A STUDY OF THE VARIABILITY IN YOUNG STANDS OF SITKA SPRUCE

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I certify that the work embodied in this thesis is my own.

4th Aug 1969 C J Mountfort

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by

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A C K N O W L E D G E M E N T S

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1. INTRODUCTION

1.1 Aims

The aim of this project is to ascertain the variation in height growth, diameter growth and crown development, between individual stems in young stands of Sitka Spruce (Picea sitchensis (Bong) Carr) up to canopy closure, to elucidate the development of the storied structure of the canopy, found at the time of first thinning. The variation in height, diameter, branchlet number and dry weight of root, shoot and needles of planting stock will be analysed. Similar measurements of height, height increment, diameter and branchlet number will be obtained in the 1, 3, 6 and 9-year old stands to assess the effect of transplant size on establishment and subsequent growth. At each age the height range will be divided into four equal vigour classes and the processes associated with the development of dominance will be examined. The spatial distribution of individuals of each vigour class will be analysed to determine whether the distribution is random or clumped.

1.2 General

The study originated from an interest in general stand development from time of planting to maturity, in relation to the effects of spacing and different grades of thinning, on the composition and performance of the vigour classes constituting the stand. Due to the time available, the study has been restricted to the determination of the variability within planting stock and its effect on establishment, subsequent growth and differentiation into vigour classes, within young stands up to time of canopy closure. It was decided to terminate the study at canopy closure, because the additional factors of crown and root competition which then become important, would constitute a separate study.

In order to reduce the variation from climatic and site factors, the areas of study were restricted to one general soil type, Peaty Gley, with a similar vegetation. To reduce altitudinal variation sites between 900-1100 feet were chosen in the Wauchope Forest in the Scottish Borders.

REVIEW OF PREVIOUS WORK

2.1.1 Outline

In reviewing the literature, the canopy structure found at a time just prior to first thinning will be described. Factors affecting height growth, diameter growth, crown development and differentiation into vigour classes of the stand will be discussed. Observations on the performance of the different vigour classes and the problems of division will be pointed out.

Having described the range of vigour which is developed a short time after canopy closure, it is proposed to examine the past history of the stand, starting in the nursery, to try and elucidate the origins of this variation. The possible variation due to genetic factors, nursery treatments, planting techniques, and their influence on survival and growth in the subsequent stand will be discussed.

2.2 Post Canopy Closure

2.2.1 General

Although a large proportion of all silvicultural investigations in established stands have been concerned with the effects of thinning, spacing and crown development on the volume production of whole stands, only some of these studies have investigated the volume contribution of the different canopy components (i.e. vigour classes) within the stand in a satisfactory manner.

2.2.2 Height Growth

Mean height growth increases with site quality for a given species over a given area. This relationship forms the basis of the Management

Tables compiled by Johnson and Bradley (1963). Hummel (1955) calculated General Volume tables for a number of species using the Volume Basal area line which depends on the regression of Volume over basal area being linear for trees within certain height limits.

Within an area of uniform site quality, mean height is little affected by spacing in the initial period of growth (Stiell 1964) or where regular thinning is carried out (Kramer 1965).

Cromer and Pawsey (1957) working with *Pinus radiata* planted at 6 spacings ranging from 6′x 6′ to 11′x 11′ found that up to 15 years of age no significant differences in Mean height growth occurred, but after this age the average Predominant Height became linearly related to spacing at the 5% level of probability.

Similar results were found by Bramble Cope and Chusman (1949) and Byrnes and Bramble (1955) for Red pine (*Pinus resinosa*) planted at 4 spacings 5′x 5′, 6′x 6′, 6′x 8′ and 10′x 10′. Canopy closure occurred at 11 years of age for the 5′x 5′ and 6′x 6′ spacings, but not until 20-25 years for the 6′x 8′ and 10′x 10′ spacings. At 16 years of age mean height growth of the closer spacings began to fall off and by 34 years of age was 6 feet behind the 10′x 10′ spacings.

This bears out the findings of Craib (1947) who carried out a series of heavy early thinnings in young stands of *Pinus elliottii*, *P. taeda*, *P. patula*, *P. pinaster* and *P. radiata* in order to minimize the interference of neighbouring crowns. He found that as the density of the stocking decreases, the mean height increases, but the increase in mean height growth with increased growing space is relatively small.

Pruning up to seven whorls branches, leaving between 4 and 14 whorls on 21 year old Norway Spruce (Picea excelsa), was found to have comparatively little effect on tree height growth (Ladefoged 1946). This indicates that such trees may undergo very severe crown competition or have a large portion of their crowns removed before height growth potential is impaired.

2.2.3 Diameter Growth

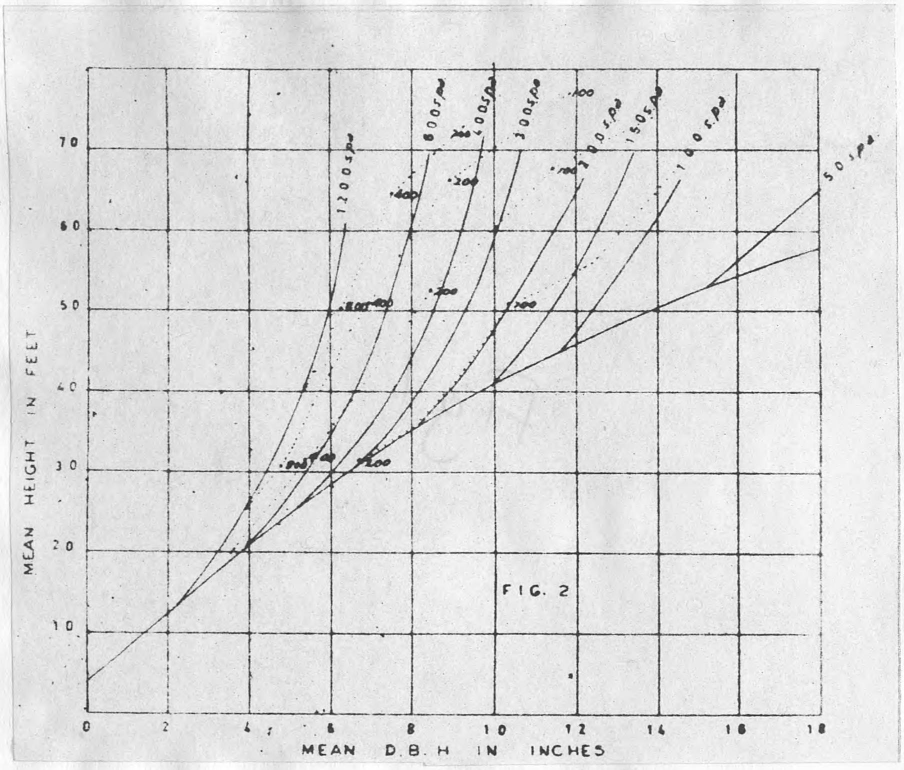
Marsh (1957), furthering work started by O'Connor (1935) and Craib (1939:1947), shows that the relationship between height and diameter at breast height (dbh) and to a lesser degree that between form factor and d.b.h. are sensitive to variations in stand density. He shows that there is a common mean height / mean diameter curve for all stocking densities before the onset of initial crown interference, after which the curve for each stocking density deviates in turn. [See Fig. 1] The onset of interference occurs at ages ranging from 4 to 12 years over this range of stocking densities.

A similar, common mean form factor / mean d.b.h. curve can be constructed for the form / d.b.h. relationship of free growing trees of all stocking densities. From this curve the form / d.b.h. curve for each stocking density deviates at the onset of interference.

The mean tree at 50 spa. growing without interference produces annual rings of the same width throughout its entire height, whereas the mean trees growing at 1200 spa. produces an annual ring which increases with height in the usually noted manner. The fall off in d.b.h. growth begins about the time of canopy closure for each spacing.

Figure 1

Mean Height / Mean D.B.H.o.b. relationship in P.patula for densities of 50 to 1,200 stems per acre, based on C.C.T. projects at Nelshoogte, Entabeni and MacMac.



Reprinted from Marsh (1957)

A near linear relationship was established for mean d.b.h. and increasing spacing by Cromer and Pawsey (1957). The mean diameters of all spacings were within 1.7 inches at age 9, but by age 15 the range had been progressively increased to 3.0 inches. [Table 1] When the mean diameters of the 300 and 100 largest trees at age 15 were examined, a 2 inch difference was found between the wider and closer spacings.

Table 1

Mean Diameter B.H. in inches for P. radiata

Age in Years	Spacing in Feet					
	6'x6'	7'x7'	8'x8'	9'x9'	10'x10'	11'x11'
9	4.17	4.53	4.89	5.25	5.61	5.97
10	4.48	4.89	5.31	5.73	6.14	6.56
12	4.84	5.34	5.84	6.34	6.84	7.34
14	5.15	5.72	6.28	6.84	7.40	7.96
15	5.25	5.85	6.45	7.04	7.64	8.24

Reprinted from Cromer and Pawsey (1957)

When the Mean Annual Increments (MAI) and Current Annual Increments (CAI) for decreasing numbers of trees are compared, it is found that the differences between spacings are less accentuated. At age 15 the current d.b.h. increment of the 100 largest trees is similar, though the mean diameters of the trees on which it is accumulated increase with wider spacing [see Table 2]. Table 3 shows the number of trees by diameter classes for the range of spacings at age 15.

The theory that current annual increment does not vary appreciably over a wide range of densities does not hold for Pinus patula generally (Marsh 1957), though it may apply over the range between 150 to 300 stems per acre at least up to 20 years of age.

This gives interesting evidence of the ability of the more vigorous stems to accumulate diameter increment at the expense of the less vigorous stems under conditions of severe interference and bears out the observations

Table 2

Increment in Mean D.B.H. (inches) for P. radiata

No.		Age	Spacing 6'x6'	7'x7'	8'x8'	9'x9'	10'x10'	11'x11'
300	M.A.I.	14	0.47	0.49	0.52	0.55	0.57	0.60
Largest trees	M.A.I.	15	0.45	0.47	0.50	0.53	0.55	0.58
per acre	C.A.I.	14-15	0.18	0.19	0.21	0.23	0.25	0.26
100	M.A.I.	14	0.51	0.54	0.58	0.61	0.65	0.68
Largest trees	M.A.I.	15	0.49	0.52	0.55	0.59	0.62	0.65
per acre	C.A.I.	14-15	0.26	0.25	0.24	0.24	0.23	0.22

Reprinted from Cromer and Pawsey (1957)

Table 3

Number of Trees per acre over various diameters (Harmonized) for P. radiata

Diameter Class	6'x6'	7'x7'	8'x8'	9'x9'	10'x10'	11'x11'
Over $8\frac{1}{2}$"	..	22	44	66	88	110
" $7\frac{1}{2}$"	25	79	134	191	224	235
" $6\frac{1}{2}$"	125	231	319	354	334	305
" $5\frac{1}{2}$"	395	484	499	461	398	340
" $4\frac{1}{2}$"	780	724	611	511	423	356
" $3\frac{1}{2}$"	1,120	854	666	531	433	360
Total	1,210	889	681	538	435	360

Reprinted from Cromer and Pawsey (1957)

of other workers, that absolute increment increases with increasing vigour, (Deetlefs 1954; Hamilton 1965). It also raises the interesting point, that the number of trees in the upper vigour class may be constant for a particular species and site quality independent of initial spacing or thinning (Warrack 1952; Erteld 1960). This is in agreement with Ladefoged, (1946) who showed that there was an interdependence between increased basal area and increasing size of the tree top, reckoned according to the number of whorls of branches in the uppermost 2/3 of the crown.

2.2.4 Crown Development

Beekhuis (1965) indicated that both Stand height and site quality have to be taken into account when predicting crown depth in Stands of *Pinus radiata*. Using sample plot data, he found that the increase in crown depth with lower stockings was linear when crown depth was plotted against average spacing between trees. When all data was combined crown depth increased by 1.6 feet for every foot increase in average spacing, expressed as the average distance to the tree's six nearest neighbours. The relationship is found to be curvilinear when crown depth is plotted over stem per acre. Crown depth increases as the stand grows taller, but stays almost constant once full canopy closure is reached.

These findings are borne out by other workers, for example, Stiell (1966) showed that crown depth was related to stand height and spacing in red pine.

Death of the lower crown, which may occur before direct interference in Red pine at wider spacings, has been attributed to site factors associated with dry sites by Stiell (1964). Kramer and Kozlowski (1960) and Kramer (1965) maintained it was due to physiological drought. Branches may overlap by up to 2 feet before dying on better sites according to Berry (1965).

Ladefoged (1946) showed that stem volume increases proportionately, with increasing size of the tree crown, reckoned according to the number of whorls of branches in the uppermost 2/3's of the crown or the dry weight of the needles in the uppermost 3/4's of the crown. He found that the lowermost part produced only 15 per cent of the total stem volume increment.

Once canopy closure is complete, the rate of crown enlargement in terms of diameter and length is reduced for Red pine (Stiell 1962) and provided stocking remains unaltered, eventually ceases.

Richards (1962) noted that crown width increases at a rate which is correlated with concurrent height growth. As canopy closure occurs later at wider spacings trees enter this stage with longer and wider crowns which individually carry more foliage. The onset of branch mortality at canopy closure due to whipping, poses the first limitations to crown expansion. Crown length extension is to some extent offset by recession at the base as the plane of greatest width begins to move upwards.

The numbers of wholly live whorls ranged from 8 to 14 per tree, though Stiell (1962) found a considerable variation between trees of the same size for red pine. Most foliage was on the main branches of the fully live whorls. Foliage weights increased from the top downwards, remaining constant for 4 to 5 whorls and then decreasing towards the base of the crown at 7′ x 7′ spacing. Crowns of 5′ x 5′ spacing were sparser and more elongated.

By calculating regressions of foliage weight over crown parameters Stiell (1966) found that foliage weight per acre tended towards a maximum for all spacings fluctuating between 7500 and 10,000 kg over dry weight for Red pine. These figures are similar to those obtained for (*Pinus sylvestris*) by Ovington (1957).

Diameter at breast height (d.b.h.) and crown size of individual stems may be correlated within a stand at one age, or rather height, but as a tree of given d.b.h. near the top of the diameter distribution at an early age occupies a different canopy position and has a larger crown than a tree of the same d.b.h. class later; no relationship is possible when crown size is restricted. Many workers have developed correlations between various crown and stem parameters for a wide variety of species (Dawkins 1963; Vezina 1962; Wile 1964; Minor 1951; Weck 1944; Vanselow 1956; Kennel 1964).

2.2.5 Contribution to Increment by Different Vigour Classes

In recent years increasing attention has been paid to the contribution of different vigour classes to the total volume of the stand, in order to identify the most desirable stems to leave as final crop trees. No investigations have been carried out on the contribution of increment by the different vigour classes in stands before canopy closure, so it is necessary to use examples from spacing and thinning trials in established stands to discuss this topic.

Working with *Pinus radiata* Ure and Jackson (1964) selected 160 pruned stems per acre ranging from the largest dominants to better sub dominants, divided them into 4 vigour classes and studied their respective increments over a 6-7 year period after thinning. They found that the contribution of annual increments (by vigour classes) expressed as a percentage of the total increment was:

Vigour classes	1	2	3	4
Annual Increment	32.7%	26.1%	24.0%	17.2%

The larger stems put on twice the volume of the smaller stems. There were a number of interchanges between groups 2 and 3. A poor correlation was found between the growth of the selected stems and the residual stocking after thinning, due to the fact that differences in the growth responses within groups was so large as to make comparison between groups impossible. The point being that when basal area or stocking indexes expressing the average spacing of the plot are used, they seldom indicate the intensity of competition between individual stems of the plot. It is apparent when taking competition into account, that vigour and dominance are the paramount factors determining subsequent growth and increment. Competition would have a greater effect on subdominants than dominants. They stress that good tree selection is essential if full subsequent growth potential of the stand is to be attained.

Matthews (1963) also drew attention to the importance of good selection, quoting work by Erteld (1960) with P. sylvestris, he stated that the most efficient trees, in terms of the space they occupy, should be chosen, i.e. the genetically and physiologically superior trees with good crown length and width and dense foliage. He drew attention to European work done on assessing the growth potential of P. sylvestris. Trees are classified into canopy classes and thereafter reference is made to their developmental stage. Trees are considered to alter their growth habit as they develop from their seedling stage to maturity.

The growth and development of even aged 60-80 year old spruce stands were studied by Lieboll (1962) to investigate the relationship between growth and physiological age. He concluded that the increment capacity of the individual trees in even aged pure stands is already settled at the thicket and sapling stage of a plantation.

Kramer (1965), using Bowmont sample plot data, studied the influence of spacing and thinning on the crown development and the increment of the various dominance class for Norway spruce (Picea abies). His findings bear out those of other workers, that the size of crown is dependent on site and thinning grade. Measurements showed that the dominant trees have the most efficient crown surface area and make the largest contribution to the stand volume increment irrespective of thinning grade. Although the performance of the lower canopy classes can be improved by crown thinning, their contribution rarely exceeds 50% of the increment possible from a similar area of a dominant tree crown. If the increment produced by the mean tree in each canopy class is considered, dominant trees taken as 100 the codominants = 54, subdominants = 9, suppressed = 4. From these findings he concluded that dominant trees should be favoured when selecting final crop trees.

Working in F.C. Thinning plots of NS, SS, SP, JL and DF, Guillibaud and Hummel (1950) found that over a period of 15-25 years and 4-8 thinnings that there was a downward movement of a proportion of the dominant trees through the canopy classes with increasing age, with the result that the proportion of the growing stock that was originally dominant becomes larger.

Hamilton (1965) concluded from his survey of the literature, that absolute increment increased with the increasing dominance of the individual stems. This increase in absolute increment is associated with increasing sizes of crowns expressed as crown volume, crown diameter, projection area, surface area or foliage weight. There is a reduction of the number of dominant trees with increasing age in even aged stands, the displaced stem accumulating in the lower canopy classes or dying.

From an assessment of FC sample plot data and his own experiment, he found that low thinning and light crown thinning were similar in their effects on overall movement within the canopy. The degree of upper canopy opening affects the proportion of downward movement, which cannot be halted by thinning, indicating the importance of selecting dominant trees for the final crop.

2.2.6 Tree Classification

A number of systems of tree classification have been developed for use in stands after canopy closure. They usually divide the canopy into 4 or 5 classes. These are Dominants, Codominants, Subdominants, Suppressed and Dead or dying trees. This last class is not present in some classifications. They vary from one another mainly in the sophistication of the code used to record the canopy class and stem and crown quality or malformation (Hummel, Locke, Jeffers and Christie 1959). Since they are basically subjective in application, no direct comparison can be made between one worker and another or between different species. These classifications can not be applied with any accuracy to stands before canopy closure, as the crown dimensions have not become stabilized and no allowance is made for development stages; because of this, some system of classification that is numerically based would be preferable.

Schotte (1912) devised a classifcation system based on the mean top height of the stand. His divisions are listed below.

Dominant 5/6 mean top height.
Codominant 5/6-2/3 mean top height.
Subdominant 2/3-1/2 mean top height.
Suppressed below 1/2 mean top height.

Reviewing the classifications from European Literature, Meyer (1962) showed that they varied mainly in the proportions into which the height range was divided. A classification based on Schotte's system is not satisfactory in young stands, as the height / diameter correlation is very variable. In addition the position of peaking in the height range varies with age; this results in a large fluctuation in the numbers of stems in each class. A simple numerical division into four equal vigour classes based on Total Height, has been adopted for this study.

2.2.7 Macro and Micro site Variation

Although the influence of macro site quality on tree growth is well appreciated and many systems of site classification and site assessment have been evolved, e.g., (Anderson 1961), little more than passing mention has been made of the possible effects of micro site variation on the growth of individual trees within a forest stand. Investigation is required into the effects of micro site variation on initial establishment, pre canopy closure development and differentiation into vigour classes in young stands.

2.3. The Effects of Nursery Treatment and Establishment Practice on the variability in young stands

2.3.1 General

A considerable amount of work has been done on evolving satisfactory and efficient nursery practices which result in the production of the greatest numbers of plantable stock per lb. of seed and area sown. This includes establishing suitable sowing and transplanting densities, finding the most effective fertilizer and herbicide spraying regimes, perfecting planting stock storage and handling practices and co-ordinating the timing of these operations. The success of these various practices has been judged in the rate of forest survival compared with the possible alternative methods. Little attention has been paid to the quality of the crop, either as to whether the optimum growth rate is attained, or to whether the incidence of malformation is lowest, in the young stands produced. It is proposed to discuss the various factors and nursery practices in chronological order to assess the processes which may induce variation in the resulting crop.

2.3.2 Seed Weight and Inherent Vigour

The relationship between seed size, seedling size and inherent vigour was studied by Righter, (1945) who analysed the sources of variation in seed weights. He concluded that these were largely due to variations in seed coat weight and endosperm weights, due to the ecology of the seed during development, i.e., position in the cone, cone size, etc. These two seed components contributed more than 90% of the total variation in seed weight. The embryo is so small that even if its variation in weight was wholly inherent, heredity could still be regarded as a negligible factor in the variation of the total seed weight. Righter (1945) thought that the variation in seedling size associated with seed size is due primarily to variation in the endosperm and may be regarded solely as a temporary environmental effect. He suggested that inherent vigour is distributed randomly amongst endosperms of all sizes. Hence any combination of vigour and seed size is possible.

This was borne out in an experiment in which seed from 2 interspecific hybrids (Pinus murrayana x P. banksiana) and (P. monticola x P. strobus), a back cross of (P. jeffreyi x (P. jeffreyi x P. coulteri)) and a self-fertilized tree (P. jeffreyi x self) were graded into seed weights and the range of height variation for each weight class measured over a 3-year period. Results showed that seedlings from self-fertilization were uniformly smaller than seedlings from the back cross. Similarly seedlings from the hybrids were uniformly larger than the natural progenies; showing that, inherently weak and vigorous embryos alike were compatible with large average and small endosperms produced by the same seed parent. In addition seeds of the same size produced seedlings that differed enormously in size and likewise seeds of different sizes produced seedlings of the same size. The initial differences in height increased until at age 3, seedlings of the hybrids and back cross were twice as tall as the corresponding respective natural progenies or self crosses. These seedlings originated from seed of the same size. Thus seed weight is correlated in a positive manner with seedling size, but not with inherent vigour. With time, differences in average seedling heights between the large and small seed weights become reduced, though they are still evident after three years. This means that if selection is carried out on the basis of seed weights, the resulting seedling population would be uniformly larger, but after a few years the variation would increase until the distribution became approximately normal. The differences within seed weight classes are more likely to be hereditary, whereas the differences between seed weight classes are as likely to be environmental as hereditary.

In a further experiment to test the nature of early variation in seedling heights, due to differences in seed size between seed parents, the hybrid (P. monticola x P. strobus), with large seed was pitted against the natural progeny of (P. strobus) from open pollination, which has small seed and slower germination times. Although the hybrid showed strong initial growth, the difference in height growth was steadily reduced over the three year period, showing that the initial differences were largely due to non-hereditary factors. Thus the relative inherent vigour of progenies arising from parents distinguished by substantial differences in seed size, can only be determined if the progeny of the smaller seed is equal, or exceeds the other progeny in seedling size unless tests are carried out over an extended period of time.

Spurr (1944) came to a similar conclusion that the effect of seed weight is related to germination, survival and early size of the plant. The correlation between plantsize and seed weight diminishes as the plant ages, but is still noticeable after 3 years. Seed germination, appearance, moisture content and seedling growth is related to seed provenance. The influence of seed provenance on plant size is as strong at the end of the third year as it was at the end of the first year.

2.3.3 Seed Germination

The height of seedlings after the first growing season depends in part on the date of sowing. The earliest sowings usually produce the tallest seedlings except where some climatic factor, such as low rainfall, must be taken into account. Overall height growth depends on the provenance, i.e. Washington provenance of Sitka spruce is consistently up to 64% taller than Queen Charlotte Island Provenance (Aldhous, Atterson, Brown, Low and Stoakley 1967). Some of the variation in first year height growth can be attributed to variation in germination times within each sowing, the first germinated maintaining their initial height advantage.

2.3.4 Sowing Densities

Sowing density trials instigated by Stevens (1928) were assessed by Pinchin (1950). Seed of S.P., D.F., E.L. and S.S. were drill and broad cast sown at a range of densities. The resulting seedlings were lined out for two years before being planted out in the forest. The yield of usable seedlings per pound of seed decreased with higher densities of sowing, particularly with drill sowing. As this latter has the effect of increasing the density, the seedlings being unable to utilize the space between the drills. Height growth of seedlings was reduced at higher densities and increased at lower densities.

The sturdiness of the seedlings (i.e. ratio of height over root collar diameter) was found to decrease with increasing density of sowing. Densities above normal give more, shorter and more delicate plants (Aldhous, Atterson, Brown, Low and Stoakley 1967).

Pinchin (1950) found that much of the initial variation due to sowing density was lost during the 2 years spent in the transplant lines. On lifting, the transplants were graded into plantable and culls. The mean height growth after the 8th growing season was found to be the same for the plantable stock from all densities of both drill and broadcast sown planting stock.

2.3.5 Grading of Seedlings prior to Transplanting

Reviewing the results of trials into the effect of grading of seedlings prior to transplanting, Pinchin (1950) found that there was no significant difference in the height growth of the plantable stock from each of four grades after 8 years growth in the forest. The trial was similar to the experiment with sowing densities. The graded seedlings having spent two years in the transplant lines, were lifted, graded into culls and usable stock before planting out in the forest.

2.3.6 Transplant Spacing

A similar investigation into the effect of different spacing distances in the nursery transplant lines on subsequent forest growth was reviewed by Pinchin (1950). After two years at four different spacings the transplants were lifted, graded into culls and plantable stock, and planted out in the forest. Results showed that after 8 years growth in the forest there were no significant differences in mean height growth and survival of the plantable stock from different transplanting densities. Assessments prior to forest planting on a later experiment showed that, the root collar diameter of transplants with 25 sq. inches per plant was significantly greater than those at narrow spacings. Plants were larger for a similar area arranged as a square compared to a narrow rectangle (Aldhous 1966).

Pinchin (1950) concluded, from his review of these seedling sowing density, seedling grading and transplant spacing trials that seed bed performance was not indicative of the ultimate performance in the forest. Though in all trials these transplants classed as culls showed significantly poorer height growth and survival compared to plantable stock. The percentages of culls for each treatment were not given.

2.3.7 Grading of Planting stock Prior to Planting

In the above mentioned trials, Pinchin (1950) transplants were graded into plantable and culls at the time of forest planting. The culls formed a heterogeneous mixture of malformed, diseased and spindly plants. This grading was largely subjective, no size criteria being given. That growth and survival of culls was in all cases inferior to the plantable stock can be seen in Table 4.

Table 4

Height Growth After Eight years forest growth of Plantable and Cull planting Stock from Pinchin (1950).

	HEIGHT GROWTH	
	Plantable Stock	Culled Stock
Sowing density trial	68.8 inches	53.1 inches
Seedling grading trial	60.2 inches	48.0 inches
Transplant spacing trial	72.2 inches	56.9 inches

Long leaf pine planting stock was separated into the following grades by Shipman (1960).

Grade 1. Top Height 12 to 15 inches; Stem diameter 0.25 to 0.50 inches; needles abundant and winter buds present.

Grade 2. Top Height 8 to 15 inches; Stem diameter at least 0.30 inches; needles moderately abundant, bud scales lacking.

Planting was carried out in winter and spring in an abandoned field. The grade 1 plants were best able to become established under both winter and spring conditions, whereas Grade 2 plants became moderately well established under winter conditions but survival was poor in spring due to slower initial growth. On similar soil types Grade 1 seedlings survived consistently better than Grade 2, though mortality of both grades was low, between the 2nd and 5th year. The rapid initial growth of Grade 1 planting stock was found advantageous on sites where severe grass growth was a problem, as small plants tended to become smothered and have difficulty getting above it. Grade 1 seedling retained the initial mean height growth advantage of 1.9' over grade 2 plants and after five years 40% had attained heights of over 7' compared to 16% of grade 2.

Investigations into the early performance of White Spruce related to planting method and planting stock height by Brace (1964), showed that growth and variability in height were related to height of planting stock. Stock less than 0.5 feet tall grew poorly on the planting site studied.

When planting stock was graded into height classes, variability still occurred in subsequent height growth, indicating the height / diameter ratio, root collar diameter, foliage colour and density, top root ratio and oven dry weights should be taken into consideration when culling.

Brace (1964) followed the rate of growth of the various planting stock height classes and found that height growth was progressively greater with increasing height at planting. The rate of growth and survival of planting stock 0.5 feet and taller was significantly superior to planting stock less than 0.5 feet. Taller stock occurred more frequently in the larger height classes in later years than shorter stock. (See Table 5). Some of the variability of height growth within planting stock height classes may be due to morphological, physiological and inherent variation and site differences.

Table 5

Relationship of Planting Height and 1962 Height for White Spruce

Planting Height	No. of Trees	No. of trees by 1962 height class							
		2.0(-)	2.1-3.0	3.1-4.0	4.1-5.0	5.1-6.0	6.1-7.0	7.1-8.0	8.1-9.0
0.3-	154	4	52	63	23	11	1	-	-
0.4	231	3	45	73	61	38	9	2	-
0.5	228	1	22	61	63	47	24	8	2
0.6	161	-	6	26	49	50	22	7	1
0.7	67	-	1	13	19	15	13	6	-
0.8+	34	-	-	1	11	7	9	4	2

Reprinted from Brace (1964)

Seedlings and transplants of Sitka spruce were graded into inch height classes and millimetre diameter classes prior to lining out and planting by Edwards and Holmes (1950). They found that the percentage survival of the various seedling height classes 1 to 10 inches after one year in the transplant lines was not significantly different, although the smallest class 1 to 2 inches showed lower survival percentages. No one height-class showed greater vigour than another. Variation in diameter had no effect on survival or vigour of growth. When graded transplants were planted out in the forest definite differences in vigour and survival were found in relation to their height and diameter at the time of planting (see Table 6). Plants showed growth proportional to their heights at time of planting. Height advantage at time of planting was retained after one year in the forest. Overall survival varied considerably between size classes. Survival within each height class varied with diameter class and was more dependent on the general sturdiness of the transplant (i.e. ratio of height to diameter). The use of taller plants had little effect on survival or height growth unless increased height was accompanied by a proportional increase in diameter.

Table 6

Effect of size of plant at time of planting on growth and survival of Sitka Spruce (reprinted from Edwards and Holmes, 1950).

Size at Planting, March, 1949		Plant Assessment, November, 1949	
Height Class inches	Diameter Class in millimetres	Mean Height Growth inches	Death percentage
1-3	$0 - \frac{1}{2}$	2.65	61.67
	$\frac{1}{2} - 1\frac{1}{2}$	3.79	30.0
4-6	$0 - \frac{1}{2}$	4.00	56.67
	$\frac{1}{2} - 1\frac{1}{2}$	5.67	23.33
	$1\frac{1}{2} - 2\frac{1}{2}$	6.47	18.33
	$2\frac{1}{2} - 3\frac{1}{2}$	6.19	13.89
7-9	$\frac{1}{2} - 1\frac{1}{2}$	7.46	16.67
	$1\frac{1}{2} - 2\frac{1}{2}$	8.29	10.0
	$2\frac{1}{2} - 3\frac{1}{2}$	9.29	6.67
	$3\frac{1}{2} - 4\frac{1}{2}$	9.20	6.67
10-12	$\frac{1}{2} - 1\frac{1}{2}$	9.7	44.44
	$1\frac{1}{2} - 2\frac{1}{2}$	9.88	16.67
	$2\frac{1}{2} - 3\frac{1}{2}$	10.33	3.33
	$3\frac{1}{2} - 4\frac{1}{2}$	11.54	8.33
	$4\frac{1}{2} - 5\frac{1}{2}$	12.05	6.67
Over 12	$1\frac{1}{2} - 2\frac{1}{2}$	11.33	30.00
	$2\frac{1}{2} - 3\frac{1}{2}$	13.16	26.67
	$3\frac{1}{2} - 4\frac{1}{2}$	13.23	10.00
	$4\frac{1}{2} - 5\frac{1}{2}$	14.93	3.34

Culling prior to planting enables the modification of the initial survival and subsequent growth in the young stands being produced, by the elimination of the plants that will not survive or grow well. In addition it all allows considerable scope for influencing the genetic complement of the planting stock once the relationships between seedling morphology and adult growth habit are known.

2.3.8 The Effects of Transplanting and Undercutting

Transplanting is usually carried out in late autumn and early spring (November or March) or mid summer (July) when growth is slight (Edwards and Holmes 1950). Undercutting in August of the first year or March or April of the second year, gives the greatest reduction in shoot weights, increase in root and the most satisfactory root form (Faulkner and Aldhous 1958).

Sowing densities for undercut plants equivalent to the lining out densities of 1 + 1 transplants (i.e. 16 per square foot for pines and larches) were found to produce the greatest root and shoot weights, root collar diameters and number of fibrous secondary and tertiary rootlets. Weights and diameters decreased at higher densities (Faulkner and Aldhous 1957).

The most desirable root form with dense fibrous root growth in the upper soil layers is achieved by undercutting at 2 to 4 inches depth. At greater depths there was some check in height growth, but inferior root form, root fibre being produced at the depth of cut rather than in the soil surface layers. (Faulkner and Aldhous 1955). Transplanting and root pruning tend to check shoot growth compared to untreated controls. The effects of transplanting is the more pronounced (Holmes and Faulkner 1954).

Both transplanting and undercutting increase the ratio of shoot to root weight compared to untreated seedlings. Transplanting produces a greater effect (Faulkner and Aldhous 1955), though this could be due to changing the position of the root collar by deeper planting.

Assessments comparing the survival of 1 + 1 transplants, 1 U 1 under cut planting stock, and 2 + 0 seedlings showed that transplants and under cut stock survived and grew appreciably better than seedling stock. There was very little difference between the behaviour of undercut and transplant stock (Faulkner and Aldhous 1955).

No work has been done on the incidence of root malformation induced by the two methods or whether this malformation, which is frequent in transplant stock, has any effect on a tree's growth potential.

The use of transplanting and undercutting techniques enables the development of planting stock to be moulded, so that better survival and more rapid establishment and subsequent growth is obtained after planting in the forest.

2.3.9 Fertilizers

Benzian (1966) carried out 600 seed bed experiments with Sitka Spruce and used measurements of mean height growth as an index of the increase in total production, resulting from applications of different nutrients or combinations of nutrients. Sampling was carried out using a sampling grid and heights were measured in 0.5 inch classes up to 1.5 inches and then in 1.0 inch classes. Calculations were based on the fact that height, and shoot weight or total weight are linearly correlated. This correlation has not yet been published. From this it may be concluded that fertilizers increase the growth of all seedlings. The results from the effects of fertilizer applications in nursery on subsequent growth in the forest are not yet available.

The growth responses of white spruce (Picea glauca) to applications of N and P were found by Armson (1956) to give a 50 to 200 per cent increase in dry weight over 2 growing seasons. Where nutrient conditions were inadequate shoot, height and weight and root weight and development were found to increase with increasing spacing (Schmidt 1961); where nutrient conditions were satisfactory, height growth decreased, diameter growth increased, root weights increased, though total weights remained stable with wider spacings.

2.3.10 Quality Criteria of Planting Stock

A number of workers have investigated the application of various quality criteria on subsequent forest performance of planting stock. Aldhous (1967) made measurements on more than 3,700 plants supplied by Forestry Commission nurseries and found that there were no generally applied standards of sturdiness. Although the plants were not fully representative it was found that some species were intrinsically sturdier than others. Regressions of root collar diameter on height were calculated and species were grouped into four classes in order of decreasing regression coefficients, the regression line being constrained through the origin. The resulting classification substantiated that published in the British Standard on Nursery Stock Part 4 Forest trees (1966b). Suitable values for the minimum height/root collar diameter ratio were chosen for each sturdiness class, together with a table of proposed minimum root collar diameters for plants of given height. See Table 24.

Various quality criteria are discussed by Schmidt (1961) and he describes a trial using 2 + 1 and 2 + 2 pine and spruce to test out these criteria for plants raised at two spacings. He found that the initial height growth of pines was not affected by spacing. For spruce plants raised at narrower spacings height increment increased with planting stock height up to 35 cms. above which it declined. Whereas for planting stock raised at wider spacing, the first years height growth rose progressively with increasing height.

Reviewing the literature on root shoot dimensions of planting stock, Jones (1968) indicated that there are two important contributing factors to the top / root ratio at any particular time: (a) genetic and (b) stage in development.

That there is a considerable degree of genetic control over the ratio of top / root can be seen by comparison between different species and even different provenances (Aldhous 1967; Rudolf 1950) and (Stoeckeler and Jones 1957).

The top / root ratio changes rapidly during the early years of a tree's life. Initially the seedling makes much greater root growth than shoot growth but this trend is reversed and eventually the top predominates. Whether a stage is reached when no further change occurs, is not known. Fraser (1967) showed that the ratio of top to root weights differed in older trees according to site.

Reviewing data for *Pinus resinosa* Jones (1968) indicated that during the first 3 years of growth the top / root ratio increases.

Transplanting checks shoot growth but increases root growth so that the ratio of top / root for 1 + 1 and 3 + 1 transplants is lower than for 1 + 0 seedlings. Transplanting has little effect on diameter growth, so that a transplant of the same age and height as a seedling has a heavier top and a much heavier root.

The amount of difference between seedlings and transplants of the same age depends, on the rate of recovery after transplanting, and the natural early growth rate of the species, i.e. Spruces showed comparatively slow initial growth. The top / root ratio would be expected to change with increasing plant size, due to natural developmental processes so that the difference between the top / root ratios of large and small plants of the same age could be partly explained by these processes.

Work is required urgently on the normal developmental processes which occur during the early growth and establishment of Sitka spruce and other commercial species, so that the effects of nursery practices can be related to some standard. In addition seedling morphology and branching habit needs to be related to subsequent adult branching habit so that culling can be more closely related to desired tree habit.

2.3.11 Storage and Handling of Seedlings and Transplants

Faulkner and Aldhous (1958) carried out experiments to investigate the period of time that seedlings could be exposed without protection, before their survival ability was impaired. Seedlings were exposed for periods of up to six hours on two days (a) Relative humidity 87% all day (b) Relative humidity 77% in the morning dropping to 54% by noon. Seedlings that had been exposed on the first day showed no difference from the controls. The plants which had been exposed under the drier conditions on the second day began to show significant losses after two hours exposure. After six hours exposure nearly all plants died. The weight losses after two hours under the drier donditions were equivalent to six hours under the moister conditions.

Two samples of 2 - 0 white spruce (Picea glauca), one dormant and the other in a state of active growth were exposed to air for periods of 0, 0.5, 1.0, 1.5, 2.0, and 2.5 hours by Mullin (1967), before planting out in a glasshouse. He found that the active plants suffered a greater mortality and inhibited growth than plants in the dormant state. Mortality increased with the length of exposure. Growth was reduced in dormant plants after exposures of 0.5 hours or more, but not to the same extent. Investigation in South Australia (1940) showed that the care of roots at the time of planting was an important factor in determining planting success on poor sites.

In a series of trials on the problems associated with seedling and transplant storage, Faulkner and Aldhous (1957; 1958) lifted seedlings and transplants over a period from mid November to mid March and stored them in polythene bags for intervals up to six months before lining them out. Species varied in their tolerance to storage. Spruces survived very well with only light losses after the longest periods. Of the pines Lodgepole and Scots pine were the most tolerant and could be stored for 4 to 6 months with only light losses, though when planted late in the growing season, they were unable to form a winter resting bud before the autumn frosts. Corsican pine was less tolerant. Larches survived well for periods up to four months, providing they were planted before spring flushing occurred towards the end of March. Douglas fir could be stored for periods up to four months, provided they were packed with dry foliage.

In general, it was concluded that transplants were better able to tolerate storage than seedlings. Plants lifted during the dormant period stored better than those which had started bud or root growth. For best storage foliage should be dry. The spread of fungus was not a problem.

Aldhous and Atterson (1960) confirmed the findings that transplants of any species could be stored safely for 3 to 4 months in polythene bags in a well ventilated shed.

When a similar trial to the one above was tried using cool stores at +2°C and -5°C, six months was found to be the maximum period that plants could be stored at the higher temperature, while at the lower temperature plants failed to survive at all. After twelve months at +2°C very few plants survived.

Investigations into the high losses sustained as a result of leaving polythene bags in the sun, Aldhous and Atterson (1963) found in a trial using alternative methods that losses were reduced if Kraft paper bags lined with polythene were used.

3.2.12 The Effect of Planting Methods and Depth on Subsequent Development

Investigating the tenth year survival and growth of Red pine (*Pinus resinosa*) planted at five different depths and two different planting methods, Mullin (1964) concluded that differences in survival and growth due to method of planting were negligible and insignificant. This bears out the general findings from the literature, that planting method may cause minor differences with some species and under certain conditions (Brace 1964; Sutton 1966; Tucker, Jarvis and Waldron 1968).

Mullin (1964) found that depth of planting produced significant differences in both survival 0.1 per cent level of probability and mean height growth 1.0 per cent level of probability. See Table 7.

Table 7

Survival and Height Growth at Five Planting Depths of Red Pine from Mullin (1964)

Depth of planting in inches	Survival percentages	Mean Height growth
- 2	86.6%	11.9feet
- 1	86.1%	12.7feet
0	83.6%	12.4feet
+ 1	73.7%	13.0feet
+ 2	67.5%	12.7feet

Planting at depths of + 1 inch was found to give best height growth, though - 2 and - 1 inches planting depth had beneficial effects on survival. As the effect of planting depth on height was slight, 2.3% over the range of planting depths from - 1 to + 1, whereas the survival over the same range was 14.8%, it was concluded that it was best to sacrifice a small increment of height growth and recommend planting out stock with the nursery soil level slightly below ground level.

Carvell (1964) found that *Pinus strobus* seedlings planted with their root collars at - 1, 0 and 3" below the soil surface, neither suffered nor benefited compared to normally planted seedlings. Though seedlings planted with their root collars 6" below the soil surface, suffered heavy mortality and depressed height growth. Results for survival and height were very similar in all respects to those of Mullin (1964).

In similar experiments to the one above with Norway spruce (<u>Picea abies</u>) and White spruce (<u>Picea glauca</u>) Sutton (1966) graded planting stock into two size classes and planted them at three depths; normal 5 cms. and 10 cms. deeper than nursery depth.

Results showed that depth of planting was highly significant for the first year height increment of White Spruce. Growth in the second year was less, but still significantly affected by planting depth. The second years height increment of Norway spruce was significantly correlated to planting depth. The loss of height derived from deep planting had not been offset by better growth at the end of the second growing season.

Trees of the large size classes in both species made significantly greater height growth in the first year than those in the small size classes. In neither species was the effect carried over into the second year probably due to the adverse environmental factors, such as frost heave and winter browning which occurred during the intervening winter. In general the trees with the best height growth were worst affected. Similar results were attained by Brace (1964); Stiell (1960); Hough (1952); and Knight (1957).

Norway spruce was not significantly influenced by site in either year. Though the first year's height increment of white spruce was strongly influenced by site, the effect of site was less pronounced but still significant in the second year.

The overall survival was 89 per cent and no significant differences occurred between treatments. Correlation coefficients for 13 relationships between pairs of variables from white spruce measurement data for the various treatments are given. Correlations were very variable, some treatment giving correlations, others showing no significance, while others were highly significant. The most consistent relationships were found between First year 1963: Height increment - Diameter of terminal bud at end of first (1963) growing season, Height increment (1964) - Terminal bud at the end of second (1964) growing season, Average terminal shoot needle length - Terminal bud diameter at the end of (1964) growing season.

2.3.13 Subsequent Growth Studies

The phenology of terminal leader growth in young healthy white spruce (Picea glàuca) was recorded for the 1965 growth season. It is discussed by Hellum (1967) in relation to seedling heights, terminal bud diameter and forest shade. Measurements were made on seedlings ranging from 2 to 26 years in age, range between 2 to 400 cms. in height, on similar sites and under 4 shade intensities.

A multiple regression analysis between the data on leader length and the independent variables of bud diameter and seedling height revealed that premordial bud size exerted a greater influence over terminal leader length than did seedling height. In general seedlings increase their annual height growth as they grow taller. This study showed that taller seedlings set their buds later. On average a seedling that grew in height for 30 days produced a leader 10 mm long while one that grew for 60 days produced a leader 296 mm long, nearly 15 times faster and 30 times longer. Similarly a terminal bud of 3 mm in diameter produces a leader 50 mm long while one 7 mm in diameter produces a leader 300 mm long. The relationship was parabolic rather than linear over the range of seedling heights.

A method of assessing the quality of spruce plantations was described by Marion (1966) for a given region. He measured the mean length of the leading shoots formed annually, for the first 12-15 years for a series of the best plantations of similar age in a number of localities. A sample study in the Vosges indicated that the length of annual increments in the 3rd to 7th years after planting can be correlated with that obtained in the first two years. A range of 30-50 cms was considered reasonable.

Miller (1965) investigated the number of branchlets in twelve 4 to 18 year old (P. resinosa) plantations in relation to the variables of height, stem diameter 1' above the ground and the number of internodes. Regressions between branchlet number, previous heights, current years growth, stem diameter, current years height growth and current number of internodes, stem diameter and current number of internodes, product of previous years height growth x previous years number of internodes gave correlation coefficients ranging between 0.89 and 0.95. Height was found to be the best indicator because of its predictive power and the ease of obtaining past measurements. See Table 8.

Yearly branchlet multiplication was studied in three representative situations where the past branchlet multiplication was reconstructed for nine sample trees. These trees could be designated into three different but typical height growth patterns (a) fast starters - fast growers; (b) moderate starters - fast growers; (c) slow starters - slow growers. The rate of branchlet multiplication (one years number divided by previous years number) was found to be highest in early plantation life just after

Table 8

Relationship of number of branchlets to certain estimators for Red Pine

Equation no.	Estimators (X) and their range	No. observations	Correlation coefficient (R)	Index of determination (R^2)	Equation for estimating no. branchlets per tree (T)
			Single estimator		
1.	Previous year's ht. (9-100in.)	137	.95	.90	$\text{Log } T = 3.88(\text{Log } X) - .69(\text{Log } X)^2 - 2.5176$
2.	Current year's ht. (23-120in.)	137	.91	.83	$\text{Log } T = 5.40(\text{Log } X) - 1.01(\text{Log } X)^2 - 4.4070$
3.	Stem diameter (0.4 to 3.3in.)	85	.89	.80	$T = 110.2\ (X) - 35$
			Dual estimators		
4.	Current year's ht. (X_1) and current no. internodes (X_2)	137	.94	.88	$\text{Log } T = 1.64\ (\text{Log } X_1) - 2.53\ (1/X_2) - .6426$
5.	Stem diameter (X_1) and current no. internodes (X_2)	85	.94	.89	$\text{Log } T = 2.2309 + 1.05\ (\text{Log } X_1) - 3.28\ (1/X_2)$
6.	Product of previous year's ht. x previous year's no. internodes	137	.90	.81	$\text{Log } T = 1.08\ (\text{Log } X) - .7953$

Reprinted from Miller (1965)

** Sample bundles of representative seedlings and transplants from material to be used for lining out and planting in the forest were selected for measurement. Samples contained 150 seedlings and 120 transplants for each category.

3. METHODS

3.1 Introduction

The study was divided into two sections:-

(a) Measurements of Nursery Stock.

(b) Measurements in Young Stands up to Canopy Closure.

In brief the study involved the measurement of total height, height increment, root collar diameter, dry weights of shoot and root, numbers of growing points and incidence of malformation within 1 + 0 seedlings, 1 + 1 and 2 + 1 transplants. The measurements of a non destructive nature, total height, height increments, diameter at soil level and mid point of the first and third years height growth, number of branchlets by internodes, and position and degree of malformation were extended to young stands 1, 3, 6 and 9 years after planting to determine the influence of the variation in the planting stock on establishment, subsequent growth and differentiation of vigour classes.

3.2 Measurements of Nursery Stock

3.2.1 General

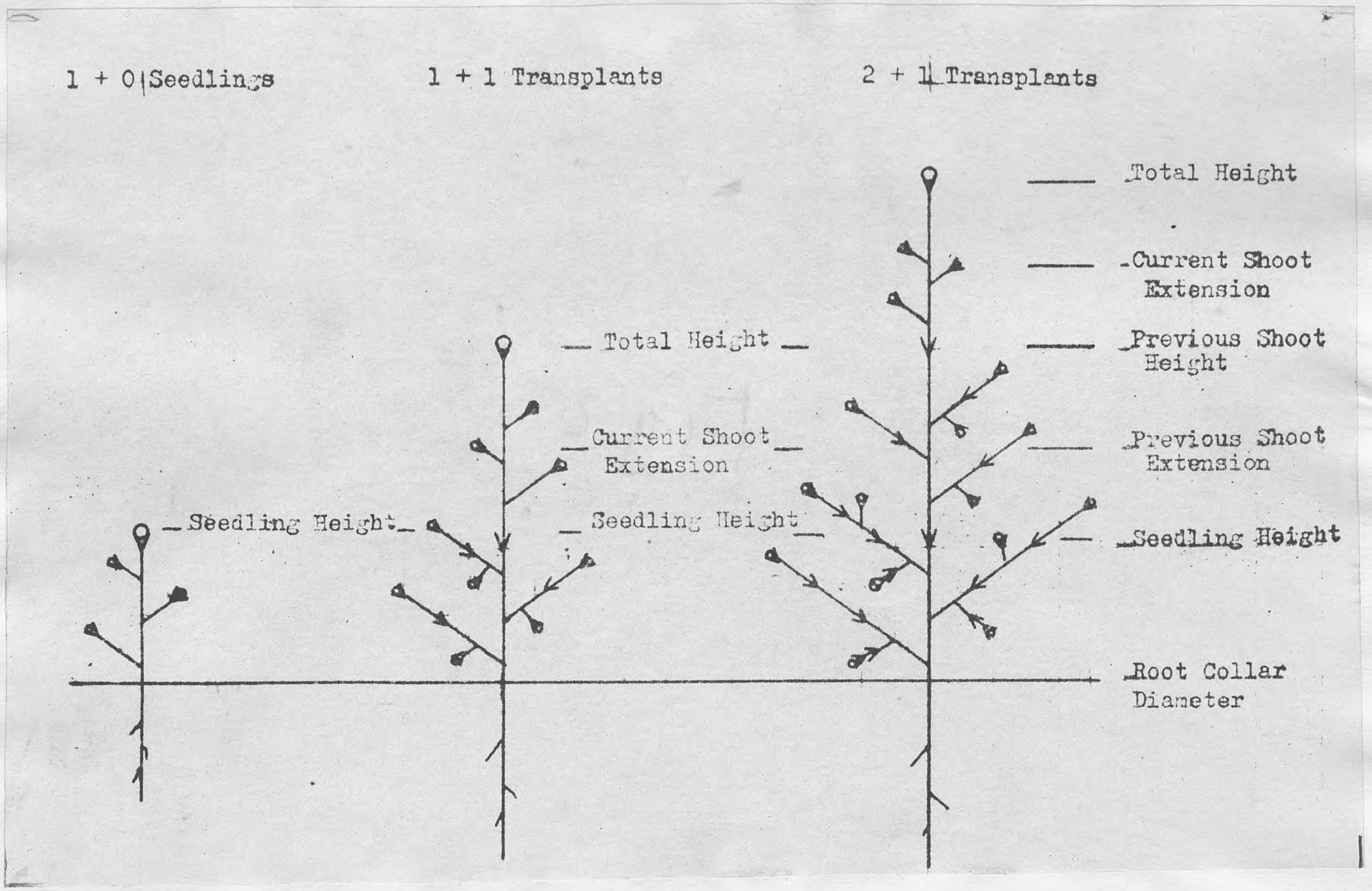
The variation in 1 + 0 seedlings, 1 + 1 and 2 + 1 transplants from Bareagle Nursery, which supplies planting stock to the study area were investigated to define the type of plants used in forest planting.** 1 + 0 seedlings were included to form a basis of comparison, so that the effects of transplanting on planting stock development could be determined. The measurements made on 1 + 0 seedlings, 1 + 1 and 2 + 1 transplants will be listed, their positions may be seen from the appropriate Figures and the methods used for each measurement will be discussed.

3.2.2 1 + 0 Seedlings

The following measurements were made on 1 + 0 seedlings. See Figure 2.

Figure 2

The Position of the Measurements made on 1 + 0 Seedlings and 1 + 1 and 2 + 1 Transplants



1. Total shoot length.
2. Root collar diameter.
3. Root weight.
4. Needle weight.
5. Weight of woody shoot material,
6. Number of growing points.
7. Malformation.

3.2.3 1 + 1 and 2 + 1 Transplants

The following measurements were made on 1 + 1 and 2 + 1 transplants. See Fig.2.

1. Total shoot length
2. Previous seasons height (i.e. height one year after transplanting; 2 + 1 transplants only)
3. Seedling height (i.e. height at time of transplanting)
4. Root collar diameter.
5. Root weight.
6. Needle weight.
7. Weight of current season's woody material.
8. Weight of previous season's woody growth.
9. Number of branchlets.
10. Malformation.

3.2.4 Root Collar Diameter

The position of the root collar of 1 + 0 seedlings was taken to be 1 cm. above the topmost rootlet. This corresponded closely to the observed soil level.

In 1 + 1 and 2 + 1 transplants the position of the root collar was more difficult to determine, due to the extreme variability in the positioning of the seedling root collar during the transplanting operation. As far as possible the criterion that the position of the root collar was 1 cm. above the topmost rootlet was used unless this was obviously unrealistic (i.e. where the seedlings had been planted deeply but had not produced adventitious rootlets). The presence of soil particles clinging to the stem was not an accurate guide as to the position of the root collar due to rain splash.

Where the lower seedling branchlets had been buried below soil level and adventitious rootlets had formed in their axils the same criterion for diameter was applied and the plant recorded as malformed.

The diameter was measured to the nearest 0.1 millimetre with a direct reading spring micro-calliper, at the position taken to be the root collar. The average of two diameters at right angles was recorded, care being taken to avoid obvious local irregularities. In cases of malformation of the stem or root it was difficult to obtain an accurate estimate of the root collar diameter. The diameter at the mid point of each year's height growth would have been less variable as is shown by results from the second part of the study. Where more than one leader was present the diameter of the tallest shoot was taken.

3.2.5 Total Height

Total Height (to the nearest millimetre) was measured from the root collar to the tip of the topmost needles.

3.2.6 Seedling Height and Previous Season's Height

Seedling height and previous season's height were measured from the root collar to the bud scales at the base of each season's shoot elongation.

3.2.7 Dry Weights

The root and shoot were severed at the root collar, placed in labelled paper bags and dried at 105°C for 48 hours in a forced draught oven. Once dry, the portions of stem and root were prepared and weighed to the nearest 0.01 gramme on a direct weighing balance. They were not cooled off first, as a desiccator sufficiently large to deal with the volume of material being processed was not available. Treatment was kept as consistent as possible as it is the relative weights rather than the actual weights which are important. Weight increase during preparation was 0.15 to 0.35 grms.

3.2.8 Root weights

As much soil as possible was shaken from the roots prior to drying. The small soil particles still attached to the roots were rubbed through a 1 mm. sieve before weighing. Unfortunately some of the finer root fibre was lost as well. This method was adopted as measurements were being performed simultaneously with the separation into roots and shoots.

The alternative method is to wash the roots prior to drying but the force of the jet of water required to remove the more stubborn soil particles also removes much of the finer root material.

3.2.9 Shoot Weights

Shoot material was removed from the oven when dry and separated into needles, current season's woody stem material and previous season's woody growth. The number of branchlets was counted at the same time. The needles were sieved gently to remove dust which may accumulate due to rain splash.

Owing to length of time required in preparation prior to weighing, material would take up moisture whether still warm or cooled off in a desiccator. The amount of moisture taken up is proportional to the length of time required in preparation. As larger plants take longer to prepare the relative weights may be reinforced.

3.2.10 Number of Growing Points and Branchlets

The number of growing points of 1 + 0 seedlings was not strictly comparable with the number of branchlets on 1 + 1 and 2 + 1 transplants. See Figure 2. These counts were made when the shoots were being separated into their component parts for weighing. The number of growing points in 1 + 0 seedlings was considered to be the number of locations where shoot and side shoot elongation had occurred in the first year of growth. Whereas the number of branchlets in 1 + 1 and 2 + 1 transplants was considered to be the number of locations where woody shoot material had been produced in the current growing season. The leader of a transplant counted as a unit is comparable to the whole of the 1 + 0 seedling.

3.2.11 Malformation

Three grades of malformation were distinguished:

a. Lost Leader

b. Double Leader: due to forking with the growth of two lateral shoots after the loss of a leader, or the growth of a buried side shoot.

c. Multiple leader: usually due to the growth of a number of buried side shoots but can result from the growth of a number of lateral shoots after the loss of a leader.

3.3 Measurement in Young Stands up to Canopy Closure

3.3.1 General

It would be preferable to follow the same plot through from planting to canopy closure. As this proved to be impracticable it was decided to investigate a series of young stands up to canopy closure at about age nine years.

Due to the excessive amount of field work which would be involved in making a complete measurement of all ages and the difficulty of finding comparable sites, it was necessary to select a few crucial ages and make detailed measurements, so that the results for intervening years could be interpolated. Four age classes only were measured.

The age range can be divided into two periods, viz.:

a) establishment and (b) subsequent growth. Silviculturally the establishment stage lasts until weeding is no longer necessary. This generally is at age three in the study area. Therefore it was decided to examine the range at three year intervals and thus plots were established in stands of 1, 3, 6 and 9 years of age.

Forests in the South Scotland Conservancy centred on Bonchester Bridge, where much new planting has been done in recent years, were thought to be suitable. From the planting records a number of compartments of each age were selected. These compartments were investigated in the field and areas with comparable soil (peaty gley) and vegetation types (predominantly Deschampsia flexuosa and D. caespitosa) at an altitude between 900-1100 feet a.s.l. were selected. All areas have been ploughed so that the planting site can be considered fairly uniform. Minor site variations indicated by minor changes in vegetation do exist but no more than is normal on these sites.

The location of the plots may be seen on the Location map. Details of planting stock, seed lot, spacing etc. can be seen in Table 9.

3.3.2 Plot Layout

Initially it was planned to carry out an exploratory survey to assess the extent of variation, and the size of plot required, then lay out additional plots to enable the comparison between two samples. Unfortunately this proved impossible, as poor weather and snow restricted field work, so that detailed assessment has been confined to a single plot for each selected age.

A square 1/10 acre plot, orientated with the rows, was laid out for each age using a compass and 66-foot tapes. This plot size was chosen because it was considered that the number of trees to be measured and plot lay-out could be handled by a single person unaided. Measurements were made systematically along the rows in one direction only. The numbers of stems in each row were recorded so that spatial arrangements of vigour classes could be represented graphically.

3.3.3 Measurements Made in Young Stands

Similar measurements to the non-destructive measurements made on seedlings and transplants were extended to young stands to determine the effect of variation in nursery stock, on establishment and subsequent growth and the process associated with the development of dominance. The measurements made in 1-, 3-, 6- and 9-year old stands will be listed, their positions may be seen from the appropriate figures and the methods used for measurement will be discussed.

3.3.4 1 Year After Planting

The following measurements were made in the 1-year old stand. See Fig. 3.

1. Total height.
2. Height at planting.
3. Diameter at soil level.
4. Diameter at the mid point of the current year's height growth.
5. No. of branchlets by internodes.
6. Degree of malformation and position.

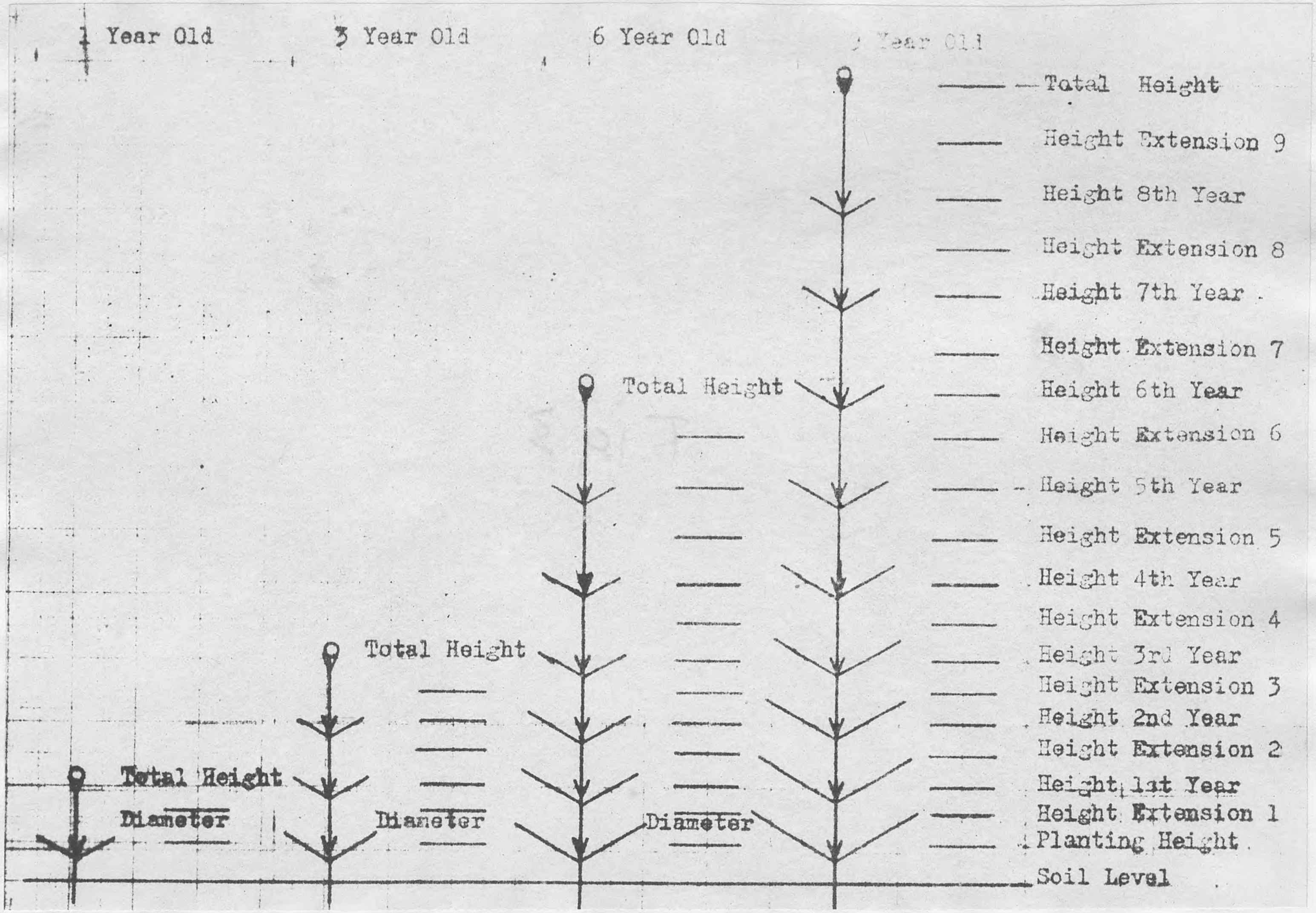
3.3.5 3 Years After Planting

The following measurements were made in the 3-year old stands. See Fig. 3.

1. Total height.
2. & 3. Height 1st and 2nd years after planting.
4. Height at planting.
5. Diameter at soil level.
6. Diameter at the mid point of the 1st year's height growth.
7. Diameter at the mid point of the 3rd year's height growth.
8. No. of branchlets by whorls.
9. Degree of malformation and position.

Figure 3

The positions of the Measurements made in young stands 1, 3, 6 and 9 years after planting



3.3.6 6 Years After planting

The following measurements were made in the 6-year old stand. See Fig. 3.

1. Total height.
2. to 6. Height each year since planting.
7. Height at planting.
8. Diameter at the mid point of the 1st year's height growth.
9. Diameter at the mid point of the 3rd year's height growth.
10. No. of branchlets on the second whorl from the top of the tree.
11. Degree of malformation and position.

3.3.7 9 Years After planting

The following measurements were made in the nine-year old stand. See Fig. 3.

1. Total height.
2. to 9. Height each year from planting.
10. Height at planting.
11. Diameter at the mid point of the 1st year's height growth.
12. Diameter at the mid point of the 3rd year's height growth.
13. Average height of canopy closure.
14. Number of side branches touching.
15. Degree of malformation and position.

3.3.8 Height Growth and Height Increment

Total height, and height growth each year, were measured from soil level, as near to the base of the stem as possible, to the tip of the top-most needles, or to the base of the bud scales respectively.

Height measurements in 1 and 3 year-old stands were made to the nearest 0.5 centimetre with a 1 metre rule. In 6-and 9-year old stands they were made to the nearest 1.0 centimetre with a 3 or 4-metre pole respectively. Measurements of the tallest leader only were recorded. Some difficulty was experienced in obtaining accurate measurements in the older stands, due to wind movement and the fact that in some cases the bud scales on the lower portions of the stems had been lost. Malformation reduced the

Table 9: Sample Plot Information for 1, 3, 6 and 9 Year old Forest Plots

Age	P year	Forest	Section	Compt	Type of Planting Stock	Seed Lot	Spa	Altitude	Aspect	Slope
1	P68	Wauchope	Hawklaw	702	1 + 1	59(7111)	1,270	1000	East	Gentle
3	P65	"	Whitrope	617	1 + 3	62(7971)	1,590	950	West	Gentle
6	P62	"	Myredykes	528	1 + 2	H56(7111)R	1,590	900	Northwest	Slight
9	P59	"	Hyndlee	87	1 + 2	H53/3	1,370	1050	West	Moderate

ease of height measurements.

3.3.9 Diameter measurements

Diameter measurements in the 1- and 3-year old stands were made to the nearest 0.1 millimetre with a direct reading spring micro-calliper. In 6- and 9-year old stands the readings were read in millimetres with steel callipers. Measurements of the tallest leader only were recorded. Where possible the average of two measurements was recorded, though in some instances these were difficult to obtain due to malformation and dense branch growth.

3.3.10 Numbers of Branchlets

In 1-and 3-year old stands, the number of branchlets were recorded for each internode, down to planting height. Where malformation occurred the number of branchlets on the second leader or fork were included with those of the whorl from which it arose.

The number of branchlets on the second major whorl from the top of the tree were recorded for six year old stands. Due to malformation this could be the whorl formed at the end of the fourth or third year. Where two whorls ran together these were separated as much as possible to give a realistic count. In 9-year old stands the average height of canopy closure and the number of sides on which this occurred was recorded.

3.3.11 Malformation

Malformation was recorded as either (a) lost leader or (b) forks.

(a) Loss of leader was considered to occur where growth continued without serious deflection of the stem. See Fig. 7.

(b) Forking was considered to occur when two or more lateral shoots became leaders, serious deflection of the stem resulted or a basket whorl was formed.

Loss of leader has a considerable effect on the height increment and the form of the tree. The extent of resulting malformation depends on the time and extent of the portion of the leader that is lost.

Malformation is recorded for the year in which results of the malformation become evident, e.g. Loss of leader at the end of the fourth growing season is recorded as Lost Leader 5.

4. RESULTS

4.1 General

The data from the Nursery and Forest samples were examined to determine:

A. The nature of the distribution of total heights, intermediate heights, height extensions, diameters and total weights.

B. The distributions of these parameters within the vigour classes.

C. The spatial arrangement of these vigour classes over the sample areas of the forest plots.

D. The inter-relationships between the various growth parameters measured.

E. The growth trends over the series of nursery and forest samples.

The results are presented in two sections, under each of the headings listed above:

a. Results from the Nursery Investigations.
b. Results from the Forest Investigations.

4.2 Growth Parameter Distributions within the Nursery and Forest Samples

4.2.1 General

Scatter diagrams were plotted, for the measurements of total height with diameter and total weight measurements for the 1 + 0 seedlings, 1 + 1 and 2 + 1 transplants. In a similar manner scatter diagrams were plotted for total height measurements with diameter at the mid-point of the height extension 1 of the young forest stands 1, 3, 6 and 9 years after planting. The distributions were divided into 10 classes and histograms were constructed showing the percentage frequency in each class. Any measurements two or more classes outside the general range were disregarded. This was necessary for one total height measurement in the six-year old sample.

From the histograms the nature of the distributions of total height, diameter and total weight can be seen to change with age. For the histograms of total height, diameter and total weight for 1 + 0 seedlings, 1 + 1 and 2 + 1 transplants, see Figure 4. Histograms of height, diameter and total height for 2 + 1 transplants from Devilla Nursery are similar to those from Bareagle Nursery. The histograms for total height and diameter and mid point of the height extension 1 for young stands 1, 3, 6 and 9 years after planting, may be seen in Figure 5.

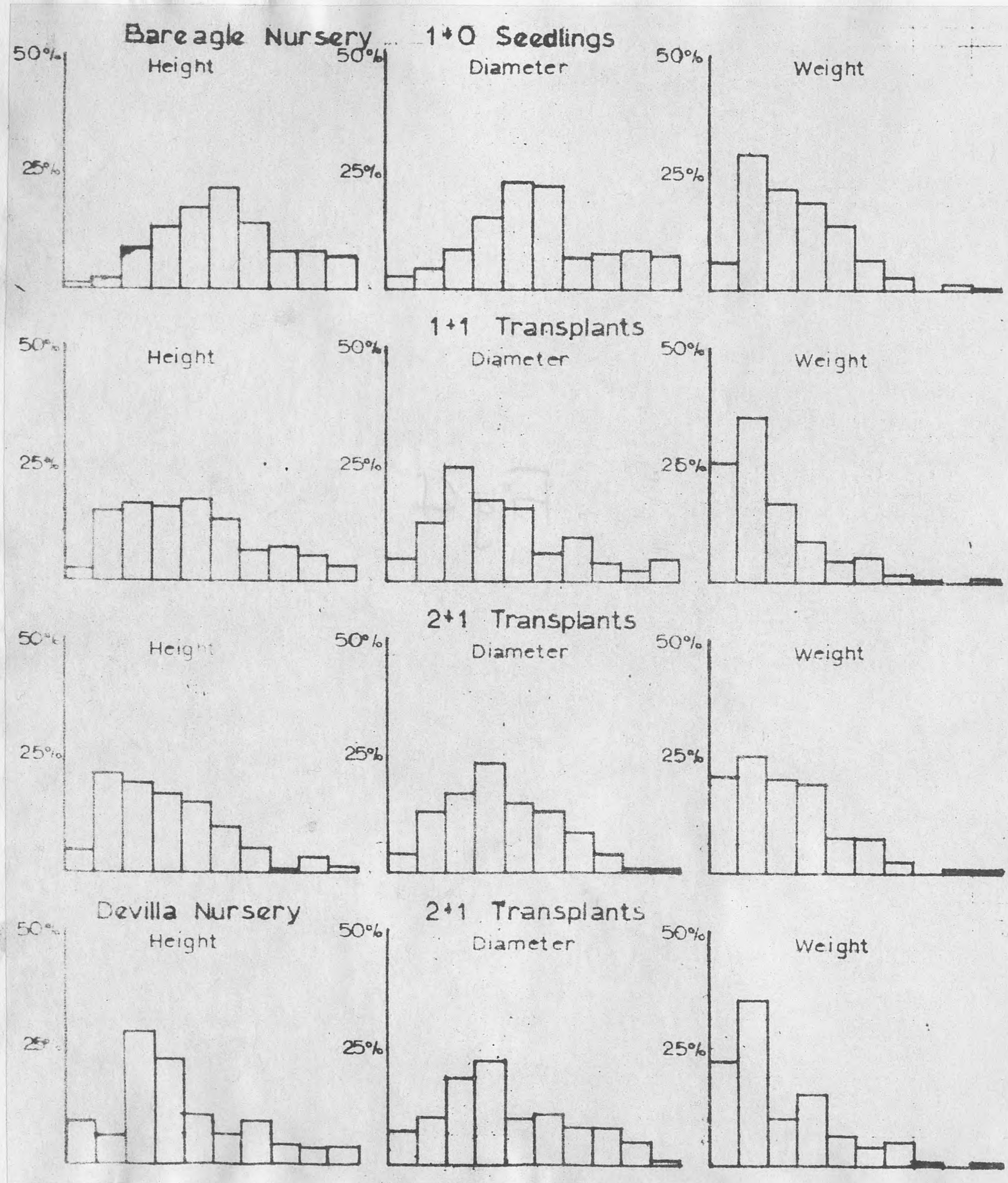
Discussion will be centred on the variation of height parameters due to their high indicative value and ease of measurement. For the position of measurements see Figures 2 and 3. Diameter and total weight distributions may be thought of as complementary to total height growth. In order to explain the reasons for this variation of the total height distributions with age, it is necessary to look at the variation of the component yearly height increments. The overall nature of the distributions, and the distribution within the various vigour classes, must be considered.

An insight can be gained into the effect of transplanting and planting on the overall growth processes and the nature of the establishment and subsequent growth phases, by detailed analysis of the component height distributions. A number of features of the distributions must be taken into consideration: (a) the amount of variation; (b) the position of the peak of the distribution in relation to the extremes of the range, and (c) the division of the distribution amongst the various vigour classes.

For the distribution of height components within vigour classes see Section 4.3. The nature of the distributions of the height components may be seen in Tables 10, 12, 14, 16, 18, 20 and 22. These tables present the data for each measurement so that the minimum, maximum, median and 25 and 75 percent. quartiles can be compared with the mean and standard deviations of the equivalent normal distribution. The nature of these distributions for the nursery and forest samples will be discussed in turn.

Figure 4

Histograms of Total Height, Diameter and Total Weight for 1 + 0 Seedlings, 1 + 1 and 2 + 1 Transplants.



4.2.2 Results from the Nursery investigations

A comparison of the distributions of total height for 1 + 0 seedlings, 1 + 1 and 2 + 1 transplants from Figure 4 shows that they range from approaching normal for 1 + 0 seedlings to an increasing degree of skewness for 1 + 1 and 2 + 1 transplants. The positions of the measurements may be seen in Figure 2.

Seedlings above 1.5 inches form 1 + 1 transplants after one season in the transplant lines. The remainder of the seedlings are left in the seed bed for another growing season and after one growing season in the transplant lines, they form 2 + 1 transplants. On lifting prior to transplanting, seedlings may be assumed to have a height distribution which approaches normal, approximating that of 1 + 0 seedlings (Figure 4).

Measurements of seedling height for 1 + 1 and 2 + 1 transplants and previous heights for 2 + 1 transplants (see Tables 10, 12 and 14) show that these heights have developed a skewed distribution in the lower portion of the range (skewed left). This indicates that plants were planted at depths that varied from nursery bed level on lining out. Larger plants, i.e. with larger seedling heights, tend to be planted deeper. This explains the distributions of seedling heights and previous heights which tend to be skewed left for 1 + 1 and 2 + 1 transplants. 2 + 1 seedlings, which remain in the nursery beds for an additional year before lining out, produce a height increment in this year (i.e. previous year's height extension), which approaches normal, see Table 14. This suggests that seedlings left undisturbed produce a distribution of height extension which approaches normality.

An analysis of the current shoot extension of the 1 + 1 and 2 + 1 transplants (see Tables 12 and 14), shows that the distributions of current shoot extension tends to be skewed right, for 1 + 1 transplants and skewed left for 2 + 1 transplants. This would appear to indicate that, as a result of a combination of deeper planting and the transplanting process, larger plants are checked to proportionately greater extent.

The plants forming the 2 + 1 transplants are generally larger, and are checked to a proportionately greater extent, especially in the middle to upper portions of the range, resulting in a skewed left distribution. Whereas the plants forming the 1 + 1 transplants are generally smaller and are checked to a lesser degree except in the lower portion of the range, resulting in a skewed right distribution. Larger plants produced greater height extensions, though for 1 + 1 transplants the height extensions were proportionately greater. The total height distributions of the 1 + 1 and 2 + 1 transplant are the net of yearly height increments (see Figure 4).

The distribution of diameters for 1 + 1 transplants is more skewed left than that of 2 + 1 transplants (see Figure 4) reflecting the additional season's growth before transplanting for the 2 + 1 transplants. The distribution of height/diameter ratio values for 1 + 1 transplants is skewed right compared to the approaching normal distribution of the height/diameter ratio values for 2 + 1 transplants. 1 + 1 transplants appear to be slightly more sturdy. In both cases the sturdiness is greatly increased compared with 1 + 0 seedlings.

Transplanting similarly increases the skewness of the distribution of weight (see Figure 4). The shoot/root ratios of the 1 + 1 and 2 + 1 transplants have distributions which are skewed left. The values are higher for 2 + 1 transplants.

There is a corresponding development of skewness in the distributions of numbers of branchlets. The skewness is greater for the 1 + 1 transplants than the 2 + 1 transplants and appears to indicate that any reduction in the height increment is accompanied by a reduction in branchlet production.

4.2.3 Results from Forest Investigations

The distribution of total height (Figure 5) for 1, 3, 6- and 9-year old stands after planting can be seen to change from skewed left for 1- and 3-year old stands, through approaching normal in the 6-year old stand to skewed right in the 9-year old stand. In order to elucidate the growth pattern the distributions of each of the component parameters will be discussed in turn working upwards. For the positions of the measurements mentioned see Figure 3.

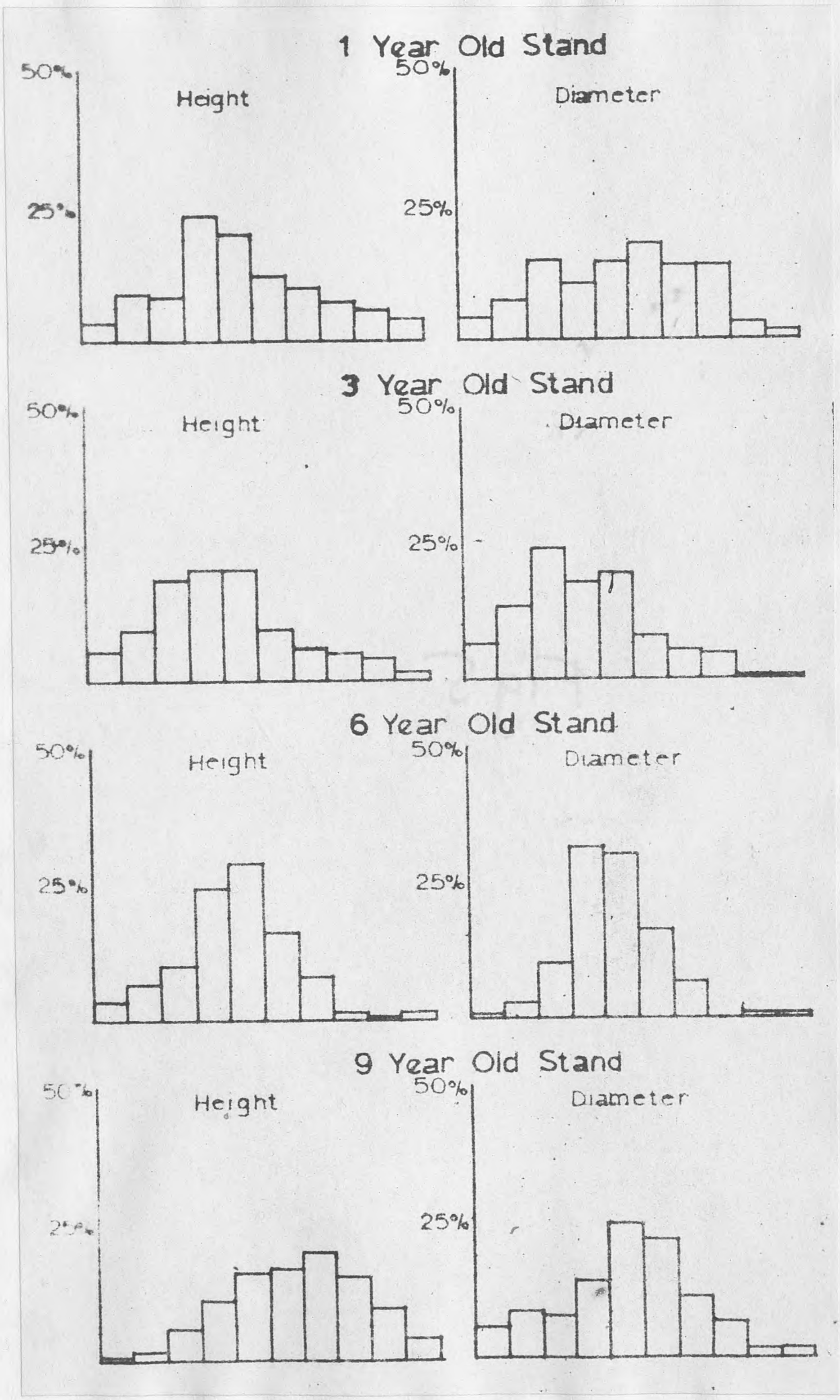
Planting may be considered as an operation which has a similar effect on height growth to transplanting. This assumption is borne out by analysis of Tables 16, 18, 20 and 22, which show the distribution of growth parameters for young stands 1, 3, 6 and 9 years after planting. Planting height for all samples shows a skewed left distribution. The erratic depth of planting probably reinforces the already skewed height distributions shown to exist in the planting stock. See Figure 4. All planting stock was of transplant origin. See Table 9. The planting stock varies in height as would be expected as it ranges from 1 + 1 to 3 + 1.

Height extension in the first season of growth (i.e., height extension 1) shows a skewed left distribution similar to that found after transplanting. From analysis of planting height and height extension 1 it can be concluded that, unless the plants are of a reasonable height and sturdiness, the length of the first year's height extension will not equal planting height. A comparison of the mean planting height and mean height extension 1 of the 1-year old stands with the mean planting height and mean height extension 1 of 3, 6- and 9-year old supports the above conclusion. It is more skewed left in the 9-year old stands, which are probably the most exposed. The variation of height extension 1 is large, indicated by the standard deviations. The mean height extension in the first years after planting, shows little increase on the mean of the first season's height extension, though the values for the upper quartile and maximum increase considerably. The distributions of height measurements at the end of the second growing season (i.e. height 2nd year) after planting range from nearly normal in the 6-year old stand, slightly skewed left in the 3-year old stand to skewed left in the 9-year old stand (see Tables 16, 18, 20 and 22). Height increment in the third growing season, i.e. Height Extension 3 has a skewed distribution in all stands, though to a slightly lesser degree in the 6 year old stand. This may be due to competition from ground vegetation as the lower whorls of branches become smothered by grass at this stage.

Third year height distributions are skewed left in all stands, though to a lesser degree in the 6-year old stands. The diagram, Figure 5, of total height distribution for young stands 3 years after planting is an accurate representation of the position found in the 6-and 9-year old stands 3 years after planting. The mean height extension and the submeans of height extensions for the various quartiles for the 1-to 3-year period shows only a slight and irregular increase on the initial height increment. It appears that unless plants have between 9 - 13 cms. of top exposed after planting, their initial growth is poor. The exact amount of exposure depends on the type of planting stock. This implies that more vigorous culling is required in the nursery to remove small and spindly trees. It is shortsighted policy to plant trees that do not measure up to the required standards, as is shown by the young stands 1 year after planting. See Table 16. Although most of the measurements of height extension 1 are arranged about or to the left of the mean, the upper range is considerably extended and

Figure 5

Histograms of Total height and Diameter mid point height Extension 1, for young stands 1, 3, 6 and 9 years after planting



reaches up to 3 times the mean value. Larger plants generally produce a proportionately larger height extensions, providing they are sturdy.

If they are not sturdy, larger trees are liable to lose proportionately larger amounts of their leaders, as is shown in Table 16. A high proportion of trees lose their leaders during this period (see Section 4.4), though the more vigorous trees appear to be less affected.

The distribution of height increment in the 4th growing season (i.e., height extension 4), in the young stands 6 and 9 years after planting is slightly skewed to the left. Although the amount of variation is still large, height growth is beginning to accelerate, particularly in the six year old stand (see Table 20). Heights in the 4th growing season (i.e. height 4) show a skewed right distribution in the 6-year old stand compared to a slightly skewed left distribution in the 9-year old stand.

The distributions of Height Extension 5 in both the 6-and 9-year old stands show a slight skewness to the right. This is more pronounced in the six-year old stand. Accelerated height growth is just beginning to start in the upper quartile of the 9-year old stand. The distribution of height 5 is skewed right in both stands. The acceleration of height growth in the nine year old stand starts in the sixth growing season. See Table 22. Both these stands are entering the accelerated growth phase.

The distribution of height increment in the 6th growing season (i.e. height Extension 6) is skewed left in both stands. The distribution of height at the end of the 6th growing season, for the stand 6 years after planting, can be seen in Figure 5. The distribution heights at 6 years after planting in the 9-year old stand approximates this closely, though the distribution is slightly more skewed to the left. The six-year old stand on a less exposed site is slightly more advanced in its development than the 9-year old at this stage.

During the 4-to 6-year period height growth starts to accelerate; this occurred slightly earlier in the 6-year old stand than the 9-year old stand. In addition the increase in height growth is earlier and proportionately greater in the larger trees than the smaller trees. The variation in height and height increment is still very large.

The distribution of height increment in the 7th growing season (i.e. Height Extension 7) is skewed to the right, indicating that a large proportion of the trees has entered the accelerated height growth phase. The distribution of heights in the 7th year is also skewed right.

Similarly, the height increment in the 8th growing season (i.e. Height extension 8) is slightly skewed to the right, though height increment is greatest in the upper quartile. The height distribution in the 8th year is approaching normal.

Height extension in the 9th growing season (i.e. Height Extension 9) has a distribution which is very skewed to the right, indicating that height growth for the upper three quartiles is attaining the growth "optimum." From Table 22 it can be seen that they are not greatly different from one another and are approaching the value of the maximum height increment. The skewed right distribution for the total height for the nine-year old stand may be seen in Figure 5.

4.3 The Distribution of the Parameters within the Vigour Classes for the Nursery and Forest Samples

4.3.1 General

Initially it was thought that Schotte's Classification (p.14) might form a useful means of dividing the height distribution into dominance classes. However, fluctuations with age (see Figure 5) resulted in large variations in the numbers within each dominance class over the period under investigation. Thus it was decided to divide each sample population into quartiles based on the distribution of total height. Using a computer the trees were sorted into ascending order, according to total height; where the heights were equal, a further sorting was carried out on the basis of diameter. Once the order was established, the ranked population was divided equally into 4 portions and the submeans of all the parameters were calculated for each quartile or vigour class together with their overall mean. This enables the submeans for the vigour class data (see Tables 11, 13, 15, 17, 19, 21 and 23) to be compared with the submeans for the equivalent quartiles for each parameter sorted independently. Tables 10, 12, 14, 16, 18, 20 and 22. Thus enabling the nature of the distribution of each parameter within the four vigour classes to be observed.

4.3.2 Results from Nursery Investigations

Tables 11, 13 and 15 show the submeans for the measurements of selected parameters within the vigour classes for 1 + 0 seedlings, 1 + 1 and 2 + 1 transplants. Each sample will be dealt with separately due to the differences in treatment.

Table 11 shows the submeans of parameters in each vigour class, for 1 + 0 seedlings. When these are compared with the submeans of the equivalent quartiles (Table 10) it is found that the submeans of the root collar diameter and total weight measurements for each vigour class vary consistently in relation to the submeans for these parameters for the equivalent quartiles. The submeans for the two lowest vigour classes are higher than those of the equivalent quartiles and those of the upper two vigour classes are lower. As the variability within each vigour class increases, the total range of the 4 submeans decreases.

The distribution of total weight is slightly more variable, due to the variation in the shoot/root ratio between vigour classes. The shoot/root ratio is slightly larger in the upper and lower quartiles of the range.

The same type of comparison shows that the variability within the vigour classes of 1 + 1 transplants has increased. See Tables 12 and 13. The current shoot extension produced after transplanting is very variable in relation to seedling height, though larger seedlings are inclined to produce proportionately larger shoot extensions. The variation in root collar diameter and total weight within the various vigour classes accompanying the fluctuations in current shoot extension are mainly a result of transplanting.

The shoot/root ratio fluctuates in a similar manner to that found for 1 + 0 seedlings, indicating that the proportions of shoot weight to root weight varies over the range of vigour classes.

It may be concluded that transplanting results in a large variation in current shoot extension in relation to seedling height which is accompanied by an increased variation in root collar diameter and total weight within each vigour class.

When Table 15, showing the submeans of the parameters within the various vigour classes, is compared with Table 14, showing the submeans of equivalent quartiles for 2 + 1 transplants, it is found that transplanting produces more variation in the current year's height growth than is observed for 1 + 1 transplants. Comparisons of the submeans of seedling height and previous shoot extension with the submeans of previous height and current shoot extension for the various vigour classes show that transplanting has had a proportionately greater effect on current shoot extension than was evident for 1 + 1 transplants.

If the submeans of "seedling height" and "previous shoot extension" are compared for the various vigour classes it can be seen that a small increase in seedling height resulted in a large increase in "previous shoot extension." Whereas when "current shoot extension" is compared with "previous height" and "previous height extension", transplanting can be seen to have a proportionately greater checking effect in the upper portion of the range, although larger plants still produce larger height extensions.

The unpredictable nature of the current shoot extension leads to a greater range of root collar diameters within each vigour class. Likewise a large variation has been introduced in the distribution of total weights and this is coupled with a similar type of fluctuation in the proportions of shoot weight to root weight over the range of vigour classes, as was found in the other nursery samples.

Transplanting is accompanied by an increase in the numbers of double and multiple leaders in the upper two vigour classes of 1 + 1 transplants and the lower three vigour classes of 2 + 1 transplants, as a result of burying the lower branchlets of the larger plants during the lining out operation. These buried lower branchlets develop rootlets in the branchlet axils and grow vigorously to form secondary leaders. The distribution of malformation between the various vigour classes is explained by the greater tendency for larger plants to be more deeply planted combined with greater checking effect of deeper planting. 2 + 1 transplants have a higher proportion of large plants, and those which are planted deeply tend to be displaced to the lower vigour classes. In 1 + 1 transplant, only the largest plants tend to be deeply planted, resulting in the distribution of multiple leaders in the upper two vigour classes.

The numbers of branchlets show a similar variation within each vigour class as a result of the reduced shoot growth induced by transplanting.

4.3.3 Results for Forest Investigations

Tables 17, 19, 21 and 23 show the submeans for selected parameters measurements within the vigour classes, for the Forest Samples.

Data for the 1-year old stand will be discussed separately from 3-, 6- and 9-year old stands.

Comparisons of the submeans of growth parameters, measured for the various vigour classes, with the submeans of the equivalent quartiles bears out the contention that poor quality planting stock has resulted in poor height growth and a high percentage of leader loss in the 1-year old stand in the year after planting. The submean of the current height extension does not equal the submean of the planting height for any vigour class. There is a considerable variation in current shoot extension compared to planting height for all vigour classes.

The current height growth in the upper 3 quartiles is much poorer than would be expected, as this normally exceeds planting height. In addition these quartiles suffer appreciably greater amounts of leader loss. If "new top height" was used the picture would be decidedly more gloomy.

The diameter mid-point of the height extension 1 shows a wide variation within each vigour class. The height diameter ratio is a good deal lower for the upper vigour classes.

Although there is considerable variation in total branchlet numbers within each of the vigour classes, there is an overall increase in numbers with increasing vigour.

When comparisons are made between the submeans of the parameters arranged according to the various vigour classes (Tables 19, 21) and the submeans of the equivalent quartiles arranged independently, for 3- and 6-year old stands, (Tables 18, 20) the establishment and subsequent growth are found to be much more satisfactory; although there is still considerable variation in the initial height extensions for a particular planting height. The submeans of the height extension 1 exceed the submeans of the planting height for all vigour classes. The submeans of the height extensions for each vigour class show only a small increase over the submeans of height Extension 1 for the first 3 years growth in the forest.

The submeans for height extension 4 in the 6-year old stand shows a marked increase over the previous years height extension in the upper three vigour classes. This accelerated growth does not occur in the lower vigour class until the sixth season. The increase in growth is highest in the upper vigour class. During the first 3 years of growth the height differences between the top three vigour classes is not great, but by the sixth year the differences between these vigour classes has been considerably increased. This indicates that the variation of height increment within each vigour class and for each stem is very considerable for the establishment phase of growth.

When Table 23 showing the submeans of the height parameters measured for each vigour class is compared with the submeans of the equivalent quartiles table (22) similar conclusions can be drawn for the first six years growth of the 9 year old stands. However, the start of the accelerated growth phase is delayed two growth seasons, probably due to the more exposed nature of the site. The increase in the submeans of height extension is rather erratic over the 7-to 9-year growth period, but gradually increase the superiority of the lead of the upper three vigour classes over the lower vigour classes. The submeans of height and height extension for measurements up to the fifth year for all vigour classes have tended greatly towards the mean of each set of measurements compared with the submeans of the equivalent quartile. The submean of planting height for the upper vigour class has become lower than that for second vigour class. This demonstrates that ability to become established quickly and to produce consistent rapid height increment, is as important as planting height, in determining the position in the height range at canopy closure. On analysing the field data it seems that only plants in the top 86% of the planting height range may appear in the upper vigour class at canopy closure.

The diameters measured at the mid point of height extension 1 show considerable variation within each of the vigour classes of the 3, 6-and 9-year old stands. This is substantiated by an analysis of data for the upper vigour classes of the 9-year old stand which shows that the trees represented in this class were drawn from the top 3/4 of the diameter range.

Malformation present in the nursery stock is retained in the young stands up to canopy closure. Although these plants may initially grow well, they are gradually displaced from the upper vigour classes due to their susceptibility to further malformation which results in a reduction in height increment. This occurred to a lesser degree in the 6-year old stand situated on a less exposed site. Leader loss is frequent during the establishment and subsequent growth phases of young stands. Lammas growth appears to be a contributing factor. Leader damage is generally more frequent in the lower vigour classes, which are also more liable to develop double leaders. Forking is more likely to accompany leader damage to heavily branched trees. Trees less susceptible to leader damage and forking tend move into the upper vigour classes.

It is probable that the upper vigour class of the 9-year old stand is not yet stable but changes from year to year, due to leader damage and malformation, as the height difference between the upper three vigour classes could be achieved in a year's height growth. The pre-requisites for a place in the upper vigour class would appear to be consistently vigorous height increments and the ability to recover rapidly from leader damage with a single replacement leader. Dominance is by no means settled at this stage. The differentiation of the dominant stems in the period following canopy closure will be determined by the ability for continued vigorous height increment, lower susceptibility to malformation, the retention of large healthy crowns and strong diameter and root growth. The future dominant trees with these attributes will come mainly from the upper two vigour classes.

Crown development can be seen from the appropriate tables for the 3; 6- and 9-year old stands. Although there is variation within each vigour class, the total numbers of branchlets increase considerably with increasing vigour in 3 year old stands. For the 6-year old stands the numbers of branchlets in the 2nd major whorl from the top increases with increasing vigour. There is a large variation in branchlet numbers within each vigour class.

In the 9-year old stand the number of sides of canopy closure and height of canopy closure is approximately equal for the upper two vigour classes, but declines for the lower vigour classes. The method of determining crown diameter and height to the widest point would probably have been more satisfactory, accompanied by detailed analysis of foliage weights and branchlet numbers for a few sample trees.

4.4 The Inter-relations between Growth Parameters measured for Nursery and Forest Samples

4.4.1 General

Single line regression equations were calculated for some of the height, height extension, diameter, total branchlets and total weight parameters.

Relationships which show significant correlations are listed in Tables 26,28,30,32, 34,36,38. In addition multiple regressions were calculated using some of height, diameter and total weight parameters as the dependent variables. The relationships of total height are the most meaningful. and are listed in Tables 39.

From Figs. 4 and 5 and Tables 10, 12, 14, 16, 18, 20 and 22, it can be seen that many of the variables have log normal distributions. Owing to the difficulty of working with part logs, the fact that the distribution of particular variables changes with age, and the large number of distributions which are similar, it was thought that transformations would not markedly change the degree of correlation, so the calculations were made in their existing form. For correlations between diameter and total weight, diameter squared was found to give straight line regression relationships from plotting scatter diagrams. The regression relationships between other parameters are of a straight line nature.

Due to the large numbers in each sample 125-150 the values of the correlation coefficients at which the level of significance changes varies only slightly. The corresponding correlation coefficients for the two extreme values of the range of sample numbers are 0.174 - 0.159 at the 5.0%, 0.228 and 0.208 at the 1.0% level, and 0.303 and 0.298 at the 0.1% level of significance. In the discussion that follows all correlations fall within the 0.1% significance range unless otherwise mentioned. Where the correlation coefficient values are significant at the 5.0% and 1.0% levels it is specifically mentioned. Correlation values which fall outside the 5.0 value of significance are considered not significant. Correlation values over 0.600 in the ranges of significance at the 0.1% level are considered to be high.

In general the significant correlations confirmed the observations made in Section 4.2 and 4.3. The degree of correlation depends to a large extent on the nature of the particular parameter distributions and the degree of variation. Parameters with similar distributions and low variation are more highly correlated.

In the light of the observations made in the previous section attention has been restricted to the regressions and correlations between heights and height diameter ratio, total weight and total numbers of branchlets.

4.3.2 Results from Nursery Investigations

For the regression equations for selected parameters see Tables 26, 28, 30. Correlation coefficients may be found in the correlation matrix tables (25, 27, 29). For the positions of the measurements see Figure 2. The seedling height of 1 + 0 seedlings is correlated with the following parameters listed in decreasing order of their correlation coefficients: total weight; root collar diameter; height/diameter ratio and number of growing points.

The total height of 1 + 1 transplants is more highly correlated with current shoot extension than seedling height. Current shoot extension is correlated with seedling height at the 5.0% level of significance. This is to be expected in view of the variable nature of shoot growth after transplanting.

Total height of 2 + 1 transplants gives the highest correlation with previous height followed by current shoot extension, previous shoot extension and seedling height. Previous height is very highly correlated to previous shoot extension and to a lesser degree with seedling height. Current shoot extension shows no correlation with either previous shoot weight or seedling height at the 5.0% level of significance.

Seedling height and total height only of 1 + 1 transplants are correlated with diameter. Current shoot extension shows no correlation with diameter. The order of correlation of the height parameters measured for 2 + 1 transplants with diameter are as follows: total height; previous height; previous height extension and current shoot extension. Total height of the 1 + 1 and 2 + 1 transplants are correlated with total numbers of branchlets. Correlation of successively lower height measurements is very variable.

Diameter was correlated with the height diameter ratio for all the nursery samples. Diameter squared is highly correlated to total weight and usually highly correlated with numbers of growing points or branchlets.

Although total height is correlated with total weight and numbers of branchlets, the correlations between the lesser height and height extension measurements are very variable.

The correlation between the shoot/root ratio and height/diameter ratio with most of the parameters measured was erratic.

4.4.3 Results from Forest Investigations

The regression equations for selected parameters are shown in Tables 32, 34, 36, 38). Correlation coefficients may be seen from the correlation matrices tables (31, 33, 35, 37). For the positions of the measurements see Figure 3. Initially it was thought that the malformed and non-malformed trees could be separated and regression relationships calculated for each group. As very few trees were found to be free from malformation due to its widespread occurrence in these young stands, a separation on this basis was found to be impracticable.

Discussion will be based mainly on the correlations of height and height extension with other height parameters. Diameter was measured at the mid point of height Extension 1. The height/diameter ratio has been calculated for the diameter of height extension 1 to ensure continuity. For the 1- and 3-year old stands attention has been restricted to total branchlets rather than branchlets for each internode, due to the fact that the nature of the relationships was found to be inconclusive. (See Section 4.3).

The total height measured for the 1-year old stands was correlated with the following parameters, in decreasing order of correlation; new top height; height/diameter ratio; seedling height; current shoot extension; total branchlets and diameter mid point height extension 1. See Table 31.

Due to poor sturdiness and small size of the planting stock, height growth was poor, especially for the taller plants, and resulted in an increasingly large proportion of the larger height extensions being lost due to winter blast.

The correlations of total height with successively lower heights measurements decreased as they tended towards planting height for the 3-year old stand. Correlations with the corresponding height extension measurements were variable and much lower. Lower height measurements followed a similar trend of correlations. Height extension measurements generally gave very erratic correlations. See Table 33.

Total height of the 6-and 9-year old stands show similar orders of correlations with successively lower heights and height extensions to the 3-year old stand. Though the correlation of total height with planting height for the 9-year old stand is not significant. See Tables 35 and 37.

The inter-relationships between height parameters measured confirm the observations made in section 4.2 and 4.3 and shows that the effect of planting height declines with age until at age nine it is not significant. Total height is more dependent on the vigour of growth after planting rather than on planting height.

Total height of all samples was correlated to diameter mid point of height Extension 1. Correlations of lower height measurements are very erratic.

Total height is correlated to total numbers of branchlets for 1 and 3-year old stands and in 6-year old stands it is correlated with the number of branchlets second whorl from the top. In 9-year old stands total height is correlated with the number of sides of canopy closure and to the height of canopy closure at the 1.0% level of significance. Diameter mid point height Extension 1 was correlated to the height/diameter ratio in 1, 3, 6-and 9-year old stands. Diameter was also correlated with the numbers of branchlets, 1-and 3-year old stands, branchlets second whorl from the top 6-year old stands and sides of canopy closure and to a lesser degree height to canopy closure 9-year old stands.

4.5 The spatial arrangement of Vigour Classes over the forest sample area

4.5.1 General

Graphs were prepared showing the position and vigour class of each stem for the forest plots (see Section 4.3). The symbols used to represent each vigour class are as follows:

Vigour Class 1 ⊗

Vigour Class 2 o

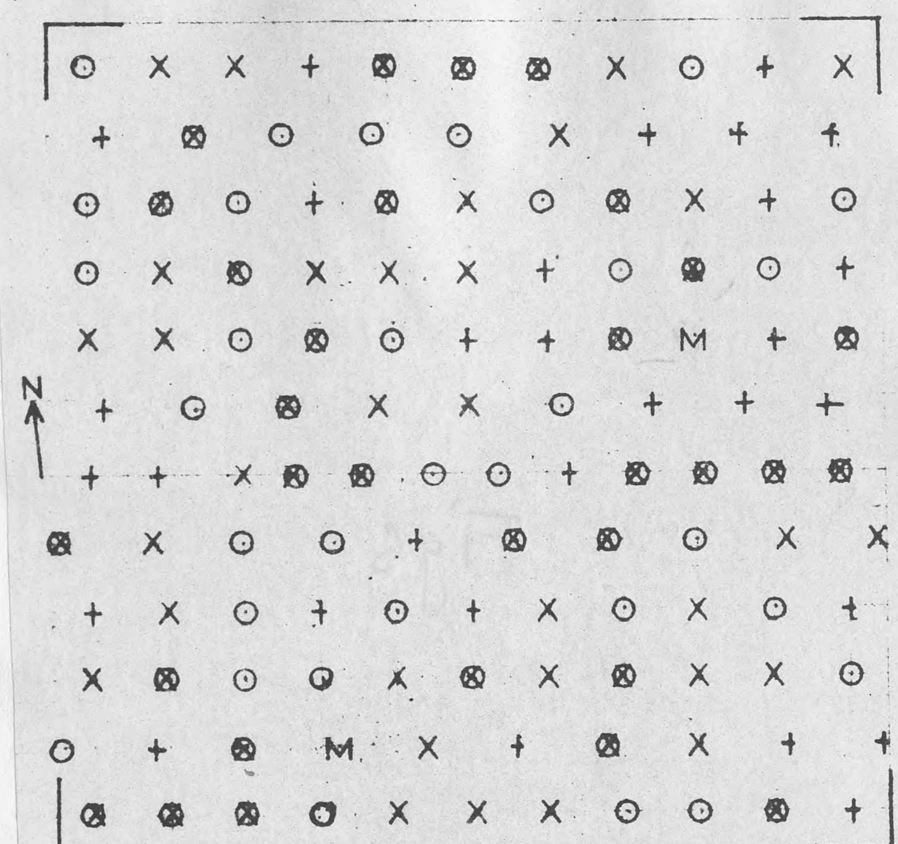
Vigour Class 3 ×

Vigour Class 4 +

In all plots the number of rows was found to be constant (12) though the spacing within rows varied. The spatial arrangement for the plots located in the young stands 1, 3, 6 and 9 years after planting may be seen in Figures 6, 7, 8 and 9. It was decided that a detailed numerical analysis of the spatial distribution was not warranted, following the conclusion reached in section 4.3 that the vigour classes were not stable in any of the stands. From observation in the younger stands it can be seen that a limited amount of clumping appears within

Figure 6

Distribution of Vigour Classes for 1 Year Old Plot



KEY

Vigour Class 1	28.0 – 20.0	⊗
Vigour Class 2	20.0 – 16.5	O
Vigour Class 3	16.5 – 14.0	X
Vigour Class 4	14.0 – 7.0	+
Missing		M

Figure 7

Distribution of Vigour Classes for 3-Year Old Plot

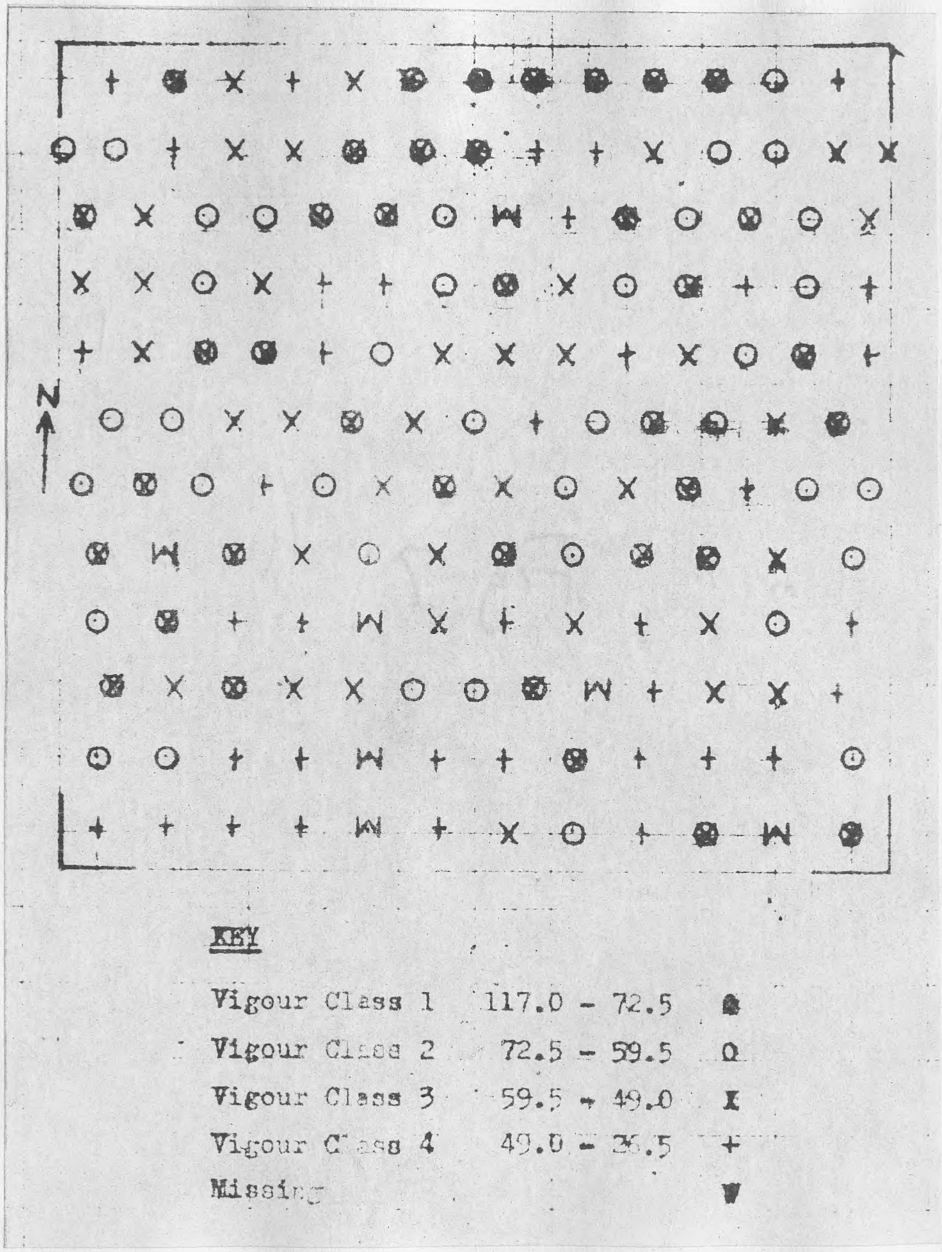
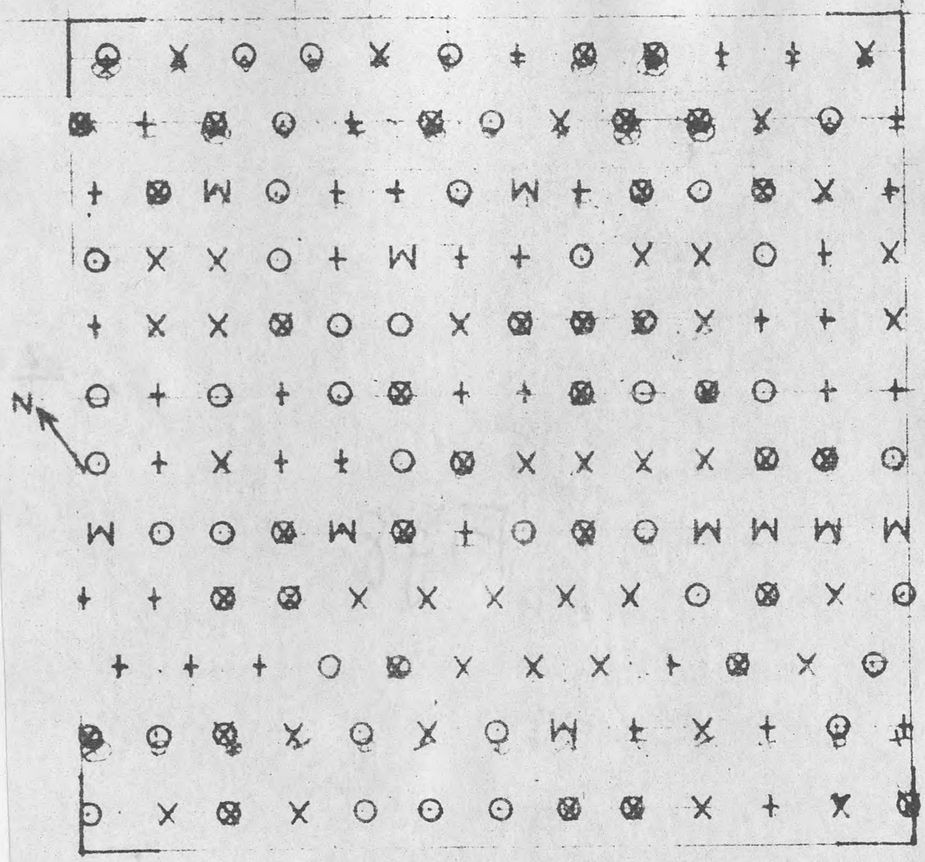


Figure 8

Distribution of Vigour Classes for 6-Year Old Plot

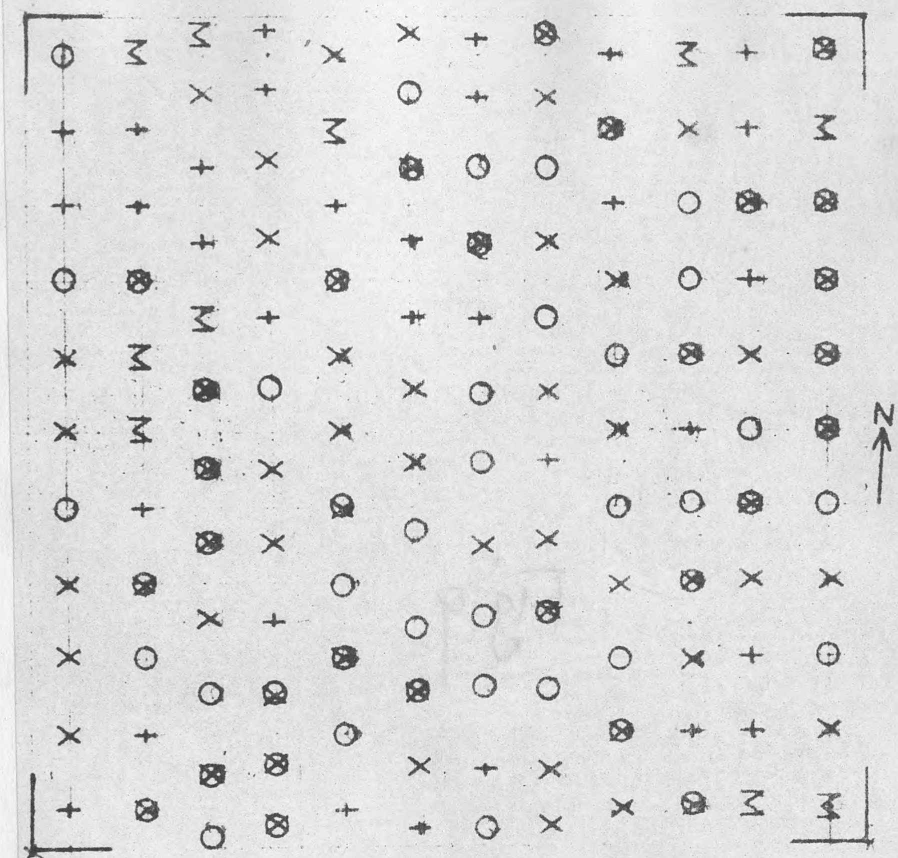


KEY

Vigour Class 1	323 - 219	⊗
Vigour Class 2	219 - 195	⊙
Vigour Class 3	195 - 179	X
Vigour Class 4	179 - 59	+
Missing		W

Figure 9

Distribution of Vigour Classes for 9-Year Old Plot



KEY

Vigour Class 1 357 - 412 ■
Vigour Class 2 327 - 357 O
Vigour Class 3 297 - 327 X
Vigour Class 4 192 - 297 +
Missing Σ

rows probably due to the planting of the bigger plants of a bundle first. This clumping is less noticeable in the older stands.

4.6 Growth trends over the series of nursery and forest samples

4.6.1 General

The growth trends for nursery and forest samples will be discussed separately.

4.6.2 Growth trends for the nursery samples

The distribution of height growth, diameter growth, height/diameter and numbers of growing points of seedlings in the first growing season after sowing approaches normal. The distribution of total weight is skewed left. For each vigour class there is a limited range of variation in diameter,height/diameter ratio and total weight. Shoot/root ratio is more variable as a result of the fall off of root weights at the higher and lower extremes of the range.

If the seedlings are left in the seed beds for an additional growing season, the distribution of height extension also approaches normal. This is shown by the previous shoot extension of 2 + 1 transplants. Height extension is proportionately greater for the taller seedlings heights.

On transplanting the seedlings after one or two growing seasons in the nursery bed the following season's height extension is considerably checked and extremely variable. The distributions of seedling heights for 1 + 1 transplants and seedling height as well as the previous season's height for 2 + 1 transplants are skewed left because of the tendency of taller plants to be more deeply planted on lining out. This results in the higher incidence of multiple leaders found in transplants. The distribution of height growth after transplanting (i.e., Current shoot extension) is skewed right for 1 + 1 transplants and skewed left for 2 + 1 transplants, indicating that the checking effect of transplanting is greater on the larger plants. As a result of the increased variation in height growth after transplanting, total height does not bear such a close relationship to the seedling height or previous height as it would if the plants had been left undisturbed.

As a result of the variation in current shoot extension the submeans of seedling heights of 1 + 1 transplants and the submeans of seedling and previous heights for 2 + 1 transplants for each vigour class are displaced towards the means of these parameters compared with the submeans of the equivalent quartiles. The inter-relationships between the parameters distributions support the observations based on the analysis of the parameter distributions; and the distributions of parameters within vigour classes.

For each portion of the height range the variation in root collar diameter and total weight is greatly increased, indicated by the reduced spread of the submeans of diameter and height/diameter ratio about the mean for the various vigour classes. The general sturdiness of the 1 + 1 transplants is slightly higher than that of the 2 + 1 transplants. The sturdiness of 1 + 1 and 2 + 1 transplants is greatly increased compared to 1 + 0 seedlings. The shoot/root ratio in both samples shows a similar variation to that of 1 + 0 seedlings. The shoot/root ratio values of 1 + 1 transplants are slightly lower.

Where height increment is checked the result is a reduction in the numbers of branchlets produced, which explains the skewed left distributions of total branchlet numbers for 1 + 1 and 2 + 1 transplants. Thus when the distribution of height increments approaches normal, so also does the distribution of branchlet numbers.

4.6.3 <u>Growth Trends over the Forest Series</u>

The pre-canopy closure stage in young stands may be divided into two phases,

(a) establishment phase (b) subsequent or accelerated growth phase. The start of the subsequent growth phase varies from the beginning of the 4th growing season for the 6-year old stand to the beginning of the 6th growing season in the 9-year old stand. This was probably due to the more exposed nature of the latter.

4.6.4 Establishment Phase

Provided the planting stock is of a reasonable size and sturdiness the mean values of height extension 1 will exceed height at planting. The effects of planting and transplanting on height growth are similar. The distribution of height extension 1 in the growing season after planting is skewed left. The skewness of height extension reinforces the already skewed distributions of planting height, resulting in distributions of heights at the end of the first growing season which are skewed left in all stands investigated. The distributions in 1-and 9-year old stands are skewed left to a greater degree. The skewness of height extension and height measurements is gradually reduced during the stablishment phase and the distributions approach normal as the stands pass into the accelerated growth phase.

During the establishment phase there is only a slight and irregular increase in the submeans of the subsequent height extensions over the height extension in the first year after planting (i.e. height extension 1). The submeans of the heights andheight extensions tend towards their respective means, particularly in the older stands, indicating that considerable fluctuations in height increment occur for individual stems, also that there is considerable interchange of individuals between vigour classes.

Some of the variation in height increment can be attributed to leader damage. Leader damage results in a reduction in height increment in the following season and may result in the formation of a double leader. In general plants that are planted with a malformation developed in the nursery, are more prone to malformation in the establishment and subsequent growth periods of development.

The inter-relationships between the growth parameters measured in the 3-year old stands support the conclusions based on analysis of the parameter distributions and distributions of measurements within vigour classes.

4.6.5 Subsequent or Accelerated Growth Phase

Young stands enter this phase of growth once the distribution of their height extensions approach normal. The distribution of height extension during this period varies between slightly skewed left, approaching normal, skewed right and very skewed right. The right skewness increases as the stand develops towards canopy closure. The peak of the height extension distribution moves from a central position in the range to a position close to the maximum height extension values. The distributions of heights changes from slightly skewed left or approaching normal at the start of the period to skewed right by time of canopy closure. The submeans of height extension for the various quartiles which are closely spaced about the mean at the start of the subsequent growth phase, become widely spaced as height increment increases. When the optimum level of growth is reached, about the time of canopy closure, the submeans of height extension for the various quartiles again approach the mean. The upper quartile starts the period of accelerated growth and reaches the optimum level of growth before the lower quartiles. The submeans for height extension of the upper three vigour classes remain more closely spaced about the mean, indicating that the increased height growth is distributed amongst these vigour classes. The lower vigour class enters the accelerated growth phase a growing season later and does not attain the same level of optimum growth in the 6-year old stands. This lag is not quite so clearly illustrated in the 9-year old stands.

The submeans of the height measurements for the upper three vigour classes, which are close to the mean at the start of the period, become more widely separated due to the greater increase in height increment in the upper two vigour classes of the stand. Though at the time of canopy closure they are not sufficiently separated to restrict interchange between the vigour classes. The range of diameter within vigour classes is large. Crown development is also variable.

Total height of the 6-and 9-year old stands shows a similar inter-relationships to the 3-year old stands. These relationships confirm the conclusion that total height is more dependent on the success of establishment and vigour of subsequent growth than planting height, though the upper vigour class contains trees from the upper 86% rds of the planting height range.

Analysis of the percentages of malformation within each vigour class shows that, although plants which are malformed on planting may initially grow well, they are gradually eliminated from the upper vigour class by the time of canopy closure, due to their liability to subsequent malformation which results in a reduction in height increment. This does not seem to have occurred to the same extent in the 6-year old stand, possibly because of the less exposed site. The members of the upper vigour classes in the older stands appear to be slightly less liable to leader damage and less prone to forking.

Dominance is not yet settled. It would appear that a number of factors, in addition to height growth, will be important in the differentiation of the dominant stems in the period following canopy closure. These are the ability to maintain continued vigorous height growth, lower susceptibility to malformation the retention of large healthy crowns and strong diameter and root growth. Trees with these attributes will come mainly from the upper two vigour classes.

D I S C U S S I O N

5.1 The implications of this work to current forestry practice will be dealt with under the following headings:

(a) Nursery growth and Establishment

(b) Subsequent growth

(c) Post canopy closure

This will be followed by a review of methods used.

5.2 Nursery Growth and Establishment

5.2.1 General

The aim of nursery techniques is to produce plants that will become established satisfactorily and grow rapidly to form stands with a high proportion of superior formed stems.

In the stands covered by this investigation the initial height growth was poor, especially in the 1 year old stand, and the incidence of malformation was high, though survival was good. A number of factors could contribute to these conditions observed, e.g., site factors; provenance and planting stock quality.

5.2.2 Site Factors

The sites investigated were generally exposed, of high elevation 900-1100 feet and situated on peaty gley soils, and are probably not capable of supporting productive high quality stands.

5.2.3 Provenance

It may be found necessary to use a more Northern provenance of Sitka spruce which might give better stem form though slower growth, on these higher elevation sites. The present provenance (Queen Charlotte Island) is capable of a fairly fast growth shown by the current height increment of

70 cms. per annum at canopy closure but suffers from slow establishment and a high incidence of malformation. A discussion of provenance is beyond the scope of this study though many of the difficulties of these sites may be removed by the development of a suitable strain of Sitka spruce by tree breeding.

5.2.4 Quality of Planting Stock

Although the quality of the planting stock for the 3, 6 and 9 year old stands appears to have been satisfactory, that used for the 1 year old stand was definitely sub-standard.

The period between planting and canopy closure is the most difficult growth period of these exposed higher sites. This is shown by the shorter establishment phase of the more sheltered 6 year old stand, compared to the nine year old stand. That rapid growth is possible during the establishment period is shown by the high maximum values of height extension compared to the mean. It may be possible to produce planting stock capable of reaching their potential growth earlier (i.e., attain a normal distribution of height extension) by the modification of nursery techniques to produce plants which are more suitable for planting on these sites. The quality of planting stock may be separated into two distinct attributes (a) Initial potential growth and (b) The capacity to produce stems of satisfactory form (stand form potential).

5.2.5 Initial Growth Potential

Aldhous (1967) using samples from Forestry Commission nurseries calculated the minimum root collar diameter values for a range of planting stock heights of a number of species including Sitka spruce. These coincided with the root collar diameters values found to give the best survival and mean height growth in the year after planting for Sitka spruce by Edwards and Holmes (1950). In the 1 + 1 and 2 + 1 transplant samples used in the investigation the root collar diameters were found to be above the minimum values given.

These values of sturdiness may give satisfactory survival and height growth on lower altitude sites, but investigation is required to determine whether initial height growth could be improved and the establishment phase shortened, by the use of more sturdy planting stock on exposed sites. Edwards and Holmes (1950) showed that survival was linked with the ability to produce a mean height growth in excess of planting height in the year after planting (see Table 6).

The present investigation shows that the lower vigour class produced an initial height extension less than planting height and shorter subsequent height extensions compared to the Upper vigour classes during the establishment phase. Components of the upper two vigour classes were from the top 86% of the range of planting height after planting in the 9-year old stand. Plants in the lower portion of the range (i.e., below 7-9 cms.) are probably not going to influence stand development to any great extent, and should have been removed by culling in the nursery.

In a study of the performance of White spruce planting stock in relation to planting stock height, Brace (1964) found that height growth was progressively greater with increasing height at planting and taller stock occurred more frequently in the larger classes in later years, though variability occurred in subsequent growth. Plants below 0.5 feet grew poorly. See Table 5.

Thus it may be concluded that height growth after planting is dependent on planting stock height; sturdiness and, of course, inherent vigour.

5.2.6 Sturdiness of Planting Stock

Many workers have carried out investigations on the effects of transplanting and undercutting on the sturdiness of planting stock. Work in Britain was initiated by Stevens (1928) and continued by Edwards and Holmes (1950); Pinchin (1950); Holmes and Faulkner (1954); Faulkner and Aldhous (1955; 1957; 1958).

Both processes check shoot growth and decrease the shoot/root ratio compared to untreated controls. Transplanting checks shoot growth and increases root growth to a slightly greater extent than undercutting (Faulkner and Aldhous, 1954; 1955). Survival and initial growth of transplanted and undercut stock is superior to untreated stock.

In the 1 + 1 and 2 + 1 transplant samples investigated in this study the height/diameter ratio and shoot/root ratio were decreased compared to the untreated 1 + 0 seedlings. The sturdiness of 1 + 1 trasplants was slightly superior, on average, to that of the 2 + 1 transplants. In addition the sturdiness decreased with height, and the proportion of root weight to shoot weight fall at the upper and lower extremes of the height range for both samples.

The effects of transplanting appear to vary over the range of vigour classes. Larger plants are affected in a proportionately greater extent. This can be seen by comparing the shoot extensions produced in the various vigour classes for 1 + 1 and 2 + 1 transplants. The upper vigour class of 1 + 1 transplants and the upper three vigour classes show proportionately greater shoot reductions compared to the remaining vigour classes. These findings support the suppositions made by Jones (1968).

Further study is required to confirm the variation in effect of transplanting on different portions of the height range.

If the proviso made by Edwards and Holmes (1950) that taller plants have little effect on survival or height growth unless increased height is accompanied by a proportional increase in diameter is accepted, then it could be postulated that taller 2 + 1 transplants should be sturdier than 1 + 1 transplants.

5.2.7 Suggested Modifications to Nursery Practice

If the sturdiness of planting stock is to be increased, then the introduction of an additional transplanting or undercutting operation into present nursery practice is required. At present transplanting is carried out in autumn and early spring (November/March) at the end of the first or second growing season, depending on whether 1 + 1 or 2 + 1 transplants are being produced. $1\frac{1}{2} - \frac{1}{2}$ or $1\frac{1}{2} - 1\frac{1}{2}$ planting stock may be produced by transplanting during the lull in growth in mid summer (July) in some nurseries. Undercutting during August of the first year or the following March/April has been found to give best results (Faulkner and Aldhous 1958).

It would probably be best to introduce an additional undercutting prior to the normal transplanting operation because of the expense of transplanting. This undercutting could be introduced during August of the first year, in the production of $\frac{1}{2}$ U $\frac{1}{2}$ + 1 transplants, or August of the first year or/and March of the second year, in the production of $\frac{1}{2}$ U$1\frac{1}{2}$ + 1 or $1\frac{1}{2}$ U $\frac{1}{2}$ + 1 transplants.

There is no reason why multiple undercutting could not be introduced in nurseries with more workable soils. For instance 1 U 1 undercut stock could be undercut in August of the first year and March/April of the second year to give ½ U ½ U 1 undercut stock . 2 U 1 undercut stock could be undercut as many times as required at August or March/April of each growing season in each consecutive year or however many times is required to give the necessary sturdiness, giving 1½ U ½ U 1 or ½ U ½ U 1 U 1 undercut stock. Initial undercutting should be early and at depths of 2-3 inches. Following cuts should be made at slightly increased depths. Undercutting prior to transplanting would produce uniformity of root lengths and improve the standard of the lining out operation. It would be worth while investigating the above proposals to see whether they produce more sturdy planting stock compared to present methods. In addition forest extension trials should be carried out on sites covering a wide range of altitudes and soil types, to test whether increased sturdiness gives more favourable establishment especially on exposed sites.

Transplanting and undercutting both have their particular advantages and disadvantages.

5.2.8 Transplanting

Transplanting has been found to check shoot growth to a greater extent and to give a greater increase in root weights, though it has the disadvantage of expense. In the present study it has been found to induce multiple leaders due to the tendency for larger plants to be planted deeper than seed bed level, burying the bases of the lower branchlets. These buried lower branchlets produce adventitious rootlets in their axials and grow to form secondary leaders which persist in competition with the main leader until after canopy closure. Not all over deeply planted seedlings are prone to this type of malformation. It appears more common amongst more heavily branched seedlings which lack apical dominance. These plants are more prone to subsequent malformation during establishment and subsequent growth, probably due to whipping.

If transplanting is not closely supervised transplants can develop a high incidence of crooked and clubbed root systems due to the bending and brunching of the root systems on lining out. The incidence of these types of root malformation was high in the 1 + 1 and 2 + 1 transplants investigated in this study.

Whether the incidence of these types of root malformation are as high in machine transplanting is not known, but should be investigated before large amounts of capital are invested in these machines.

Investigation into the effect of root malformation on establishment and wind firmness is required.

5.2.9 Undercutting

Undercutting has the advantage of being cheaper and does not interfere with the spatial arrangement of the root system in the soil, if the soil conditions are suitable. Whether it induces similar root malformation or the processes of root growth stimulation similar to transplanting is not known.

Undercutting has the disadvantage of being difficult in heavy soils, though equipment designed for use on these soils has been developed. At present one of the limitations to its more widespread use is the lack of really accurate drill or broadcast sowing equipment which will allow the accurate sowing of seed to get the best production of seedlings. In addition more land is usually required to produce the same number of plants.

5.2.10. Culling and Grading

An additional means of controlling the standard of planting stock is the use of culling and grading. Pinchin (1950) found that those plants classed as plantable survived and grew significantly better than those classed as culls in a series of investigations into nursery techniques. Plants classed as Grade 1 by Shipman (1960) grew appreciably better than Grade 2 planting stock on the site investigated. Similarly Brace (1964) showed that rate of growth and survival of planting stock under 0.5 feet was significantly poorer than those above 0.5 feet in height.

In the present study no plants with a planted height of less than 7-9 cms. appeared in the upper two vigour classes, in the 6-and 9-year old stands. Plants below 9-12 cms., depending on type of planting stock, were found to be unable to produce a mean height extension equalling planting height. Thus the first requirement for culling is a minimum height which must take into account depth of planting. In current practice a guide line has been laid down that Sitka spruce planting stock should have a minimum height of 6 inches (approximately 15 cms.) but this is not adhered to in practice. From the results of this study it is felt that planting stock should have a minimum height of 4-5 inches (i.e., 10 to 13 cms.) after planting and that any plants that do not meet this requirement should be rejected.

On the basis of the work by Edwards and Holmes (1950) (see Table 6), and the 1 + 1 and 2 + 1 transplant samples investigated it is felt that Sitka spruce planting stock should be upgraded to sturdiness class II in the Standards of Sturdiness for forest plants compiled by Aldhous (1967) (see Table 24). The minimum root collar diameters listed for the various height classes should be used with an overall minimum of 3 mms.

Table 24

MINIMUM ROOT COLLAR DIAMETERS (IN MILLIMETERS TO THE NEAREST HALF MILLIMETER) FOR TREE OF GIVEN HEIGHTS

Height		Sturdiness Class*			
Inches	(Cm)	I (60:1)	II (80:1)	III (100:1)	IV (120:1)
6	(15)	2.5	2.5	2.5	2.5
9	(23)	4.0	3.0	2.5	2.5
12	(30)	5.0	4.0	3.0	2.5
15	(38)	6.5	5.0	4.0	3.0
18	(45)	7.5	6.0	4.5	4.0
21	(53)	9.0	7.0	5.5	4.5
24	(60)	10.0	8.0	6.0	5.0

Reprinted from Aldhous (1967)

Class I: Scots pine; Corsican pine
Class II: Lodgepole pine; Norway spruce; Western red cedar
Class III: Larches; Douglas fir; Sitka spruce
Class IV: Western hemlock

*A plant falling between two height values given in Col. 1 of Table 22 should have the minimum root collar diameter of the higher value.

Jones (1968) reviewed quality criteria and discussed height/diameter ratio and shoot/root ratio of the various types of transplants in relation to untreated controls. Continued research is needed into the effects of nursery techniques on the development of planting stock in relation to untreated controls and the quality criteria adopted. From the experience gained with nursery stock in this study heights and diameters were found to be more easily measured than weights. In any further investigations it is suggested that the height range be divided into 4 quartiles to facilitate comparison between the various portions of the range.

5.2.10 Stand Form Potential

The present study gives a strong indication that malformation in the nursery is retained in the young stand after planting. Plants which develop malformation in the nursery are more prone to malformation during the establishment and subsequent growth phases.

At present the knowledge of the relationships between seedling morphology and adult growth habit are not well enough understood to carry out selection for a particular desired growth form prior to planting. Though from observations made during field work it appears that transplants with excessive branchlet development or malformation, due to lack of apical dominance are more prone to forking if they suffer leader damage particularly on exposed sites. Plants with strong apical dominance are less likely to form forks after leader damage. The relationship of seedling morphology to adult branching habit and the factors associated with the development of malformation require further study. Lammas growth which appears to be a contributing factor to leader damage should also be investigated. Plants with malformation or excessive branchlet development suggesting a lack of apical dominance should be eliminated during culling prior to planting in the forest.

5.3 Subsequent Growth

5.3.1 The establishment and subsequent Growth Phases

Planting has a similar effect on height growth in the first year after planting as transplanting and results in a distribution of height extension 1 which is skewed left. The skewness is gradually reduced over the establishment phase until at the stage when the stand passes into the subsequent growth phase, the height extension distribution approaches normal. At this stage plants may be considered to have become established. The length of the establishment phase is longer on more exposed sites due to the higher incidence of leader damage. Once the subsequent growth phase is reached height extension accelerates until "optimum growth" is attained. The distribution of height extension becomes increasingly skewed right as the optimum levels of growth are approached. The distribution of heights develops from skewed left in the first year after planting through approaching normal shortly after the stand enters the subsequent growth phase to skewed right at canopy closure.

Whether it is possible to attain the subsequent growth phase at an earlier age by the use of sturdier planting stock, as is suggested in the earlier section, can only be shown by further investigation. That planting effects height extension in a similar manner to transplanting could indicate that the planting stock has not been sufficiently prepared to meet the severe exposure found on the planting site.

5.3.2 Growth Studies

Very little work has been published on the subsequent growth stage of stand development.

Marion (1966) evolving a method of assessing the quality of young stands, measured the mean length of the leading shoots formed annually for the first 12 to 15 years of the stand's life. He found that the mean annual length in the first two years after planting was correlated with the mean annual length in the 3rd to 7th years after planting. In the present study height growth appeared considerably more variable.

Dividing the height growth into 3 year growth periods for the 6-and 9-year old stands the correlations between periods were very low tending to non-significance and negative, although they were slightly better for the 6-year old stand. Though correlations were between the various growth periods and total weight increment or total height were highly significant.

Further investigation is required into stand development over a wide range of sites. Stand development studies should be first carried out on low elevation sheltered sites on suitable soil types where the growth of the species is at its optimum. Once the growth patterns are understood on these sites studies should then be extended to embrace a range of altitudes and variety of problem soil types. It is difficult to ascertain the effects of exposure or difficult rooting conditions on growth patterns unless the growth patterns under normal conditions are understood, so as to form a basis of comparison. The methods used in the present study whereby the population of each sample is divided into four numerically equal vigour classes based on the height range is ideally suited for use in growth studies as it allows the four portions of the range to be followed independently.

5.3.3 Crown Development

Investigating branchlet development in relation to height and diameter 1' above the ground Miller (1965) found that yearly branchlet multiplication increased up to the stage when optimum growth was reached; and yearly branchlet additions increased up to canopy closure.

This present study was not particularly satisfactory as far as the determination of crown development was concerned. It showed that the numbers of branchlets increased with vigour class though the numbers of branchlets within each vigour class varied considerably. Branchlet numbers are not particularly meaningful in isolation from other crown parameters as they do not take the growth habit of the crown into account. Two trees of the same height may have widely varying growth habits but equal numbers of branchlets.

Whether any particular growth habit is related to vigour or development of dominance requires further study. Very likely the degree of exposure influences the growth habit best suited to the site. As the exposure increases growth habits less susceptible to malformation are advantageous as is shown by the 9-year old stand compared to the 6-year old stand. Influence of malformation on crown development requires further study.

The most satisfactory method of investigating crown development in a study of this nature would be to measure the average crown diameter and height of the widest diameter for all the stems in the plot. A count of the number of branches in the widest whorl or some index of foliage or branchlet density could also be included. Then selecting a number of sample trees for each vigour class an analysis of the foliage distribution and branching pattern similar to the study by Stiell (1966) should be carried out. Once the relationships of foliage weight for the various crown parameters measured are established, the foliage weights for each stem, vigour class and the whole stand could be calculated.

5.3.4 Development of Vigour

The components of the various vigour classes change with age. This can be seen from an analysis of the lower height parameters in the 3, 6-and 9-year old stands. The initial growth in the establishment period is strongly influenced by planting height. As the stand grows older total height growth becomes more dependent on the height growth produced after planting, until at age 6 and 9 trees over 7-9 cms. in planting height may appear in the upper two vigour classes. (i.e. With age an increasingly wider range of planting heights are found in the upper vigour classes.) This supports the contention of Righter (1945) that inherent vigour is distributed randomly throughout planting stock capable of becoming established satisfactorily. Also the conclusion reached by Pinchin (1950) that seed bed performance is not indicative of ultimate performance in the forest.

Miller (1965) in his investigation into branchlet development found that sample trees could be designated into three distinct but typical height growth patterns (a) fast starters - fast growers; (b) moderate starters - fast growers; (c) slow starters - slow growers. Matthews (1963) draws attention to the concept of developmental stages in European literature. If these height growth patterns are present in Sitka spruce this may help to explain some of the variation in height growth during the establishment and subsequent growth phases; and the range of planting heights included in the upper vigour classes at canopy closure in the 6-and 9-years old stands measured in this study. Further study into stand development is required to determine whether these height growth patterns (or developmental stages) exist for Sitka spruce.

5.3.5 Malformation

This study indicates that malformation developed in the nursery is retained during the establishment and subsequent growth phases. These stems appear more susceptible to subsequent malformation. Malformation plays a considerable part in the determination of vigour class, as leader damage and forking result in a considerable reduction in height extension in the following year. Leader damage probably contributes to the extended establishment phase in the more exposed 9-year old stand. It would appear that as a result of malformation the components of the upper vigour classes on more exposed sites are different from what they would be on a less exposed site. On less exposed sites trees liable to leader damage and malformation are able to retain their positions in the upper vigour classes as the occurrence of leader damage is less frequent. Thus defect is less important to growth on sheltered sites compared to exposed sites and trees with this defect may become dominant. Whereas on exposed sites they would be eliminated.

Leader loss appears to be associated with heavy branching which is a reflection of poor apical dominance. Investigation into the relationship between growth habit and malformation is required as it has a special bearing on seed source selection, tree breeding programmes, and culling in the nursery.

5.3.6 Development of Dominance

Dominance is not yet settled at canopy closure though the trees most likely to become dominant can be identified. The differentiation of the dominant trees in the period after canopy closure is not solely dependent on height, but depends on a tree's ability for continued vigorous height growth, to recover rapidly from leader damage with a single replacement leader, to retain a large healthy crown and strong stem and root growth. These trees should be selected as final crop trees during thinning operations.

5.4. Post Canopy Closure

5.4.1 General

From the high incidence of malformation observed on these exposed sites saw log production would appear to be optimistic due to the very high proportion of lower grades that would be produced. Unless the general form can be improved by tree breeding or improved planting stock, high and exposed areas, i.e. over 900 feet, should be restricted to pulp wood production. Urgent economic analysis into the feasibility of high elevation areas for saw log production is required so that suitable long term management of these areas can be developed.

5.4.2 Thinning

Thinning should be carried out in the next two or three years if the continued rate of diameter growth of the larger trees is to be maintained (Marsh, 1957). Already crown development of the upper vigour classes is starting to be restricted due to whipping. The volume of production which is proportional to crown size will decline for the larger trees unless the continued development of large crowns is encouraged by thinning. This would have to be a thinning to waste as neither the volume or the piece size would warrant a commercial thinning.

In the region of 60% of the stems should be removed as it is unlikely that these stems will contribute greatly to the volume of the stand or reach commercial sizes if thinning is delayed. This large reduction in stems numbers is justified by the fact that only limited number of trees, perhaps 40-100 can be expected in the upper dominance class or final crop (Warrack, 1952), (Enteld, 1960).

If thinning is carried out before the lower branches die movement through the stand is not too unpleasant. This would open up the stand and allow easier access and alleviate the need for brashing. Carrying out a thinning at this stage could enable an earlier commercial second thinning or the stands could be left with no further treatment till clear felling on a pulpwood rotation. The trees on these exposed sites have rotations which are restricted to be limited top height of perhaps 45-55 feet due to wind blow. Therefore it seems realistic to try and get as much volume as possible on the largest stems before clear felling or salvage is necessary. This proposed régime may not be feasible for deeper peats but should be investigated for shallow peaty soils.

5.4.3 Spacings

Wider spacings than are used at present, i.e. 7′x 7′ may be warranted on the less exposed sites where establishment and subsequent growth is more rapid.

The growth period from planting to canopy closure, is the most difficult, on these more exposed sites and the mutual shelter offered by neighbouring stems is probably an important factor in determining the time when the stand enters the subsequent growth phase. Closer spacings, i.e. 5′ x 5′, may be warranted in order to speed the attainment of canopy closure on these high exposed sites where establishment and subsequent growth is slow (Rothkirch 1968).

Investigation is required into the effects of spacing on stand development and the importance of mutual shelter and canopy closure in the subsequent growth phase of stands on exposed sites.

5.5 Review of Methods

5.5.1 General

Height and height extension measurements have high indication value. The analysis of the distributions of the parameters by order statistics dividing the range into quartiles enables the much more detailed interpretation of growth trends than the use of means and standard deviations. The division of the height range into quartiles or vigour classes and the analysis of the other parameters within these vigour classes allows the detailed comparisons between the various portions of the height range.

Although the methodology is sound in principle the modification of some of the techniques of measurement is required to remove some discrepancies.

5.5.2 Nursery Investigation

Height Measurements

The more accurate measurement of total height, is required to enable closer comparison between height and height extension measurements. In the present study total height was measured to the tips of the topmost needles whereas height extension was measured to the base of the corresponding bud scales, meaning that total heights contain an additional portion from the base of the terminal bud to the tips of the topmost needles. This system of measurement of total height should be retained as it can be used in nursery beds without fear of damaging the terminal bud but a correction factor should be subtracted to give true height increment.

Diameter

Due to the large variations found at the root collar as a result of malformation and variation of the depth of lining out diameter at the mid point of seedling height would give a less variable diameter estimate.

Weights

One of the disadvantages of this study was the large number of weights required for each nursery sample. These were very time consuming and very difficult to carry out accurately. Smaller replicated samples would be more manageable (i.e. 40) and would enable a greater standardization of techniques and consistency of application. Weights will increase during preparation and weighing whether these are done cool or still warm. Much of this error could be reduced by standardizing the time for preparation and weighing. Then by subtracting a correction factor based on the weight of the sample, time for preparation and weighing, and the humidity of the atmosphere, the true weight could be obtained.

Size of Sample

Although the size of the total samples must remain large (i.e. 100-200) due to the often very skewed nature of many of the growth parameter distributions, procedure could be streamlined and statistical analysis improved by measuring a number of smaller replicated samples (i.e. 2 x 80 or 4 x 40).

5.5.3 Field Work

An assistant to do the recording and help set out the plot would greatly improve the rate of data collection in the field.

Height Measurements

These measurements should be carried out as before though the addition of a correction factor is probably not necessary as this degree of accuracy would be difficult to attain especially in older stands.

Diameter Measurements

Diameter at the mid point of height extension 1 was found to be the most meaningful diameter measurement in young stands up to canopy closure, though in the older ages some basal swelling may occur.

Crown Development

The general crown parameters of, average diameter, height to the widest diameter and perhaps some index of crown growth habit should be taken, i.e. number of branches on the widest whorl, foliage density or numbers of branchlets on a certain whorl.

These parameters should be related to a detailed analysis of foliage weights for a number of sample trees for each vigour class, followed by the calculation of foliage weights per stem, vigour class and stand as a whole.

Sample Size

The size of the plot could be reduced to a 1/20 or 1/40 of an acre provided a number of replications were taken. The total numbers sampled should be of the same order as recommended for nursery samples (i.e. 100-200).

6. CONCLUSION

The distribution of heights, height extensions and diameters of undisturbed seedlings approaches normality. Transplanting checks shoot growth and results in distributions of height extension and height which are skewed to the left or the right of the mean. The checking effect is proportionately greater for larger plants. The height/diameter ratio showed that the sturdiness decreased with increasing height of plants. The shoot/root ratio shows that the proportion of root weight to shoot weight was lower for the upper and lower extremes of the range. 1 + 1 transplants were found to be slightly more sturdy on average than 2 + 1 transplants, though in both cases sturdiness greatly increased compared to 1 + 0 seedlings.

Transplanting results in an increased variation, in diameter and total weight in relation to height. Height extensions are extremely variable and bear little relationship to the height prior to lining out. Secondary leaders may be induced by burying the lower branchlets below soil level during lining out.

The pre-canopy closure development of stands may be divided into the establishment phase and the subsequent growth phase. Planting results in a distribution of height extension with a high proportion of values in the lower range (i.e. skewed left). The skewness of height extension is reduced over the establishment phase until it approaches normality at the time when the stand passes into the subsequent or accelerated growth phase. The increase in mean height extension over the establishment period is very slight. The length of the establishment phase increases with exposure, due to leader damage. Mutual shelter probably contributes to the onset of accelerated growth on exposed sites. Over the subsequent growth phase height growth accelerates until optimum height growth is reached.

The components of the upper vigour classes start accelerated growth and reach optimum growth before the lower vigour classes. The distribution of heights and height extensions becomes increasingly skewed to the right as canopy closure is approached. At the beginning of the subsequent growth period the differences in height of the upper classes are small but as height growth accelerates the superiority of the upper classes is increased, though the composition of this class is not stable. With increasing age the range of planting heights in the upper vigour classes increases. Total height shows greater dependence on the height growth after planting than planting height at canopy closure.

Malformation developed in the nursery is retained in the young stands up to canopy closure. A reduction in height growth results from leader damage. It appears that the proneness to leader damage and forking has a strong influence on the composition of the upper vigour class, and results in different components being represented in this class on exposed sites compared to non-exposed sites. Trees susceptible to leader damage may be retained in the upper vigour class on a sheltered site due to less frequent leader damage, whereas on exposed sites these trees would be eliminated.

Thus a position in the upper vigour class is determined by rapid establishment, vigorous subsequent growth, and the ability to recover from leader loss and lower susceptibility to leader loss

The dominant trees will differentiate from trees of the upper two vigour classes.

They will be trees with the following attributes: capacity for continued vigorous height growth, ability to recover from the leader loss with a single replacement leader, retention of a large healthy crown and strong diameter and root growth.

Height measurements were found to have very high indicative value. The analysis of the parameter distributions by order statistics enables the natures of distributions to be compared. The sorting of parameters in vigour classes or quartiles based on the total height measurements enables the growth trends within the various portions of the height range to be followed independently. When the vigour class values are compared with the values for the parameters sorted independently, the extent of variation within each vigour class can be determined.

The following recommendations arise from this work.

(a) Culling in the nursery should eliminate all planting stock that shows a tendency to malformation. Also plants which have root collar diameters below 3 mm., or heights which are insufficient to give 4-5 inches of exposed top after planting should be eliminated.

(b) Investigation into the techniques for producing more sturdy planting stock should be coupled with forest extension studies to determine whether increased sturdiness improves establishment and subsequent growth on exposed sites.

(c) Further study is required into stand development in relation to growth pattern, development of dominance and effect of malformation. The influence of spacing and mutual shelter on canopy closure and subsequent growth should be investigated for exposed sites. Use of height based on vigour classes is recommended.

(d) Economic analysis of the feasibility of saw log production on sites over 900 feet altitude is required.

(e) The possibility of thinnings to waste in the first 2 - 3 years after canopy closure to retain rapid crown development and volume growth in order to reduce rotations for pulp production should be investigated.

7. APPENDIX I

Tables 10 and 11

Table 10: Distributions of growth Parameters measured for 1 + 0 seedlings

Variable Name	Minimum	Quartile 4 Submean	25 Percent. Quartile	Quartile 3 Submean	Median	Quartile 2 Submean	75 Percent. Quartile	Quartile 1 Submean	Maximum	Mean	Standard Deviation	Type of Distribution
Total Height cms.	4.50	6.95	7.90	8.54	9.10	9.67	10.40	11.58	13.00	9.18	1.79	Approaching normal
Root Collar Diameter mms.	0.80	1.08	1.20	1.33	1.40	1.48	1.60	1.76	2.00	1.41	0.26	Approaching normal
Height/Diameter Ratio	4.28	5.26	5.73	6.15	6.46	6.87	7.20	7.97	9.23	6.56	1.05	Approaching normal
Total Shoot Weight grms.	0.03	0.17	0.22	0.26	0.31	0.36	0.41	0.51	0.87	0.32	0.14	Very skewed left
Root Weight grms.	0.02	0.05	0.07	0.08	0.10	0.12	0.14	0.19	0.34	0.11	0.06	Very skewed left
Shoot/Root Ratio	1.38	2.07	2.44	2.68	2.90	3.30	3.77	4.95	8.50	3.25	1.22	Very skewed left
Total Weight grms.	0.11	0.23	0.29	0.35	0.40	0.47	0.55	0.70	1.21	0.44	0.19	Very skewed left
Number of growing points	1.00	2.32	3.00	3.42	4.00	4.18	5.00	5.57	8.00	3.87	1.33	Approaching normal

Table 11: The Means of the Growth Parameters measured by Vigour Classes for 1 + 0 seedlings

Variable Name	Minimum	Vigour Class 4 Submean	25 Percent. Quartile	Vigour Class 3 Submean	Median	Vigour Class 2 Submean	75 Percent. Quartile	Vigour Class 1 Submean	Maximum	Mean
Total Height	4.50	6.95	7.90	8.54	9.10	9.67	10.40	11.55	13.00	9.18
Root Collar Diameter mms.		1.19		1.36		1.49		1.61		1.41
Height/Diameter Ratio		5.94		6.41		6.62		7.28		6.56
Total Shoot Weight grms.		0.21		0.27		0.36		0.45		0.32
Root Weight grms.		0.07		0.10		0.12		0.15		0.11
Shoot/Root Ratio		3.31		2.98		3.36		3.34		3.25
Total Weight grms.		0.28		0.37		0.49		0.60		0.44
Number of growing points		3.24		3.50		3.92		4.79		3.87
% Double leaders		5.30		2.70		2.70		-		
% Multiple leaders		-		2.70		-		-		

Total Samples Tested = 150

Tables 12 and 13

Table 12: Distribution of Growth Parameters Measured for 1 + 1 Seedlings

Variable Name	Minimum	Quartile 4 Submean	25 Percent. Quartile	Quartile 3 Submean	Median	Quartile 2 Submean	75 Percent. Quartile	Quartile 1 Submean	Maximum	Mean	Standard Deviation	Type of Distribution
Total Height cms.	14.30	18.16	20.20	22.44	24.30	25.78	27.50	32.10	37.70	24.63	5.35	Approaching normal
Current Shoot Extension cms.	2.50	6.24	8.90	11.01	13.00	14.24	15.60	18.27	25.30	12.47	4.67	Skewed right
Seedling Heights cms.	5.10	7.66	9.90	10.80	11.80	13.04	14.40	17.06	23.70	12.16	3.65	Skewed left
Root Collar diameter mms.	2.70	3.62	4.10	4.42	4.80	5.24	5.80	7.03	9.20	5.08	1.34	Skewed left
Height/Diameter Ratio	2.03	3.65	4.16	4.63	5.04	5.32	5.67	5.41	7.69	5.01	1.08	Very skewed left
Total Shoot Weight grms.	0.78	1.69	2.28	2.97	3.55	4.55	5.49	8.94	18.33	4.53	3.14	Very skewed left
Root Weight grms.	0.45	0.72	0.95	1.31	1.62	1.92	2.40	3.90	7.43	1.96	1.33	Very skewed left
Shoot/Root Ratio	0.87	1.58	1.96	2.14	2.35	2.57	2.75	3.60	8.55	2.48	0.99	Skewed left
Total Weight grms.	0.23	2.51	3.43	4.26	5.02	6.41	7.72	12.52	25.67	6.42	4.27	Very skewed left
Number of branchlets	4.00	7.71	10.00	12.29	15.00	17.72	22.00	30.59	69.00	17.08	9.77	Very skewed left

Table 13: The means of the Growth Parameters Measured by Vigour Class for 1 + 1 Transplants

Variable Name	Minimum	Vigour Class 4 Submean	25 Percent. Quartile	Vigour Class 3 Submean	Median	Vigour Class 2 Submean	75 Percent. Quartile	Vigour Class 1 Submean	Maximum	Mean
Total Height cms.	14.30	18.16	20.20	22.44	24.30	25.78	27.50	31.96	37.70	24.64
Current Shoot Extension cms.		7.77		11.41		13.64		16.91		12.47
Seedling Height cms.		10.38		11.03		12.05		15.08		12.16
Root Collar Diameter mms.		4.19		4.76		5.22		6.12		5.08
Height/Diameter Ratio		4.50		4.96		5.09		5.46		5.01
Root Weight grms.		1.24		1.61		2.00		2.98		1.96
Shoot/Root Ratio		2.19		2.33		2.68		2.67		2.48
Total Weight grms.		3.55		5.25		6.82		9.97		6.42
Number of branchlets		13.65		15.62		16.13		22.67		17.08
% Double leaders		9.30		3.10		21.70		6.20		
% Multiple leaders		-		3.10		3.10		-		
% Leader losses		3.10		3.10		3.10				

Total Samples Tested = 129

Tables 14 and 15

Table 14: Distributions of Growth Parameters Measured for 2 + 1 Seedlings

Variable Name	Minimum	Quartile 4 Submean	25 Percent. Quartile	Quartile 3 Submean	Median	Quartile 2 Submean	75 Percent. Quartile	Quartile 1 Submean	Maximum	Mean	Standard Deviation	Type of Distribution
Total Height cms.	19.20	22.18	24.00	25.68	27.50	29.52	32.00	36.34	46.10	28.44	5.64	Skewed left
Current Shoot Extension "	0.90	7.94	9.90	11.26	12.10	13.25	14.70	17.25	22.00	12.44	3.60	Skewed left
Previous Shoot Height "	4.80	10.90	12.70	14.31	15.50	17.09	18.80	21.35	27.70	15.93	4.12	Skewed left
Previous Shoot Extension "	3.00	6.52	8.00	9.26	10.80	12.32	13.60	15.60	19.10	10.93	3.57	Approaching normal
Seedling Height cms.	1.80	2.98	3.90	4.39	5.00	5.55	6.20	7.32	10.20	5.07	1.68	Approaching normal
Root Collar Diameter mms.	3.00	4.00	4.50	4.88	5.20	5.73	6.20	6.92	9.20	5.39	1.14	Skewed left
Height/Diameter Ratio	3.40	4.27	4.78	5.03	5.31	5.59	5.90	6.60	8.00	5.38	0.91	Approaching normal
Total Shoot Weight grms.	1.97	3.24	4.47	5.39	6.56	7.87	9.30	12.99	21.69	7.37	3.96	Skewed left
Root Weight grms.	0.70	1.07	1.36	1.76	2.16	2.68	3.22	4.39	10.11	2.48	1.43	Very skewed left
Shoot/Root Ratio	1.10	2.17	2.57	2.82	3.05	3.26	3.50	4.31	8.44	3.14	0.95	Approaching normal
Total Weight grms.	2.70	4.41	5.92	7.15	8.59	10.53	12.67	17.13	31.80	9.83	5.26	Very skewed left
Number of Branchlets	6.00	13.32	19.00	22.97	28.00	32.97	38.00	49.22	81.00	29.64	14.25	Very skewed left

Table 15: The Means of the Growth Parameters Measured by Vigour Classes for 2 + 1 Transplants

Variable Name	Minimum	Vigour Class 4 Submean	25 Percent. Quartile	Vigour Class 3 Submean	Median	Vigour Class 2 Submean	75 Percent. Quartile	Vigour Class 1 Submean	Maximum	Mean
Total Height cms.	19.20	22.18	24.00	25.68	27.50	29.52	32.00	36.21	46.10	28.44
Current Shoot Extension "		9.92		11.23		12.11		16.39		12.44
Previous Shoot Length "		12.19		14.45		17.11		19.92		15.93
Previous Shoot Extension "		8.02		9.58		12.01		14.06		10.93
Seedling Height cms.		4.17		4.86		5.39		5.85		5.07
Root Collar Diameter mms.		4.47		4.94		5.64		6.48		5.39
Height/Diameter Ratio		5.11		5.35		5.35		5.67		5.38
Total Shoot Weight grms.		4.28		5.76		8.18		11.23		7.37
Root Weight grms.		1.51		1.99		2.72		3.58		2.45
Shoot/Root Ratio		3.08		2.77		3.22		3.40		3.11
Total Weight grms.		5.79		7.48		10.85		14.80		9.74
Number of Branchlets		21.94		24.00		34.53		38.27		29.64
% Double leaders		3.10		-		9.30		3.10		
% Multiple leaders		21.70		12.40		6.20		-		

Total Samples Tested = 129

Tables 16 and 17

Table 16: Distributions of Growth Parameters Measured for Young Stands 1 Year After Planting

Variable Name	Minimum	Quartile 4 Submean	25 Percent. Quartile	Quartile 3 Submean	Median	Quartile 2 Submean	75 Percent. Quartile	Quartile 1 Submean	Maximum	Mean	Standard Deviation	Type of Distribution
Total Height cms.	7.50	11.75	14.00	15.40	16.50	17.90	20.00	23.39	28.00	17.10	4.47	Skewed left
Height Extension 1 cms.	0.00	3.58	5.50	6.02	6.50	8.21	9.50	13.15	21.00	7.74	3.84	Skewed left
Planting Height cms.	3.00	4.72	6.50	7.82	8.50	10.13	12.00	14.76	21.00	9.37	3.88	Skewed left
New Total Height cms.	7.00	10.00	12.00	13.36	14.50	15.52	16.50	20.32	26.00	14.82	4.02	Approaching normal
Leader Loss cms.	0.00	0.00	0.00	0.27	2.00	2.74	3.50	6.29	17.00	2.31	2.89	Slightly skewed right
Diameter mid point Extension 1 mms.	1.50	2.01	2.30	2.60	2.80	3.07	3.20	3.58	4.30	2.82	0.60	Approaching normal
Height/Diameter Extension 1 Ratio	22.20								117.50	62.22	16.98	Approaching normal
Total Branchlets	4.00								69.00	18.36	11.78	

Table 17: The Means of the growth Parameters Measured by Vigour Classes for Young Stands 1 Year After Planting

Variable Name	Minimum	Vigour Class 4 Submean	25 Percent. Quartile	Vigour Class 3 Submean	Median	Vigour Class 2 Submean	75 Percent. Quartile	Vigour Class 1 Submean	Maximum	Mean
Total Height cms.	7.50	11.75	14.00	15.30	16.50	17.90	20.00	23.28	28.00	17.10
Height Extension 1 cms.		5.30		7.12		7.21		11.28		7.74
Planting Height cms.		6.45		8.29		10.63		12.00		9.37
New Total Height cms.		11.08		13.62		15.65		18.72		14.82
Leader Loss cms.		0.83		1.68		2.21		4.56		2.31
Diameter mid point Extension 1 mms.		2.50		2.66		2.96		3.15		2.82
Height/Diameter Extension 1 Ratio		49.22		60.40		62.68		75.90		62.22
Total Branchlets		12.80		15.97		20.23		24.91		18.36
% Double leaders		54.40		73.60		54.40		51.20		
% Multiple leaders		48.00		67.20		41.60		32.00		
% Leader losses		67.20		96.00		76.80		92.80		

Total Samples Tested = 125

Tables 18 and 19

Table 18: Distributions of Growth Parameters Measured for Young Stands 3 years After Planting

Variable Name	Minimum	Quartile 4 Submean	25 Percent. Quartile	Quartile 3 Submean	Median	Quartile 2 Submean	75 Percent. Quartile	Quartile 1 Submean	Maximum	Mean	Standard Deviation	Type of Distribution
Total Height	26.50	41.59	49.00	54.72	59.50	67.34	72.50	88.12	117.50	63.00	18.39	Skewed left
Height Extension 3	4.50	10.19	13.50	16.05	19.00	21.54	24.00	31.17	56.00	19.76	8.53	Skewed left
Height 2nd Year	17.50	27.43	34.50	38.55	43.00	47.47	51.50	60.45	82.50	43.52	12.97	Skewed left
Height Extension 2	2.50	8.00	11.50	14.14	16.50	19.07	22.00	27.37	38.50	17.17	7.61	Approaching normal
Height 1st Year	10.00	16.39	20.00	22.76	26.00	28.78	31.50	37.57	57.00	26.40	8.44	Skewed left
Height Extension 1	0.00	6.77	10.00	12.10	13.50	16.11	19.00	22.37	36.00	14.36	6.16	Skewed left
Planting Height	3.50	7.07	9.00	9.77	11.00	13.07	15.50	19.51	31.00	12.37	5.09	Skewed left
Diameter mid point Extension 1	4.10	6.15	7.60	8.34	9.00	10.09	11.00	13.25	19.10	9.47	2.80	Slightly skewed left
Height/Diameter Extension 1 Ratio	46.40	55.44	60.50	63.79	66.90	10.05	72.80	79.91	96.20	67.33	9.62	Approaching normal
Total Branchlets	9.00								315.00	66.89	46.75	

Table 19: The Means of the Growth Parameters Measured by Vigour Classes for Young Stands 3 Years After Planting

Variable Name	Minimum	Vigour Class 4 Submean	25 Percent. Quartile	Vigour Class 3 Submean	Median	Vigour Class 2 Submean	75 Percent. Quartile	Vigour Class 1 Submean	Maximum	Mean
Total Height	26.50	41.59	49.00	54.72	59.50	67.54	72.50	87.72	117.50	63.00
Height Extension 3		13.09		16.10		20.55		28.67		19.76
Height 2nd Year		28.77		38.50		47.54		59.31		43.52
Height Extension 2		10.41		15.13		18.47		24.77		17.17
Height 1st Year		18.31		23.59		29.27		34.37		26.40
Height Extension 1		9.97		13.29		16.03		18.10		14.36
Planting Height		8.92		10.29		13.32		16.91		12.37
Diameter mid point Extension 1		6.61		8.33		10.05		12.81		9.47
Height/Diameter Extension 1 Ratio		64.76		66.98		68.24		69.24		67.33
Total Branchlets		39.02		50.56		69.35		108.54		66.89
% Double leaders		53.00		53.00		45.00		31.80		
% Muliple leaders		31.80		21.20		26.50		10.60		
% Leader losses		132.50		76.80		45.00		63.60		

Total Samples Tested = 151

Table 20

Table 20 : Distribution of Growth Parameter Measured for Young Stands 6 years After Planting

Variable Name	Minimum	Quartile 4 Submean	25 Percent. Quartile	Quartile 3 Submean	Median	Quartile 2 Submean	75 Percent. Quartile	Quartile 1 Submean	Maximum	Mean	Standard Deviation	Type of Distribution
Total Height	59.00	148.92	179.00	186.95	195.00	206.89	219.00	239.51	323.00	195.59	36.84	Slightly skewed left
Height Extension 6	9.00	25.51	35.00	39.55	44.00	48.58	55.00	63.25	77.00	44.47	14.67	Slightly skewed left
Height 5th Year	48.00	112.38	133.00	143.24	153.50	161.08	168.00	185.89	255.00	150.88	30.06	Skewed right
Height Extension 5	7.00	23.81	33.00	38.18	42.00	46.45	51.00	56.84	84.00	41.33	13.06	Approaching normal
Height 4th Year	12.00	75.16	91.00	102.00	112.00	118.53	125.00	139.62	183.00	108.85	26.04	Skewed right
Height Extension 4	0.00	19.68	29.00	31.89	35.00	38.57	43.00	49.54	63.00	34.92	11.65	Approaching normal
Height 3rd Year	19.00	51.59	63.00	68.45	74.00	78.77	86.00	98.76	131.00	74.38	18.79	Approaching normal
Height Extension 3	2.00	11.22	16.00	18.29	21.00	24.66	28.00	33.11	42.00	21.81	8.58	Slightly skewed left
Height 2nd Year	14.00	35.03	43.00	47.37	52.00	56.45	61.00	71.84	97.00	52.66	14.56	Approaching normal
Height Extension 2	0.00	9.30	14.00	16.95	20.50	23.24	26.00	33.62	54.00	20.77	9.71	Slightly skewed left
Height 1st Year	5.00	20.43	26.00	28.50	32.00	34.71	38.00	46.00	62.00	32.40	10.13	Slightly skewed left
Height Extension 1	0.00	7.54	11.00	13.45	16.00	18.97	22.00	28.59	43.00	17.13	8.30	Skewed left
Planting Height	5.00	9.43	11.00	13.55	15.00	16.50	19.00	22.00	32.00	15.37	4.87	Skewed left
Diameter Mid Point Extension 1	13.00	31.69	36.00	38.82	42.00	44.21	47.00	53.32	76.00	42.00	8.89	Approaching normal
No. of Branchlets 2nd Whorl from Top	13.00	37.14	49.00	55.82	63.00	72.89	82.00	95.49	131.00	65.32	22.73	Very skewed left
~~Height Increment 1st 3 years~~	~~9.00~~	~~38.38~~	~~48.00~~	~~53.50~~	~~58.50~~	~~63.66~~	~~70.00~~	~~81.35~~	~~109.00~~	~~59.24~~	~~16.94~~	~~Skewed left~~
Height/Diameter Extension 1	24.20	37.49	42.50	44.24	47.15	49.62	52.60	58.05	75.20	47.34	8.22	Approaching normal

Total Samples Tested = 150

Table 21

Table 21: The Means of the Growth Parameters Measured by Vigour Classes for Young Stands 6 Years After Planting

Variable Name	Minimum	Vigour Class 4 Submean	25 Percent. Quartile	Vigour Class 3 Submean	Median	Vigour Class 2 Submean	75 Percent. Quartile	Vigour Class 1 Submean	Maximum	Mean
Total Height cms.	59.00	148.92	179.00	186.98	195.00	206.89	219.00	238.97	323.00	195.59
Height Extension 6 cms.		34.11		40.97		45.18		57.45		44.47
Height 5th Year cms.		114.81		145.97		160.79		181.58		150.88
Height Extension 5 cms.		32.51		39.34		42.45		51.08		41.33
Height 4th Year cms.		79.35		106.63		118.18		130.71		108.85
Height Extension 4cms.		24.14		35.03		36.45		44.05		34.92
Height 3rd Year cms.		56.78		71.88		81.74		86.66		74.38
Height Extension 3 cms.		16.46		20.55		23.26		26.63		21.81
Height 2nd Year cms.		40.59		51.29		58.47		60.16		52.66
Height Extnnsion 2 cms.		15.24		18.29		24.63		24.74		20.77
Height 1st Year cms.		25.49		33.52		35.66		35.16		32.40
Height Extension 1 cms.		13.14		18.50		17.87		19.18		17.13
Planting Height cms.		12.49		15.08		17.26		16.47		15.37
Diameter Mid Point Extension 1 mm.		35.14		40.34		44.53		47.92		42.00
No. of Branchlets 2nd Whorl from Top		51.08		64.00		68.21		77.47		65.32
Height/Diameter Mid Point Extension 1		43.08		47.79		47.79		50.61		47.34
% Forked Stems		104.00		93.30		66.70		69.30		
% Malformed at Planting		21.30		16.00		16.00		21.30		
% Leader losses		122.30		88.00		90.70		48.00		

Sotal Samples Tested = 150

Table 22

Table 22 : Distributions of Growth Parameters Measured for Young Stands 9 years After Planting

Variable Name	Minimum	Quartile 4 Submean	25 Percent. Quartile	Quartile 3 Submean	Median	Quartile 2 Submean	75 Per cent. Quartile	Quartile 1 Submean	Maximum	Mean	Standard Deviation	Type of Distribution
Total Height	192.00	266.00	297.00	310.59	327.00	341.84	357.00	378.39	412.00	324.24	43.65	Skewed right
Height Extension 9	10.00	39.65	63.00	68.91	75.00	80.44	87.00	96.81	116.00	71.50	22.53	Very skewed right
Height 8th Year	147.00	205.48	226.00	237.94	250.00	262.53	275.00	296.68	348.00	250.65	35.44	Approaching normal
Height Extension 8	12.00	27.55	36.00	42.16	48.00	53.75	61.00	73.10	160.00	49.12	19.02	Skewed right
Height 7th Year	90.00	157.55	180.00	189.72	201.50	214.25	225.00	246.84	282.00	202.09	34.87	Very skewed right
Height Extension 7	0.00	21.32	31.00	36.12	42.00	46.97	51.00	60.94	86.00	41.34	15.66	Slightly skewed left
Height 6th Year	92.00	124.29	141.00	150.19	160.00	172.62	185.00	204.68	243.00	162.92	31.44	Skewed left
Height Extension 6	0.00	19.32	25.00	28.03	31.50	36.88	42.00	51.10	72.00	38.81	12.57	Skewed left
Height 5th Year	70.00	96.32	108.00	119.91	130.50	139.44	149.00	164.03	216.00	129.92	27.17	Skewed right
Height Extension 5	0.00	12.58	17.00	21.66	26.00	29.63	34.00	43.52	64.00	26.83	12.23	Slightly skewed left
Height 4th Year	54.00	75.03	85.00	92.72	100.00	109.09	116.00	132.29	170.00	102.26	22.29	Slightly skewed left
Height Extension 4	4.00	13.68	18.00	21.34	26.00	29.34	34.00	40.81	51.00	26.28	10.48	Approaching normal
Height 3rd Year	39.00	52.19	60.00	67.53	74.50	62.16	89.00	101.81	123.00	75.90	19.40	Slightly skewed left
Height Extension 3	3.00	12.32	17.00	19.78	22.00	25.88	29.00	37.16	56.00	23.77	9.75	Skewed left
Height 2nd Year	20.00	33.19	41.00	46.34	51.00	56.63	61.00	73.00	94.00	52.28	15.42	Approaching normal
Height Extension 2	4.00	9.58	13.00	15.53	18.00	21.19	25.00	35.65	100.00	20.45	12.17	Skewed left
Height 1st Year	13.00	19.42	24.00	27.69	31.00	35.56	40.00	47.52	68.00	32.53	10.91	Very skewed left
Height Extension 1	4.00	7.81	11.00	13.28	16.00	18.81	24.00	29.32	41.00	17.29	8.42	Very skewed left
Planting Height	5.00	9.55	12.00	13.72	15.00	16.72	18.00	21.68	33.00	15.41	4.86	Skewed left
Diameter Mid Point Extension 1	48.00	65.06	80.00	85.16	90.00	95.50	101.00	112.74	141.00	89.63	18.48	Slightly skewed left
No. of sides Canopy Closure	0.00	0.61	2.00	2.00	2.00	2.94	3.00	3.45	4.00	2.25	1.13	
Height Canopy Closure	0.00	50.32	100.00	105.63	115.00	19.22	125.00	134.35	160.00	102.54	37.75	
Height/Diameter 1st Extension	23.40	29.31	31.90	34.05	35.95	38.30	40.80	47.97	59.20	37.39	7.45	Approaching normal

Total Samples Tested = 124

Table 23

Table 23 : The Means of the Growth Parameters measured by Vigour Class for Young Stands 9 Years After Planting

Variable Name	Minimum	Vigour Class 4 Submean	25 Percent. Quartile	Vigour Class 3 Submean	Median	Vigour Class 2 Submean	75 Percent. Quartile	Vigour Class 1 Submean	Maximum	Mean
Total Height	192.00	266.00	297.00	310.59	327.00	341.84	357.00	377.72	412.00	324.24
Height Extension 9		53.19		70.31		79.31		83.16		71.50
Height 8th Year		210.23		240.59		162.59		288.41		250.65
Height Extension 8		47.52		44.91		47.50		56.50		49.12
Height 7th Year		167.68		195.69		212.47		231.91		202.09
Height Extension 7		37.52		40.03		42.66		45.53		41.34
Height 6th Year		135.00		155.34		174.00		186.37		162.92
Height Extension 6		28.94		32.34		34.84		38.44		33.81
Height 5th Year		106.39		126.12		138.78		148.06		129.92
Height Extension 5		19.52		25.19		28.34		33.72		26.83
Height 4th Year		86.52		97.81		110.75		114.22		102.26
Height Extension 4		21.81		26.47		27.97		29.06		26.28
Height 3rd Year		64.90		70.84		82.78		85.16		75.90
Height Extension 3		19.48		24.34		23.56		27.72		23.77
Height 2nd Year		45.48		46.38		59.22		58.06		52.28
Height Extension 2		16.26		19.34		24.38		21.84		20.45
Height 1st Year		29.16		29.84		34.84		36.25		32.53
Height Extension 1		15.13		15.22		18.22		20.47		17.29
Planting Height		14.03		14.62		16.78		16.28		15.41
Diameter Mid Point Extension 1		83.19		83.19		97.50		101.37		89.63
No. of sides Canopy Closure		1.61		2.31		2.72		2.37		2.25
Height Canopy Closure		84.68		101.87		112.03		111.88		102.54
Height/Diameter 1st Extension		36.11		39.01		36.01		38.21		37.39
% Forked Stems		193.70		196.80		184.10		123.80		
% Malformed at Planting		19.00		25.40		22.20		3.20		
% Leader Losses		63.50		60.30		66.70		60.30		

Total Samples Tested = 126

8. APPENDIX II

Table 25: Correlation matrix of Measurements for 1 + 0 Seedlings

Total Height	Root Collar Diameter	Height/Diameter Ratio	Total Shoot Weight	Root Weight	Shoot/Root Ratio	Total Weight	No. of Branchlets
0.627							
0.490	-0.356						
0.667	0.818	-0.106					
0.478	0.759	-0.261	0.826				
0.079	-0.145	0.252	-0.019	-0.484			
0.639	0.841	-0.164	0.979	0.914	-0.164		
0.451	0.607	-0.143	0.714	0.593	-0.026	0.706	

Table 26

Regression Equations and Correlations Coefficients between Selected Growth Parameters measured for 1 + 0 Seedlings

Parameters	Regression Equations	Correlation Coefficients
	$Y = a + b\ X$	
Total Height (Y)	$Y = 3.0744 + (4.3229)X$	0.6271 ***
Root Collar Diameter (X)		
Total Height (Y)	$Y = 6.5541 + (6.0181)\ X$	0.6886 ***
Total Weight (X)		
Root Collar Diameter Squared (Y)	$Y = 0.6225 + (3.2959)\ X$	0.6099 ***
Total Weight (X)		

Table 27: Correlation matrix of Measurements for 1 + 1 Transplants

Total Height	Current Shoot Extension	Seedling Height	Root/Collar Diameter	Height/Diameter Ratio	Total Shoot Weight	Root Weight	Total Weight	No. of Branchlets
0.743								
0.521	-0.181							
0.601	0.142	0.710						
0.271	0.534	-0.299	-0.550					
0.655	0.284	0.599	0.844	-0.310				
0.558	0.085	0.709	0.871	-0.430	0.860			
0.637	0.228	0.643	0.874	-0.358	0.985	0.917		
0.415	-0.047	0.671	0.817	-0.492	0.830	0.862	0.845	

Table 28

Regression Relationships and Correlation Coefficients between Selected Growth Parameters measured for 1 + 1 Transplants

Parameters	Regression Equations	Correlation Coefficients
	$Y = a + b\ X$	
Total Height (Y) Current Shoot Extension (X)	$Y = 14.018 + (0.85174)\ X$	0.7428 ***
Total Height (Y) Seedling Height (X)	$Y = 15.352 + (0.76364)\ X$	0.5206 ***
Total Height (Y) Root Collar Diameter (X)	$Y = 12.478 + (2.3946)\ X$	0.6011 ***
Total Height (Y) Total Weight (X)	$Y = 19.512 + (0.79782)\ X$	0.6369 ***
Root Collar Diameter Squared (Y) Total Weight (X)	$Y = 7.1215 + (3.1648)\ X$	0.8779 ***

Table 29: Correlation matrix of Measurements for 2 + 1 Transplants

Total Height	Current Shoot Extension	Previous Shoot Height	Previous Shoot Extension	Seedling Height	Root Collar Diameter	Height/Diameter Ratio	Total Shoot Weight	Root Weight	Total Weight	No. of Branchlets
0.697										
0.764	0.096									
0.696	0.065	0.896								
0.425	0.097	0.488	0.106							
0.669	0.373	0.580	0.459	0.487						
0.309	0.343	0.140	0.216	-0.134	-0.454					
0.678	0.328	0.636	0.538	0.456	0.852	-0.256				
0.539	0.252	0.509	0.471	0.282	0.818	-0.347	0.852	[illegible]		
0.656	0.317	0.615	0.540	0.400	0.856	-0.282	0.982	0.912		
0.429	0.090	0.468	0.396	0.416	0.724	-0.429	0.791	0.709	0.784	

Table 30

Regression Equations and Correlation Coefficients between Selected Growth Parameters measured for 2 + 1 Transplants

Parameters	Regression Equations	Correlation Coefficients
	Y = a + b X	
Total Height (Y) Current Shoot Extension (X)	Y = 14.860 + (1.0915) X	0.6971 ***
Total Height (Y) Previous Shoot Length (X)	Y = 11.758 + (1.0470) X	0.7641 ***
Total Height (Y) Root Collar Diameter (X)	Y = 10.605 + (3.3111) X	0.6691 ***
Total Height (Y) Total Weight (X)	Y = 21.657 + (0.69572) X	0.6562 ***
Root Collar Diameter Squared (Y) Total Weight(X)	Y = 10.393 + (2.0730) X	0.8277 ***

<u>Table 31</u>: Correlation Matrix of Measurements for 1 Year Old Stand

Top Height	Planting Height	New Top Height	Diameter Mid Point Extension 1	Height/Diameter Ratio	No. of Branchlets
0.594					
0.767	0.725				
0.414	0.371	0.424			
0.590	0.249	0.386	-0.445		
0.417	0.554	0.505	0.231	0.197	

Table 32

Regression Equations and Correlation Coefficients between Selected Growth Parameters measured for Young Stands 1 Year after Planting

Parameters	Regression Equations	Correlation Coefficients
	Y = a + b X	
Total Height (Y)	Y = 10.815 + (0.67093) X	0.5826 ***
Planting Height (X)		
Total Height (Y)		
	Y = 8.3956 + (3.0884) X	0.4175 ***
Diameter Mid-Point		
Height Extension 1 (X)		

Table 33: Correlation Matrix of Measurements for 3 Year Old Stand

Total Height	Height Extension 3	Height 2nd Year	Height Extension 2	Height 1st Year	Height Extension 1	Planting Height	Diameter Mid-Point Height Extension 1	Total Number of Branchlets
0.761								
0.923	0.471							
0.739	0.358	0.799						
0.740	0.397	0.804	0.346					
0.542	0.191	0.650	0.299	0.740				
0.617	0.451	0.589	0.252	0.680	0.111			
0.896	0.696	0.823	0.696	0.638	0.449	0.556		
0.652	0.456	0.623	0.500	0.496	0.235	0.563	0.734	

Table 34

Regression Equations and Correlation Coefficients between Selected Growth Parameters measured for Young Stands 3 Years after Planting

Parameters	Regression Equations	Correlation Coefficients
	$Y = a + b X$	
Total Height (Y) Height 2nd Year (X)	$Y = 6.0304 + 1(1.3089)X$	0.9230 ***
Total Height (Y) Height 1st Year (X)	$Y = 20.431 + (1.6124)X$	0.7401 ***
Total Height (Y) Planting Height (X)	$Y = 35.414 + (2.2305)X$	0.6172 ***
Total Height (Y) Diameter Mid Point Height Extension 1 (X)	$Y = 7.2724 + (5.8866)X$	0.8957 ***

Table 35: Correlation Matrix of Measurements for 6 Year Old Stands

Total Height	Height Extension 6	Height 5	Height 4	Height 3	Height 2	Height 1	Height Extension 1	Planting Height	Diameter Mid Point Extension 1	No. of Branchlets 2nd Whorl from top
0.610										
0.926	0.271									
0.794	0.205	0.870								
0.693	0.144	0.770	0.867							
0.602	0.125	0.666	0.748	0.253						
0.438	0.034	0.519	0.599	0.228	0.787					
0.325	-0.007	0.406	0.441	0.148	0.617	0.805				
0.379	0.104	0.406	0.480	0.216	0.562	0.616	0.113			
0.613	0.240	0.626	0.521	0.409	0.414	0.252	0.159	0.256		
0.486	0.307	0.450	0.406	0.362	—	—	—	—	0.366	

— not calculated

Table 36

Regression Equations and Correlation Coefficients between Selected Growth Parameters measured for Young Stands 6 years after Planting

Parameters	Regression Equations	Correlation Coefficients
	$Y = a + b X$	
Total Height (Y) Height 5th Year (X)	$Y = 24.348 + (1.1349)X$	0.9263 ***
Total Height (Y) Height 3rd Year (X)	$Y = 94.482 + (1.3593)X$	0.6933 ***
Total Height (Y) Planting Height (X)	$Y = 15.158 + (2.8638)X$	0.3787 ***
Total Height (Y) Diameter Mid Point Extension 1 (X)	$Y = 88.897 + (2.5402)X$	0.6131 ***

Table 37: Correlation Matrix Measurements for 9 Year Old Stand

Top Height	Height 8	Height 7	Height 6	Height 5	Height 4	Height 3	Height 2	Height 1	Planting Height	Diameter Mid Point Extension 1	Sides Canopy Closure	Height Canopy Closure
0.533												
0.842												
0.712	0.777											
0.641	0.756	0.786										
0.560	0.637	0.660	0.869									
0.473	0.558	0.625	0.781	0.848								
0.400	0.457	0.592	0.710	0.736	0.878							
0.351	0.407	0.536	0.616	0.619	0.748	0.865						
0.264	0.284	0.460	0.448	0.453	0.551	0.691	0.771					
0.254	0.267	0.399	0.395	0.409	0.510	0.602	0.670	0.970				
0.172	0.170	0.380	0.340	0.340	0.383	0.525	0.591	0.681				
0.521	0.489	0.526	0.609	0.507	0.493	0.472	0.351	0.219	0.230			
0.308	0.308	0.267	0.295	0.199	0.267	0.233	0.198	0.152	0.135	0.238		
0.276	0.317	0.251	0.289	0.297	0.301	0.286	0.245	0.182	0.113	0.116	0.618	

Table 38

Regression Equations and Correlation Coefficients between Selected Growth Parameters for Young Stands 9 Years after Planting

Parameters	Regression Equations	Correlation Coefficients
	Y = a + bX	
Total Height (Y) Height 8th Year (X)	Y = 64.237 + (1.0373)X	0.8422 ***
Total Height (Y) Height 6th Year	Y = 179.35 + (0.88930)X	0.6406 ***
Total Height (Y) Height 3rd Year	Y = 225.89 + (0.90046)X	0.4001 ***
Total Height (Y) Diameter Mid Point Extension 1 (X)	Y = 213.85 + (1.2317)X	0.5215 ***

Table 26

Regression Equations and Correlations Coefficients between Selected Growth Parameters measured for 1 + 0 Seedlings

Parameters	Regression Equations	Correlation Coefficients
	$Y = a + b\ X$	
Total Height (Y) Root Collar Diameter (X)	$Y = 3.0744 + (4.3229)X$	0.6271 ***
Total Height (Y) Total Weight (X)	$Y = 6.5541 + (6.0181)\ X$	0.6886 ***
Root Collar Diameter Squared (Y) Total Weight (X)	$Y = 0.6225 + (3.2959)\ X$	0.6099 ***

9. BIBLIOGRAPHY

Aldhous, J.R. Atterson, J. Brown, R.M. Low, A.J. Stoakley, J.T.	1967	Date of Sowing - a Comparison of Two Provenances of Sitka Spruce, For. Comm. Rep. For. Res. 1967. H.M.S.O. London.
Aldhous, J.R.	1967	Standards of Sturdiness for Forest Tree Plants, For. Com. Res. Dev. paper No.36. London.
Aldhous, J.R.	1966	Cold Storage of Seedlings, Spacing in Transplant lines, For. Com. Rep. For. Res. 1966, H.M.S.O. London.
Aldhous, J.R. Atterson, J.	1963	Survival and Growth of Undercut Seedlings in the Nursery and Forest. For. Comm. Rep. For. Res. 1963. H.M.S.O. London.
Aldhous, J.R. Atterson, J.	1960	Nursery Investigations. For. Comm. Rep. For. Res. 1960. H.M.S.O. London.
Anderson, M.L.	1961	The Selection of Tree Species. Oliver & Boyd, Edinburgh (2nd edn.)
Anon.	1966	British Standard 3936: Part 4. Specification for Nursery Stock. Part 4. Forest Trees. H.M.S.O. London.
Armson, K.A.	1958	The Effects of NPK Fertilizers on the Growth of White Spruce, Annual Report of Forest Research, Glendon Hall, Faculty of Forestry. Ontario.
Bailey, N.T.J.	1959	Statistical Methods in Biology, The English Universities Press, London.
Beekhuis, J.	1965	Crown Depth of Radiata Pine in Relation to Stand Density and Height. N.Z. Journ. For.10 (1).
Benzian, B.	1966	Experiments on Nutrient Problems in Forest Nurseries. For. Comm. Bull. No.37. (Vol.1).
Berry, A.B.	1965	Effect of Heavy Thinning on Stem Form of Plantation - Grown Red Pine. Dep. Forestry, Canada, Pub No.1126.
Brace, L.G.	1964	Early Development of White Spruce as related to planting method and Planting Stock Height. Canada Dept. Forestry, For. Res. Branch Pub.1049.

Bramble, W.C.
Cope, H.N.
Chusman, H.H. 1949 Influence of Spacing on Growth of Red Pine in Plantations. J. For. 47(9).

Byrnes, W.R.
Bramble, W.C. 1955 Growth and Yield of Plantation Growth Red Pine at Various Spacings. Journ. of For. 53(8)

Carvell, K.L. 1964 Planting Depth Affects Survival and Growth of White Pine. W. Virginia. Agric. Exp. Sta. Bull. 480.

Craib, I.J. 1947 Silviculture of Exotic Conifers in South Africa. British Empire Forestry Conference 1947.

Craib, I.J. 1935 Thinning, Pruning and Management Studies on the Main Exotic Conifers in South Africa. Sci. Bull, No.196. Dept. Agr. & Forestry. Pretoria.

Cromer, D.A.N.
Pawsey, C.K. 1957 Initial Spacing and Growth of Pinus Radiata. Forestry and Timber Bureau. Bull. No.36. Canberra.

Dawkins, H.C. 1963 Crown Diameter, their Relation to Bole Diameter in Tropical Forest Trees. Commonwealth For. Rev. Vol.42(4).

Deetlefs, P.P.DuT. 1954 The Relationship Between Stand Density, Crown Size, and Basal Area Growth in Stands of _P.taeda_ in the Natural Habitat of the Species. J. S.Afr. For. Ass (24).

Edwards, M.V.
Holmes, G.D. 1950 Effect of Weight and Diameter on Growth and Survival. For. Comm. Rep.For. Res. 1950. H.M.S.O. London.

Erteld, W. 1960 Investigations on Increment and Development of Pine Under the Influence of Different Silvicultural Treatments. Archiv fur Forstwesen 9(4). Eng. Summary.

Faulkner, R.
Aldhous, J.R. 1958 Undercutting Seed beds. For. Comm. Rep. For. Res. 1958. H.M.S.O. London.

Faulkner, R.
Aldhous, J.R. 1957 Nursery Investigation. For. Comm. Rep. For. Res. 1957. H.M.S.O. London.

Faulkner, R.
Aldhous, J.R. 1955 Nursery Investigations. For. Comm. Rep. For. Res. 1955. H.M.S.O. London.

Ford, E.D.	1968	Stand Structure and Production in Sweet Chestnut Coppice Cycle. (unpublished Ph.D., University of London).
Fraser, A.I.	1967	Rooting and Stability in Sitka Spruce. For. Com. Bull. No.40, H.M.S.O. London.
Guillebaud, W.H. Hummel, F.C.	1950	A Note on the Movement of Trees Classes. Forestry Vol.23 (1).
Hamilton, C.J.	1965	The relationship between Increment and Dominance in Individual Trees as a Basis for Thinning Method. (unpublished M.Sc. Thesis, 1965, Univ. of Edinburgh).
Hellum, A.K.	1967	Periodicity of Height Growth in White Spruce Reproduction. For. Chron. 43(4).
Holmes, G.D. Faulkner, R.	1954	Nursery Investigations. For. Comm. Rep. For. Res. 1954. H.M.S.O. London.
Hough, A.E.	1952	Relationships of Red Pine seed Source, Seed weight, Seedling Weight and Height Growth in Kane Test Plantation. U.S. Dept. Agric., Forest Service, Nor.east. For. Exp. Sta. paper 50.
Hummel, F.C. Locke, G.M.L. Jeffers, J.N.R. Christie, J.M.	1959	Code of Sample Plot Procedure. For. Com. Bull. No.31, H.M.S.O., London.
Hummel, F.C.	1955	The Volume - Basal Area line. For. Comm. Bull. No.24. H.M.S.O. London.
Johnson, D.R. Bradley, R.T.	1963	Forestry Management Tables Commonwealth Forestry Review. Vol.42.
Jones, E.W.	1968	A Note on the Dimensions of Shoots and Roots of Planting Stock. Forestry 41 (2).
Kennel, R.	1964	The Influence of Some Tree Dimensions on Individual Trees in a Stand. Mitt. St. Forstverw Ba yerns 34.
Knight, H.	1957	Growth and Survival of Experimental Plantations of Douglas Fir. B.C. Forest Service. Res. Note 33.
Kramer, H.	1965	Crown Development in conifer Stands in Scotland as influenced by Initial Spacing and Subsequent Thinning. Forestry 39 (1).

Kramer, P.J. Kozlowski, T.T.	1960	Physiology of Trees. McGraw-Hill Book Col. Inc. New York.
Ladefoged, K.	1946	The Productive Importance of the Individual parts of the crown in Spruce Picea excelsa. Det Forstlige Forsøgsvaesen i Danmark. Vol.5. (Eng. Summary).
Liebold, E.	1962	Wachstum und Entwicklung in Gleichaltigen Fichtenreinbestand. Archiv für Forstwesen 11. (Eng. Summary).
Marion, J.	1966	How Soft wood Plantations Get Away: A Method of assessing their Vigour. Practical Applications. Rev. of Frac. 18(5). F.A.66 (6518).
Marsh, E.K.	1957	Some Preliminary Results from O'Connor's Correlated Curve Trend Experiments on Thinnings and Espacements and their Practical Significance. Commonwealth Forestry Conference Aus. NZ. 1957. Union of S. Africa.
Matthews, J.D.	1963	Some Applications of Genetics and Physiology in Thinning. Forestry 36(2).
Meyer, W.H.	1962	Studies on Tree Classification and Recommendations concerning their further Development. Archiv fur forstwesen 10(2). (Eng. Summary).
Miller, W.E.	1965	Number of Branchlets on Red Pine In Young Plantations. For. Sci. 11(1).
Minor, C.O.	1951	Stem-Crown diameter relations in Southern Pine. J. For. 49(7).
Mullin, R.E.	1967	Root Exposure of White Spruce Nursery Stock. For. Chron. 43. 1967.
Mullin, R.E.	1964	Influence of Planting Depth on Survival and Growth of Red Pine. For. Chron. 40(3).
O'Connor, A.J.	1935	Forest Research with Special Reference to Planting Distances and Thinning. British Empire Forestry Conference 1935.
Ovington, J.D.L.	1957	Dry Matter Production by Pinus Sylvestris Annals of Bot. XXI (82).
Pinchin, R.D.	1950	Nursery Extension Experiments at Radnor Forest, For. Comm. Rep. For. Res. 1950 H.M.S.O. London.

Richards, N.A. Morrow, R.R. Stone, E.L.	1962	Influence of Soil and Site on Red Pine Plantations in New York. Univ. Agr. E.S. N.Y. Coll. Agr., Bull. 977.
Righter, F.I.	1945	Pinus: The Relationship of Seed Size and Seedling size to Inherent Vigour. J. of For. XLIII (2).
Rothkirch, F.V.	1968	Investigations on the Development of Crown shape in Sitka and its Influence on the Time of Canopy Closure. (Unpublished Project Report, Univ. of Edinburgh).
Rudolf, P.O.	1950	Forest Plantations in the Lake States. U.S. Dept. Agric. Tech. Bull. 1010.
Schmidt, H.	1961	Assessing the Quality of Forest Planting Stock. For Abs. (1962) 3509.
Schotte, G.	1912	Om gallrings försök. Medd. f. Statens skogs försöksanstalt, Hft 9. Stockholm.
Shipman, R.D.	1960	Survival and Growth of Graded Longleaf Nursery Stock. J. For. 49.
Snedecor, G.W. Cochran, W.H.	1967	Statistical Methods. The Iowa State University Press, Ames, Iowa U.S.A (6th edn.)
Spurr, S.H.	1944	Effect of Seed Weight and Seed Origin on the Early Development of Eastern White Pine. Jour. Arnold Arboretum 25(4).
Stevens, H.M.	1928	Nursery Investigations. For. Comm. Bull. No.11. H.M.S.O. London.
Stiell, W.M.	1966	Red Pine Crown Development in Relation to Spacing. Dept. of Forestry. Publ No.1145. Canada.
Stiell, W.M.	1964	Twenty Year Growth of Red Pine Planted at three Spacings Dept. Forestry Pub. No. 1045. Canada.
Stiell, W.M.	1962	Crown Structure in Plantation Red Pine Forest.Res. Br. Tech. Note No. 122. Dept. of Forestry. Canada.
Stiell, W.M.	1960	A Co-operative Experimental Planting Project in Ontario. Woodland Review, Pulp and Paper Magazine of Canada 61 (2).

Sutton, R.F.	1966	Influence of Planting Depth on Early Growth of Conifers. The Commonwealth Forestry Review. Vol.46(4).
Stoeckeler, J.H. Jones, G.W.	1957	Forest Nursery Practice in the Lake States U.S.D.A. Forest Service, Agr. Hand Book. No.110.
Smith, D.M.	1962	The Practice of Silviculture. John Wiley & Sons Inc., New York. (7th edn.).
Tucker, R.E. Jarvis, J.M. Waldron, R.M.	1968	Early Survival and Growth of White Spruce Plantations, Riding Mountain National Park Manitoba. Forestry Branch Dept. Pub. No.1239. Canada.
Ure, J. Jackson, D.S.	1964	The Control of Basal Area Increment in Young <u>Pinus radiata</u> N.Z. Jour. For. 9(1).
Vanselow, K.	1956b	Crown and Increment of Spruce in Pure Even-Aged Stands. Forstwiss Cbl. 70(12).
Vezina, P.E.	1962	Crown Width D.B.H. Relationships for Open grown Balsam Fir and White Spruce in Quebec. For. Chron. 38 (4).
Warrack, G.	1952	Comparative Observations of the Change in Class in a Thinned and Natural Stand of Immature D. Fir. For. Chron. 28(2).
Weck, H.	1944	Crown Dimensions and Increment Production. Forst. Archiv (20).
Wile, B.C.	1964	Crown Size and Stem Diameter in Red Spruce and Balsam fir. Canada Dept. of Forestry. Pub. No.1056.