5.86
070224	106.50	12.83	26.39	33.00	59.94	62.11	2.89
070225	137.04	36.88	68.29	74.04	115.83	66.58	6.99
070226	176.50	36.50	57.78	77.78	125.94	74.67	8.07
070227	160.25	13.25	44.63	57.04	102.92	71.42	5.13
070228	150.83	26.56	53.56	64.83	100.00	60.78	7.83
070231	156.33	22.17	40.75	75.96	114.38	76.00	7.27
070232	109.67	19.17	38.33	47.08	95.17	64.00	4.78
070233	104.78	12.28	20.17	38.44	79.72	50.11	3.66
070235	109.33	21.89	44.11	58.17	114.22	65.67	5.77
070238	146.64	27.94	49.78	65.89	110.83	63.86	7.11
080122	112.08	19.25	34.50	39.42	89.17	67.83	4.55
080123	102.78	18.67	40.17	45.72	87.61	62.94	5.43
080124	154.50	24.67	21.50	32.83	94.83	42.33	4.70
080125	44.75	16.25	46.25	19.63	184.63	77.25	4.53
080126	129.72	18.36	42.06	51.06	95.92	71.83	6.12
080128	86.67	13.04	35.25	45.00	77.71	44.58	3.52
080130	57.00	21.25	21.50	20.00	70.63	29.00	2.08
080131	126.46	30.33	43.92	52.96	95.38	62.08	5.81
080132	120.67	20.96	36.54	35.21	97.29	69.03	5.08

## APPENDIX VB CONTINUED

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080136	143.11	14.28	34.44	50.83	97.67	63.33	6.48
080221	141.50	15.11	37.56	43.69	102.58	74.22	4.97
080224	94.25	24.44	32.89	40.36	95.53	56.61	4.55
080227	56.92	9.67	26.75	37.92	96.58	39.00	2.97
080229	94.76	14.78	35.22	47.89	108.06	58.25	5.17
080232	122.92	27.94	36.19	46.25	120.92	64.17	5.97
080233	92.79	17.54	29.46	42.46	79.96	50.92	4.88
080235	113.61	20.22	38.17	39.44	88.89	60.28	4.50
080236	128.58	20.42	27.03	39.15	108.00	59.69	5.67
090121	106.44	23.03	44.72	48.44	123.11	75.72	5.61
090122	108.75	21.08	35.39	50.11	119.31	55.64	5.19
090124	123.19	25.72	36.50	64.44	130.89	71.72	6.32
090125	140.28	28.42	45.36	58.00	102.71	67.22	6.54
090128	114.58	27.88	41.44	48.14	93.76	61.94	6.08
090131	121.38	23.08	36.04	47.21	105.63	68.50	5.73
090134	147.72	33.29	52.53	60.04	88.76	72.17	7.37
090137	132.17	29.50	66.78	72.39	120.60	70.72	7.56
090140	128.58	23.53	51.61	56.56	119.35	70.81	6.59
090141	122.96	19.86	32.92	46.65	103.22	78.86	5.54
090223	114.36	22.32	45.94	51.40	133.43	73.22	6.47
090231	114.51	26.44	42.92	55.88	126.97	66.00	5.09
090232	74.64	20.28	38.22	46.11	112.00	56.72	4.94
090233	10.00	8.38	24.75	18.38	87.38	32.00	1.58
090234	102.79	16.38	30.29	39.79	76.38	49.00	4.09
090235	109.54	30.75	39.42	46.88	95.92	63.75	4.77



## APPENDIX VB CONTINUED

090236	133.26	22.75	52.06	62.19	106.08	59.39	5.33
090240	134.13	27.60	45.10	54.76	89.11	78.08	5.86
090241	112.32	26.78	52.46	55.42	123.93	64.97	6.88
100122	115.17	13.11	29.61	47.39	93.17	76.50	5.89
100123	120.56	25.22	45.61	49.39	117.56	66.72	5.49
100128	85.67	18.67	27.42	43.42	74.42	48.00	3.17
100130	125.25	26.43	39.83	53.21	103.81	65.92	5.67
100133	72.17	27.42	31.92	34.67	88.17	52.00	3.92
100135	116.38	24.53	39.39	46.79	104.93	68.39	5.00
100136	118.88	18.92	26.83	36.65	104.24	59.50	5.05
100222	131.31	25.01	40.22	49.38	117.42	70.61	5.03
100223	66.88	16.54	22.32	36.82	108.83	51.28	3.18
100224	94.64	18.79	35.58	42.31	84.03	55.92	4.63
100225	123.72	32.88	34.96	44.63	103.42	54.06	5.74
100229	97.33	17.33	37.39	43.50	81.89	71.00	4.72
100230	107.17	22.42	41.67	48.25	114.83	78.50	5.67
100234	105.28	21.22	32.83	35.64	80.44	54.72	4.46
100235	120.92	27.88	46.83	46.75	122.50	67.67	5.32
100236	133.07	34.82	46.79	54.76	125.36	74.06	7.07
130121	165.36	32.67	44.18	70.72	122.08	59.03	6.83
130123	116.03	29.29	44.03	61.08	123.42	71.67	5.98
130124	149.64	23.14	35.22	28.44	103.89	69.25	5.48
130127	98.67	20.94	37.11	49.56	110.00	58.00	4.44
130128	62.50	8.00	18.00	33.50	72.00	42.00	1.90
130129	129.28	26.94	45.17	52.65	109.78	57.50	6.11

## APPENDIX VB CONTINUED

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130130	102.81	22.03	62.61	61.92	106.58	52.72	5.11
130131	155.28	18.22	45.06	69.56	118.78	69.11	6.18
130132	114.94	24.00	41.11	45.89	104.44	58.78	4.62
130134	121.35	31.96	51.11	62.56	107.81	55.69	6.17
130221	156.19	25.32	47.39	57.82	118.28	56.19	5.76
130223	119.75	36.14	41.92	42.33	94.25	69.94	5.07
130224	145.25	32.58	44.81	55.24	97.39	73.00	6.54
130225	138.71	33.25	49.75	58.58	102.38	66.25	6.14
130227	139.46	22.71	50.83	74.00	133.75	68.17	7.27
130228	120.13	17.21	54.25	75.71	118.13	59.83	7.28
130229	102.92	21.88	57.58	100.04	116.54	74.83	6.33
130230	139.19	23.01	43.65	48.43	103.64	73.17	5.17

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APPENDIX VC  
CLONE MEAN OF SYLLEPTIC COUNTS

CLONE#	SYL88	SYL89	SYL94	SYL95
010121	0.17	5.58	5.61	6.14
010122	0.11	8.08	5.06	4.14
010123	0.00	5.58	5.50	2.50
010129	0.92	4.36	3.06	10.83
010131	0.00	2.00	5.22	5.00
010132	0.25	6.11	3.17	3.11
010133	0.78	7.81	5.33	8.50
010134	0.33	6.58	3.61	3.92
010136	0.00	4.17	1.33	5.06
010137	1.83	19.92	13.17	15.92
010222	0.25	9.00	3.39	7.78
010225	0.00	1.08	1.44	1.67
010226	4.28	17.14	17.28	13.22
010227	0.00	7.75	6.42	10.03
010229	2.33	12.00	8.44	13.58
010232	0.00	2.44	7.39	11.53
010233	0.00	0.17	1.56	2.06
010234	0.00	0.50	1.11	3.06
010235	1.56	27.06	20.00	15.61
010238	0.00	0.00	0.00	0.78
020121	0.00	5.03	6.17	4.53

## APPENDIX VC CONTINUED

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020124	0.00	2.42	5.22	8.14
020126	0.00	2.22	8.69	6.42
020127	0.00	2.44	0.50	3.22
020128	0.00	6.33	5.67	6.08
020130	0.00	6.94	5.50	7.17
020132	0.00	0.67	4.17	7.61
020133	0.00	11.94	14.25	10.89
020136	0.00	4.39	3.22	3.64
020137	0.00	6.75	5.58	5.42
020221	0.25	1.33	6.72	9.39
020223	0.00	0.28	3.42	6.17
020225	0.00	4.78	8.97	8.11
020226	0.00	0.22	2.22	3.33
020227	0.00	1.22	0.11	1.28
020230	0.00	1.11	2.44	3.39
020232	0.00	0.17	0.78	1.92
020233	0.00	2.67	2.83	7.00
020235	0.00	1.92	2.06	3.58
020236	0.11	4.22	0.00	9.33
030125	0.00	0.11	0.00	0.17
030126	1.50	12.50	13.89	12.08
030127	0.00	0.89	0.67	5.44
030128	0.00	3.42	3.17	6.00
030129	0.11	7.28	17.33	13.61
030130	0.00	4.31	5.33	7.00

## APPENDIX 5C CONTINUED

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030133	0.00	8.44	7.89	10.56
030134	0.00	1.00	2.67	1.25
030135	0.00	2.69	2.00	1.78
030221	0.00	3.81	6.33	8.39
030222	0.00	0.44	0.22	0.69
030226	0.00	0.25	1.33	0.75
030228	0.00	0.00	0.00	0.00
030229	3.33	0.78	3.94	5.58
030230	0.00	2.33	4.56	6.67
030232	0.00	1.83	5.25	6.92
030234	0.08	0.75	1.92	3.92
030235	0.17	0.42	5.33	3.25
030236	0.00	0.11	2.17	2.67
040122	0.00	0.08	0.33	0.50
040124	0.00	4.53	5.25	7.92
040126	0.00	1.75	1.78	3.11
040128	0.00	1.89	0.67	2.31
040129	0.00	0.17	0.08	0.25
040130	0.00	0.17	0.58	1.78
040131	0.17	1.83	2.22	2.00
040133	0.00	0.00	1.33	4.67
040134	0.83	1.50	25.94	6.50
040136	0.08	1.78	4.69	9.44
040223	0.50	2.89	5.11	5.19
040224	0.00	0.83	4.00	3.17

## APPENDIX 5C CONTINUED

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040225	0.00	4.17	2.00	1.94
040226	1.50	6.83	4.56	7.17
040227	0.00	1.53	0.72	1.67
040228	0.00	1.08	0.00	1.92
040230	0.00	0.33	0.00	2.11
040234	0.00	3.83	3.78	2.92
040235	0.58	2.08	0.33	4.25
050122	0.00	2.56	7.33	13.56
050125	0.56	4.94	13.72	14.89
050126	0.00	3.25	0.00	4.00
050127	0.00	2.00	0.78	3.08
050128	0.50	7.86	7.06	10.92
050129	0.11	1.08	1.75	3.89
050131	0.00	2.94	6.92	13.53
050133	0.00	8.92	8.92	10.89
050134	0.00	1.00	1.83	6.39
050221	0.00	2.00	6.50	12.67
050223	0.50	2.61	3.50	6.94
050226	0.42	0.89	0.00	1.75
050227	0.00	0.11	0.33	4.33
050228	0.00	0.33	2.22	7.11
050229	0.69	2.56	4.78	3.61
050231	1.00	0.00	0.00	4.17
050232	0.00	8.25	10.89	13.83
050233	0.00	0.78	7.67	11.00

## APPENDIX 5C CONTINUED

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050234	0.00	3.06	2.89	9.11
060121	1.58	3.42	15.67	13.50
060124	0.00	0.42	1.86	6.44
060125	0.42	1.00	3.17	3.25
060126	4.92	13.58	9.67	10.67
060129	0.00	0.00	0.00	0.00
060130	0.00	8.83	5.89	9.08
060132	0.28	5.33	9.97	10.97
060133	0.17	1.53	7.78	5.33
060134	0.67	3.58	4.00	4.50
060135	0.00	5.17	8.44	11.22
060222	2.22	3.50	7.39	5.42
060224	0.50	0.58	0.00	4.03
060225	3.92	5.08	4.81	8.56
060229	0.11	0.58	3.44	1.58
060230	1.25	9.11	4.78	3.58
060232	0.00	1.08	3.00	7.25
060233	5.75	19.17	13.94	12.44
060235	0.00	0.33	2.17	2.06
060236	0.56	1.25	2.14	2.86
060237	0.89	7.06	0.00	4.58
070121	2.58	7.86	10.39	15.83
070122	0.00	5.28	9.11	8.44
070124	0.00	1.17	0.17	12.17
070126	0.00	3.00	0.00	2.33

## APPENDIX 5C CONTINUED

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070128	0.00	2.69	4.94	16.58
070132	0.00	0.11	0.00	0.11
070133	0.00	1.64	1.42	6.11
070134	0.00	1.08	5.17	13.31
070137	0.00	0.22	0.33	0.89
070138	0.00	0.17	4.17	8.94
070224	0.00	0.00	0.00	5.33
070225	0.00	0.50	2.00	4.50
070226	0.89	4.22	7.67	4.89
070227	0.00	6.50	5.50	11.42
070228	0.00	2.89	6.61	6.67
070231	0.00	2.00	4.75	10.33
070232	0.00	2.33	4.00	8.00
070233	0.00	0.00	0.67	0.67
070235	0.00	2.44	1.67	8.44
070238	1.50	7.31	10.56	15.78
080122	0.00	1.33	4.00	5.17
080123	0.00	0.67	2.17	3.67
080124	0.00	0.00	0.00	0.00
080125	0.00	1.25	0.00	0.00
080126	0.00	2.17	2.56	3.61
080128	0.00	0.00	0.00	0.00
080130	0.00	0.00	0.00	0.00
080131	0.00	2.25	1.00	3.25
080132	0.00	1.39	1.83	3.83

## APPENDIX 5C CONTINUED

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080136	0.00	5.56	0.00	12.11
080221	0.00	0.11	0.33	0.50
080224	0.00	0.00	0.00	1.61
080227	0.00	0.67	0.17	3.33
080229	0.00	2.89	1.00	4.81
080232	0.00	0.33	0.00	9.06
080233	0.00	0.92	0.00	1.83
080235	0.00	0.00	0.00	0.83
080236	0.00	0.61	1.44	5.81
090121	0.00	0.67	1.56	7.89
090122	0.00	0.22	0.00	2.75
090124	0.00	1.67	0.00	2.06
090125	0.00	0.00	0.00	0.00
090128	0.00	0.00	0.00	0.61
090131	0.00	0.00	0.44	0.42
090134	1.33	2.33	4.39	8.44
090137	1.33	4.64	0.00	6.61
090140	0.00	3.47	2.11	7.58
090141	0.00	0.33	2.25	10.17
090223	0.00	0.25	0.00	1.50
090231	0.00	0.19	1.00	7.78
090232	0.00	0.00	2.83	3.33
090233	0.00	0.00	0.00	0.75
090234	0.00	0.33	0.11	0.67
090235	0.00	0.00	0.00	1.33

## APPENDIX 5C CONTINUED

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090236	0.00	4.22	3.11	5.33
090240	0.00	0.00	0.00	1.61
090241	0.00	1.00	2.22	2.78
100122	0.00	0.00	0.00	4.39
100123	0.00	1.89	0.00	2.89
100128	0.00	0.00	3.33	7.00
100130	0.22	0.00	1.08	6.83
100133	0.00	1.33	0.00	0.00
100135	0.00	0.11	0.11	0.50
100136	0.00	2.17	0.67	3.14
100222	0.00	0.97	1.92	6.03
100223	0.00	0.00	0.00	3.33
100224	0.00	1.00	0.56	3.31
100225	0.00	0.08	1.00	3.22
100229	0.00	0.00	0.00	6.00
100230	0.00	5.00	1.83	3.50
100234	0.00	0.00	0.00	0.61
100235	0.00	0.00	0.00	0.42
100236	0.89	0.50	0.28	5.39
130121	5.22	1.22	4.56	9.36
130123	0.00	2.28	0.89	5.67
130124	0.00	0.78	0.33	2.83
130127	0.00	0.00	0.00	0.22
130128	0.00	0.00	0.00	0.00
130129	0.08	1.17	0.97	0.97



## APPENDIX 5C CONTINUED

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130130	0.00	0.22	0.67	6.50
130131	0.00	3.89	3.72	11.78
130132	0.00	0.22	0.00	0.78
130134	0.78	1.86	0.61	2.14
130221	1.44	3.44	4.25	6.69
130223	0.00	1.00	0.67	0.50
130224	1.00	1.33	2.17	3.56
130225	0.25	1.67	1.53	3.92
130227	0.42	5.00	1.31	4.83
130228	0.00	1.58	0.00	3.42
130229	0.00	1.58	0.00	5.83
130230	0.00	2.08	4.64	3.86

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