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# THE STATUS AND POTENTIAL OF THE SLASH-CARIBBEAN HYBRID IN QUEENSLAND

by

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The studies carried out for this thesis formed part of the tree-breeding programme of the Queensland Department of Forestry, and departmental facilities were freely used. Consequently the data for the height and girth measures and the crossability calculations were gathered by the assistant staff, under the direction of the author. However if direct supervision was necessary this was provided. All other data were gathered by the author and all calculations, deductions and interpretations were made by the author.

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## ABSTRACT

The Slash-Caribbean complex includes the two varieties of *Pinus elliottii* (Engelm.) and the three of *Pinus caribaea* (Mor.).

The Slash Pine (*P. elliottii* var. *elliottii* L. and D.) and the Honduras Caribbean Pine (*P. caribaea* var. *hondurensis* B. and G.) are the most important exotic trees planted in Queensland and are suited to environments in the south and the north of the State respectively. Thus much of Queensland's coastal region is environmentally intermediate between the best for these two varieties.

As far as is at present known, each of the varieties of the complex has features which complement those of another variety. Thus Honduras Caribbean Pine has poor wet-site tolerance, whilst Slash Pine grows well on such sites.

The situation of an intermediate environment and complementary characteristics is one in which hybrids usually do well and the purpose of this thesis is to determine as far as possible the potential that the hybrids within the complex might have in Queensland.

The height and girth growth patterns of Slash Pine, Honduras Caribbean Pine and the hybrid between them were studied at one centre (Beerwah), and the extent to which this same hybrid and in some cases its derivatives expressed the important characteristics of vigour, stem straightness, branch size, wind-firmness and wood density was assessed at up to three centres. The root distribution pattern of this hybrid was also studied. The other hybrids, *P. caribaea* var. *caribaea* B. and G. x *P. caribaea* var. *hondurensis*, and *P. elliottii* var. *elliottii* x *P. caribaea* var. *caribaea* were assessed for height growth at age 18 months at two centres. Crossability patterns were determined

and flowering periods noted to ascertain the possibilities of commercial production of hybrid seed. These production studies included as far as possible P. elliottii var. densa L. and D. and P. caribaea var. bahamensis B. and G.

The studies of growth pattern showed Slash Pine to have vigorous spring growth and a dormant winter phase. In lower latitudes than Beerwah spring growth is restricted by the dry spring periods. Honduras Caribbean Pine made most height in the late summer when weather conditions were most favourable, but made appreciable growth throughout the year. The hybrid combined both these height growth patterns and consequently exhibited hybrid vigour.

In all other features studied the hybrids were intermediate between the parental types unless intermediacy in an associated characteristic induced heterosis. Examples of such induced heterosis were found in rate of growth, particularly on wet sites, wind-firmness and mean wood density on wet sites. The root distribution was shallower in Slash Pine than in Honduras Caribbean Pine, a factor important in determining performance on wet sites and in strong winds.

In all but a few cases (var. elliottii x var. caribaea, and var. densa, and possibly var. hondurensis x var. bahamensis) crossabilities were low but as flowering periods of var. elliottii and var. caribaea and of var. hondurensis and var. bahamensis were coincident, production by means of uniclonal orchards would be possible. However backcrosses or inter-hybrid crosses might be more easily produced.

# CONTENTS

# INTRODUCTION

The Slash-Caribbean complex includes the two varieties of Pinus elliottii, Engelm., var. elliottii L. and D. and var. densa L. and D. and the three of Pinus caribaea Mor., var. caribaea B. and G., var. bahamensis B. and G. and var. hondurensis B. and G. Two of these P. elliottii var. elliottii and P. caribaea var. hondurensis are the most important exotic trees planted in Queensland, with var. elliottii best suited to the southern coastal areas and var. hondurensis to the northern coast (Hawkins and Muir, 1967; Slee and Nikles, 1967). Consequently much of the coastal region of Queensland has an environment intermediate between that to which these varieties are best suited. In such conditions hybrids are expected to do well (Anderson, 1949). The var. elliottii x var. hondurensis hybrid has been produced in Queensland since 1958 (Nikles, 1962) and an initial survey of the potential of this hybrid and the others of the complex has been made in this thesis.

The growth patterns of var. elliottii var. hondurensis, their hybrid and hybrid derivatives have been studied, in order to determine the relationship of these varieties with the prevailing climate, and to deduce which areas would be suitable for hybrid establishment.

The characteristics of height and girth growth, stem straightness, branch size, wind-firmness and wood density variation have been studied in var. elliottii, var. hondurensis and their hybrid, as these features are of considerable economic importance. Where possible the other hybrids of the complex were also included in these assessments.

Finally crossability patterns and flowering periods of the individuals of the complex have been determined in order to assess the possibilities of large scale production of hybrid seed.

# PART I

# THE PLACE OF HYBRIDIZATION IN TREE IMPROVEMENT PROGRAMMES

(Literature Review)

## The Aim of Plant and Tree Breeding Programmes.

The aims of plant breeding are the same for both agricultural crops and forest trees (Borlaug, 1966). The basic aim has been defined by Cooper (1963) as the development of varieties showing the most effective conversion of solar energy in a particular climatic environment. Both Hayes et al (1958) and Allard (1960) have enlarged upon this definition; Allard, for example summarizes the aims of a plant breeding programme as:-

(i) an increase in yield through the use of varieties with improved physiological efficiency,

(ii) the development of better varieties for new areas, frequently by adjusting the growth cycle to suit the available growing season,

(iii) improvement in the overall characteristics and quality of the product,

(iv) production of varieties resistant to pests and diseases.

These objectives may also be regarded as the aims of the forest-tree breeder.

As many forest trees are highly cross-pollinated, the experience gained in breeding cross-pollinated annual species has numerous implications and potential applications in forestry (Borlaug, 1966). Elliott (1958), Hayes et al (1958), Allard (1960), Andrus (1963) and others, have outlined in detail the methods used for breeding cross-pollinated plants, to develop varieties with the capacity to achieve the aims outlined above. These methods can be classified as mass selection, pedigree selection, hybridization, or a combination of these methods. Each of the methods is discussed.

Mass Selection.

In the method of mass selection desirable individuals are selected within the commercial population. Seed from these is harvested, composited without progeny testing and utilized to produce the following generation. This method is effective in increasing the gene frequencies of characters that can be readily seen or measured, and is effective in adapting varieties to fit them to new areas and environments (Elliott, 1958 p286; Allard, 1960 p255).

The method has been used extensively from the very early stages of agriculture. Allard (1960) for example, cites gains in production made in sugar beet (Beta sp.), and in adaption in Alfalfa (Medicago sp.). Sugar beet now averages 16% sugar content compared with 7.8% in the nineteenth century, and at least part of this is due to mass selection. Alfalfa originally was introduced to America as a non-hardy species suitable only for equable climates such as California; varieties developed naturally by mass selection are now grown successfully in areas of Utah, Kansas and Nebraska, which experience the extremes common in continental climates.

In forestry mass selection has been practised by the selection of the better trees in the stand as seed trees both for natural and artificial regeneration, and also by the selection of seed production areas (Wright, 1962; Matthews, 1963). In a study of the resulting improvement in Slash Pine (Pinus elliottii (Engelm) var. elliottii L. and D.) in Queensland, Haley (1959) found that the number of stems per acre reaching a standard acceptable for pruning increased in progenies of selected trees to 200 compared with 112 in unselected material. Slee and Reilly (1966) similarly have shown that locally collected material of Loblolly Pine (Pinus taeda L.) and Slash Pine is superior to all other imported material in provenance tests in Queensland. Part of this superiority is certainly due to mass selection.

It is probably true to say that mass selection at present constitutes the most commonly used method for producing improved forest tree seed.

Despite these substantial improvements the gains possible with mass selection are limited by the difficulty of recognising superior genotypes without progeny testing, and to the lack of control of the pollen source (Srb and Owen, 1952 p476; Allard, 1960 p253). These limitations are removed in the methods of pedigree and mass pedigree selection

Pedigree Selection and Mass-pedigree Selection.

The methods of pedigree and mass-pedigree selection include a wide range of techniques all with a basically similar procedure, namely,

(1) selection of desirable individuals,

(2) evaluation of these by progeny testing,

(3) inter-crossing of the best to provide bulk quantities of seed (Elliott, 1958 p293; Hayes et al, 1958 p113; Allard, 1960 p44).

As there are great variations in the agencies and mechanisms controlling pollination, in self-compatibility, and in the effects of inbreeding (Allard, 1960 p45), many techniques have been developed for progeny testing and inter-crossing. The most appropriate technique depends on the propagation system of the particular species concerned. For example Elliott (1958 pp286-292) lists five different methods, each of which was developed and had application in the first instance for one particular species.

The testing procedure can be greatly facilitated by the use of inbreeding if the species concerned is self-compatible (Elliott, 1958 p292), as is shown in the very refined techniques developed for the breeding of maize - Zea mays L. - (Hayes et al 1958; Elliott, 1958; Allard, 1960; Hayes, 1963; and numerous others). However, inbreeding is merely an adjunct to the technique. Even in maize, Hayes (1963 p28) feels that testing and selection by other means would have yielded equivalent results. Also Borlaug (1966) details Wellhausen's methods used for maize breeding in Mexico, where the use of inbred lines is disastrous because of the lack of disease resistance in such homogeneus populations. Elliott (1958 pp284-295) details several techniques of recurrent selection applicable to species that cannot be inbred.

Thus although inbreeding is a valuable tool it is not essential to plant breeding and may even be inimical. Certainly a large expenditure on inbreeding of normally outbreeding populations for testing purposes can only be justified if it gives better or cheaper results than other methods.

Initial results of the applicationof the mass-pedigree method to tree breeding indicate that gains may be considerable. The usual tree breeding systems consist of parent tree selection, progeny testing and establishment of either the parent trees in a clonal seed orchard or their progeny in a seedling orchard (Zobel et al, 1958; Wright, 1962; Andersson, 1963; Burley, 1966; and others). Haley (1959) has reported that in Queensland, crosses between selected trees of Slash Pine included in seed orchards gave 412 trees per acre with vigour and straightness standards suitable for pruning compared with 112 such trees per acre from unselected material. Later results quoted by Nikles (1966 a) and Slee and Reilly (1966) suggest a volume increase of 30% from clonal orchards of Slash Pine in trees from seed. Such improvement also seems likely in other species elsewhere, particularly P. taeda in America (Zobel, pers. comm.) and many Forest Services have embarked on such programmes of mass-pedigree selection.

When the methods of mass-pedigree selection are repeated over several cycles they constitute a system known as recurrent selection. (Elliott, 1958 p293; Allard, 1960 p282). The common tree breeding systems are the first stage in a system of recurrent selection for recurrent selection may be practised with inbred lines, clones, and mass selected, pedigree selected or mass-pedigree selected populations of the same or different ecotypes, races or species.

## The place of hybridization in plant breeding programmes.

When different ecotypes, varieties or species are involved in a programme of mass-pedigree selection, the products may be regarded as hybrid[1] varieties. In any breeding programme there is considerable advantage in hybridization, and indeed, severe restrictions may be imposed where the programme can only exploit the genetic variation within the one population. Maximum advance may depend on the combination of genetic material from different populations. Numerous authors have commented on this (e.g. Muntzing. 1961 p277). There is little doubt that many of the notable gains from plant

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(1) For the purposes of this thesis the term "hybrid" defined as "Any cross-bred animal or plant" (Henderson and Henderson, 1963) will be confined to the products of crossing of individuals belonging either to taxonomically distinct entities such as species and varieties or to genetically distinct groups such as ecotypes or clinal extremes. It will not be used to describe crosses between separate closely related individuals in a normally outbreeding species.

breeding have resulted from the introduction of genetic diversity by hybridization. Muntzing (1961, p278) cites the incorporation of the English "Squarehead" wheat into Sweden to add high yield and straw stiffness to the baking qualities of the local variety. Hutchinson (1959) notes the importance of inter-biotype hybridization in the production of cotton (Gossypium sp.); Jassid (Empoasca sp.) resistance was introduced into the Southern Rhodesian variety Barberton U.4 when the variety had been exploited to the limit of the existing genetic pool. In sugar cane (Saccharum sp.) the original varieties, the noble canes, have been replaced by hybrids as the noble canes could not tolerate poor soil conditions and lacked resistance to disease (Stephenson, 1965).

Indeed many of the highly publicised gains in hybrid corn have resulted from the wide hybridization used. Hayes (1963, p28) comments that corn breeders learned the hard way that it was difficult to produce a good cross from inbreds selected within a single variety.

Thus plant breeders may gain in two ways from the use of hybrids. A hybrid may combine the desirable features of both parents as in the wheat, cotton and sugar-cane examples described above or it may exhibit hybrid vigour. In this case it is superior in growth or some other characteristic to both parents, as in maize.

There are two definitions of hybrid vigour. In one hybrid vigour means the hybrid is more vigorous than both parents, in the other definition the hybrid performance is superior to the mean of the parents (Hayes, 1952). In this thesis the former definition of hybrid vigour indicating superiority over both parents will be used. Wherever the hybrid is intermediate in performance between its parents it will be described as "intermediate" regardless of the mean value of the parents.

The process by which hybrid vigour is produced is known as heterosis, a term derived from "stimulus of heterozygosity". However current genetic usage regards hybrid vigour and heterosis as synonymous (Srb and Owen, 1952 p337; Hayes et al, 1958 p53; Elliott, 1958 p262; Righter, 1960 and others) and they will be used in this way in this thesis.

The actual genetic mechanism of heterosis is not fully understood. Two main theories have been propounded. Namely -

(i) the dominance hypothesis originally proposed by Davenport (1908),

(ii) the over-dominance hypothesis (East, 1936).

Briefly the dominance theory considers heterosis as due to the interaction of dominant genes at different locii. Some of these genes originate from one parent and some from the other and they would not normally occur together in the same organism. The overdominance theory suggests that the interaction is between heterozygous alleles at the same locus. These exert a complementary action giving superiority over both parents which are normally homozygous for these alleles. As Allard (1960 p227) points out there seems no reason why both theories cannot be correct with either or both applicable to specific cases.

Pau ley (1963) suggests a further explanation of hybrid vigour applicable to perennial plants including trees. He regards heterosis as due to a favourable photoperiodic reaction in the hybrid, i.e. that the hybrid is better adapted to exploit the day length pattern as this changes throughout the year.

This can probably be extended to encompass all climatic factors which affect tree growth and which fluctuate throughout the year. As such this concept appears very possible and of considerable importance to forest tree breeding.

The application of hybridization in forest tree breeding.

The apparent importance of hybridization to forest tree breeding has been commented on by Srb and Owen (1952) Hayes et al (1958) and Muntzing (1961). Duffield (1962) feels that once the genetic diversity existing in forest populations as we find them has been well exploited we can expect to turn to hybridization as a powerful tool for introducing genetic diversity. Schreiner (1966) states that forest tree improvement programmes have too often been narrowly orientated toward selection and breeding within a single species. For forest trees it is the genus not the species that will provide through selective interspecific hybridization the maximum diversity of genotype needed for maximum improvement.

Most authors feel that hybridization in forest trees will be particularly important because of the possibilities both for character combinations and the exploitation of heterosis (Hayes et al, 1958; Srb and Owen, 1952; Muntzing, 1961; Morandini (1963) ). Vidakovic (1963) and Wright (1964) add the possibility of producing a population better able to utilize new environments. Duffield and Snyder (1958), Righter (1960) and Allard (1960) are also in general agreement but feel that as hybrid growth rates in forest trees are usually intermediate between the parental species the major use of hybrids in forestry will be in the improvement of growth rates within the range of the slower growing species.

There are numerous examples in forestry of interspecific hybrids that have achieved each of these different types of gain, and there are also examples of similar achievement with intra-specific-inter-provenance hybrids.

Valuable character combinations have been recorded in Pinus rigida Mill. x Pinus taeda in Korea where the stem straightness of P. taeda supplements the cold hardiness of the P. rigida (Hyun, 1961). In California the frost hardiness of Pinus jeffreyi Greve. and Balf. is combined with vigour and resistance to the pine reproduction weevil (Cylindrocopturus eatoni Buch.) of Pinus coulteri D. Don (Miller, 1950; Libby, 1958; Righter, 1960; Smith, 1966). Larix decidua Mill. x L. gmelini (Rupr.) Litv. combines the resistance to fungal and animal damage of the former with the high shade tolerance and good vigour of the latter in Bavaria (Rohmeder, 1963), and both the Pinus strobus L. x P. parviflora Sieb. and Zucc. and P. strobus x P. griffithii McClel. hybrids combine the good quality of P. strobus timber with the pine reproduction weevil resistance of the other species (Patton, 1966). Pinus palustris Mill. and P. elliottii are two species each of which is resistant to the other's principal disease namely brown spot (Scirrhia acicola (Dearn.) Siggers) and fusiform rust (Cronartium fusiforme (A. and K.) Hedge ) respectively. The hybrid between them is less susceptible than either parent to the relevant fungus and also combines other features of the parents (Derr, 1966).

Hybrid vigour is dependant for its expression on the locality of planting (Duffield and Snyder, 1958; Mirov, 1967) as has been shown by Clausen et al (1948) for Achillea sp. and by Wright (1962) and Nilsson (1963) in forest trees. Hybrid vigour is also markedly dependent for its expression on the individual parent trees involved (Righter 1960; Eifler, 1960; Vidakovic, 1963; Rohmeder, 1963;

Dimpfleimer 1963; Nilsson 1963; and Smith 1966) and their locality of origin (Wright, 1962; Rohmeder, 1963; Pauley, 1963). When considering hybrid vigour it is therefore necessary to note the planting locations, and the origin and quality of the particular trees involved. Care is needed when making generalizations.

Hybrid combinations in forest trees which have displayed better growth than both parents, at least once, have been summarized by Wright (1962). These have been reported in the genera Pinus, Abies, Picea, Quercus and Castanea. Other examples are quoted by Pauley (1963) in Populus tremuloides Michx. x P. tremula L.; Rohmeder (1963) in Larix leptolepsis Sieb. and Zucc. x L. decidua, Abies veitchii Lindl. x A. alba Mill., and Abies concolor (Gord.) Engelm. x A. Veitchii and Moulopoulus and Mpasiotes (1961) in Pinus brutia Ten. x P. halepensis Mill.

Inter-racial crosses in Populus tremula have exhibited hybrid vigour both in Bavaria (Rohmeder, 1963) and in Sweden (Johnsson, 1956) as have nursery seedling of Pseudotsuga menziesii (Mirb.) Franco. in Canada (Orr-Ewing, 1966).

Besides growth superiority, hybrid vigour may be manifest in other aspects. Improved survival following planting is reported by Rohmeder (1963) for the Larix leptolepis x L. decidua hybrid. Increased root growth in the first year is found in Pinus ponderosa Laws. x P. engelmanii Carr. (Wright, 1962) and increased needle length in Pinus radiata D. Don x P. attenuata Lemm. (Bannister, 1958).

Hybrids that have proved better than their parents in habitats where the parental species do not occur naturally include Juniperus ashei Buch. x

J. virginiana L. (Hall and Carr, 1964).

As hybrid vigour depends on the local environment for its expression so hybrid performance varies with locality and is often best in a habitat intermediate between those in which the parental species occur. (Anderson, 1949). One example of such a hybrid is Quercus havardii (Rydb.) x Q. stellata (Wangh.) (Wright, 1964).

The ability to utilize habitats to which the parent species are not adapted provides the justification for the claim of Morandini (1964), Vidakovic (1963) and Wright (1964) that hybrids may be particularly useful as exotics. For example that between Populus monilifera Ait. and P. nigra var. italica (Munchh.) Koehne at Grafton, Australia appears to have considerable potential (Pryor and Willing, 1965). Another hybrid that may prove valuable as an exotic is Pinus radiata x P. attenuata in New Zealand (Bannister, 1958).

## Difficulties of production of forest tree hybrids.

Despite the large number of forest tree hybrids that have been shown to possess valuable characteristics very few are being used in general forestry practices. The production of hybrids is now planned or under way for commercial purposes in Pinus rigida x P. taeda in Korea (Hyun 1956), Larix leptolepis x L. decidua in England (Faulkner, 1965), Populus sp. in Northern Italy (Einspahr and Benson, 1964), Eucalyptus viminali Labill. x E. camaldulensis Dehn. x Morocco (Morandini, 1964) and the backcross between Pinus jeffreyi and Pinus jeffreyi x P. coulteri (Libby 1958). As Vidakovic (1963) notes this is a very modest result in view of the large number of works dealing with interspecific hybridization.

The slow development of commercial hybridization programmes is partly due to the relatively late realization of the value of breeding in forestry. It is likely that only in Queensland is sufficient seed from a seed orchard available to meet requirements and that is only the case in one species Pinus elliottii (Slee and Reilly, 1967). There is a consequent need for most forest services to presently engage in crash programmes for the production of improved seed usually by the production of synthetic varieties within the species concerned and probably within one provenance of that species (Schreiner, 1966). Thus for practical reasons facilities are not at present generally available for hybrid seed production.

More important however is the difficulty of obtaining hybrid seed due to the various isolating mechanisms that hinder or prevent the making of the parental types. Such mechanisms have been elemental in the evolution of species; they have been discussed by numerous authors and summarized by Dobzhansky (1955) as follows:-

I. Mechanisms that prevent the production of hybrid zygotes or else engender such disturbances in development that no hybrids reach the reproductive stage.

A. Parental forms do not meet.

(a) Ecological isolation. The parents are confined to different habitats and seldom or never come together.

(b) Seasonal or temporal isolation. The representatives of two or more species reach the adult stage at a different season or the breeding periods fall at different times a year.

B. Parental forms occur together but hybridization is excluded or the development of hybrid is arrested.

(a) Sexual or psychological isolation - lack of mutual attraction.

(b) Mechanical isolation - physically impossible to cross.

(c) Pollen tube growth is arrested.

(d) Hybrid inviability. Fertilization occurs by the hybrid zygote dies before becoming a sexually mature organism.

II. Hybrid sterility prevents the reproduction of hybrids that have reached the developmental stage at which the parents normally breed. Sterile hybrids produce either no functional gametes or else gametes that give inviable zygotes.

Some of these mechanisms are relatively unimportant in the production of forest tree hybrids. For example, the major plantation species are generally gymnosperms and are wind pollinated, so that the mechanisms of sexual or psychological isolation and mechanical isolation have little, if any, effect. Again, hybrid sterility may not affect the value of the F1 generation. Of the other mechanisms, ecological, seasonal or temporal isolation can be overcome artificially by bringing the parents together or by storing pollen. These can present problems when mass production is considered as will be seen below, but they do not inhibit the existence of artificially produced hybrids.

Mechanisms which limit the pollen tube growth or render the hybrid inviable determine whether or not the existence of a hybrid is possible. These seriously inhibitory mechanisms are well known in forest trees. Inhibition of pollen tube growth, failure of the pollen to stimulate ovule development, or breakdown of the zygote following fertilization have all been reported in inter-specific hybrids between forest tree gymnosperms (McWilliam 1959; Ueda et al 1961; Hagman and Mikkola 1963; Kriebel 1967; and others).

In some cases, particularly with closely related or incipient species the isolating mechanisms are only partially effective due to their polygenic nature (Mather, 1943 p52). In these cases some viable hybrid seed is produced but this is much less than would normally be obtained from an intra-population cross. This gives use to the concept of "crossability" defined as "the ease with which two species can be crossed" (Critchfield, 1962, 1967).

Critchfield (1962) measures crossability by comparing the mean yield of sound hybrid seed per cone with the mean number of sound seed per cone in crosses within the material population. If control cross data are lacking then the mean sound hybrid seed yield per cone is compared with the mean sound seed yield within the material population. (Critchfield, 1967). Using this definition Critchfield (1967) regards the crossability of 69-85% found in several crosses between P. radiata and P. attenuata as very high indicating that barriers to crossing are extremely low.

In the genus Pinus many species, often belonging to distant groups cross freely whilst many, even in the same group, possess strong barriers to intercrossing (Mirov, 1967). Critchfield (1962, 1965, 1967) Vidakovic (1963) and Brown (1966) have studied crossability patterns in several groups of Pinus, whilst Mergen et al (1965) and Clausen (1965) have done the same in Abies and in Betula respectively.

Methods of producing forest tree hybrids.

It is obvious that any method of mass producing hybrids must overcome the isolating mechanisms to be successful, consequently the method employed depends on the operative mechanism.

The inhibition of fertilization or hybrid development must at present be regarded as impossible to overcome for mass production purposes. However there are reports of attempts to breakdown these barriers in forest trees by the use of dead pollen of the maternal population or irradiated pollen (Stairs and Mergen, 1963; Vidakovic, 1963) and chemical methods (Hagman and Mikkola, 1963) with some success. Similar indications of success with these methods have been obtained in non-forest species such as _Prunus_ sp. (Brock, 1954; Yenikeyev, 196[illegible] and _Brassica_ sp. (Davies and Well, 1961).

The general methods available for the production of hybrid plants using natural pollen have been considered by Hartmann and Kester (1959) and the methods applicable to forestry have been utilized in a few cases.

In cases where the species concerned will cross naturally they can be brought together in hybrid orchards as has been done for the hybrid larch _Larix decidua_ x _L. leptolepis_ (Faulkner, 1965). In this case natural hybrids occur mixed with the pure species and the seedlings can be segregated in the nursery.

It may be more desirable to restrict the pollen of one species to reduce or eliminate the pure seedlings of that species. Wright (1962) suggests the use of a single self-incompatible clone of one species in the midst of the other to ensure that all seed produced was hybrid. Trees producing only sterile pollen could be similarly utilized. If a species produces cone flowers at a much younger age than it does pollen flowers, e.g. _Pinus peuce_ Grisab. and _Pinus strobus_, seedlings planted among heavy pollinators of another species capable of hybridization would yield hybrid seed until pollen flowers appeared (Wright, 1962).

Alternatively pollen of the other species could be sprayed onto such cone producing trees.

Controlled pollinations are being used in Korea for the P. rigida x P. taeda hybrid (Hyun, 1960) and on a limited scale in California for the backcross P. Jeffreyi x (P. jeffreyi x P. coulteri) (Libby, 1958). However this method is so expensive that despite Korea being a country with low labour costs this is only an interim measure there and present plans are to produce seed from hybrid orchards (Hyun, 1961).

If the species or even one hybrid individual can be reproduced vegetatively then mass production becomes relatively simple. Expensive techniques can be used to produce the initial hybrids which are then propagated vegetatively. Examples of such production are well known in Populus sp. (except in the aspens) (Wright, 1962) and Cryptomaria japonica (Nohara, 1963).

Duffield and Snyder, (1958) and Righter (1960) suggest the use of a few expensively produced hybrid trees per acre in a matrix of the non-hybrid material. The hybrid trees would thus provide the final crop trees. This may be possible for characters other than vigour but if different rates of growth occur between the hybrids and the matrix then the plantations become as difficult to manage as those of mixed species. As many forest trees of plantation importance are strongly intolerant management of this nature would be most difficult and impracticable in many cases.

If F1 hybrid seed is difficult to obtain it may be possible to utilize F2 or later generations or backcrosses if those retain the advantages of the F1 (Johnsson 1960; Wright 1964). Burk's (1965) results suggest that F2 and F3 generations could be used in Quercus hybrids and this certainly seems a distinct possibility in Pinus. Mirov (1967) notes that the incompatibility mechanisms are much reduced in generations of a higher order than the F1 in this genus. This suggests that good seed sets may be obtained naturally from crosses between hybrids. Thus the expensive techniques can be used for the production of the initial hybrids followed by natural crosses between these to produce large quantities of seed.

## Conclusions.

In view of the potential of hybrids to satisfy the general aims of tree breeding and the results that have been obtained by their use in plant breeding generally their possibilities in forestry need to be seriously considered.

The procedure for assessing the potential of hybrids for a particular region which has been outlined by Wright (1964) contains three distinct steps. These are the assessment of the qualities of the hybrid in comparison with the parental populations, the assessment of the crossability pattern of the species concerned, and the assessment of the possibilities of large scale production.

# PART II

## MATERIALS AND METHODS

An account of the general environmental characteristics of the exotic forests of Queensland, the natural environments and the characteristic features of the species and varieties within the Slash - Caribbean complex, the hybridization that has been carried out within the complex and an outline of the methods used to determine hybrid potential.

<u>Chapter 1.</u> The exotic forests of Queensland.

<u>Chapter 2.</u> The taxonomy and occurrence of the Slash - Caribbean complex.

<u>Chapter 3.</u> Important characteristics of the Slash - Caribbean complex.

<u>Chapter 4.</u> History of hybrid establishment in Queensland and details of the material available for study.

<u>Chapter 5.</u> The experimental approach to determining hybrid potential.

## Chapter 1. The exotic forests of Queensland.

### Location.

Queensland's major exotic forests are situated on the eastern coastline of the State at various centres in the 1,200 miles between Brisbane and Cairns. Intensive development is confined to this region which contains 90% of the State's population of 1,700,000 (Hawkins and Muir, 1967). The main exotic forest plantations will supply the timber needs of the larger population centres and are situated as follows:-

Beerwah (including Beerburrum)[1] Latitude 26°50'S 50 miles north of Brisbane.

Toolara (including Tuan)[1] Latitude 26°10'S 20 miles north of Gympie and 10 miles south of Maryborough.

Gregory - Latitude 25°10'S. 15 miles south of Bundaberg.

Bowenia - Latitude 22°50'S. 50 miles north of Rockhampton.

Cathu - Latitude 20°40'S. 50 miles north of Mackay.

Kennedy - Latitude 18°20'S. 100 miles north of Townsville.

The locations of these exotic plantations are illustrated in Figure 1.

### Climate.

The climatic data for these centres is given in Table 1 (mean monthly rainfall) and Table 2 (temperature and relative humidity), and illustrated by climograms in Figure 2. Data for Cairns has also been included.

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1 Beerburrum and Tuan are separate forests but very close to Beerwah (six miles) and Toolara (adjacent) respectively. For this thesis Beerwah and Beerburrum have been grouped as the one forest centre "Beerwah" and Tuan and Toolara as "Toolara".

FIG. 1. THE LOCATIONS OF MAJOR FORESTRY CENTRES AND TOWNS IN QUEENSLAND

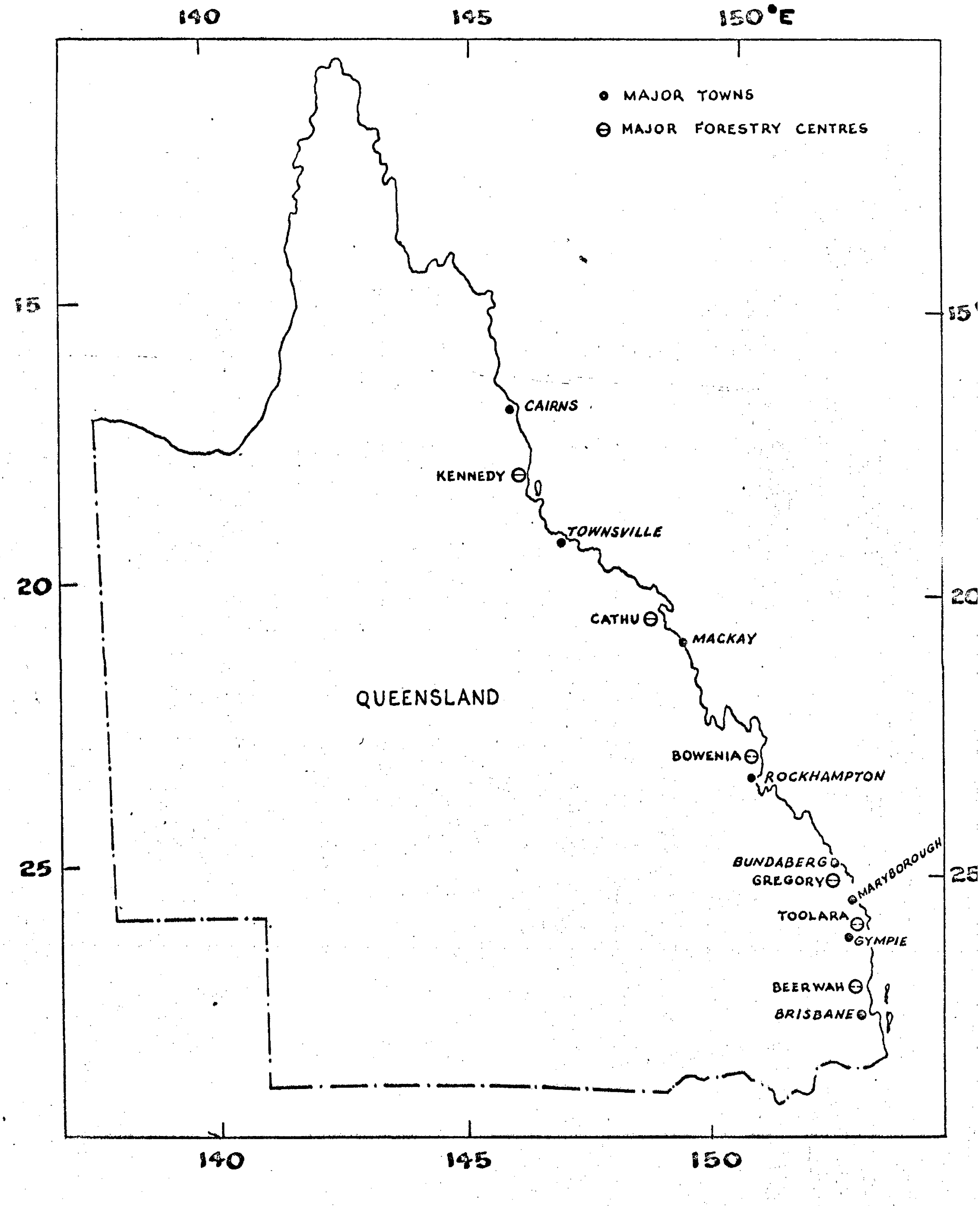


Table 1. Mean monthly rainfall for major exotic plantation centres in Queensland (from Queensland Forest Service Records and Anon., 1958)

| Plantation Centre | Latitude (°S) | Mean monthly rainfall (inches) Jan. | Feb. | Mar. | Apr. | May | June |
|---|---|---|---|---|---|---|---|
| Beerwah | 26°50' | 8.9 | 10.7 | 10.1 | 6.3 | 4.1 | 3.3 |
| Toolara | 26°19' | 6.9 | 7.8 | 8.9 | 4.3 | 3.2 | 3.3 |
| Gregory[1] | 25°10' | 8.6 | 6.5 | 5.2 | 3.3 | 2.6 | 2.9 |
| Bowenia | 22°50' | 12.3 | 15.0 | 10.4 | 5.3 | 4.2 | 4.3 |
| Cathu | 20°40' | 9.5 | 8.7 | 6.5 | 3.1 | 1.1 | 0.9 |
| Kennedy[2] | 18°20' | 16.9 | 17.0 | 15.9 | 8.8 | 3.6 | 2.0 |
| Cairns | 16°55' | 16.6 | 15.7 | 18.1 | 11.3 | 4.4 | 2.9 |

| Plantation Centre | Altitude (feet) | Jul. | Aug. | Sept. | Oct. | Nov. | Dec. |
|---|---|---|---|---|---|---|---|
| Beerwah | 107 | 2.6 | 1.7 | 2.1 | 4.1 | 4.1 | 6.3 |
| Toolara | 170 | 3.0 | 1.7 | 1.7 | 2.7 | 3.3 | 5.8 |
| Gregory[1] | 250 | 1.8 | 1.3 | 1.6 | 2.1 | 2.7 | 5.1 |
| Bowenia | 50 | 2.3 | 2.0 | 1.3 | 2.3 | 3.4 | 5.6 |
| Cathu | 280 | 0.7 | 0.8 | 0.3 | 1.0 | 4.0 | 7.2 |
| Kennedy[2] | 21 | 1.4 | 1.3 | 1.5 | 2.0 | 4.2 | 8.2 |
| Cairns | 16 | 1.6 | 1.7 | 1.7 | 2.1 | 3.9 | 8.7 |

1 Data for Bundaberg.

2 Data for Cardwell (four miles south of Kennedy).

The overall rainfall pattern is one of heavy summer rain and a relatively dry winter, with the driest part of the year the period from July through to early November. The summer rain is generally heavier and the winters drier in the more northern centres. While Gregory and Cathu conform to this pattern, they are noticeably drier than elsewhere.

Table 2. Mean monthly temperatures and temperature ranges for alternate months at the major exotic forest centres in Queensland (from Queensland Forest Service Records and Anon. (1958)

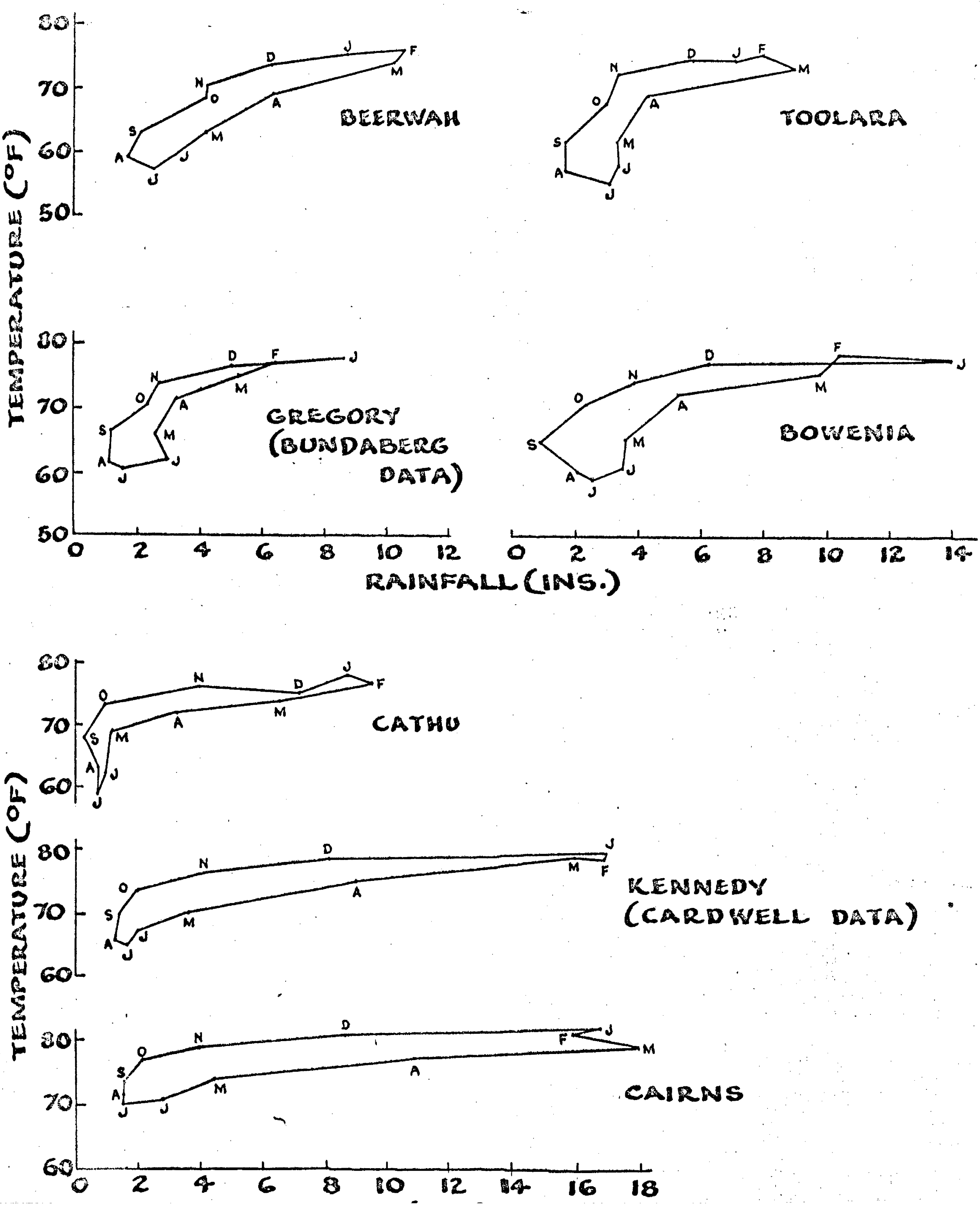
| Plantation centre | Jan. | Mar. | May | July | Sept. | Nov. |
|---|---|---|---|---|---|---|
| | Mean monthly temperature (°F) | | | | | |
| Beerwah | 74.9 | 73.5 | 63.1 | 56.8 | 62.4 | 71.0 |
| Toolara | 74.5 | 73.2 | 62.0 | 55.5 | 61.8 | 71.9 |
| Gregory[1] | 77.8 | 75.7 | 66.1 | 60.4 | 66.4 | 74.2 |
| Bowenia | 77.7 | 76.3 | 65.8 | 58.9 | 65.2 | 74.5 |
| Cathu | 77.6 | 74.3 | 69.1 | 59.2 | 68.0 | 76.5 |
| Kennedy[2] | 80.0 | 78.4 | 70.6 | 65.1 | 70.0 | 76.7 |
| Cairns | 82.0 | 79.9 | 73.8 | 69.9 | 73.6 | 79.2 |
| Plantation centre | Mean monthly temperature range (°F) | | | | | |
| Beerwah | 18 | 17 | 22 | 24 | 26 | 23 |
| Toolara | 18 | 17 | 24 | 26 | 26 | 21 |
| Gregory[1] | 16 | 17 | 20 | 23 | 22 | 18 |
| Bowenia | 16 | 16 | 22 | 26 | 24 | 21 |
| Cathu | not available | | | | | |
| Kennedy[2] | 16 | 16 | 18 | 21 | 22 | 19 |
| Cairns | 16 | 15 | 15 | 17 | 19 | 17 |

1 Data for Bundaberg.

2 Data for Cardwell.

Table 2 shows that mean temperatures increase steadily from higher to lower latitudes except that Toolara is cooler than Beerwah and Bowenia cooler than Gregory. The mean daily temperature ranges (thermoperiods) decrease correspondingly although again Toolara and Bowenia have larger thermoperiods than Beerwah and Gregory respectively.

FIG. 2. CLIMOGRAMS (MEAN MONTHLY TEMPERATURE : MEAN MONTHLY RAINFALL) ILLUSTRATING THE CLIMATES OF MAJOR EXOTIC PLANTATION CENTRES IN QUEENSLAND



Queensland's forests are periodically affected by the tropical cyclones of the south western Pacific Ocean (Swain, 1928). Brouard (1967) describes cyclones as storms revolving round a moving centre of low pressure, the direction of circulation being clockwise in the southern hemisphere. A focus is formed in the low pressure area and the cyclone gathers momentum and strength until reaching maturity; a stage which may last several days. The low pressure centre fills and peters out as the cyclone moves to higher latitudes. Those affecting Queensland usually follow a parabolic path approaching from the north east and moving away to the south east (Swain 1928; Rogers, 1957). Areas close to the path of a cyclone experience heavy rain of the order of several inches in 24 hours, and strong to very strong winds. The wind direction changes during the passage of the cyclone due to its revolving nature, and considerable damage may be caused to the forests.

## Soils.

The soils of the major forest centres are generally derived from mesozoic sandstones south of Bundaberg and lower palaezoic metamorphics elsewhere (Hill and Denmead, 1960) carrying low quality dry sclerophyll eucalypt forest (Hawkins and Muir, 1967).

In the southern coastal area the soils have been broadly classified in to the following main groups, after Coaldrake (1961) and Pegg (1967):-

(i) well drained areas -

(a) red earth residuals:- deep (over 30") sandy loams occupying rolling ridge positions,

(b) lateritic podzolics:- medium (12") to deep (over 30") sandy loam soils with a horizon of lateritic nodules. Clay content increases with depth.

(ii) poorly drained areas -

(a) ground water podzols (hard pan soils):- shallow (10-20") sand with single grain structure over a hard impermeable pan,

(b) podzolic gleys:- shallow silty loams over heavy clay,

(c) gleys or low humic gleys (sandy swamp soils):- deep structureless sands poorly drained due to perched water tables,

(d) humic gleys:- medium to deep organic clay-loam to organic clay over heavy clay.

For the remainder of this thesis the well drained areas will be referred to as "ridge" sites and the poorly drained areas as "swamp"sites.

Similar soil types cover most of the other forest areas (see for example Rogers (1957) description of the Bowenia soils).

To date plantations have been mainly established on the ridge sites but the swamp areas, classified as unplantable, constitute a large part of the forest area enclosed within the fire protection system. This unused land may amount to as much as 40% of the forest (Hawkins and Muir, 1967). Some attempt at planting poorly drained areas are being made (Pegg, 1967; Hawkins and Muir, 1967), but at present these are only intended to supply pulp sized material (Pegg, 1967). Successful establishment of vigorous plantations on these types remains a major problem.

<u>Species.</u>

Pinus elliottii var. elliottii (Slash Pine) and Pinus caribaea (Mor.)

var. *hondurensis* (Caribbean Pine) are the major species in the State's exotic plantations.

In the coastal region south of Bundaberg containing the forests of Gregory, Toolara (And Tuan) and Beerwah (and Beerburrum) *Pinus elliottii* constitutes 89% of the total plantation area of over 44,000 acres and 95% of the current annual planting of 3,600 acres (Anon. 1967).

The northern coastal region includes the plantation areas of Bowenia, Kennedy and Cathu. The total plantation area in this region in 1967 was 8,200 acres of which 67% was *Pinus caribaea* var. *hondurensis* and 31% *P. elliottii* var. *elliottii*. The current annual planting rate is approximately 1,000 acres of which 91% is *P. caribaea* var. *hondurensis*. *P. elliottii* var. *elliottii* is no longer regarded as suitable for this region and only 12 acres were planted with this species in 1966/67 (Anon. 1967).

*Pinus elliottii* var. *elliottii* and *Pinus caribaea* var. *hondurensis*, and associated varieties within each of the two species are referred to in this thesis as the Slash - Caribbean complex. In the following chapters the taxonomic status, and the characteristics of importance to forestry for each of the species and varieties are described.

## Chapter 2. The taxonomy and occurrence of the Slash-Caribbean complex.

The taxonomy of the Slash - Caribbean Pine complex has a confused history which has been summarised in detail by Little and Dorman (1954). The complex is currently classified into the two species *Pinus elliottii* and *Pinus caribaea*. *P. elliottii* is further subdivided into two varieties *elliottii* and *densa* (Little and Dorman, 1954) and *P. caribaea* into three varieties *caribaea*, *hondurensis* and *bahamensis* (Barrett and Golfari, 1962). The occurrence and distribution of these five varieties is shown in Figure 3.

The complexity of the taxonomy involved is well illustrated by a review of the nomenclature that has been accorded these varieties. Shaw (1914) grouped all the present five varieties together as *Pinus caribaea* based on Morelet's description made in 1851 of what is now *P. caribaea* var. *caribaea* from the Isle of Pines, Cuba. The Central American variety (now *P. caribaea* var. *hondurensis*) was segregated and accorded specific rank as *Pinus hondurensis* by Loock (1950). This classification was modified by Little and Dorman in 1954 who proposed the present species demarkation. They regarded the Pines of the complex occurring in the United States of America as *Pinus elliottii* and the others on the islands of the Caribbean and the Mainland of Central America as *Pinus caribaea*, which incorporated and replaced Loock's *Pinus hondurensis*. Little and Dorman also segregated *P. elliottii* into the two varieties *elliottii* and *densa*, mainly on the absence

Table 3. Key to P. caribaea and P. elliottii and varieties after Little and Dorman(1952)

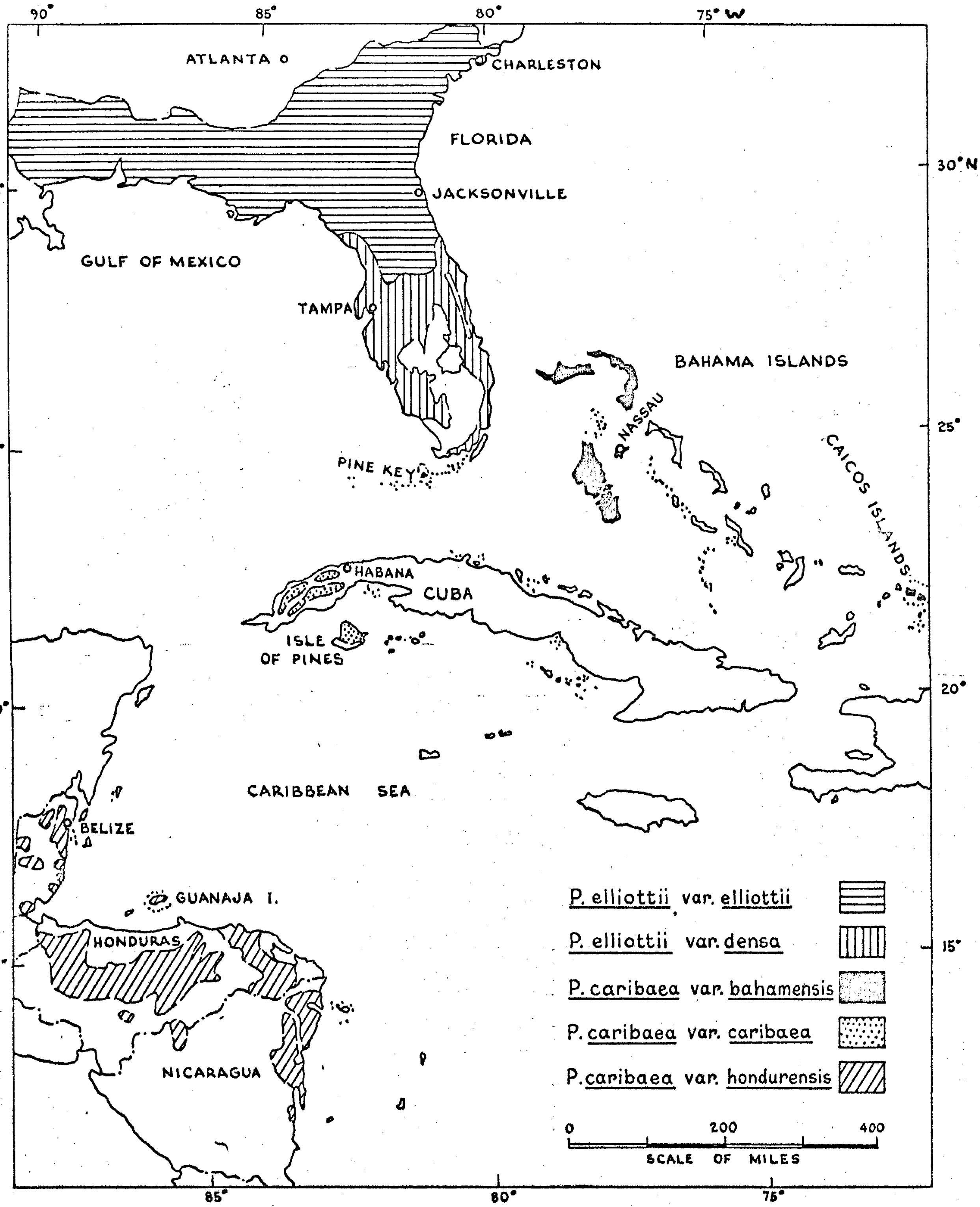
A. Needles in fascicles of 3 (sometimes 4 or 5 on young trees); cones usually small (5-10 cm long), with small weak prickles less than 1 mm long, seeds narrowly ovoid, about twice as long as broad, averaging less than 6 mm long, wings usually remaining attached - *Pinus caribaea* Morelet, Caribbean Pine.

AA. Needles in fascicles of 2 and 3; cones usually larger (7-14 cm long), with stout prickles 1-2 mm long; seeds ovoid, less than twice as long as broad, averaging 7 mm long, wings becoming detached - *Pinus elliottii* Engelm., slash pine - B.

B. Needles in fascicles of 2 and 3; seedling normal with erect, slender, pencil-like stem - *Pinus elliottii* var. *elliottii*, slash pine (typical).

BB. Needles in fascicles of 2 (infrequently 3); seedling with grasslike, almost stemless stage with very short stem, many crowded needles, and thick taproot - *Pinus elliottii* var. *densa* Little and Dorman, South Florida slash pine.

FIG. 3. THE NATURAL DISTRIBUTION OF THE SLASH CARIBBEAN PINE COMPLEX (FROM NIKLES 1966b)



or presence of a grass-stage in the seedlings. The key proposed by Little and Dorman is shown in Table 3. Barrett and Golfari (1962) and also Luckhoff (1964) subsequently divided *P. caribaea* into three varieties *caribaea*, *bahamensis* and *hondurensis*.

Barrett and Golfari's key is detailed in Table 4 and is based mainly on cone sizes, needle numbers for fascicle and adnate or articulate seed wings. Luckhoff's key also given in Table 4 adds the most distinctive difference which is the dark green colour and early production of secondary needles of the *bahamensis* and *caribaea* varieties, compared with the glaucous green colour and later secondary needle production of the variety *hondurensis*. The bushy habit of the variety *caribaea* as young seedlings is also very obvious.

In older trees the differences between all five varieties becomes much less marked and occasionally it is difficult to be sure of the varieties without careful examination.

In *Pinus elliottii* both varieties have dormant winter phases, and a tendency to heavier branching with irregular internodes. All the *Pinus caribaea* varieties have a year round growth habit (Luckhoff, 1964; Slee, Q.F.S. records, unpublished) and a much more uniform appearance to the crown. Variety *caribaea* generally has lighter coloured new shoots and blackish needle fascicle sheaths. Other differences are few.

It is likely that the taxonomy of these pines is not yet completely finalised. Nikles (1966 b) found some evidence of introgression between P. elliottii var. elliottii and P. caribaea var. bahamensis. P. caribaea var. caribaea has a flowering period distinct from the two other varieties of the species, which suggests this variety could require a wider separation from the others (Slee and Nikles, 1967). Luckhoff (1964) felt that in P. caribaea sub-specific classification would have been preferable to the present varietal one. Mirov (1967) regards P. elliottii var. densa as more closely allied to the pines of the Caribbean than to those of the mainland including P. elliottii var. elliottii. The situation is therefore confused.

For the purpose of this thesis, the complex will be regarded as consisting of the five varieties of the two species as defined by Little and Dorman (1954) and Barrett and Golfari (1962). For simplicity, they will be referred to solely as varieties. Thus Pinus caribaea var. hondurensis becomes var. hondurensis and Pinus elliottii var. elliottii simply var. elliottii.

Variety elliottii is found in the south eastern U.S.A. between latitudes $28^{o}$N and $34^{o}$N and extending west from the coast as far as south-eastern Louisiana (Critchfield and Little, 1966). (See Figure 3). Var. densa occurs in Florida from latitude $28^{o}$N to $24^{o}$N (See Figure 3). Climatic data for this region is summarised in Tables 5 and 6 and climograms included in Figure 4. The significant climatic patterns vary continuously over the complete P. elliottii range (Squillace, 1966). Mean January temperatures decrease from $70^{o}$ in South Florida to $50^{o}$ at the northern limits but mean July (summer) temperature is about $80^{o}$ F throughout the region. Thermoperiod increases with movement

Table 4. Keys to varieties of P. caribaea after Barrett and Golfari (1962) and Luckhoff (1964)

a. After Barrett and Golfari.

A. Needles commonly 3 per fascicle, sometimes more.

B. Seeds with adnate wing: needles 3, rarely 4; cones 5 to 10 cm long. Isle of Pines and Pinar del Rio, Cuba.

1. P. caribaea var. caribaea.

BB. Seeds with articulate wing with a low percentage of adnate; leaves 3, sometimes 4 and 5; cones from 6 to 14 cm in length. British Honduras, Guatemala, Honduras, and Nicaragua.

2. P. caribaea var. hondurensis.

AA. Needles 2 and 3 per fascicle; seeds with articulate wing rarely adnate; cones 4 to 12 cm in length. Bahama Islands.

3. P. caribaea var. bahamensis

b. After Luckhoff.

A. Needles in fascicles of 2 or 3 (sometimes 4, very rarely 5 in young trees), resin ducts 7 to 9, less frequently 3 to 4; cones small, averaging 6 to 7 cm long, apophyses generally somewhat swollen and raised along radial lines, or raised along a distinct transverse keel; seeds averaging slightly more than 5 mm long, wings articulate; seedlings relatively slow growing, bright green, with very early (after 3 to 4 months) formation of secondary needles. ...Pinus caribaea Morelet var. bahamensis (Griseb.) Barrett and Golfari.

AA. Needles in fascicles of 3, rarely 4 or 5 in mature trees and very rarely 2, resin ducts typically 3 to 4 (2-7); cones generally 7 to 10 cm long, apophyses typically with well defined transverse keels, seeds 5.7 to 6.5 mm long. . . . . . . . . . . B

B. Seedlings bright green with bushy growth habit and exhibiting very early formation of secondary needles (after 3 to 4 months); seedlings and young trees slow growing; seed wings adnate. ...Pinus caribaea Morelet var. caribaea.

BB. Seedlings slender and glaucous-green, development of secondary needles delayed and only starting after nine months or longer; seedlings and young trees fast growing; seed wings articulate. ...Pinus caribaea Morelet var. hondurensis (Sénéclauze) Barrett and Golfari.

away from the sea from $14^{o}F$ to $22^{o}F$. Rainfall shows distinctive patterns, being equally distributed in the northern parts of the species range whilst the southern areas have a tendency to winter drought and a heavy concentration of summer rain (Squillace, 1966). The climate of central to southern coastal Queensland appears very similar to that of the P. elliottii range from south Florida to Georgia.

Although originally confined to wet sites, both varieties now grow in drier areas due to the fire protection accorded by man (Cooper, 1957).

In Pinus caribaea the variety caribaea is confined to Cuba between latitude $21^{o}N$ and $23^{o}N$. (Barrett and Golfari, 1962; Luckhoff, 1964). The climate is tropical and details for Habana, Cuba, are given in Tables 5 and 6 and the climogram in Figure 4. There is a tendency to a dry winter but rainfall is generally dependable with over two inches in each month. Mean temperatures are between 72 and $82^{o}F$ and vary by only $10^{o}$ annually and $14^{o}$ daily. Large fluctuations and frosts are unknown (Luckhoff, 1964). The variety caribaea is found on fairly shallow well drained soils from sandstones or shales (Luckhoff, 1964).

The variety bahamensis occurs mainly between latitudes $23^{o}N$ and $27^{o}N$. The climate is sub-tropical with details for Nassau given in Tables 5 and 6 and illustrated as a climogram in Figure 4. The rainfall is greatest in the summer and low in winter when a dry period occurs between December and April. Mean temperatures are between $70^{o}$ and $83^{o}F$ and vary little by $10^{o}$ annually and $13^{o}$ daily. Frosts are unknown but tropical cyclones common. Var. bahamensis occurs only on very shallow or skeletal soils derived from limestones (Luckhoff, 1964).

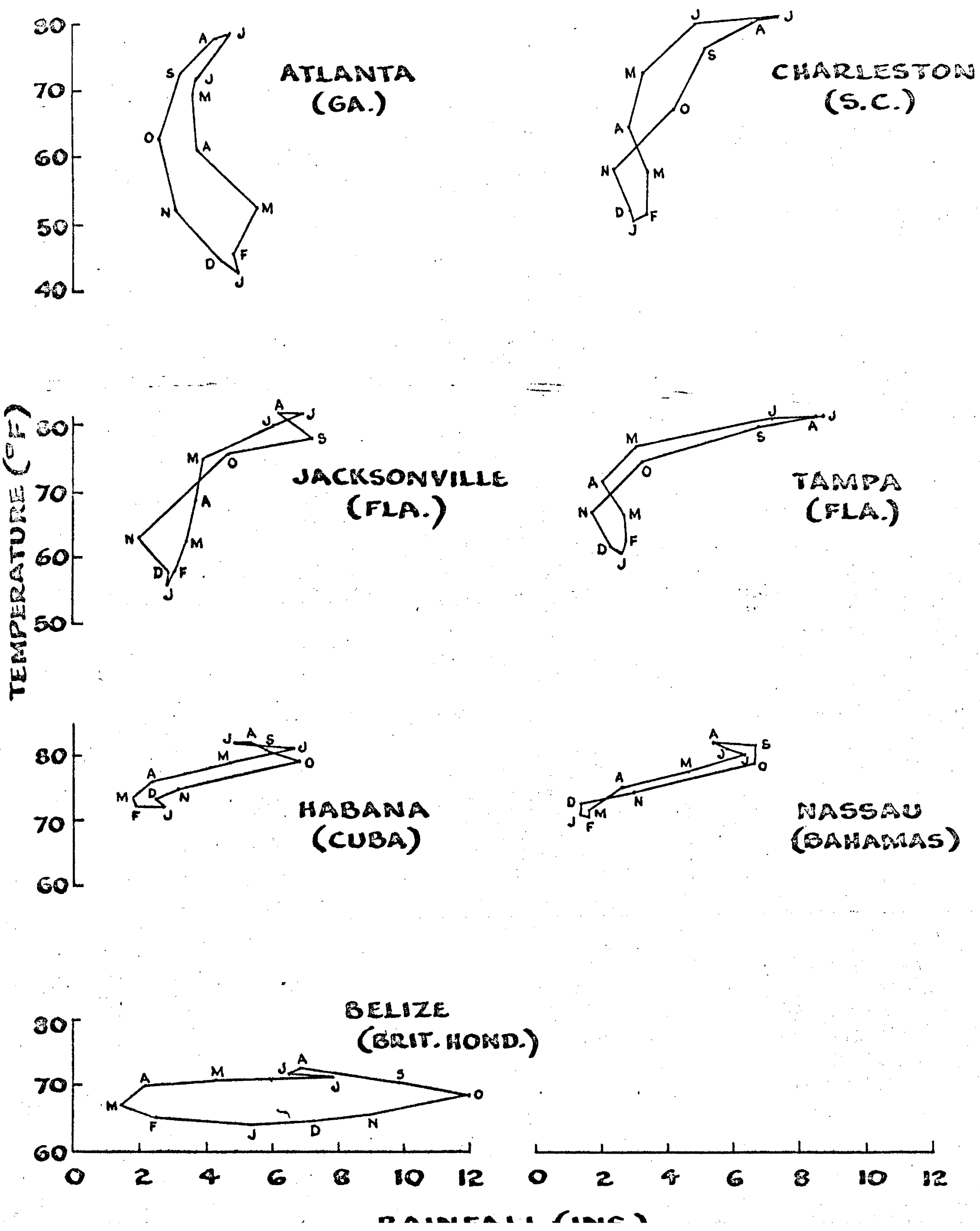
Table 5. Mean monthly rainfall for several centres within the natural ranges of Pinus caribaea and Pinus elliottii (from Anon., 1958)

| Centre | Latitude (°N) | Mean monthly rainfall (inches) | | | | | |
|---|---|---|---|---|---|---|---|
| | | Jan. | Feb. | Mar. | Apr. | May | June |
| var. elliottii | | | | | | | |
| Atlanta (Ga) | 33° 45' | 4.9 | 4.8 | 5.5 | 3.7 | 3.6 | 3.7 |
| Charlston (S.C.) | 32° 47' | 2.9 | 3.3 | 3.4 | 2.8 | 3.2 | 4.7 |
| Jacksonville (Fla) | 30° 20' | 2.8 | 3.0 | 3.3 | 3.7 | 3.9 | 6.0 |
| Tampa (Fla) | 27° 57' | 2.6 | 2.7 | 2.7 | 2.0 | 3.0 | 7.2 |
| var. caribaea | | | | | | | |
| Habana (Cuba) | 23° 08' | 2.8 | 1.8 | 1.8 | 2.3 | 4.7 | 6.5 |
| var. bahamensis | | | | | | | |
| Nassau | 25° 05' | 1.4 | 1.5 | 1.4 | 2.5 | 4.6 | 6.4 |
| var. hondurensis | | | | | | | |
| Belize | 17° 31' | 5.4 | 2.4 | 1.5 | 2.2 | 4.3 | 7.7 |
| **Centre** | **Altitude ft.** | **July** | **Aug.** | **Sept.** | **Oct.** | **Nov.** | **Dec.** |
| var. elliottii | | | | | | | |
| Atlanta | 1054 | 4.7 | 4.3 | 3.2 | 2.6 | 3.1 | 4.5 |
| Charlston | 9 | 7.3 | 6.6 | 5.1 | 3.2 | 2.3 | 2.8 |
| Jacksonville | 18 | 6.9 | 6.2 | 7.2 | 4.6 | 2.0 | 2.9 |
| Tampa | 35 | 8.7 | 8.6 | 6.3 | 2.8 | 1.7 | 2.3 |
| var. caribaea | | | | | | | |
| Habana | 80 | 4.9 | 5.3 | 5.9 | 5.8 | 3.1 | 2.3 |
| var. bahamensis | | | | | | | |
| Nassau | 12 | 5.8 | 5.3 | 6.9 | 6.5 | 2.8 | 1.3 |
| var. hondurensis | | | | | | | |
| Belize | 17 | 6.4 | 6.7 | 9.6 | 12.0 | 8.9 | 7.3 |

Table 6. Mean monthly temperatures and temperature ranges by alternate months for several centres within the natural ranges of P. caribaea and P. elliottii (from Anon., 1958)

| Centre | Mean monthly temperature (°F) | | | | | |
|---|---|---|---|---|---|---|
| | Jan. | Mar. | May | July | Sept. | Nov. |
| var. elliottii | | | | | | |
| Atlanta | 43 | 53 | 70 | 79 | 78 | 52 |
| Charlston | 51 | 58 | 73 | 82 | 77 | 59 |
| Jacksonville | 56 | 63 | 75 | 82 | 78 | 62 |
| Tampa | 61 | 67 | 77 | 82 | 80 | 67 |
| var. caribaea | | | | | | |
| Habana | 72 | 74 | 79 | 82 | 81 | 75 |
| var. bahamensis | | | | | | |
| Nassau | 71 | 73 | 78 | 82 | 82 | 76 |
| var. hondurensis | | | | | | |
| Belize | 74 | 78 | 81 | 81 | 81 | 76 |
| **Centre** | **Mean monthly temperature range (°F)** | | | | | |
| var. elliottii | | | | | | |
| Atlanta | 16 | 19 | 19 | 17 | 17 | 18 |
| Charlston | 15 | 16 | 16 | 13 | 12 | 15 |
| Jacksonville | 18 | 18 | 16 | 16 | 15 | 17 |
| Tampa | 18 | 18 | 18 | 15 | 16 | 18 |
| var. caribaea | | | | | | |
| Habana | 14 | 14 | 14 | 14 | 13 | 12 |
| var. bahamensis | | | | | | |
| Nassau | 12 | 13 | 13 | 13 | 13 | 11 |
| var. hondurensis | | | | | | |
| Belize | 14 | 13 | 12 | 12 | 13 | 15 |

FIG. 4. CLIMOGRAMS OF REGIONS WITHIN THE NATURAL RANGES OF Pinus elliottii AND Pinus caribaea



The variety hondurensis has a fragmented distribution scattered through several countries of Central America between latitudes 12°N and 18°N. Although generally within 80 miles of the Atlantic coast, it is found at altitudes as high as 2,500 feet, and is the only variety of the complex to occur at any but low altitudes. The climate is generally tropical with a dry to semi-dry winter. Details for Belize, British Honduras are given in Tables 5 and 6 and diagrammatically in Figure 4. Winters are generally dry and summers wet. At Belize, mean temperatures range between 74 and 81°F with daily ranges of the order of 12-15°. The variety grows on a wide range of soil types. (Luckhoff, 1964).

Thus there is a distinct difference between the climatic conditions of the P. elliottii range and that of the P. caribaea. Summer temperatures are not appreciably different but winter is warmer in the P. caribaea range, and temperature fluctuations less. Rainfall has a tendency to become more seasonal in the P. caribaea areas with summer wet and winter dry periods.

Coastal Queensland differs from most of the P. caribaea areas, particularly the var. caribaea and the var. bahamensis regions in having an even more seasonal rainfall and a much greater temperature variation.

## Chapter 3. The Important characteristics of the Slash - Caribbean complex

Both the major varieties elliottii and hondurensis have some features of considerable economic importance and some in which improvement would be desirable.

Var. elliottii exhibits inter-provenance variation both in America (Squillace, 1966) and Queensland (Slee and Reilly, 1966). But as all Queensland's seed supplies are collected locally from what was originally a central Florida provenance (Slee and Reilly, 1967) variation in performance due to provenance variation is not found within the bulk of the State's plantations.

Var. elliottii has excellent stem straightness, usually producing 74% of the total stems of a straightness standard sufficiently high to justify pruning. (Q.F.S. records).

The wood quality of the species is also satisfactory having a basic density of 25.99 lb.per cu. ft., a latewood percentage of 31.8 and a tracheid length of 3.48 in. at age 11 years at Beerwah (Dadswell and Nicholls, 1959). It is likely however that these figures vary in different localities. Scott (1952) has reported such variation in the variety in South Africa.

The variety characteristically inhabits poorly drained areas with shallow sandy soils in its natural range (Cooper, 1957) and has given fairly satisfactory results on many of the swamp soils in Queensland particularly when site preparation by draining or mounding has taken place. The growing of pulp crops on such sites is now planned (Pegg, 1967).

The vigour of the variety is good. In the early years following planting the variety has average increments of nearly four feet per annum in height (Rogers, 1957) and basal area increment at age ten years can be as high as 16 sq. ft. per acre per annum (Bevege, 1965; Robinson, 1967). However later vigour shows a marked decline to between 2.1 and 3.4 sq. ft. per acre maximum basal area increment at age 35 years. (Bevege, 1965; Robinson, 1967) and some concern is felt as to whether it is possible to attain the management objective of 80 stems per acre with a girth at breast height[1] (g.b.h.) of 60 inches in a reasonable rotation period (Robinson, 1967). Thus late rotation vigour in the variety is very seriously wanting.

In the more northern areas of the State the vigour of the variety elliottii declines. Thus at age 15 years at Bowenia on a most fertile well drained site the variety had a mean height of 48 feet whilst at Beerwah on a site of poorer fertility comparable var. elliottii had a mean height of 55 feet (Queensland Forest Service (Q.F.S.) records). Consequently plantations of var. elliottii are now limited to areas south of Bundaberg.

Var. elliottii is also liable to damage by wind, particularly those associated with tropical cyclones. Generally only young trees are affected and these are pushed into a leaning position by the wind. This is rectified manually by standing the tree back in a vertical position and firming the soil at the base (Slee and Nikles, 1967). Following a cyclone in January 1967, 1460 acres of var. elliottii had to be treated in this manner at a cost of $5,341 (Q.F.S. records).

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1 Breast height is defined as four feet three inches above ground level.

Very little data is available for the performance of var. densa. This variety appears to be a more tropical form of var. elliottii, retaining most of that variety's characteristics whilst growing in warmer environments. Thus Nikles (1966 b) found no difference between these two varieties in tracheid length in samples collected within the varieties' natural ranges, but in the same study mean specific gravity of var. densa was slightly higher than that of var. elliottii.

Var. densa is known to grow faster than var. elliottii in the more northern areas of Queensland. In a 1952 planting at Bowenia at age 15 years var. densa had a predominant height[1] of 54 feet whilst associated var. elliottii was three feet lower (Q.F.S. records). Similar results have been reported from Zambia (Lamb, 1965). This greater vigour of var. densa in the more tropical localities may be useful if the var. elliottii characteristics are expressed in this variety and are considered desirable for plantations in central and northern coastal Queensland.

P. caribaea var. hondurensis exhibits considerable variation depending both on the seed source and the planting locality (Nikles, 1962; Luckhoff, 1964; Slee and Nikles, 1967). Very nearly all Queensland's plantings are from seed originating from the Mountain Pine Ridge area of British Honduras, but several trial plantings have provided details of provenance variation (Nikles, 1962; Slee and Nikles, 1967).

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1 Predominant Height - Mean height of twenty tallest trees per acre.

Vigour of the P. caribaea varieties is generally excellent and there is little inter-provenance variation. McWilliam and Richards (1955) report average early growth rates in Queensland of over 3 feet per year whilst Slee and Nikles (1967) quote figures of over 5 feet. This latter figure is taken from sites representative of those on which var. hondurensis is usually planted whilst McWilliam and Richard's figure of 3 feet includes material on shallow poorly drained sites. An average early growth rate of over five feet per year may be regarded as typical of all provenances tested in Queensland and a high subsequent growth rate is maintained. At Kennedy in North Queensland (See Figure 3) a 13 year old plot of Mountain Pine Ridge provenance at a stocking of 340 stems per acre had a predominant height of 79 feet, a mean girth at 4 feet 3 inches of 32.8 inches and a standing merchantable volume of 40,300 super. feet Hoppus per acre (Anon., 1966).

It is accepted in Queensland that var. hondurensis will not grow well on poorly drained shallow, or poorly aerated sites although no reports have been published. This agrees with similar reports from elsewhere (Poynton, 1967; Lamb, 1965; Yeom, 1966). Var. hondurensis cannot therefore be planted successfully in the swampy locations.

The straightness of var. hondurensis is generally poor, and may be very bad in some provenances, particularly those from the Republic of Honduras (Nikles, 1962; Slee and Nikles, 1967). Even the best provenances at Beerwah only produce 21% of stems of a straightness standard high enough to justify pruning; although this does improve in more northern locations (Slee and Nikles, 1967). Consequently it is difficult to find sufficient trees to satisfy the

Queensland policy of pruning 120 stems per acre at the present planting spacing of 9 feet x 8 feet. Improvement in stem straightness is therefore regarded as a most important requirement in this variety.

Var. honduransis is also regarded in Queensland as more liable to wind damage than var. elliottii, although no comparative studies have been made. This is confirmed by observations in Fiji (Lamb, 1965). There is evidence in Queensland of considerable inter-provenance variation in wind-firmness with material from the Republic of Honduras being most liable to damage. (Slee and Reilly, 1966; Slee and Nikles, 1967).

The wood quality of the variety in Queensland plantations is still largely unknown as the trees are too young. Slee and Nikles (1967) have assembled the available data compiled by Schmidt, Smith and Eccles of the Queensland Forest Service. Large variations occur in latewood percentage with consequent variations in basic density depending on the outplanting locality. Areas subject to seasonal drought produced trees with more latewood and higher basic density than localities with more equable climates.

The latewood percentage in 10 year old trees in Queensland varied between 6% and 29%, basic density between 24.06 and 29.00 lb. per cu. ft.and tracheid length between 2.96 and 3.16 mm. Luckhoff (1964) regards the var. hondurensis in South Africa as more uniform in texture and density than comparable var. elliottii and as less resinous outside the core, with a lighter colour, better working properties and less twist. Luckhoff also records serious degrade due to resin infiltration of the core wood and there are reports of poor pulping results with the species in South Africa (Luckhoff, 1964) and Malaya (Palmer and Peh, 1967).

A better pulp was produced in Fiji (Chittenden et al, 1967).

On the basis of the available data from South Africa (Luckhoff, 1964) and Queensland, Slee and Nikles (1967) feel that var. hondurensis may be best suited to tropical lowlands between latitudes $17^{o}$ and $26^{o}$.

The performance of the other two varieties, caribaea and bahamensis in Queensland is less well documented.

Var. caribaea is known to grow slowly initially but after the third year to attain a growth rate comparable to var. hondurensis, and this has so far been maintained to five years of age (Slee and Nikles, 1967). The variety also exhibits even better stem straightness than P. elliottii both in Queensland (Slee and Nikles, 1967) and South Africa (Luckhoff, 1964).

In southern Queensland, var. bahamensis equals var. hondurensis in rate of height growth but in northern regions there are indications that growth is inferior (Slee and Nikles, 1967). The stem straightness of the variety is excellent and comparable with var. elliottii and wind-firmness may be superior to var. hondurensis and var. caribaea (Slee and Nikles, 1967).

Both var. caribaea and var. bahamensis are known to be more resistant to frost damage than hondurensis. (Nikles, 1966; Slee and Reilly, 1966). Both varieties have wood apparently similar to var. hondurensis and are also liable to severe resin impregnation in the core (Slee and Nikles, 1967). The pulping qualities of var. caribaea are reported as unsatisfactory in South Africa (Luckhoff, 1964).

Slee and Nikles (1967) feel that var. bahamensis is best suited to sub-tropical lowlands between latitudes 23° and 31° and var. caribaea possibly to slightly lower latitudes.

In summary therefore, P. elliottii var. elliottii is limited to the southern regions of the State, has satisfactory wood qualities and early vigour even in poorly drained sites. The variety has excellent stem straightness but lacks late-rotation vigour. Any improvements on wind-firmness would be advantageous.

P. elliottii var. densa is not well known but is probably more vigorous than var. elliottii in more tropical regions.

P. caribaea var. hondurensis grows well throughout the State except on shallow or poorly drained sites. The variety's vigour is outstanding but it has poor stem straightness and wind-firmness. The wood qualities vary with the locality but in areas with equable climates timber may have low latewood percentage and lack strength. Resin impregnation of the core wood may also be a problem, and pulping properties, although untested in Queensland, are generally poor elsewhere.

The other varieties of P. caribaea are also very vigorous but var. caribaea is inferior to hondurensis in the first year of the rotation and var. bahamensis may be in tropical areas. Both have excellent straightness and bahamensis may be slightly more wind-firm than the other two varieties of P. caribaea.

In many characteristics therefore the five varieties are complementary; one desirable characteristic lacking in one variety may be present in another and vice-versa. For example P. elliottii var. elliottii has good wet site tolerance but is comparatively slow growing whilst the fast growing P. caribaea var. hondurensis lacks the ability to grow on shallow poorly drained areas. A combination of the two could be envisaged as a fast growing species suitable for poorly drained sites.

As such combinations could result from hybridization, hybrids within the complex, may have considerable value in Queensland, particularly as the environments in which these varieties grow well overlap in the southern - central region of the State. Not only therefore could the hybrids complement each other but they could also be well suited to parts of Queensland.

## Chapter 4. History of hybrid establishment in Queensland and details of the material available for study.

Interest in the potential of hybrid stock, particularly that between var. elliottii and var. hondurensis, followed the investigations of McWilliam and Richards (1955) into the growth patterns of these two varieties. The very fast growth and the lack of a dormant phase in var. hondurensis were seen as desirable characters to introduce into var. elliottii. The first hybrids between these varieties were therefore made by controlled pollination in 1955, and the resulting seedlings outplanted at Beerwah forest in 1958 on both a well drained and a poorly drained site.

The early results of this trial were most promising (Nikles, 1962). The hybrid exhibited outstanding vigour on both sites and also improved straightness over the var. hondurensis.

Following this early promise, additional hybrids have been produced articically with selected breeding trees of P. elliottii var. elliottii as cone parents crossed with pollen of P. caribaea var. hondurensis, also from the best quality trees available. The resulting seedlings have all been outplanted at Beerwah, except in 1963 and 1966 when plantings were made at Bowenia. In 1966 a small trial was also established at Cathu on a swamp site. The 1963 planting of the hybrid at Bowenia was associated with outplanting of other hybrid derivatives, and the 1966 planting with other hybrids of the complex. The Cathu planting represents the most northerly planting of any hybrids in the complex.

The reciprocal cross var. hondurensis x var. elliottii was made artifically in 1960, the seed collected in 1962 (Nikles, 1964) and the resulting seedlings incorporated in the 1963 planting.

The 1958 planting of var. elliottii x var. hondurensis hybrids flowered in 1960 and allowed the production of second generation hybrids and also backcrosses to the parental varieties. These hybrid derivatives were outplanted in 1963 at both Beerwah and Bowenia and again at Beerwah the following year.

Naturally maturing cones on var. elliottii x var. hondurensis hybrids were also collected in 1963. These could have resulted from pollination by the surrounding full-sib hybrids or else by early pollen fly from var. elliottii. The resulting seedlings, presumably a mixture of trees with hybrid x hybrid and hybrid x var. elliottii parentage were incorporated into the 1964 planting at Beerwah.

The earliest plantings in Queensland of var. caribaea and var. bahamensis flowered in 1963 and permitted the initiation of a complex series of inter-varietal crosses. This series included the two P. elliottii varieties as well as the three of P. caribaea. The first outplanting of the complex was made in 1966 at both Beerwah and Bowenia.

The details of these experimental plantings covering locations, soil types, and the seed batches have been summarized in Table 7; (a seed batch being either a full or half-sib family from selected breeding trees or else a portion of a seed collection, made locally or imported, for general use). Table 8 summarizes the layouts used for each planting. Full details of these plantings are provided in Appendix 1.

Table 7. Details of the experimental plantings of the hybrids and parental controls in the Slash-Caribbean complex, showing dates of establishment, locations, site types, and the original seed batches of each included

| Date planted | Location[1] | Soil type[2] | Hybrids and parental controls represented and the number of batches of each included[3] | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | X | EX | CH | XE | XH | XX | E | H | C |
| 1958 | Be | R, S | 1 | - | - | - | - | - | 2 | 1 | - |
| 1961 | Be | R | 1 | - | - | - | - | - | 1 | 1 | - |
| 1962 | Be | R | 2 | - | - | - | - | - | 1 | 1 | - |
| 1963 | Be | R, S | 5 | - | - | 2 | 1 | 1 | 3 | 2 | - |
| 1963 | Bo | R | 3 | - | - | - | 1 | - | 3 | 1 | - |
| 1964 | Be | R, S | 7 | - | - | 1 | 2 | - | 1 | 1 | - |
| 1966 | Be | R | 5 | 6 | 3 | - | - | - | 3 | 1 | 2 |
| 1966 | Bo | R | 1 | 3 | 3 | - | - | - | 2 | 1 | 2 |
| 1966 | C | S | 1 | - | - | - | - | - | - | 1 | - |

1 Be = Beerwah; Bo = Bowenia; C = Cathu

2 R = Ridge planting; S = Swamp planting

3 For details of coding used see Part II Chapter 4.

For simplicity in the presentation of tables throughout this thesis the followi coding has been adopted to represent the various hybrids and the parental varieties.

E - var. elliottii
H - var. hondurensis
C - var. caribaea
B - var. bahamensis
D - var. densa
X - var. elliottii x var. hondurensis hybrid (F1)
XH - backcross (var. elliottii x var. hondurensis) x var. hondurensis
XE - backcross (var. elliottii x var. hondurensis) x var. elliottii
XX - F1 hybrid x F1 hybrid (var. elliottii x var. hondurensis)
XO - open pollinated hybrid (var. elliottii x var. hondurensis)
EC - var. elliottii x var. caribaea hybrid (F1)
CH - var. caribaea x var. hondurensis hybrid (F1)
ES - progeny of selected breeding trees of var. elliottii (1958 planting only)

Table 8. Summarized details of the layouts and treatments included by site types in the experimental hybrid plantings (for coding used see Part II Chapter 4)

| Date planted (location) | Site type | No. rand. blocks | No. batches | Batch patentage | Plot size | Tree spacing |
|---|---|---|---|---|---|---|
| 1958 (Be) | R, S | 5 | 4 | X, E, ES, H | 3 x 10 | 8′x 8′ |
| 1961 (Be) | R | 4 | 3 | X, E, H | 7 x 7 | 8 x 8 |
| 1962 (Be) | R | 3 | 3 | X, E, H | 8 x 8 | 8 x 8 |
| | R | 4 | 4 | 2X, E, H | 1 x 8 | 10 x 10 |
| 1963 (Be) | R | 5 | 5 | X, E, XH, XE, H | 6 x 7 | 10 x 10 |
| | S | 5 | 6 | X, E, XH, XE, H, B | 1 x 10 | 10 x 10 |
| 1963 (Bo) | R | 4 | 4 | X, XH, E, H | 7 x 7 | 9 x 8 |
| | R | 5 | 4 | X, XH, E, H | 1 x 10 | 10 x 10 |
| 1964 (Be) | R | 2 | 6 | X, XH, E, XO, XX, H | 7 x 7 | 10 x 10 |
| | R | 2 | 9 | 4X, E, H, XO, 2X | 1 x 10 | 10 x 10 |
| | S | 1 | 9 | 4X, E, XX, XO, XH, H | 7 x 7 | 10 x 10 |
| | S | 3 | 6 | 2X, E, XO, XH, H | 1 x 10 | 10 x 10 |
| 1966 (Be) | R | 3 | 6 | 2EH, 2EC, CH, H, E, C | 7 x 7 | 10 x 10 |
| | R | 3 | 6 | 2EH, 2EC, CH, H, E, C | 7 x 7 | 10 x 10 |
| | R | 1 | 3 | E, 2EC | 7 x 7 | 10 x 10 |
| 1966 (Bo) | R | 3 | 7 | X, 2CH, H, EC, C, E | 7 x 7 | 10 x 10 |
| | R | 3 | 6 | 2EC, CH, H, E, C | 7 x 7 | 10 x 10 |

In all plantings the var. elliottii used both as the pure variety and for the hybrids was of local Beerwah origin and is therefore of central Florida, U.S.A., provenance with some adaption to south-eastern Queensland's conditions. Similarly, the var. hondurensis material originated from the Mountain Pine Ridge area of British Honduras. In some cases, this var. hondurensis stock came directly from imported seed, in others the seed or pollen came from plantations at Cairns, north Queensland or Bowenia - central Queensland.

The var. caribaea was exclusively material from five selected trees at Banyabba Forest, N.S.W. Australia (latitude $29^{o}$ 30'S), selected in 1957 as having the best straightness and vigour in small trial plot aged 23 years. Grafts of all five were established at Bowenia in 1958 and provided the material for pollination work carried out in 1963 and subsequent years.

Very little has been done with var. bahamensis. The only material available was planted in 1961 at Bowenia and this originated from Grand Bahama Island. Thus the few results obtained are based on material from this provenance.

The hybrids have been produced by artificial pollinations using the technique described by Mergen et al (1955). In some cases, the cone parents were sufficiently far from an effective source of pollen to obviate the need for the use of the isolation bags. The pollen was therefore applied without bagging. This was done at Beerwah in 1960 on var. elliottii grafts aged four years in the seed orchard, one var. hondurensis graft aged two years, and on the hybrids planted in 1958. In the seed orchard no significant pollen contamination could occur due to an isolation of several miles (Florence, 1955). In the other instances, the surrounding trees were too young to produce sufficient pollen. The consequent

F1 hybrid and backcrosses from the 1958 hybrids were out-planted in 1963.

The Beerwah plantings have been on both the ridge and the swamp site types. In the other centres of Bowenia and Cathu the planting sites have also been designated as ridge or swamp, whichever approximates most closely to that actually utilized.

The silvicultural techniques employed in the establishment of var. elliottii and var. hondurensis forests in Queensland have been described by Rogers (1957). With some minor variations, the hybrids plantings have received the same treatment as var. hondurensis.

The hybrids are planted as tubed stock in the period January - March, this being the wettest and warmest part of the year (see Figure 2 and Tables 1 and 2). The spacing between trees has varied (Table 8). Initially the hybrids were accorded the same treatment as the routine plantations. Thus a spacing of 8 feet x 8 feet was adopted at Beerwah, a var. elliottii centre, and 9 feet x 8 feet, that usual for hondurensis, at Bowenia. However, from 1963, onwards, a 10 feet x 10 feet spacing has been used. This 10 feet x 10 feet spacing allows all trees to be retained to age 10 years or more, and also facilitates comparisons of complete populations over this long period. This spacing also allows a direct comparison of performance with var. elliottii seed orchard material planted for experimental purposes at 10 feet x 10 feet spacing and carried through to an age of 13 years, without thinning.

At Beerwah, but not elsewhere, one fertilizer application of rock phosphate is applied in the early years following planting at a rate of $2\frac{1}{2}$ cwt. per acre. In the older hybrid experiments as each batch attained sufficient size, pruning was carried out on all stems. The ground pruning to 8 feet was applied when all but a few stems were 20 feet in height. Subsequent prunings to 12 feet 6 inches and 16 feet followed at one or two yearly intervals on the best 120 stems per acre selected on the basis of straightness and vigour.

The oldest planting, that established in 1958 at Beerwah, at 680 s p a (8 feet x 8 feet spacing) was thinned to 400 s p a in 1964. All other plantings have been retained at their original stocking.

## Chapter 5. The experimental approach to determining hybrid potential

By 1965 a considerable quantity of data relating to species and hybrid performance was available and an initial survey of the components of the hybrid complex could be made.

The status and potential of the hybrids of the complex were considered to depend on whether they achieved or more nearly achieved the aims of the tree breeders in Queensland and if so whether they could be produced in sufficiently large quantities to permit their general use.

The aims of the breeders have been defined (Part I) as the development of higher yielding material due to an improved physiological efficiency, the development of new material for new areas and the improvement of the economically important characteristics of the material. A study of growth pattern and general characteristics of the components of the species and hybrid complex was therefore undertaken to assess the extent to which these aims were being achieved.

The growth patterns were considered to be of importance as physiological efficiency obviously depends to some extent on the relationship between growth patterns and the environment. Consideration of this relationship and its interpretation for other environments would also suggest the range over which any improved physiological efficiency could be maintained. In practice it was found that the height growth pattern was reflected in the whorl pattern of var. elliottii and a study of var. elliottii trees at several different centres enabled firm conclusions to be drawn concerning the relationship between the growth pattern of var. elliottii and the environment. This provided additional grounds for theoretically assessing the hybrid's potential range over which improved physiological efficiency would be exhibited. Moreover growth patterns are known to be strongly associated with the density of wood produced (Zahner, 1963; Kramer, 1964 and others) and these studies would therefore be expected to yield information on wood properties.

The silvicultural characteristics studied were those considered to be of economic importance in that they affected wood yield and wood quality. These were vigour, stem straightness, wood density and branch size. These are all features in which improvement is generally considered to yield valuable returns. As such they are frequently listed important characters which should be considered when selecting and assessing trees for their breeding qualities (see for example Fielding, 1957; Matthews and McLean, 1957). All receive consideration in selecting breeding trees in Queensland. For example when comparing selected breeding trees under the Queensland points system, eighty points are awarded for vigour, stem straightness and branch size out of a possible total of 100 (Slee and Reilly, 1967).

Wind-firmness was also studied in view of the high cost of rectifying wind damage in young Queensland plantations.

Studies were also made in the root distribution of the hybrids in comparison with the parental varieties in view of the obvious importance of this in the growth on shallow sites and the association with wind-firmness (Mergen, 1954).

Sufficient material was available to permit detailed study only for the var. elliottii x var. hondurensis hybrid (Table 7). Studies were made on the material available in the other hybrids of the complex, but most deductions for these have followed the determination of the inheritance pattern in var. elliottii x var. hondurensis. Where a particular character is shown to be of an intermediate nature in this hybrid it is presumed to be similarly intermediate in other hybrids of different parentage.

Finally, crossability patterns within the complex were determined as far as possible to gain some conception of whether the hybrids or hybrid derivatives could be mass produced at reasonable cost and of the methods that might appropriately be used.

# PART III

## STUDIES ON THE SLASH-CARIBBEAN COMPLEX IN QUEENSLAND

## Chapter 1. Pattern of growth

### Material.

Material used for studies of seasonal growth pattern must be so located as to permit frequent and numerous measures. This study was limited therefore to the one centre (Beerwah) where periodic measures of height and girth could be readily made.

(a) Height growth study. The height growth study was commenced in mid-1965 using stock outplanted early in 1964; this was the most comprehensive planting available containing stock of a suitable size. The planting contained the var. *elliottii* x var. *hondurensis* hybrid, the backcross from this hybrid to var. *hondurensis*, open-pollinated material from the same hybrid and the parental controls; all varieties, hybrids and derivatives were established on both a ridge and a swamp site. Full details of this planting are given in Appendix 1.

A height growth study was not carried out on the swamp planting as this was still in the establishment phase and would not have given a true picture of seasonal height growth. However, some effect of site could be measured as it was possible to demarcate the ridge planting into two sections; in one section, the plants had been influenced by an ash-bed but in the other section the ash-bed effect had been negligible.

The ash-bed effect is not fully understood, but tree growth in ash-beds resulting from the pre-planting burn of the residue of the original forest, show significantly increased vigour in their early years. Humphreys and Lambert (1965) and Cromer (1967) have examined this phenomenon. The former noted an increased availability of phosphorus and the latter suggested the improved fertility was due to the increased ash and also the soil heating.

For the purpose of this study, the site with an ash-bed effect was classified as a "plus site", whilst unaffected areas were regarded as an "average site".

On each "site type" individual 49-tree plots were selected containing seedlings with the following parentages.

Plus Site:-

var. hondurensis
var. elliottii
F1 Hybrid (G21[1] x C53[1])
Backcross (F1 Hybrid x C51)
F1 Hybrid open-pollinated

Average Site:-

var. hondurensis
var. elliottii
F1 hybrid (G21 x C51)
Backcross (F1 hybrid x C51)

The height study showed var. elliottii to have growth pattern reflected in the branch pattern. The first inter-whorl in each growing season is distinctive. This is above the heavy branches produced by the overwintering buds and is longer than the subsidiary later season inter-whorls. This allows the number of whorls produced in any one year's growth to be determined (see Figure 5). To compare the growth patterns at different centres an investigation was made of the whorl production of var. elliottii at 24 different

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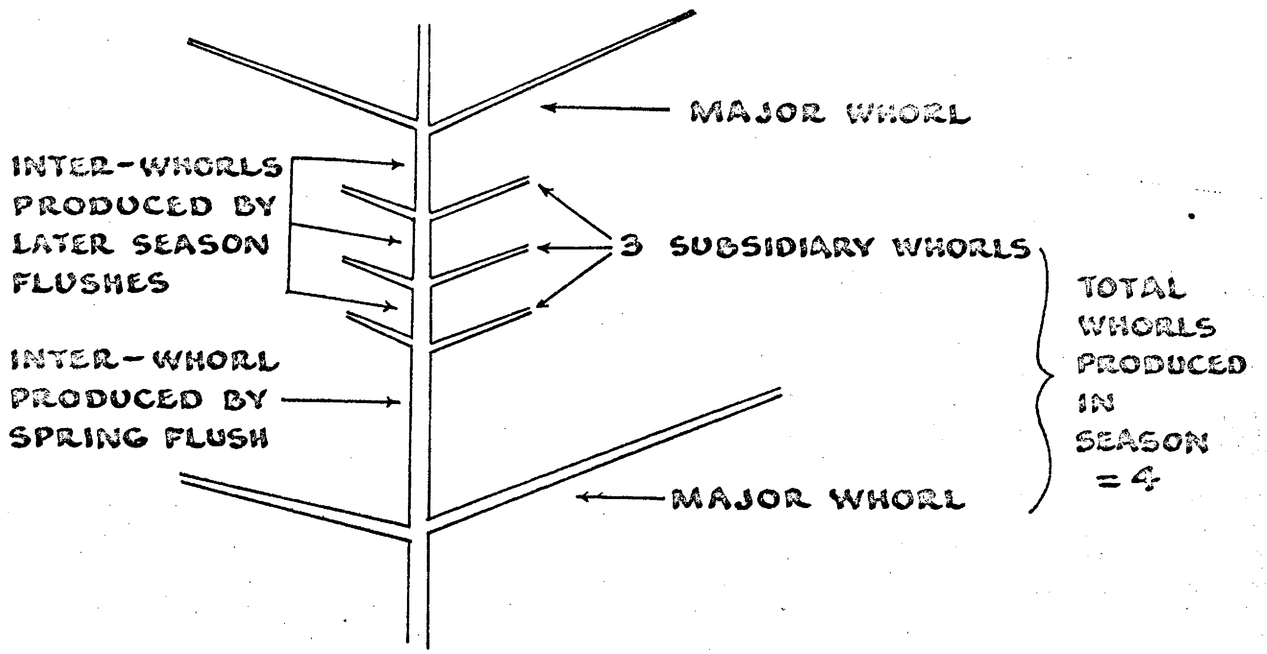
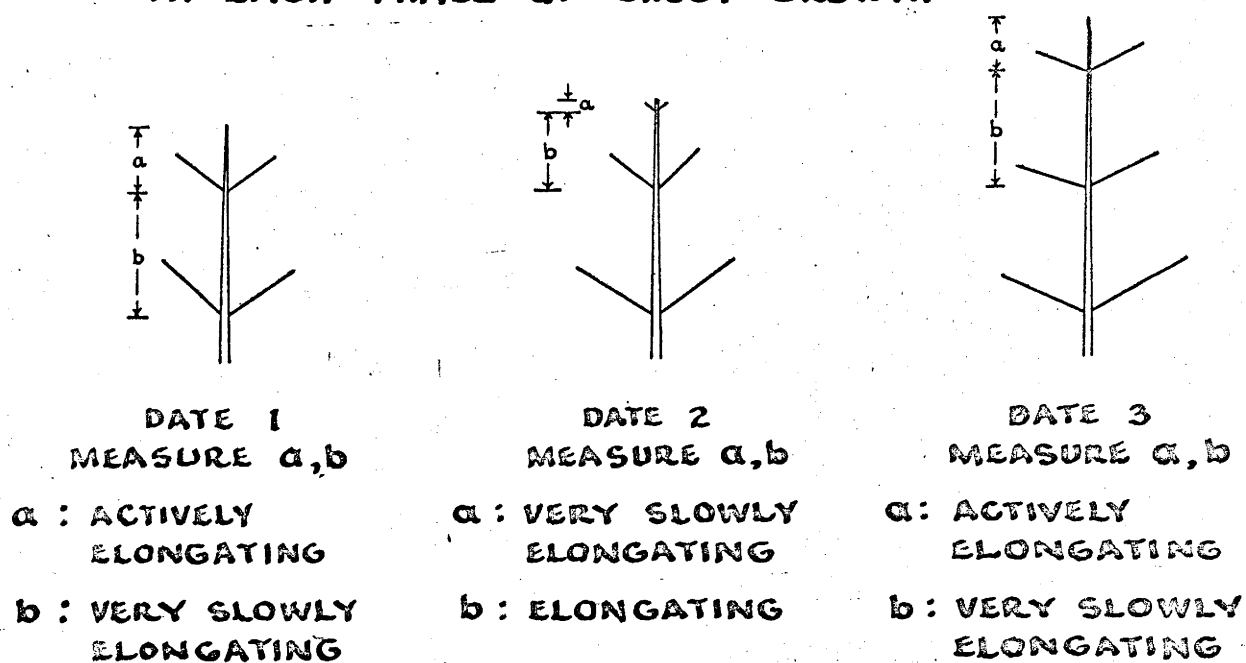
1 The numbers used indicate individual plus trees of the species involved. G indicates a tree of var. elliottii, C one of var. hondurensis or var. caribaea. The first tree referred to is the cone parent.

FIG. 5: DIAGRAM OF THE WHORL PATTERN OF *Var. elliottii* SHOWING MAJOR AND SUBSIDIARY WHORLS AND NUMBER OF WHORLS PRODUCED IN ONE SEASON




TOTAL NUMBER OF WHORLS PRODUCED IN SEASON = 4

FIG. 7. DIAGRAM SHOWING THE LENGTHS MEASURED AT EACH PHASE OF SHOOT GROWTH



locations in Queensland from Beerwah to Cathu. These are detailed in Figure 6.

(b) Girth growth study. In 1966, when the girth growth study was initiated, the only material large enough for accurate girth measures was the 1958 planting.

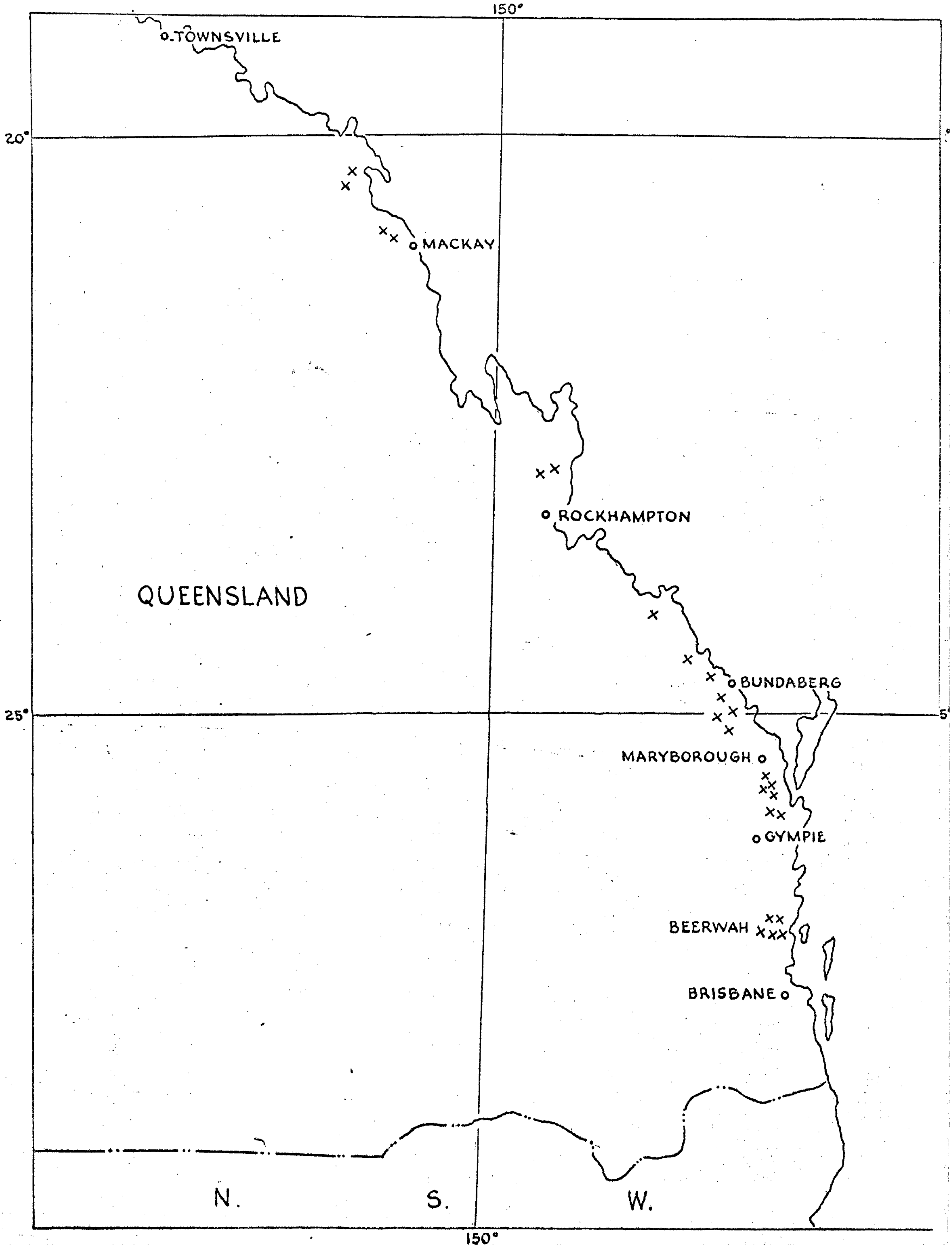
This planting included the F1 hybrid var. *elliottii* x var. *hondurensis* and the unselected parental varieties and is situated on both ridge and swamp sites. Full details are given in Appendix 1.

Ten trees of each of the parental varieties were selected at random on both sites. These were located in the middle row of the three-row plots, and were scattered over several different plots. Each was classified subjectively as a dominant, co-dominant, or a sub-dominant according to its crown position in the stand.

Method.

(a) Height growth study. The pattern of shoot growth in this material was found to be very similar to that in Short Leaf Pine (*P. echinata*, Mill.) which has been described by Byram and Doolittle (1950). "A tree may put forth two or more leaders during the growing season............ The elongation of each leader requires only a few weeks. Near the end of each elongation period buds form at the tips of the new shoots. During the following rest period the succulent new growth changes colour and becomes darker, and the thickness of the new shoot increases. After a month or more the recently formed buds begin to elongate and the growth of a new shoot starts the process all over again".

FIG. 6. LOCATIONS OF PLANTINGS OF *var. elliottii* SAMPLED FOR WHORL COUNTS AT THE 15' LEVEL



In this study every six weeks over the period 17th June, 1965 to 3rd June 1966 the total height, ground to leading tip, of each stem was measured using height sticks graduated in inches. Measurements were made every six weeks over the period 17th June, 1965 to 3rd June, 1966. The average height for each plot at the end of each six week period was calculated.

Every two weeks in the same period the lengths of both the leading shoot, or bud, and the penultimate shoot of each tree was measured to the nearest quarter inch. A bud was considered to be present when the production of young needles ceased and the tip was enclosed in bud scales; at this stage branch buds were usually present as well. With the production of each new bud the base for measure moved up to the next whorl (see Figure 7). In the few cases of a long burst of uninterrupted growth the length of the leading shoot only was measured.

The base of the penultimate shoot was found to remain static for height growth, and was used as a base line. The number of stems growing an inch or more from this line in each two-week period was determined. (As there was no measure on 21st April the growing stems at this time were those with an increment of two inches between 7th April and 5th May).

Var. elliottii was the only variety or hybrid with a well defined dormant phase. As some individuals of this variety did not attain dormancy until later in the season than others observations were made to determine whether such individuals produced more inter-whorls and were taller than others.
The date of height growth cessation before the onset of the dormant phase was noted by individual trees, as was the number of inter-whorls each tree produced in the one growing season. Growth was defined as ceasing when it fell below

one inch per fortnight. The date of growth cessation was compared with the number of whorls produced and also with the individual tree height the following winter.

In the study of the branching patterns at each of the 24 centres visited, approximately 15 trees were examined and the number of whorls produced in the year each tree reached 15 feet above the ground were noted.

The trees examined were grouped in five districts and the overall figures calculated for each district. The districts were (i) Mackay; (ii) Rockhampton; (iii) Bundaberg; (iv) Maryborough - Gympie; and (v) Beerwah (see Figure 6).

(b) Girth growth study. Dendrometers capable of reading to $^1/_{100}$ of an inch were constructed using aluminium tape and coil springs as described by Liming (1957). These were fitted to each stem 3 feet above ground level. This avoided butt swell and did not interfere with the normal measures made on these trees trees at the 4 feet 3 inches level. Before fitting most of the outer bark was shaved off to ensure as snug a fit as possible.

The dendrometers were fitted in February, 1966 and readings commenced at the end of July. Any slackness in fitting dendrometer bands had therefore been taken up by the start of the study. On the faster growing trees it was necessary to replace the initial dendrometers when these had reached the end of the scale. This was done by fitting the new band immediately above the old, well before the scale on the latter was exhausted. Thus again any slackness at fitting was taken up before the band was used.

Readings were made at fortnightly intervals from 28th July, 1966 to 25th August, 1967. Mean increments for each six weekly period from 28th July were calculated for each treatment and all stems growing by 0.03 and 0.1 inch in each fortnight were also noted.

Temperature and rainfall records were kept daily at Beerwah over the periods of both studies.

Results.

The mean monthly maximum and minimum temperatures and the monthly rainfall for the periods of each study are detailed as Appendix 6 and illustrated in Figure 8. The mean monthly rainfall for Beerwah is also shown.

The results of the periodic height and girth growth measures are given in Table 9. This details for each site the initial heights and girths at the commencement of the study, the mean six-weekly increments for each treatment on each site throughout the period and the overall increment and final height and girth. The six-weekly increments are shown as percentages of the overall increment in Table 10 and these are illustrated diagrammatically in Figure 9.

The number of stems in the height study growing by one inch in each two-weekly period are detailed in Table 11. Similarly the numbers of stems growing in girth by 0.03 and 0.1 inches in each two week period of the girth study are given in Table 12. These are shown diagrammatically in Figures 10 and 11. The number of stems in the height study setting buds in each two-weekly period are given in Table 13 and diagrammatically in Figure 12.

FIG. 8. MEAN MONTHLY TEMPERATURE AND MONTHLY RAINFALL COMPARED WITH THE AVERAGE MONTHLY RAINFALL AT BEERWAH OVER THE PERIOD OF BOTH STUDIES

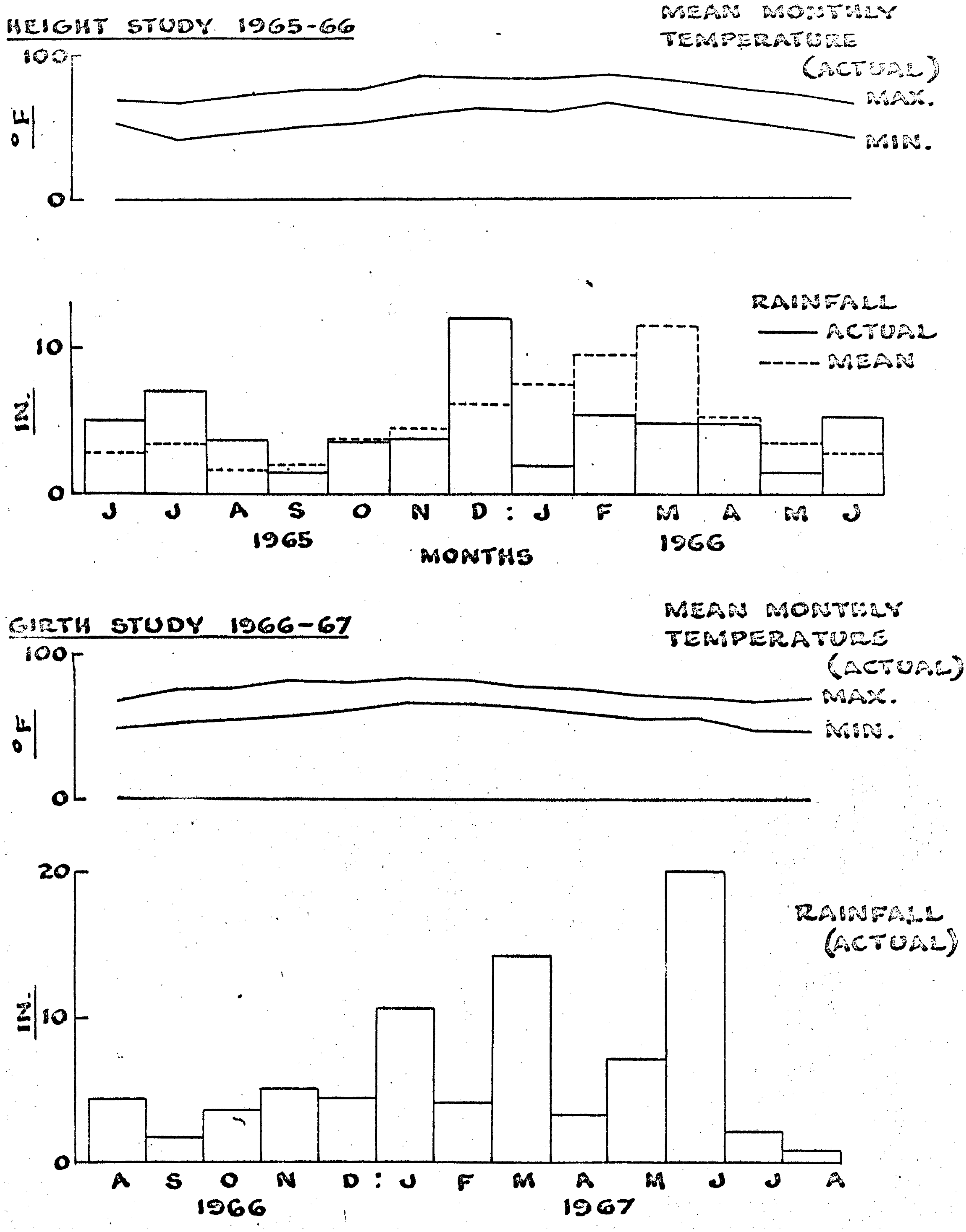


Table 9. Results of the 6-weekly height and girth measures over the periods of each study

| Site[1] | Initial height (inches) 17/6/65 | Mean height increment (inches) over six-week period to:-[2] | | | | | | | | Total Increment 17/6/65 - 3/6/66 |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 29/7 | 14/9 | 21/10 | 2/12 | 13/1 | 24/2 | 7/4 | 3/6 | |
| (a) Height. | | | | | | | | | | |
| elliottii (E) | | | | | | | | | | |
| + | 29.6 | 0.0 | 5.3 | 16.6 | 8.1 | 6.7 | 4.1 | 2.3 | 0.8 | 43.9 |
| Av. | 27.9 | 0.0 | 5.8 | 14.9 | 8.4 | 6.5 | 3.8 | 1.6 | 0.5 | 41.5 |
| hondurensis (H) | | | | | | | | | | |
| + | 38.8 | 3.8 | 6.5 | 6.6 | 5.6 | 6.5 | 8.3 | 10.6 | 9.8 | 57.7 |
| Av. | 30.1 | 1.9 | 4.9 | 5.2 | 6.2 | 5.3 | 5.5 | 7.4 | 7.5 | 45.9 |
| F1 hybrid (X) | | | | | | | | | | |
| + | 43.7 | 2.7 | 12.3 | 8.9 | 13.7 | 11.7 | 11.9 | 9.0 | 4.7 | 74.9 |
| Av. | 34.4 | 1.6 | 9.0 | 6.3 | 9.9 | 8.5 | 9.3 | 7.3 | 3.4 | 55.3 |
| Backcross F1 hybrid x var. hondurensis (XH) | | | | | | | | | | |
| + | 43.9 | 2.9 | 8.4 | 7.2 | 9.2 | 9.2 | 9.2 | 8.7 | 8.4 | 63.2 |
| Av. | 38.5 | 2.7 | 7.0 | 6.3 | 8.1 | 7.7 | 8.6 | 8.7 | 8.5 | 57.6 |
| F1 hybrid open-pollinated (XO) | | | | | | | | | | |
| + | 39.0 | 1.6 | 11.1 | 11.1 | 11.5 | 8.7 | 9.0 | 7.3 | 3.5 | 63.8 |

| Site[1] | Initial girth (inches) 15/9/66 | Mean girth increment (inches) over six week period to:-[2] | | | | | | | | | Total Increm 15/9/6 - 25/8/6 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 29/9 | 10/11 | 21/12 | 2/2 | 20/3 | 5/5 | 13/6 | 28/7 | 25/8 | |
| (b) Girth. | | | | | | | | | | | |
| elliottii (E) | | | | | | | | | | | |
| R | 19.0 | .56 | .27 | .28 | .25 | .40 | .25 | .04 | .02 | .12 | 2.19 |
| S | 17.5 | .58 | .36 | .38 | .29 | .46 | .30 | .07 | .03 | .16 | 2.63 |
| hondurensis (H) | | | | | | | | | | | |
| R | 22.0 | .41 | .25 | .34 | .21 | .42 | .29 | .18 | .18 | .15 | 2.43 |
| S | 17.7 | .44 | .29 | .33 | .32 | .43 | .38 | .15 | .35 | .17 | 2.86 |
| F1 hybrid (X) | | | | | | | | | | | |
| R | 22.8 | .51 | .26 | .31 | .24 | .36 | .28 | .11 | .11 | .20 | 2.39 |
| S | 20.3 | .60 | .31 | .39 | .33 | .50 | .44 | .19 | .28 | .27 | 3.41 |

1 + = Plus
Av. = Average
R = Ridge
S = Swamp

2 Day/Month

Table 10. Percentages of total growth made in each six-weekly period by the varieties and hybrids in both the height and girth growth studies

| Var[1] | Site[2] | % of total increment over the period of study in six week period ending:-[3] | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 29/7 | 14/9 | 21/10 | 2/12 | 13/1 | 24/2 | 7/4 | 3/6 | |
| (a) Height. | | | | | | | | | | |
| E | + | 0 | 12 | 38 | 18.5 | 15.5 | 9 | 5 | 2 | |
| | Av. | 0 | 14 | 36 | 20 | 16 | 9 | 4 | 1 | |
| H | + | 7 | 11 | 12 | 10 | 11 | 14 | 18 | 17 | |
| | Av. | 6.5 | 11 | 11.5 | 14 | 12 | 12 | 16 | 17 | |
| X | + | 4 | 16 | 12 | 18 | 16 | 16 | 12 | 6 | |
| | Av. | 4 | 16 | 11.5 | 18 | 15.5 | 17 | 13 | 6 | |
| XH | + | 5 | 13 | 11 | 14.6 | 14.6 | 14.6 | 14 | 13 | |
| | Av. | 5 | 12 | 11 | 14 | 13 | 15 | 15 | 15 | |
| XO | + | 3 | 17 | 17 | 18 | 14 | 14 | 11.5 | 5.5 | |
| | | 29/9 | 10/11 | 21/12 | 2/2 | 20/3 | 5/5 | 13/6 | 28/7 | 2[illegible] |
| (b) Girth. | | | | | | | | | | |
| E | R | 26 | 12 | 13 | 11.5 | 18 | 11.5 | 2 | 1 | [illegible] |
| | S | 22 | 14 | 14 | 11 | 18 | 11 | 3 | 1 | [illegible] |
| H | R | 17 | 10 | 14 | 9 | 17 | 12 | 7.5 | 7.5 | [illegible] |
| | S | 15 | 10 | 12 | 11 | 15 | 13 | 5 | 12 | [illegible] |
| X | R | 22 | 11 | 13 | 10 | 15 | 12 | 4 | 4 | [illegible] |
| | S | 18 | 9 | 11 | 10 | 15 | 13 | 6 | 8 | [illegible] |

1 For coding used see Part II Chapter 4.

2 + = Plus
Av. = Average
R = Ridge
S = Swamp

3 Day/Month

FIG. 9(a). PERCENTAGE OF TOTAL GROWTH IN THE PERIOD 17/6/65 - 3/6/66 PLOTTED AGAINST TIME (AVERAGE SITE FIGURES, HEIGHT GROWTH STUDY)

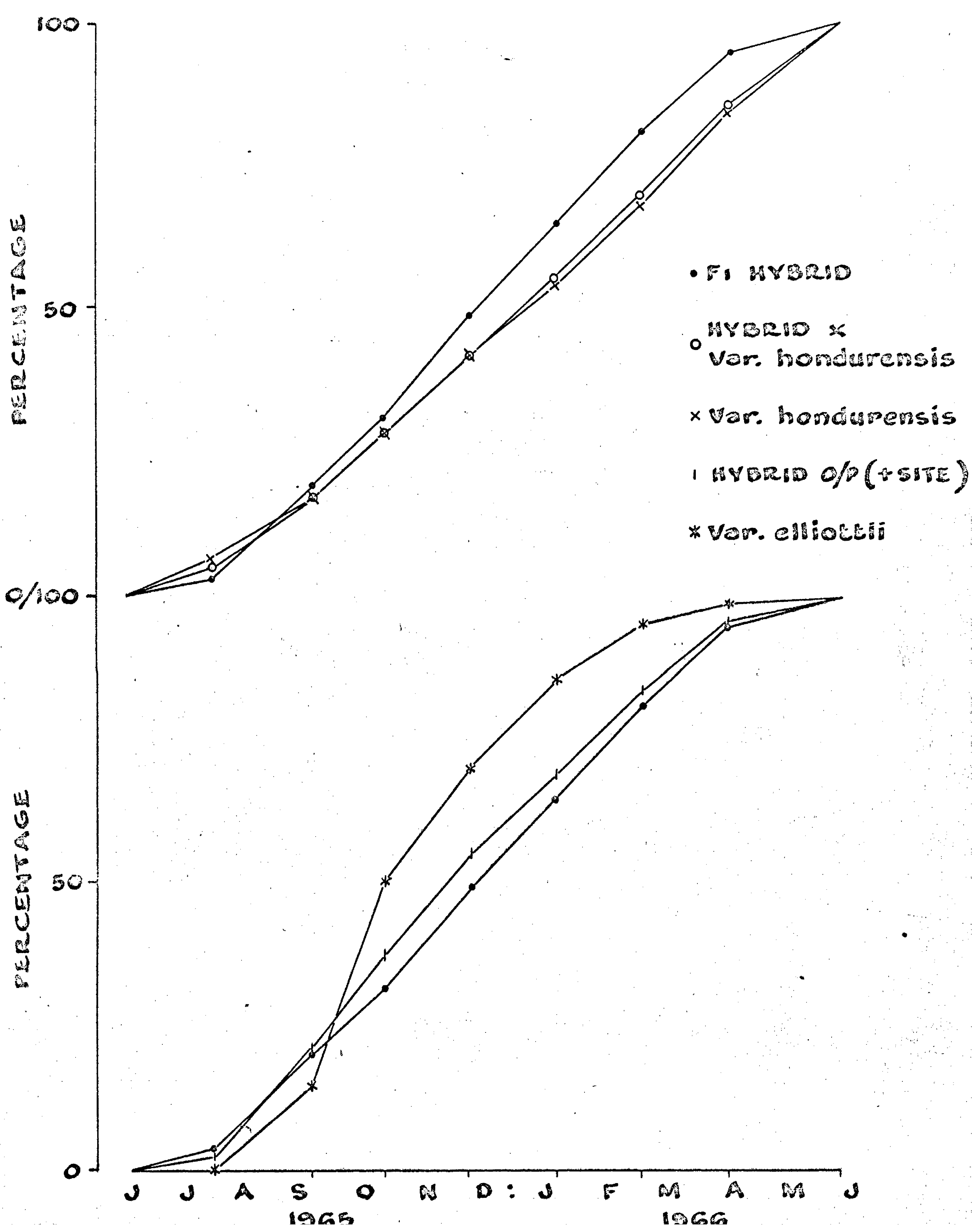


FIG. 9(b). PERCENTAGE GROWTH MADE IN EACH SIX WEEK PERIOD BY THE VARIETIES AND HYBRID IN THE GIRTH GROWTH STUDY

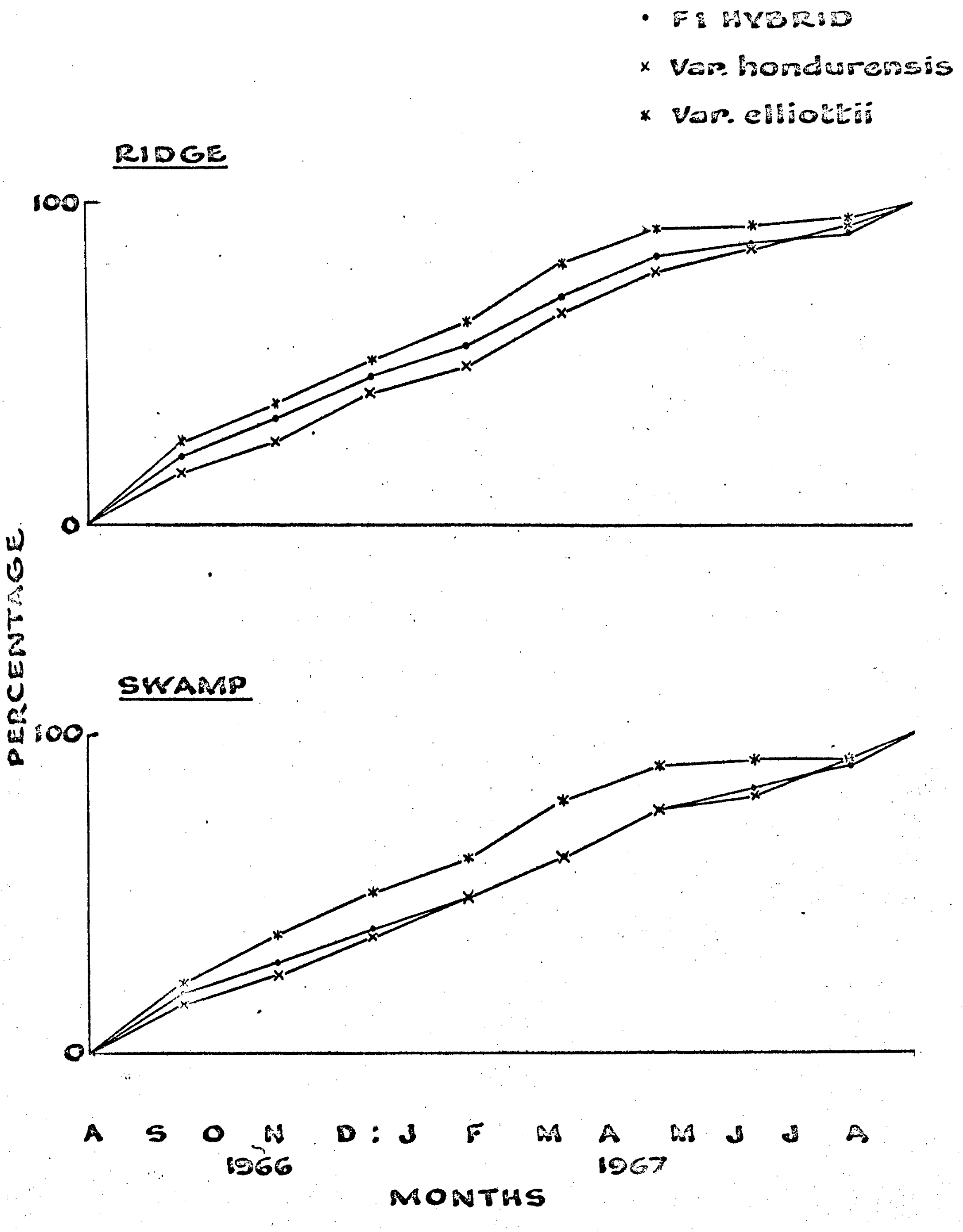


Table 11. % of stems growing in height by one inch or more in each two weekly period

| Var[1] | Site[2] | No. Stems | % growing 1" or more for period ending:-[3] 1/7 | 15/7 | 29/7 | 12/8 | 27/8 | 14/9 | 23/9 | 7/10 | 21/10 | 4/11 | 18/11 | 2/12 | 16/12 | 31/12 | 13/1 | 27/1 | 10/2 | 24/2 | 10/3 | 28/3 | 7/4 | 5/5 | 19/5 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| E | + | 48 | 0 | 0 | 0 | 2 | 29 | 100 | 100 | 100 | 100 | 100 | 96 | 100 | 100 | 98 | 77 | 67 | 65 | 38 | 23 | 23 | 4 | 2 | 0 | |
| | Av. | 40 | 0 | 0 | 0 | 0 | 25 | 100 | 100 | 100 | 100 | 100 | 100 | 95 | 98 | 95 | 65 | 58 | 58 | 28 | 18 | 5 | 0 | 0 | 0 | |
| H | + | 46 | 57 | 70 | 70 | 80 | 91 | 91 | 72 | 80 | 91 | 98 | 96 | 85 | 80 | 87 | 72 | 80 | 93 | 91 | 93 | 96 | 85 | 96 | 80 | 8 |
| | Av. | 48 | 52 | 44 | 63 | 63 | 81 | 90 | 56 | 79 | 83 | 92 | 85 | 77 | 77 | 94 | 67 | 67 | 96 | 90 | 87 | 96 | 79 | 75 | 79 | 5 |
| X | + | 43 | 26 | 33 | 54 | 77 | 98 | 100 | 88 | 98 | 98 | 100 | 100 | 98 | 100 | 100 | 100 | 96 | 98 | 94 | 86 | 65 | 60 | 63 | 45 | 2 |
| | Av. | 48 | 21 | 23 | 40 | 69 | 94 | 100 | 83 | 94 | 98 | 98 | 100 | 98 | 100 | 100 | 96 | 96 | 98 | 98 | 87 | 79 | 61 | 42 | 10 | [illegible] |
| XH | + | 45 | 53 | 51 | 60 | 91 | 98 | 98 | 62 | 96 | 98 | 100 | 96 | 82 | 91 | 100 | 98 | 80 | 91 | 93 | 91 | 87 | 78 | 91 | 76 | 6 |
| | Av. | 47 | 53 | 60 | 53 | 72 | 91 | 94 | 72 | 87 | 91 | 94 | 91 | 83 | 94 | 91 | 85 | 66 | 91 | 96 | 98 | 94 | 80 | 87 | 62 | 6 |
| XO | + | 43 | 26 | 21 | 39 | 54 | 81 | 98 | ·98 | 100 | 100 | 100 | 100 | 90 | 96 | 100 | 81 | 93 | 98 | 93 | 81 | 72 | 58 | 52 | 19 | 1 |

1 For coding used see Part II Chapter 4.

2 + = Plus
Av. = Average

3 Day/Month

FIG. 10. HISTOGRAMS INDICATING THE PERCENTAGE OF STEMS GROWING 1 INCH OR MORE IN HEIGHT IN EACH TWO-WEEK PERIOD BY VARIETIES OR HYBRIDS

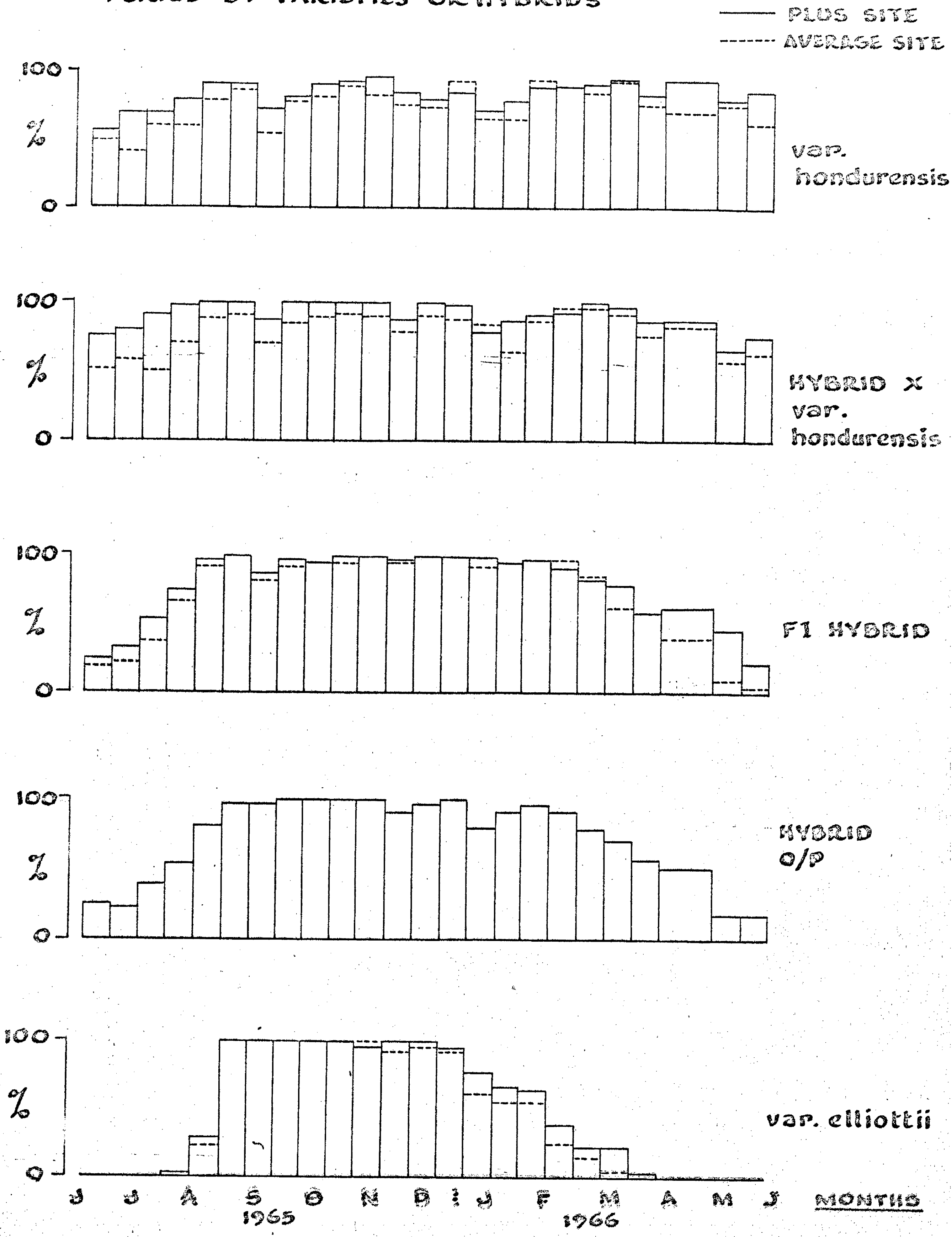


Table 12. Details of the number of stems growing by at least 0.03 inches and 0.1 inches in the girth growth study (for coding used see Part II Chapter 4)

| Var. | Crown Class[1] | No. trees | 29/8 | 14/9 | 29/9 | 13/10 | 28/10 | 10/11 | 24/11 | 7/12 | 21/12 | 5/1 | 18/1 | 2/2 | 15/2 | 3/3 | 20/3 | 4/4 | 19/4 | 5/5 | 19/5 | 13/6 | 29/6 | 14/7 | 28/7 | 11/8 | 25/8 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | No. trees growing by 0.03 inches in the two week period ending:-[2] | | | | | | | | | | | | | | | | | | | | | | | | |
| **Ridge** | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| H | D | 4 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | 3 | 3 | — | — | — |
| | C | 5 | — | — | — | 4 | — | — | — | — | — | — | — | — | — | — | — | — | — | 4 | — | — | — | 4 | — | 4 | — |
| | S | 1 | — | — | — | 0 | — | — | — | — | — | — | — | — | — | — | — | — | — | | — | — | — | 0 | — | 0 | — |
| X | D | 4 | — | — | — | 3 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | 3 | 3 | 2 | 1 | — | — | — |
| | C | 4 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | 2 | 1 | 1 | 1 | 3 | — | — |
| | S | 2 | — | — | — | 1 | 1 | — | — | — | — | — | — | — | — | — | — | — | — | — | 0 | 0 | 0 | 0 | 0 | 0 | — |
| E | D | 3 | — | — | — | 2 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | 1 | 1 | 1 | 0 | 0 | 3 | — |
| | C | 5 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | 2 | 0 | 1 | 0 | 0 | 1 | 4 |
| | S | 2 | — | — | — | — | — | — | — | — | 1 | — | — | — | — | — | — | — | — | 1 | 0 | 0 | 0 | 0 | 0 | 0 | — |
| **Swamp** | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| H | D | 2 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — |
| | C | 3 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | 2 | — | 2 | — | 2 | — |
| | S | 5 | — | — | — | 4 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | 3 | — | — | — | — | — |
| X | D | 2 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — |
| | C | 6 | — | — | — | 5 | — | — | — | — | 5 | — | — | — | — | — | — | — | — | — | — | — | — | 5 | — | — | — |
| | S | 2 | — | — | — | — | 1 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | 1 | 1 | 1 | — | — | — |
| E | D | 3 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | 2 | — | 1 | 0 | 1 | 2 | — |
| | C | 4 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | 3 | — | — | 1 | 0 | 0 | 0 | 0 | 1 | — |
| | S | 3 | — | — | — | — | — | — | — | — | — | 2 | — | — | — | — | — | — | — | — | 2 | 1 | 1 | 0 | 0 | 2 | — |
| | | | No. of stems growing by 0.1 inches in the two week period ending:-[2] | | | | | | | | | | | | | | | | | | | | | | | | |
| **Ridge** | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| H | D | 4 | — | — | — | 0 | 2 | — | 3 | — | 2 | — | 3 | — | 2 | — | 3 | 3 | 1 | 2 | 0 | 1 | 1 | 0 | 3 | 0 | — |
| | C | 5 | — | — | — | 0 | 0 | 3 | 4 | — | — | — | 2 | — | 3 | — | 4 | — | 1 | 3 | 2 | 0 | 0 | 0 | 2 | 0 | 3 |
| | S | 1 | — | — | — | 0 | 0 | 0 | — | — | — | — | — | — | — | — | — | — | — | 0 | 0 | 0 | 0 | 0 | 0 | 0 | — |
| X | D | 4 | — | — | — | 1 | 1 | — | 3 | — | 1 | 1 | 2 | 1 | 2 | — | 3 | — | 2 | 2 | 2 | 0 | 0 | 0 | 1 | 1 | — |
| | C | 4 | 3 | — | 2 | 0 | 3 | 2 | 3 | — | 0 | 0 | 2 | 1 | 1 | — | 2 | 2 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 2 | — |
| | S | 2 | 1 | — | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| E | D | 3 | — | 2 | — | 0 | — | — | 1 | — | 0 | 0 | — | 1 | — | — | — | — | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | — |
| | C | 5 | 3 | — | — | 0 | 4 | 4 | 3 | 4 | 2 | 0 | 4 | 2 | 4 | — | — | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 |
| | S | 2 | 1 | — | — | 0 | 0 | 1 | 0 | 2 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| **Swamp** | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| H | D | 2 | — | — | — | 0 | — | — | — | — | 1 | 1 | 2 | 1 | — | — | — | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | — |
| | C | 3 | 0 | — | — | 0 | 1 | — | 2 | — | 1 | 0 | 2 | 1 | 2 | — | 2 | 2 | 0 | 1 | — | — | 2 | 0 | 2 | 0 | 1 |
| | S | 5 | 2 | — | 3 | 0 | 1 | — | 2 | — | 2 | 1 | — | — | 4 | — | — | 4 | 4 | 1 | — | — | 1 | 1 | — | 1 | — |
| X | D | 2 | 1 | — | — | 0 | 1 | — | — | — | 0 | 1 | 1 | 1 | 1 | — | — | — | — | — | — | 0 | 1 | 0 | — | — | — |
| | C | 6 | — | 4 | — | 1 | — | — | — | — | 3 | 2 | 5 | 4 | — | — | — | 4 | 4 | 4 | 2 | 0 | 0 | 2 | — | 5 | — |
| | S | 2 | — | — | — | 0 | 1 | — | — | — | 1 | 1 | 0 | 1 | — | — | — | — | — | — | — | 1 | 1 | 1 | 1 | — | — |
| E | D | 3 | 0 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | 2 | 0 | 0 | 0 | 0 | 0 | 2 | — |
| | C | 4 | 1 | — | — | 2 | — | — | — | 3 | 2 | 0 | — | 2 | 3 | — | 3 | 3 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 3 |
| | S | 3 | 1 | — | — | 0 | 1 | 1 | 1 | — | 1 | 0 | 1 | — | — | — | — | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 2 | — |

1 D = Dominant; C = Co-dominant; S = Suppressed.

2 A single line indicates all stems are growing, otherwise the actual number of stems growing is shown.

FIG. 11. HISTOGRAMS INDICATING THE NUMBER OF STEMS GROWING IN GIRTH BY MORE THAN 0·03 INCHES PER TWO WEEKLY PERIOD AND 0·1 INCHES PER TWO WEEKLY PERIOD

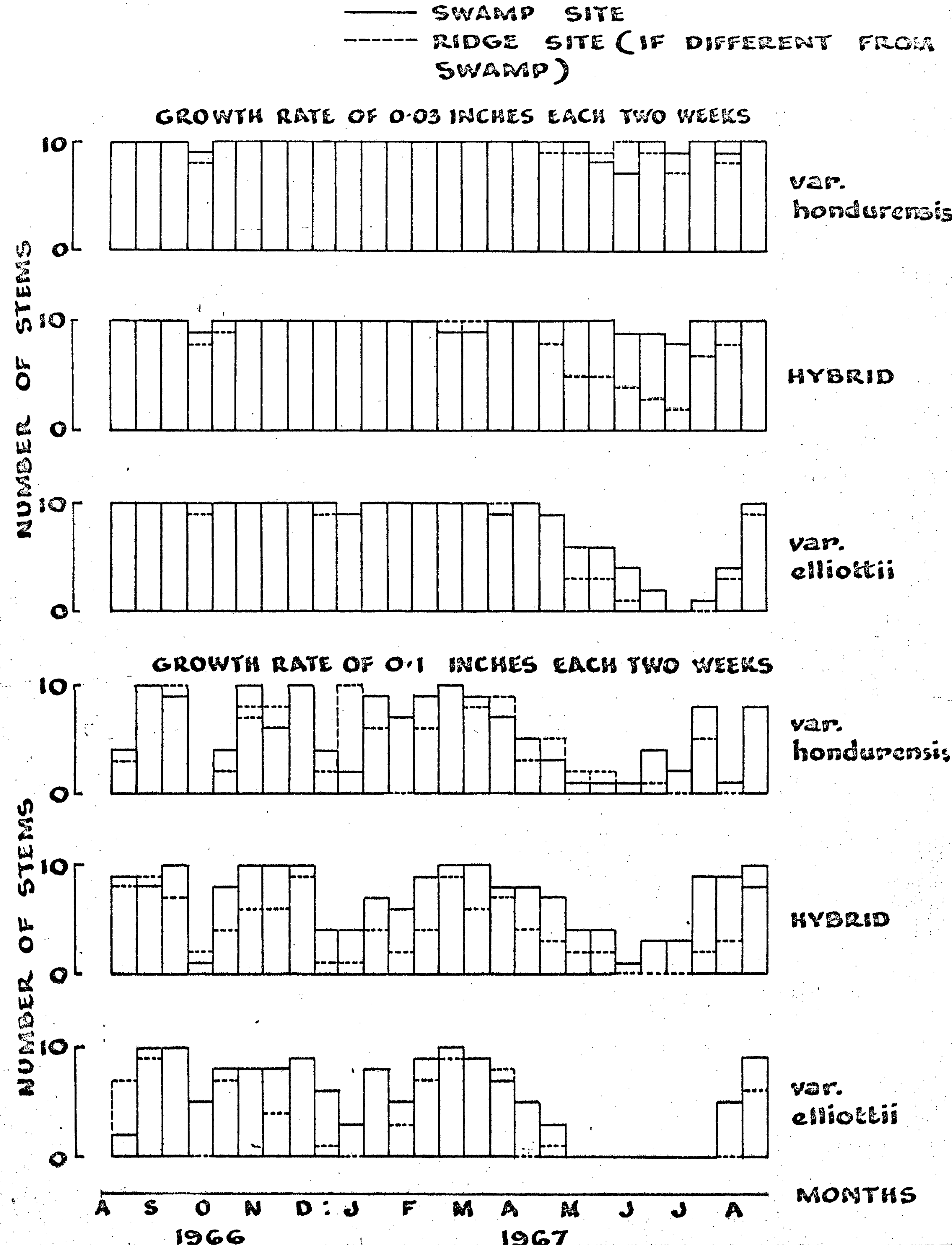


Table 13. Percentage of stems setting buds in each two-weekly period

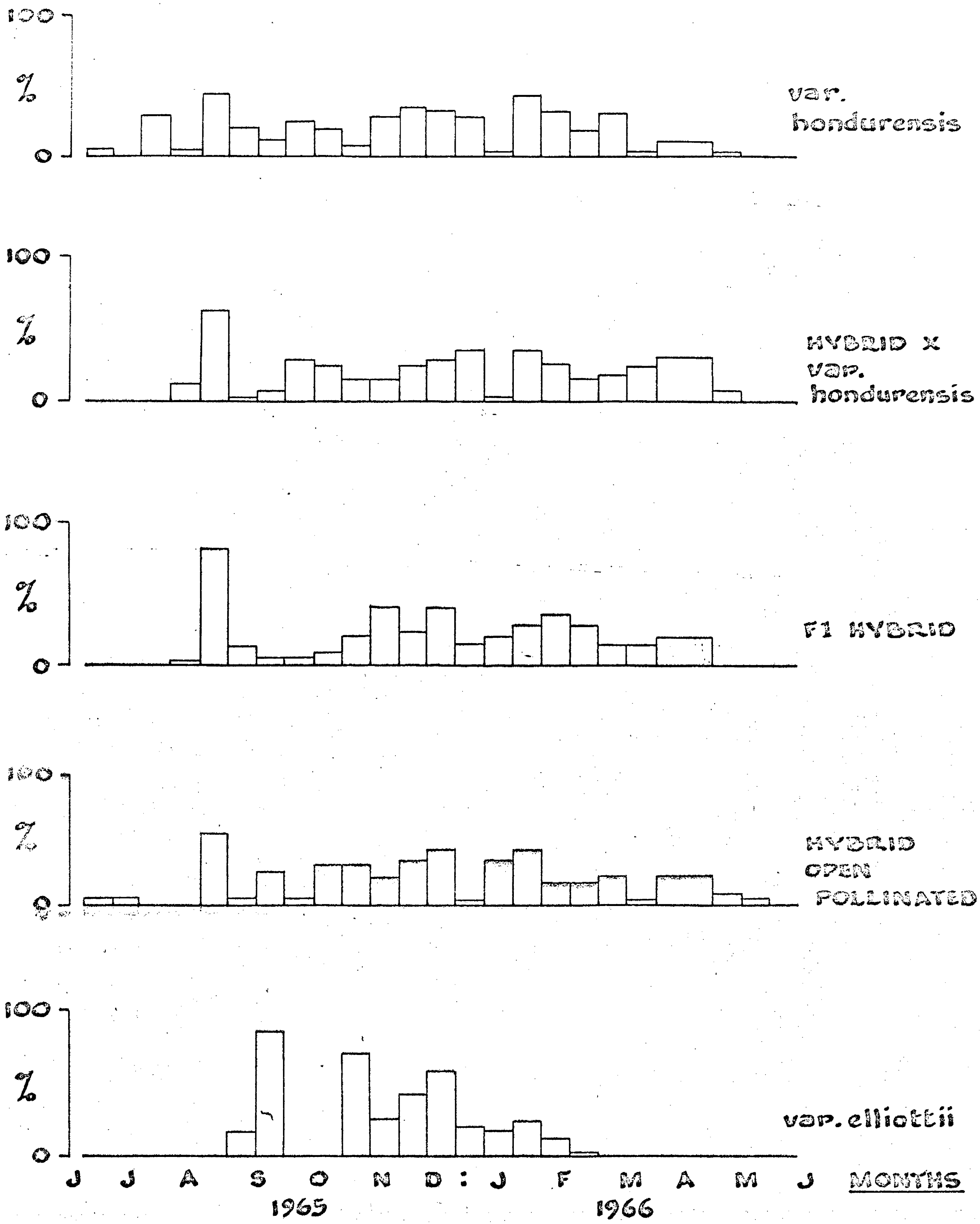
| Var[1] | Site[2] | No. Stems Assessed | % new buds produced in period ending:-[3] | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 15/7 | 29/7 | 12/8 | 27/8 | 14/9 | 23/9 | 7/10 | 21/10 | 4/11 | 18/11 | 2/12 | 16/12 | 31/12 | 13/1 | 27/1 | 10/2 | 24/2 | 10/3 | 28/3 | 7/4 | 5/5 | 19/5 | 3/6 |
| E | + | 48 | 0 | 0 | 0 | 0 | 0 | 4 | 88 | 8 | 6 | 65 | 21 | 38 | 52 | 17 | 27 | 15 | 17 | 2 | 0 | 0 | 0 | 0 | 0 |
| | Av. | 40 | 0 | 0 | 0 | 0 | 0 | 15 | 85 | 0 | 0 | 70 | 25 | 42 | 58 | 20 | 18 | 23 | 13 | 2 | 0 | 0 | 0 | 0 | 0 |
| H | + | 46 | 2 | 17 | 15 | 4 | 57 | 13 | 22 | 24 | 15 | 22 | 15 | 35 | 37 | 17 | 17 | 35 | 35 | 24 | 24 | 26 | 37 | 17 | 11 |
| | Av. | 48 | 4 | 0 | 28 | 4 | 44 | 20 | 12 | 24 | 20 | 8 | 28 | 36 | 32 | 28 | 4 | 44 | 32 | 20 | 32 | 6 | 13 | 4 | 0 |
| X | + | 22 | 0 | 0 | 5 | 18 | 73 | 14 | 0 | 9 | 9 | 50 | 27 | 14 | 45 | 36 | 18 | 18 | 41 | 45 | 9 | 14 | 50 | 0 | 0 |
| | Av. | 24 | 0 | 0 | 0 | 4 | 80 | 12 | 4 | 4 | 8 | 20 | 40 | 24 | 40 | 16 | 20 | 28 | 36 | 28 | 16 | 16 | 20 | 0 | 0 |
| XH | + | 22 | 5 | 4 | 18 | 18 | 50 | 0 | 9 | 36 | 18 | 9 | 27 | 32 | 18 | 23 | 32 | 32 | 23 | 18 | 27 | 14 | 54 | 9 | 14 |
| | Av. | 24 | 0 | 0 | 0 | 12 | 64 | 4 | 8 | 28 | 24 | 16 | 16 | 24 | 28 | 36 | 4 | 36 | 28 | 16 | 20 | 24 | 32 | 8 | 0 |
| XO | + | 24 | 4 | 4 | 0 | 0 | 52 | 4 | 24 | 4 | 28 | 28 | 20 | 32 | 40 | 4 | 32 | 40 | 16 | 16 | 16 | 4 | 20 | 8 | 4 |

1 For coding used see Part II Chapter 4.

2 + = Plus
Av. = Average

3 Day/Month

FIG. 12. HISTOGRAMS SHOWING THE PERCENTAGE OF STEMS SETTING BUDS IN EACH TWO-WEEK PERIOD IN EACH VARIETY OR HYBRID



The results of the comparison of the dates of height growth cessation in var. elliottii with the number of inter-whorls each tree produced and the total height of the trees are given in Table 14. The results have been kept separate by site types. The comparison of date of height growth cessation with tree height is also shown diagrammatically in Figure 13.

The whorl pattern study at the 24 different Queensland centres has been summarized by the five districts and the results are presented in Figure 14. These are detailed in full as Appendix 7.

## Discussion.

### (i) Height and girth growth patterns

Figure 8 shows that the weather conditions over the periods of both studies were rarely, if ever, limiting to growth. The growth patterns exhibited are therefore considered as representative of the variety or hybrid in the locality. Girth fluctuations due to de-hydration and re-hydration have been ignored.

The overall size differences between the sites are typical as will be shown later in this thesis. In the height study comparable material on the plus site was superior to that on the average site and in the girth study all material in the ridge planting exceeded that in the swamp (Table 9).

Similarly the comparative sizes of the respective varieties, hybrids and derivatives are also typical. In the height study (Table 9), the hybrid var. elliottii x var. hondurensis was slightly taller than pure var. hondurensis which in turn was taller than pure var. elliottii. The backcross to var. hondurensis

Fig. 13. DIAGRAMS SHOWING THE MEAN HEIGHT, HEIGHT RANGE AND STANDARD ERROR OF Var. elliottii STEMS WHICH CEASED GROWTH AT THE DATES INDICATED

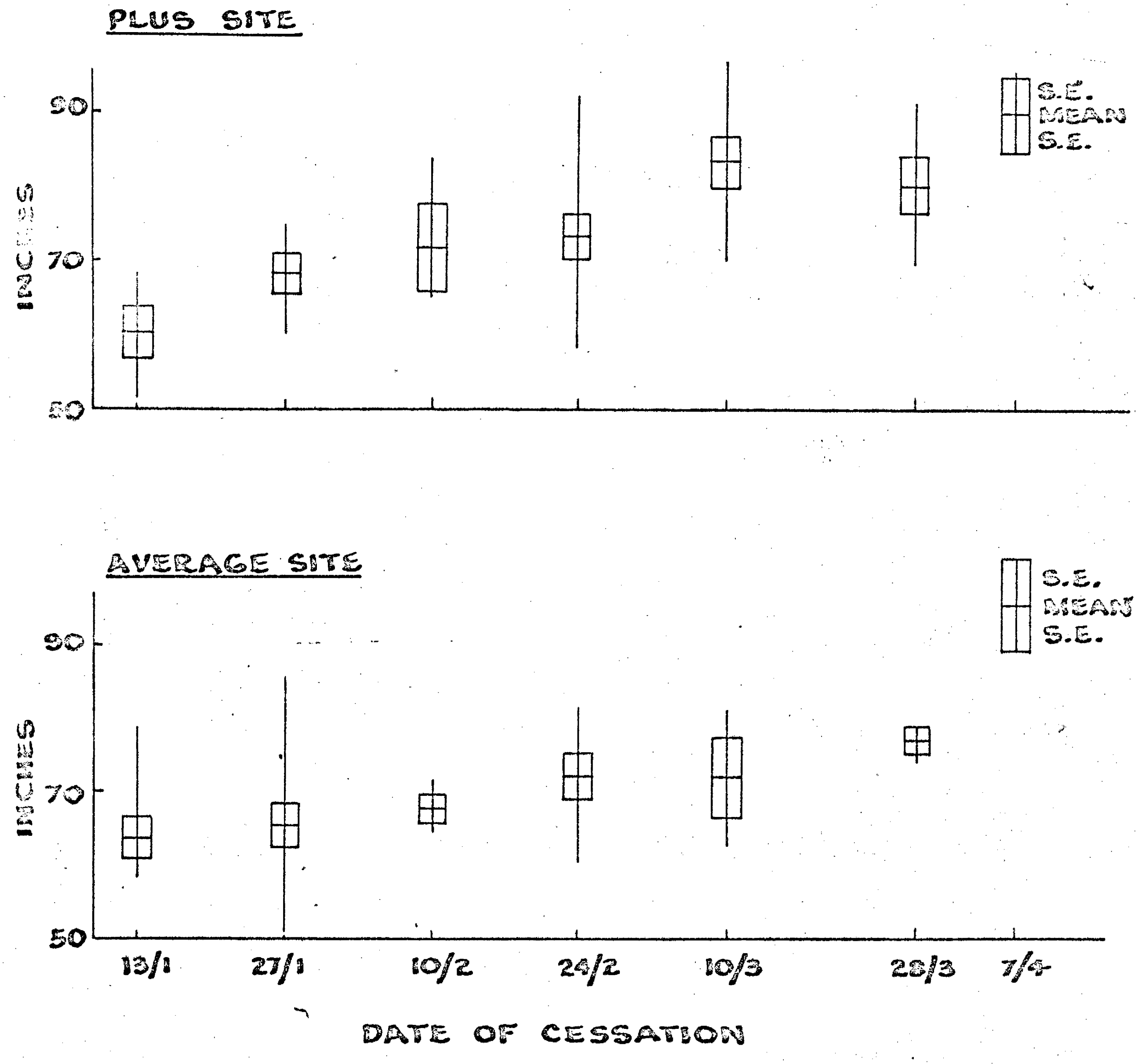
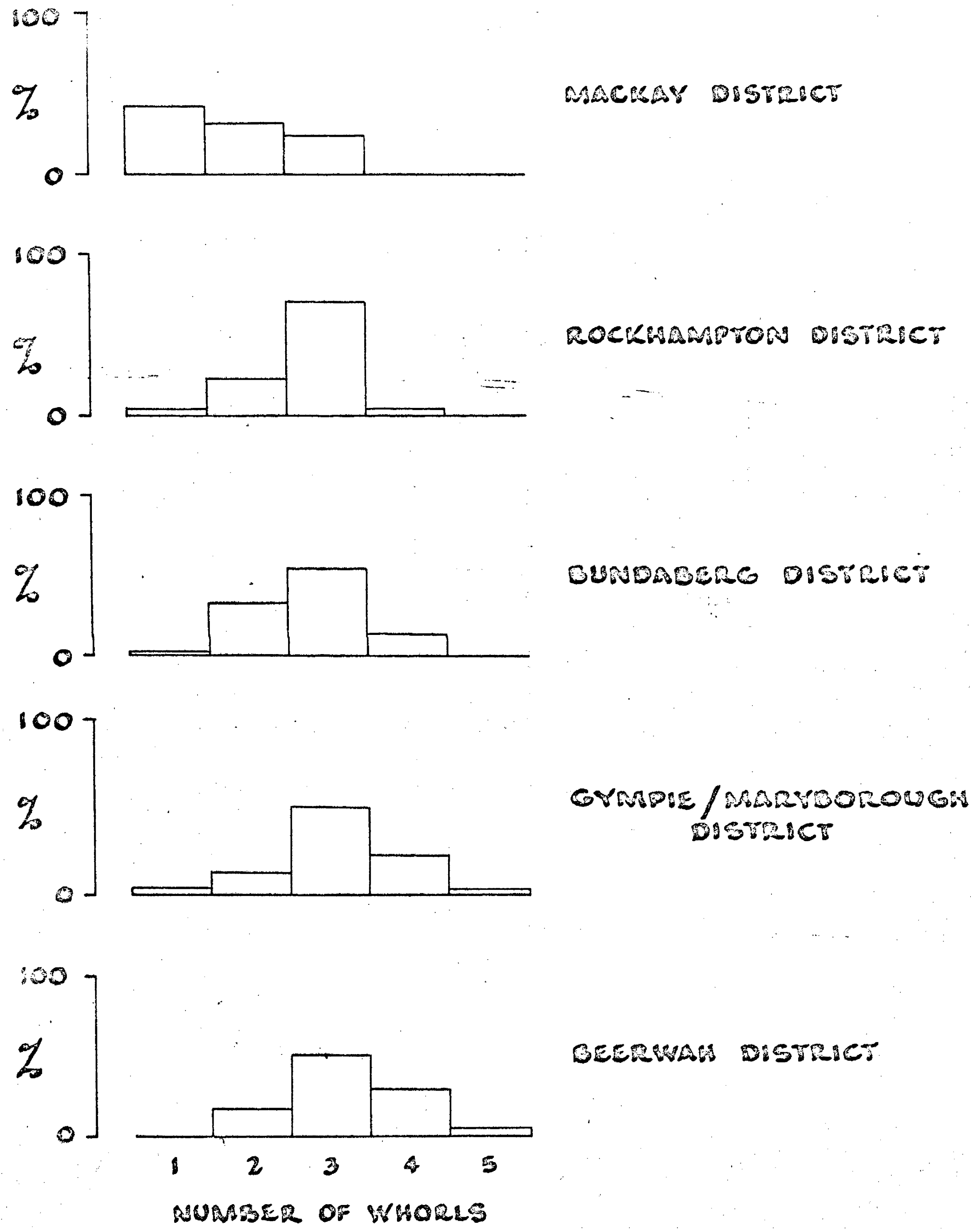


Table 14. Showing the mean heights at June 1966 by date of growth cessation and number of branch whorls produced in individual stems of var. elliottii

| No. of branch whorls | Date of growth cessation (day/month) | | | | | | |
|---|---|---|---|---|---|---|---|
| | 13/1 | 27/1 | 10/2 | 24/2 | 10/3 | 28/3 | 7/4 |
| Plus site | | | | | | | |
| 3 | 60.6 | 68.4 | 65.0 | 65.0 | - | - | - |
| 4 | - | - | 75.5 | 74.7 | 82.6 | 85.3 | - |
| 5 | - | - | - | - | 92.0 | 76.0 | 90.5 |
| Mean | 60.6 | 68.4 | 72.0 | 73.8 | 83.7 | 80.7 | 90.5 |
| Average site | | | | | | | |
| 3 | 63.7 | 65.1 | 67.7 | 81.0 | - | - | - |
| 4 | - | - | - | 71.0 | 72.0 | 76.0 | - |
| 5 | - | - | - | - | - | 79.0 | 95.5 |
| Mean | 63.7 | 65.1 | 67.7 | 71.9 | 72.0 | 77.0 | 95.5 |

FIG. 14. HISTOGRAMS SHOWING THE PERCENTAGE OF *var. elliottii* TREES PRODUCING THE INDICATED NUMBER OF WHORLS AT THE 15′ LEVEL IN EACH DISTRICT



was intermediate in height between the variety and the F1 hybrid on the plus site and slightly superior to both on the average site. Open pollinated hybrid material was intermediate between var. elliottii and the F1 hybrid on the plus site, the one site on which it was planted. This material is presumably a mixture with two different parentages, hybrid x hybrid and hybrid x var. elliottii. This accords with this result.

In the girth study, the same comparative sizes in var. elliottii, var. hondurensis and the F1 hybrid were found in the ridge planting. But on the swamp site as is usual the var. hondurensis was inferior to the hybrid and approximately the same size as var. elliottii (Table 9).

The increments over the periods of study shown in Table 9 are in accord with the respective sizes, except that in the girth study the increment of the stems on the ridge was inferior to that of those on the swamp. This is assumed to be due to the effect of the plantations in lowering the water table. This has improved conditions on the swamp site to the extent that the water table is now rarely high enough to impede growth. The swamp sites now are at an advantage in dry periods as they have moisture available whilst more freely drained areas are deficient. Examination of the available measure data (Q. F. S. records) indicates that the 1966/67 season was the first occasion that better growth on the swamp has been recorded. At all previous measures the ridge plots recorded a higher increment.

With some exceptions Tables 9 and 10 show that although the actual increment differed on the various site types the percentage of total growth made in any six-weekly period tended to be independent of site. For example in the girth study from 10th November - 21st December the mean growth of var. elliottii was 0.28 and 0.38 inches on the ridge and swamp plantings respectively. Despite this difference, the growth in the period represented 13% - 14% of the total growth on each site.

Thus within the limits of this study it is possible that site type and fertility have only a modifying effect on the main growth patterns.

Var. elliottii grew very fast in the early spring period at Beerwah but subsequently the rate decreased through the summer until the variety became dormant in winter. Table 10 and Figure 8 show that the variety made 50% of its annual height growth between mid-August and mid-October, 80% by mid-January and very little for the five months between February and August. During the early spring the variety attained a mean monthly growth rate close to 12 inches per month (16 inches in a six-week period) and this steadily decreased through the remainder of the growing season, approaching cessation after February, and virtually ceasing in June (Table 9).

Girth growth followed a similar pattern, but with a less pronounced early spring peak of about 0.35 inches per month and also continued longer (Table 9). No signs of cessation were determined before late May, but after May very little winter growth occurred (Tables 9, 10 and 12).

In contrast var. hondurensis grew very evenly in height throughout the year generally averaging 11 - 12% in each six-weekly period. The rate rose in autumn (March-April) to 16 - 17% and fell in winter (June) to 6% (Table 10). Corresponding actual values were 4 inches per month, with an autumn rate of $5\frac{1}{2}$ inches and winter growth of 2 inches per month.

The var. elliottii x var. hondurensis hybrid also grew actively throughout the year but the rate of height growth fluctuated rather more than that of var. hondurensis. From August to early April the monthly variation was between 8 and 12% of the annual total and this rate fell in winter to 2%. Corresponding actual values were, August to April 5 - 7 inches per month, and winter growth 1 inch per month (Tables 9 and 10). The hybrid has an early height growth peak similar to that of var. elliottii but the peak is less pronounced, 7 inches per month (hybrid) compared with 12 inches per month (var. elliottii); moreover the peak occurs slightly earlier than that of var. elliottii in mid-September. There was no indication of the var. hondurensis late summer peak of height growth being reproduced in the hybrid (Table 9).

The hybrid girth growth was generally intermediate between that of the parental varieties on the ridge site and superior on the swamp. Most girth growth occurred in September when the rate was between 0.3 and 0.4 inches per month, but vigorous growth occurred throughout the year even in the winter when the rate was close to 0.1 inch per month (Table 9).

The major features of the growth pattern of the parental varieties elliottii and hondurensis are therefore the early spring vigour and winter dormancy of var. elliottii and the general uniformity of growth of the var. hondurensis including appreciable winter growth. This confirms the finding of McWilliam and Richards (1955) and Ryan (1962). These authors studied the growth of these varieties over several years at Beerwah, noting that elliottii had a strong early season burst of growth and a dormant winter phase whilst var. hondurensis grew evenly throughout the year.

The F1 hybrid between var. elliottii and var. hondurensis has both an early spring burst of growth and maintains growth through the winter, and is therefore intermediate between the parental varieties.

The height growth studies showed each hybrid derivative as intermediate between the F1 hybrid and the respective parent. Thus open pollinated hybrid material was intermediate between the F1 hybrid and pure var. elliottii and the backcross to hondurensis intermediate between the F1 and the pure variety. The only exception was on the average site where the growth of the backcross to var. hondurensis exceeded that of both the F1 and var. hondurensis between April and June (Tables 9 and 10).

(ii) Physiological basis of the pattern

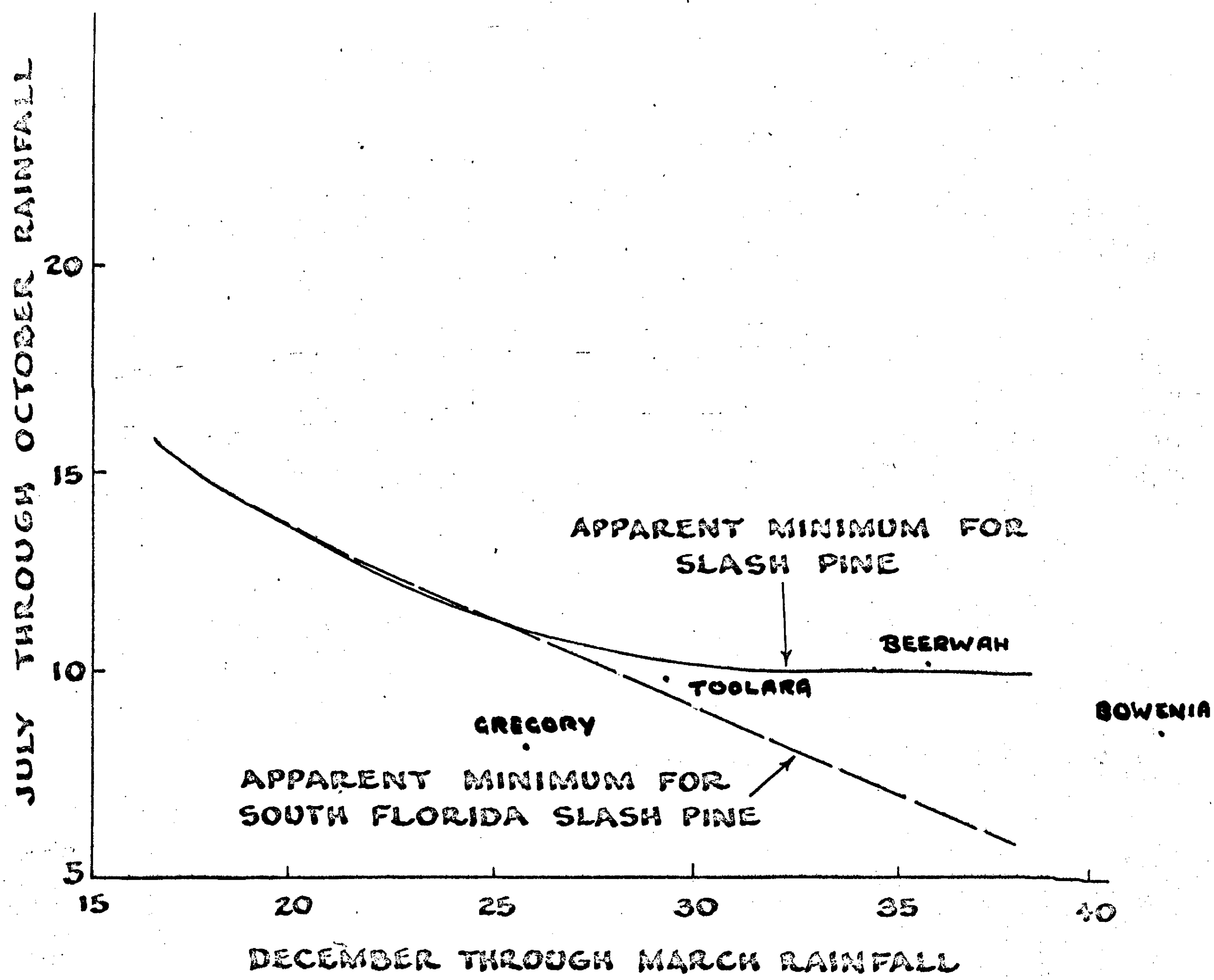
Tree growth is determined by a complex interaction of environmental factors and physiological processes (Kramer and Kozlowski, 1960; Gaertner, 1964; Heisey and Milner, 1965; and numerous others). The environmental factors are defined as climate, soil, and biota by Clausen et al (1948), with climate the most important as it determines the character of the others. Climatic control is exercised mainly through the agencies of solar radiation, temperature and precipitation (Clausen et al 1948; Mayer et al 1960; Kramer and Kozlowski 1960) and if periods of unfavourable climatic conditions occur it is usual for woody plants to become dormant and cease growth during such periods.

The growth pattern of any individual species or variety is markedly affected by the presence or absence of a dormant phase and the length of the period when favourable conditions are experienced. Thus Kozlowski (1962) notes that the winter dormant species of the temperate zone usually complete their height growth very quickly and very early in the spring whilst species from more tropical areas make measurable height growth over a much longer period. Kozlowski (1958) showed that the initial spring growth was made at the expense of stored carbohydrates from the previous season but adds (1962) that species with long growing seasons use current season photosynthate late in the growing season. Species or varieties that have no definite dormant period depend on current photosynthates.

Species utilizing stored carbohydrates for height growth are dependant on the environmental conditions of the previous year for satisfactory growth unless very severe environmental stresses occur during the period of height growth (Kozlowski, 1962). Thus the winter dormant var. elliottii is presumably using stored photosynthates from the previous summer when making its initial growth flush but relies on current photosynthate for its later season growth.

Conditions at Beerwah are probably most favourable for growth in the mid to late summer when temperatures and rainfall are both high. The var. elliottii presumably utilizes this favourable period by storing the photosynthates for its vigorous spring flush the following August. Subsequently the variety's growth from October through to January may depend on currently produced photosynthates and if environmental conditions are limiting at that time then this late season growth could be reduced. In America, Squillace and Kraus (1959) have suggested that for satisfactory growth var. elliottii requires at least 10 inches of rain in the early spring (January - April inclusive, northern hemisphere) and adequate rainfall in the late season (June - September inclusive). The rainfall requirements suggested by these authors are illustrated in Figure 15.

FIG. 15. RAINFALL DISTRIBUTION OF THE CHIEF SLASH PINE PLANTATION CENTRES IN SOUTH EAST QUEENSLAND RELATIVE TO THE RELATIONSHIP POSTULATED BY SQUILLACE AND KRAUS (1959)



Also included in this figure are the comparative rainfalls of the southern exotic plantation centres in Queensland; the American figures have been transported by six months to accommodate the change of hemisphere.

Squillace and Kraus (1959) definitions of the moisture requirements are strongly supported by the findings of the growth study. Late season moisture is required for synthesis of the carbohydrates for the following spring flush and early season rain for sustenance of growth into mid-summer. It is unfortunate that Jackson (1962) in his comprehensive study of climatic effects on growth of var. elliottii did not consider the rainfall combinations suggested by Squillace and Kraus (loc cit). But it is noticeable that Jackson (loc cit) found that var. elliottii took 7 months to complete 90% of its seasonal height growth in New Zealand, at latitude 38°S. Jester and Kramer (1939) noted the variety as completing the same percentage in 4 months at latitude 32°N and Bennett (1956) 5½ months at latitude 36°N. Jackson regards this as a latitudinal effect but in view of the rainfall patterns in America (Table 5 and Figure 4) and the equable rainfall in New Zealand of two to three inches monthly (Anon, 1958) it seems equally explicable as a rainfall effect. Thus areas with drier spring periods have shorter growing seasons.

The results of the height growth study at Beerwah tend to confirm this. Here, at 27°S, the variety took 5 months to complete 90% of the seasonal height growth. This disagrees with a latitudinal pattern but is explicable on a rainfall basis.

The emphasis on rainfall pattern is not to deny the very important effects of other climatic factors including those associated with latitude, such as photoperiod. These are discussed in more detail below. But it does appear that rainfall regimes exercise close control over var. elliottii growth and that critical periods occur during which failure to receive a certain level of rainfall results in severe retardation of growth. These critical periods are immutable because of the fixed growth pattern of var. elliottii with its definite period of dormancy.

It is apparent from Figure 14 that if Squillace and Kraus (1959) figures are correct then Gregory and Bowenia are outside the range for effective establishment of var. elliottii plantations.

Var. hondurensis has no dormant period and the variety presumably depends on current environmental conditions. The most vigorous phase of growth occurs in late summer when conditions are best, whilst growth under cooler and drier conditions is slower. McWilliam and Richards (1955) found that the variety ceased height growth in a dry period and Lojan (1965) noted that girth growth was closely associated with rainfall. It appears that at Beerwah and presumably elsewhere that var. hondurensis does not have the stringent seasonal rainfall requirements of var. elliottii and that growth is adjusted to suit the prevailing conditions.

The F1 hybrid between var. elliottii and var. hondurensis combines the best features of the growth of both parental varieties; it has a spring growth flush that is similar to, but not so marked nor so vigorous as that of var. elliottii. In the late summer period when var. elliottii growth is slowing, hybrid growth is still fast and similar to that of var. hondurensis. Presumably the hybrid spring growth phase requires the utilization of stored photosynthates though when these are accumulated is not clear. The hybrid may produce these by winter or by synthesising more than sufficient for the current growth in late summer.

The presence of the early spring flush in the hybrid may necessitate adequate rainfall at particular periods but it is not clear when these might be. On the basis of the parental requirements, it seems likely that good summer rains are desirable. Spring rains may also be important for if a checking of spring growth occurs the hybrid may be unable to respond to adequate conditions in the following summer.

The hybrid derivatives also combine the parental growth patterns, the extent to which they do so being determined by the proximity of their relationship to each parental variety. At present it can be assumed that their requirements approximate to those of the parental variety.

(iii) Synchronization of growth within varieties

For each variety or hybrid the proportion of stems growing in each two week period reflects the growth patterns (Tables 11 and 12, and Figures 10 and 11).

In the early spring, 100 per cent of the var. elliottii stems grew more than 1 inch per fortnight and more than 0.1 inch in girth. All stems maintained this rate of height growth to late December but on one occasion in early October girth growth slowed appreciably (Table 12). As all trees under observation regardless of variety or parentage behaved similarly this is assumed to be due to a period of moisture stress caused by persistant strong dry winds of force 3 - 4 (Beaufort Scale) at that time (Q. F. S. records). After December the number of var. elliottii stems growing in height decreased steadily until by May all had ceased growth. Most stems maintained girth growth until April after which a steady cessation occurred. By July all were dormant.

As is evident from both Table 13 and Figure 12 synchronization of growth between individual stems was good early in the season in var. elliottii. All stems set buds in late September - October and the majority again in November. Late season growth was much more haphazard.

In the var. hondurensis over 50% of all stems are growing in height 1 inch per fortnight throughout the year (Table 11 and Figure 10) and the individual patterns are thus haphazard and asynchronous with very few stems setting buds together (Table 13, Figure 12).

In comparison with the height growth pattern there was a much more definite pattern to the girth growth of var. hondurensis. Most stems grew in girth at a rate exceeding 0.03 inches per fortnight throughout the year but more vigorous growth of 0.1 inch per fortnight was confined to periods in September, November and February - March.

Except in winter the F1 hybrid had the vast majority of stems actively growing in height at any one time. Some girth growth occurred in most stems at all periods except the winter, but active girth growth exceeding 0.1 inch per fortnight was limited to the same periods as the var. hondurensis, namely September, November and February - March (Tables 11, 12, Figures 10 and 11). It was particularly noticeable that most hybrid stems commenced vigorous growth earlier in the spring than did those of var. elliottii. In this early spring phase good stem to stem synchronization occurred and most stems set buds in September, but after this growth became asynchronous (Figure 12).

The proportion of stems growing in height by 1 inch per fortnight in the hybrid derivatives was generally intermediate between the F1 hybrid and the respective parental variety (Figure 10). The degree of synchronization was similarly intermediate.

The very good synchronization in the early spring growth of var. elliottii indicates a very strong control of growth by climatic factors at this time. The cessation of girth growth in late June also suggests a strong climatic control. On the other hand the lack of growth synchronization in var. hondurensis points to the lack of any one factor or set of factors that strongly influences growth of this variety. In the hybrid, the var. hondurensis faction has apparently modified the expression of the factors strongly regulating the growth of var. elliottii. The possible nature of the factors controlling growth is discussed below.

(iv) Possible environmental factors controlling growth pattern in the varieties and hybrids

It is apparent from Table 14 and Figure 13 that the var. elliottii individuals that maintain growth longest in the growing season are also the tallest. This also applies with some exceptions, to girth growth; the largest trees, the dominants generally made girth growth in more of the fortnightly measure periods than did trees in lower crown classes (Table 12). Moreover var. elliottii individuals with the longest growing season produce more branch whorls (Table 14). It follows therefore that the number of whorls produced in different localities could give an indication of the length of the growing season providing the initial spring flush occurred at approximately the same time.

The examination in November 1966 of the 24 plots on which whorl counts were made showed that all plots had completed spring growth and that second growth flushes had commenced. In consequence, as the number of whorls produced tends to decrease in the lower latitude (Figure 14) it can be inferred that the length of the growing season of var. elliottii also decreases in lower latitudes in Queensland.

As noted earlier this correlation of latitude and growing season is thought to be particularly due to the rainfall patterns but other climatic factors may also have an effect. Generally in Queensland movement to lower latitudes results in increasing mean temperatures, decreasing thermo periods and modified photoperiods (See Part II Chapter 1) all of which are known to affect tree growth.

Temperature usually has an indirect effect on growth through its effect on factors which in their turn directly affect growth (Billings, 1952; Kramer and Kozlowski, 1960; Hellmers, 1962 and others). Nevertheless these indirect effects such as that on photoperiod (Nitsch, 1957 and others) result in definite growth changes.

There are instances of temperatures affecting growth directly thus in extreme cases mean temperatures can have a direct effect as has been shown my Mikola (1962) for Pinus sylvestris L. and Picea abies (L.) Karst. close to the northern timber line. In many species variations in thermoperiod (temperature ranges) have been shown to exert direct effects (Kramer, 1957; Hellmers 1962, 1966). Jackson (1962) concluded that reduced thermoperiod led to increased growth in var. elliottii but Kramer (1957) and Hellmers (1962) showed that the opposite was the case in the closely related P. taeda.

At Beerwah the growing season (assumed to be September to January inclusive) temperature range[1] is 16$^{o}$F and this decreases at lower latitudes (Table 2). As the growing season temperature range used by Jackson (1962) as a measure of thermoperiod had a minimum value of 16$^{o}$F. Most Queensland environments are outside the range sampled by Jackson. Consequently the decreasing thermoperiods experienced with movement north could well be associated with the poorer growth found in var. elliottii with such movement.

Wareing (1964) noted that any species showing photoperiodic responses with respect to extension growth will be affected by changes in latitude and Nitsch (1957) has shown var. elliottii to respond to photoperiod. There is little doubt that the decreasing summer photoperiods experienced with movement north in Queensland would affect var. elliottii growth.

Thus the reduced growth of var. elliottii in northern centres is felt to be due to a combination of climatic effects, possibly modified by site effects. Moisture relationships appear particularly important.
It is not possible to make such detailed deductions from the growth patterns of var. hondurensis or the hybrid. However homoclinal considerations (see Part II Chapter 1 and 2) would suggest var. hondurensis as being better suited to lower latitudes in Queensland (Slee and Nikles, 1967).

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1 Highest mean maximum monthly temperature in growing season less lowest mean minimum monthly temperature in same period.

The hybrid exhibits the responses of var. elliottii modified by var. hondurensis. It seems probable therefore that some at least of the requirements of var. elliottii for good growth will also be necessary for satisfactory growth of the hybrid. Thus the early spring growth flush of the hybrid, although commencing slightly earlier and less vigorous than in var. elliottii, must require the presence of sufficient stored photosynthates and the absence of limiting climatic conditions at that time. The hybrid growth could therefore become poorer with movement northwards towards conditions unfavourable to var. elliottii.

The combination of the growth patterns of the two parental species in conjunction with the intermediate environment is thought to explain the excellent growth attained in the hybrid. The hybrid is able to exploit the climatic factors determining growth better than either parent. Thus it has inherited the good spring growth from var. elliottii and this is presumably determined by the same controlling factors that govern the spring growth of var. elliottii. The hybrid also retains vigorous growth much later than var. elliottii due to the late season vigour of var. hondurensis, again presumably because the factors controlling growth cessation in var. elliottii have been modified by the association with var. hondurensis in the hybrid. Thus the hybrid may be regarded as better adapted than the parental varieties to the prevailing environment.

(v) Variation in tree to tree response; significance in breeding

It is clear that under conditions for growth that are found in Queensland considerable tree to tree variation in response of var. elliottii occurs. Table 14 and Figures 13 and 14 show that in a particular locality some trees grow far longer than others, produce more branch whorls and, at least at Beerwah, are taller. There is thus a range in adaptability within the variety even within the one seed source (Central Florida) that provided the bulk of Queensland's seed.

Presumably Queensland's tree breeding programme has exploited this variability. The trees selected for breeding purposes are amongst the biggest in the plantations presumably because they grow for a longer season. Crosses between these selected breeding trees have produced 30% more volume than material from local seed collections (Nikles 1962, 1966; Slee and Reilly, 1966). These local collections themselves represented at least a partial improvement over unselected material as they came from the best trees in the stands.

This agrees with Wareing's (1964) opinion that duration of extension growth is of paramount importance to the tree breeder, and that breeding for extended growth periods will be most feasible for areas having a mild winter.

Table 14 shows that var. elliottii trees growing longest in the season also have more whorls of branches.

These larger trees therefore may have a denser more highly branched crown. This too would explain their vigour advantage as several authors have found a correlation between total needle weight and stem diameter in gymnosperms. (Details of these studies have been reviewed by Matthews, 1963).

The great variability of var. hondurensis is well known (Luckhoff, 1964; Yeom, 1966) and it is to be expected that similar results will follow selection of breeding trees in this variety with better adaption to the locality. Certainly this can be inferred from the girth growth figures (Table 12); the bigger trees maintain girth growth for longer than the smaller trees in the stand.

The continuing use of the best trees as seed sources, and in breeding, improves the adaption of the population to the environment in var. elliottii and presumably also in var. hondurensis. The use of selected breeding trees as hybrid parents would therefore be expected to yield hybrids that would perform rather better than those of unselected parentage.

(vi) Summary of conclusions

Var. elliottii has a definite growth pattern. Following winter dormancy height and girth growth commence in September. The initial spring growth is very fast but subsequently becomes less vigorous until height growth ceases in the period January to April and girth growth stops in June. Climatic requirements for var. elliottii are stringent necessitating at least a mean of 10 inches of rain in the early spring. Good late season rain is also required. Rain at these periods assists late season growth and assists the production of photosynthates stored for the following spring flush. Because of these and other climatic considerations the variety appears best adapted to southern coastal Queensland's conditions and less well suited to areas further north.

Var. hondurensis has no definite growth pattern and appears able to adjust to take advantage of prevailing conditions. At Beerwah height and girth growth continue all year round, but both are slower in winter and faster in summer. It is difficult to specify climatic requirements for the variety because of the lack of a definite growth pattern. However other findings and homoclinal considerations suggest that the variety becomes better suited with movement northwards.

The hybrid between these varieties combines both growth patterns but climatic requirements cannot be finally deduced at this stage. It seems likely that adequate rainfall is required at the same times as is necessary for var. elliottii, but how much is required is not known. The good performance of the hybrid in southern coastal Queensland suggests adaption to this area. This agrees with the classical concepts of hybrids performing best in areas with environments intermediate between those to which the parental types are best suited. It is suggested that the intermediate nature of the hybrid enables it to respond to the prevailing climatic conditions of this area better than either of the parents.

All three types, both parental varieties and the hybrid, show between-tree variation in growth patterns and consequently in adaption to the local environment. The best var. elliottii trees are those that continue growth longest in the season producing more whorls of branches and becoming taller as they do so. In the hybrid and var. hondurensis the biggest trees maintain girth growth over longer periods than smaller stems.

## Chapter 2. Assessment of characteristics of the hybrids of the complex.

### Materials.

Plantings established in 1966 and earlier years were available for comparative assessment of varieties and hybrids of the complex. These plantings have been summarized in Tables 7 and 8. In general specific studies were restricted to trees that had attained a sufficient size to permit the expression and observation of a particular characteristic. For example the study of wood density variation was necessarily restricted to older trees producing mature wood, so that this study was carried out only in the 1958 planting, aged 9 years at assessment. Height growth was assessed in all plantings although the values obtained in the youngest (18 months at time of measure) would not be reliable indications of later vigour.

Vigour. Height growth measures were made in all plantings at all locations including Bowenia and Cathu. These measures covered several different plantings of the var. elliottii x var. hondurensis hybrids. In nearly every case, the growth on both ridge and swamp site types was compared.

Girth growth measures had to be limited to stems that had been ground pruned and therefore exceeded 20 feet in height. Only in stems of this size is the stem sufficiently large to be accurately measured for girth and such measures are greatly assisted by the pruning. Girth measures were thus only possible in experiments including the var. elliottii x var. hondurensis hybrid and its derivatives, i.e. the 1958, 1960, 1961, 1962 and 1963 plantings. These covered both ridge and swamp site types and full details of these plantings are given in Appendix 1.

Stem Straightness. Assessment of stem straightness was made only on pruned stems, as evaluation of straightness is dependent upon a clear view of the bole. Accordingly the plantings used were those established in 1958, 1962 and 1963 (ridge only). These included the var. elliottii x var. hondurensis hybrid and its derivatives, on two site types. Full details of these plantings are given in Appendix 1.

Wind-firmness. Assessment of wind-firmness was of necessity limited to damaged areas, and only the 1963 and 1964 were sufficiently affected by the cyclone of January 1967 to yield useful results. In these plantings, the sections on the swamp sites were barely affected and were not covered by the assessment. The wind-firmness assessment was therefore only made on ridge sites and included the var. elliottii x var. hondurensis hybrid and its associated backcrosses. Details of the 1963 and 1964 plantings are provided in Appendix 1.

Branch size and wood density variation. Both branch and wood studies required the use of the oldest material possible. It was considered that studies on material younger than eight years of age would not yield representative results. Consequently, these studies were made only on the 1958 planting comparing the var. elliottii x var. hondurensis hybrid with its parental varieties on both ridge and swamp sites. This planting is detailed in Appendix 1.

Methods of Assessment.

Vigour. Vigour assessments were made in 1966 or 1967 by direct measurements of height on all stems in all plantings and also of girth at breast height of all stems in all plantings that had been ground pruned.

Measurement of height was by graduated sticks placed alongside the trees and of girth by graduated metal tapes around the tree at the 4 feet 3 inches level, this latter being determined by a stick of that length placed against the tree.

Stem straightness. Shelbourne (1966) has reviewed in detail the possible methods of assessing bole straightness. He concludes that, "whilst subjective methods have limitations due to the amount of variation between observers in skill, consistency, and objectivity they are the only practical method for large numbers of observations and are sufficiently precise and repeatable to give useful data. More accurate methods of assessing bole straightness will only be required where it is necessary to make fine distinctions between individual groups of trees with similar straightness". Distinctions of this order would yield no immediate practical returns and are thus unnecessary in this broad comparison of the hybrids with the parental species. Accordingly subjective techniques were used.

The assessment was applied to all trees in the 1958 planting and to the interior blocks of 25 and 20 trees respectively in each plot in the 1962 and 1963 plantings. Each stem was examined and subjectively awarded a point score to the scale detailed in Table 15.

This scale necessitated distinguishing between slight and serious defects. In the 1962 and 1963 plantings a serious defect was defined as

Table 15. Scale used to score trees for straightness

| Score | Definition of Class |
|---|---|
| 10 | No straightness defect visible |
| 9 | One slight defect only |
| 8 | A few slight[1] defects |
| 7 | One serious[1] defect and up to two slight defects or several slight defects |
| 6 | Up to three serious defects or numerous slight defects or equivalent combinations |
| 5 | Several serious defects, could possibly return a saw log of 6 feet length |
| 4 or less | Correspondingly worse |

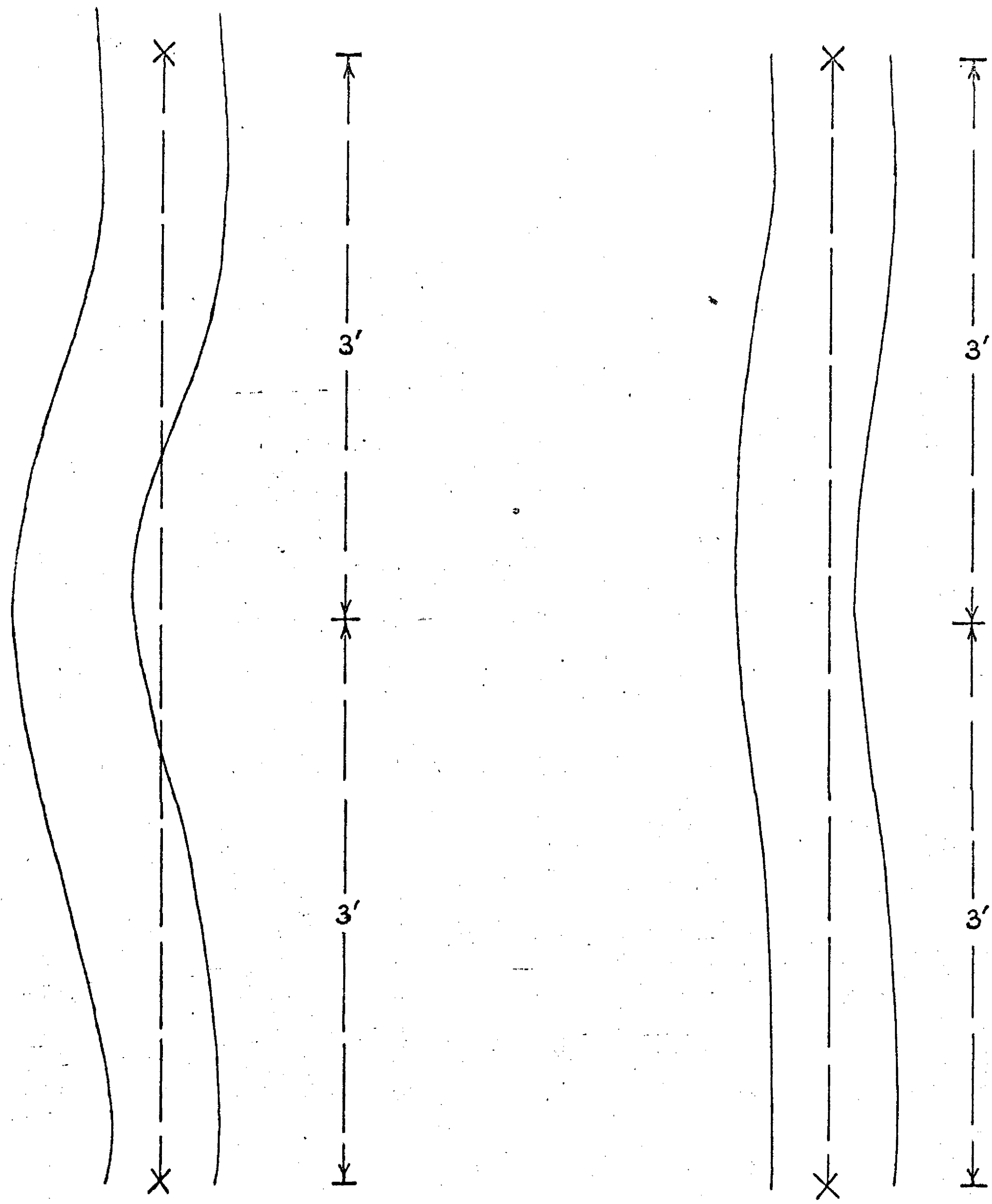
1 Definitions of slight and serious are given in the text and Figure 16.

"a bend in the stem in which the outside edge of the tree cut or approached an imaginary line joining the mid points of the stem three feet on either side of the centre of the defect, the stem being viewed at right angles to the plane of the bend". Slight defects were "bends in which the line did not cut the outside edge of the stem". These definitions are illustrated diagramatically in Figure 16.

In the 1958 planting the trees were larger, and it was necessary to adjust the definitions so that bends of the same order as those in the 1962 and 1963 plantings were placed in the same category. This was done subjectively.

In such assessments there is a tendency for the standards to change with plot changes. Thus a good tree in a generally poor plot tends to be awarded a

FIG. 16. DIAGRAMATIC REPRESENTATION OF THE GRADES "SERIOUS" AND "SLIGHT" USED IN THE CLASSIFICATION OF BOLE STRAIGHTNESS




SERIOUS.

SLIGHT

STEM CUTS IMAGINARY LINE JOINING CENTRES 3 FT. EITHER SIDE OF DEFECT

STEM DOES NOT CUT IMAGINARY LINE JOINING CENTRES 3 FT. EITHER SIDE OF DEFECT higher value than the same tree in a better plot. To avoid this plots were not assessed as individual units. Instead plots were assessed together in groups by working firstly along one row of trees through several plots assessing each tree, and then returning along the next row through the same plots. Thus the assessment was always covering trees and plots of widely differing standards and this tended to prevent fluctuations in the assessment standards applied.

In the actual assessment, stems were evaluated in terms of half-categories (e.g. $7\frac{1}{2}$). This ensured a much more precise assessment, although for simplicity in the presentation of the results whole categories only have been used. During assessment an attempt was made to ensure uniformity of standards by periodic re-assessment of completed plots or portions of plots.

Wind-firmness. Following the cyclone of 29th - 30th January, 1967 the ridge plantings of 1963 and 1964 were assessed for damage. The swamp plantings of these years were not assessed as they were only slightly damaged, probably because of their more sheltered position.

The interior 20 and 25 trees respectively in each planting were classified subjectively for damage into one of the following categories.

| | | |
|---|---|---|
| (i) | Severe Damage: | Stem Lean $30^{o}$ or more from vertical or stem bent at a point above ground or stem broken. |
| (ii) | Moderate Damage: | Stem leans between $5^{o}$ and $30^{o}$ from the vertical. |

(iii) Slight Damage: Stem leans by up to $5^{o}$ from the vertical.

(iv) Nil No lean.

In the assessment bends were regarded as a more serious fault than leans, because the point at which a bend occurs remains a permanent source of weakness in the tree stem (Mergen, 1954). Queensland's successful treatment of young leaning trees by pushing upright and firming the soil at their base suggests that a temporary lean may not have a permanent effect on stem quality. Moreover there is no evidence that trees with corrected leans are particularly susceptible to subsequent storm damage unless the interval between storms is only a few months. On the other hand, the author has noted that bent trees have a tendency to recurrent bends.

Branch size. Snyder (1961) regarded branch development as differentiated into three zones on the tree. In the first, the upper zone the topmost branches are competing with the leader and have a diameter comparable to that of the leader. The relative size of the branches compared to the stem decreases rapidly lower in this zone until in zone two the stem diameter : branch diameter stabilizes at about 100 : 30. In this zone, consisting in *Pinus palustris* of between two to seven whorls, limb diameter increases to a maximum branch size for the tree. Below this zone is the third zone the region of branch senesence; here branches are smaller and die as the tree ages. Snyder regarded zone two as the position in which branch studies should be carried out, a practice followed by Barber (1964) and Woessner (1965) in their studies on *P. elliottii* var. *elliottii* and *P. taeda* respectively.

For the comparisons between the var. elliottii x var. hondurensis hybrid and its parental varieties, measurements were made on the trees planted in 1958, both on the ridge and the swamp. Three trees in the centre row of each plot containing the hybrid, var. hondurensis or the controlled cross of var. elliottii were taken at random and Snyder's zone two selected by eye. This zone was regarded as running from the largest branches in each tree upward to include the first whorl from the top at which bole diameters above and below the whorl did not differ noticeably (See Snyder, 1961).

Within this zone the girth of all branches in two consecutive whorls was measured two inches from the stem and stem girth measured two inches above each whorl. The two inch distance being taken to avoid the swelling associated with branch : stem unions.

Regressions were calculated of mean branch girth at each whorl or stem girth at that whorl. The results for var. elliottii were subdivided into two sections, and separate regressions calculated for branches associated with the major whorls produced from the over-wintering buds, and for branches associated with the subsidiary whorls (see Figure 5). No such divisions were made in the data collected from var. hondurensis or the var. elliottii x var. hondurensis hybrid. In var. hondurensis where whorls were associated with "foxtail" growth[1] they were omitted from calculations. Separate regressions were produced for each site type, the ridge and the swamp, and for

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1 "Foxtail" growth is the term used to describe a long inbranched stem caused by the leading tip failing to stop growth and set a bud. (Lanner, 1966). Branch size was thought likely to be atypical in association with such growth.

each parental and hybrid type.

Wood density variation. On the ridge site of the 1958 planting five trees were taken at random from the hybrid plot, and from the unimproved elliottii and hondurensis plots. Similarly four trees of each were randomly chosen on the swamp site.

Half inch cores were extracted, bark to pith, from the northern side of each tree at a height of 3 feet 6 inches using an increment borer. If compression wood was likely to be included in the core the direction of boring was adjusted to minimise its occurrence. No boring varied by more than 45$^{o}$ from magnetic north. The cores were maintained in a green condition and transported to Canberra, where they were dried in a vacuum oven to a very low moisture content, and subjected to Soxhlat extraction using a 50-50 benzene-absolute alcohol mixture for 24 hours. Each core was planed on two parallel transverse sides to a thickness of 0.690 cm. The sides at right angles were also trimmed with the plane leaving the core with a rectangular cross section. Finally all were brought to 11% moisture content.

Density variations were examined by the use of an X-ray-microspectrophotometric technique as outlined by Polge (1963, 1965 and 1966) and Rudman (1967). In this technique the cores were irradiated with X-rays generated at 23 Kv, 20 ma which had passed through an aluminium screen placed 12 inches from the source. The cores were eight feet from the source in contact with Kodak AA X-ray film and had standards of known density associated. All cores from the ridge site were irradiated together on one film with an exposure of five minutes and all from the swamp site on another with an exposure of six minutes.

Each film was developed and a trace bark to pith made of each core using a Joyce-Loeble microdensitometer on a 1 : 5 ratio, i.e. the trace length was five times the core length. This trace recorded graphically density variations along the core and by the comparison with the traces from the standards the density at any particular point on the curve could be calculated. Examples of typical traces covering two seasons growth rings are given in Figure 19.

Comparative observations were made on the last four annual rings in each variety and the hybrid. For each ring the maximum density and minimum density, were recorded. Also the percentage width of each ring that exceeded densities of 0.44, 0.55 and 0.68 gm per cc was noted and by using an integrator attached to the densitometer the area beneath each curve was found and the mean density for each ring calculated.

Analyses. Analyses of variance of plot mean were made on the data for height, girth, stem straightness and wind-firmness. Arcsin transformations were applied to percentage data. In the 1966 planting, height measure data common to the two locations Beerwah and Bowenia was pooled to obtain comparisons between these locations and also to see if any variety or hybrid-location interaction was present. Similarly the data from the 1958 planting for height growth, girth growth and stem straightness and from the 1964 planting for height growth was pooled over site-types at Beerwah to determine whether a site-variety interaction existed. As significant site-variety interactions were found separate analyses were performed on each site-type to determine the significance of the difference between the varietal means. In the 1966 planting some material was not common to both locations. This was omitted from the overall analyses but included in the separate analyses performed for each location.

The analyses of wood density variation were performed on the individual ring values. The main breakdown was by individual trees and ring values. Table 16 shows how the sums of squares for these were partitioned to compare varieties (or hybrids), sites, variety-site, ring-site, ring-variety and ring-variety-site interactions.

The site and variety-site terms were tested in comparison with the remainder 1 term and the ring-site, ring-variety and ring-variety-site with the remainder 2 term as described by Steel and Torrie (1960 p233).

Where significant site-variety interaction occurred separate analyses were calculated for each site type.

In all analyses tests of significance of individual items were made using Duncan's new multiple range test (Steel and Torrie, 1960 p 107) as the number of individual means for comparison was as large as six or seven in some cases. Substitutions were obtained for missing plots using the method of Yates (1937), with degrees of freedom reduced accordingly. Bias was ignored.

## Results.

Vigour. The hybrid and varietal means for height and girth in 1967 are given

Table 16. Method used to partition the sums of squares for analyses of variance purposes in the wood study

Site Types, 2 (ridge and swamp); Varieties, 3 (elliottii, hondurensis, and their hybrid). 5 trees in each variety sampled on the ridge site and 4 in each on the swamp site. 4 ring values obtained from each tree.

Details - (one missing plot)

| Source of Variation | Degrees of Freedom | Source of Variation | Degrees of Freedom |
|---|---|---|---|
| Trees | 26 | Rings | 3 |
| Varieties | 2 | (Ring-trees) | 77 |
| Site | 1 | Ring-site | 3 |
| Var-site | 2 | Ring-var | 6 |
| Remainder 1 | 21 | Ring-var. -site | 6 |
| | | Remainder 2 | 62 |
| | | Total | 106 |

in Table 17. The results are presented separately by date of planting, location of planting (Beerwah, Bowenia or Cathu), site of planting (ridge or swamp) and plot size (multi- or single-line).

Where several batches of the same hybrid type but different parentage occurred together in the same planting, the mean of the batch means was taken to indicate the hybrid performance. The one exception was in the 1966 planting, which contained two separate randomized blocks both at Beerwah and Bowenia. Each block contained the same hybrid types var. caribaea x var. hondurensis, var. elliottii x var. caribaea and var. elliottii x var. hondurensis as well as the parental varieties. But the parentage differed between the different blocks and results are presented separately for each block in Table 18.

The possibility of examining the results for parentage effects was considered. Such a course would determine whether or not any one parent gave particularly outstanding or particularly poor hybrids. However the lack of replication in most families and confusing site effects in the 1964 planting meant that any such deductions made would be most unreliable. Effects due to individual parentage have not therefore been considered.

Analyses of variance of the vigour data are included in those summarized in Table 19. Full details of these analyses are given in Appendix 2. The analyses of variance for the 1966 planting are presented separately in Table 18 including the one in which it was possible to analyse over the two locations.

Stem straightness. The results obtained from the stem straightness assessment have been summarized in Table 17. This table compares the proportions of stems in each batch of sufficiently good straightness to justify high pruning. Additional results showing the breakdown of the assessment by categories are given in Appendix 3 and depicted diagrammatically in Figure 17.

Analyses have been summarized in Table 19 and detailed in Appendix 2.

Wind-firmness. Results of the wind firmness assessment have been summarized in Table 17, where the percentage of trees moderately or severely damaged in each hybrid or variety are compared. Full details are provided as Appendix 3. Analyses of variance data is summarized in Table 19 and detailed

Table 17. Comparisons of varietal and hybrid means by planting dates, plot types, and locations for height and g.b.h. at the 1967 measure, straightness and wind-firmness. (For coding used see Part II, Chapter 4)

(a) Beerwah Ridge

| Character | Height (feet) | | g.b.h. (inches) | Straightness (% scoring 7 or more) | Wind-firmness (% mod. or sev. damaged) |
|---|---|---|---|---|---|
| Plot type[1] | M | L | M | M | M |
| 1958 planting | X[2] 39.1[3] | - | X 25.4 | E[4] 85 | - |
| | H 37.9 | - | H 24.0 | X 54 | - |
| | ES 34.3 | - | ES 21.6 | ES 49 | - |
| | E 31.8 | - | E 20.3 | H 17 | - |
| 1961 | H 27.7 | - | X 17.7 | - | - |
| | X 27.0 | - | H 17.0 | - | - |
| | E 21.5 | - | E 14.3 | - | - |
| 1962 | X[2] 19.3 | 20.2 | - | E 91 | - |
| | H 18.6 | 19.5 | - | X 55 | - |
| | E 15.3 | 15.7 | - | H 33 | - |
| 1963 | XH 23.1 | - | X 14.5 | E 81 | XE 11 |
| | X 21.4 | - | XH 14.0 | XE 77 | X 17 |
| | H 21.4 | - | XE 14.0 | X 61 | E 18 |
| | XE 19.5 | - | H 14.0 | XH 26 | XH 29 |
| | E 18.0 | - | E 8.9 | H 5 | H 50 |
| 1964 | X 16.8 | X 16.4 | - | - | XH 17 |
| | XH 16.4 | XH 15.9 | - | - | XO 27 |
| | XO 15.5 | H 15.2 | - | - | E 31 |
| | XX 15.5 | XO 14.7 | - | - | X 35 |
| | H 13.8 | E 11.4 | - | - | H 47 |
| | E 11.7 | | | | |

(b) Beerwah Swamp

| Character | Height (feet) | | g.b.h. (inches) |
|---|---|---|---|
| Plot type | M | L | M |
| 1958 | X 38.5 | - | X 24.5 |
| | H 31.7 | - | H 20.3 |
| | ES 30.4 | - | ES 19.9 |
| | E 30.3 | - | E 18.9 |
| 1963 | - | X 16.8 | X 11.5 |
| | - | XH 16.2 | XE 11.0 |
| | - | XE 15.5 | XH 10.2 |
| | - | B 14.9 | B 9.3 |
| | - | H 12.1 | H 7.8 |
| 1964 | X 9.2[5] | X 10.6 | - |
| | XO 8.9 | XO 8.4 | - |
| | E 8.3 | E 7.1 | - |
| | XX 7.7 | XH 6.2 | - |
| | XH 7.4 | H 5.5 | - |
| | H 5.6 | - | - |

(c) Bowenia Ridge

| | | | |
|---|---|---|---|
| 1963 | H 14.1 | H 17.1 | - |
| | XH 13.9 | XH 16.4 | - |
| | X 13.1 | X 14.7 | - |
| | E 11.0 | E 11.5 | - |

(d) Cathu Swamp

| | | | |
|---|---|---|---|
| 1966 | H 4.3[5] | - | - |
| | X 3.6 | - | - |

1 M = Multi-line; L = Single-line.
2 1966 height measure.
3 Lines join all items not significantly different at the 5% level.
4 Joint swamp and ridge results (no variety x site interaction)
5 No tests of significance could be applied.

Table 18. Results of the 1967 height measure of the 1966 planting comparing the inter-varietal hybrids of var. elliottii, var. hondurensis and var. caribaea with the parental varieties at two locations, summarized details of the analyses of the data are also included.

Height Figures.

| Location | Beerwah | | | | Bowenia | | | |
|---|---|---|---|---|---|---|---|---|
| Group | A | | B | | C | | D | |
| Heights (inches) | X[1] | 60.2 | X | 54.7 | X | 58.7 | H | 39.2 |
| | H | 46.6[3] | H | 49.7 | CH | 56.5 | EC | 38.7 |
| | CH | 45.2 | CH | 46.1 | EC | 54.1 | CH | 38.7 |
| | EC | 43.6 | EC | 45.5 | H | 51.6 | E | 34.1 |
| | E | 35.3 | C | 36.7 | E | 43.1 | C | 25.1 |
| | C | 32.0 | E | 35.3 | C | 38.3 | | |

Analyses.

| Source of Variation | Degrees of freedom | | | | Mean sum of square | | | | Significance[2] | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Group | A | B | C | D | A | B | C | D | A | B | C | D |
| Blocks | 2 | 2 | 2 | 2 | 18 | 10 | 397 | 6 | NS | NS | ** | NS |
| Varieties | 7 | 7 | 6 | 5 | 373 | 163 | 178 | 119 | *** | *** | ** | ** |
| Error | 11 | 11 | 12 | 10 | 9 | 9 | 28 | 25 | - | - | - | - |

Combination Groups B and C

| Source of Variation | Degrees of freedom | Mean sum of square | Significance |
|---|---|---|---|
| Blocks | 5 | 139 | ** |
| Locations | 1 | 125 | NS |
| Bl. x Loc. | 4 | 142 | - |
| Varieties | 4 | 436 | *** |
| Var. x Bl. | 18 | 22 | - |
| Var. x Loc. | 4 | 14 | NS |
| Remainder | 14 | 25 | - |

1 For coding used see Part II Chapter 4.
2 NS means not significant; *, ** and *** indicate significance at the 5, 1 and 0.1 percent levels respectively.
3 Lines join all items not significantly different at the 5% level.

Table 19. Summarised data from analyses of variance on the height, girth, straightness and wind-firmness results

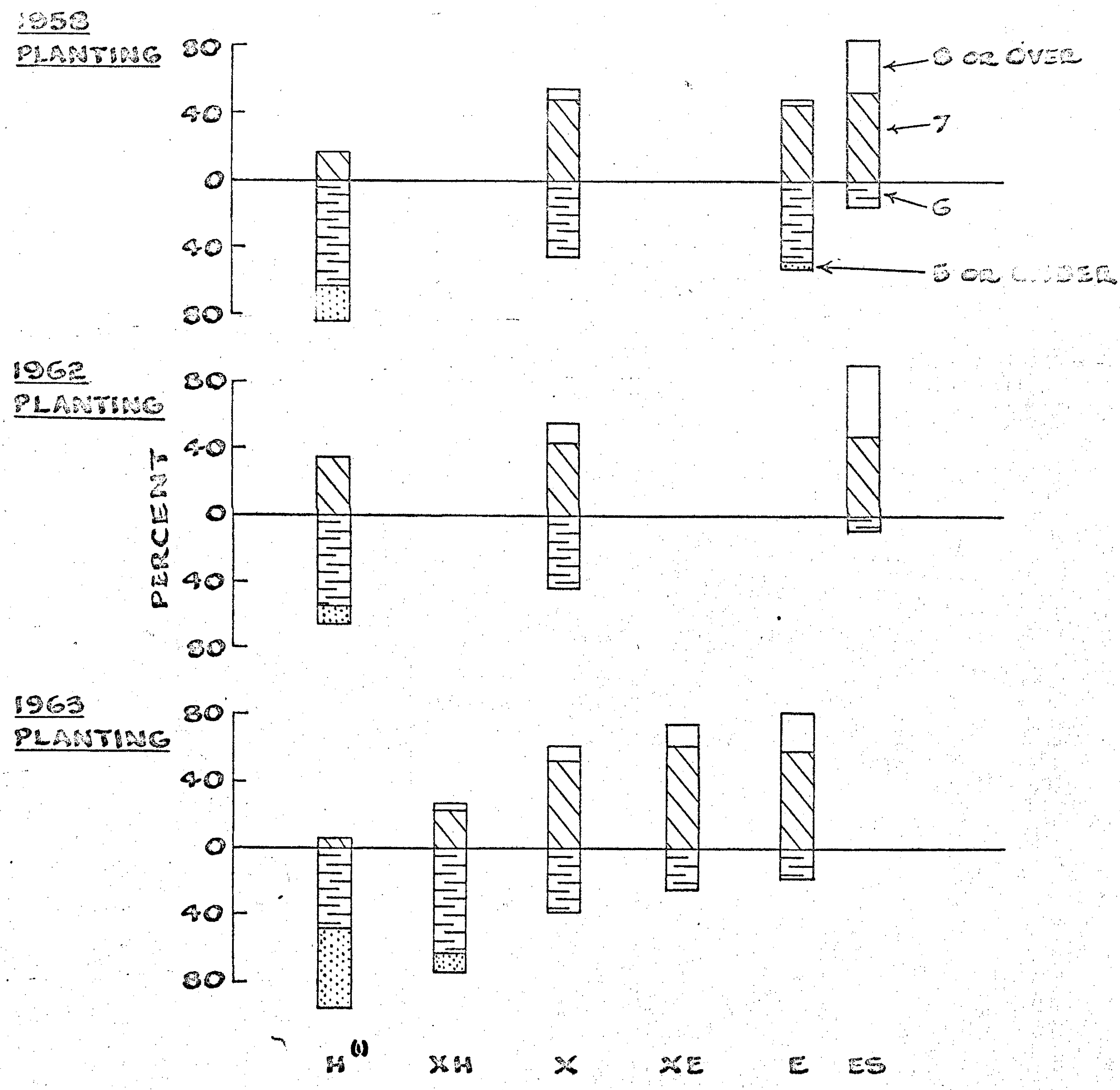
(a) Joint analyses (between site-types (only the sections relevant to variety x site interaction are shown here)

| Source of Variation | Degrees of freedom | Mean sum of squares: Height | Mean sum of squares: g.b.h. | Mean sum of squares: S'ness | Significance[1]: Height | Significance[1]: g.b.h. | Significance[1]: S'ness |
|---|---|---|---|---|---|---|---|
| 1958 planting | | | | | | | |
| Var. x block | 27 | 4 | 1 | 57 | - | - | - |
| Var. x site | 3 | 17 | 4 | 32 | *** | ** | NS |
| Rem. 2 | 24 | 2 | 0.5 | 60 | - | - | - |
| 1964 planting | | M | L | Height M | Height L | M | L |
| Var. x block | | 9 | 20 | 2 | 2 | - | - |
| Var. x site | | 5 | 5 | 2 | 6 | NS | * |
| Rem. 2 | | 4 | 15 | 1 | 1 | - | - |

| Source of Variation | Degrees of freedom | Mean sum of squares: Height | Mean sum of squares: g.b.h. | Mean sum of squares: S'ness | Mean sum of squares: W-f'ness | Significance: Height | Significance: g.b.h. | Significance: S'ness | Significance: W-f'ness |
|---|---|---|---|---|---|---|---|---|---|
| (b) Beerwah Ridge. | | | | | | | | | |
| 1958 | | | | | | | | | |
| Blocks | 4 | 2 | 2 | - | - | NS | NS | - | - |
| Varieties | 3 | 56 | 79 | - | - | *** | *** | - | - |
| Error | 12 | 1 | 4 | - | - | - | - | - | - |
| 1961 | | | | | | | | | |
| Varieties | 2 | 94 | 26 | - | - | *** | *** | - | - |
| Error | 9 | 3 | 1 | - | - | - | - | - | - |
| 1962 (Multi-line plots) | | | | | | | | | |
| Blocks | 2 | 1 | - | 10 | - | NS | - | NS | - |
| Varieties | 2 | 14 | - | 1136 | - | ** | - | ** | - |
| Error | 4 | 0.6 | - | 36 | - | - | - | - | - |
| 1962 (Single-line plots) | | | | | | | | | |
| Blocks | 3 | 6 | 2 | - | - | NS | NS | - | - |
| Varieties | 3 | 18 | 5 | - | - | * | NS | - | - |
| Error | 9 | 3 | 1 | - | - | - | - | - | - |
| 1963 | | | | | | | | | |
| Blocks | 4 | 6 | 3 | 71 | 237 | ** | *** | NS | NS |
| Varieties | 4 | 17 | 27 | 2324 | 682 | *** | *** | *** | ** |
| Error | 16 | 1 | 0.3 | 83 | 94 | - | - | - | - |
| 1964 (Multi-line plots) | | | | | | | | | |
| Blocks | 1 | - | - | - | 68 | * | - | - | NS |
| Varieties | 4 | - | - | - | 98 | - | - | - | * |
| Error | 4 | - | - | - | 35 | - | - | - | - |
| 1964 (Single-line plots) | | | | | | | | | |
| Blocks | 1 | 17 | - | - | - | * | - | - | - |
| Varieties | 5 | 7 | - | - | - | NS | - | - | - |
| Error | 5 | 1.8 | - | - | - | - | - | - | - |
| (c) Beerwah Swamp. | | | | | | | | | |
| 1958 | | | | | | | | | |
| Blocks | 4 | 4 | 5 | - | - | NS | NS | - | - |
| Varieties | 3 | 78 | 93 | - | - | *** | ** | - | - |
| Error | 12 | 4 | 9 | - | - | - | - | - | - |
| 1963 (Single-line plots) | | | | | | | | | |
| Blocks | 4 | 2 | 1 | - | - | NS | NS | - | - |
| Varieties | 4 | 17 | 10 | - | - | *** | *** | - | - |
| Error | 15 | 1 | 1 | - | - | - | - | - | - |
| 1964 (Single-line plots) | | | | | | | | | |
| Blocks | 5 | 41 | - | - | - | ** | - | - | - |
| Varieties | 2 | 59 | - | - | - | *** | - | - | - |
| Error | 10 | 11 | - | - | - | - | - | - | - |
| (d) Bowenia Ridge. | | | | | | | | | |
| 1963 (Multi-line plots) | | | | | | | | | |
| Blocks | 3 | 3 | - | - | - | NS | - | - | - |
| Varieties | 3 | 8 | - | - | - | ** | - | - | - |
| Error | 9 | 1 | - | - | - | - | - | - | - |
| 1963 (Single-line plots) | | | | | | | | | |
| Blocks | 4 | 8 | - | - | - | * | - | - | - |
| Varieties | 3 | 30 | - | - | - | *** | - | - | - |
| Error | 12 | 1.1 | - | - | - | - | - | - | - |

1 NS indicates not significant; *, ** and *** indicate significance at the 5, 1 and 0.1 percent levels respectively.

FIG. 17. RESULTS OF THE STEM STRAIGHTNESS ASSESSMENTS SHOWING THE PERCENTAGE OF STEMS IN EACH VARIETY OR HYBRID PLACED IN EACH CATEGORY




(1) FOR CODING USED SEE PART II CHAPTER 4

in Appendix 2.

Branch size. The regressions calculated and the correlation co-efficient and significance of each are given in Table 20 and illustrated diagrammatically in Figure 18.

Wood density variation. Examples of typical densitometer traces for each varietal or hybrid type are given in Figure 19, together with the values of the various density components obtained from these actual traces.

The comparisons made in maximum, minimum and mean densities and percentages of wood in each season's growth exceeding densities of 0.44, 0.55 and 0.68 gm per cc are summarized in Table 21 and Figures 20 and 21. The analysis of variance data is summarized in Tables 22 and 23. Full details of all results are given as Appendix 4 and of the analyses in Appendix 2.

Discussion.

Vigour. In nearly all plantings significant and usually very highly significant differences were found between batches in both height and girth. (Tables 17, 18 and 19). The only exception is the 1964 ridge planting of single-line plots at Beerwah and in this case the "F" value is high (3.97) and the application of Duncan's New Multiple Range Test does give significant differences between batches. Such a procedure is legitimate as this test is not dependent on significant "F" values (Steel and Torrie, 1960 p107).

On all ridge plantings at Beerwah the var. *elliottii* and var. *hondurensis* hybrid is significantly superior to var. *elliottii* in both height and girth growth,

FIG. 18. RESULTS AND REGRESSION LINES CALCULATED FROM THE BRANCH STUDY PLOTTING MEAN BRANCH GIRTH AGAINST MEAN STEM GIRTH

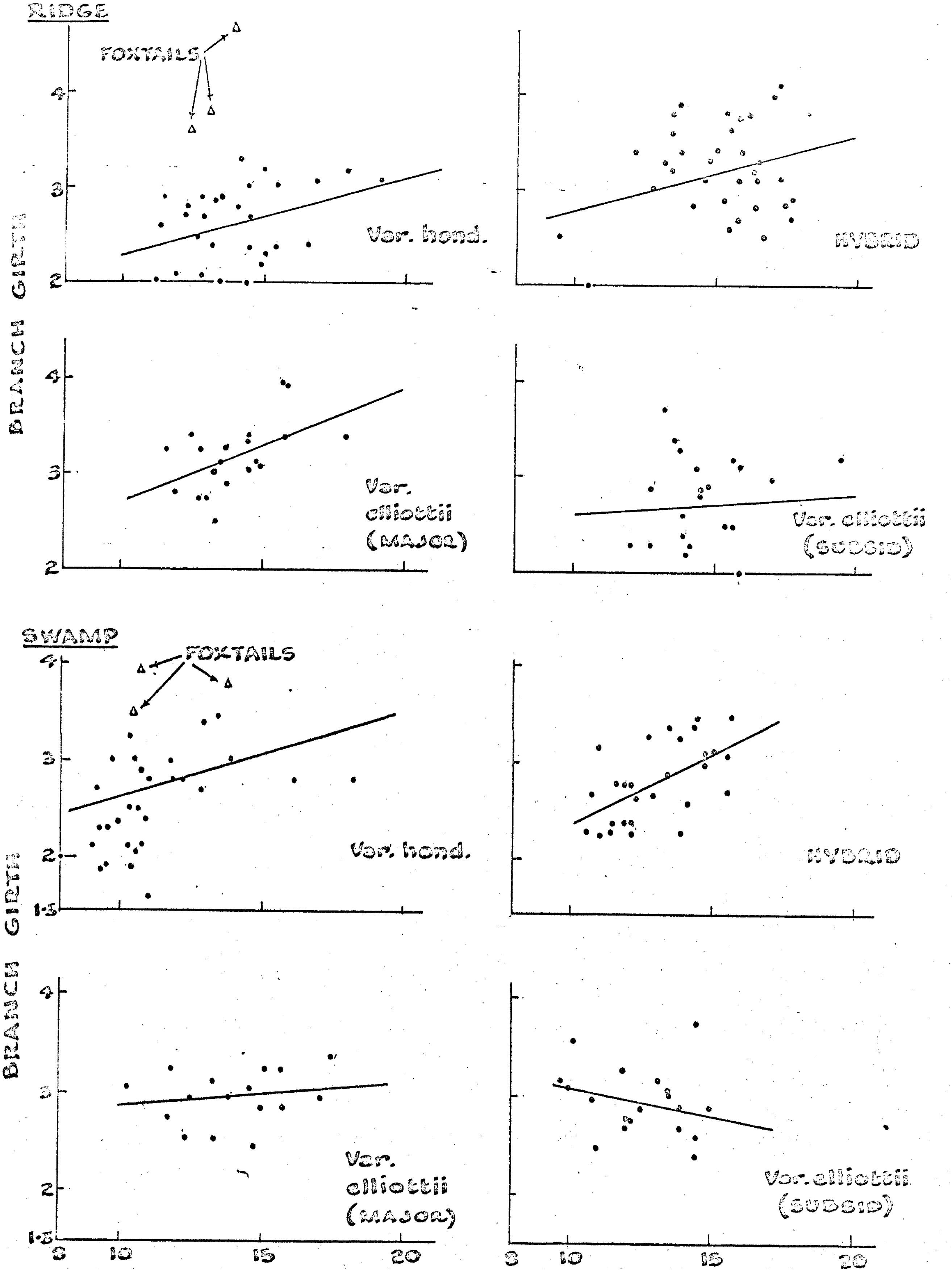
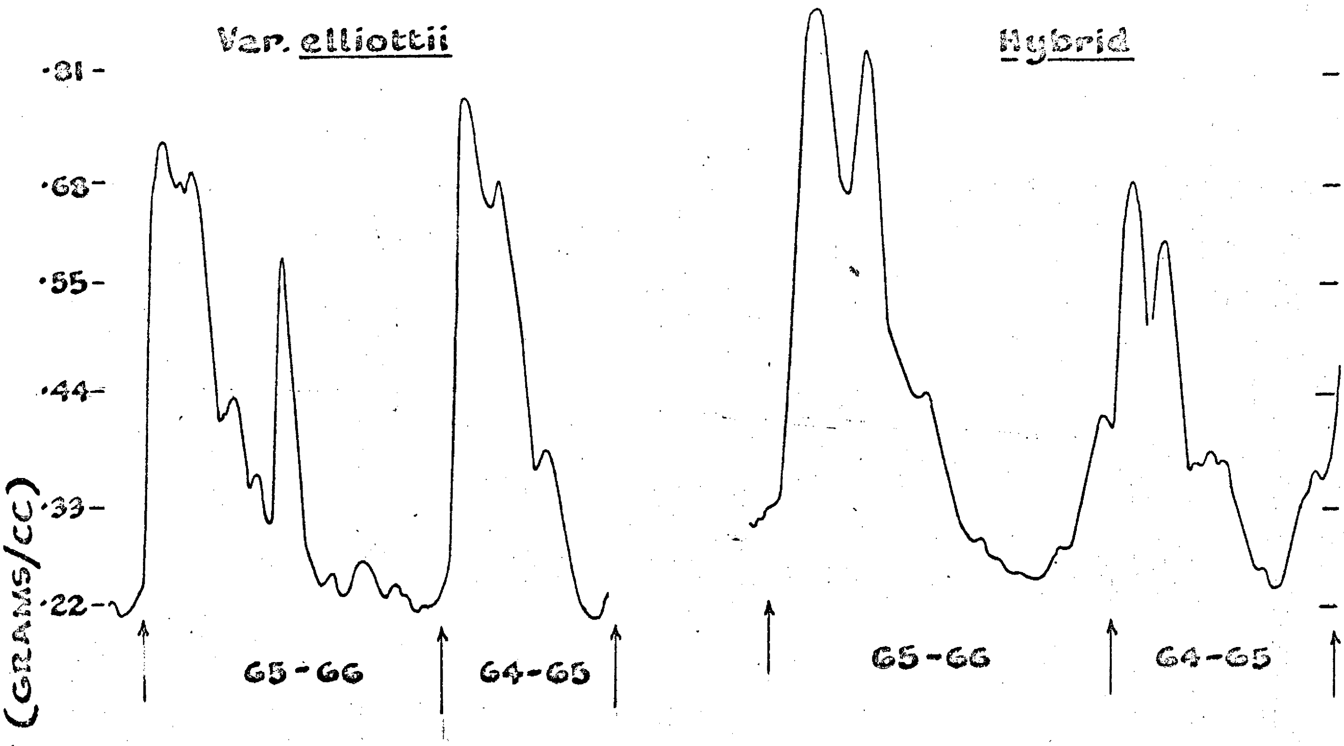
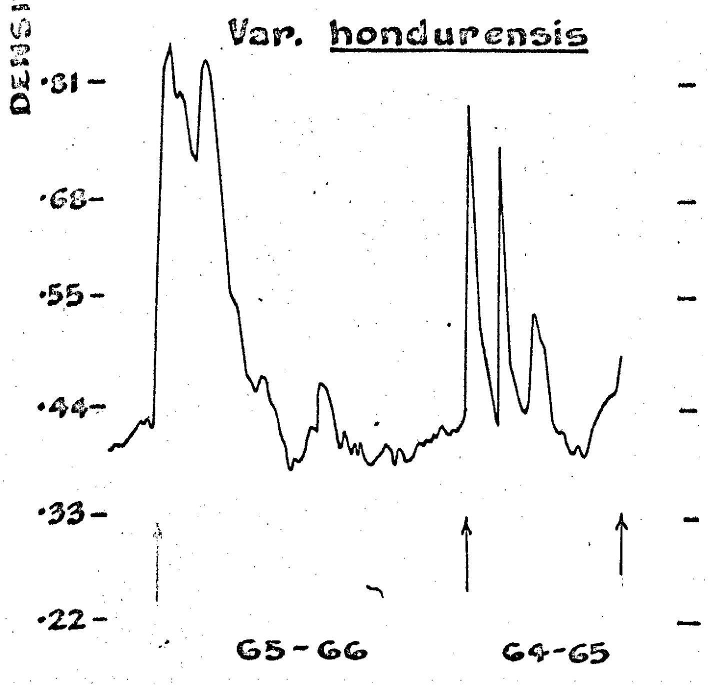


FIG. 19. DENSITOMETER TRACES FOR INDIVIDUAL TREES OF Var. *elliottii*, var. *hondurensis* AND THEIR HYBRID FOR SEASONS 1965-66 AND 1964-65



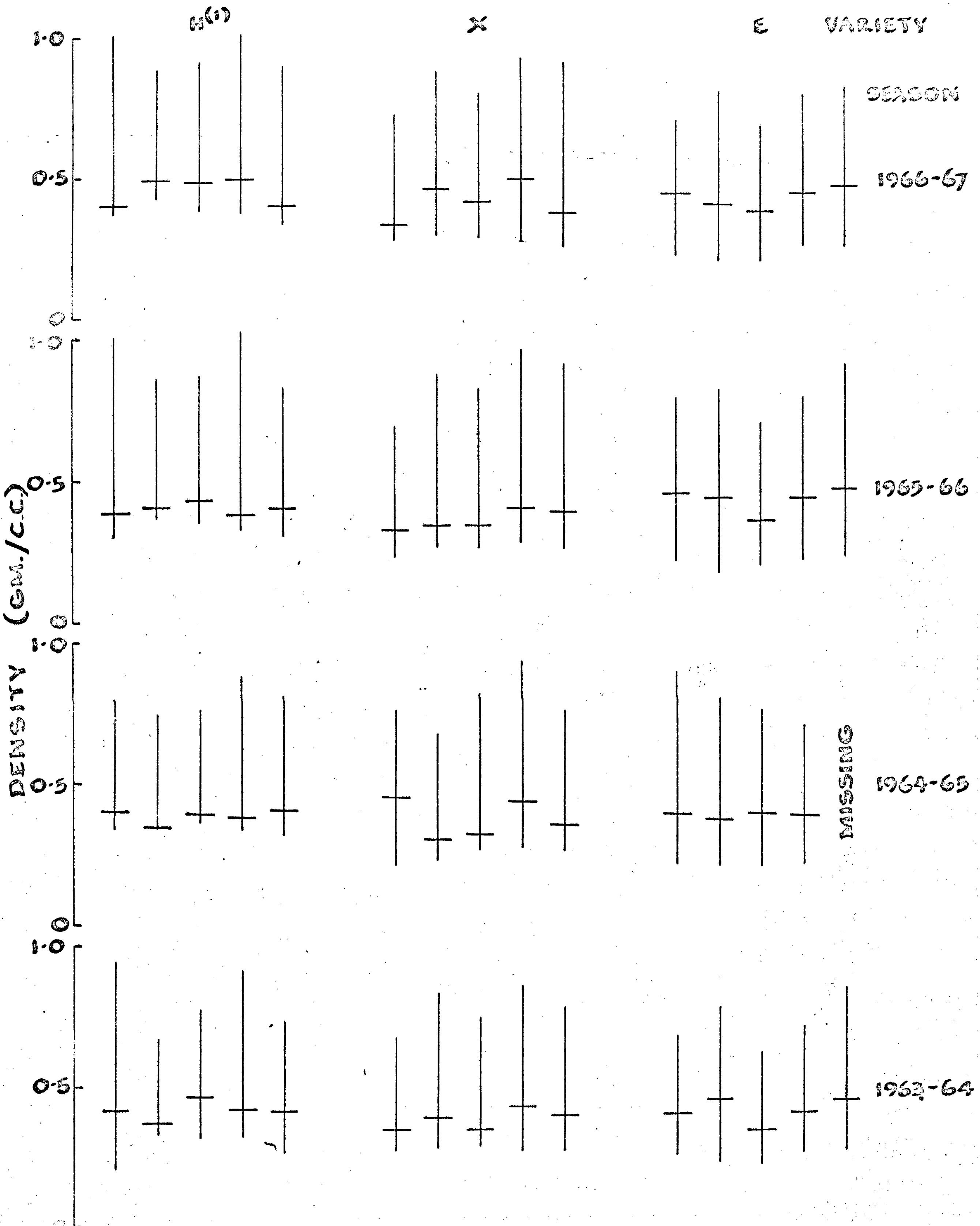




DATA FOR THESE TRACES

| VARIETY | E | | X | | H | |
|---|---|---|---|---|---|---|
| YEAR (1) | A | B | A | B | A | B |
| Max. D | ·73 | ·78 | ·89 | ·68 | ·87 | ·77 |
| Min. D | ·22 | ·22 | ·26 | ·24 | ·36 | ·37 |
| Mean D | ·37 | ·41 | ·35 | ·32 | ·43 | ·40 |
| % ring over:- | | | | | | |
| ·44 | 37 | 41 | 38 | 29 | 37 | 41 |
| ·55 | 21 | 32 | 25 | 16 | 22 | 9 |
| ·68 | 13 | 17 | 21 | 2 | 18 | 6 |

(1) A = 1965-66
B = 1964-65

FIG. 20. RESULTS OF THE STUDIES ON DENSITY VARIATION MADE ON FIVE TREES OF EACH VARIETY OR HYBRID OVER FOUR SEASON'S GROWTH SHOWING THE MEAN DENSITY AND DENSITY RANGE FOR EACH TREE IN EACH SEASON **(RIDGE SITE)**




(1) FOR CODING USED SEE PART II CHAPTER 4

FIG. 21. RESULTS OF THE STUDIES ON DENSITY VARIATION MADE ON FOUR TREES OF EACH VARIETY OR HYBRID OVER FOUR SEASON'S GROWTH SHOWING THE MEAN DENSITY AND DENSITY RANGE FOR EACH TREE IN EACH SEASON (SWAMP SITE)

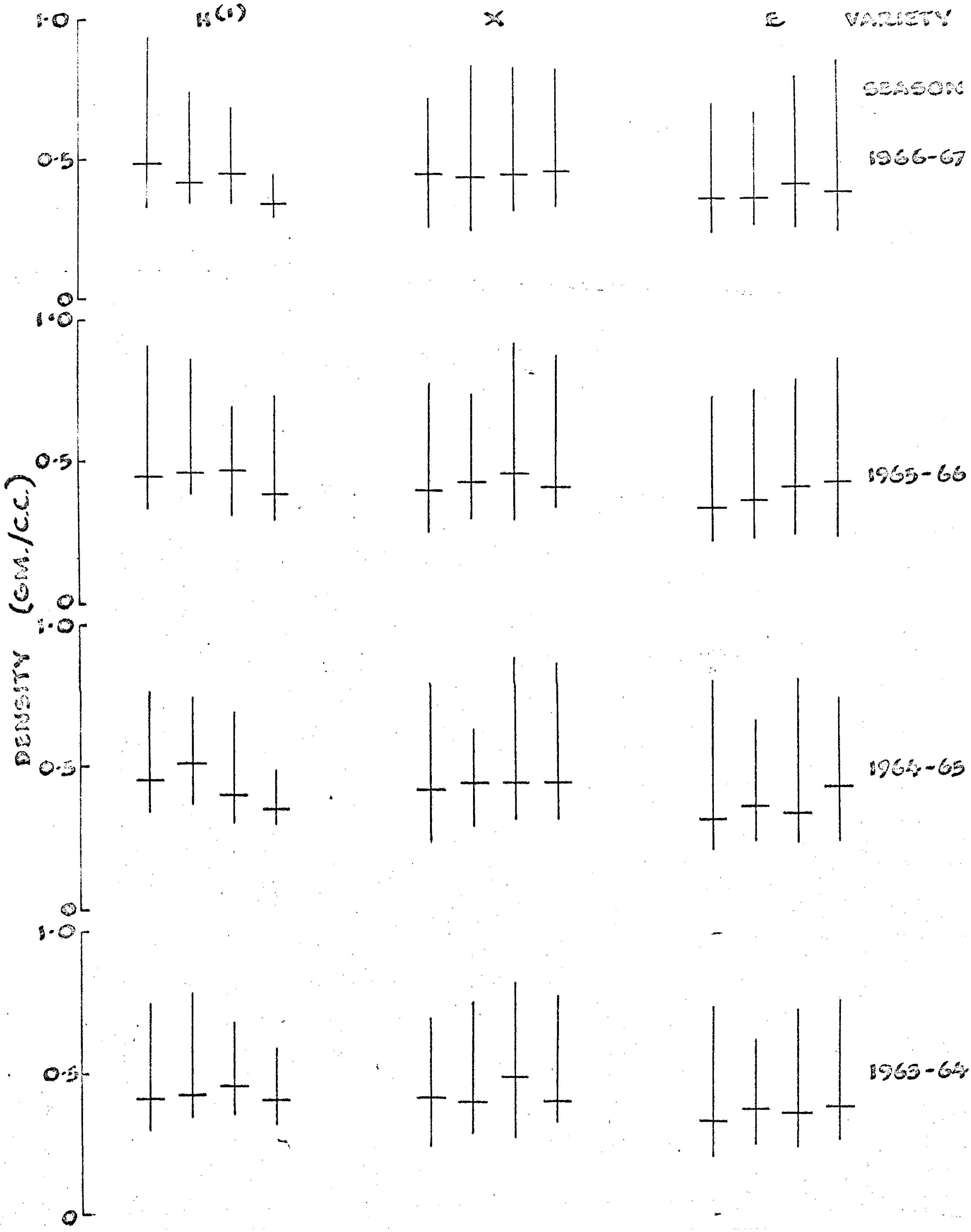


Table 20. Details of the regression lines established for the mean branch girth at each whorl on stem girth at that whorl for the two whorl types of var. elliottii, the one of var. hondurensis and the var. elliottii x hondurensis hybrid by site types

| Variety | elliottii (major) | elliottii (subsid.) | hondurensis | elliottii x hondurensis |
|---|---|---|---|---|
| Ridge | | | | |
| Regression Y[1] = | 0.13X + 1.41 | .02X + 2.38 | .09X + 1.44 | 0.08X + 1.93 |
| Corr. coeff. | 0.53 | 0.08 | 0.43 | 0.31 |
| Significance | * | NS | * | NS |
| Mean br. g. | 3.19 | 2.70 | 2.63 | 3.18 |
| Mean st. g. | 14.02 | 14.72 | 13.94 | 14.86 |
| Swamp | | | | |
| Regression Y = | 0.02X + 2.68 | -.06X + 3.71 | .11X + 1.35 | .15X + 0.88 |
| Corr. coeff. | 0.17 | -0.27 | 0.48 | 0.57 |
| Significance | NS | NS | ** | ** |
| Mean br. g. | 3.01 | 2.94 | 2.55 | 2.83 |
| Mean st. g. | 14.20 | 12.61 | 11.25 | 13.00 |

1 Y = mean branch girth per whorl
X = stem girth at that whorl

2 NS = not significant; *, ** indicate significance at the 5 and 1 per cent levels respectively.

Table 21. Summarized mean data from the wood density study comparing the items studied by varieties (and the hybrid) and site types

| Site | Ridge | | | Swamp | | |
|---|---|---|---|---|---|---|
| Variety | H[1] | X | E | H[2] | X | E |
| Mean density gm/cc | 0.42 | 0.39 | 0.43 | 0.43 | 0.43 | 0.37 |
| Max. density gm/cc | 0.87 | 0.83 | 0.79 | 0.77 | 0.81 | 0.75 |
| Min. density gm/cc | 0.34 | 0.27 | 0.24 | 0.33 | 0.28 | 0.23 |
| % ring over 0.44 gm/cc | 52 | 37 | 47 | 47 | 46 | 42 |
| % ring over 0.55 gm/cc | 26 | 24 | 37 | 21 | 28 | 32 |
| % ring over 0.68 gm/cc | 16 | 15 | 22 | 18 | 18 | 14 |

1 For coding used see Part II Chapter 3.
2 One atypical tree omitted.

from age 18 months to at least $8\frac{1}{2}$ years (Table 17). Although rarely significantly different from var. hondurensis the hybrid nearly always slightly exceeds this variety in both height and girth growth on these ridge sites. Older plantings show the hybrid as having significantly superior growth of girth and it appears therefore that at age eight years the volume production of the hybrid exceeds that of both parental species on the ridge sites.

This superiority becomes much more marked when the var. elliottii x var. hondurensis hybrid is planted on the poorly drained sites at Beerwah. In

Table 22. Summarized data of the analyses of variance of wood density variation

| Source of Variation | Degrees of freedom | Mean sum of squares | | | | | | Significance of differences[2] | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Mean[1] den | Max[1] den | Min[1] den | Over 0.44 | Over 0.55 | Over 0.68 | Mean den | Max den | Min den | Over 0.44 | Over 0.55 | Over 0.68 |
| Trees | 26 | 47 | 304 | 85 | 137 | 194 | 267 | *** | *** | *** | *** | *** | *** |
| Varieties | 2 | 36 | 152 | 885 | 107 | 880 | 347 | NS | NS | *** | NS | ** | NS |
| Site | 1 | 0 | 1450 | 1 | 68 | 244 | 612 | NS | * | NS | NS | NS | NS |
| Var. x site | 2 | 182 | 399 | 20 | 341 | 317 | 343 | * | NS | NS | NS | NS[3] | NS |
| Remainder | 21 | 38 | 255 | 19 | 124 | 115 | 236 | - | - | - | - | - | - |
| Years | 3 | 33 | 385 | 12 | 168 | 159 | 338 | * | *** | * | ** | *** | *** |
| Error | 77 | 11 | 35 | 3 | 39 | 21 | 40 | - | - | - | - | - | - |
| Years x site | 3 | 13 | 34 | 3 | 44 | 35 | 84 | NS | NS | NS | NS | NS | NS |
| Years x Var. | 6 | 12 | 74 | 7 | 71 | 44 | 66 | NS | * | * | NS | * | NS |
| Year x Var. x site | 6 | 21 | 37 | 7 | 64 | 30 | 34 | NS[3] | NS | * | NS | NS | NS |
| Remainder | 62 | 9 | 31 | 3 | 34 | 18 | 36 | - | - | - | - | - | - |

1 Mean squares quoted are $10^4$ times greater than actual values.
2 NS means not significant; *, ** and *** indicate significance at the 5, 1 and 0.1 percent levels respectively.
3 Close to significance at the 5 percent level.

Table 23. Summarized data by separate sites for wood density characteristics that exhibited a significant variety - site interaction

| Source of Variation | Degrees of freedom | Mean squares: Mean[1] den | Mean squares: Over[1] 0.55 | Significance[2]: Mean den | Significance[2]: Over 0.55 |
|---|---|---|---|---|---|
| **Ridge** | | | | | |
| Trees | 14 | 40 | 103 | ** | *** |
| Varieties | 2 | 86 | 395 | NS[3] | ** |
| Remainder | 12 | 32 | 54 | - | - |
| Years | 3 | 42 | 158 | * | *** |
| Error | 41 | 13 | 21 | - | - |
| Var. x year | 6 | 21 | 32 | NS | NS |
| Remainder | 35 | 11 | 19 | - | - |
| **Swamp** | | | | | |
| Trees | 11 | 61 | 306 | *** | *** |
| Varieties | 2 | 183 | 802 | * | NS[3] |
| Remainder | 9 | 34 | 196 | - | - |
| Years | 3 | 4 | 38 | NS | NS |
| Error | 33 | 8 | 21 | - | - |
| Var. x year | 6 | 5 | 42 | NS | * |
| Remainder | 27 | 9 | 16 | - | - |

1 Mean squares quoted are $10^4$ times greater than actual values.
2 NS means not significant; *, **, *** indicate significance at the 5, 1 and 0.1 percent levels respectively.
3 Close to significance at the 5 percent level.

all such plantings the hybrid is significantly better than either of the parental varieties, (Tables 17 and 19) in both height and girth and must be regarded as having a much greater volume production capacity on such sites.

The poor growth of var. hondurensis on swamp sites is particularly evident in the younger plantings where it is inferior to var. elliottii (Table 17). The var. hondurensis performance is apparently better in the 1958 planting on the swamp site where it has a mean height and mean g.b.h. superior to var. elliottii, though not significantly so. But this is thought to be due to the successful growth of the hybrid and var. elliottii in the adjacent plots lowering the water table and effectively improving the site for var. hondurensis. Nine year old var. hondurensis on swamp sites would probably not do as well as these results indicate when established as a large scale block planting away from the effects of other varieties.

This difference in the var. hondurensis growth on the different site types accounts for the very highly significant variety-location interaction found in the analyses of the 1958 and 1964 plantings (Table 19). Despite the significance of this interaction term there are also real differences in growth between locations. Examination of the data in Table 17 indicates that in all cases growth on the swamp sites is inferior to growth on the ridge sites, at least to nine years of age.

The results from the Bowenia and Cathu plantings both suggest that in tropical latitudes the var. elliottii var. hondurensis hybrid is inferior in growth to pure var. hondurensis. At Bowenia on a ridge site the hybrid has significantly poorer girth growth and poorer height growth (Table 17). At Cathu after eighteen months in the field on a swamp site the hybrid is noticeable poorer in height growth. The author has noted a moribund appearance of the hybrids in this planting, which lacks the long vigorous and succulent new growth evident in the associated var. hondurensis and characteristic of the more southerly hybrid plantings.

It appears therefore that the var. elliottii x var. hondurensis hybrid is superior to both parental varieties in vigour on both ridge and swamp sites in southern Queensland with a very marked superiority on the swamp sites. In northern Queensland at latitude $20^{o}$S var. hondurensis appears likely to do better on all site types. In central Queensland at latitude $22^{o}$S the hybrid performance is slightly inferior to var. hondurensis, on ridge sites. The position on swamp sites at these latitudes is not known but the marked superiority of the hybrid on these sites further south would suggest continued but reduced superiority here.

The hybrid derivatives, namely the backcrosses, the hybrid x hybrid material and the naturally pollinated hybrid material perform in a manner generally intermediate between their parents assuming that naturally-pollinated hybrid seed contains a large proportion of backcrosses to var. elliottii (Table 17). However, the backcross from the var. elliottii x var. hondurensis hybrid to var. hondurensis is superior in height growth to both the pure var. hondurensis and the F1 hybrid in the 1963 planting on the ridge site at Beerwah. This suggests that even greater vigour gains may be possible than have been achieved with the F1 hybrid. On swampy sites and in the more northerly location of Bowenia this backcross to hondurensis becomes intermediate between the variety and the hybrid.

Comparisons of the growth to 18 months of some of the other hybrids in the complex can be made from the data in Table 18. This details the results of the height measures of four separate group plantings of these hybrids and the pure varieties on ridge sites. Two separate plantings were at Beerwah (groups "A" and "B") and two at Bowenia (Groups "C" and "D"). The combined analysis of the groups "A" (Beerwah) and "C"(Bowenia) showed no significant differences between these two locations at this age and no significant variety by location interaction. Thus individual varieties and hybrids within the complex have comparative initial growth rates at both centres.

At Bowenia there is little difference between pure var. hondurensis and the three hybrid types var. elliottii x var. hondurensis, var. elliottii x caribaea and var. caribaea x var. hondurensis. But at Beerwah there is a definite tendency for the var. elliottii x var. hondurensis hybrid to grow faster than the others and after 18 months this hybrid exceeds all other material in this planting by 12 inches.

At both centres pure var. elliottii and pure var. caribaea are appreciably smaller than the hybrids and var. hondurensis. Var. caribaea is initially slow and of bushy habit (Barrett and Golfari, 1962; Luckhoff, 1964; Slee and Nikles, 1967) and these results were expected but it is interesting to note that the presence of var. elliottii in the hybrid has changed this growth habit. Consequently the hybrid exhibits definite heterosis at this age. As the growth rate of pure var. caribaea improves after the third year in the field (Slee and Nikles, 1967) it is probable that the growth rate of this var. elliottii x var. caribaea hybrid will also increase at that time. The var. caribaea x var. hondurensis hybrid should do the same. If so these hybrids could well rival the var. elliottii x var. hondurensis hybrid in vigour in southern locations and possibly do better in the more northern locations. If this is the case the performance of the var. caribaea x var. hondurensis hybrid in tropical areas may become very important. Both these varieties are of tropical origin and their hybrid could be expected to do well at low latitudes where var. elliottii x var. hondurensis has a tendency to perform poorly as already noted.

Stem straightness. The differences in stem straightness between the parental varieties elliottii and hondurensis and their hybrid are highly or very highly significant (Tables 17 and 19). It is evident that the general straightness of the hybrid is intermediate between the parental varieties and also that the backcrosses are similarly intermediate between the hybrid and the respective parental variety (Table 17).

It is probable that the differences are exaggerated in some plantings due to parental and environmental effects. The importance of parentage is shown in the results from the 1958 planting where the cross between selected breeding trees of var. elliottii yielded 85% of stems scoring seven or more, whilst unselected var. elliottii gave only 49%. No records are available of the one var. elliottii tree used to produce the hybrid in this planting, but it was probably of above average straightness. Crossed with a variety of poor straightness it has therefore produced hybrids equal to the average for unselected var. elliottii.

The 1962 planting contains selected material of var. elliottii, hybrids produced by crossing selected var. elliottii with both selected and unselected hondurensis, and unselected pure hondurensis (Appendix 1). Therefore the results quoted may unjustly favour var. elliottii at the expense of the hybrid and also the hybrid at the expense of the var. hondurensis.

Some environmental effects may be present in the 1963 planting which had not fully recovered from the effect of the cyclone eight months before the assessment. The damage in the form of bends and leans was much more severe in var. hondurensis and is thought to explain the very low proportion (5%) of trees scoring seven in that variety in the experiment. A more usual figure would be 21% (Slee and Nikles 1967).

The thinning in the 1958 planting would have removed the worst stems in each batch and the values are therefore high in comparison with the other experiments. The 17% of stems scoring seven in var. hondurensis is therefore low. This is attributed to chance distribution of such stems and the necessity to remove some of the thinning.

The low stem straightness scores recorded for var. hondurensis have particular silvicultural significance in Queensland. Present procedure in that state requires 120 stems per acre to be pruned to 22 feet. At 8 feet x 8 feet planting spacing this is approximately 18% of the initial planting, at 9 feet x 9 feet, 22% and at 10 feet x 10 feet 25%. The actual proportion of stems required is considerably higher to allow for even distribution and adequate size of the pruned stems, and a figure of 50% would be desirable to accommodate all possible planting combinations. This percentage is readily obtainable in selected var. elliottii and the backcross to var. elliottii from the hybrid with var. hondurensis. The F1 hybrid and unselected var. elliottii will supply an adequate number of prunable stems and presumably an improvement could be effected in the hybrid by the use of selected parents. Selected material in var. hondurensis and in the backcross from the F1 to var. hondurensis would be absolutely essential if the desired standard of straightness is to be attained in this material.

Wind firmness. Highly significant differences in wind firmness were found between the varieties, their hybrid and hybrid derivatives Tables 17 and 19. No data is available on differences in different regions and there were no significant differences between blocks in the two experiments sampled. There was however a tendency for the plus site in the 1964 planting to be more heavily damaged than the average site due to a more exposed position in this instance when the damaging wind came predominantly from the north.

A plantation may be regarded as wind susceptible once the trees attain a certain size which subjects them to wind effects. Once maximum susceptibility is attained wind-firmness increases with age and size. (Slee and Nikles, 1967). In comparing the two plantings assessed it is apparent from Table 17 that the younger (1964) planting was generally more severely damaged than the older. Such a result agrees with the general trend. However, the var. hondurensis and the backcross (var. elliottii x var. hondurensis) x var. hondurensis were more badly affected in the older (1963) planting. Reasons for this are very difficult to determine and in view of the lack of significant differences (Table 17) may not be necessary. It is conceivable that much of the damage in the 1963 planting resulted from strains imposed during a previous period of wind damage in November 1965 (Q. F. S. records). The 1964 planting was also damaged at that time but it is possible that recovery was much more rapid in this younger material, and consequently in 1967 the var. hondurensis and the hybrid x var. hondurensis material were actually in a less susceptible condition in the 1964 planting.

When comparing varieties for wind-firmness the inter-relationship of size and age must be considered. As resistance to wind increases with size in these varieties (Slee and Nikles, 1967) we may assume that each variety attains a state of adequate resistance at a certain size and that the actual size necessary may differ between varieties. For forest management the important period is that during which the variety is in a state susceptible to wind damage. Thus even though one variety may only need to attain a small size if it is slow growing it may be liable to damage over a longer period than a fast growing variety that has to attain a larger size.

From Table 17 it is apparent in both plantings that var. elliottii is superior in wind resistance to var. hondurensis of the same age, whilst there is little difference between var. elliottii and the hybrid (var. elliottii x var. hondurensis).

The backcross F1 hybrid x var. elliottii is better than var. elliottii in the 1963 planting though not significantly so. In the 1964 planting the naturally pollinated hybrid material which presumably contains a large quantity of F1 hybrid x var. elliottii, is also slightly better than the pure var. elliottii.

Presumably size for size the var. elliottii is the most resistant. Certainly var. elliottii is more resistant than larger sized var. hondurensis in both plantings and is therefore markedly more resistant than var. hondurensis of equal size.

When ages are considered the most resistant material appears to be the backcross hybrid to var. elliottii. In the 1963 planting this backcross hybrid tended to have greater wind-firmness than var. elliottii (although not significantly different), presumably because of the greater size (14.0 in g.b.h. compared with 8.9 in g.b.h. for var. elliottii).

However there is little difference between var. elliottii, the backcross to var. elliottii and the F1 hybrid var. elliottii x var. hondurensis, all of which are superior to the backcross hybrid to var. hondurensis. This backcross is in turn superior to pure var. hondurensis. The backcross had 29% of stems badly damaged in the 1963 planting and 17% in the 1964 whilst respective comparative figures for pure var. hondurensis were 50% and 47%. Although in the latter case the difference was not significant it was sufficiently large to strongly suggest a real difference. Thus the backcross represents a considerable improvement over the pure variety and any infusion of var. elliottii into var. hondurensis adds appreciably to the wind-firmness of the latter.

Branch size. The regressions of mean branch girth per whorl against stem girth at that whorl illustrated in Figure 18, show differences between var. elliottii, var. hondurensis and their hybrid. Considering only the major whorls of var. elliottii the regressions indicate var. elliottii as having branches with a girth approximately 0.5 inches larger than var. hondurensis for the same sized main stem. The hybrid var. elliottii x var. hondurensis is intermediate, but exhibits a much less definite correlation between stem and branch size.

It is clear that branches in the subsidiary whorls of var. elliottii are of a size independent of stem size, and these are accordingly difficult to compare with other material. However, some branches in these subsidiary whorls can be large and as their mean value overall exceeds that of all whorls of var. hondurensis (Table 20 Figure 18) it is clear that var. elliottii must be regarded as more heavily branched than var. hondurensis.

This difference between the var. elliottii factions may explain the poor correlation between stem and branch size in the hybrid. There are three factions, two elliottii and one hondurensis, incorporated in the hybrid, one of which has branch sizes independent of stem size. The resulting complex pattern of genetic control could well be the cause of its indefinite branch arrangement.

The hybrid with its generally intermediate habit does represent some improvement on var. elliottii and would be expected to give higher grade timber than the variety under the proposed grading rules for Queensland softwoods which assess knotiness of boards by comparing the sum of all knot diameters with board width (Q.F.S. records). The hybrid would, of course, compare poorly in this regard with var. hondurensis.

The subsidiary branches are laid down following later season growth flushes and their size is an indication of the quantity of photosynthetic material they carry. These branches must therefore be of considerable importance to the tree. This confirms the findings of the growth pattern study (Part III Chapter 1) that late season growth of var. elliottii is essential for the variety's satisfactory development.

The study did not include sufficient trees in a wide enough range of size classes to determine whether or not differences in branch : stem ratios occur on the different site types. Tentative conclusions from this study are that such differences would not be large.

The var. hondurensis regression line in Figure 18 is well below the graphical position of the branches on trees with a foxtail growth habit. These branches are thus atypical and larger in comparison to the stem girth than is usual in the variety. This indicates that trees with the foxtail habit are deficient in photosynthetic material as is also evident from the inability of similar stems in P. radiata to make satisfactory girth growth (Lange, 1966). The production of unusually heavy branches is an attempt to overcome this deficiency.

Wood density. The comparative traces shown in Figure 19 show definite differences between the parental varieties. The most striking is in the quantity of higher density wood produced in the 1964/65 season. Var. elliottii had 32% of the ring width composed of wood exceeding 0.55 gm per cc whilst var. hondurensis had only 9%. However there is some year to year variation as is shown by the relatively low percentage of wood exceeding 0.55 gm per cc produced by the same var. elliottii in the 1965/66 season (Figure 19). Mean values for all trees sampled on the ridge site over four years were 37% for var. elliottii and 26% for var. hondurensis; and on the swamp 32% versus 16% respectively (Table 21). Differences which were significant (Table 23).

High density wood may be regarded effectively as late-wood and thus var. elliottii at age eight years is producing appreciably more late-wood than var. hondurensis. This is in agreement with the findings of Dadswell and Nicholls (1959) and Schmidt, Smith and Eccles (Q.F.S. records unpublished, see Slee and Nikles, 1967). The hybrid is producing approximately the same quantity of late-wood as var. hondurensis on the ridge site but an intermediate quantity on the swamp site.

Similar differences were not obtained in the results for the 0.44 and 0.68 density levels because these are respectively too low and too high. The 0.44 gm per cc level is sufficiently close to the minimum density of the ring to be affected by very minor fluctuations in density whilst the 0.68 level was not reached in some trees and only fleetingly in others. (Figure 19).

It is also clear from Figure 19 that var. elliottii has definite seasons for the production of relatively low density wood (the early-wood) and relatively high density wood (the late-wood) whilst var. hondurensis does not. The typical var. hondurensis trace of the 1964/65 season has very marked peaks when high density wood is produced and these occur intermittently throughout the growing period. These represent narrow bands of high density wood and have the appearance of false rings.

It is currently considered that when the leading bud of any tree is actively growing hormonal control stimulates the production of relatively low density wood over the tree bole and that high density wood is produced when the leading bud ceases active growth (Zahner, 1963; Kramer, 1964). These studies support this. Var. elliottii has been shown to grow with a succession of very fast spurts of height growth from spring to mid-summer or later whilst girth growth continues after height growth has ceased. Var. hondurensis grows continuously in a succession of height growth spurts. Thus var. elliottii produces low density wood early in the season with very short periods between successive height growth shoots during which wood of higher density is formed. This accounts for the occasional high density peaks in the early season growth evident in Figure 19. When the over-wintering bud has been set the high density late-wood is produced. Var. hondurensis only produces high density wood when tip growth ceases and this has been shown to be for only short periods. During these periods the high density bands, the false rings, are laid down.

This study shows that significant differences exist between the maximum density of the wood produced on the different site types. Differences due to site are particularly evident in var. hondurensis. Table 15 shows that the maximum density of wood produced in this variety is higher on the ridge than on the swamp by 0.1 gm per cc or 6 lb. per cubic foot. Similarly the percentages of wood with a density above each of the 0.44, 0.55 and 0.68 gm per cc levels are higher (but not significantly so) on the ridge than on the swamp. On the other hand the minimum values remained unchanged. Despite the higher maximum and the greater proportions of relatively high density wood produced the mean value surprisingly remained unchanged. This emphasises the importance of collecting all these separate items of data for wood density. This occurred because on the swamp site the minimum density was recorded for only a very short period after which a steady rise in the density of wood produced occurred. On the ridge the production of wood produced of minimum density continued for a much longer period.

It may be inferred from the concept of terminal growth and wood density outlined previously that fast terminal growth is associated with low density wood and slower terminal growth with slightly higher density wood. This would explain this result. The slower swamp growth has produced higher density wood.

In var. elliottii all values except that for minimum density were reduced on the swamp compared to the ridge by about 0.05 gm per cc or 0.3 lb. per cubic foot. This is obviously inexplicable on the basis of slower growth leading to higher density wood and it is suggested that in this variety with its pre-determined growth pattern the rate is independent of site and the densities attained are due more to the quantity of photosynthates available than to speed of growth. The poorer site thus gives lower density wood. The higher maximum density of the var. hondurensis on the ridge site tends to support this.

Possibly therefore for both varieties sampled the rate of tip growth is only affecting the early-wood density, the low density wood, whilst site quality determines the maximum densities achieved.

The hybrid presumably is little affected by the site change, being well adapted to both types and is capable of synthesizing wood of as high a density on the swamp as on the ridge. Thus the maximum and minimum densities have remained unchanged between the two sites but the slower swamp growth produces a slightly higher mean density on this site.

Considering the ridge site alone the two parental varieties differ both in the maximum and minimum densities and in the proportion of relatively high density wood each produces. These factors combine to give approximately equal mean densities in the two varieties. The hybrid has intermediate density extremes but only the same proportion of wood exceeding 0.55 gm per cc, and consequently a mean density below that of the pure varieties.

On the swamp site the minimum densities are the same for each variety and the hybrid as they were on the ridge, but the maximum density of the hybrid exceeds both parental varieties. The proportions of relatively high density wood over 0.55 gm per cc differ between the varieties as follows, 16% var. hondurensis, 32% var. elliottii with the hybrid intermediate (28%). On this site the mean density of the hybrid exceeds var. elliottii and is approximately the same as that of var. hondurensis.

Pulp yield is associated with mean density, and the relative production of pulp from the hybrid would be lower on the ridge and higher on the swamp sites than that from the parental varieties. At present the late-wood percentage of 11% found in mature P. radiata is considered too low to provide really good pulp under Australian conditions (Rudman, pers. comm.). Assuming that the density level of 0.55 gm per cc approximates to late-wood it is apparent that good quality pulp may be obtained from both the hybrid and var. elliottii and possibly also from var. hondurensis on both site types.

Strength properties remain to be determined but as higher quantities of relatively high density wood make for greater strength (Larsen, 1964 and others) it is probable that the strength properties of the hybrid will be intermediate between those of the parental varieties.

Conclusions.

Vigour. The hybrid var. elliottii x var. hondurensis exhibits hybrid vigour in volume production on both site types. The difference between the hybrid and var. hondurensis is relatively slight on ridge sites but large on swamp sites. Var. elliottii is inferior in volume production when compared with the hybrid on both site types.

This vigour advantage disappears in more tropical latitudes. At Bowenia (22°S) it is probable that the hybrids advantage is still retained on swamp sites but it is not on ridge sites where vigour is intermediate between the parental varieties. At Cathu (20°S) no vigour advantage seems likely on either site-type.

The hybrid derivatives, the backcrosses to the parental varieties, exhibit vigour intermediate between the respective parental variety and the F1 hybrid and in one ridge planting the backcross to var. hondurensis has exceeded the growth of the F1 hybrid. This suggests that even greater gains may be possible than those presently possible with F1 hybrids.

The early growth of the var. elliottii x var. caribaea and the var. caribaea x var. hondurensis hybrids exhibits hybrid vigour but the slow initial growth of pure var. caribaea makes extrapolation as to potential difficult. It is possible that the var. caribaea x var. hondurensis hybrid will be a most vigorous tree for use in the tropical areas, where the var. elliottii faction is unsuited.

Stem straightness. There is a simple gradation in stem straightness from the best, the var. elliottii, through the hybrid derivatives and the F1 to the worst, var. hondurensis. Selected breeding parents will have to be used for the production of the backcross to var. hondurensis to ensure even a minimal standard of straightness.

Wind-firmness. Judging wind-firmness on the length of the period the hybrid or variety is in the stage susceptible to damage there is very little difference between the pure var. elliottii, the backcross, F1 hybrid x var. elliottii and the F1 hybrid. The backcross to var. hondurensis is poorer but nevertheless considerably better than the pure var. hondurensis.

Branch size. Comparing only the pure varieties elliottii and hondurensis and their F1 hybrid there appears to be a clear gradation from var. hondurensis with the lightest branches through the hybrid to pure var. elliottii with the heaviest. No site differences were detected.

Wood density. The different growth patterns and possibly the dependence of maximum density on site quality are thought to explain many of the wood density differences found. Generally var. elliottii has lower maximum and minimum densities than var. hondurensis but because of the latter's habit of continual growth var. elliottii has a much higher proportion of relatively high density wood.

The varieties also performed differently on the different sites. In var. hondurensis the maximum density and the proportion of relatively high density wood both decreased on the swamp site compared with the ridge. The minimum density remained unchanged and so too did the mean density value due to a general increase in the density of most of the relatively low density wood. All values for var. elliottii except that for minimum density were reduced on the swamp site.

On the ridge site the hybrid was intermediate between the parents in both the values recorded for the density extremes and also in the proportion of relatively high density wood produced. In consequence the hybrid had a resulting mean density slightly lower than the parental varieties.

However, on the swamp the reduction in the parental maximum densities was not reflected in the hybrid which accordingly was heterotic for this characteristic. Minimum values remained unchanged and the proportion of relatively high density wood increased compared with the ridge. Mean density values therefore were equivalent to var. hondurensis and better than var. elliottii.

Pulp yield of the hybrid is accordingly expected to be reduced in comparison with the parental varieties on the ridge but increased on the swamp. Pulp quality may be better than that of P. radiata. The increased proportions of high density wood should produce stronger timber in the hybrid compared to var. hondurensis.

## Chapter 3. Studies of root distribution in var. elliottii, var. hondurensis and the hybrid between them.

### Material.

The seedling trees used in the root distribution study were var. *elliottii*, var. *hondurensis* and the hybrid var. *elliottii* x var. *hondurensis*. Their parentage was as follows:-

var. *elliottii* selected tree G11 x pollen mix from selected trees G15, 21 and 40.

var. *hondurensis* imported British Honduras seed.

var. *elliottii* x var. *hondurensis* hybrid crosses between selected trees G11 x G57 (2 seedlings) and G21 x G53 (1 seedling).

Three seedlings of each variety or the hybrid were used, originating from a drill sowing at Beerwah nursery in March 1965 followed by tubing in September 1965. All nine seedlings were thus aged 12 months from tubing when the study commenced in September 1966.

For the purposes of the study all were planted at Beerwah nursery on a red earth residual soil type (see Part II chapter 1). This has a sandy loam texture with silt present in increasing quantities at depth. Root penetration thus becomes more difficult lower in the profile.

### Method.

The tubed seedlings of var. *elliottii* var. *hondurensis*, and the hybrid between them, were grown behind glass panels at Beerwah nursery over the period September 1966 - November 1967. The glass panels, size 2 feet x 2 feet were held by stakes in the sides of trenches dug to a depth of two feet, and the seedling planted two inches from the glass. Two layers of .004 black polythene sheeting covered each glass panel excluding light and a hessian cover across each trench ensured relatively cool conditions in the trenches.

Three separate trenches were employed each being used to observe three seedlings, one of each parental type. The glass panels abutted onto each other and thus each seedling was 2 feet from the nearest neighbour. Between trench spacing was 5 feet.

Initially it was hoped that observations on root growth could be made throughout the year, but thus was not possible as the seedlings were so close together. Within three months roots had penetrated from one seedling over to the next glass panel and accurate observations become impossible.

After 14 months the roots were excavated hydraulically using a hose to wash away the soil. The root system of each seedling was removed entire for a horizontal distance of 3 inches behind each panel and to a vertical depth of 20 inches below ground level. Thus all roots in a soil volume of 20 x 24 x 3 cubic inches behind the glass panel were excavated.

The excavated roots of each seedling were divided by five inch levels; all the roots in the top five inches were placed together and those in each of the other five-inch depths treated similarly. The roots were also divided into size classes of less than 0.08 in., 0.08 to 0.25 in., and over 0.25 in. Thus each seedling had its excavated root volume subdivided into twelve different parts by depth and root size.

Each part was dried to constant weight at a temperature of 70°F over a period of 72 hours. The weight of roots in each size class at each depth level was determined, and the percentage of the weight for each class in each level calculated. For each seedling the height and top weight above ground level were noted at sampling.

Analyses of variance were applied to the percentage root weight figures using an arcsin transformation and comparing basically individual trees and depth levels. The error total sum of squares term (tree x depth interaction) was partitioned to determine the significance of variety x depth interaction.

## Results.

Mean values for shoot height, shoot and root weights and root : shoot ratio are given in Table 24. This table also details the percentage weight of roots of each size class at each level, and the total root weight for each size class for the varieties and the hybrid. Table 25 summarizes the results of the analyses of variance. These analyses are recorded in full in Appendix 2.

## Discussion.

Table 24 gives the relative sizes of the seedlings at sampling. These are fairly typical for this stage of development except that the var. *hondurensis* (39 inches) was small in comparison with var. *elliottii* (55 inches). This was partly due to the November sampling including most of the current season's growth of var. *elliottii*, and a much lower proportion of that of var. *hondurensis*; despite this the var. *hondurensis* is smaller than usual. Whether this affected

Table 24. Detailing the mean height, shoot and root weight and root : shoot ratio and also the percentage weight of roots of each size class in each depth class for each variety or hybrid

| Variety | H | X | E |
|---|---|---|---|
| Shoot height (in.) | 39 | 64 | 55 |
| Shoot weight (gm) | 847 | 1940 | 1102 |
| Root weight (gm) | 156 | 322 | 220 |
| Root : shoot | 0.18 | 0.17 | 0.20 |

| Item | | Percentage weight of roots of each size class at each level | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Root size | | Small | | | Medium | | | Large | | |
| Variety | | H | X | E | H | X | E | H | X | E |
| Depth (in.) | 0-5 | 14 | 10 | 21 | 16 | 15 | 22 | 69 | 67 | 64 |
| | 5-10 | 26 | 40 | 39 | 46 | 32 | 44 | 28 | 31 | 29 |
| | 10-15 | 36 | 31 | 24 | 21 | 30 | 20 | 3 | 2 | 4 |
| | 15-20 | 24 | 19 | 16 | 17 | 23 | 14 | - | - | 3 |
| Total weight | | 3.0 | 4.5 | 3.8 | 19 | 21 | 33 | 30 | 48 | 70 |

the root distribution or not is unknown.

Between the varieties and the hybrid there is very little difference in the root : shoot ratios but a markedly different depth distribution of the small and medium sized roots (Table 24). This is supported by the analyses of variance (Table 25). The variety - depth interaction is significant in the

Table 25. Summarized results of the analyses of variance of the percentage weight of roots of each size class by depth classes and variety or hybrid

| Source of Variation | Degrees of freedom | Mean sum of squares | | | Significance[2] | | |
|---|---|---|---|---|---|---|---|
| Root size | | S[1] | M | L | S | M | L |
| Trees | 8 | 4 | -[3] | 16 | NS | NS | - |
| Varieties | 2 | 0 | -[3] | 2.5 | NS | - | - |
| Remainder 1 | 6 | 0.7 | -[3] | 20 | - | - | - |
| Depth | 3 | 383 | 503 | 5719 | *** | *** | *** |
| Trees x Dep. | 24 | 42 | 31 | 55 | - | - | - |
| Var. x Dep. | 6 | 72 | 65 | 11 | NS[4] | * | NS |
| Remainder 2 | 18 | 32 | 20 | 70 | - | - | - |

1 S = small; M = medium; L = large.
2 NS = not significant; *, *** indicate significance at the 5 and 0.1 percent levels respectively.
3 Differences too small to give valid significance data.
4 Close to significance at the 5 percent level.

medium sized roots class and very close to significance at the five percent level in the small size class.

Var. elliottii has a much higher proportion of small and medium sized roots in the upper soil levels than var. hondurensis. Comparative figures for the ten inches below ground level are 60% against 40% for the small roots and 66% against 62% for the medium sized roots (Table 24). The figure of 62% for var. hondurensis is high due to the inclusion of some of the main tap root in this variety in the 5-10 inch level. The larger-sized var. elliottii had only lateral roots included in this size class.

The hybrid is intermediate in the proportion (50%) of small roots in the ten inches below ground level. In the medium size classes the hybrid has a lower proportion (47%) in the same depth (Table 24) but if the tap-roots included in var. hondurensis are ignored the difference between the hybrid and the variety would be reduced.

The large size classes are generally composed entirely of tap-roots and the proportional distribution shows little difference between each variety and the hybrid.

It is likely that wet site tolerance is associated with the presence of superficial roots. Death on such sites is due to lack of aeration of the roots (Bergman, 1920; Heinicke, 1932; Kozlowski, 1958; and Fraser and Dirks, 1959). Gail and Long (1935) exaplined the occurrence of _Pinus contorta_ Dougl. on perched water tables and sphagnum bogs in North America as due to a shallow root distribution in the species. Lees (1964) found resistance to submersion decreased markedly with total, rather than partial submersion in White Spruce (_Picea glauca_ (Moench.) Voss) in Canada. Although Lees was referring to foliage there seems no reason why his findings should not apply equally well to roots. Consequently the presence and quantity of superficial roots rather than the shoot : root ratio would seem to be better associated with the ability to tolerate poorly drained conditions, although other factors such as the ability to survive immersion and root regeneration potential must be of considerable importance.

The difference in proportions of superficial fine roots thus at least partially explains the better performance of both var. elliottii and the hybrid compared to var. hondurensis on wet sites.

The differing proportions of fine roots at the different levels in var. hondurensis compared with var. elliottii suggests different spheres of root activity. Var. hondurensis has a greater proportion of small sized roots in the lower levels whilst those of var. elliottii are comparatively higher. It is possible therefore that these varieties tend to exploit different soil levels. In consequence it is possible that var. hondurensis is more drought resistant than var. elliottii as rooting depth is well known to be associated with the ability to withstand dry conditions (Gail and Long, 1935; Haig, 1936; Glock and Agerter, 1962; Bacvarov, 1964 and others). Similarly if var. elliottii does exploit mainly superficial layers of the soil this could partially explain the variety's inability to grow well in dense stands and its lack of late rotation vigour. In both cases the competition for nutrients and water within these superficial layers could be intense.

The var. elliottii x var. hondurensis hybrid having an intermediate root distribution may be fairly well adapted to drought conditions and may also be able to tolerate heavier stockings than var. elliottii and to retain vigour later in the rotation.

Wind-firmness in tree species is largely dependent on the presence of superficial lateral roots (Mergen, 1954). But Edwards et al (1963) ascribed the superiority in resistance to wind-blow in European Larch over Scots Pine as due partially to the development of an intense mat of fine roots in the former. Thus both the small and medium sized roots in this study can be regarded as determining wind-firmness. Clearly var. elliottii has both a greater proportion of roots than var. hondurensis in the upper soil levels (Table 24) and this accords well with the comparative wind-firmness of the varieties (Part III Chapter 2). The hybrid has an intermediate proportion of small sized roots and a lower proportion of medium sized roots than either parental variety in the upper soil layers (Table 24). But it is the lateral roots rather than the tap-root that determine wind-resistance (Mergen, 1954) and as previously noted var. hondurensis has tap-roots included in the medium sized root class at the 5-10 inch depth. Presumably the hybrid has sufficient (if not more) lateral roots in comparison with var. hondurensis for the exhibition of greater wind-firmness (Part III Chapter 2). The hybrid's denser mat of superficial fine roots in the upper ten inches of soil would also greatly assist in this.

Conclusions.

Although var. elliottii, var. hondurensis and their hybrid have approximately the same root : shoot ratios there are significant differences in the distribution of the roots of each. Var. elliottii has a higher proportion of small (less than 0.08 in.) and medium sized (less than 0.25 in.) roots than does var. hondurensis. The hybrid is intermediate in the proportion of small roots present in the upper layers but poorer than both parental varieties in the proportion of medium sized roots present.

These different root distributions are thought to explain the greater tolerance of wet sites found in var. elliottii and the hybrid in comparison with var. hondurensis. They may also indicate greater drought tolerance in var. hondurensis and provide an explanation for the lack of late-rotation vigour in var. elliottii. This variety may suffer from intense competition for root space in the upper layers of the soil particularly in the later stages of the rotation. The root distributions also explain the greater wind-firmness of the var. elliottii. Comparison of the hybrid with var. hondurensis on a root distribution basis is difficult due to the presence of tap-roots in the medium sized class in var. hondurensis . Tap-roots are not as important as laterals as regards wind-firmness (Mergen, 1954) and root distribution may also explain the greater wind-firmness of the hybrid.

# PART IV

## ASSESSMENT OF THE FACTORS DETERMINING THE POSSIBILITIES OF LARGE SCALE PRODUCTION OF HYBRID SEED

## Chapter 1. The crossabilities of the hybrids of the complex.

Information on crossability patterns within the Slash-Caribbean complex would be essential in considering possible mass production programmes for hybrids or hybrid derivatives. Data on crossability has therefore been gathered from the crosses made to produce the hybrids.

### Material.

The cone and pollen parents used were mostly selected breeding trees from Queensland plantations, except where var. bahamensis was included and also in some of the early crosses when selected breeding material was unavailable. Where crosses were made with young material pollen and cones were usually bulked by varieties as the supply from an individual tree was generally inadequate.

With selected parents, either the ortet or clonal material was used. Any ramets used were grafts established on stock plants of the same variety at either Beerwah or Bowenia. One exception was the selected var. caribaea trees which were grafted onto var. elliottii stock plants.

The age of the ortet varied from 4 years upwards to maximum of 35 years.

The pollen used was as fresh as conditions allowed, and in most cases was used within a few weeks of collection. As var. hondurensis and var. bahamensis flower at a much earlier season than the other varieties, it was necessary to store the pollen of these varieties from late May to July or August. Storage was done under refrigeration in a dessicator over silica-gel and this same method was also used if pollen was retained from one flowering season for use in the next.

Method.

The crossability of the various combinations has been compared using Critchfield's (1962) definition viz:

Crossability of any particular cross =

$$100 \times \frac{\text{(Mean no. of viable seed per cone in that cross)}}{\text{(Mean no. of viable seed per cone when material parent is pollinated with pollen of the material variety)}}$$

This necessitated making inter-varietal crosses between the various combinations, determining the number of viable seed per cone and comparing this with the number of viable seed per cone produced by intra-varietal crosses, on the cone parent. This was done keeping all results separate by individual tree combinations.

The standard controlled pollination technique as described by Mergen et al (1955) was used. Cones were enclosed within cellophane bags prior to their emergence from the enclosing braces. When the conelets had emerged and were receptive the required pollen was injected into the bag using a hypodermic syringe. Later when the cone scales had closed the bags were removed and the cones tagged. Each year check cones were bagged and left unpollinated to test the validity of the technique. The mature cones were collected at the season of seed-fall approximately 18 months later, and all seed extracted by hand following air drying for two weeks under shade and subsequently under full sun.

All seed collected was retained under refrigeration ($4^{O}F$) until required. Generally sowing followed very quickly after extraction from the cone. In all cases sowing was by hand in drills 6 or 8 inches apart at a rate of 16 to 20 seeds per foot. Full details of nursery treatments in Queensland have been given by Rogers (1957).

For each cross the number of cones pollinated, the number collected, and the mean quantity of seed per cone, were noted. Following sowing and germination the mean number of viable seed in each cone was calculated, as the number of seed in each cone that germinated.

A considerable quantity of data was available for var. elliottii x var. hondurensis crosses by 1963, but concurrent comparative crosses within the parental variety had generally not been made at the same time. For comparison purposes data were required on the mean number of viable seed per cone from intra-varietal crosses. These were obtained from crosses made in other years as part of the Queensland tree breeding programme. Comparisons were made by individual cone parents where intra-varietal data were available for those parents. Alternatively the mean value for viable seed per cone from intra-varietal crosses using other parent trees was used as a substitute.

By this method the crossability was determined for 21 crosses between separate var. elliottii cone parents and var. hondurensis pollen parents made between 1958 and 1962 inclusive, and also for 9 crosses made in 1964.

In 1963 attempts to determine the crossability between other varieties in the complex commenced. In that year 9 var. caribaea x var. hondurensis, 9 var. elliottii x var. caribaea and an additional 12 var. elliottii x var. hondurensis crosses were made. Controls were made at the same time using individual intra-varietal crosses in var. caribaea and a pollen mix for the var. elliottii intra-varietal crosses.

Subsequent attempts to gain additional data on the other combinations have been hindered by a very poor flowering generally at Bowenia in 1964 and 1965 and by the young age of the var. bahamensis material. A few crosses were made which included var. caribaea, var. bahamensis and var. densa. Crossability estimates involving the var. caribaea cone parents were made using the intra-varietal figures from the 1963 pollinations. No direct estimates of crossability involving the var. densa, var. bahamensis and hybrid cone parents could be made as intra-varietal material was not available. Accordingly mean numbers of viable seeds per cone were compared directly to determine if a particular combination was more easily produced than others. In this way the crossability of var. bahamensis var. elliottii, var. bahamensis x var. hondurensis, var. bahamensis x var. caribaea, var. densa x var. bahamensis and var. densa x var. hondurensis, were compared as were the var. elliottii x hondurensis hybrid derivatives, F1 x F1 and backcrosses.

Results.

The results of the 1963 crosses comparing the crossability of var. elliottii, var. caribaea and var. hondurensis are given in Table 26.

Table 26. Crossability indices calculated from the 1963 pollinations

| Cone parents | Pollen parents | | | | | |
|---|---|---|---|---|---|---|
| | var. hondurensis | | | var. caribaea | | var. dens |
| | C24 | C53 | C57 | C33 | C35 | DA |
| **Beerwah sowing** | | | | | | |
| var. elliottii | | | | | | |
| G11 | 0.1 | 52 | 58 | 127 | 124 | - |
| G15 | 0.1 | 30 | 28 | 112 | 72 | - |
| G21 | 0 | 10 | 7 | 89 | 53 | - |
| G40 | 0.3 | 7 | 3 | 14 | 19 | - |
| var. caribaea | | | | | | |
| C33 | 0.8 | 22 | 97 | - | - | 1 |
| C34 | 43 | 53 | 97 | - | - | 43 |
| C35 | 6 | 34 | 33 | - | - | - |
| C36 | - | - | - | - | - | - |
| **Bowenia sowing** | | | | | | |
| var. elliottii | | | | | | |
| G11 | - | 52 | 56 | 121 | 119 | - |
| G15 | - | - | - | - | 77 | - |
| G21 | - | - | - | 100 | 71 | - |
| G40 | - | 7 | 4 | 20 | 36 | - |
| G Bow. | - | - | - | - | 3 | 34 |
| var. caribaea | | | | | | |
| C33 | - | - | 140 | - | - | - |
| C34 | - | - | 83 | - | - | - |
| C35 | - | - | - | - | - | 46 |
| C36 | - | - | 104 | - | - | 40 |

Table 27 lists the overall crossability range obtained for each varietal combination and the proportion of crosses exceeding 40 and 70 in value.

The numbers of viable seeds per cone obtained in combinations for which maternal data was not available and for which crossabilities could not be determined are detailed in Table 28. The combinations covered are var. densa x var. bahamensis and var. hondurensis and also the hybrid derivatives.

Tables 29 and 30 list the crossabilities determined by individual crosses in var. elliottii x var. hondurensis, var. bahamensis, var. caribaea and var. densa; var. caribaea x var. hondurensis, var. bahamensis and var. densa.

The crossabilities obtained following the 1963 pollinations and detailed in Table 26 may be regarded as very accurate due to the extensive pollinations carried out at the one time and to the availability of parental intra-varietal controls. The results, even under these conditions, vary considerably within the one combination. Thus the range for the crossability of var. elliottii x var. hondurensis varies from 14 to 127. This suggests that the wide variation recorded in the other, less accurately controlled, data would be expected and that variability in the data is not necessarily due to lack of accurate control. Therefore basic deductions as to crossabilities have been made on the data compiled over all crossings and summarized in Table 27.

Table 27. Summarized crossability data for all combinations with var. caribaea and var. elliottii

| Combination[1] | No. crosses made | Range of crossabilities determined | % crosses with crossability over | |
|---|---|---|---|---|
| | | | 40 | 70 |
| CH | 10 | 1 - 140 | 50 | 30 |
| CB | 3 | 0 - 17 | 0 | 0 |
| CD | 4 | 20 - 45 | 25 | 0 |
| X | 28 | 0 - 123 | 24 | 5 |
| EB | 3 | 13 - 79 | 33 | 33 |
| EC | 8 | 14 - 127 | 75 | 50 |
| ED | 3 | 44 - 121 | 100 | 67 |

1 for coding see Part II Chapter 3.

Critchfield (1962) regards a crossability value of 70 as high and indicative of the existence of only very few barriers to crossing between the trees involved. However all varietal combinations containing eight or more individual crosses were found (Table 27) to have a wide range of crossability values, and comparisons were made between combinations by regarding each as highly cross-compatible if 50 percent of the individual crosses had values of 70 or more, as fairly cross-compatible if 50 percent had values of 40 or more, and as poorly cross-compatible if they were below this.

Table 27 shows that var. elliottii must be regarded as highly cross-compatible with var. caribaea as 50 percent of all crosses had values exceeding 70. On the other hand var. elliottii x var. hondurensis has relatively poor

Table 28. Numbers of viable seed per cone produced by the different varietal or hybrid combinations tested for which controls were not available

| Cone[1] parents | Pollen[1] parents | | | | | | |
|---|---|---|---|---|---|---|---|
| var. densa | var. bahamensis $B_1$ | $B_2$ | var. hondurensis C53 | C57 | | | |
| DA | 2 | 0 | 0.9 | 1.6 | | | |
| var. bahamensis | var. caribaea C33 | C35 | var. hondurensis C53 | C57 | | var. elliottii G11 | |
| $B_3$ | 28 | 1.4 | 17 | 38 | | 0 | |
| $B_4$ | - | - | 68 | 0.2 | | | |
| F1 hybrid | F1 hybrid $X_1$ | | var. hondurensis C51 | C53 | $M_1$ | var. elliottii G15 | $M_2$ |
| $X_1$ | 27 | | 34 | 51 | 68 | 40 | 30 |

1 Individual tree numbers are used except in the following cases:-

| | | |
|---|---|---|
| $B_1$, $B_2$, $B_3$, $B_4$ | - | Miscellaneous trees in 1961 planting Bowenia. |
| $M_1$ | - | Mixture miscellaneous Bowenia trees. |
| $M_2$ | - | Mixture G2, G15. |
| $X_1$ | - | Miscellaneous trees in 1958 planting of var. elliottii x var. hondurensis hybrid at Beerwah. |

crossability. Only 5% of the crosses exceeded 70 in crossability and 76% had values below 40. The var. caribaea x var. hondurensis combination is intermediate between the two just discussed and with 50% of crosses having a crossability of 40 is of fair crossability. Var. elliottii gives strong indications of crossing well with var. densa and possibly with var. bahamensis whilst the var. caribaea x

Table 29. Crossability indices obtained for individual crosses between var. elliottii and var. hondurensis

| Cone parents (E)[1] | Av. viable seed/cone intra-varietal crosses | Pollen parents (H)[1] | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | $M_1$ | $M_2$ | $M_3$ | $M_4$ | 24 | 29 | 51 | 53 | 57 | 62 |
| G 1 | 77[2] | 10 | - | - | - | - | - | - | - | - | - |
| 2 | 77[2] | - | - | 12 | 23 | - | - | - | - | - | - |
| 8 | 96 | - | - | - | - | - | - | 33 | - | - | - |
| 11 | 95/134[3] | - | 48 | - | - | 0.1 | - | - | 47 | 57 | - |
| 13 | 69 | - | - | - | - | - | - | - | 12 | - | - |
| 15 | 69/87[3] | - | - | - | 0 | 0.1 | 31 | 74)<br>34)[4] | 30 | 36 | 16 |
| 20 | 43 | - | - | - | - | - | - | 8 | - | - | - |
| 21 | 72/11[3] | - | - | - | - | 0 | - | 123)<br>40)[4] | 10 | 7 | - |
| 23 | 79 | - | - | - | - | 8 | - | - | - | - | - |
| 40 | - /80[3] | - | - | - | - | 0.3 | 10 | - | 7 | 5 | 4 |
| G Bow. | 28 | - | - | - | - | - | - | - | 25 | - | - |

1 For coding used see Part II Chapter 4. n.b. $M_1$, $M_2$, $M_3$, $M_4$ are all separate pollen mixes from unselected Bowenia trees, others are individual trees.
2 Mean of all other values. No data available for these parents.
3 Data differs for ortets and ramets and both figures are quoted, ortet/ramet.
4 Two separate years crosses included.

Table 30. Crossability indices obtained for individual crosses between var. elliottii and var. bahamensis, var. caribaea and var. densa and between var. caribaea and hondurensis

| Cone parents | | Av. viable seed/cone intra-varietal crosses | Pollen parents: B[1] | | | |
|---|---|---|---|---|---|---|
| | | | B[1] | C | | D′ |
| | | | B1 | C33 | C35 | DA |
| E[1] | G2 | 77 | - | - | - | 90 |
| | G11 | 134 | - | 124 | 123 | - |
| | G15 | 87 | - | 112 | 70 | - |
| | G21 | 111 | - | 95 | 62 | - |
| | G33 | 77 | - | - | - | 44 |
| | G40 | 80 | - | 17 | 27 | - |
| | G Bow. | 28 | 32 | - | - | 121 |
| | | | H | | | |
| | | | 24 | 53 | 57 | |
| C | C33 | 12 | 1 | 22 | 120 | |
| | C34 | 33 | 43 | 53 | 97 | |
| | C35 | 70 | 6 | 34 | 33 | |
| | C36 | 22 | - | - | 104 | |

1 For coding used see Part II Chapter 4. Parentage is indicated by individual tree numbers except for $B_1$ which is a mixture from unselected trees at Bowenia.

var. bahamensis combination may be poor. The additional evidence presented in Table 28 suggests that var. bahamensis x var. hondurensis may have fair crossability, but that var. densa x both var. bahamensis and var. hondurensis and var. bahamensis x both var. elliottii and var. caribaea are all of poor crossability.

The accurately recorded data presented in Table 26 shows the very large differences existing between individual crosses in the same varietal combination; e.g. :- from 0.1 to 58 in var. elliottii x var. hondurensis. However where this variation occurs it is apparent that some individual cross consistently well and others consistently poorly. For example var. elliottii tree G11 always has high values regardless of the varietal combination except when crossed with an individual having consistently low values, such as C24. Examination of Tables 29 and 30 confirms this. Individuals that consistently combine well with individuals in other varieties are G11, and perhaps G15, of var. elliottii, C51, 53 and 57 of var. hondurensis and most of the var. caribaea trees tested.

These highly cross compatible individuals may prove very valuable as by their use a varietal combination usually of low crossability may be induced to yield satisfactory seed sets.

It is also evident from Table 29 that crossability within the one cross e.g. G15 x C51 and G21 x C51 may vary appreciably depending on the year of pollination. This year to year variation may be due in part to variations in pollen viability. The viability of pollen is difficult to retain in storage and even apparently viable pollen according to laboratory tests may still give poor seed sets due presumably to death before fertilization (Wright, 1962 p341).

Purely mechanical effects may also affect the result, for example wet weather at the time of pollination would be expected to reduce success. Humidity, temperature and time of day the pollen was applied have been shown to affect the pollination of Soybeans (Glycine max. (L.) Merrill) (Byth, 1966).

There is some variation between sowings at different nurseries but this was usually slight when direct comparisons could be made as in the 1963 crosses (Table 26). Consequently big nursery to nursery variations are regarded as fortuitous due for example to faulty division of the seed batch.

Some amazingly high crossability values were found. Tables 26, 29 and 30 indicate that some crosses exceeded 100 consistently and that the individual cone parent crossed more easily with the other variety's pollen than it did with pollen from its own variety. This is particularly evident in the var. elliottii x var. caribaea crosses. It should be noted that the pollinations were made with pollen from var. caribaea grafts made onto var. elliottii stock plants. It is possible that such a combination could reduce the effectiveness of the incompatibility mechanism. Muntzing (1961) quotes the results of Pissarev in Russia who showed that the incompatibility barriers between wheat and rye were reduced in wheat plants nourished by rye endosperm.

Nevertheless the ease of crossing does suggest a very strong genetic relationship between the varieties concerned. It is interesting to note that the two most closely related according to these results var. elliottii and var. caribaea are currently regarded taxonomically as separate species.

(Subsequently the author has verified that natural crosses occur between these var. caribaea grafts and the surrounding var. elliottii (Slee Q.F.S. records unpublished) ). This does indicate the likelihood of future taxonomic changes in the complex.

Table 28 shows that relatively high seed sets were obtained in the crosses made on the hybrids. The hybrid x hybrid, and both backcrosses all gave between 27 and 68 viable seed per cone but the data available is not sufficient to allow comparisons of crossability between these hybrid derivatives.

These relatively high seed sets in the hybrid derivatives suggest that the backcrosses and subsequent hybrid generations have reduced incompatibility values. Mirov (1967) has noted that this is usual in Pinus. Thus the production of straight backcrosses from the F1 hybrid to the parental varieties appears to be little affected by incompatibility reactions in var. elliottii and var. hondurensis. Whether similar results occur in other combinations is not known, but if they do and if the reduced incompatibility extends to unrelated material within the complex then a multitude of combinations appears possible. It is not inconceivable that entirely different hybrid combinations could be crossed for example (var. elliottii x var. hondurensis) x (var. caribaea x var. bahamensis).

## Conclusions.

Accepting Critchfield's (1962) definition of good crossability as an index between 50 and 70 it is evident that crossability between var. elliottii and var. caribaea is very high indeed, and that virtually no internal barriers to crossing exist between the individuals tested in these two varieties.

The crossability of var. caribaea with var. hondurensis is also high but that of var. elliottii x var. hondurensis is low and will probably hinder the production of satisfactory seed sets.

However individual trees occur in all these three varieties with above average crossability, and careful selection of parents would raise the viable seed production considerably.

All other varieties are capable of inter-crossing but the facility with which they do is not yet fully determined.

The crossability between individual trees of the var. elliottii x var. hondurensis hybrid is apparently high and the incompatibility barriers are reduced in such derivatives. Backcrosses to the parental varieties are similarly fertile and production of hybrid derivatives appears to be little hindered by internal barriers.

Further investigation is needed as the effect of inter-varietal grafting to reduce incompatibility. These studies may be a case where the grafting of one variety onto another has reduced their natural resistance to crossing. If so this will obviously greatly assist large scale production of hybrid seed.

## Chapter 2. Studies of the flowering times of the members of the complex.

Mass production possibilities depend on coincidental flowering as well as crossability patterns. Although the flowering times of the parental varieties are known (see for example Slee and Nikles, 1967) those of the hybrids are not. Accordingly in 1967 studies were made on the var. elliottii x var. hondurensis hybrid at Beerwah. Similar observations could not be made on other hybrids of the complex as none of the material available had reached the flowering stage.

### Material.

The flowering times of the var. elliottii and var. hondurensis hybrid, and its derivatives were studied at Beerwah in 1967. The plantings used were those established in 1958, 1961, 1962 and 1963 including, in all, seven different crosses of var. elliottii and var. hondurensis, and the parental varieties. The 1963 planting also contains the two backcrosses from the hybrid elliottii x hondurensis to the parental varieties.

The 1958 planting had been thinned in 1964 to 400 stems per acre (spa.) from 680 spa but all others were unthinned. The 1961 and 1962 plantings were at 8 feet x 8 feet spacing and the 1963 at 10 feet x 10 feet.

Full details of the layouts and treatments accorded these plantings are given in Appendix 1.

### Method.

Each planting was examined at two-weekly intervals or occasionally more frequently from mid-April to late-June in 1967. Field glasses were used for observations and at each inspection the number of trees flowering in each plot and the stage of development of the conelets noted.

The number of trees producing flowers, either pollen or cone were assessed as either -

(i) less than 10% of the plot population,

(ii) between 10% and 50% of the plot population, or

(iii) over 50% of the plot population.

The developmental stages of the cone flowers on each tree were categorized as -

Stage 1 Cone flower in bud form, bud scales closed.
Stage 2 Cone flower in bud form, bud scales open and conelet visible.
Stage 3 Conelet emerging from bud scales, cone scales opening.
Stage 4 Conelet fully emerged, cone scales fully open.
Stage 5 Conelet enlarging, no longer erect, cone scales closed.

Pollen flowers were classified as -

Stage 1 Pollen flower buds present and elongating.
Stage 2 Pollen flowers open and shedding pollen.
Stage 3 Pollen flowers withering, pollen exhausted.

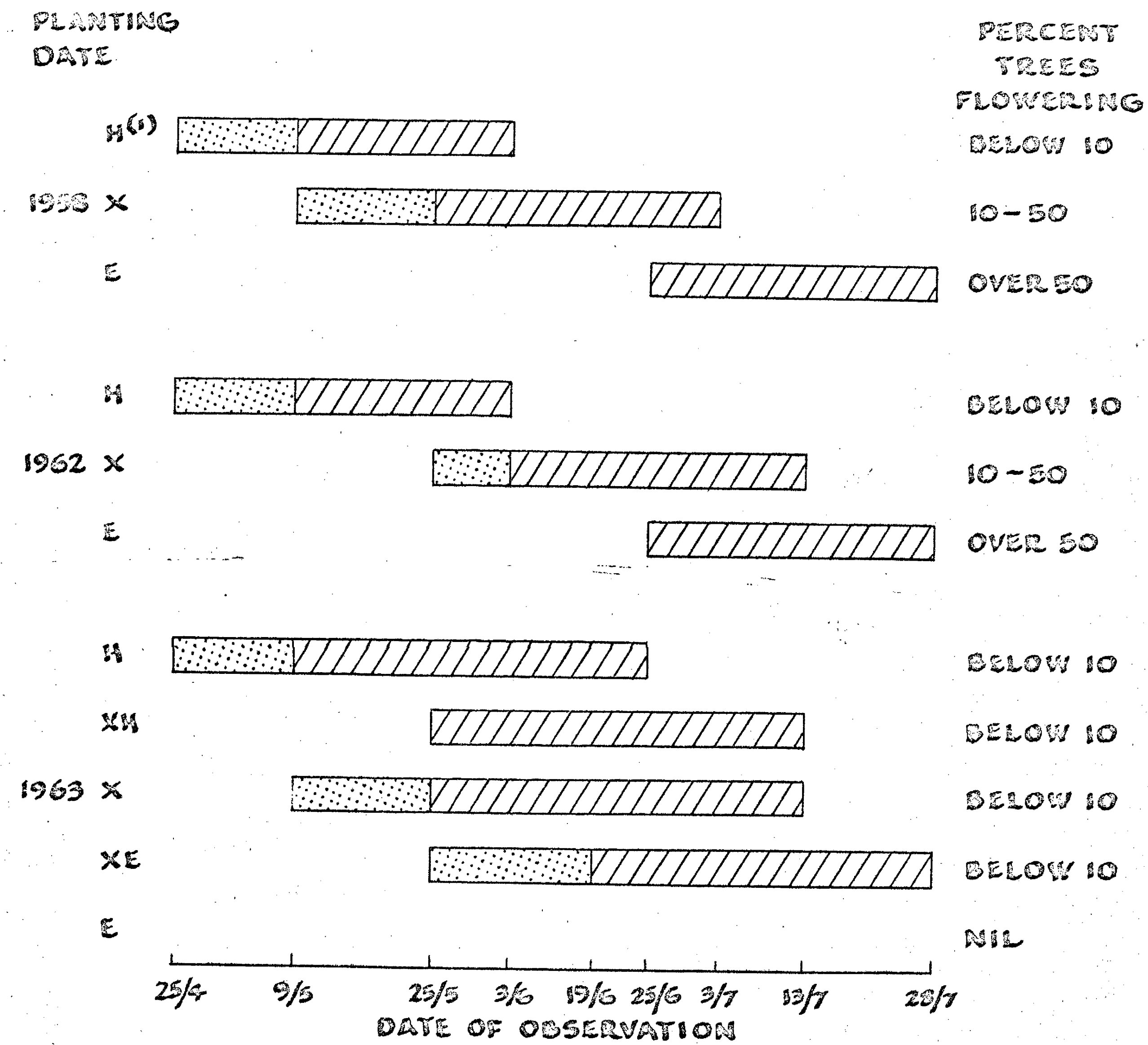
Results.

The results have been summarized by plantings in Figure 22. Cone flowers were regarded as being "buds" when in stages 1 and 2 and "receptive" in stages 3 and 4. Flowering was deemed complete at stage 5. For each planting the periods have been noted when (i) buds were evident and (11) cone flowers were receptive or pollen was being shed.

Discussion.

There is a tendency to intermediacy in time of flowering in the hybrid

Fig. 22. PERIODS OF ANTHESIS OBSERVED IN THREE SEPARATE PLANTINGS AT BEERWAH IN 1967 IN THE VARIETIES *elliottii* AND *hondurensis*, THE HYBRID BETWEEN THEM AND THE DERIVATIVES OF THIS HYBRID




(1) FOR CODING USED SEE PART II CHAPTER 4.

BUDS PRESENT

POLLEN FLY OR CONE FLOWERS RECEPTIVE

compared with the parental varieties as is shown in Figure 22. The flowering periods become more definite with increasing age of this young material and in the 1958 planting, aged nine years, the following were the dates of anthesis:-

| | |
|---|---|
| var. honndurensis | - May 5th - June 8th |
| var. elliottii | - July 3rd - July 28th |
| var. elliottii x var. hondurensis hybrid | - May 25th - July 3rd |

The hybrid is thus intermediate in flowering time between the parental varieties.

The 1962 planting behaved in a very similar manner except that flowering of var. elliottii commenced slightly earlier and that of the hybrid continued for a little longer.

In the 1963 planting no flowers occurred on either parental variety but some very long drawn out flowering periods occurred in the hybrid and its derivatives. These indicated that the flowering time of each backcross was intermediate between the hybrid and the respective parental variety. The length of the flowering periods may result from the immaturity of this planting, and may shorten and become more definite with age, as more trees commence flower production. It is also possible that the flowering period becomes lengthened in material derived from hybrids due to segregation and recombination of the controlling genetic factors and that the length recorded will be maintained in future years.

It is clear that natural crossing between var. elliottii and var. hondurensis is very rare if not impossible. No instance of the two varieties var. elliottii and var. hondurensis flowering together was found, but this could occur at Bowenia where the flowering period of var. hondurensis may be very prolonged (Slee and Nikles, 1967). Var. elliottii flowering remains the same at Bowenia as at Beerwah (Q.F.S. records).

Slee and Nikles (1967) found that var. bahamensis in Queensland flowered at approximately the same time as var. hondurensis, whilst var. caribaea flowered at the same time as var. elliottii. It appears therefore by combining the results of this study and those of Slee and Nikles (1967) that coincident flowering periods occur in the following combinations of varieties or hybrids.

(i) var. elliottii and var. caribaea.

(ii) var. hondurensis and var. bahamensis.

(iii) F1 hybrid (var. elliottii x var. hondurensis) and the backcrosses to the parental varieties.

(iv) var. elliottii and the hybrid x var. elliottii backcross.

(v) var. hondurensis and the hybrid x var. hondurensis

The position of var. densa has not been studied but it is thought to approximate to that of var. elliottii as the pollinations were made at that time.

It may be possible eventually to control flowering environmentally and thus facilitate crossing between trees that are temporally separated. However in the immediate future it will be necessary to reply on natural flowering periods and it is considered impossible to produce crosses between trees that do not flower coincidentally for commercial purposes. For practical forest use it may be assumed that the var. elliottii and var. caribaea cannot be crossed with either var. hondurensis or var. bahamensis and vice-versa.

If we regard the parental varieties as covered by a flowering time scale of approximately three months, then var. hondurensis and var. bahamensis are at one extreme of this scale and var. elliottii and var. caribaea at the other.

The intermediate nature of the flowering of the hybrid combinations observed to date suggests flower production is controlled multi-genically. This accords with the views of Hiesey and Milner (1965) that most complex characters are so controlled. Flowering times of combinations within the complex may therefore be expected to be intermediate between the times of the parental types.

If this is so it is probable that flowering times will overlap between all combinations except those whose parentages are wholly limited to opposite extremes of the scale. Thus a var. elliottii x var. caribaea hybrid would be unlikely to flower coincidentally with a var. hondurensis x var. bahamensis but a var. elliottii x var. hondurensis hybrid would probably flower at the same time as a var. caribaea x var. bahamensis hybrid.

## Conclusions.

The flowering time of the var. elliottii x var. hondurensis hybrid is intermediate between the periods of the parental varieties. The backcrosses to the parental varieties are also probably intermediate between the F1 hybrid and the respective parental variety. However the flowering periods of these hybrid derivatives were unusually prolonged.

The flowering periods of the complex are regarded as situated on a time scale of three months and varieties at opposite ends of the scale do not flower coincidentally. Var. bahamensis and var. hondurensis are at one extreme of the scale and var. caribaea and var. elliottii at the other. Presumably the hybrids are intermediate with their position depending on the parental positions.

Thus coincident flowering times appear to be restricted in the pure varieties to var. hondurensis and var. bahamensis and to var. caribaea and var. elliottii. However substantial overlapping of flowering may be possible using hybrid combinations.

# PART V

# CONCLUSIONS AS TO THE STATUS AND POTENTIAL OF THE HYBRIDS OF THE SLASH-CARIBBEAN COMPLEX IN QUEENSLAND

## The status and potential of the hybrids of the Slash-Caribbean complex in Queensland

The status and potential of the hybrids of the Slash-Caribbean complex have been determined by assessing whether the hybrids more nearly achieve the aims of tree breeding than do the other alternatives, and whether they can be effectively produced in sufficiently large quantities to permit their economic utilization.

The aims of the tree breeder outlined in Part I Chapter 1 as a summarized form of Allard's (1960) definition are:-

(i) to increase the yield through improved physiological efficiency,

(ii) to provide material for new areas,

(iii) to improve the overall characteristics of the product,

(iv) to provide increased resistance to pests and diseases.

To assess the extent to which these aims have been achieved within the complex, detailed studies have been made on the var. elliottii x var. hondurensi hybrids, whilst only very superficial examinations were possible on the other hybri in the complex. The inheritance patterns determining the exhibition of the hybrid characteristics were deduced for the var. elliottii x var. hondurensis hybrid, and by extrapolation it was possible to estimate the degree to which certain characteristics would be exhibited in the other hybrids of the complex. Thus, estimates of the status of these hybrids have been made.

### The var. elliottii x var. hondurensis hybrid.

It is clear from Part III Chapter 2 that in south-eastern Queensland the hybrid var. elliottii x var. hondurensis exhibits hybrid vigour and that increased volume production would result from its commercial exploitation. On ridge sites the hybrid maintains approximately the same rate of height growth as var. hondurensis that is five feet per annum over the first eight years. The hybrid exceeds var. hondurensis in girth growth in this period with 25.4 inches at age nine compared with 24.0 inches. The hybrid is much more vigorous than var. elliottii in both height and girth growth; comparative figures being 39 versus 34 feet for height at age eight and 25 versus 21 inches for girth at age nine years.

This result may be regarded as due to improved physiological efficiency resulting, at least in part, from a seasonal growth pattern better adapted than those of the parents to the prevailing conditions. It was shown in Part III Chapter 1 that the hybrid combines the early spring flush of var. elliottii with the late season and winter growth of var. hondurensis. This habit enables the hybrid to utilize the early part of the growing season by storage of photosynthates from the favourable summer period. Var. hondurensis, relying entirely on current photosynthates, is generally slow growing in this period which is usually slightly adverse to growth. Conditions are not sufficiently poor to limit the utilization of the stored material and both var. elliottii and the hybrid make appreciable growth in this period. Later in the season growth of var. elliottii declines and both var. hondurensis and the hybrid grow actively.

Following the early spring flush var. elliottii continues to grow, completing several successive flushes before mid-summer. These latter flushes are thought to be dependent on current photosynthates produced in the early spring period. The climate of this period becomes harsher and further removed from the var. elliottii homocline with movement north in Queensland.

This effectively limits the growth of var. elliottii in these areas, and the variety is not regarded as a plantation tree north of Rockhampton (22$^{o}$S) and may even prove poorly adapted as far south as Bundaberg (25$^{o}$S).

The initial evidence suggests that the factors that limit the growth of var. elliottii at lower latitudes also tend to do the same with the hybrid. The hybrid is less vigorous than var. hondurensis at Rockhampton and poor development on a swamp site at Cathu indicates that it has little future at this latitude.

The hybrid's vigour superiority in the southern regions becomes even more pronounced on wet sites. On these low humic or podzolic gleys the var. hondurensis performs poorly probably because of a lack of superficial roots. This lack of a root system in the upper soil layers is in distinct contrast to var. elliottii which is accordingly well adapted to these swampy wet sites, where it exhibits better growth than var. hondurensis. The hybrid has an intermediate rooting habit and is able to grow vigorously on such sites, presumably maintaining the same pattern as on the ridge. In consequence therefore of the intermediate growth pattern and the intermediate rooting habit the hybrid exhibits pronounced hybrid vigour on these swamp sites. Thus the hybrid is able to utilize the areas of south-east Queensland more effectively than either parent variety, and this effectiveness is particularly pronounced on the poorly drained areas. These areas with the low humic or podzolic gley soil types are at present regarded as unplantable or able to produce only a pulp crop.

The hybrid therefore has increased yield over the parental varieties due to improved physiological efficiency and it also provides material for use in new areas.

As noted in Part II Chapter 3, both parental varieties have some good features, and some that could be improved with advantage. Besides vigour, the characteristics of stem straightness, wind-firmness, branch size, and wood density variation were examined (Part III Chapter 2). The hybrid was found to be intermediate in stem straightness and branch size and equivalent to var. elliottii in wind-firmness. The hybrid's wood density varied with the different sites, being below both parents on the ridge and superior to both on the swamp. Minimum density values and the proportion of relatively high density wood (late-wood) were intermediate on both sites as were maximum density values on the ridge sites. On the swamp the hybrid had higher maximum density values than either parent.

The straightness of the hybrid made with unselected breeding material is adequate to meet Queensland's requirements but improvement would be desirable. It is expected that this will be achieved by the use of selected breeding trees in both varieties for the production of this hybrid.

The wind-firmness of the hybrid with 17 percent of stems affected in this study at age four is similar to that of var. elliottii (18%) and clearly superior to var. hondurensis (50%). This result is probably due to a combination of the greater size of the hybrid and its putative intermediate root distribution.

It is difficult to generalize from the wood density variations concerning pulp yields. The hybrid should exceed both parents in comparative pulp yield on the swamp sites but not on the ridge. Judged on the percentage of relatively high density wood present, the quality of the pulp from the hybrid should be better than that of var. hondurensis (and also than P. radiata), but poorer than var. elliottii. Also the timber from the hybrid should be stronger than var. hondurensis and more uniform than var. elliottii due to the intermediate quantities of relatively high density wood present.

In many characteristics therefore the hybrid is an improvement on one or other of the parental varieties and in some cases on both. The combination of the characteristics assessed in the hybrid is therefore of general advantage.

Clearly the var. elliottii x var. hondurensis hybrid satisfies many of the aims of the tree breeder in south-east Queensland it gives increased yields over both parental types particularly on swamp sites, and adds considerably to the vigour of var. elliottii at the expense of straightness and perhaps some wood qualities. (The hybrid may also add desirable wood qualities, such as uniformity to var. elliottii). The hybrid improves most features of var. hondurensis except branch size.

The study also showed that the backcrosses from the F1 hybrid var. elliottii x var. hondurensis to the parental varieties were intermediate between the F1 hybrid and the respective parent in stem straightness, and close to intermediacy in vigour and wind-firmness. This is in accord with the expression of the characters in the F1. In general most are intermediate or if not they are determined by characteristics that are, for example the vigour of the hybrid is heterotic but this is due to intermediacy in the growth patterns. Presumably most of these characters being complex are controlled multi-genically (Heisey and Milner, 1965) and thus such an inheritance pattern is to be expected.

Other hybrids of the complex.

As the characteristics of the var. elliottii x var. hondurensis hybrid are generally intermediate, it seems probable that this will be true of the other hybrids of the complex too. The early results (Part III Chapter 2) indicate that this may be so in the vigour of both the var. elliottii and var. caribaea hybrid and the var. caribaea x var. hondurensis. In both examples the hybrid vigour would probably be due to intermediacy in other associated characteristics.

Assuming that intermediate expression of the characteristics is common, the hybrids could have considerable value. The straightness of var. caribaea or var. bahamensis could be incorporated into var. hondurensis or the tolerance of wet sites of var. elliottii and var. densa could be added to the varieties of P. caribaea in which it proves to be lacking. The possible hybrids available will probably depend on homoclinal considerations. Thus these studies indicated that var. elliottii x var. hondurensis may have little value north of Rockhampton where the climate is conspicuously different from the natural range of var. elliottii.

Slee and Nikles (1967) regarded var. hondurensis as best suited to sites at latitudes lower than 26$^{o}$ and var. bahamensis and var. caribaea to latitudes 23$^{o}$ to 32$^{o}$. The studies of this thesis and others indicate that in Queensland var. elliottii is unsuitable at latitudes lower than 22$^{o}$, and from homoclinal considerations it may be presumed that var. densa is best at latitudes lower than var. elliottii. Clearly therefore the complex between P. elliottii and P. caribaea is suitably adapted to much of Queensland and the possible hybrid combinations must be regarded as incorporating features of considerable value.

Production.

The possibilities for large scale production of hybrid seed are governed by the flowering periods and the crossabilities of the combinations. Good seed production would be possible from combinations in which the varieties flower coincidentally and have good crossability such as var. elliottii x var. caribaea.

However even if crossabilities are high the production of hybrid seed will necessitate some method of impeding and preferably preventing intra-varietal crossing. By definition intra-varietal hybrids have a crossability of approximately 100 and a consideration of the mechanisms involved in determining crossability indicates that if two pollen types are the possible combinants with the cone parent then most of the seed produced will be of that with the higher crossability index. The greater the difference between the indices the greater the difference in the quantities of seed produced. Thus if intra-varietal crossing is possible the production of hybrid seed will be reduced.

Problems also arise with the segregation of the hybrid from the pure varietal seed. As seed differences are not apparent morphologically in the artifical crosses, and the author knows of no such differences ever being reported, the seedlings will have to be segregated in the nursery on juvenile characters. Such a practice is expensive and possibly wasteful of pure-varietal stock.

The possible methods of preventing intra-varietal pollen contamination of hybrid production were discussed in Part I. These centre on the use of trees which produce pollen only late in life, the use of male-sterile clones, or uni-clonal orchards.

As all these varieties have given evidence of producing pollen at an early age there is no possibility of having young cone parents surrounded by the other pollen bearing variety.

Production by means of male-sterile or uni-clonal orchards appears possible. These orchards are composed of one variety and surrounded by the other. Intra-varietal crossing is prevented in the orchard variety either because there is no pollen available if male-sterile clones are used, or because of self-incompatibility in uni-clonal orchards. Obviously in the latter, self-compatible clones could not be used. In the absence of known male-sterile clones within the complex for the Slash-Caribbean hybrid production it seems quite feasible to establish uni-clonal orchards of one variety scattered through plantations of another variety. The clones used would be selected as having high crossability values with the other variety. For example one uni-clonal orchard could be established at one location and others composed of different clones at other locations. The distance apart of the orchards would depend on the relative crossabilities involved. If the combination has a low crossability a comparatively small amount of intra-varietal pollen would effectively swamp the inter-varietal and thus the orchards would need to be some distance apart. Conversely with good crossability within the combination the distance between orchards could be reduced. The use of such orchards to produce hybrid seed of var. elliottii x var. caribaea could be established immediately, provided trees of suitable quality were available as parents. These varieties flower co-incidentally and also have high crossabilities. It may also be possible to establish similar orchards for the production of hybrid seed from var. elliottii x var. densa, var. densa x var. caribaea, and var. bahamensis x var. hondurensis. But the crossability of these combinations is not fully known and in some cases it may be low, and even this method appears limited.

Perhaps the most suitable method for the production of hybrid material will be the use of hybrid derivatives if these give satisfactory seed sets. For example large scale production of the backcross from the F1 hybrid var. elliottii x var. hondurensis to var. elliottii could be effected by the establishment of uni-clonal orchards of selected F1 hybrid clones in a var. elliottii population. (This assumes self incompatibility in the hybrid).

It remains to be determined whether multi-varietal crosses such as (var. hondurensis x var. caribaea) x (var. bahamensis x var. elliottii) are possible. If they are a multitude of complex groupings would be available.

## Conclusions.

The hybrids within the Slash-Caribbean complex are potentially most valuable for Queensland. The var. elliottii x var. hondurensis hybrid combines several characteristics of importance from both varieties, gives increased yield due to heterosis and will probably prove a suitable tree for the low humic, podzolic gley or similar soil types which at present are regarded as virtually unplantable.

The other hybrids of the complex may prove equally useful particularly in the more northern areas of the State, where var. elliottii is unsuited both as the pure variety and as one parent of an F1 hybrid.

For production purposes it is possible that some F1 hybrids could be used, but it is more likely that backcrosses to parental types or possibly even multi-varietal combinations would be preferable. The simplest production method appears to be scattered uni-clonal orchards of one parental type in a matrix of the other.

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# APPENDIX 1

<u>Details of the layouts and treatments accorded the various experimental plantings used in these studies</u>

1958 Planting

Beerwah Forest

Location - Compartment 22, Rose Creek Logging Area, R. 611

| | | |
|---|---|---|
| Treatments included | - | Three |
| Hybrid | - | One var. elliottii x var. hondurensis cross between unselected local trees, the var. elliottii at Beerwah, the var. hondurensis at Cairns. |
| Var. hondurensis | - | One unselected imported batch. |
| Var. elliottii | - | Two batches - one unselected local collection, one a controlled cross between selected trees (G2, G8) included in the Beerwah var. elliottii seed orchard. |

Layout - Two site types -

(i) A lateritic podzolic of loamy sand texture - nodulation occurring at 30" depth. No impedance to roots - flat.

(ii) A podzolic gley with clay at approximately 18" but varying with the slope. Clay is at a deeper level at the higher end of each plot.

The layout is the same on each site type. Five randomized blocks with each treatment represented in each block, both var. elliottii batches are included in each block. The unit plot is 3 trees wide and 10 trees deep forming a continuous belt of 20 plots. Tree spacing is 8 feet x 8 feet.

Silvicultural treatment - Planted as tubed stock in 1958 except the unselected var. elliottii batch as open root stock the following winter. $2\frac{1}{2}$ cwt. per acre of rock phosphate applied 1962. Thinned to 400 stems per acre 1964. Pruned as development of each treatment permitted.

1961 Planting

Beerwah Forest

Location - Compartment 4, Donnybrook Logging Area, R. 611

Treatments included - Three

Hybrid - One var. elliottii x var. hondurensis cross between a selected elliottii parent (G11) at Beerwah and unselecte var. hondurensis pollen from six year old trees at Bowenia.

Var. hondurensis - One unselected imported batch.

Var. elliottii - Unselected local collection.

Layout - One site type -

A well drained lateritic podzolic of loamy sand texture with nodulation occurring at 30" depth. No impedence to roots - flat.

The layout is a random arrangement of four plots of each treatment. There are therefore twelve plots in all grouped as a four plot x three plot block. Each plot is of 49 trees, 7 rows of 7 at 8 feet x 8 feet spacing.

Silvicultural treatment - Planted as tubed stock - February 1961.

$2\frac{1}{2}$ cwt. per acre of rock phosphate applied November 1962. Unthinned. Pruned as development of the stand allowed.

<u>1962 Planting</u>

<u>Beerwah Forest</u>

<u>Location</u> - Compartment 12, Storrs Logging Area, R. 611

<u>Treatments included</u> - Three

<u>Hybrid</u> - Two <u>elliottii</u> x <u>hondurensis</u> crosses. Batch (i) selected <u>elliottii</u> at Beerwah (G2) x unselected pollen from 7 year old trees at Bowenia. Batch (ii) selected <u>elliottii</u> at Beerwah (G23) x selected <u>hondurensis</u> (C29) at Cairns, North Queensland.

Var. <u>hondurensis</u> - One from unselected seed from Cairns, North Queensl

Var. <u>elliottii</u> - One. A controlled cross between selected Beerwah trees (G2 x G8).

<u>Layout</u> - One site type -

A lateritic podzolic of sandy loam texture nodulation occurring at 33" - no impedence to room penetration.

Two randomized block layouts were used.

(i) Three randomized blocks of the three treatments. Nine plots in all, grouped as a square block, three plots x three plots. Each plot of 64 trees, 8 rows of 8 at 8 feet x 8 feet spacing.

One block containing hybrid batch (i) G2 x unselected pollen, the other batch (ii) G23 x G29.

(ii) Four randomized blocks with all batches included in each block. 16 plots in all as a continuous belt. Each plot one row of eight trees at a spacing of 10 feet x 10 feet.

<u>Silvicultural treatment</u> - Planted as tubed stock - January 1962.

Fertilized $2\frac{1}{2}$ cwt/acre rock phosphate - 1965.

1963 Planting

Beerwah Forest
Location - Compartment 9, Storrs Logging Area, R 611.

| | | |
|---|---|---|
| Treatments included | - | Six |
| Hybrid | - | Five var. elliottii x var. hondurensis crosses batches (i - iii) - (G2, 21, 23). Three selected var. elliottii trees at Beerwah, crossed with pollen from an unselected var. hondurensis at Bowenia.<br>Batch (iv) - open cones in var. elliottii seed orchard dusted with the same pollen (no var. elliottii pollen in locality).<br>Batch (v) - selected var. hondurensis (CA) graft at Beerwah crossed with pollen of a selected Beerwah var. elliottii (G20). |
| Hybrid x elliottii | - | Two batches. Several trees of the var. elliottii x var. hondurensis hybrid planted in 1958 at Beerwah with (Batch i) - pollen of a selected var. elliottii, G15 (Batch ii) - pollen mix from two selected var. elliottii trees (G2, G15). |
| Hybrid x var. hondurensis | - | One batch. Several trees of var. elliottii x var. hondurensis hybrid (1958 planting) crossed with pollen from unselected trees at Bowenia. |
| Var. elliottii | - | Three batches. Open pollinated seed of G2, G15, G23 selected trees at Beerwah. |

Var. hondurensis - Two batches. (i) Open pollinated seed from selected tree C46 at Bowenia. (ii) Seed selected from unselected trees at Cairns, North Queensland.

Var. bahamensis - Unselected Grand Bahama material.

Layout - Two site types -

(i) A lateritic podzolic of sandy loam texture . Nodulation occurring at 30" depth. No impedence to roots. Flat.

(ii) A podzolic gley with clay at approximately 18" but varying with the slope, the clay is at a deeper level at the higher end of each plot.

On site type (i), the layout is five randomized blocks, each containing five treatments (var. bahamensis not included). The hybrid x var. hondurensis was the same in each block butthe batches used in the other treatments differed in the different blocks viz:-

| Block | Hybrid | Hybrid x var. elliottii | Var. elliottii | Var. hondurensis |
|---|---|---|---|---|
| 1, 2 | G2 x H | Hyb. x G15 | G2 | C46 |
| 3 | G21 x H | Hyb. x G15 | G21 | C46 |
| 4 | G21 x H | Hyb. x G2, 15 | G21 | N. Q'ld |
| 5 | G23 x H | Hyb. x G2,15 | G23 | N. Q'ld |

The layout is a block of twenty-five plots, five by five. Each plot is of 42 trees, 6 rows of 7 trees at 10 feet x 10 feet spacing.

On site type (ii), the layout is five randomized blocks each with the six treatments. As with site type (i), there is some variation in the batch of each treatment in the different blocks, viz:-

| Block | Hybrid | Hybrid x var. elliottii | var. elliottii |
|---|---|---|---|
| 1 | (v) | Hyb. x G15 | G2 |
| 2 | SO x GH (iv) | Hyb. x G15 | G2 |
| 3, 4 | SO x H (i - iii) mix | Hyb. x G15 | missing |
| 5 | | | missing |

The hybrid x var. hondurensis, var. hondurensis (N. Q'ld) and var. bahamensis were the same throughout.

The blocks formed a row of 30 plots, each plot being one row of 10 trees at 10 feet x 10 feet spacing.

Silvicultural treatment - Planted as tubed stock - January 1963.

Fertilized $2\frac{1}{2}$ cwt/acre

1963 Planting

Bowenia Forest

Location - Compartment 8, Waterpark Logging Area, R. 20

| | | |
|---|---|---|
| Treatments included | - | Four |
| Hybrid | - | Three batches. Three selected var. elliottii at Beerwah G2, G21, G23, crossed with pollen from an unselected var. hondurensis at Bowenia. All crosses kept separate. |
| Hybrid x var. hondurensis | - | One batch. Several trees of var. elliottii x var. hondurensis hybrid planted at Beerwah in 1958 crossed with pollen collected from unselected var. hondurensis at Bowenia. |
| Var. elliottii | - | Three batches. Open pollinated seed of G2, G21, G23 selected trees at Beerwah. |
| Var. hondurensis | - | One batch. Open pollinated seed of C46 a selected tree at Bowenia. |

Layout - One site type - A shallow lateritic podzolic with clay present below 18". Two randomized block layouts were used.

(i) Four randomized blocks each containing one batch of each treatment. The batches varied between blocks in the var. hybrid and var. elliottii treatments. In blocks 1 and 3 each of these treatments was represented by the batches containing G2 progeny in block 2 by G23 progeny and in block 4 by G21 progeny.

There were sixteen plots arranged in two rows of eight, each plot being 49 trees, 7 rows of 7, at a spacing of 9 feet x 8 feet.

(ii) Five randomized blocks each containing one batch of each treatment. The batches varied between blocks in the hybrid and var. elliottii treatments. Block 1 contained the batches with G2 progeny for both treatments, blocks 2 and 3 the G21 batch for var. elliottii and G2 batch for the hybrid, and blocks 4 and 5 the G23 batch for var. elliottii and the G21 batch for the hybrid.

There are a total of 20 plots arranged in two groups, one of four plots constituting block 1, the other a belt of 16 plots. Each plot consists of one row of 10 trees at a spacing of 10 feet x 10 feet.

Silvicultural treatment - Planted as tubed stock - January 1963.

No other silvicultural treatments have been applied.

1964 Planting

Beerwah Forest

Location - Compartment 12, Tripchony L. A., R. 700

| | | |
|---|---|---|
| Treatments included | - | Six |
| Hybrid | - | Seven var. elliottii x var. hondurensis batches. Each is a cross between selected trees viz:- |
| | | G15 x C51 |
| | | G15 x C53 |
| | | G21 x C51 |
| | | G21 x C53 |
| | | G11 x C53 |
| | | G13 x C53 |
| | | G40 x C53 |
| Hybrid x var. hondurensis | - | Two batches. Each is a cross between the hybrids planted in 1958 at Beerwah and var. hondurensis viz:- |
| | | Hybrid x C51 |
| | | Hybrid x C53 |
| Hybrid x Hybrid | - | F2 generation. One batch. A cross between hybrid var. elliottii x var. hondurensis trees planted in 1958 at Beerwah. All trees crossed were full sibs. |
| Hybrid (Open) | | One batch. Open pollinated seed of the hybrid var. elliottii x var. hondurensis planted in 1958 at Beerwah. Likely to be a mixture of F1 x F1 hybrid seed and the backcross to var. elliottii. |

<u>Var. elliottii</u> - One batch. Bulked open-pollinated seed collected from selected trees at Beerwah.

<u>Var. hondurensis</u> - One batch. Seed collected from unselected trees at Cairns, North Queensland.

<u>Layout</u> - Two site types -

(i) A lateritic podzolic of sandy loam texture. Nodulation occurring at approximately 30". No impedence to root penetration.

(ii) A podzolic gley. Gleyed clay loam impedes root penetration at a depth varying from 9" in the lower portion of the plots to 12" in the higher. Ironstone pan present at depths varying similarly between 15" and 30".

Site type (i) can be further sub-divided according to the clearing history. The residue from the roads was burnt in the area alongside them which forms the exterior plots but there was no such additional debris in other parts. The fertility of the area beside the roads is thus increased due to the increased ash-bed effect there.

There are two layouts on each site type.

On the ridge site, the deep lateritic podzolic, the first layout consists of two blocks, one on the area of higher fertility next to the road contains eight plots, the other on the area of lower fertility has ten plots. Both blocks contain all treatments except that the hybrid x hybrid is missing from the high fertility area. In both blocks the hybrid batch is G11 x C53 and the hybrid x <u>hondurensis</u> batch hybrid x C51. The extra plots are filled with unreplicated hybrid and hybrid x <u>hondurensis</u> batches.

Each plot is of 49 trees, 7 rows of 7, at a spacing of 10 feet x 10 feet.

The other layout is also two randomized blocks, one on the high fertility site, one on the other. Both contain five of the six treatments (hybrid x hybrid is missing), and nine batches are replicated in each block. These are single batches of treatments hybrid (open) var. elliottii and var. hondurensis, hybrid batches G11 x 53, G13 x C53, G15 x C51, G21 x C51 and hybrid x hondurensis batches hybrid x C51, hybrid x C53. Miscellaneous unreplicated batches were added to make a total of eleven plots in each block. Each plot consists of a single row of ten trees at a spacing of 10 feet x 10 feet.

On the swamp site, the podzolic gley, the first layout consists of single plots of ten batches. All six treatments are represented. There are four hybrid batches (G11 x C53, G13 x C53, G15 x C53, G21 x C53) and the hondurensis batch is represented in two plots. Each plot is of 49 trees, 7 rows of 7 at 10 feet x 10 feet spacing.

The other layout is three randomized blocks containing all the treatments except the hybrid x hybrid. Each block contains six plots, the hybrid treatment being represented by two batches. There is some variation in the hybrid representation, between the different blocks. Batch G11 x C53 is in all three but blocks 1 and 3 include batch G15 x C51 whilst G13 x C53 is present in block 2. Similarly hybrid x hondurensis batch hybrid x C51 is in blocks 1 and 3 whilst hybrid x C53 is in block 2. Each plot is a single line of ten trees. All three blocks are adjacent thus giving a continuous belt of 21 plots. Spacing is 10 feet x 10 feet.

Silvicultural treatment - Planted as tubed stock in March 1964.

1966 Planting

Beerwah Forest

Location - Compartment 11, Elimbah Logging Area, R.700

| | | |
|---|---|---|
| Treatments included | - | Six |
| Hybrid var elliottii x var. hondurensis | - | Four batches. Individual crosses between selected trees var. elliottii at Beerwah, var. hondurensis at Bowenia.<br>G11 x C53 G15 x C53<br>G11 x C57 G15 x C57 |
| Hybrid var. elliottii x var. caribaea | - | Six batches. Individual crosses between selected trees of var. elliottii at Beerwah, var. caribaea at Banyabba N.S.W.<br>G11 x C33 G15 x C33 G21 x 33<br>G11 x C35 G15 x C35 G21 x 35 |
| Hybrid var. caribaea x var. hondurensis | - | Two batches. Individual crosses between selected trees. Var. caribaea at Banyabba, N.S.W. var. hondurensis at Bowenia.<br>C34 x C57 C36 x C57 |
| Var. hondurensis | - | One batch. Unselected imported batch. |
| Var. caribaea | - | Two batches. Individual crosses between selected trees at Banyabba, N.S.W.<br>C34 x C33 C34 x C35 |

_Var. elliottii_ - Three batches. Crosses of selected trees at Beerwah with a pollen mixture from selected trees also at Beerwah.

G11 x mix. G15 x mix. G21 x mix.

_Layout_ - One site type. A lateritic podzolic of sandy loam texture with modulation occurring at 30" depth. Two randomized block layouts with an additional unreplicated single block planting. Each randomized block layout consists of three blocks with all the six treatments represented and with the _elliottii_ x _caribaea_ hybrids each having two batches in each block. These randomized blocks are referred to in the text as Group A and Group B. Detailed representation in each layout is as follows:-

Randomized Block Layout -

| A | B |
|---|---|
| G11 x C53 | G15 x C53 |
| G11 x C57 | G15 x C57 |
| G11 x C33 | G15 x C33 |
| G11 x C35 | G15 x C35 |
| C34 x C57 | C36 x C57 |
| var. _hondurensis_ | var. _hondurensis_ |
| C34 x C33 | C34 x C35 |
| G11 x mix. | G15 x mix. |

In each layout the third replication has three missing plots of treatments var. _hondurensis_, var. _caribaea_ and hybrid var. _caribaea_ x var. _hondurensis_.

The unreplicated section consists of three plots of G21 x mix., G21 x C33, and G21 x C35.

The total number of plots if 45 arranged as a single group 9 plots x 5 plots.

Each plot contains 49 trees, 7 rows of 7, at a spacing of 10 feet x 10 feet.

Silvicultural treatment - Planted as tubed stock, March, 1965.

1966 Planting

Bowenia Forest

Location - Compartments 2 and 3, Pocket Logging Area, R.20

| | | |
|---|---|---|
| Treatments included | - | Six |
| Hybrid var. elliottii x var. hondurensis | - | One batch. Individual crosses between selected breeding trees of var. elliottii and var. hondurens at Bowenia.<br>G11 x C53 |
| Hybrid var. elliottii x var. caribaea | - | Three batches. Individual crosses between select breeding trees of var. elliottii at Beerwah and var caribaea at Banyabba, N.S.W.<br>G11 x C33 G21 x C35<br>G21 x C33 |
| Hybrid var. caribaea x var. hondurensis | - | Three batches. Individual crosses between select breeding trees of var. caribaea at Banyabba, N.S. and var. hondurensis at Bowenia.<br>C34 x C53 G36 x C57<br>C36 x C53 |
| Var. hondurensis | - | One batch. Unselected imported batch. |
| Var. caribaea | - | Two batches. Individual crosses between selectec breeding trees at Banyabba, N.S.W.<br>C34 x C33 C35 x C33 |

<u>Var. elliottii</u> - Two batches. Crosses between selected breeding trees at Beerwah and a mixture of pollen from other selected breeding trees at Beerwah.

G11 x mix. G21 x mix.

<u>Layout</u> - One site type. A lateritic podzolic freely rootable to 30". Two randomized block layouts are included with each treatment represented at least once in each block. In the text the two blocks are referred to as Group C and Group D. Detailed representation is as follows:-

Randomized Block Layout -

| C | D |
|---|---|
| G11 x C53 | G21 x C35 |
| G11 x C33 | G21 x C33 |
| C34 x C53 | C36 x C57 |
| C36 x C53 | var. <u>hondurensis</u> |
| var. <u>hondurensis</u> | C35 x C33 |
| C34 x C33 | G21 x mix. |
| G11 x mix. | |

There are three replications in each making a total of 21 plots in Group C and 18 plots in Group D. Each plot is of 49 trees at a spacing of 10 feet x 10 feet.

<u>Silvicultural treatment</u> - Planted as tubed stock, January 1965.

1966 planting

Cathu Forest

Location - Plot 16, Cpt. 6 Moolooloo Logging Area, R. 658

Treatment included - Two

Hybrid - One var. elliottii x var. hondurensis cross between selected breeding trees G11 and C53.

Var. hondurensis - One unselected imported batch.

Layout - One site type. A podzolic gley with clay present at 15 inches. Simple block plantings of both treatments, no replications.

Silvicultural treatment - Planted as tubed stock, April 1966.

# APPENDIX 2

## Details of the analyses of variance

(a) Analyses of variance performed on the vigour, stem-straightness and wind-firmness results

1958 Planting (Beerwah) (Height)

| Source | Degrees of freedom | Sum of squares Total | Sum of squares Mean | Variance ratio | Significance |
|---|---|---|---|---|---|
| Joint analysis | | | | | |
| Block | 9 | 116 | 13 | 4 | ** |
| Site | 1 | 95 | 95 | 35 | *** |
| Rem. 1 | 8 | 22 | 3 | - | - |
| Variety | 3 | 352 | 117 | 32 | *** |
| Var. x Bl. | 27 | 99 | 4 | - | - |
| Var. x Site | 3 | 50 | 17 | 8 | *** |
| Rem. 2 | 24 | 49 | 2 | - | - |
| Ridge only | | | | | |
| Block | 4 | 7 | 2 | 2 | NS |
| Variety | 3 | 170 | 57 | 59 | *** |
| Rem. | 12 | 12 | 1 | - | |
| Swamp only | | | | | |
| Block | 4 | 15 | 4 | 1 | NS |
| Variety | 3 | 233 | 78 | 25 | *** |
| Rem. | 12 | 38 | 3 | - | |

1958 planting (Beerwah) (g.b.h.)

| Source | Degrees of freedom | Sum of Squares Total | Sum of Squares Mean | Variance ratio | Significance |
|---|---|---|---|---|---|
| Joint analysis | | | | | |
| Block | 9 | 45 | 5 | 6 | *** |
| Site | 1 | 37 | 37 | 40 | *** |
| Rem. 1 | 8 | 8 | 1 | - | - |
| Variety | 3 | 161 | 54 | 60 | *** |
| Var. x Bl. | 27 | 24 | 1 | - | - |
| Var. x Site | 3 | 11 | 4 | 7 | ** |
| Rem. 2 | 24 | 13 | 0.5 | - | - |
| Ridge only | | | | | |
| Block | 4 | 2 | 0.5 | 11 | NS |
| Variety | 3 | 79 | 26 | 79 | *** |
| Rem. | 12 | 4 | 0.3 | - | - |
| Swamp only | | | | | |
| Block | 4 | 5 | 1 | 2 | NS |
| Variety | 3 | 93 | 31 | 41 | *** |
| Rem. | 12 | 9 | 1 | | |

1958 Planting (Beerwah) (Straightness)

| Source | Degrees of freedom | Sum of squares Total | Sum of squares Mean | Variance ratio | Significance |
|---|---|---|---|---|---|
| Joint analysis | | | | | |
| Block | 9 | 857 | 95 | 2 | NS |
| Site | 1 | 62 | 62 | 0.6 | NS |
| Rem. 1 | 8 | 795 | 99 | - | - |
| Variety | 3 | 10627 | 3542 | 62 | *** |
| Var. x Bl. | 27 | 1531 | 57 | - | - |
| Var. x Site | 3 | 95 | 32 | 0.5 | NS |
| Rem. 2 | 24 | 1436 | 60 | - | - |

1961 Planting (Beerwah) (Height)

| Source | Degrees of freedom | Sum of squares Total | Sum of squares Mean | Variance ratio | Significance |
|---|---|---|---|---|---|
| Variety | 2 | 94 | 47 | 168 | *** |
| Plot x Var. | 9 | 3 | 0.3 | - | - |
| **1961 Planting (Beerwah) (g.b.h.)** | | | | | |
| Variety | 2 | 26 | 13 | 93 | *** |
| Plot x Var. | 9 | 1 | 0.1 | | |
| **1962 Planting (Beerwah) (Height)** | | | | | |
| Multiline plots | | | | | |
| Block | 2 | 2 | 1 | 1.9 | NS |
| Variety | 2 | 28 | 14 | 22 | ** |
| Block x Var. | 4 | 3 | 1 | | |
| Single line plots | | | | | |
| Block | 3 | 17 | 6 | 2.07 | NS |
| Variety | 3 | 55 | 18 | 6.88 | * |
| Block x Var. | 9 | 22 | 3 | | |
| **1962 Planting (Beerwah) (Straightness)** | | | | | |
| Multiline plots | | | | | |
| Block | 2 | 20 | 10 | - | NS |
| Variety | 2 | 2272 | 1136 | 32 | ** |
| Block x Var. | 4 | 143 | 36 | - | - |

1962 Planting (Beerwah Ridge) (Height)

| Source | Degrees of freedom | Sum of squares Total | Sum of squares Mean | Variance ratio | Significance |
|---|---|---|---|---|---|
| Block | 4 | 23 | 6 | 5 | *** |
| Variety | 4 | 67 | 17 | 14 | ** |
| Bl. x Var. | 16 | 19 | 1 | - | - |
| **1963 Planting (Beerwah Ridge) (g. b. h.)** | | | | | |
| Block | 4 | 13 | 3 | 11 | *** |
| Variety | 4 | 109 | 27 | 94 | *** |
| Bl. x Var. | 16 | 5 | 0.3 | - | - |
| **1963 Planting (Beerwah Ridge)(Straightness)** | | | | | |
| Block | 4 | 282 | 71 | - | NS |
| Variety | 4 | 11297 | 2824 | 34 | *** |
| Bl. x Var. | 16 | 1332 | 83 | - | - |
| **1963 Planting (Beerwah Ridge) (Wind-firmness)** | | | | | |
| Block | 4 | 948 | 237 | 2.5 | NS |
| Variety | 4 | 2728 | 682 | 7 | ** |
| Bl. x Var. | 16 | 1504 | 94 | - | |

1963 Planting (Beerwah Swamp) (Height)

| Source | Degrees of freedom | Sum of squares Total | Sum of squares Mean | Variance ratio | Significance |
|---|---|---|---|---|---|
| Block | 4 | 7 | 2 | 2 | NS |
| Variety | 4 | 67 | 17 | 19 | *** |
| Bl. x Var. | 15 | 14 | 1 | - | - |
| **1963 Planting (Beerwah Swamp) (g.b.h.)** | | | | | |
| Block | 4 | 4 | 1 | 1.5 | NS |
| Variety | 4 | 39 | 10 | 15 | *** |
| Bl. x Var. | 15 | 10 | 0.7 | - | - |
| **1963 Planting (Bowenia Ridge) (Height)** | | | | | |
| Multi-line plots | | | | | |
| Block | 3 | 9 | 3 | 3 | NS |
| Variety | 3 | 24 | 8 | 8 | ** |
| Bl. x Var. | 9 | 9 | 1 | - | - |
| Single-line plots | | | | | |
| Block | 4 | 33 | 8 | 5 | * |
| Variety | 3 | 93 | 31 | 20 | ** |
| Bl. x Var. | 12 | 19 | 2 | - | - |

1964 Planting (Beerwah) (Height)

| Source | Degrees of freedom | Sum of squares Total | Sum of squares Mean | Variance ratio | Significance |
|---|---|---|---|---|---|
| Joint analysis (Multi-line plots) | | | | | |
| Block | 2 | 210 | 105 | 58 | *** |
| Site | 1 | 204 | 204 | 34 | NS |
| Rem. 1 | 1 | 6 | 6 | - | - |
| Variety | 5 | 31 | 6 | 3.5 | * |
| Bl. x Var. | 9 | 16 | 2 | - | - |
| Var. x Site | 5 | 12 | 2 | 2.4 | NS |
| Rem. 2 | 4 | 4 | 1 | - | - |
| Joint analysis (Single-line plots) | | | | | |
| Block | 4 | 451 | 113 | 45 | *** |
| Site | 1 | 375 | 375 | 15 | * |
| Rem. 1 | 3 | 76 | 25 | - | - |
| Variety | 5 | 47 | 9 | 3.7 | * |
| Bl. x Var. | 20 | 51 | 2.5 | - | |
| Var. x Site | 5 | 30 | 6 | 4.5 | * |
| Rem.2 | 15 | 20 | 1 | | |

1964 Planting (Beerwah Ridge) (Height)

| Source | Degrees of freedom | Sum of squares | | Variance | Significance |
|---|---|---|---|---|---|
| | | Total | Mean | | |
| Multi-line plots | | | | | |
| Block | 5 | 35 | 7 | 8.8 | * |
| Variety | 1 | 7 | 7 | 8.8 | * |
| Rem. | 4 | 3 | 0.8 | | |
| Single-line plots | | | | | |
| Block | 1 | 17 | 17 | 9.5 | * |
| Variety | 5 | 36 | 7 | 4 | NS |
| Rem. | 5 | 9 | 2 | - | - |
| 1964 Planting (Beerwah Ridge) (Wind-firmness) | | | | | |
| Multi-line plots | | | | | |
| Block | 1 | 1 | 1 | - | NS |
| Variety | 4 | 495 | 124 | 2 | NS |
| Rem. | 4 | 258 | 65 | - | - |
| 1964 Planting (Beerwah Swamp) | | | | | |
| Single-line plots | | | | | |
| Block | 2 | 59 | 30 | 26 | *** |
| Variety | 5 | 41 | 8 | 7 | ** |
| Rem. | 10 | 11 | 1 | - | - |

1966 Planting (Beerwah and Bowenia) (Height)

| Source | Degrees of freedom | Sum of squares Total | Sum of squares Mean | Variance ratio | Significance |
|---|---|---|---|---|---|
| Joint analysis | | | | | |
| Block | 5 | 694 | 139 | 6.3 | ** |
| Location | 1 | 125 | 125 | - | NS |
| Rem. 1 | 4 | 569 | 142 | - | - |
| Variety | 4 | 1742 | 436 | 20 | *** |
| Bl. x Var. | 18[1] | 404 | 22 | - | - |
| Var. x Loc. | 4 | 55 | 14 | - | NS |
| Rem. 2 | 14 | 349 | 25 | - | - |
| 1966 Planting (Beerwah) (Height) | | | | | |
| Group A | | | | | |
| Block | 2 | 36 | 18 | 2 | NS |
| Variety | 7 | 2189 | 313 | 33 | *** |
| Rem. | 11 | 103 | 9 | | |
| Group B | | | | | |
| Block | 2 | 21 | 10 | - | NS |
| Variety | 7 | 1140 | 163 | 18 | *** |
| Rem. | 11 | 98 | 9 | - | - |

1 Two missing plots.

1966 Planting (Bowenia) (Height)

| Source | Degrees of freedom | Sum of squares Total | Sum of squares Mean | Variance ratio | Significance |
|---|---|---|---|---|---|
| Group C | | | | | |
| Blocks | 2 | 794 | 397 | 14 | *** |
| Variety | 6 | 1070 | 178 | 6 | ** |
| Rem. | 12 | - | - | - | - |
| Group D | | | | | |
| Blocks | 2 | 13 | 6 | - | NS |
| Variety | 5 | 596 | 119 | 4.8 | ** |
| Rem. | 10 | 248 | 25 | - | - |

(b) Analyses of variance of the wood properties.

| Source | Degrees of freedom | Sum of squares Total | Sum of squares Mean | Variance ratio | Significance |
|---|---|---|---|---|---|
| **Percent ring with density over 0.68 gm/cc** | | | | | |
| Trees | 26 | 6947 | 267 | 6.7 | *** |
| Variety | 2 | 694 | 347 | 1.5 | NS |
| Site | 1 | 612 | 612 | 2.6 | NS |
| Var. x Site | 2 | 685 | 343 | 1.4 | NS |
| Rem. 1 | 21 | 4956 | 236 | - | - |
| Years | 3 | 1014 | 338 | 8.4 | *** |
| Y. x Tree | 77[1] | 3085 | 40 | - | - |
| Y. x Site | 3 | 252 | 84 | 2.3 | NS |
| Y. x Var. | 6 | 396 | 66 | 1.8 | NS |
| Y. x S. x V. | 6 | 205 | 34 | 1.0 | NS |
| Rem. 2 | 62 | 2232 | 36 | - | |
| **Percent ring with density exceeding 0.55 gm/cc** | | | | | |
| Tree | 26 | 5050 | 194 | 9.1 | *** |
| Variety | 2 | 1760 | 880 | 7.7 | ** |
| Site | 1 | 244 | 244 | 2.1 | NS |
| Var. x Site | 2 | 634 | 317 | 2.8 | NS |
| Rem. 1 | 21 | 2412 | 115 | - | - |
| Years | 3 | 477 | 159 | 7.4 | *** |
| Y. x Tree | 77[1] | 1646 | 21 | - | - |
| Y. x Site | 3 | 105 | 35 | 2.0 | NS |
| Y. x Var. | 6 | 261 | 44 | 2.5 | * |
| Y. x S. x V. | 6 | 181 | 30 | 1.7 | NS |
| Rem. 2 | 62 | 1099 | 18 | - | - |

| Source | Degrees of freedom | Sum of squares Total | Sum of squares Mean | Variance ratio | Significance |
|---|---|---|---|---|---|
| Percent ring with density exceeding 0.44 gm/cc | | | | | |
| Trees | 26 | 3561 | 137 | 3.5 | *** |
| Variety | 2 | 213 | 107 | 0.9 | NS |
| Site | 1 | 68 | 68 | 0.6 | NS |
| Var. x Site | 2 | 681 | 341 | 2.8 | NS |
| Rem. 1 | 21 | 2599 | 124 | - | - |
| Years | 3 | 505 | 168 | 4.3 | ** |
| Y. x Tree | 77 | 3023 | 39 | - | - |
| Y. x Site | 3 | 133 | 44 | 1.3 | NS |
| Y. x Var. | 6 | 426 | 71 | 2.1 | NS |
| Y. x S. x V. | 6 | 386 | 64 | 1.9 | NS |
| Rem. 2 | 62 | 2078 | 34 | - | - |
| Mean density per ring | | | | | |
| Tree | 26 | 1225 | 47 | 4.4 | *** |
| Variety | 2 | 72 | 36 | - | NS |
| Site | 1 | 0 | 0 | - | NS |
| Var. x Site | 2 | 364 | 182 | 4.8 | * |
| Rem. 1 | 21 | 789 | 38 | - | - |
| Years | 3 | 99 | 33 | 3.1 | * |
| Y. x Tree | 77 | 825 | 11 | - | - |
| Y. x Site | 3 | 40 | 13 | 1.4 | NS |
| Y. x Var. | 6 | 72 | 12 | 1.3 | NS |
| Y. x S. x V. | 6 | 125 | 21 | 2.2 | NS |
| Rem. 2 | 62 | 588 | 9 | - | |

| Source | Degrees of freedom | Sum of squares Total | Sum of squares Mean | Variance ratio | Significance |
|---|---|---|---|---|---|
| Maximum density | | | | | |
| Trees | 26 | 7902 | 304 | 8.8 | *** |
| Variety | 2 | 304 | 152 | - | NS |
| Site | 1 | 1450 | 1450 | 5.7 | * |
| Var. x Site | 2 | 797 | 399 | 1.6 | NS |
| Rem. 1 | 21 | 5351 | 255 | - | - |
| Years | 3 | 1155 | 385 | 11.1 | *** |
| Y. x Tree | 77 | 2668 | 35 | - | - |
| Y. x Site | 3 | 103 | 34 | - | NS |
| Y. x Var. | 6 | 441 | 74 | 2.4 | * |
| Y. x S. x V. | 6 | 221 | 37 | 1.2 | NS |
| Rem. 2 | 62 | 1903 | 31 | - | - |
| Minimum density | | | | | |
| Trees | 26 | 2202 | 85 | 24.7 | *** |
| Variety | 2 | 1770 | 885 | 47.4 | *** |
| Site | 1 | 1 | 1 | - | NS |
| Var. x Site | 2 | 39 | 20 | 1.0 | NS |
| Rem. 1 | 21 | 392 | 19 | - | - |
| Years | 3 | 37 | 12 | 3.6 | * |
| Y. x Tree | 77 | 264 | 3 | - | - |
| Y. x Site | 3 | 9 | 3 | 1.1 | NS |
| Y. x Var. | 6 | 41 | 7 | 2.4 | * |
| Y. x S. x V. | 6 | 39 | 7 | 2.3 | * |
| Rem. 2 | 62 | 175 | 3 | - | - |

(c) Analyses of variance of the results of the root study.

| Source | Degrees of freedom | Sum of squares Total | Sum of squares Mean | Variance ratio | Significance |
|---|---|---|---|---|---|
| Large roots | | | | | |
| Trees | 8 | 125 | 16 | - | NS |
| Variety | 2 | 5 | 3 | - | NS |
| Rem. 1 | 6 | 120 | 20 | - | - |
| Depth | 3 | 17157 | 5719 | 10.4 | *** |
| Tr. x Dep. | 24 | 1336 | 55 | - | NS |
| Var. x Dep. | 6 | 67 | 11 | - | NS |
| Rem. 2 | 18 | 1269 | 701 | - | - |
| Medium roots | | | | | |
| Tree | 8 | 8 | - | - | - |
| Variety | 2 | 7 | - | - | - |
| Rem. 1 | 6 | 1 | - | - | - |
| Depth | 3 | 1508 | 503 | 16.2 | *** |
| Tr. x Dep. | 24 | 747 | 31 | - | |
| Var. x Dep. | 6 | 392 | 65 | 3.3 | * |
| Rem. 2 | 18 | 355 | 20 | - | |
| Small roots | | | | | |
| Tree | 8 | 4 | 1 | - | NS |
| Variety | 2 | 0 | 0 | - | NS |
| Rem. 1 | 6 | 4 | 4 | - | - |
| Depth | 3 | 1150 | 383 | 9.1 | *** |
| Tr. x Dep. | 24 | 1015 | 42 | - | NS |
| Var. x Dep. | 6 | 433 | 72 | 2.3 | NS |
| Rem. 2 | 18 | 582 | 32 | - | - |

# APPENDIX 3

## Results of the Stem-straightness assessment

| Variety | No. trees assessed | percentage scoring | | | | |
|---|---|---|---|---|---|---|
| | | 4 | 5 | 6 | 7 | 8 |
| 1958 Planting (Ridge) | | | | | | |
| H | 70 | 16 | 64 | 20 | - | - |
| X | 75 | 1 | 40 | 52 | 7 | - |
| E | 75 | 1 | 48 | 47 | 4 | - |
| ES | 71 | - | 14 | 54 | 31 | 1 |
| 1958 Planting (Swamp) | | | | | | |
| H | 72 | 25 | 61 | 13 | 1 | - |
| X | 69 | - | 51 | 45 | 4 | - |
| E | 72 | 3 | 50 | 44 | 3 | - |
| ES | 71 | - | 15 | 52 | 34 | - |
| 1962 Planting (Ridge) | | | | | | |
| H | 48 | - | 11 | 54 | 35 | - |
| X | 69 | - | - | 45 | 43 | 12 |
| E | 69 | - | 9 | 48 | 42 | 44 |
| 1963 Planting (Ridge) | | | | | | |
| H | 88 | 2 | 45 | 48 | 5 | - |
| XH | 93 | - | 12 | 62 | 23 | 3 |
| X | 86 | - | - | 39 | 51 | 10 |
| XE | 86 | - | - | 23 | 61 | 16 |
| E | 92 | - | 1 | 18 | 58 | 23 |

# APPENDIX 4

## Results of the Wind-firmness assessment

| Variety | No. trees assessed | % unaffected | % wind damage slight | % wind damage moderate | % wind damage severe |
|---|---|---|---|---|---|
| <u>1963 Planting</u> | | | | | |
| H | 75 | 36 | 15 | 37 | 12 |
| XH | 77 | 44 | 27 | 20 | 9 |
| X | 78 | 58 | 27 | 9 | 8 |
| XE | 75 | 71 | 19 | 4 | 6 |
| E | 77 | 64 | 19 | 12 | 5 |
| <u>1964 Planting</u> | | | | | |
| H | 49 | 29 | 24 | 23 | 24 |
| XH | 47 | 55 | 32 | $6\frac{1}{2}$ | $6\frac{1}{2}$ |
| X | 50 | 58 | 24 | 8 | 10 |
| XO | 49 | 37 | 37 | 10 | 16 |

# APPENDIX 5

## Results of the studies on wood density

| Season | 1966/67 | 1965/66 | 1964/65 | 1963/64 |
|---|---|---|---|---|
| Ridge Site | | | | |
| Mean density | | | | |
| H | 0.45 | 0.41 | 0.39 | 0.42 |
| X | 0.42 | 0.37 | 0.38 | 0.38 |
| E | 0.44 | 0.44 | 0.40 | 0.42 |
| Maximum density | | | | |
| H | 0.94 | 0.92 | 0.80 | 0.80 |
| X | 0.85 | 0.86 | 0.80 | 0.78 |
| E | 0.78 | 0.83 | 0.81 | 0.74 |
| Minimum density | | | | |
| H | 0.37 | 0.34 | 0.34 | 0.32 |
| X | 0.27 | 0.26 | 0.26 | 0.28 |
| E | 0.25 | 0.22 | 0.22 | 0.25 |
| % over 0.44 | | | | |
| H | 61 | 44 | 46 | 57 |
| X | 42 | 29 | 20 | 48 |
| E | 55 | 44 | 41 | 45 |
| % over 0.55 | | | | |
| H | 34 | 26 | 16 | 26 |
| X | 34 | 16 | 23 | 24 |
| E | 41 | 33 | 35 | 38 |
| % over 0.68 | | | | |
| H | 25 | 19 | 8 | 11 |
| X | 22 | 12 | 10 | 14 |
| E | 26 | 26 | 21 | 15 |

| Season | 1966/67 | 1965/66 | 1964/65 | 1963/64 |
|---|---|---|---|---|
| Swamp Site | | | | |
| Mean density | | | | |
| H | 0.42 | 0.44 | 0.43 | 0.44 |
| X | 0.45 | 0.43 | 0.44 | 0.43 |
| E | 0.38 | 0.39 | 0.36 | 0.36 |
| Maximum density | | | | |
| H | 0.70 | 0.79 | 0.64 | 0.70 |
| X | 0.81 | 0.83 | 0.79 | 0.79 |
| E | 0.75 | 0.79 | 0.75 | 0.70 |
| Minimum density | | | | |
| H | 0.32 | 0.33 | 0.32 | 0.33 |
| X | 0.31 | 0.29 | 0.28 | 0.28 |
| E | 0.24 | 0.23 | 0.22 | 0.24 |
| % over 0.44 | | | | |
| H | 52 | 42 | 37 | 54 |
| X | 55 | 39 | 39 | 42 |
| E | 48 | 39 | 42 | 39 |
| % over 0.55 | | | | |
| H | 15 | 19 | 11 | 18 |
| X | 31 | 24 | 26 | 31 |
| E | 41 | 32 | 30 | 25 |
| % over 0.68 | | | | |
| H | 7 | 9 | 3 | 6 |
| X | 19 | 22 | 12 | 19 |
| E | 18 | 18 | 10 | 11 |

# APPENDIX 6

## Details of the rainfall and temperatures recorded at Beerwah over the periods of the height and girth growth studies

(a) Height growth study.

| Month | | Mean monthly | | |
|---|---|---|---|---|
| | | Rainfall (in.) | Max. temp. ($^{o}F$) | Min. temp. ($^{o}F$) |
| 1965 | June | 5.1 | 68 | 54 |
| | July | 7.1 | 66 | 42 |
| | August | 3.8 | 70 | 45 |
| | September | 1.4 | 75 | 49 |
| | October | 3.6 | 75 | 51 |
| | November | 3.9 | 83 | 56 |
| | December | 12.0 | 82 | 61 |
| 1966 | January | 1.9 | 82 | 59 |
| | February | 5.3 | 84 | 64 |
| | March | 4.9 | 80 | 58 |
| | April | 4.9 | 76 | 54 |
| | May | 1.7 | 72 | 48 |
| | June | 5.3 | 66 | 43 |

(b) Girth growth study.

| Month | | Mean monthly Rainfall (in.) | Max. temp. ($^oF$) | Min. temp. ($^oF$ |
|---|---|---|---|---|
| 1966 | August | 4.6 | 89 | 50 |
| | September | 1.8 | 76 | 52 |
| | October | 3.7 | 77 | 54 |
| | November | 5.0 | 83 | 59 |
| | December | 4.7 | 82 | 63 |
| 1967 | January | 10.9 | 84 | 67 |
| | February | 4.3 | 83 | 66 |
| | March | 14.2 | 79 | 64 |
| | April | 3.4 | 77 | 60 |
| | May | 7.1 | 72 | 55 |
| | June | 20.1 | 70 | 57 |
| | July | 2.2 | 68 | 48 |
| | August | 1.0 | 70 | 48 |

# APPENDIX 7

<u>Details of the number of whorls produced at the 15 foot level by var. elliottii at various centres</u>

| Location | Age (yr) | No. stems examined | No. of stems with prescribed no. of whorls at 15 foot level 1 | 2 | 3 | 4 | 5 whor |
|---|---|---|---|---|---|---|---|
| Cathu 1 | 8 | 15 | 12 | 1 | 2 | - | - |
| Cathu 2 | 8 | 10 | 4 | 3 | 3 | - | - |
| Andersgrove | 20 | 15 | 3 | 7 | 5 | - | - |
| Farleigh | 17 | 14 | 4 | 6 | 4 | - | - |
| Mackay District | | | 23 | 17 | 14 | - | - |
| Bowenia 1 | 11 | 14 | 1 | 4 | 9 | - | - |
| Bowenia 2 | 17 | 15 | - | 3 | 11 | 1 | - |
| Rockhampton District | | 29 | 1 | 7 | 20 | 1 | - |
| Miriam Vale | 16 | 13 | - | 2 | 9 | 2 | - |
| Yandaran | 18 | 14 | - | 1 | 10 | 3 | - |
| Ferrymead | 15 | 5 | - | 4 | 1 | - | - |
| Stanton 1 | 18 | 15 | 1 | 8 | 5 | 1 | - |
| 2 | 18 | 14 | - | 3 | 7 | 4 | - |
| 3 | 18 | 14 | - | 4 | 9 | 1 | - |
| 4 | 17 | 15 | - | 7 | 8 | - | - |
| Bundaberg District | | 90 | 1 | 29 | 49 | 11 | - |
| Tuan 17W | 12 | 15 | 5 | 2 | 5 | 3 | - |
| 21E | 14 | 36 | - | 3 | 23 | 10 | - |
| 20E | 14 | 31 | - | 4 | 21 | 6 | - |
| 41E | 11 | 26 | - | 4 | 16 | 6 | - |
| Toolara 42 Ell | 14 | 20 | 1 | 5 | 10 | 4 | - |
| 1 Demp | 17 | 29 | 1 | 4 | 12 | 11 | 1 |
| M'boro/Gympie District | | 159 | 7 | 22 | 87 | 40 | 1 |
| Beerburrum 12 N | 13 | 15 | - | 5 | 5 | 4 | 1 |
| 13 N | 13 | 17 | - | 4 | 10 | 2 | 1 |
| 15 WH | 13 | 15 | - | - | 12 | 3 | - |
| 13 GC | 10 | 32 | - | 3 | 11 | 16 | 2 |
| 22 RC | 7 | 31 | - | 7 | 17 | 7 | - |
| Beerwah District | | 110 | - | 19 | 55 | 32 | 4 |