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SILVICULTURE

A Short Course on the Principles of Silviculture for Trainees of the W.A. Forests Department

PREFACE

This course was written with the intention of providing an elementary text on the fundamentals of Silviculture both for Trainees and for those junior Field Staff Officers interested in broadening their general forestry education.

The course does not provide detailed descriptions of the silvicultural practices currently carried out in the forests of Western Australia, as this information is readily available in the form of various Departmental publications.

Particular emphasis is placed here upon discussion of the principles upon which current practices are based. These principles are basic to the practice of forestry itself and are essential background knowledge for every forester.

TABLE OF CONTENTS

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GENERAL INTRODUCTION TO SILVICULTURE

THE PLACE OF SILVICULTURE IN FORESTRY

Forestry as a whole is concerned with the management, protection and utilisation of forests. Its basic aim is to produce, conserve and protect forests so that future generations will always be assured of adequate forest resources.

There are several branches of forestry which work towards the fulfilment of this aim. For instance, Forest Protection is the branch of forestry concerned with the preservation of the forest against injuries such as fire and disease; Forest Management is the branch concerned with regulation and planning of timber-cutting so that future timber supplies are not depleted. Silviculture is a further branch of forestry, and is concerned with the replacement of cut-over forests by new forest crops and with the care of these new crops so that they will develop into fully productive forests.

A DEFINITION OF SILVICULTURE

The word "Silviculture" comes from two Latin words: silva meaning a "wood" or a forest and culture meaning "the growing of". Thus the word originally meant "the growing of forests".

Today we define silviculture more specifically. It is "the art and science of establishing, raising and tending a forest so that it will produce wood".

Silviculture is the backbone of nearly all forestry practice, and is a subject which must be studied thoroughly by the young forester.

THE PURPOSE OF SILVICULTURE

Most people realise that a forest is quite capable of growing wood and reproducing itself without the assistance of man. (The forests of Australia did so for thousands of years before the white man arrived.) The question might therefore be asked, "Why is silviculture necessary at all?"

There is a simple answer to this question. It is true that forests are capable of growing and reproducing by themselves but the end result is often not the most desirable from man's point of view. Man desires from the forest the maximum production per acre of usable wood, grown in the shortest time.

Under natural conditions the forest does not meet this requirement. There are a number of reasons why this is so. These are:

1. In the natural forest, trees which do not produce usable timber (called "unmerchantable" species) often flourish at the expense of trees that do produce usable timber. When this situation occurs, the forest is producing a lower volume per acre of usable timber than it is capable of producing. In these circumstances, silvicultural treatment is clearly required.

THE PURPOSE OF SILVICULTURE (continued)

2. The natural forest is often too densely or too sparsely stocked with trees. Both of these conditions have the effect of reducing the production of timber from the forest. With the too sparsely stocked forest, part of the forest area is not producing at all. With the over-stocked forest, the trees tend to stagnate through excessive competition for sunlight, nutrients and moisture - the result is smaller trees, slower growth and lower timber production per unit area.

3. The natural forest generally contains a high proportion of crooked, rotten and otherwise useless trees which are occupying valuable growing space. To ensure the maximum yield from the forest these must be removed and replaced by vigorous, healthy trees.

The above points explain the reasons why silviculture is necessary from man's point of view. But silviculture is also often necessary for the sake of the forest. Since the coming of the white man many changes have occurred in the forest. For instance:

(i) Large numbers of trees have been cut down which otherwise would still be standing.

(ii) There has been an increase in the severity of fires.

(iii) Large areas of forest have been cleared for agriculture.

(iv) Diseases and pests have been introduced from other parts of the world.

In many cases the forest has not been able to cope with these massive changes in its environment and it has reacted by showing either a marked deterioration, or a failure to regenerate. When this occurs, the forester must step in, and by the application of sound silviculture nurse the forest back to health and vigour.

THE STUDY OF SILVICULTURE

The study of silviculture is divided into two equally important parts.

The first is called the Foundations of Silviculture. This subject is concerned with the study of the nature of forests and forest trees - how they grow, how they reproduce and how they respond to changes in their environment. Chapters Two, Three and Four of this course deal with the Foundations of Silviculture.

The other part is called the Practice of Silviculture. This subject is concerned with the study of the ways in which silvicultural knowledge can be applied to particular forest crops, so that they will produce the desired products. Chapters Five, Six and Seven of this course deal with the Practice of Silviculture.

BACKGROUND READING

Since silviculture is concerned with the growing of large plants (trees), it is necessary that the student of silviculture has some background knowledge of general Botany and Forest Botany. Useful references are:

"Forestry in Western Australia" Chapters II and III.
Forests Department Bulletin No.63.

"Forest Botany" Course for Trainees of the W.A.Forests Department.

FURTHER READING IN SILVICULTURE

These notes are primarily intended as an introduction to the principles and practice of silviculture and consequently the reader may find he wishes to study a particular aspect of the course in greater detail.

To help him in this regard a short list of suggested reading has been appended to each chapter. The publications listed are available from the Forests Department of W.A.library.

SILVICULTURE IN WESTERN AUSTRALIAN FORESTS

Detailed coverage of the silvicultural operations carried out in the forests of W.A. is not given in this course, because the subject is covered fully in -

"The Foresters' Manual" Pamphlets 5 and 6, Western Australian Forests Department Bull. 58.

To obtain full value from this course, the Manual pamphlets must be studied in conjunction with these notes.

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CHAPTER I - TYPES OF FOREST STAND

A forest is defined as a community of plants, composed mainly of trees and occupying an extensive area of land.

When speaking of a small area of forest, or part of a forest, the term Stand is used. Broadly speaking, a Stand is defined as an individual body of trees, sufficiently uniform in composition, age arrangement condition to be distinguishable from other bodies of trees. Thus we speak of a "Jarrah pole stand" or a "mature Karri stand".

There are several contrasting types of forest stands. These are:

- Virgin and Second Growth stands.
- Pure and Mixed stands.
- Even and Un-even Aged stands.
- Managed and Unmanaged stands.

VIRGIN AND SECOND GROWTH STANDS

A virgin forest stand is one in which no timber cutting has taken place. It is a forest in its original and natural condition. Such forests usually contain a high volume of large, over-mature trees. In Western Australia, large areas of Karri forest still remain in a virgin condition.

A general characteristic of the virgin forest is that the loss in timber volume due to the mortality and internal decay of old trees is usually just balanced by the increase in timber volume resulting from the development of young trees.

Second Growth stands are younger stands of smaller trees which have arisen following the logging of the original virgin stand. The major difference between a virgin stand and a second growth stand is that the virgin forest has developed independently of the activities of man, whereas the second growth stand has arisen as a direct result of the activities of man.

Many fine stands of second growth Jarrah forest exist in the Dwellingup Division and second growth Karri stands can be seen near Pemberton (e.g. Big Brook and Treen Brook).

PURE AND MIXED STANDS

Forests stands may either be composed of a single species making a Pure Forest, or composed of several species growing in association, forming a Mixed Forest.

Jarrah and Karri can both be found growing as pure stands, but more often grow as mixed forests in association with Marri. Pine plantations are the best local examples of pure stands.

PURE AND MIXED STANDS (continued)

Pure stands are generally more simple and economic to manage than are mixed forests. The main disadvantages of the Pure forest are that -

(i) as "monocultures" they are more susceptible to insect or disease epidemics, and

(ii) they may lead to deterioration of the soil (especially in the case of pines).

EVEN AND UN-EVEN AGED STANDS

An Even Aged Stand is one in which nearly all the trees of the stand are of the same age. This may arise either from the natural germination of one or two consecutive years or from all trees having been planted at the same time.

Un-even Aged stands contain trees of all ages, ranging from seedlings to mature trees. The Jarrah and Karri forests of Western Australia generally occur as un-even aged forests.

Later in the course we will see that the type of Silvicultural System applied to the even aged forest is different from that applied to the un-even aged forest.

MANAGED AND UNMANAGED STANDS

An unmanaged forest stand is one in which no silviculture is practiced. In other words, it is a stand in which no attention is given by man to the tending, protection and reproduction of the forest crop. Unmanaged stands generally have the following defects:

(i) Unmerchantable trees occupy space which could be growing merchantable trees.

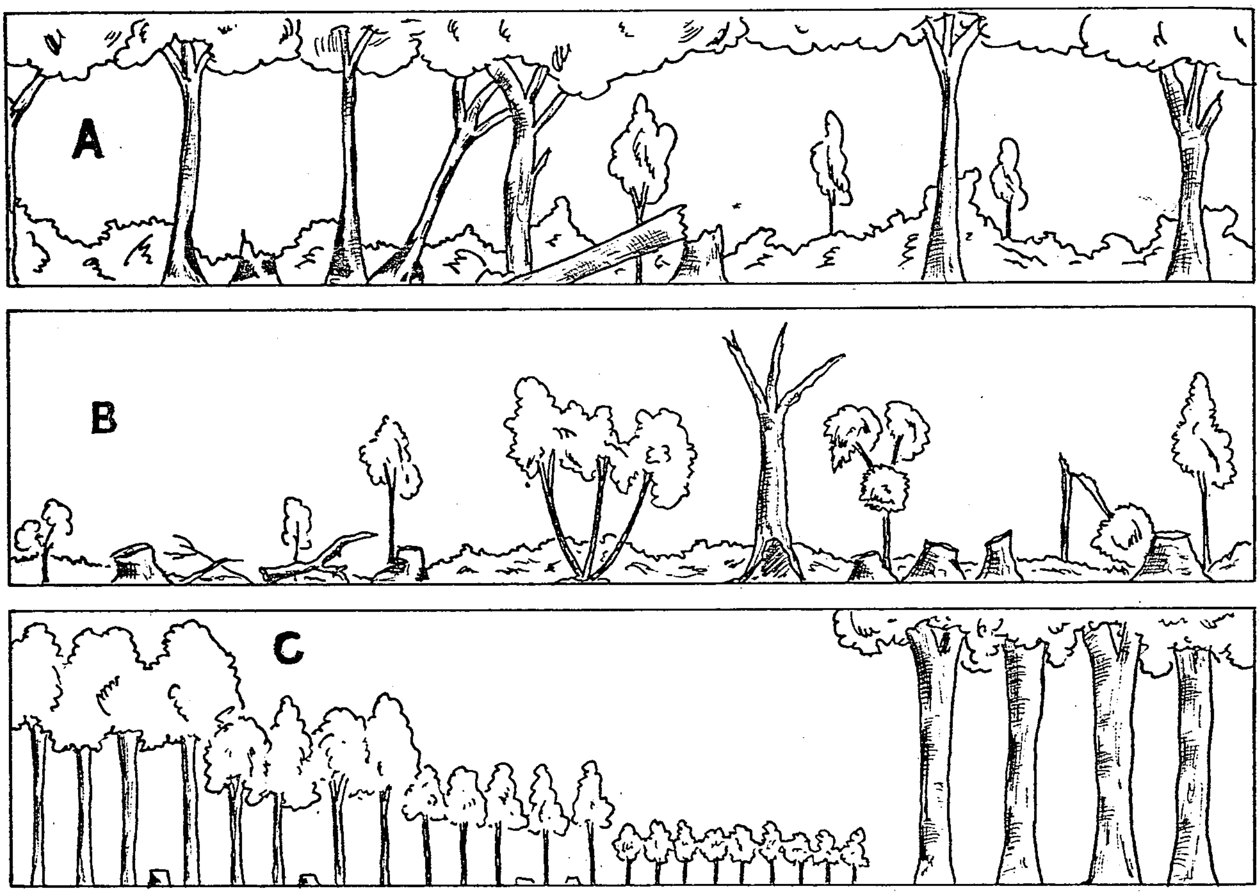
(ii) There is much damage and disease present, caused by fire, insects and fungi.

(iii) Large over-mature trees with their centres decaying remain standing in the forest.

(iv) Regeneration is either absent, or present in such large numbers that the growth of the young trees is impaired.

In the managed forest, the forester has attempted to rectify these defects. Unmerchantable trees are culled out; fire control is carried out to protect the forest; overmature trees are felled and sold; regeneration is established where it is absent, or thinned out where it is growing too densely. The well-managed forest, in fact, is producing the quantity and quality of timber desired by man and, at the same time, maintaining its capacity to produce again in the future.

DIAGRAMMATIC REPRESENTATION OF SOME DIFFERENT FOREST STANDS



STAND "A" : Virgin forest stand - trees are mainly mature to over-mature; very little regeneration present; insect, fire and fungal damage prevalent.

STAND "B" : Unmanaged forest stand - all good mill timber has been removed with consequent damage to remaining stems. Little regeneration.

STAND "C" : Managed forest stand - a regular succession of all age classes present. Stand well tended and protected.

FURTHER READING

1. "The Practice of Silviculture" by R.C.Hawley (1946) Chapter 1.

2. "The Foundation of Silviculture" by Toumey & Korstian (1928) Chapter XIII (page 322).

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CHAPTER 2 - THE NUTRITION OF THE FOREST

Silviculture was defined (page 1) as the art and science of establishing, raising and tending a forest. This means that silviculture is basically concerned with the growth of forests. In this section we examine the requirements for forest growth. This subject is called the Nutrition of the forest.

The growth of a forest is obviously the sum of the growth of the individual trees that make up the forest. The growth of the individual tree is a result of the increase in the size and the number of cells in the meristematic regions of the tree (root and shoot tips and cambium).

There are three basic requirements for growth to occur:

1. Water.
2. Carbon dioxide and Oxygen.
3. Essential plant nutrients.

Carbon dioxide and oxygen occur as gases in the air. They are always present in sufficient quantity to meet the demands of the forest tree. The supply of carbon dioxide and oxygen is therefore not of vital interest to the forester. On the other hand, the supply of water and Nutrients is often not sufficient to meet the demands of the forest. Consequently, this is a subject in which the forester must take a vital interest.

WATER

As water is indispensable to all forms of life on the earth, so it is indispensable to the life of the tree. If it is not present in adequate quantities, germination becomes impossible, growth is retarded and all life processes are slowed down.

Water Absorption. Water enters the tree through the hair cells of the young roots. The force which draws the water from the soil comes from a combination of (i) suction caused by the evaporation of water from the leaves (transpiration tension), and (ii) other pressures, many of which are not as yet properly understood.

Internal Uses of Water. The tree draws large quantities of water from the soil. The majority of this (99%) is lost through transpiration to the atmosphere. This transpired water has merely acted as a means of transporting the essential plant nutrients from the soil up into the live cells of the tree. However, the remaining 1% plays an immensely important role in the tree. For instance:

1. Water is a raw food material. It is an essential participant in the process of photosynthesis and enters into the make-up of all plant tissues.

2. The cell protoplasm, where the vital processes of the plant occur, is made up mainly of water.

3. Water serves to transport food materials made in the leaves to all living parts of the tree.

The tree clearly cannot live without water, and cannot function normally without an adequate supply of water.

WATER (continued)

The Supply of Water to the Forest. Forest trees obtain their water requirements from the water which falls as rain and is trapped by the soil. This water is called the soil moisture.

The amount of water which is available to the tree depends upon the amount of rainfall, and the amount of that rainfall which is retained in the soil and is available to the tree roots.

This second point is an important one. Generally only a very small percentage of the rain which falls on the forest enters the soil and is retained there as available soil moisture. The remainder -

(i) is intercepted by the tree crowns and evaporated back to the atmosphere;

(ii) runs off the surface of the soil into creeks and rivers and is ultimately lost to the ocean;

(iii) seeps down to such a depth in the soil that the tree roots are unable to reach it;

(iv) is lost from the surface layers of the soil by evaporation and the transpiration of small ground plants.

The water not lost in these ways is probably something less than 20% of the total rainfall, and is available for the trees of the forest.

Silvicultural Practice and Soil Moisture. In a dry climate, like that of the northern forest regions of Western Australia, high summer temperatures cause heavy soil moisture losses through evaporation and transpiration. Under these conditions, the forester must aim to conserve the moisture in the soil. The two important principles that he should always bear in mind are :

1. Maintenance of forest canopy will provide shade for the upper layers of the soil. This will lower soil temperatures and decrease evaporation from the soil.

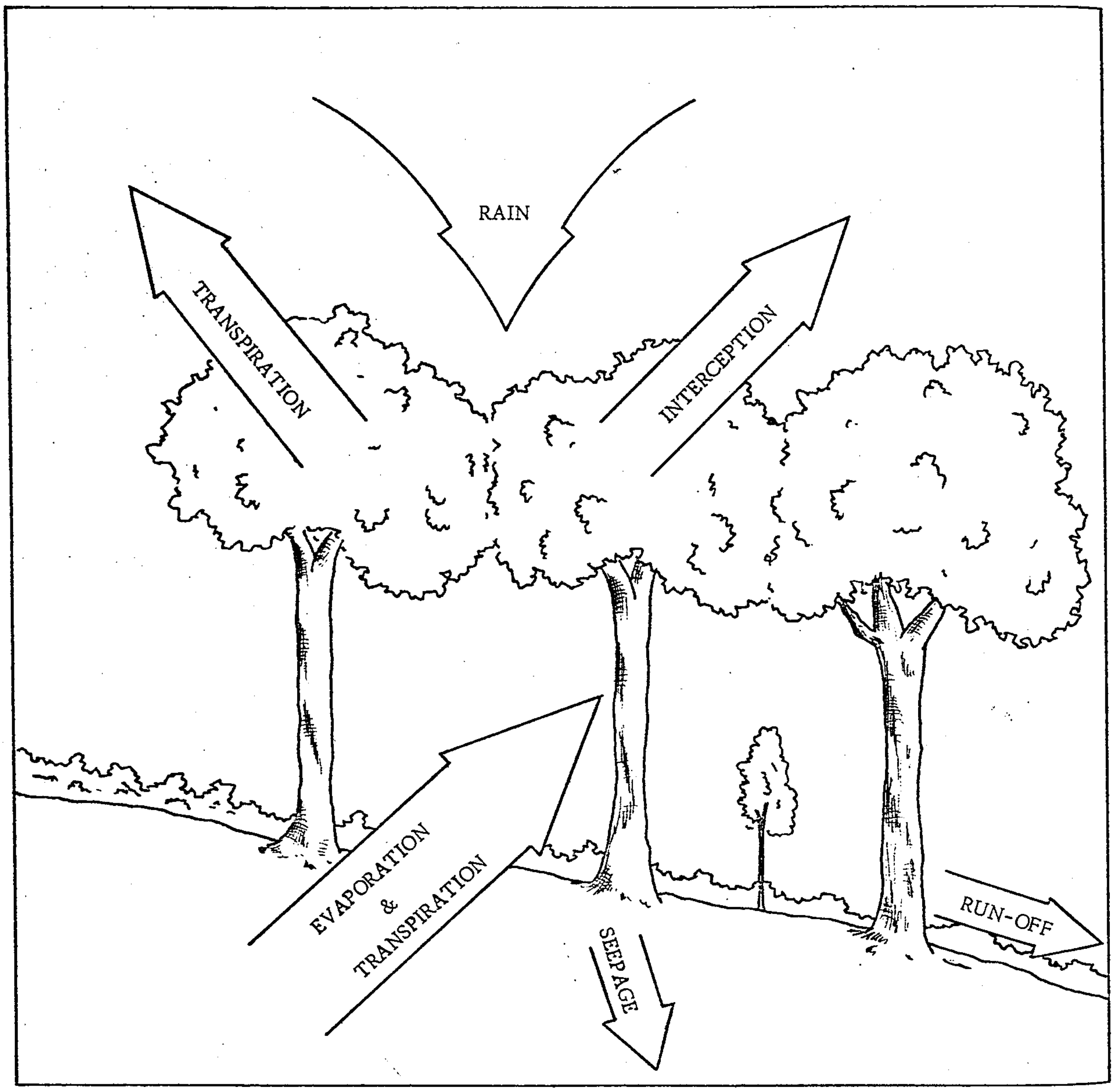
2. Reduction of the number of useless stems and the amount of shrubby undergrowth will decrease the amount of water transpired by unproductive members of the stand.

The forester must also realise that the planting of forest crops on soils that cannot hold sufficient soil moisture to sustain a mature forest may be an unsuccessful enterprise. Soils that are shallow, rocky or very steep may often be deficient in soil moisture, and the forester should study them carefully before he establishes a forest crop on them.

Similarly, it must be remembered that different tree species require a different amount of soil moisture. The introduction of a tree species from a forest area of high rainfall to a forest area of low rainfall is therefore unlikely to be successful.

DIAGRAMMATIC REPRESENTATION OF THE

FOREST WATER CYCLE



NITROGEN AND THE MINERAL NUTRITION OF THE FOREST

The requirements of the forest for nitrogen and the mineral nutrients are of equal importance to its requirements for water. These nutrients are required for the formation of the complex substances in the tree, such as the cell proteins and chlorophyll.

A very large number of different mineral nutrients are required by the tree. Some are required in very large quantities: these are called the Major Elements. Others are equally essential for the health and growth of the tree, but are required in only minute quantities. These are called the Trace Elements.

Examples of the major elements are nitrogen, phosphorus, potassium and magnesium. Examples of the trace elements are zinc and copper.

NITROGEN. We will consider Nitrogen separately from the other essential nutrients because unlike the others it does not come from the rocks beneath the soil. In other words, nitrogen is not a mineral. Nitrogen is an element which occurs, mixed with oxygen and carbon dioxide, as a gas in the air. Plants are not able to draw nitrogen gas directly out of the air, as they can carbon dioxide and oxygen. Their only source of nitrogen is from nitrogen which has combined with oxygen and hydrogen and become dissolved in the soil moisture. This is a strange and botanically unfortunate phenomenon because nitrogen, although abundant in the air, is often far from abundant in the soil.

There are three ways in which nitrogen reaches the forest soil:

1. Rainfall: Lightning causes nitrogen to combine with oxygen, which is then absorbed by raindrops. (World average yield from this source is 4 lbs/acre/ann.)

2. Through the action of certain "nitrogen-fixing" bacteria which can take nitrogen gas from the air and deposit it (in a more complex form) in the soil.

3. Through the decomposition of plant and animal remains which accumulate in the upper layers of the soil.

The amount of nitrogen which reaches the soil annually through rainfall or by the action of the nitrogen-fixers is extremely small but the effect is cumulative. The main immediate source of nitrogen is through the decomposition of plant remains.

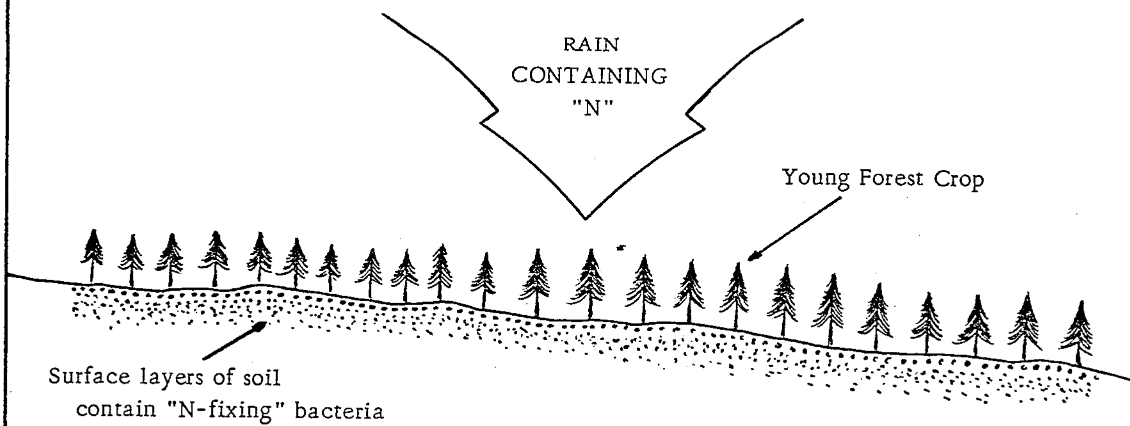
The absorption of nitrogen from the soil by plants and the return of nitrogen to the soil through the ultimate decomposition of those plants is called the Nitrogen Cycle. The nitrogen cycle is essential for maintaining the supply of nitrogen to the forest.

MINERAL NUTRITION. The essential plant nutrients other than nitrogen are known as the mineral nutrients. They come from the rocks which are found in and under the soil.

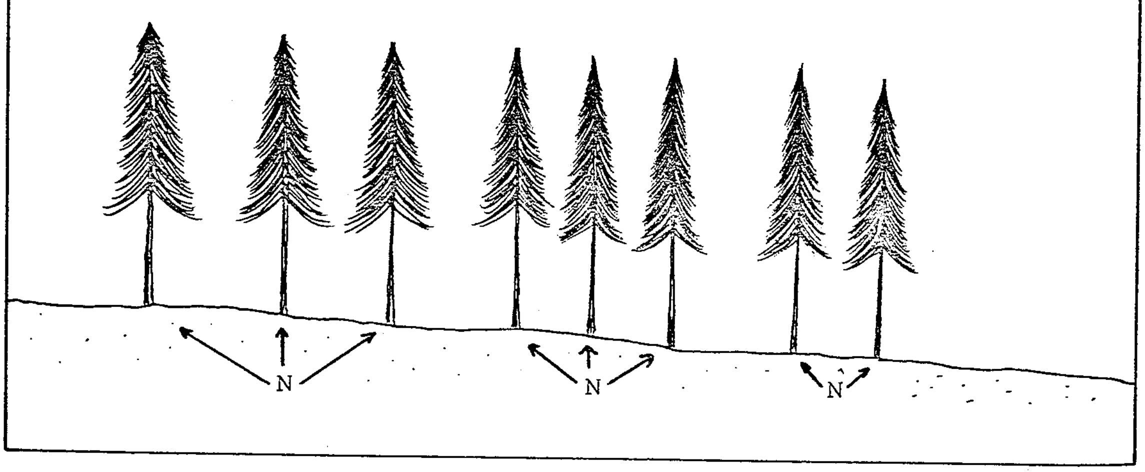
A cycle of mineral nutrients similar to the cycle of nitrogen occurs in the forest. After their absorption from the soil, the mineral nutrients are mainly located in the living parts of the tree i.e. the leaves and the sapwood and bark. These parts of the tree are generally short lived and so form the major proportion of the litter on the forest floor. From the decomposition of this litter the minerals are released to the soil and are again available for utilization by the forest tree.

DIAGRAMMATIC ILLUSTRATION OF THE NITROGEN CYCLE

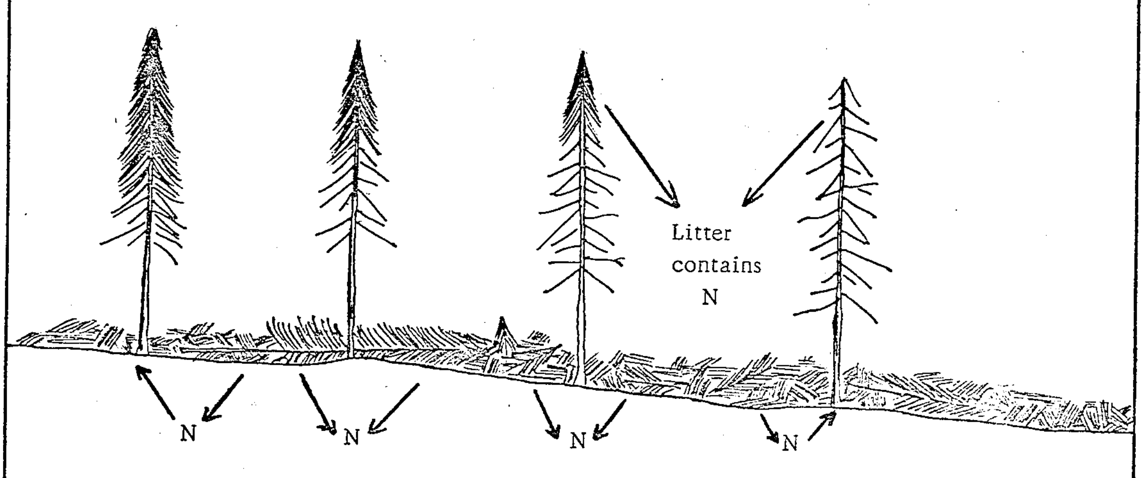
1. Nitrogen enters the soil through:
   (a) Rainfall
   (b) Certain soil bacteria



2. Nitrogen in the soil is taken up by the growing forest



3. Nitrogen returned to the soil via the decomposition of forest litter and slash.



NITROGEN AND THE MINERAL NUTRITION OF THE FOREST (continued

NUTRIENT DEFICIENCIES. If a forest soil is unable to provide sufficient quantities of the essential nutrients to maintain a healthy, growing forest then that soil is termed a nutrient-deficient forest soil.

In the early days of Australian forestry many disastrous failures occurred through the establishment of pine plantations on nutrient-deficient soils. Today all potential plantation soils are carefully surveyed to ensure that such failures do not occur again. In addition, soils which are low in phosphorus are dressed with superphosphate, a fertilizer which contains phosphorus in a form available to trees. Treatments for most of other nutrient-deficiencies are also known.

The subject of the mineral nutrition of the forest is covered in further detail in the course on "Forest Soils" in this series.

FURTHER READING

1. "The Theory and Practice of Silviculture by Baker (1934). Chapters III and V.

2. "The Nutrition of the Pine" by Stoate and Kessel F.D.Bulletin No.50 (1938).

3. "The Fertilizer Factor in Pinus Pinaster Ait. Plantations on the Swan Coastal Plain of Western Australia" by E.R. Hopkins F.D.Bulletin 68 (1960).

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CHAPTER 3 - THE REPRODUCTION OF THE FOREST

One of the major aims of silviculture is to reproduce (or "regenerate") a forest naturally and effectively, with the desired species comprising the new crop.

The forester must have as a prime objective the complete re-stocking of all cut-over forest. To ensure this, he must have a thorough understanding of :

(i) Seed production and supply.

(ii) The factors affecting the germination of the seed.

(iii) The factors affecting the successful establishment of the germinated seedlings.

These points are examined in order.

SEED SUPPLY IN THE FOREST

The production of seed is rarely a limiting factor in the reproduction of the forest crop; forests normally produce much more seed than is required for successful regeneration. (A notable local exception is Karri, whose seed production is frequently inadequate.)

The seed in excess of that required for regeneration usually provides food for ants and other small insects, or is destroyed by fire.

Seed Requirements. The normal mature forest generally contains less than 100 stems per acre and experience has shown that an original stocking of between 1,000 and 10,000 seedlings per acre may be required to obtain this forest.

In the Karri forest an area with a stocking of anything over 4,000 seedlings per acre is considered by local foresters to be successfully regenerated.

Factors Affecting Seed Production. There are several factors that affect the production of seed in the forest. These are :

(i) Dominance of the canopy : the dominants and co-dominants produce over 90% of the seed crop of a forest.

(ii) Aspect : more seed is produced on the warmer aspects (northerly and westerly) than on the cooler aspects (easterly and southerly) in Western Australia.

(iii) Good and Poor Seed Years : most local forest trees are only capable of producing a heavy seed crop once every few years.

(iv) Age of the crop : seed production varies with age. The best age for seed production is said to be when the rate of height growth of the crop is beginning to fall - i.e. between the ages of 20 and 40 years.

SEED SUPPLY IN THE FOREST (continued)

Factors Affecting Seed Production (continued)

(v) Tree Health : large quantities of seed are often borne by unhealthy or badly injured trees. This is due to a nutritive upset in the tree. Seed thus produced can be inferior to normal seed.

Seed Dispersal. The seed of most forest trees is dispersed by either wind or gravity, although under unusual circumstances seed may also be borne by water or by birds and animals.

With Eucalypts it is a general rule that the distance of seed dispersal from the parent tree approximates the height of the tree. Seed can be carried greater distances than this, but not usually in sufficient numbers to ensure an adequate stocking for regeneration.

High wind velocities and steep slopes will increase the distance of seed dispersal.

GERMINATION IN THE FOREST

Under normal circumstances, conditions suitable for germination occur in the forest every year, and germination will "take care of itself". Nevertheless, germination may sometimes fail to occur and the forester must know what has prevented it.

Factors Affecting Germination. The main factors which affect germination are the suitability of the seed bed, the temperature and the availability of moisture. In ~~local forests~~ the temperature in June, July and August may occasionally be too low for germination to occur but during most of the year germination will occur at any time when moisture conditions are favourable. This is generally during the late autumn or early spring.

Other factors affecting germination of seeds are light and oxygen. A deficiency of either may sometimes hinder the germination of seeds.

On the whole the most important single factor affecting germination in local forests is the nature of the seed bed. Careful observation (in Karri and Wandoo forests in particular) has shown that germination on ash beds, or on soil disturbed by logging, is nearly always superior to germination on unburnt or undisturbed soil. Silvicultural practice in the Karri and Wandoo forests aim at providing an ash seed-bed beneath every potential seed crop.

If conditions are not favourable for germination, seed may lie dormant in the soil until they do become favourable. Jarrah seed is believed to be capable of lying dormant for many years until satisfactory germination conditions prevail.

SEEDLING ESTABLISHMENT IN THE FOREST

When the above conditions controlling germination are all favourable, an extremely high proportion (e.g.80%) of fallen seed will germinate. However, only an extremely low proportion (e.g.1%) of the germinated seedlings survive to become permanently established regeneration.

The reason for this high mortality is that the young seedling is a very delicate plant. It is highly susceptible to the effects of :

(i) Drought and high temperature,

(ii) Frost,

(iii) Fungal and insect attack and browsing by large animals, and

(iv) Fire,

all of which can occur in local forests.

Furthermore, unsuitable seed-bed conditions will completely preclude the successful establishment of seedlings. As mentioned above, the best seed beds are either ash beds caused by fire or soil disturbed by logging. One of the most important requirements for seedling establishment is that the seed germinates in mineral soil.

THE FORESTER AND REPRODUCTION OF THE FOREST

The regeneration of the forest is one of the most basic and important considerations of the forester. By ensuring that a new crop replaces the old, he is ensuring the continued productivity of the forest.

The job of the forester in obtaining the successful regeneration of the forest can be resolved into three fields. These are :

(i) He must have a thorough knowledge of the factors governing the seed supply and production in his forest, and know when to expect a major seedfall.

(ii) He must aim at providing the most favourable seed bed conditions for a potential seed crop. This may involve burning or some form of soil disturbance.

(iii) Finally, he must make sure that fire is excluded from regenerated areas until the seedlings are sufficiently mature to withstand its effects.

OTHER METHODS OF FOREST REPRODUCTION

The forester may replace or renew a forest crop by methods that do not rely on natural seedfall and seedling regeneration. These methods are generally used when natural seedling regeneration is either unsuccessful or undesirable. The methods that can be used are :

OTHER METHODS OF FOREST REPRODUCTION (continued)

(a) Artificial seeding from the air or by hand.

(b) Planting of nursery-grown seedlings (e.g. the establishment of a pine plantation), or the transplanting of wild seedlings ("wildings").

(c) Regeneration from coppice on stumps or roots.

(d) Regeneration from lignotubers.

These methods will be discussed in more detail in the section on Silvicultural Systems (Chapter 5).

FURTHER READING

1. "The Growth Habits of the Eucalypts" by Jacobs (1956). Chapter V, Section 5.

2. "Jarrah (Eucalyptus marginata) and Karri (Eucalyptus diversicolor) Regeneration in the South West of Western Australia" by O.W.Loneregan (1961).

3. "The Development of Jarrah Regeneration" by A.C.van Noort, Forests Department Bulletin No.65 (1960).

4. "The Regeneration of Jarrah, Eucalyptus marginata" by A.C.Harris, Paper given to A.N.Z.A.A.S., (1955).

5. "Ash Bed Effects in Western Australian Forest Soils" by A.B.Hatch. Forests Department Bulletin No.64 (1960).

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CHAPTER 4 - FOREST INFLUENCES

In the previous two Chapters we discussed the nutrition and the regeneration of the forest.

In this Chapter we examine external factors which influence forest growth.

The overall combination of all the external factors which influence a forest is called the environment of that forest. Discussion of the forest environment generally centres around the Site, which means the environment of a small forest area.

THE SITE AND SITE QUALITY

It is obvious to even the untrained observer that the quality of forest stands growing on various sites differ considerably. Some areas carry higher quality forest stands than other areas.

We describe the ability of an area to produce forest as its Site Quality. The site quality of a forest area is defined as the capacity of the area to grow timber.

Thus an area which has a poor capacity to grow timber is said to have a low site quality and vice versa.

Areas used for the planting of *Pinus radiata* in Western Australia are classified by their site quality. They can range from Site Quality I, which produces the highest volume of timber per acre, to Site Quality VI, which produces the lowest.

The Site Factors. There are many factors which determine whether an area will have a low or a high Site Quality. These are called the Site Factors.

Most of the Site Factors can be grouped under three headings:

1. Climatic Factors.
2. Soil Factors.
3. Physiographic Factors.

THE CLIMATIC FACTORS

The climate of a forest region has a great influence on the growth and the type of the forest stands in that region. The main climatic factors are rainfall, temperature, wind and lightning.

(1) Rainfall. Areas of high rainfall are capable of growing forests of higher quality than are areas of low rainfall. One has only to compare the timber production per acre in the Dwellingup region (annual average rainfall of over 40 inches) with that in the Kalgoorlie region (less than 15 inches) to realise the truth of this.

There is a simple explanation for this fact. Soil moisture is directly controlled by rainfall, and adequate quantities of soil moisture are essential for tree growth.

THE CLIMATIC FACTORS (continued)

(2) Temperature. Forests generally grow better under warm rather than cold conditions, providing soil moisture does not become limiting. Extremely low temperatures, such as occur during a heavy frost, can cause death in the forest tree, particularly when it is young.

(3) Wind. Wind affects the forest in two ways: (i) it assists in the pollination of flowers and the dispersal of seeds, and (ii) if strong enough it can cause mechanical damage to trees and the production of poor quality timber. Storm damage is not a problem in local forests.

(4) Lightning. Lightning influences forests in three ways: (i) it can severely damage any tree which it strikes; (ii) if not accompanied by rain it can cause serious forest fires; and (iii) it assists in the supply of nitrogen to the forest by changing it into a form which is soluble in rain water.

THE SOIL FACTORS

The soil has two important influences on the forest tree. It supplies the moisture and nutrients necessary for life, and at the same time provides a medium in which the supporting roots of the tree can anchor themselves.

Different types of soils vary greatly in their ability to provide moisture, nutrients and support for the forest tree. This variation in soil properties causes considerable variation in forest growth and thus site quality. High site quality forest stands are generally to be found on the best soils.

The properties of soils which influence forest growth are soil depth and drainage, soil texture, soil structure and soil fertility.

These aspects are dealt with in detail in the course on "Forest Soils".

THE PHYSIOGRAPHIC FACTORS

Physiography (or "topography") has an important influence on the growth of forests. The main physiographical influences are altitude, slope and aspect.

(1) Altitude. Generally as altitude increases, forest growth tends to decrease. This is probably due to a drop in temperature at the higher altitudes. This factor is not of great importance in the forest regions of Western Australia due to a marked absence of extremes of height, but can be clearly seen in the alpine areas of the Eastern States.

THE PHYSIOGRAPHIC FACTORS (continued)

(2) Slope. Forests develop most satisfactorily on areas having a moderate slope (between five and thirty degrees). On slopes which are steeper than this, soils tend to be thin and rocky and heavily eroded. Soils on flat lands tend to be poorly drained and do not grow the best forests.

(3) Aspect. Aspect refers to the direction of slope of the land. This determines the amount of sunlight received by a site and thus its soil moisture content and air temperature. The effect of aspect on soil moisture content is of most importance in warm, dry climates and its effect on air temperature most important in cold, wet climates.

Aspect is an important site factor only in the drier, marginal forests of Western Australia.

OTHER FOREST INFLUENCES

Other external factors besides climate, soil and physiography can influence the growth and development of forests. Two of the most important are Fire and Man.

The Effect of Fire. It is now generally accepted that in Western Australia, fire is as much a natural part of the forest environment as climate or soil. Attempts by man to exclude fire from the forest have always resulted in a massive accumulation of litter and, eventually, disastrous fires.

Consequently, it is normal forest practice these days to deliberately set fire to the forest at intervals of four to five years. This operation is termed "Controlled Burning". These frequent fires not only reduce the fire hazard in the forest, but have several other beneficial effects. For instance :

(1) Fires destroy undergrowth and other subsidiary vegetation which compete with the forest trees for moisture and nutrients.

(2) Fire assists in the regeneration of the forest by removing litter and providing an ash seed-bed.

(3) Fire reduces the population of insects in the forest and this assists in the development of young seedlings.

Fire is the one factor of the environment which the forester can manipulate at will. He must realise that fire can be his master or servant depending upon the wisdom with which it is used.

OTHER FOREST INFLUENCES (continued)

The Effect of Man. Among the environmental factors that we have so far considered, Man alone has the knowledge and power to control at will the condition of the forest: if he so desires he has sufficient power to conserve or completely destroy a forest stand.

The past effect of man on the forests of Western Australia has been a profound one. Heavy logging and indiscriminate firing, ringbarking and clearing have caused not only the loss of vast volumes of timber, but often the disappearance of forests altogether.

Today man is more careful with his power, for he realises the need to conserve present resources as well as to develop new ones. He must think of the needs of the forest as well as the needs of himself if the forests of our country are to survive.

FURTHER READING

1. "The Foundations of Silviculture" by Toumey and Korstian (1928), Chapter 1.

2. "Controlled Burning in Western Australian Forest Practice" by A.C.Harris and W.R.Wallace. Paper given to A.N.Z.A.A.S. (1959).

3. "The Growth Habits of the Eucalypts" by Jacobs (1956), Chapter V, Sections 15, 16 and 17.

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CHAPTER 5 - SILVICULTURAL SYSTEMS

A Silvicultural System is defined as an "orderly procedure for the harvesting, protecting and regenerating of a forest crop". In other words it is a method of practising silviculture, or a method of raising, tending and utilising a forest.

There are many different types of Silvicultural Systems, the majority of which were designed in Europe to suit specific local conditions there. Many of these systems do not apply to the forests of Western Australia and will not be discussed in this course.

Nevertheless, there are several "classical" silvicultural systems about which every forester must have some knowledge. These are briefly examined in this chapter.

The "classical" silvicultural systems are:

1. The Clear-felling System.
2. The Clear-felling with Seed Trees System.
3. The Uniform System.
4. The Selection System.
5. The Coppice System.
6. The Coppice with Standards System.

THE CLEAR-FELLING SYSTEM

The Clear-felling system involves cutting an area clean of all forest, i.e. removal of the whole stand. Regeneration is then obtained either by artificial seeding, planting, allowing natural seedfall from adjacent uncut stands or advance growth or alternatively from seed already on the ground from the cleared stand.

The pine forests of W.A. are managed on a clear-felling system. The final crop is clearcut and replaced by the hand planting of nursery grown seedlings.

Advantages of the Clear-felling system are :

(i) It is simple to organise and control. No treemarking is required.

(ii) Logging is concentrated on small areas and thus the costs of utilization and regeneration are reduced.

(iii) The new crop has complete freedom from competition.

(iv) The new crop is roughly even-aged and thus more easily managed.

THE CLEAR-FELLING SYSTEM (continued)

Disadvantages are:

(i) By clearcutting all standing forest, the protective canopy is destroyed. This allows erosion and dessication of the soil and exposes the regeneration to frost, drought and wind.

(ii) All unmerchantable and immature timber in the stand is destroyed. Thus if the system is applied to an un-even aged stand, there is great wastage of young trees.

Application of the system. The system is best applied to even aged stands where the great majority of trees are merchantable. An essential requirement of a stand to be clear-felled is that the regeneration is able to withstand the effects of exposure in its early years.

THE CLEAR-FELLING WITH SEED TREES SYSTEM

A modification of the clear-felling system is the Clear-felling with Seed Trees system. In this system the logging area is clear cut except for certain trees (called seed trees) which are left standing to provide seed for the cut-over area. After the new crop has become established, the seed trees are then either logged or left standing to be removed at the next cut.

Character of the Seed Trees. Since they are the source of the new crop, seed trees must be selected with great care. Points to be considered are :

(i) Stability and Health : trees must be wind-firm and showing no signs of disease.

(ii) Age : trees must be old enough to produce fertile seed.

(iii) Quality : trees of the best form and vigour should be retained so as to improve the genetic quality of the future crop (See chapter 7).

Advantages and Disadvantages. This system has all the good points of the clear-felling system and the additional advantage of an assured seed supply. The main disadvantages are that (i) it affords little protection for the soil and for the new crop of seedlings, and (ii) established regeneration is usually damaged by the felling of the seed trees.

THE UNIFORM SYSTEM

This system is designed for forest species whose seedlings are not sufficiently tough to withstand the exposure of clear-felling. It involves the gradual removal of the old crop and the establishment of regeneration under the cover of this parent crop. The old crop is finally removed when the regeneration is old enough to endure the exposure.

THE UNIFORM SYSTEM (continued)

The system is called the Uniform system because the new crop is more or less of uniform age. The main point about the system is that the old crop performs three functions : (i) the provision of timber for industry, (ii) the provision of seed for the establishment of the new crop and (iii) the provision of protection for the established seedlings.

Advantages and Disadvantages : The system provides good protection for the forest and also produces an even-aged crop. The major disadvantages are that (i) part of the regeneration is always destroyed when the old crop is logged, and (ii) logging costs are higher than they are with clear falling, due to the fact that several operations over the same area are necessary.

The Uniform System has not been applied in Western Australia to date, for it is believed that under normal conditions the seedlings of local forest species do not require protection by an overstory. However, the system may find limited application in sites subject to regular winter frosts.

SELECTION SYSTEMS

Selection systems involve the logging and regenerating of the forest in small separate areas. A stand is never completely cleared off, but instead small openings are made here and there. Regeneration then becomes established in the openings so created.

Selection systems can be of two kinds : (i) Group Selection, in which groups of trees are removed as they mature and regeneration is allowed to develop in the remaining gap; and (ii) Single Tree Selection where single trees only are removed.

The Group Selection system, or variations of it, are commonly used in Australian eucalypt forests. The result of the system is an un-even aged forest containing all ages from mature trees to seedlings.

Advantages are:

(i) The forest site is well protected as canopy is maintained.

(ii) Seed supply is generally adequate.

(iii) There is no wastage of unmerchantable or immature trees as occurs in the clear-felling system.

(iv) Excellent trees can be retained so that a progressively better seed source for future crops is obtained.

Disadvantages are:

(i) Mature trees ready for utilisation are scattered throughout the forest. Logging costs are therefore high.

(ii) The system requires treemarking and close supervision of logging operations.

COPPICE SYSTEMS

Many trees (including most Eucalypts) will produce shoots from dormant buds in the stump after they have been cut down. These "coppice" shoots can be allowed to grow into new trees.

A silvicultural system based on this kind of reproduction is called a Coppice System. The forest is clear cut and the new crop starts immediately from the stumps of the trees which formed the old stand. This system is generally only applied to low quality forest, run on a short rotation, for the production of small-sized products (e.g. firewood, struts and posts).

Coppice forests are maintained by introducing new seedlings to the crop from time to time and allowing them to develop into new trees.

COPPICE WITH STANDARDS SYSTEM

A modification of the coppice system is the Coppice with Standards system.

In this system a two-layered forest is produced :

(i) The lower storey is composed of the coppice crop and recently established seedlings. This crop is clear-felled every 20 to 40 years depending on the desired rotation age.

(ii) The upper storey is composed of the "standards"; these are stems of very good form and quality which are left at each cutting of the coppice. The standards are selectively logged when required.

The main advantage of this method over the Coppice method is that an area managed to produce predominantly low-quality small logs (the coppice), can also be allowed to produce occasional large-size, high quality logs (the standards).

Coppice forest systems are not favoured in Western Australia although they are used in some Eastern States (for firewood production in the Australian Capital Territory and for Eucalyptus Oil production in western New South Wales).

FURTHER READING

"The Growth Habits of the Eucalypts" by Jacobs (1956) Chapter VI, Section 2.

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CHAPTER 6 - TENDING OPERATIONS

A definition of silviculture given early in this course was that it was the "raising and tending of the forest crop".

In the previous sections we discussed methods of raising forest crops. In this section methods of tending the forest are examined.

Tending operations in the forest are carried out after the establishment and before the final felling of a stand. Their purpose is to increase the amount and the value of the final crop.

The five major types of tending operations are :-

1. Weeding : a treatment applied to young stands to remove competing growth from around young trees.

2. Thinning : a cutting made in immature stands aimed at increasing the rate of growth and the value of the trees that remain.

3. Improvement and Salvage Cutting : cutting made for the purpose of removing undesirable species, or damaged or diseased trees from the stand.

4. Pruning : the cutting of branches from standing trees for the purpose of increasing the quality of the final product.

5. Tops Disposal : the cleaning away of logging debris from around future crop trees to protect them from fire scarring.

All of the above operations are carried out in Western Australian forests, either as a general practice (e.g. thinning) or when required (e.g. salvage cutting following wild fires).

WEEDING

Weeding is the removal of competing vegetation from around young forest trees. In W.A. the operation is entirely confined to pine plantations, where it is necessary if useless scrub species are overtopping young pines. When this happens the scrub weeds are either slashed back, poisoned or cultivated under.

Weeding is an expensive operation and is only carried out if absolutely necessary.

THINNING

The aim in thinning out a forest is to increase the growth of the remaining trees and thus to increase the value of the forest.

THINNING (continued)

The Necessity to Thin. The theory behind thinning emerges from our knowledge of what happens naturally in a young forest stand. The normal stand starts life with a large (e.g. greater than 1000) number of stems per acre. At the end of its life, when ready for cutting, there are usually less than 100 trees on each acre. This decrease in numbers has been the result of great competition within the young stand for light, moisture and nutrients.

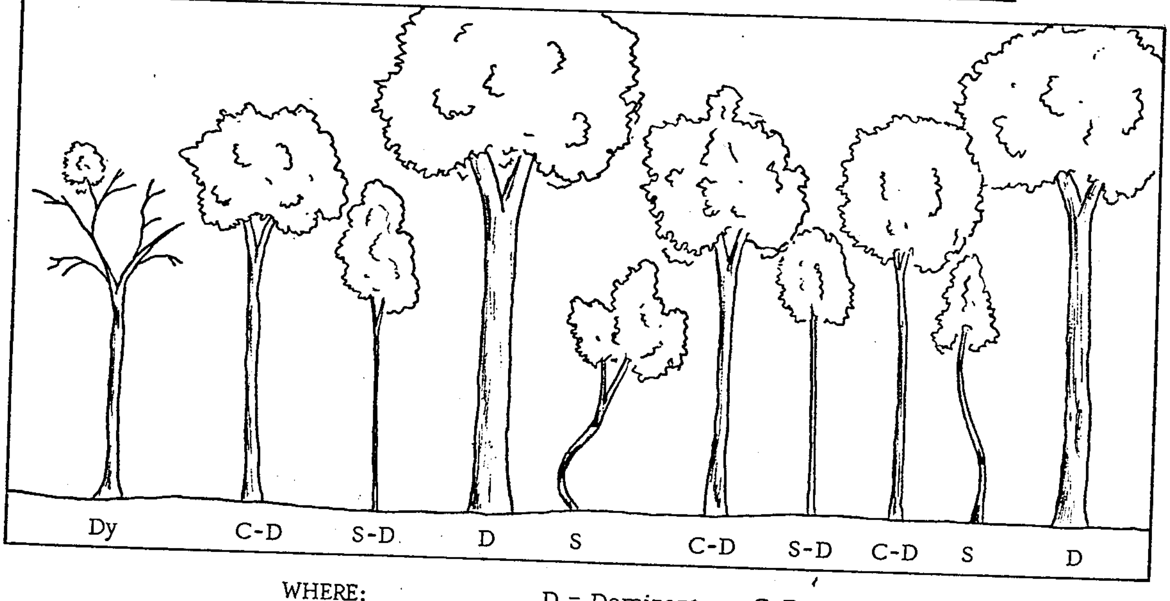
This intense competition not only causes death among the weak members of the stand but causes a reduction in the growth rate of the stronger members.

The aim of thinning is to eliminate competition from the stand by removing all unnecessary stems. The smaller number of trees which remain are then able to enjoy all the moisture, light and nutrients that the site can supply. Increased growth on these stems is the result.

Classification of Tree Crowns. The struggle for existence found within an unthinned stand is indicated by the tree crowns of that stand. According to the position in the canopy, or the health of the crown, trees are classified as :

1. Dominants : trees with vigorous crowns above the general level of the canopy.
2. Co-dominants : trees with crowns forming the general level of the canopy.
3. Sub-dominants : trees shorter than the co-dominants, or immature trees, with crowns just below the general level of the canopy.
4. Suppressed : trees with crowns well below and overtopped by the general level of the canopy.
5. Dead and Dying : trees with crowns anywhere in the canopy which are either dead or nearly dead.

DIAGRAM ILLUSTRATING THE CLASSIFICATION OF TREE CROWNS



WHERE: D = Dominant C-D = Co-dominant
S-D = Sub-dominant S = Suppressed Dy = Dying

THINNING (continued)

Classification of Tree Crowns (continued)

The crown of any tree in an unthinned stand can be classified into one of the above categories. The classification is used in describing methods of thinning.

Time to Commence Thinning. In theory the best time to commence thinning a stand is when competition is starting to affect the rate of growth of the stand. This time will vary greatly with different types of stand.

In actual fact, time of thinning is usually decided by economic factors. Thinning is delayed until the trees to be removed are of sufficient size to be sold.

If stands are not held until the thinning products are saleable, a Thinning to Waste can be carried out. Thinning to Waste is often necessary in Eucalypt forests. Because of the tendency of small logs to "spring" when sawn, small size eucalypt trees are not marketable. Thinning to Waste is not carried out in pine forests.

It is important to remember when carrying out a Thinning to Waste operation, that the costs of the operation must be kept below the expected increase in the value of the stand as a result of the thinning. Otherwise the operation is a waste of time, money and trees.

Methods of Thinning. There are three methods of making a thinning in a stand. These are :

1. Low Thinning, or "Thinning from Below" : Here the principle is to remove the poorest crown class trees from the stand. Steps could be :

   1st Thinning : remove all dead, suppressed and dying trees.

   2nd Thinning : remove sub-dominant trees, and some co-dominants.

   3rd Thinning : remove all co-dominants.

   This type of thinning aims at producing a final crop out of the dominant trees of the stand.

2. Crown Thinning or "Thinning from Above" : In this case the principle is to cut in the upper crown classes so as to aid the development of the best upper class trees. All dead and dying trees are also removed. This method is often favoured over the low thinning method as the cash returns from it are higher.

3. Mechanical Thinning : Here trees are selected for retention in the final crop on the basis of spacing alone. Mechanical thinning is generally used only as a first thinning technique in dense, young stands.

THINNING (continued)

Desirable Spacing for Thinned Eucalypt Stands. The spacing left between trees after thinning has an important bearing on the success of the thinning operation. If the thinning operation has been too light (i.e., insufficient space left between trees) competition for crown and root space will soon re-exert itself and the full value of the thinning will not be realised. If, on the other hand, the thinning has been too heavy (i.e., spacing between trees is unnecessarily great), the over-all productivity of the forest will be below its possible maximum.

A clue to the most desirable (or "optimum") spacing to aim at in a thinning operation is obtained from a study of the Crown Ratio of the species in question.

Crown Ratio (the abbreviation is K/D) is an expression of the ratio of the diameter of the crown of the tree to the diameter of its bole at breast height (4'3" from the ground). In other words it denotes the number of times the diameter of the tree crown is greater than the diameter of the tree bole. Crown ratio is a more or less constant figure for a given species of a given size, growing in a specific locality. Therefore if we know the crown ratio for a particular species and the average bole size, we can readily calculate how much crown space each tree requires for optimum growth. Furthermore, if we know the rate of diameter growth of the bole we can calculate the rate of diameter growth of the crown and thus anticipate how much crown space a tree will require in the future.

In this way, crown ratio can be a useful guide to the optimum spacing in the stand to be thinned.

Example : Assume the K/D ratio of open-grown Jarrah poles near Dwellingup is 18 and the average diameter of trees in the stand is 10 inches.

K/D ratio = 18

Average tree diamter = 10"

Therefore, crown diameter of trees should be 18 x 10" = 15 ft.

Therefore, optimum spacing between trees should be = 15 ft.

(Or, more exactly, something greater than 15 feet to allow for future growth of the crown after thinning.)

The Advantages of Thinning. The major advantages in thinning a forest stand are :

1. After a stand has been thinned, the remaining trees grow faster. This means that the length of time between establishment and harvest of the crop is reduced and thus higher financial returns from the forest are obtained.

2. Trees that are retained after thinning grow bigger than trees in an unthinned stand. Large logs are worth more money to the forester than small logs.

3. Thinning increases the overall value of the forest. By removing trees of poor form and defective trees, the quality of the final crop is raised. An unthinned stand may carry the same volume of timber as a thinned stand but the latter will carry this volume on fewer, larger and thus more valuable trees.

THINNING (continued)

The Advantages of Thinning (continued)

4. When the products from a thinning are saleable, an early financial return from the forest is obtained. In the case of pine plantations, early thinnings can almost completely cover the initial cost of establishing the pines.

5. Thinning keeps the stand free from diseased and insect-infested trees.

IMPROVEMENT AND SALVAGE CUTTING

The purpose of these Intermediate cuttings is to improve the health and composition of the forest.

(a) Improvement Cutting is the removal of undesirable species from the forest;

(b) Salvage Cutting is the removal of moribund (dying), diseased, or damaged trees from the forest.

These types of cutting serve two main uses in the forest :

1. The initial step in converting the virgin forest to the managed forest (see Chapter I) can be an improvement and/or a salvage cut. Trees of undesirable species or trees of poor form or diseased trees are removed from the forest. If possible, these are sold to cover the cost of the operation. In this way young potentially productive trees are able to make full use of the site.

2. When the forest has suffered large-scale damage from an agency such as a fire, cyclone or a disease epidemic, a salvage cut is necessary to retrieve dead and dying trees before their timber becomes unacceptable to the sawmiller.

Much of the Jarrah forest which was badly burnt in 1961 was subsequently given a salvage cut.

PRUNING

Pruning is the operation that removes branches from standing trees. Pruning is necessary for the production of knot-free (high value) timber from tree boles.

There are two types of pruning:

(i) Natural Pruning : as young trees grow in height and develop heavier crowns, the lower branches no longer receive their requirements of sunlight and consequently die and drop off. Some tree species (e.g. the Eucalypts) are naturally very efficient "self pruners". Others, like the Pines, are not.

PRUNING (continued)

(ii) Artificial Pruning : in trees that do not naturally prune themselves efficiently, it is necessary to remove their branches by hand. Such artificial pruning is standard practice in West Australian pine plantations.

The Effect of Pruning. The pruning of tree limbs will not affect the growth or health of the tree as long as two points are considered:

1. If pruning is carelessly done, injury can be done to the cambium and wood of the tree. This will cause a defect in the bole of the tree and also, perhaps, allow the entry of fungi or insects. Pruning operations must be well supervised to see that a minimum of damage is done.

2. If the pruning of limbs is carried too high up the tree, the crown volume will be so greatly reduced that a decreased rate of growth of the tree will result. No more than 30% of the green crown of a pine tree should ever be removed.

The Cost of Pruning. Pruning is only worth doing if the difference in value between knotty and knot-free timber is greater than the cost of the pruning operation. It is essential that the forester knows what his maximum allowable pruning costs are and that he maintains sufficient vigilance to ensure that field costs are kept below this figure.

Pruning and Fire Control. The removal of the lower branches of the trees in dense, young pine stands is desirable from the point of view of fire control as well as economics. There are two reasons :

1. Lower limbs impede the access of fire fighters trying to control a fire, and

2. Lower limbs assist in carrying a fire from the ground up into the crowns of the trees, thereby causing a damaging crown fire.

In Western Australian pine plantations two types of pruning are carried out :

(i) Low Pruning : this is done on all trees in young stands when they reach a certain size. It is fundamentally a fire precautionary measure.

(ii) High Pruning : this is only done on selected "final crop" trees for the production of knot-free, high-value timber from the boles of these trees.

Current pruning practices in local pine forests are described in detail in Pamphlet 5 of the Foresters' Manual.

TOPS DISPOSAL

Tops disposal consists of clearing all debris away from the base of future crop trees. The aim of the operation is to prevent the formation of fire scars at the base of these trees.

TOPS DISPOSAL (continued)

A tops disposal operation is essential in forests where (i) the crop is uneven aged, so that future crop trees grow mixed with currently millable stems, or (ii) regular fires or control burns occur. Under these conditions, logging debris will accumulate at the base of the immature stems and if ignited by a passing fire will scar or kill the young tree. Fire scars are serious defects in the boles of young trees; they detract from the value of the timber, allow the entry of fungal or insect pests and in extreme instances cause hollow-butting and stem-break.

Tops disposal has been standard practice in Western Australian forests for many years; it is considered to be one of the most important silvicultural operations in the hardwood forests.

FURTHER READING

1. "The Practice of Silviculture" by R.C.Hawley (1946) Chapter XI (Thinning) and Chapt.XIII (Pruning)

2. "Thinning in Cut-over Jarrah Stands" by W.R.Wallace and F.D.Podger Paper given to A.N.Z.A.A.S. (1959).

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CHAPTER 7 - TREE IMPROVEMENT

In our study of the general aspects of silviculture in this course we have examined the principles of forest tree growth and the methods of raising, tending and harvesting forest crops.

To conclude the course we will examine a particular aspect of silviculture which is becoming increasingly important in modern plantation forest practice. This is the improvement of the forest crop by the techniques of Tree Improvement or "Tree Breeding".

THE TREE IMPROVEMENT PROGRAMME

The Need for a Tree Improvement Programme in W.A. The "pedigree" of the seed has a marked bearing on the quality of artificially established plantations. Seed sources for Western Australian plantations have for many years been South Australia in the case of Pinus radiata, and Portugal in the case of Pinus pinaster. Investigations into these seed sources disclosed the fact that the seed collected there for overseas use was not necessarily taken from the elite tree, but in fact was usually taken from those trees which (irrespective of their other qualities) bore the heaviest seed crop. As a result, seed for local plantations often came from poorly formed or basically inferior trees.

To overcome this problem, a Tree Improvement programme has been instituted in Western Australia. The object of this programme is to improve the quality of our plantation crops, using seed obtained from the best parent trees growing in local stands. This programme involves three basic procedures :

1. The selection of the most suitable parent trees.

2. The propagation (or reproduction) of these parent trees so that there is enough of them to produce the desired quantity of seed.

3. The establishment of Seed Orchards, comprising small plantations of "superior trees" from which seed may be collected to meet local plantation requirements.

In this chapter we will examine these aspects of Tree Improvement. However, before doing so it is first desirable to examine some of the theory behind this work.

BACKGROUND TO TREE IMPROVEMENT WORK

Genetical Background. Tree Improvement has as its basis the science of Genetics, which is concerned with the study of the inheritance of characteristics by offspring from their parents and with the similiarities and differences occuring between the offspring of the same (or similar) parents.

The forester who requires a working knowledge of the aims and techniques of tree breeding need not have an extensive knowledge of genetics; nevertheless there are two important concepts which he must grasp : the concepts of the Genotype and the Phenotype. These are now explained.

BACKGROUND TO TREE IMPROVEMENT WORK (continued)

Every forester must have noticed that in any stand of trees (even those of the same age and species), great variation occurs between any two individuals of that stand. Variations in such characteristics as stem straightness and length, vigour of growth and branching habit are common differences.

There are two sources of this variation : (i) the genetical constitution (or "make-up") of the individual tree and (ii) the effects of the environment.

1. Genetical Constitution. The inheritance of characteristics is controlled by tiny cellular units called genes which are passed on from parents to offspring so that the offspring inherits some of its genes from the female parent and the others from the male parent. The inheritance of genes is an extremely complex process and need not concern us here, but the result of the process is that every individual has a slightly different set of genes to every other individual. This produces variation in the characteristics of individuals.

The genetical constitution of an individual is called its Genotype and variations in individuals caused by variations in genetical constitution is called genotypic variation.

2. Environment. We saw in Chapter 4 that the forest environment is a complex of mainly climatic, soil and physiographic influences. Variations in environment cause variations in individual trees (we say that the environment "modifies" the genotype).

Variations in individuals due to environmental influences is called phenotypic variation, and the individual genotype, modified in some way by the environment, is called the Phenotype.

Thus every tree we see in the forest is a phenotype, for its appearance represents the combined effects of its genotype and the environment.

The Application of Genetics to Tree Improvement. The basic aim in tree improvement is to take advantage of the natural variation between the individuals of a population of trees in order to select and use the best trees of that population as parents for an improved seed source.

This brings us to the first step in the tree improvement programme : the selection of parent trees.

THE SELECTION OF PARENT TREES

The selection of parent trees suitable for a tree breeding programme involves four steps : (i) a definition of the features which are desirable for a parent tree; (ii) provenance testing of the desired species; (iii) the selection of plus phenotypes; and (iv) progeny testing of the plus phenotypes.

THE SELECTION OF PARENT TREES (continued)

1. DESIRABLE FEATURES FOR BREEDING. Before any selection of likely parents can be made, the features desirable for breeding must be clearly defined. In W.A. our major purpose for growing trees is to produce sawlogs; we must therefore define those properties of a tree which ideally suit that tree for sawlog production.

Basically, trees of high vigour, good stem form and good crown condition are required. The ideal parent tree should meet the following requirements:

(1) Symetrical cross-section of bole.

(2) Straightness of bole (no kinks, sweeps or S-bends).

(3) Slow rate of taper.

(4) Wide angle, thin branches (easy to prune and leaving only small pruning scars).

(5) Long internodes between branch whorls (more clear wood per unit length of bole is produced).

(6) Deep, full crown.

(7) Dominance in the canopy.(indicative of vigour).

There are many other factors which can be used as criteria for the selection of the parent tree, depending on the precise requirements for which the trees are grown. For instance, under certain conditions, the following may be important and desirable features of the parent tree : (i) resistance to a certain disease or insect pathogen; (ii) hardiness under conditions of frost or drought; or (iii) specific timber properties (such as long fibred wood for pulp).

2. PROVENANCE TESTING. Having defined those characteristics desired for the breeding programme, the next step is to carry out tests to determine which is the best race of the desired species. These tests are called Provenance Tests. They involve the collection of seed samples ("provenances") from all the geographic localities where the species is known to occur and the raising of seedlings from these seed samples under local conditions. The search for likely parent trees is then confined to the provenance which proves itself to be best suited to local forest conditions.

Comprehensive provenance testing of Pinus pinaster in W.A. proved that the Leiria strain was the provenance most ideally suited for W.A. coastal plain conditions. Extensive provenance testing of Pinus radiata has not been necessary, for the natural range of this species is extremely limited.

3. SELECTION OF "PLUS PHENOTYPE" TREES. Having decided upon the features to be used in selection and having determined the best provenance of the desired species, likely parent trees may then be selected.

In Pinus pinaster, this is done by making a careful examination of all stands of the Leiria strain which are over 20 years of age. (Stands in W.A. and Portugal were examined). The very best trees (those which satisfied the criteria of selection) in these stands were located and distinctively marked. These "superior" trees are called Plus Phenotypes, or simply Plus Trees.

The selection of Plus Trees is one of the most important steps in the breeding programme.

THE SELECTION OF PARENT TREES (continued)

4. PROGENY TESTING OF PLUS TREES. The plus trees selected in the field represent the best available phenotypes of the desired species. As we shall see shortly, cuttings and seed from these trees can be (and are) immediately used for the raising of improved trees, but to carry out a proper tree improvement programme, a further step is necessary. The genotype of the plus trees must be tested by examining the growth and development of their offspring. This procedure is called Progeny Testing, and involves the following steps :

(1) Selected pairs of plus trees are artificially cross-pollinated. This is done by introducing pollen from one tree onto the ripe female cones of the other, (the technique is called "Controlled Pollination").

(2) Seed developing on these cross-pollinated trees is collected, germinated and planted out in the field.

(3) These trial plots are carefully observed as they develop. When they are old enough to enable a decision to be made, each tree is examined to see whether it has inherited the desirable qualities of its plus tree parents.

(4) Plus trees which do pass on their desirable properties to their offspring (or "progeny") are retained in the breeding programme: those which do not are discarded.

Progeny testing enables the separation of genetically superior trees from those merely phenotypically good. The ultimate result of the testing is the production of a Seed Orchard of genetically superior trees ("elite" trees) from which all plantation seed requirements can be obtained.

Progeny testing is an essential part of the tree breeding programme, but unfortunately it is a procedure which can take many years to complete (over ten years for P.pinaster). Since local plantation establishment programmes cannot wait this long, a procedure has been developed which provides an immediate supply of partially improved seed from the selected plus trees while the progeny tests are under way. This procedure will now be discussed.

VEGETATIVE PROPAGATION OF PLUS TREES

In order to obtain some improvement in the seed source while waiting for the progeny test results, the vegetative propagation of plus trees is carried out. This is done in W.A. by grafting cuttings from the plus trees (called "scions") onto small potted seedlings of the same species (called "stocks").

The Procedure. The procedure used in the vegetative propagation of plus trees is as follows:

(1) Small cuttings are taken from the plus trees. These are taken from young terminal shoots on the lateral branches near the tip of the crown.

VEGETATIVE PROPAGATION OF PLUS TREES (continued)

The Procedure (continued)

(2) The scions are grafted onto small seedlings grown in pots (the grafting technique is described below).

(3) The grafted seedlings (which now have an identical genotype to their parent plus trees) are planted out into a small plantation called a Scion Arboretum, and carefully tended as they grow. A number of grafted seedlings taken from the same plus tree is called a Clone, so that a Scion Arboretum normally consists of a number of clones taken from different plus trees.

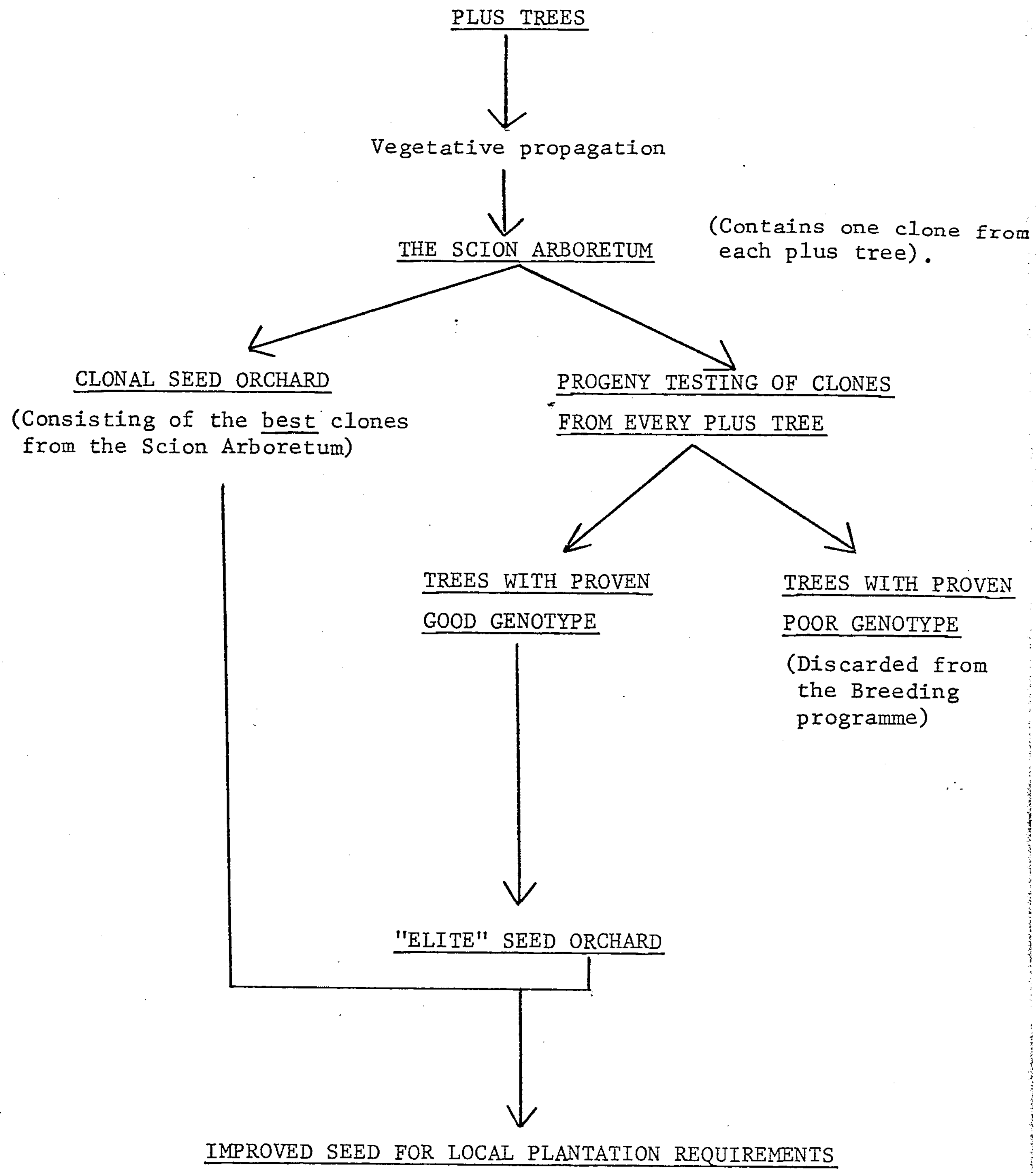
(4) When the trees in the Scion Arboretum are old enough (2 years with P.pinaster), female cones develop. These are control-pollinated with a standard pollen parent. The seed developing in these cones is collected and once again progeny tested (as described above).

(5) The best clones from the Scion Arboretum are further vegetatively propagated. The grafted seedlings from these superior clones are planted out into a Clonal Seed Orchard. Within the clonal seed orchard, trees from different superior clones are randomly intermixed and allowed to pollinate each other naturally.

Seed ultimately developing in the Clonal Seed Orchard is used in local plantation establishment and represents the first source of improved seed from the Breeding programme.

A schematic diagram showing the steps in a Tree Breeding programme is given below.

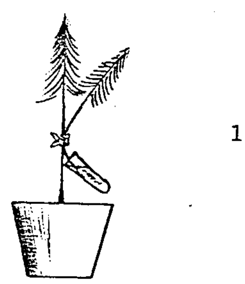
SCHEMATIC REPRESENTATION OF THE TREE BREEDING PROGRAMME



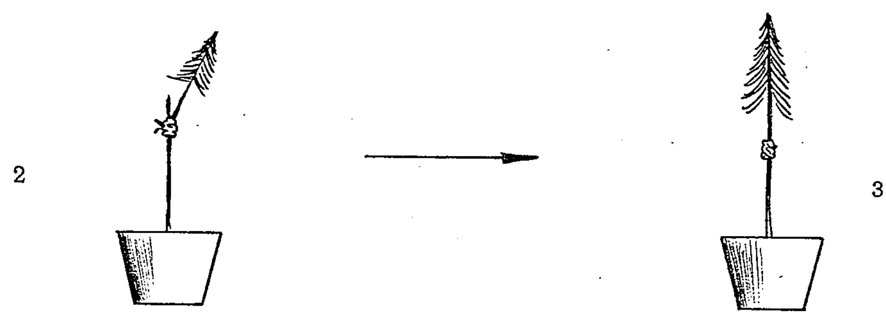
GRAFTING TECHNIQUES

There are several techniques which can be used to graft plus tree scions onto root stocks. The two techniques commonly used in W.A. are Bottle Grafting and Tip Cleft Grafting.

1. Bottle Grafting. The freshly cut scion from the plus tree is fixed into a test tube containing water. A slice is taken off the stem of the scion and off the stem of the stock. These cuts are matched and the union bound with rafia or plastic tape.

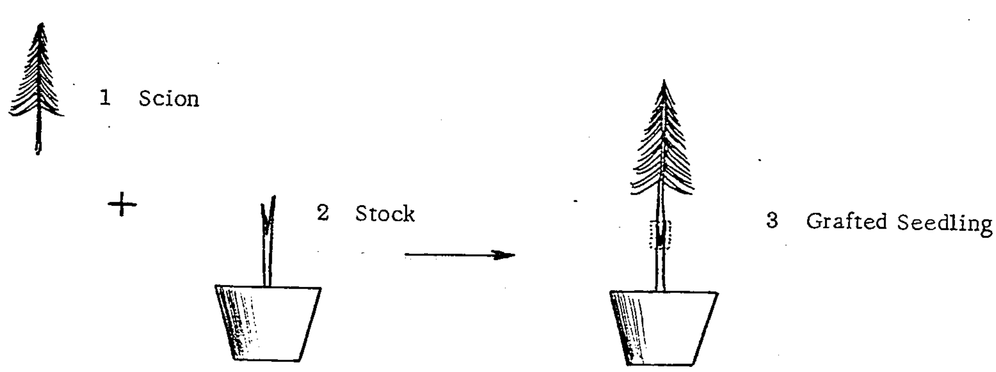


When the graft has "taken" the top of the stock and the bottom of the scion are cut off.



Bottle Grafting is an expensive method, but the percentage survival of grafted seedlings is generally very high. The method is no longer favoured in W.A. for large scale propagation.

2. Tip Cleft Grafting. A cleft is cut into the top of the stock and a wedge fashioned on the base of the scion. The two cuts are then matched and bound with plastic tape.



The Tip Cleft grafting technique is favoured by W.A. tree breeders and is commonly used for the propagation of Pinus pinaster plus trees.

ESTABLISHMENT OF THE SEED ORCHARD

The final stage in the tree improvement programme is to raise a large number of seedlings from the progeny tested plus trees and to plant these seedlings out in a Seed Orchard.

A seed orchard (sometimes called a seed garden) is a small plantation of carefully selected trees especially established and managed for the production of high quality seed for local plantation requirements.

The requirements of a seed orchard are :

(1) Wide spacing between trees (22 x 22 feet for P.pinaster) to encourage wide branching and heavier flowering.

(2) High site quality.

(3) Freedom from contamination from foreign pollen.

(4) Accessability.

(5) Safety from fire and other injurious agencies.

FURTHER READING

1. "Progress in the Application of Tree Breeding in our Plantations" by C.Haley, Australian Forestry 23-24, 1959,60.

2. "The Breeding of Monterey Pine in the A.C.T." by J.M.Fielding. Paper presented to the 7th British Commonwealth Forestry Conference, 1957.

3. "Forest Tree Breeding and Genetics" by R.H.Richens, Joint Publication No.8, Imperial Agricultural Bureaux.

4. "Tree Improvement in the Eastern States of Australia" by E.R.Hopkins, Forest Department of W.A. Report.

5. "Report on Trip to the Eastern States" by D.Perry, Forest Department of W.A. Report.

6. "Genetics of Forest Tree Improvement" by J.W.Wright. F.A.O. Publication (1962).

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