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# Silviculture in Extra-Tropical Regions

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Silvicultural studies of the forests of the Southern Hemisphere are of comparatively recent origin, and a long period must elapse before forestry practice can be based on accumulated traditional knowledge. In the absence of empirical data collected in the course of silvicultural operations extending over several rotations, recent developments in many fields of science can be summoned to the aid of the forester, but the path of those who seek to interpret and apply the research work and theories of bio-chemists, ecologists, plant physiologists and pedologists to the forest crop, is strewn with pitfalls. In Australia to-day foresters are striving to gain a proper appreciation of local conditions, and, with the help of the basic sciences, to adapt and use the technique which has been developed in European countries. In the brief compass of this paper an attempt is made to indicate the trend of silvicultural practice and thought in extra-tropical regions, with particular reference to forestry operations which have been carried out on a considerable scale in Western Australia during the past decade.

The term "extra-tropical" appears to be used by botanists to refer particularly to the temperate zone of the Southern Hemisphere, and, in the absence of any standard definition, it is used in this sense in this paper. In comparison with similar latitudes in the Northern Hemisphere, the land masses of the temperate zone of the Southern Hemisphere are of very limited extent and are not linked with the polar regions, so that conditions of extreme cold are restricted to relatively few high mountain areas. The outstanding difference botanically between the temperate zones of the two hemispheres is the absence of extensive coniferous forests from the Southern Hemisphere and the general paucity of well-wooded regions.

Within the extra-tropical regions of the Southern Hemisphere the forests of Australia are possibly the most distinctive and important. These forests, which are dominated by the genus Eucalyptus, are essentially sclerophyllous in character. Large areas of merchantable forest occur in regions of high winter and low summer rainfall, but the essential characteristics of the Eucalypt forest persist throughout all types from the savannah woodlands of the semi-arid interior to the temperate rain forests of certain coastal areas, and extend also to the forests of the mountain regions of the South-East of the continent, where frost-resisting types occur at elevations of 4,000 feet and upwards.

There are few, if any, virgin forests in extra-tropical regions which have not been affected in some manner by the march of civilisation. Under primeval conditions, the forest as a biotic community may attain a condition of dynamic equilibrium, but extraneous factors which disturb the delicately balanced relations within the forest community or between bird, animal, and plant life may lead to surprisingly rapid succession acceleration, and this means usually the rapid deterioration of the tree crop. Fire is unquestionably the most important single factor leading to forest deterioration, but it is by no means the only factor, and in all silvicultural studies of indigenous forests it is essential that alterations which may be taking place in the plant community or the habitat shall be recognised and the probable rate of change appreciated.

In Australia, as in most new countries, the first delineation of the broad forest zones has been the work of botanists. This has been followed by attempts to assess merchantable timber values in connection with exploitation projects. In some instances, timber assessment has been carried out intensively over large areas, as, for example, in Western Australia, where, during the years 1918 to 1921, over 3 million acres were assessed with a view to the demarcation of State Forest boundaries and to provide a basis for management and sustained yield calculations. Work of this nature enables forest regions to be recognised and divided into broad quality classes, but it is found in practice that these classes are not sufficiently homogeneous for use in connection with detailed treatment and growth studies.

Measurement of site quality on the basis of the numerous factors influencing the growth of the tree crop is confusing and difficult, because of the complicated relationship of these various factors. In regional survey work in Western Australian forests, site quality is determined in terms of productive capacity of the principal timber species of each region. In the preliminary investigation to determine the nature of the problem intensive studies of a number of areas of virgin and cut-over forest have been made, which include the delineation of unit soil types on a profile basis, vegetative types, and a complete tree assessment.

These studies have shown that, in the Eucalypt forests of the South-West of Western Australia, the mean height of dominant trees may be accepted as a measure of site quality based on productive capacity. In virgin Jarrah (*Eucalyptus marginata*) forest differences of 4 to 6 feet in mean height have been found sufficiently significant and constant for this purpose. The problem becomes more involved in forest areas which have been considerably changed by heavy fires or intensive logging operations, and to delineate quality sites in such areas soil and vegetative types must be used in association with height figures obtained from such mature trees as remain. In marginal forest types the larger problem of general land use, involving both Forestry and Agriculture, may justify even more intensive work on these lines than in high-quality forest.

A great deal of useful information of immediate practical value in connection with regeneration and management problems may emerge from such intensive regional survey work, in addition to the delineation of forest types. An analysis of data accumulated in this way has provided the first reliable estimate of the cumulative effect of repeated burning on the Jarrah forest. On many types the damage to mature and semi-mature trees is so serious that 30 to 40 per cent. of the timber volume is affected in some way, and 25 to 30 per cent. of the trees show severe fire scars on the stem. Large areas of sapling growth which have developed unaided in cut-over forest have been ruined, with the result that the cost of regeneration operations is greatly increased when the forest is brought ultimately under intensive management.

Possibly the most serious outcome of frequent burning is the deterioration of the forest canopy. In Eucalypt forest types, which become reclothed with green leaves a few months after burning, the cumulative effect of repeated fires is not apparent to the casual observer, but the forest canopy is opened more and more by each fire stimulating a dense growth of woody scrub, and leaving the trees with a gaunt framework supporting only a few leaves. Already high forest conditions in many parts of Australia show regression almost to the stage of savannah woodlands, and, unless fire protection measures are introduced in the near future, either the underwood species will take possession of the site or the forests will revert to heath formations of low sclerophyllous scrub.

The factors influencing the establishment of regeneration in Eucalypt forests have been the subject of some experimentation and considerable conjecture in Australia and it is only recently that a start has been made to study the problem in the light of the separate factors: light, moisture, heat, plant nutrients, soil microfauna and flora, and the even more subtle factors such as soil tilth and crumb structure. In cut-over Eucalypt forests regeneration operations based on some further selective cutting or ringbarking followed by fire protection have met generally with a considerable measure of success. Within one or two years adequate regeneration becomes established either from seed or from advance growth in the form of coppice from woody root stocks already established on the forest floor. Contrary to oft-expressed popular belief, Eucalypt seedlings in the indigenous forest develop from seed which has fallen since the last fire and not from seed stored under the ground, although fire is frequently responsible for providing a satisfactory seed bed and for causing a general fall of the seed held on the trees in woody seed vessels. These regeneration methods have been accepted as entirely satisfactory and little or no thought has been given to possible damage to the site which may be caused by a severe "final burn," or the sudden break in the canopy resulting from wholesale ringbarking.

In Western Australia a study is being made also of the effect of such regeneration measures on the form of the young saplings. It is thought that early forking may be due in part to this exposure and that, in many forest types, regrowth may develop more satisfactorily to the small pole stage if a sparse cover of high forest is retained. The over-emphasis placed during recent years on soil moisture as a limiting factor in regeneration and growth problems has tended to obscure the study of many issues such as those referred to above.

The frequency of general seed years varies greatly in different Eucalypts. Many species produce a plentiful crop of seed every year. This is usually the case in fire-tender species, such as Mallet (*Eucalyptus astringens*), and is frequently associated with an absence of ligno-tubers in the seedling stage and weak coppicing powers. Other species produce a plentiful crop of seed simultaneously over a considerable region at intervals of several years. In the case of Karri (*Eucalyptus diversicolor*), there is usually an interval of three years between general seed years, and, in the absence of ground fires, the seed may remain twelve to twenty-four months on the trees after ripening. In the Tuart (*Eucalyptus gomphocephala*) forest, the usual interval between general seed years is seven, and this species provides an exception to the general rule in that natural regeneration is not readily secured. It would appear that, in the Tuart forest, the site has suffered considerably through a combination of annual burning and constant grazing since the advent of white settlement. The Tuart seedlings, although germinating in great abundance, die off in early summer shortly after passing out of the cotyledonary stage, except on ash beds which have resulted from the burning of logs or large heaps of lop and top. The successful development of seedlings on such ash beds and the low standard of fertility of the sands on which this species grows suggest the importance of plant nutrients or factors other than heat, light or moisture as the reason for the general failure of regeneration. The distribution of semi-mature Tuart as groups of piles scattered through the forest, however, bears witness to the fact that regeneration 80 to 100 years ago had the same characteristics, namely, ease of establishment on ash beds and almost total failure elsewhere.

Jarrah and the associated species Marri (*E. calophylla*) provide an outstanding example of large-scale regeneration operations depending on seedling coppice instead of direct seeding. Both species show a marked development of ligno-tubers in the seedling stage even before the cotyledons disappear, and, under certain conditions, these ligno-tubers will swell to considerable dimensions and continue to send up coppice shoots for a long period of years. It is this characteristic of the species which enables Jarrah regeneration in the form of thickets of low coppice to become widely established in virgin stands of Jarrah in which the canopy has been opened up by frequent fires. Over very large areas this seedling coppice has proved capable of rapid development into the sapling stage following further opening of the canopy and protection from fire. An interesting exception is provided by one type of Jarrah forest, which occurs on a soil type of yellow sand of varying depth over laterite. In this type, frequent burning and logging operations have resulted in a general rise in the water table. This has been followed by an invasion of the ground vegetation by a woody scrub (*Agonis parviceps*), which is capable also of vigorous coppicing from a woody root stock. On this site seedding Jarrah does not live far beyond the cotyledonary stage, and it is necessary to experiment with various methods of artificial establishment, while protection from fire is being accorded the forests as a first step towards the restoration of forest cover.

In Australia there has been relatively little statistical work carried out on the economics of thinning in second-growth indigenous forests, although evidence tends to show that much faster growth is maintained by individual trees in a stand which have enjoyed more than average crown space over a period of years. In considering the thinning problem in particular relation to Eucalypts, there are several characteristics shared by the great majority of members of this genus which are of importance. While passing through the sapling and pole stages, the lower branches are shed, and from this latter stage onwards, the mature form of crown is developed and the main branches become persistent. The leaves tend to be carried on the ends of the branches, which are comparatively flexible, allowing considerable windsway, thus leading to the rubbing off of the fragile naked buds by branches of adjacent trees. It may be for this reason that, whether growing in crowded or open stands, eucalypt crowns do not interlace freely although they may come into close contact and to some extent overlap.

There is a considerable difference in the rate at which Eucalypts, when growing on satisfactory sites and afforded protection from fire, thin themselves. In Karri, for example, dominants in a young stand suffer far less from competition with their fellows than they do in stands of Jarrah and Mallet of a similar age or size. The Murray River Redgum (*Eucalyptus rostrata*) provides an interesting example at the other end of the scale. Regeneration, which comes up prolifically following periodic flooding of the river flats on which this species grows, tends to develop to the small sapling stage and stagnate. As site quality improves, the height growth at which the first intense competition develops increases, and the capacity of certain members of the stand to establish dominance is somewhat greater, but without artificial aid, even on the better sites, the struggle is so severe that the rate of growth of dominant trees of an unthinned stand is only a fraction of the increment of trees of the same age in a stand which has been thinned.

Measurements of individual trees in a number of forest regions throughout Australia have indicated that the ratio of diameter to crown spread may prove reasonably constant for many Eucalypt species within fairly wide limits of age and site quality. If such ratios can be established by systematic measurement of sapling, pole and pile trees which are regarded as having well balanced normal crowns, the figures will prove of considerable value as guides in thinning practice, when used in conjunction with girth increment figures obtainable from measurement plots which have been established for some years now in many of the important merchantable forests.

Whether the acceleration in the rate of growth and the favouring of the most desirable forms and species in a mixed stand, which can be secured by thinning, will justify the expenditure on the operation is a problem for each forest type, which can only be answered by adequate series of sample plots, the establishment of which is a work long overdue in most forest regions in Australia. Evidence is accumulating to show that in vigorous coppicing species crown thinning to assist selected dominants is the soundest practice and that, despite the comparatively open nature of the canopy in a Eucalypt forest, the maintenance of maximum cover by the retention of sub-dominants and dominated members of the principal crop and of second-story species, is of considerable importance. Thinning problems are discussed further in subsequent sections of this paper, which deal more particularly with exotic plantations.

In countries of the Southern Hemisphere, with Western Australia possibly as the only important exception, much more attention and money have been devoted to afforestation with introduced trees than to the protection, regeneration and tending of indigenous forests. Softwoods have been planted on a very extensive scale, under a great variety of soil and climatic conditions, and with varying degrees of success. In South Africa large areas have been planted also with Eucalypts and Wattles.

In view of the capital involved and the period over which many of these planting programmes have extended, remarkably few scientific papers have been published dealing with the silvicultural factors on which the success of the plantations depends. A paper of outstanding interest published recently is that by Dr. I. J. Craib, entitled "The Place of Thinning in Wattle Silviculture and its Bearing on the Management of Exotic Conifers." (2) It is interesting to note that, in working on problems in connection with the cultivation of Acacia mollissima, Dr. Craib has been dealing with a species which in its natural habitat is essentially an underwood tree, and which does not thin itself readily, a characteristic shared with many other Australian members of the Acacia family.

In discussing silvicultural problems in relation to plantation work, it should be borne constantly in mind that a large percentage of plantations are established on very indifferent sites. This unfortunate fact may be due in some cases to ignorance or errors of judgment, but where every care is exercised it is a difficult matter to assess the potential value of a site for the establishment of plantations of exotic trees, and, with few exceptions, the forester is offered the choice of sites which have been refused or found of small value for every other agricultural and pastoral pursuit. A very useful paper might be prepared on the questionable economy of this policy, and it is probable that a survey of the losses which various parts of the Empire have sustained through attempting to grow trees on poor soils would demonstrate conclusively the wisdom of restricting planting operations to good quality sites, even where these have to be repurchased.

On good quality sites in extra-tropical regions, it is seldom that the establishment of coniferous plantations presents serious difficulties and when such plantations have formed canopy the possession of the site is never in doubt. Within reasonable limits on such sites, methods of tending and management may be governed largely by considerations of economic utilisation without exposing the plantation or the site to any serious risk of damage or deterioration. It is on less favourable sites, which in Australia represent such a large proportion of the planted areas that the difficult silvicultural problems arise, and the outstanding impression to be gained from a general inspection of Australian softwood plantations is the extent to which the same species may show widely varying responses to similar treatment on different sites, and, in the opinion of the writer, too much emphasis cannot be given to the need for recognition of site differences before attempting to draw conclusions or decide cultural treatments.

In Western Australia pine planting has been restricted to a programme of 1,000 acres per annum, which is estimated to be sufficient to supply internal requirements at the end of the first rotation, but even with this small programme great difficulty has been experienced in finding suitable areas. Rainfall considerations restrict plantation sites to the South-West of the State, which consists of a very ancient land mass with soils derived principally from granites characterised by a high silica content. True primary soils are rare, and throughout the low ranges (800ft.-1,800ft.) carrying the main Eucalypt forests the most important geological structure is the Laterite, which, over large areas, takes the form of a massive concretionary capping on which the best of the Jarrah forest has developed. The outstanding physical characteristics of Western Australian soils are their extreme sandiness and coarseness, the preponderance of lateritic gravel throughout the profiles, and the imperfect development of the "B" horizon.

In studying the results of plantations already established, and as a basis for a further planting programme, intensive soil surveys, based on the complete soil profile, have been carried out. As a result of this work, there has been found to exist a striking correlation between pine growth and soil type, differences in growth being encountered on the boundaries of practically every soil type. On the other hand, a careful classification of the numerous indigenous plants occurring on each type has not resulted in the detection of reliable plant indicators. The extreme patchiness and general poverty of the soils dealt with may be explained by regarding them as skeletal soils, either as podsols or fossil laterites lacking the usual association with the parent rock for constant renewal of plant nutrients and colloidal material.

Associated with these unattractive soil conditions are two further major problems in the establishment of softwood plantations. The first is the paucity or absence of the usual soil microflora associated with pine roots, rendering the artificial infection of nursery sites with mycorrhizal fungi essential, and the second is the poor distribution of the rainfall. The average annual precipitation throughout the region referred to varies from 30 inches to 47.5 inches and 85 per cent. falls in the winter months, and the balance in light showers or sudden thunderstorms during the hot months from December to April inclusive.

To meet these conditions it has been necessary to depart from many of the conventional methods followed in planting practice in Australia, which consist essentially in clear felling the indigenous forest, burning and planting among the debris of logs and branchwood, and to develop a new husbandry of pine planting which includes various combinations of cultivation, and site improvement by advance crops and manurial treatment, nurse crops and regulated grazing on lines more akin to methods followed in certain European countries, notably Denmark, Holland and Belgium.

With the artificial infection with mycorrhizal fungi (Rhizopogon sp. and Boletus sp.) of the soils of nursery sites, by applying a light dressing of soil taken from under a well-established pine stand, the most serious of our nursery problems passed. Constant experiments are in progress to determine the most satisfactory manurial treatment for each soil type, but on the whole little difficulty is experienced in raising without transplanting a satisfactory class of planting stock (1 + 0) or (2 + 0), in nurseries which are neither shaded nor watered throughout the long dry summer.

On the coastal plain between Perth and Bunbury establishment in the plantation and survival of pines during the first and second summer following planting is dependent on elimination of scrub competition from the indigenous woody undergrowth which, if not checked, develops very strongly following the felling of the tree crop. The practice is to plough to a depth of eight inches below the surface to prevent coppicing of the undergrowth species, and to ensure that any recolonisation must be from seed, which is a comparatively slow process. On areas where the preparation of the planting site for ploughing, following clear felling of the Eucalypts, may be expected to exceed £2 or £3 per acre, attention is being given to a reversal of the general procedure, with a view to leaving the high cover formed by a sparse stocking of large Eucalypts, and the eradication of the scrub underneath by thorough cultivation. Evidence is accumulating in plantations in the Darling Ranges which have been established on areas following a burn, and without cultivation, that provided the pine crop can struggle through to a stage when it begins to form canopy and suppress the woody undergrowth, greatly increased development then takes place. Similarly growth can be stimulated by scrub eradication and continued cultivation between the rows of pines, a practice whereby cultivation on agricultural lines takes the place of the normal soil cover of silviculture.

From time to time references are noted in forestry publications to the impracticability of ploughing either before planting or between the planted rows, usually on the grounds of cost, although the possibility of root injury is sometimes mentioned. It may be questioned whether the latter is a practical issue worth considering, but the former would certainly appear to depend on securing the right appliances for the work. In Australia sturdily built two-disc reversible stump-jump ploughs are available, which can be worked by two horses between rows of pines eight feet apart, even on roughly-cleared land still carrying odd large stumps and logs, at a cost of less than fifteen shillings per acre, which represents only a small percentage addition to the capital cost of establishment.

In conjunction with mechanical analyses necessary as a basis for soil surveys of plantation areas, a considerable number of partial chemical analyses have been made, and some typical results are given in the table on the following page. It has not proved possible to associate the better growth of pines on certain sites with any particular or general increase in the elements examined in the course of this chemical work, nor to use the figures as a guide to the responses which may be anticipated from the use of specific fertilisers. The one important conclusion which has emerged from a study of numerous analyses is the general poverty of many important Western Australian forest soils in respect to all the essential plant nutrients examined.

## ANALYSES OF WESTERN AUSTRALIAN FOREST SOILS.

| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) |
|---|---|---|---|---|---|---|---|---|---|---|
| Locality ... ... | Gnangara. W.A. | Ludlow. W.A. | Bedfordale. W.A. | Pardelup. W.A. | Mundaring. W.A. | Tallanalla. W.A. | Pemberton. W.A. | Dartmoor, W.A. | Blackheath, Surrey, England. | Teynham, Kent, England. |
| Soil Type ... ... | Grey sand | Yellow sand | Yellow-brown gravelly sand | Yellow gravelly sand | Chocolate brown loam | Yellow gravelly sand | Red sandy loam | Dark brown sand | | |
| Indigenous Trees ... | E. Todtiana Banksia spp. | E. gomphocephala | E. marginata | E. calophylla E. marginata | E. redunca v. elata | E. patens | E. diversicolor | E. foecunda v. loxophleba | | |
| Horizon ... ... | Ao | Ao | Ao | Ao | A | Ao | Ao | Ao | | |
| Depth ... ... | 0"—12" | 0"—4" | 0"—4" | 0"—15" | 0"—10" | 0"—4" | 0"—6" | 1"—5" | | |
| Mechanical Analysis: | | | | | | | | | | |
| Stones and Gravel | — | — | 43·0 | 37·6 | — | 45·0 | 32·0 | — | — | — |
| Fine Earth ... | 100·0 | 100·0 | 57·0 | 62·4 | 100·0 | 55·0 | 68·0 | — | — | — |
| Coarse Sand ... | 96·5 | 90·9 | 36·9 | 64·1 | 18·3 | 37·8 | 17·6 | 65·3 | 65·9 | 2·1 |
| Fine Sand ... | 2·2 | 6·0 | 37·6 | 29·0 | 34·0 | 31·0 | 37·3 | 21·3 | 23·7 | 39·1 |
| Silt ... ... | 0·0 | — | 5·8 | 2·8 | 14·3 | 10·4 | 8·1 | 2·3 | 4·4 | 34·7 |
| Clay ... ... | — | — | 11·4 | 4·5 | 22·9 | 12·6 | 25·1 | 10·3 | 0·9 | 11·7 |
| pH ... ... | 5·4 | 6·2 | 6·0 | 6·2 | 5·9 | 5·6 | 6·3 | 6·4 | — | — |
| Chemical Analysis: | | | | | | | | | | |
| Water soluble Nitrogen ... ... | 0·02 | 0·08 | 0·085 | 0·06 | 0·158 | 0·167 | 0·204 | 0·023 | 0·033 | 0·198 |
| Soluble in con. HCl: | | | | | | | | | | |
| CaO ... ... | *trace | trace | 0·130 | trace | 0·897 | 0·292 | 0·412 | 0·070 | 0·050 | 0·41 |
| $K_2O$ ... ... | ” | 0·01 | 0·019 | 0·01 | 0·166 | 0·058 | 0·032 | 0·140 | 0·025 | 0·44 |
| $P_2O_5$ ... ... | ” | 0·02 | 0·016 | 0·02 | 0·060 | 0·044 | 0·035 | 0·047 | 0·081 | 0·161 |
| Depth of A Horizon | Up to 60 feet | Up to 15 feet | 15 inches | 30 inches | 10 inches | 15 inches | 18 inches | 30 inches | — | — |

* Trace indicates less than 0·00.

NOTE.—The soil types listed in columns (1) and (2) are typical of coastal sands on which Pinus pinaster is being successfully established. Columns (3) and (4) show typical soils of the extensive Jarrah habitat. Columns (5) and (6) are typical of small pockets of better soil which occur scattered through the Jarrah forest region. Column (7) is a typical Karri soil. Column (8) is a typical Western Australian Wheat Belt soil (rainfall 12" — 14" per annum). Columns (9) and (10) are extracts from "The Soil," by Sir A. D. Hall, (5) and are included for purposes of comparison. With regard to No. (9), Hall describes this as "a barren heath clothed only with heather and bracken," but the analysis compares favourably with certain Western Australian forest soils. No. (10) Hall describes as "Fertile alluvial soil, excellent for wheat, potato, and fruit growing in the climate of the East and South of England."

In Agriculture the symptoms and treatment of nitrogen, phosphorus and potassium starvation are well known and described in detail in most textbooks on Agricultural Science, but the application of this work to the forest crop has not received sufficient attention to provide reliable guides for the silviculturalist who is called upon to deal with growth problems arising from soil nutrient deficiencies. The recent publication by Harold L. Mitchell setting out the results of comprehensive series of Pot Culture Tests of Forest Soil Fertility carried out in the Black Rock Forest, New York, U.S.A.,(6) gives many useful leads to forest soil workers in all parts of the world. In this work it is suggested that the needle colour of pines as an index to nutrient conditions follows very closely the recognised colour responses of agricultural crops. With yellow-green or yellowish colour of needles he associates nitrogen deficiency; with a purplish colour of the lower needles a phosphorus deficiency; with a stunted growth and chlorosis of the upper needles, as evidenced by a whitish colour, a potassium or calcium deficiency, although, as Mitchell points out, deficiencies of several other nutrients, notably iron, cause chlorosis. These colour indications are in general accord with Swedish observations noted by Wahlgren,(8) who extends the list by associating a dull green needle colour with lack of potassium and light orange-yellow needle tips with magnesium deficiency. In Western Australia phosphorus deficiency appears to be indicated in young Pinus pinaster by short needles of a peculiar translucent bronze colour, particularly on the lower whorls.

It is only in very exceptional cases that macroscopic features such as needle colour or chemical analyses of soils, needles or other portions of the tree will give a reliable lead to specific soil deficiencies and, in the present state of our knowledge, replicated field experiments provide the only basis on which the economy of the general use of a fertiliser in plantation practice can be judged. It is necessary, even when dealing with the same species of pine, that the reaction of the pine crop to the fertiliser be tested for each main soil type. For example, on deep coastal sands in the vicinity of Perth, which chemical analyses indicate to be very deficient in essential plant nutrients (see Table I., col. 1, page 8), applications of one cwt. of superphosphate to the acre have given very striking results with P. pinaster, both when used at time of planting and also when applied several years after planting, to young pines of very stunted appearance. In both instances improved growth resulting from a single dressing has been maintained for periods of five years, which is as far as the observations extend at present. On P. pinaster plantations established on similar coastal sand-plain country 70 miles further south, and on plantations in the Darling Ranges—both in the same climatic zone—one cwt. dressings of superphosphate have given no results, and four cwts. has had only a slight effect. In one instance eight cwts. per acre were necessary to secure any response. Results with blood and bone fertiliser have been even more contradictory. On coastal sands of the Perth district superphosphate and blood and bone give equally good results when applied to P. pinaster at time of planting. On coastal sands of the Busselton district, 140 miles south, where climatic conditions are very much the same, the application of blood and bone to young P. pinaster under similar conditions is definitely harmful. These contradictory results have been checked by replicated experiments extending over three planting seasons.

Numerous investigations of unhealthy stands of P. radiata throughout Australia have failed to associate the condition of the pines with any definite causative factor or to transmit infection to healthy individuals. It is possible that the poor growth is due to metabolic disturbances caused by irregularities in nutrient uptake, and there are grounds for regarding the condition known as "curly needle" or "needle fusion" as a soil deficiency disease. For some unexplained reason this condition is seldom seen in Western Australian plantations however poor the growth of P. radiata. It is interesting to note that a condition of Tung trees (*Aleurites* Fordii) known as bronzing or rosetting, a withering of the foliage which subsequently kills the trees, has been traced to soil deficiency and has been overcome by the use of a small amount of zinc sulphate.

In all these matters silviculturists will continue to grope in the dark until silvicultural research stations are established and staffed with soil chemists, biochemists, and other scientific workers whose specialised training and laboratory controlled experiments enable them to advise the forester on many problems which, unaided, he can only guess at and laboriously follow up by costly and tedious empirical methods.

In plantation practice initial spacing, tending and thinning are phases of the problem of securing the maximum return consistent with the objects of management, and it is necessary that each be considered in relation to the site and species concerned. Experience throughout Australia suggests that the young plantations do not show optimum development while growing in competition with woody undergrowth. Contrary to accepted practice, it would appear that the presence of Eucalypt coppice growth may prove an advantage in young plantations in helping to form canopy, provided it is not allowed sufficient start to overtop the young pines. All observations tend to show the prime importance of establishing and maintaining tree canopy and in this respect Western Australian experience agrees with Toumey's statement[9] that "where the soil is too poor to furnish the necessary material and water to meet the new activities of the tree, a thinning . . . . may not result in increased growth of the plant, but there may be retarded growth because the removal of part of the forest cover causes the soil conditions to become less favourable."

For a number of reasons, much closer initial espacement than has been adopted in Australia during recent years may be advisable. With a view to reducing establishment costs, Pinus radiata has been planted as wide as 12 feet by 12 feet. Even on good soils, where this species is capable of taking possession of the site with such wide planting, it is contended that 300 stems per acre may be insufficient to allow the selection of good forms for the final crop, at least until much more attention is paid to strain selection. With certain strains of Pinus pinaster an initial spacing of 6 feet by 6 feet (1,210 per acre) may prove necessary to ensure that the final crop shall consist of good form trees. In Western Australia, after careful consideration of all factors, 8 feet by 8 feet for fast growing and 7 feet by 7 feet for slower growing species has been adopted as maximum spacing distance on good quality sites. On poorer sites, these espacements are reduced by at least one foot each way.

Wider initial espacement may be justified on second-quality sites if suppression of the scrub by repeated cultivation is practicable. The advantage accruing to the pine crop by this practice cannot be interpreted wholly in terms of extra soil moisture available, as is frequently suggested. Many influences are at work in the soil in consequence of any changed conditions arising from cultivating, fertilising, or changes in canopy density, and may affect the availability of any or all plant nutrients. Nitrogen content is increased by cultivation and Richardson and Gurney,[10] of the Waite Institute, Adelaide, have shown that "the accumulation by biological processes of Nitrate-Nitrogen to a high level in poor fallow soils is an important factor in producing superior yields of wheat on such soils. As available Nitrogen is no longer a limiting factor of such soils, full advantage can be taken by the crop of the soluble phosphates applied to the soil and of the rains which fall during the growing period." In addition, there is the effect of the repeated cultivation on the physical properties of the soil affecting soil tilth and crumb structure, and the nature of the soil solution as affected by the summer activity of micro-organisms. For similar reasons, the value of break trees as indicators of the results which may be expected to follow thinning are of doubtful value, and any data obtained from these trees must be used with extreme caution.

Sample plot work has not proceeded to a sufficient stage in Western Australian plantations for complete thinning schedules to be prepared for any species or site, but results to date indicate that, despite a climate with long, dry summers, the poorer the site and the slower growing the species, the closer the initial espacement should be, and the greater the caution necessary in thinning practice. It would appear that, in examining a stand to determine the need for thinning, as much attention should be paid to the condition of the forest floor as to the state of the crowns, and that, if a woody undergrowth persists under the stand, no benefit, and possibly some damage to the tree crop, may result from thinning operations. The acceptance of the old maxim concisely expressed by Craib[2] that "thinning should anticipate suppression and not relieve it," is believed to be the correct angle of approach to the thinning problem, but the need for thinning cannot be deduced solely from tabulation of numbers of trees per acre and growth figures, or interpreted in terms of absolute crown vigor, without a careful study of all factors of the locality for each site.

While the practising forester may speculate on these many issues and be guided by the advice of research workers in highly specialised branches of science, there are many investigations and experiments he can carry out in the course of his work, but if faulty conclusions are to be avoided, some training in modern methods of field experimentation is necessary. Nearly all forestry experiments are complex, and every treatment, even if it is proposed to test one factor only, may be influenced by numerous other factors which are difficult to control over a series of plots. Replication serves to increase the precision of the experimental comparisons and to provide an estimate of error. The general adoption of replicated plots in connection with silvicultural experiments will do much to eliminate faulty observations and deductions which have marred much past work in this field.

Certain views expressed by the writer are based on unpublished work carried out by research officers of the Forest Service of Western Australia working under the direction of Mr. T. N. Stoate, M.Sc., Dip. For., Senior Assistant Conservator. It is hoped that, in the near future, a number of these investigations will reach a stage which will justify publication of results in bulletin form, thus making available the complete data.

A perusal of this paper may suggest that many more detailed investigations have been carried out in connection with pine plantation establishment and growth than in connection with the much more extensive silvicultural operations proceeding in indigenous forests. This is due in part to the comparative ease with which natural regeneration is secured as a first stage in reforestation work in the more important forest regions, and in part to the quicker results obtainable in pine establishment experiments. The major problem of large-scale forestry work in the Eucalypt forests of Australia in their present stage of development is fire control, but the considerable advance which has been made in solving this problem during the past decade is outside the scope of this paper, although having a considerable bearing on silvicultural methods. Experience is demonstrating also that many research projects initiated with the object of improving technique in exotic plantations are throwing new light on general silvicultural practice, and are assisting to a better understanding of problems of regeneration and growth of native species.

## SUMMARY.

Silvicultural studies in the Southern Hemisphere are of comparatively recent origin, and the paper is written with a view to setting out the trend of silvicultural practice and thought in extra-tropical regions, with particular reference to forestry operations and investigations carried out in Western Australia during the past decade. The term "extra-tropical" is accepted as referring particularly to the temperate zone of the Southern Hemisphere, in which the Eucalypt forests of Australia are the most distinctive and important. In common with all extra-tropical forests, these have suffered from the march of civilisation and, as a result of interference with the biotic communities of the primeval forests, in many regions high forest conditions are rapidly deteriorating. Fire is the greatest single factor leading to succession acceleration, and in the indigenous forests of Australia it is the most serious and difficult problem in all reforestation work.

The need for regional survey work as a basis for all intensive management and experimentation is stressed, and factors influencing regeneration methods and tending and thinning operations in second growth Eucalypt forests are discussed.

In the Southern Hemisphere much more attention has been devoted to the planting of exotics than to the care and regeneration of indigenous forests. On good quality sites in extra-tropical regions it is seldom that the establishment of coniferous plantations presents serious difficulties, and tending and thinning practice can be governed largely by considerations of economic utilisation without exposing the stand or the site to serious risk of damage or deterioration.

It is on poor sites, which in Australia represent a very large proportion of planted areas, that difficult silvicultural problems arise. The survey of planting sites on a basis of complete soil profile is indicated as the only sound method of approach to establishment, growth and cultural problems. These matters are discussed at some length in the light of research work proceeding in Western Australian plantations, where difficult climatic and soil conditions have led to departure from conventional methods, and the increasing use of cultivation, fertilisers and other means of soil improvement. Early establishment and maintenance of tree canopy, particularly on poor sites carrying sclerophyllous scrub species, is regarded as a matter of first importance having great influence on all silvicultural measures, particularly thinning.

The difficulty, in the present state of our knowledge, of interpreting chemical analyses of soils, pine needles, etc., in relation to problems arising from general or specific soil deficiencies in plant nutrients is discussed. In these and other problems referred to silviculturalists will continue to grope in the dark until silvicultural research stations are established and staffed with scientific workers with specialised training, who may assist the forester to apply recent developments in many fields of science to his particular problems.

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## COMMON AND BOTANICAL NAMES OF CERTAIN EUCALYPTS REFERRED TO.

Jarrah (*Eucalyptus marginata*).
Karri (*Eucalyptus diversicolor*).
Tuart (*Eucalyptus gomphocephala*).
Mallet (*Eucalyptus astringens*).
Marri (*Eucalyptus calophylla*).
Wandoo (*Eucalyptus redunca* v. *elata*).
Blackbutt (*Eucalyptus patens*).
York Gum (*Eucalyptus foecunda* v. *loxophleba*).
Coastal Blackbutt (*Eucalyptus Todtiana*).
Murray River Redgum (*Eucalyptus rostrata*).

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