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THE METHODOLOGY OF CONSERVATION OF FOREST GENETIC RESOURCES

Report on a Pilot Study

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS

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REPORT

ON A PILOT STUDY

ON THE METHODOLOGY OF CONSERVATION OF FOREST GENETIC RESOURCES

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ABSTRACT

The purpose of the report is to formulate guidelines to the methodology of conservation of forest genetic resources, as a basis for long-term action on conservation within a global programme. It consists of an introductory part enunciating the general principles of conservation, a central part comprising seven case studies which accounts for two-thirds of the total length, and a final part of guidelines and recommendations.

Conservation should not be considered in isolation but should be an integral part of forest management and of programmes for the improved use of gene resources. Methods of conservation must be adapted to individual cases, and conservation of natural ecosystems in situ, of artificial stands ex situ and of seed in seed banks each has its part to play.

Many of the priorities for research and international action lie in developing countries. There is therefore a need for international financing as well as international coordination. The basis for a pilot programme over a five year period is available in the FAO document "Proposals for a Global Programme for Improved Use of Forest Genetic Resources" and it is recommended that these be implemented to the extent that funds are available. Results obtained in the pilot programme should be used as the basis for planning an expanded long-term programme. It is recommended that UNEP should play a leading role in financing conservation activities. Research, training and the conservation and dissemination of information all need to be given high priority during the pilot phase.

Action for conservation of forest genetic resources should be closely coordinated with complementary action in crop plants, through the International Board on Plant Genetic Resources.

CONTENTS

SUMMARY OF CONCLUSIONS AND RECOMMENDATIONS

A. Technical

1. Conservation, or the "wise use", of forest resources, including forest genetic resources, should be conceived as an integral part of dynamic forest resource management and, as such, should find a place in all forest management plans.

2. Great variation occurs in the complexity of forest ecosystems, in the genetic variability and breeding systems of species, and in the kinds of administrative constraints on effective action. There can be no universal guide to conservation. Methods must be adapted to local conditions. Conservation of natural ecosystems *in situ*, of artificial stands *ex situ* and of seed in seed banks each has its part to play.

3. Assessment of current conservation status is a prerequisite for action to improve conservation. Distribution maps, inventory data and vegetation surveys, maps of Forest and Strict Natural Reserves and of National Parks, are all useful tools in determining the extent to which representative samples of forest ecosystems and their constituent species are already adequately conserved.

4. Where effective measures for protection are possible, *in situ* conservation of whole ecosystems is the ideal method. This should be done through the establishment of Strict Natural Reserves, of recognised legal status, within units of larger area such as Forest Reserves and National Parks.

5. Conservation of forest genetic resources should, whenever possible, be combined with other conservation objectives, such as wildlife and watershed conservation and National Parks.

6. In establishing Strict Natural Reserves in forest ecosystems, provision should always be made to surround the inviolable "core" area with one or more buffer zones, in which the environment of the forest is maintained, while certain forms of controlled utilization, such as selective forest exploitation or tourism, are permitted.

7. For conservation of forest genetic resources, intra-specific variation and the minimum number of breeding individuals for a viable gene-pool must be considered rather than the area of the Strict Natural Reserve *per se*. Judgements as to the relative merits of one large Strict Natural Reserve compared with several smaller separate ones must depend on the circumstances of each case.

8. In some areas local pressure for total clearance of natural forests in favour of agriculture or other forms of land development is so great that destruction of the *in situ* gene resource is inevitable. In such cases steps must be taken to collect seed of endangered species of potential economic importance, before it is too late, and to conserve them in seed banks or by planting artificial conservation stands *ex situ*, in localities where protection and management can be assured.

B. Administrative and Financial

1. The priorities for research and international action relate predominantly, though not exclusively, to the genetic resources of tree species of value in tropical, subtropical, Mediterranean and arid zones.

2. Many of the countries in the above zones are developing countries which have very limited funds available to finance measures for effective conservation. There is thus an urgent need for international financing, as well as international coordination, of action to conserve forest genetic resources.

3. The basis for a five year programme is contained in FAO's "Proposals for a Global Programme for Improved Use of Forest Genetic Resources" (FO: MISC/74/15 of November 1974). It is recommended that these proposals be implemented to the extent that funds can be made available.

4. The above five year programme should be considered as a pilot phase leading to a greatly expanded long-term programme. Progress should be assessed towards the end of the period and the results achieved used as a basis for further planning.

5. It is imperative that plans for action in forest genetic resources be closely coordinated with complementary plans in crop plants. The recently established International Board for Plant Genetic Resources provides the means for overall coordination and direction. It should continue to be advised on forestry aspects by FAO's Panel of Experts on Forest Gene Resources.

6. It is expected that funds for the Global Programme will come from a variety of sources. It is recommended that UNEP assume responsibility for financing those parts of the proposals which relate directly to Conservation of Forest Genetic Resources i.e.

		Total Cost ($ 000) over 5 years
(1)	Seed collection for conservation *ex situ*	125
(2)	Establishment costs of *ex situ* conservation stands of two *Pinus* spp. and two *Eucalyptus* spp., ten provenances in eleven developing countries	356
(3)	Development of pilot projects for *in situ* conservation in Central America, Brazil, India, West and East Africa	310
(4)	Dissemination of information on conservation of forest genetic resources	60
	Total	851

7. In addition, it is recommended that UNEP consider further financial support to those items in the programme which relate indirectly to Conservation i.e.

		Total Cost ($ 000) over 5 years
(1)	Research on seed storage and handling	250
(2)	Research on data storage and retrieval	250
(3)	Establishment of prototype conservation/selection stands *ex situ*	63
(4)	Appraisal of the need for international forest gene centres	50
	Total	613

8. It is recommended that priority be given to the training of staff from developing countries in the specialised field of conservation of forest genetic resources. In a number of countries, the work of maintaining existing Strict Natural Reserves and establishing new ones, and of planting and maintaining *ex situ* conservation stands, justifies the appointment of a full-time forest officer.

9. Principles of conservation of forest genetic resources should be an integral part of courses in forest management given in universities and schools of forestry.

10. In order to decide on the most appropriate methods for conservation under local conditions, there is need for a great increase in research and in the acquisition of field data. In addition to ecological and genetic research, it is recommended that programmes of research in the testing and storage of seed of tropical tree species be developed. At the same time standards for testing and certification and a concomitant nomenclature to ensure repeatability of genetic material should be developed.

11. Conservation measures for forest genetic resources must be accompanied by the conservation of information about these resources and thus by the development of a system for gathering, storing and retrieving information. To assist this development, it is recommended that a pilot project should be established in an institution already engaged in this work and having computer facilities.

INTRODUCTION

In terms of a methodology of conservation, forest trees have a number of distinguishing characteristics. The first is that the vast majority are still in the wild state. Except for a very small number which have been planted both within and outside their range, and diverse ornamental mutant forms, there are very few land races and domesticated species. Secondly until very recent times the biology of most tree species was unknown. Even now only those which are planted as commercial species have been studied in any detail, and, for the most part, the vast majority of tree species are known only taxonomically, particularly those species of the tropics and subtropics.

Most forests of the world from very ancient times have been exploited as a non-renewable resource. That is, they have been mined rather than managed. Hence the emphasis on understanding wood as a raw material, and the ignorance of trees and forests as biological entities. With some major exceptions, particularly in the tropics, this has now changed, and it is increasingly recognised that the forests of the world and their resources must be conserved and managed in perpetuity, and that trees can be selected and domesticated for many purposes just as the wild forms of modern agricultural and horticultural crops have been domesticated.

The question is how can this be done, and to what extent are the past and present methods and current concerns of scientists involved in the exploration, conservation and utilization of non-forest plant gene resources applicable to trees in natural and man-made forest ecosystems. A second question relates to the adequacy of ongoing programmes of exploration, conservation, and utilization of forest genetic resources.

Conservation of forest genetic resources is here understood as a dynamic component of plans for the management and utilization of a renewable natural resource, and is compatible with other conservation objectives, for example, with respect to wildlife, watersheds and protection against erosion.

The report is divided into three parts. Part I deals with the biological background and practical constraints. Part II contains seven Case Studies of forest genetic resources conservation, and Part III deals with guidelines, priorities and recommendations.

It is recognized that the 7 Case Studies presented do not embrace the problems of forest genetic resources conservation in all the major forest ecosystems of the world. For example there is no case study of conservation of the forest genetic resources of the Mediterranean region, or of exotic genetic resources adapted to this region and other more arid areas of the world depleted of forest cover. However, since many of the principles and methods presented have general application this deficiency may be more apparent than real.

The relevance to this report of that project in the UNESCO Programme on Man and the Biosphere (MAB project 8) which is concerned with the conservation of natural areas and of the genetic material they contain is also recognized. Attention is,therefore, drawn to aspects of that project in appropriate sections of this report.

The problems related to developing a methodology of conservation of forest genetic resources are not simple, and as Dasmann (1973) has stated the complexity of the general problems of conservation cannot be overestimated. "Guidelines for the conservation of whales or elephants, for migratory birds, or golden mole rats, for desert annuals, rare orchids, rainforest trees, arctic tundra communities, or antarctic terrestrial invertebrates are not easy to define and may well be impossible to attain. Nevertheless, it is certain that an improvement can be made over our present situation, in which available knowledge is widely scattered and some of the important issues, no doubt, have yet to be formulated" (Dasmann 1973).

It is hoped that the present document will result in the improvement suggested by Dasmann, at least in regard to developing a methodology for the conservation of forest genetic resources.

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PART I

GENERAL PRINCIPLES

1

BIOLOGICAL BACKGROUND

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PRINCIPLES AND PROBLEMS OF GENETIC CONSERVATION

One of the most recent and most comprehensive general statements on plant genetic resources, their exploration, conservation and utilization, is that contained in Frankel and Bennett (1970). The value of this document is enhanced by the fact that it also embraces forest genetic resources, and material from this book relevant to the present discussion is summarized in this section (see also UNESCO 1973).

The important distinction is made between nature conservation and gene pool conservation. "Nature conservation aims to protect areas representing habitats and communities which can be identified. Gene pool conservation goes further. It is concerned with genetic differences which often can only be surmised, but not identified. It is therefore concerned with population samples, possibly along latitudinal or altitudinal transects, often over extensive areas; hence a 'genetic reserve' should include a spectrum of ecological variability so as to provide a spectrum of genetic variability. It may, therefore have to be either extensive, or scattered - the latter, as conservationists know, being difficult to manage" (Frankel 1970).

Nature conservation can, of course, result in gene pool conservation of constituent species. Its efficacy for this purpose is closely related to the size, number and distribution of nature reserves being protected.

Richards (1971) suggested that an area greater than 100 ha would be necessary to include a representative selection of species in a species-rich, high forest ecosystem in Malaya, and that "to be self-maintaining it would undoubtedly have to be considerably larger still". Anderson, quoted by van Steenis (1971) stated that for Sarawak National Parks should not be smaller than 400 ha, except where there is an urgent need to conserve remnants of vegetation of great scientific interest. Van Steenis (1971) recommended an area of 500 ha as the minimum required for a virgin jungle reserve. Petrides quoted by Hepper (see Hedberg and Hedberg 1968) considered 1000 ha as the minimum area for Strict Natural Reserves in Africa. Nichols (personal communication) suggested that 250 ha may be on adequate area for scientific reserves in indigenous forests in New Zealand. Shanklin (1951) has stated that 400 ha is enough for any one type in North America. The United States Forest Service Natural Areas are at least 120 ha. Franklin and Trappe (1968) suggested 200 ha as a minimum.

Thus, while scientific evidence is lacking, there is a fair consensus of informed opinion that representative samples of most forest ecosystems can be maintained if given effective protection in areas within the range of 100 to 1000 ha.

If, however, a species occupies numerous habitats through a wide range of latitudes and altitudes e.g. _Pinus contorta_ in Canada and the United States, a single Nature Reserve of even 1000 ha would not be remotely sufficient to conserve the spectrum of genetic variation in this species. Hence a number of Strict Natural Reserves (SNR)strategically placed to sample the range of ecological variation would be required to conserve the genetic resources of this species adequately _in situ_.

The extent to which the genetic resources of a tree species are already adequately conserved in Strict Natural Reserves and National Parks may be determined in the manner described for the Californian conifers in Chapter 4, and clearly one of the first steps in forest genetic resources conservation is to make this determination.

The principal components upon which a strategy of genetic conservation depends have been identified by Frankel (1970). They are the nature of the material and the objective and scope of conservation. "The nature of the material is defined by the length of the life-cycle, the mode of reproduction, the size of individuals, and the ecological status-whether wild, weed or domesticated. The objective - research, introduction, breeding, etc. - may determine the degree of integrity which it is essential or desirable to maintain. The scope is the time scale over which preservation is projected, and the area, or space, to which it relates - a locality, a region, the world. The strategy will determine methodology, including the size of a population or sample which it is appropriate to preserve; in particular, whether to seek the preservation of a population as such, or of its genetic potential".

There are a number of ways in which genetic resources may be conserved, and the methodology chosen will be determined by the factors referred to above. The ideal method of long-term conservation is conservation _in situ_. "There can be little doubt that valuable gene pools of the wild plants we use in forests, pastures and elsewhere, and those which are related to our domesticated plants, not only should be preserved in perpetuity, but as far as possible with the genetic integrity of their natural state. A community in balance with a stable environment - the stability being subject to the general vagaries of natural environments - is the ideal model of long-term conservation" (Frankel 1970).

The ideal model, however, is frequently not attainable, and there are numerous examples of forest tree species which are cultivated in many parts of the world as important commercial species while undergoing massive genetic impoverishment in their natural habitat. For a significant number of forest tree species of commercial importance, both hardwoods and softwoods, the centres of genetic diversity lie outside the areas where they are planted. For such species _ex situ_ conservation is frequently essential (see Chapter 8 and the discussion of _ex situ_ conservation of the genetic resources of _Pinus radiata_, _Cupressus macrocarpa_ and _Sequoiadendron giganteum_ in Chapter 4 and of _Picea glauca_ in Chapter 3).

In the case of _ex situ_ conservation of forest trees the objective is by careful selection of the plantation zone, and by the development of appropriate techniques of cultivation, to prevent losses rather than to maintain specific gene frequencies - which in any case is impossible to achieve, as Frankel (1970) has pointed out.

On the other hand for the gene resources of a large number of tropical hardwoods, which are being subjected to heavy exploitation and disruption or destruction of their ecosystems, _ex situ_ conservation is not possible at the present time. Not enough is known of the biology of individual species and appropriate silvicultural techniques have not been determined. Furthermore, many of these species are constituents of climax forests, and the conservation of their genetic resources depends on the continued integrity of the ecosystems to which they belong. The development of a methodology for the conservation of tropical hardwoods, therefore, poses a number of complex problems which are discussed in Chapter 6.

In many respects the genetic resources of light demanding, colonizing tree species with wide ecological amplitude are more easily conserved than species of the climax forest, for they are more easily cultivated, and local seed sources can be used to regenerate a logged area. It is not necessary, therefore, to conserve an ecosystem to ensure their perpetuation. If these species are regenerated naturally and left unmanaged they will, of course, in time be superseded by species of the climax forest. A methodology for the conservation of the genetic resources of a colonizing species, _Pinus banksiana_, is described in Chapter 3 and, although this species is a conifer, the general principles discussed in this case study are likely to have wide application, not only to other colonizing conifers, but also to broadleaved species with similar ecological status, e.g. the light demanding, colonizing, short-lived species of the tropics.

Agriculturists are concerned with the conservation of primitive cultivars or land races. These are the products of man's interaction with the wild ancestors of these modern forms. In some instances the wild forms have been lost to man, while even land races are now being eliminated under the impact of plant breeding and modern agricultural techniques. Land races, which are of such vital importance in agriculture are not, in conservation terms, of great importance in forestry, though their existence is known and documented in a number of cases. The search for primitive forms of modern cultivars in agriculture does, however, underline the importance of conserving where possible samples of the gene resources of natural forest ecosystems which are being replaced by plantations of selected material (Roche 1971).

There are obvious limits to conservation and compromises between technical, administrative and economic factors will be repeatedly necessary. But as emphasized by Frankel (1970) there is one area in which compromise seems wholly inappropriate, and that pertains to storage facilities for seed. Such facilities in relative terms are not unduly expensive and the facilities required are not complex. Despite this the number of major forest tree seed banks in the world is very small and virtually non-existent in the tropics. Yet as Frankel (1970) has concluded "For all plant gene pools which need and deserve conserving and which cannot be conserved in their natural habitat, the most effective, and in many instances the only effective, manner is in collections wherever and whenever possible maintained in storage". Harrington (1970) has discussed in some detail the methods of seed and pollen storage for conservation of plant gene resources and Chapter 9 of the present report deals specifically with the storage of forest tree seed and pollen. It is clear from this study that storage of forest tree seed and pollen is a valuable method of conservation of the genetic resources of certain species. It is not yet known, however, because of lack of research results, to what extent the method can be used for many tropical species which at the present time rapidly lose viability in storage.

The increasing manipulation of forest genetic resources in programmes of exploration, conservation and utilization has necessitated the development of a nomenclature paralleling that for agricultural and horticultural crops. A recent attempt to codify this nomenclature has been made by Jones and Burley (1973). Fig 1 summarises their recommendations.

The conservation of forest genetic resources must be accompanied by the conservation and dissemination of information about these resources. This problem has been discussed in general terms by Finlay and Konzak (1970) and Burley et al (1974) have summarised the literature pertaining to information collection, storage and retrieval in forestry, and indicated the value of computer based programmes in relation to information retrieval in forest genetic resources conservation and utilization. These authors also give a working example of an international data bank at the Commonwealth Forestry Institute on tropical tree species and provenance research.

The methods of scientists involved in the exploration, conservation and utilization of non-forest plant gene resources are often applicable to the genetic resources of forest trees, and have in fact been applied in many parts of the world as is indicated in the case studies (see also Kemp et al 1972, Fowler and Yeatman 1973, Roche 1971). Furthermore, the concern of foresters for the conservation of natural forest ecosystems, particularly in the tropics, is now shared by ecologists and wildlife managers. Cooperative effort is necessary, for as Richardson (1970) has pointed out, the difficulties in the reservation of stands solely for use in forest genetics make it necessary to combine these objectives with resource conservation for other scientific and economic purposes, e.g. wildlife management, recreation and amenity, water conservation and catchment protection.

ECOLOGICAL NICHES OF FOREST TREES

It is not inappropriate to discuss the concept of the niche under the broad heading of genetics, for the characteristics of the niche determine the genetic architecture of the species and its populations. The niche is defined as the environmental conditions that permit a population to survive permanently and with which this population interacts (Stern and Roche 1974). The width of a niche may often be determined by investigations of one or more environmental components. An example is provided by the length of the growing season, which is taken to begin when the temperature sum reaches a certain level in the spring and to finish when a critical day length is reached in the Autumn. Adaptations to length of growing season may also depend on early and late frosts. Thus there are at least four niche factors which must be considered; date and size of the temperature sum needed to initiate the vegetative and reproductive cycle (Figs 2 and 3) frequency and distribution in time of spring frosts and date of the critical day length in the Autumn.

Frost does not occur at low altitudes in the tropics, and is, therefore, not a niche factor in this zone, but there are numerous others which prevail and which have allowed specialization for a multitude of narrow niches and, as a result, a greater degree of speciation than in the north temperate zone.

The concept of the niche in the present context is important for two reasons. First it is basic to an understanding of inter- and intraspecific genetic variation and its conservation, and secondly it shifts the emphasis from the traditional approach in forest ecology to ecological genetics. This shift in emphasis is necessary if Frankel's (1970) distinction between nature conservation and gene pool conservation referred to above is to be incorporated in a methodology of forest genetic resources conservation. The point is illustrated in Chapters 3 and 4, where it is indicated that experimental data on the genetics of the species provided the criteria for decisions on *ex situ* and *in situ* conservation of valuable forest genetic resources.

INTRASPECIFIC VARIATION AND ITS CONSERVATION

Almost all species of forest trees which have been investigated have shown intraspecific variation. Nearly always the variation is striking and easily demonstrated. Its causes are less easily demonstrated, though often understood. Most experimental work has been carried out on species of the north temperate zone. However, the relatively few tropical species that have been investigated also show intraspecific variation. This poses a major problem in relation to genetic resources conservation both *in situ* and *ex situ*. The case studies describe how the problem can be overcome for particular species and regions, and in at least one country of the north temperate zone there is a well-planned national programme of forest genetic resources conservation designed to conserve the full spectrum of genetic variation of the four principal commercial species that lie within the national territory. The importance of this programme warrants its description in some detail, for it could be emulated with advantage in countries with similar ecosystems and, while its entire methodology does not have relevance in the tropics, much of it is also relevant to these ecosystems.

In Finland stands of natural origin representative of each of the broad climatic zones of the country have been selected and protected from felling (Fig. 4). No stand is selected that may be contaminated by pollen from adjacent non-native plantations. In most cases these standard stands consist of a plot 100 by 100 m, with a surround 100 m wide, sited in an extensive block of forest of native origin. The effective size of "buffer zone" is thus much greater than the 100 m surround protected from felling, and the standard stand is simply a sample of a larger area of forest throughout which genetic integrity is maintained for all practical purposes.

Following measurements and mapping, each stand is permanently registered. All seed for experimental purposes, including genecological research, is collected from these standard stands, and kept separate by trees if sufficient seed is available. When a standard stand becomes overmature, it is regenerated either naturally or artificially using seed from the same stand, and only seed from the standard stand is presently used to establish local plantations (Hagman 1971). In time improved strains from local sources will also be used.

The merit of the Finnish programme of forest genetic resources conservation is that it is thought out and planned at a national level and forms part of a dynamic forest management plan. It provides the basis for a programme of genetic improvement and utilization which is part of, not separate from, the national reforestation programme. Phenological investigations of the reproductive and vegetative cycles in the different climatic zones provide criteria for decisions on where to establish seed orchards and what provenances to include in them (see Figs 2 and 3). In this way intraspecific variation is known, conserved and utilized.

POPULATION STRUCTURE AND EFFECTIVE POPULATION SIZE

These are major problems which relate to both *in situ* and *ex situ* conservation, and which have been discussed in some detail by Stern and Roche (1974), Koski (1974), and Dyson (1974). The genetic structure of a population is determined by its environment and one or more individuals may be an adequate sample of that population, depending on its mating system which itself is under genetic control. In general terms three types of mating systems may be distinguished in forest trees: (i) random mating where every individual mates with the same probability with every other individual of the opposite sex (ii) genotypic assortative mating where the probability of mating is determined by the degree of relationship (negative genotypic assortative mating occurs in obligate cross-pollinators, positive genotypic assortative mating in self-pollinators) (iii) phenotypic assortative mating, positive and negative, where phenotypic characters are responsible for the deviation from random mating (Stern and Roche 1974).

The mating systems of a number of coniferous species of the north temperate zone have been studied in considerable detail for many years. Furthermore, long-term genecological investigations combined in recent years with the latest isoenzyme techniques of population analysis have elucidated the patterns of intraspecific variation particularly in *Picea abies* and *Pinus sylvestris*. Despite this detailed research over a long period of time, there is still no general agreement among workers as to what constitutes an effective population size, and to the sizes of areas required to ensure the perpetuation of particular populations of these species in a given ecosystem. The best summary of available information has recently been given by Koski (1974) who concluded:

> "Empirical material collected from areally continuous, natural forest populations concurs in many respects with the model based on large effective population size. This pattern as such, however, cannot be applied to all forests. Crossing cannot occur on an equally large scale, especially when the whole area of dissemination has shrunk to small or separate islets. The mating pattern certainly takes an essentially different from also if the mean density of the population is very small, e.g. one tree per hectare. No estimate can be advanced at present as to how thin the population can be, or how great the gaps may be in a forest before the pollination situation and the population structure change. In any case, the prerequisites for the existence of great effective populations prevail in enormous, important forest areas in the North American and Eurasian continents" (Koski 1974).

Most trees of the north temperate zone are wind pollinated and cross pollinators to one degree or another. Thus their effective breeding population in a continuous forest is large as suggested by Koski (1974) and Toda (1965) who suggested a population of 10,000 individuals. On the other hand few tropical hardwoods are wind pollinated and the majority are pollinated by insects, birds and bats. Unlike northern coniferous species, tropical species may occur as widely scattered individuals, in many instances only one every one or two hectares (see Table 1 Chapter 6). Furthermore, though all forms of mating systems are prevalent in tropical hardwood species, there is evidence that autogamy is common and hence the effective breeding population is likely to be small compared with species of the north temperate zone. Ashton (1969) has characterized the situation in the Dipterocarp forests of southeast Asia as follows: "An unspecialized pollination system in which autogamy is usual, but outcrossing between individuals of a clump, and to a lesser but significant extent, between clumps of a population frequent enough to allow gene exchange throughout populations in a continuous habitat" (see Fig 2 Chapter 6).

As already indicated, the mating system itself is under genetic control, and can change under pressures of the environment. Examples of two well documented tropical species will suffice. Theobroma cacao is an equatorial species with its distribution centre in the lower elevations of the eastern slopes of the Andes Mountains. Here the species shows broad genetic variation and is self-incompatible. With increasing distance from the centre, the proportion of self-incompatible individuals diminishes, as does the genetic variability of the population. Theobroma is pollinated by midges. Cross pollination is possible only when trees in a stand occur in groups as in the case of the central area. Thus the lower population density towards the end of the range may have caused the observed increase in the proportion of self-fertile trees. It is noteworthy that these peripheral populations are also self-fertile when introduced to other areas. In the case of Hevea brasiliensis, another species of the tropical rainforest that has been investigated, apparently similar conditions prevail (Cope, 1962a, b, Purseglove 1964, cited in Stern and Roche 1974).

These examples have been given to illustrate some of the important biological factors that have a direct bearing on genetic resources conservation. For the majority of tropical tree species there is a paucity of experimental data of the kind given for Theobroma and Hevea, and for Picea glauca and Pinus banksiana in Chapter 3. This is a major obstacle to the development in the long run of a scientific methodology of conservation and utilization of the genetic resources of these species. Clearly, however, as is emphasized above and in Chapter 6, conservation action cannot be delayed until more information is available on the population structure and on effective population size of tropical hardwood species. A methodology capable of immediate application is required. Such a methodology, with particular reference to Africa, is described in Chapter 6, which also outlines a supporting research programme. In this connection attention is drawn to Hedberg and Hedberg (1968) and Finol and Melchior (1969, 1974). Both of these works are important source documents in relation to in situ conservation of the genetic resources of tropical hardwoods. The former deals with conservation of the vegetation in African states south of the Sahara, and the latter describes the methodology of forest genetic resources conservation proposed for the hardwood species of a Latin American country.

Allard (1970) has discussed in some detail the problem of population structure and the sampling of genetic variability. He also gave an example of a sampling methodology for wild oats (Avena fatua) in Central California based on quantitative studies of intra-specific variation in that species. He concluded that most of the significant genetic variability in wild oat species, in an area in California extending approximately 600 km in a north-south and 200 km in an east-west direction, was likely to be included in a sample of one million seeds, provided the sample was structured as follows: Ten seeds (one panicle) per plant, 200 plants per local population (defined as occupying a site approximately 50 x 50 m), 5 local populations per region (defined as an area of approximately 5 x 5 km) 20 regions per east-west transect and 5 transects distributed at more or less 200 km intervals from northern California to the Mexican border. The distance between transects might be less than 200 km in areas of rough topography and greater in the flatter terrain.

It is doubtful if such specific recommendations could presently be made for a single tree species, including those that have been studied intensively e.g. Pinus sylvestris and Abies excelsa. Even for other agricultural crops "the number of cases which have been studied in enough detail to provide the required information is distressingly small" (Allard 1970).

Allard's example is, however, important in regard to the provision of sampling guidelines in general, for as he has indicated "... In formulating sampling procedures for unstudied or incompletely studied cases, there is no practical alternative to developing plans from well-studied cases and extrapolating from them to cases where basic information is not available. Guidelines obtained in this way, while far from what we should prefer, are better than entirely arbitrary guidelines, particularly if they are applied with biological common sense".

Therefore the absence of data, based on research results, allowing reasonable estimates of effective population size and genetic diversity in forest trees, particularly those of the tropics, must not deter the implementation of programmes of conservation. Precise information will be lacking for a long time to come and meanwhile conservation measures are urgently required. The suggested guidelines contained in Part III are intended to provide a basis for immediate action. They will be subject to modification in the light of experience and to meet local conditions.

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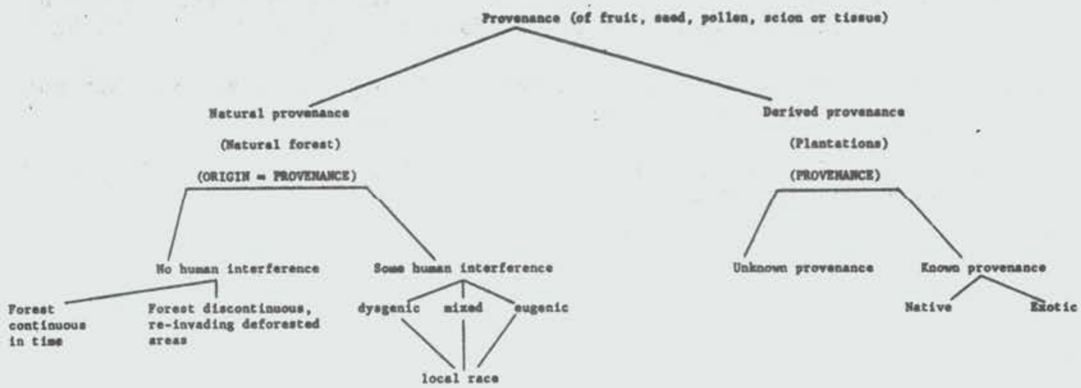
Figure 1. From Jones and Burley (1973)

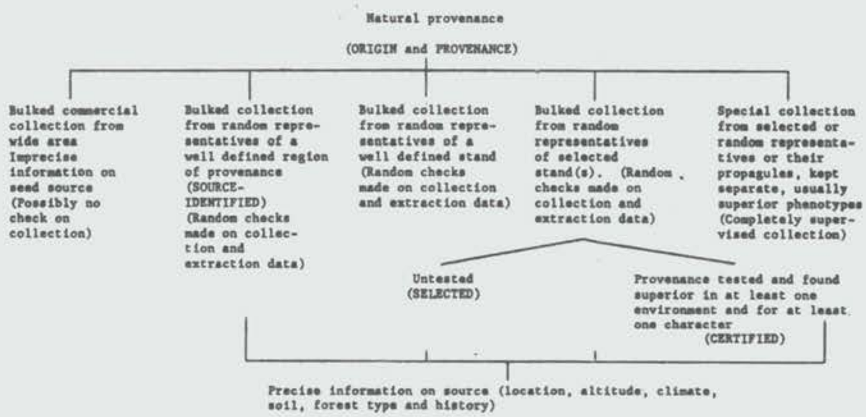
A stylised classification of genetic history

A. Classification into natural and derived provenances



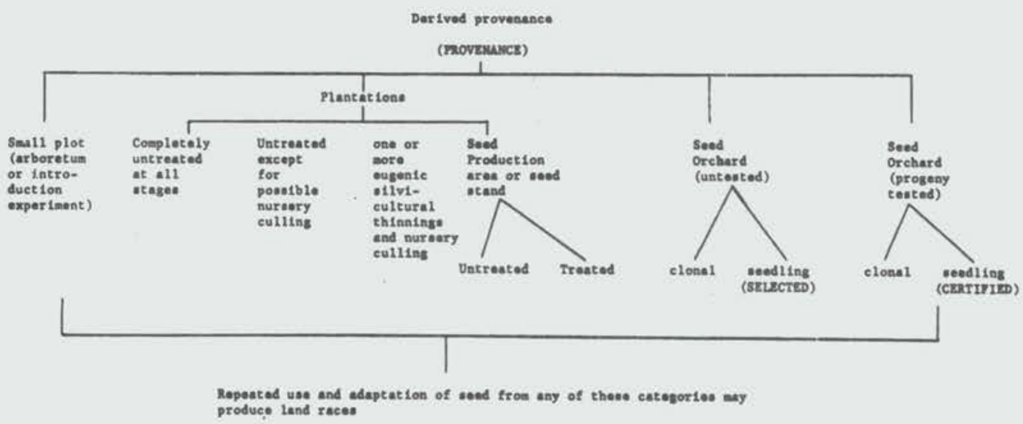
N.B. The entire system or any level of it could be repeated for parentages of 1 parent tree, 2-10 parent trees, or more than 10 parent trees; similarly by year of collection. Equivalent terms from the O.E.C.D. system are given in capital letters in brackets.

B. Sub-classification of natural provenance



N.B. Information, value and uniformity increase from left to right.

C. Sub-classification of derived provenance



N.B. Information, value and uniformity increase from left to right.

Figure 2. Picea abies, Provenance Brouard. 1, 1964. Cumulative frequency distribution of temperature sums of syngamy, that is, the fusion of the fertilizing nucleus derived from pollen (see Fig. 3). The temperature sum is expressed in degree days, the mean in this instance being 401. In this manner the reproductive cycle of a natural population of forest trees is monitored in relation to a major environmental factor prevailing where the population occurs, and to which it is adapted (From Sarvas 1968).

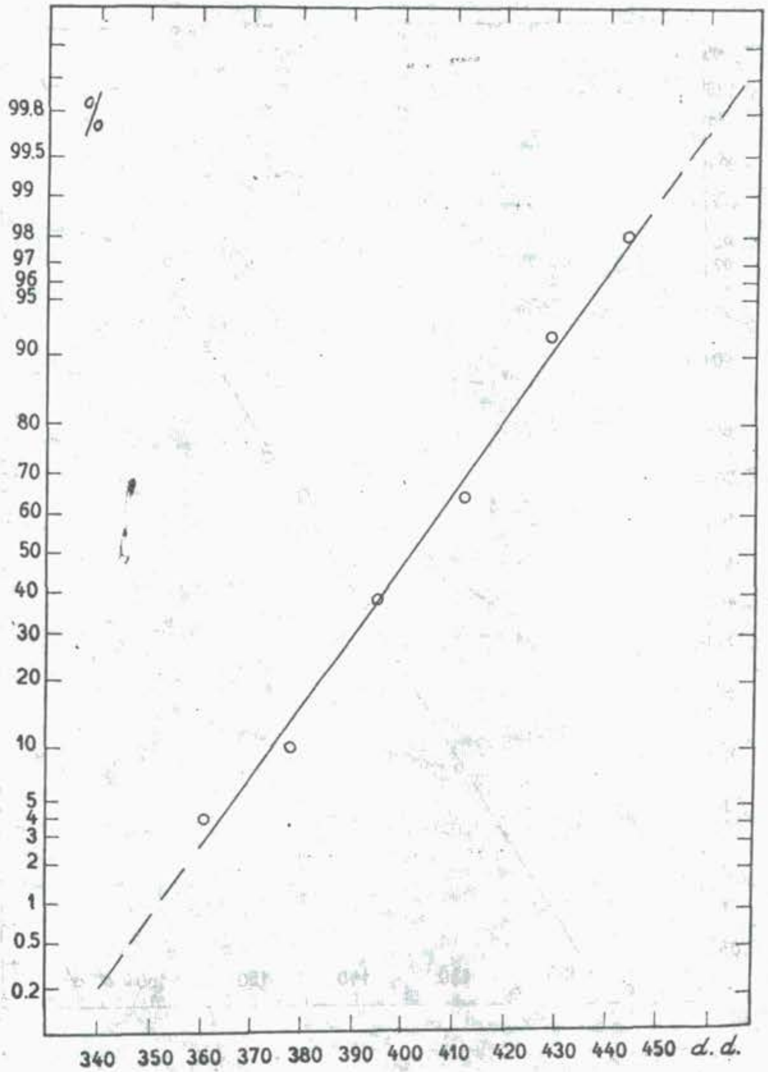


Figure 3. Picea abies, provenance Tuusula xxx, 1962. Cumulative frequencies of the temperature sums of the pollen catches, on frequency paper. The mean obtained from the levelled line is = 131.5 d.d. (degree days), and the standard deviation of the distribution S = 9.0 d.d. Observations such as those given above and in Fig. 2 effectively characterize the population and provide criteria for location of seed orchards and for selection of provenances for inclusion in these seed orchards (From Sarvas 1968).

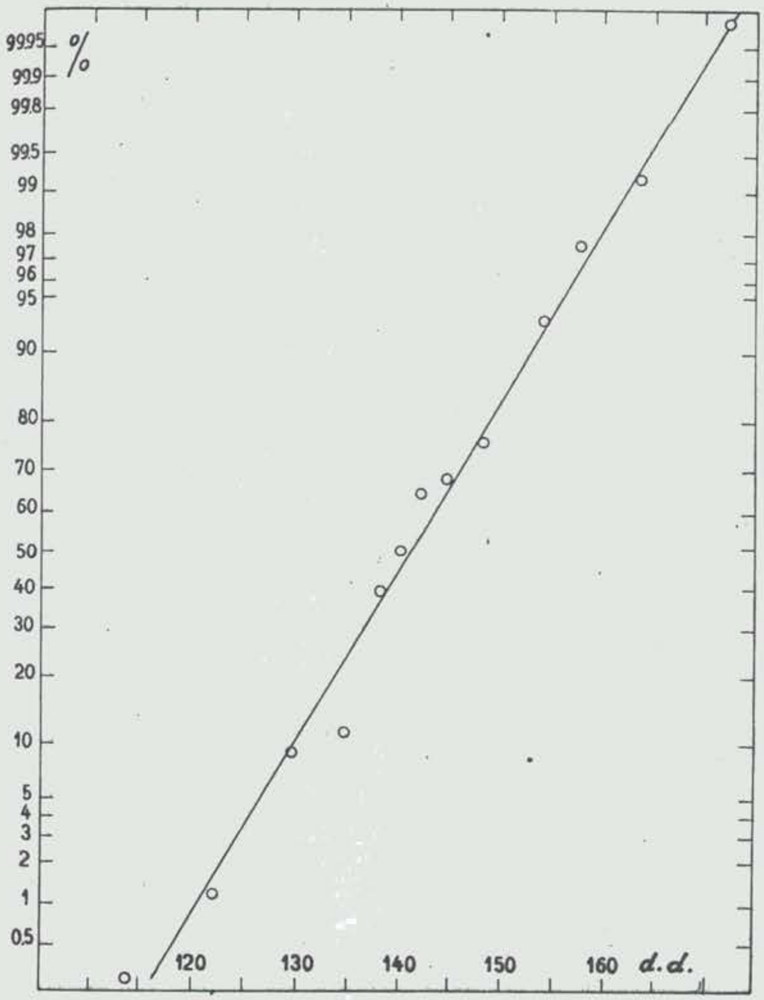
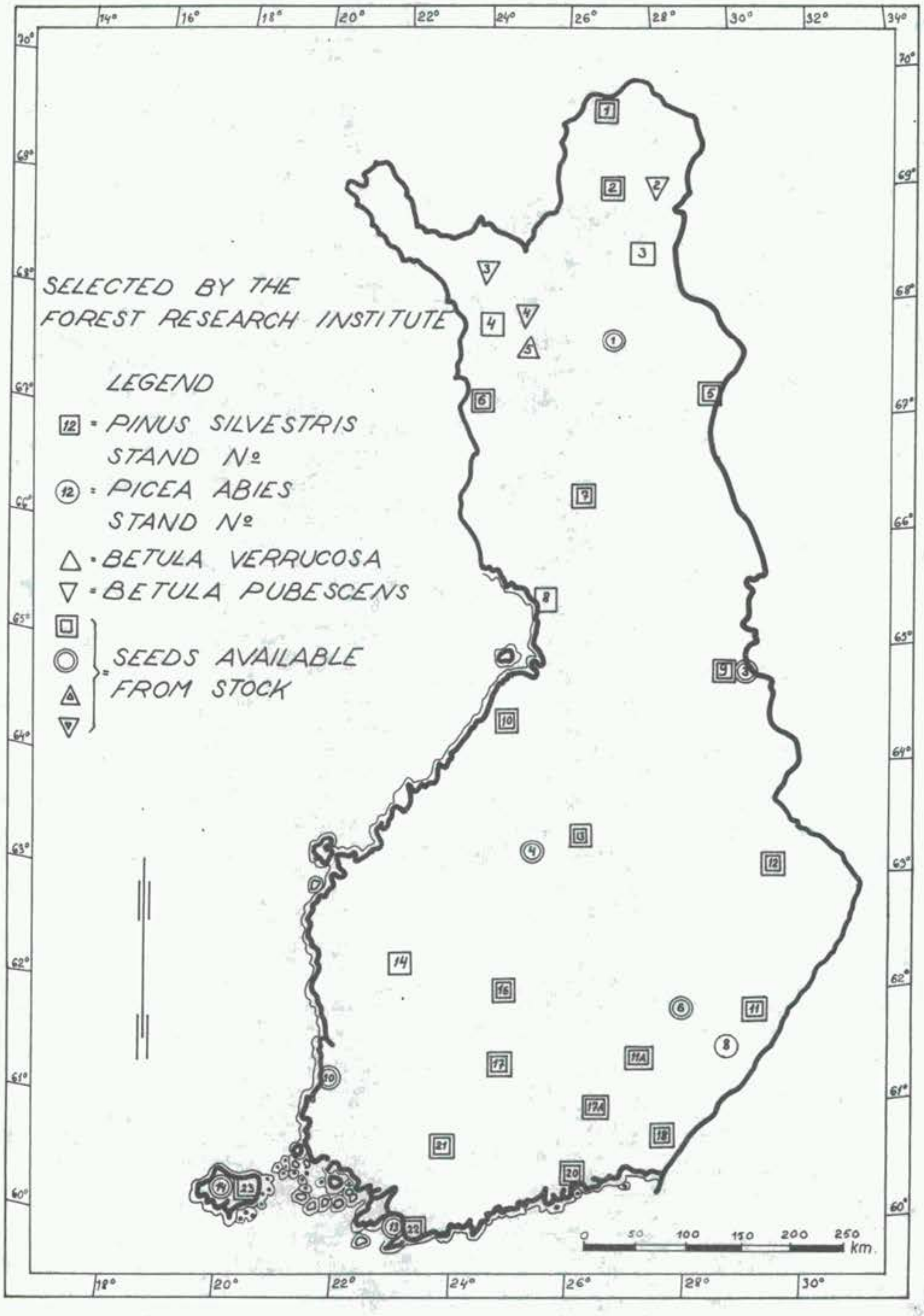


Figure 4. Finnish Standard Stands for Provenance and Progeny Experiments and Conservation of Gene Resources (From Hagman 1971).



2

PRACTICAL CONSTRAINTS

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COMPETING DEMANDS FOR FOREST LAND

With the current rapid population increase and the demand for higher living standards, economic pressure for the conversion of forest land to agriculture or other uses and for the short-term destructive exploitation of the forest crop poses an acute threat to the objectives of genetic conservation in many areas. The pressure can be resisted only if conservation of gene resources can be seen as an integral part of long-term dynamic resource management.

This emphasises the need to combine conservation with other non-destructive activities such as tourism and silviculture, wherever possible. On the other hand, where conservation is defined as the dominant objective of management, as in a Strict Natural Reserve, standards of protection and management must be strict and uncompromising.

EDUCATION, PUBLIC OPINION AND POLICY

Education, public opinion and policy are interdependent, as Dasmann (quoted in UNESCO 1973) has pointed out in relation to the programme of Man and the Biosphere "There seems no way of speeding these commitments except by public demand from within each nation, and this requires a growing level of public awareness not only of the problem but of the means and machinery required for its solution".

In the context of forest genetic resources conservation, education and dissemination of information must take three forms. The first is concerned with public awareness of the problem. The second is concerned with developing awareness of the problem and the techniques for its resolution among senior government officials responsible for the management of the national forest estate. The third is concerned with undergraduate education and postgraduate research in forest genetic resources conservation and utilization. On all three forms the activities of international organizations (FAO, IUCN, IUFRO, UNEP, UNESCO) can have a significant impact.

The developing educational programme of Man and the Biosphere (UNESCO 1972a) will have an important role in educating the public on the needs of genetic conservation. That section of the International Biological Programme concerned with the conservation of terrestrial communities (Nicholson 1968) has already done much in this respect. Franson et al (1973) have shown how important was the role of this programme in the designation of Strict Natural Reserves and the formulation of their legal status in British Columbia. The full participation of professional forestry organizations in such programmes which have an important public education component must be increased and intensified (see Weetman 1970, Roche 1971, Fowler and Yeatman 1973).

An analysis of the problem of forest genetic resources conservation and its methodology at a national level can do much to formulate government policy (see FAO, 1969, 1972, 1974).

The detailed and practical programme for Venezuela drawn up by Finol and Melchior (1974) is a case in point. The great merit of this programme is that it is based on a pragmatic assessment of what is immediately possible within present government structures, and the ongoing forest management plan. As the authors stated " ..... we insist that national forest policy in conservation aspects should be based on nationally managed forest reserves". It is worth repeating here what is emphasized in Chapter 6 in relation to tropical hardwoods, that in most countries in tropical Africa and other parts of the world the forest estate is controlled by government departments of forestry, while in some countries part of it is under the control of National Parks administrations. Effective measures for the conservation of forest genetic resources, therefore, can be implemented only through the agency of these government departments. Any proposed methodology must recognise this fact.

LEGAL

There are a number of important legal constraints to *in situ* and *ex situ* forest genetic resources conservation. Chapter 6 refers to the vulnerability of Strict Natural Reserves (SNR) in Nigeria and Uganda because their legal status does not ensure their inviolability. SNR in Kenya on the other hand have the formal protection of law, and a legal status different from that of the forest reserves in which they are situated.

Franson *et al* (1973) in a symposium on forest genetic resources conservation have examined the legal and administrative requirements for gene pool maintenance. This is an important reference document as it combines both a knowledge of legal problems and the ecological imperatives of genetic resources conservation. The authors pose the following questions in relation to the setting up of SNR:

(i) "How are selected areas to be given long-term tenure and legally enforceable protection against encroachments from external and incompatible land-users?"

(ii) "How is on-site use of an ecological reserve, after its establishment, to be regulated to ensure perpetuation of those features for which the reserve was selected?"

The answers to these questions in a Federal context have been outlined by the authors, and reference is also made to the manner in which the British Columbia programme has provided legal guarantees for SNR. The authors concluded, however, that many questions remain unanswered concerning SNR, making it more difficult to convince government officials of their validity. These officials

> "..... would like to know how much the programme will cost; yet the uncertainty about the appropriateness of classification schemes (and one could add effective breeding population, etc.) makes it impossible to give realistic estimates of the number of plant communities that must be protected and consequently of the total land area that will be required. Other questions involve the use that is to be made of the sites. For example, how often is it realistic to assume that educational use can be made of the sites by our secondary schools? Or, ... are the research needs of plant breeders compatible with the management criteria to be established for ecological reserves, or will additional land be necessary for them. The sooner firm answers can be provided to these questions and others like them, the sooner we will be able to convince public officials that the ecological reserves programme is well thought out and worth establishing".

There is clearly a need for further examination of the legal requirements of SNR, and when appropriate legislation has been promulgated, as for example in the U.S.A., Canada and Kenya, it should be examined for applicability to requirements elsewhere.

Legislation pertaining to seed certification has important implications in regard to forest genetic resources conservation, and there is a need to examine legislation such as that drawn up by the OECD countries in relation to the requirements of other nations particularly in the developing world. An excellent review of the entire question of forest tree seed certification, provenance nomenclature, and genetic history has been given by Jones and Burley (1973). Government officials in developing countries considering the need for legislation in this field will find this document most useful.

FINANCE AND STAFF

The lack of sufficient financial measures and appropriate professional and technical staff are major constraints in forest genetic resources conservation, particularly in tropical countries. Hence these countries will need assistance to train staff and to implement conservation measures. Furthermore, if those institutions in non-tropical countries, which are already involved in forest genetic resources conservation, are to initiate or increase activities in tropical forest ecosystems, they will also require increased assistance from home governments or international agencies.

Lack of a clear policy on conservation of forest genetic resources and lack of finance and staff to implement it are usually interdependent. Provision of staff and finance can itself lead to the strengthening of government policy and the education of public opinion on conservation.

RESEARCH

Many of the difficulties encountered in the formulation of a methodology for the conservation of forest genetic resources, particularly in the tropics, result from the lack of data on the genetics and ecology of tree species and ecosystems. This applies not only to the non-commercial but also to the major commercial indigenous species. Yet in the short run it is not the lack of research results that is a major constraint but the lack of synthesis and codification of all available information which has a bearing on the problem.

There is a major need for this kind of synthesis and codification to precede, or be initiated simultaneously with, the development of research programmes. The works of Hall (1974), Hall and Redhead (1974) and IYAMABO and Ola-Adams (1974) on tropical hardwoods in Nigeria are good examples of synthesis and codification of relevant information which is prerequisite to implementing a programme of genetic resources conservation, and to the development of a supporting research programme. International support for such work should be made available to workers in specific regions, and for particular species or groups of species.

In the long run, of course, lack of research results will constitute a major constraint in forest genetic resources conservation and there is a need to develop research programmes in the following areas:

(i) Seed storage and testing particularly for tropical species

(ii) Intraspecific variation and its causes

(iii) Breeding systems

(iv) Phenology of fruiting and flowering

(v) Effective population size

(vi) Size of Strict Natural Reserve to ensure integrity of ecosystem

(vii) Size of buffer zone surrounding such reserves

(viii) Sexual and vegetative propagation

(ix) Feasibility of seed orchard establishment for particular species

(x) Management of natural forest ecosystems in the tropics.

If such research is to be initiated on the scale required and if results are to have a positive effect on forest genetic resources conservation within the next fifteen years, then international support both technical and financial will be immediately necessary.

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PART II

CASE STUDIES

3

IN SITU AND EX SITU CONSERVATION OF GENE RESOURCES OF PINUS BANKSIANA AND PICEA GLAUCA

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INTRODUCTION

Increasing world-wide demand for forest products and conversion of forestland for agriculture and urbanization in many parts of the world is causing concern among resource managers about shrinking productive forest base. Examples of the extinction and paucity of certain ancestral types for the genetic improvement of agricultural and horticultural material, with a long history of selection and intensive culture (F.A.O. 1969, Frankel and Bennet 1970), has lent support to growing concern for the conservation of forest gene resources in Canada (Fowler and Yeatman 1973) where almost all of the forest being harvested is primeval and intensive utilization rather recent (Maini, 1973). This report briefly describes the forests of Canada, their composition, utilization and the extent and nature of natural and artificial regeneration. Attention is focussed on the conservation of gene resources of two commercially important species, namely *Pinus banksiana* Lamb. (jack pine) and *Picea glauca* (Moench) Voss (white spruce).

THE FOREST SCENE

The Forest Resource

Forests are the most predominant feature of the Canadian landscape extending 7240 km (4500 miles) from east to west and covering 48% of the 922 million ha. (3.56 million square miles) of Canada's land surface. About 50% of this forest land is capable of producing merchantable wood under present utilization standards (Anon. 1970). Most of Canada was covered by ice during the Pleistocene and the present forests are characterised by their relative youth; in the boreal forests the land has been under trees for between 5,000 and 10,000 years (Maini 1968). About 130 native tree species constitute Canada's native forests and most commercially important species, except those on the west coast, are widely distributed (Carlisle and Maini 1974).

Impact of Man

Prior to settlement by Europeans, the activities of indigenous man apparently had little impact on Canada's forests, particularly from the viewpoint of gene resources. Following settlement, almost 2% of the total forestland in Canada has been cleared for agriculture and urbanization. Not even a single plant species has become extinct in eastern Canada since European settlement (Rousseau 1966) and this observation is apparently equally applicable to the rest of Canada, particularly to tree species. However, the above-mentioned human activity and selective cutting of certain southern hardwoods for the furniture industry has undoubtedly resulted in some impoverishment of forest tree gene resources in local populations.

At present about one million ha. (2.5 million acres) of productive forest are harvested annually (clear cut 87%; selection cut 12%; other 1%). From the viewpoint of gene resources, it is significant to note that of the total area of forest harvested, 69% regenerates naturally, 14% is planted, seeded or silviculturally treated for seedbed preparation (for natural seedings) and another 17% of the land requiring treatment is left untreated (R. Waldron, Personal Communication). It is estimated that nearly 300 million tree seedlings will be planted in Canada during 1974.

Pinus banksiana and Picea glauca have a trans-continental distribution and rank high in commercial value. Pinus banksiana is an intolerant pioneer species that reproduces well following fire and is commonly found in extensive pure stands. Some 16,000 ha. (40,000 acres) of cut-over forest is planted or seeded annually by Pinus banksiana and this area is expected to increase to 27,000 ha. (67,000 acres) by 1980. In contrast, Picea glauca is relatively shade tolerant and grows in association with a number of other conifers and deciduous tree species. About 26,000 ha. (64,000 acres) of cut-over forest is planted or seeded annually by Picea glauca and this area is expected to increase to over 40,000 ha. (100,000 acres) by 1980. Because of the commercial importance of these species and the magnitude of the programmes for artificial regeneration, certain measures have been initiated to conserve selected gene pools of jack pine and white spruce in situ (population regenerated naturally or artificially in place of origin) and ex situ (population sample planted and identity perpetuated artificially at location(s) other than the original). These measures are based on present knowledge of the genetics and ecology of the two species and the current status of populations of particular value for future supply of high-quality seed.

IN SITU PROVENANCE CONSERVATION IN JACK PINE

Silvics

This two needle pine has a transcontinental distribution in Canada and northeastern United Sates and is an important source of timber and fibre throughout much of this range (Figure 1). Present utilization is expecially intense in Ontario with an annual cut of some 4 million cub. m. (1.4 million cunits), 80% pulpwood, which accounts for one third of all wood harvested in the province (Anon. 1972, 1973).

Jack pine (Pinus banksiana Lamb.) is intolerant of shade, adapted to well drained, light soil of low fertility (Rudolf, 1958). The climate within the natural range varies from maritime in the east to cold continental in the north and northwest. In nature, regeneration commonly follows fire in standing timber when seed is released from closed serotinous cones. The resulting forests form even-aged stands of pure jack pine or in mixture with other pioneer species such as aspen (Populus spp.), birch (Betula spp.) and black spruce (Picea mariana (Mill.) BSP). Sporadic regeneration occurs on suitable seed-beds in the absence of fire, especially from young sapling that more frequently bear open cones than do older trees.

Natural regeneration after harvest by clear cutting is frequently inadequate and poorly distributed, necessitating additional planting or direct seeding to increase stocking and to maintain productivity (Cayford et. al., 1967). Forecasts for artificial regeneration of jack pine include annual rates of 16,000 ha. (40,000 acres) in Ontario and 11,000 ha. (27,000 acres) in Quebec, two third by direct seeding and one third by planting. These programmes alone will require some 3,000 kg. (6,600 lbs.) of seed each year. The collection, extraction and distribution of tree seed on such a scale will lead in very few decades to heterogeneous mixing of gene pools if steps are not taken to protect the genetic integrity of selected natural populations that are still to be found within areas of commercial jack pine.

Although jack pine is in no danger of extinction, there is an urgent need to protect gene pools from loss or dilution in areas of extensive exploitation and large scale seeding and planting.

Genetic Background

Provenance studies under controlled laboratory conditions and in field tests consistently have demonstrated broadly clinal patterns of variation associated with seed origin (eg. Schantz-Hansen and Jensen 1952, Rudolph 1964, King 1966, Yeatman 1966, Canavera 1969, Yeatman 1974). The range-wide response in growth, cold hardiness, pest resistance and associated physiological and biochemical characteristics reflects evolutionary genetic adaptation to climate that occurred as jack pine migrated from southern glacial refugia following the retreat of the Wisconsin ice sheet (Yeatman 1967). Widely dispersed plantings of range-wide provenance collections have shown local seed to be reliable and usually among the best provenances in growth and survival. In the absence of clear experimental evidence to the contrary, jack pine seed for reforestation should be collected locally, i.e. from the same ecogeographic district in which the seed is to be used.

In Situ Conservation Measures

Genetic conservation in a widespread and commercially important indigenous species such as jack pine is not primarily concerned with the retention of rare or unique genes. Furthermore, since harvesting is normally by complete clearcutting and regeneration is from slash or by artificial means, dysgenic selection is not a factor for concern. The pressing concern is with the particular gene frequency distributions characterising the gene pools of populations in dynamic balance with the diverse climates in which they are evolving and to which they are adapted.

Initial action in Canada has been taken by the establishment of seed zones designed to protect the forest resource from extreme losses due to misplacement of seed sources (Wang and Sziklai 1969). The number of seed zones varies by Province according to need and in general their delineation is based on climate, topography and ecological associations. Within such ecogeographic regions substantial differences of growth potential and pest resistance are found among jack pine populations. The best populations can be used to advantage if they can be identified and retained for seed production and improvement (Yeatman and Teich 1969). In Nova Scotia, New Brunswick, Quebec and Ontario plus stands of jack pine and of some other species have been reserved for seed collection. Field trials are being initiated to determine which stands are genetically superior. In the meantime, if regeneration of such stands becomes necessary, it will be confined to natural seeding or by planting with stock from the same source. The selected stands will be used as general seed sources for reforestation and in due course the best will be managed intensively for the mass production of superior seed (Figs. 2 and 3).

Jack pine stands are commonly distributed as a mosaic occupying particular sites in the forest landscape, although extensive areas of many thousands of hectares occur in some regions. Major centres of distribution can be identified from which suitable areas can be chosen for *in situ* provenance conservation and consequent preservation of gene pools. To be effective for an indefinite time, an area so defined needs to be large enough to maintain a dominantly indigenous pollen background and bounded by natural topographic or vegetational features. Such an area may occupy several hundred to a thousand or more hectares. It is not essential, or even desirable, for the designated forest to be of one age or site class.

In situ provenance preserves are most effectively established in conjunction with normal and on-going operational requirements. A single preserve may, with mutual benefit, encompass a diversity of activities and objectives, including wood production, seed supply, parkland and natural areas. In some instances it may be appropriate to include two or more species in a single genetic preserve, e.g. jack pine, pine (*Pinus resinosa* Ait.) and black spruce. It is necessary that provision be made for seed collection and that adequate regeneration of the protected populations be assured.

The single and essential constraint is that all regeneration of protected species within a provenance preserve be from local seed only, whether by natural means, by direct seeding or by planting (Yeatman 1972).

The establishment of a provenance preserve does not preclude genetic improvement but rather provides the basis for selection (Figure 4) and breeding within an established adaptational (genetic) and environmental background. The polygenic balance within the genepool will not be harmed if an adequate breeding population is maintained. Unimproved seed production areas may be replaced by successive generations of improved stock of local origin, creating seed orchards that guarantee continuity of seed supply and resulting in the steady upgrading in quality and productivity of the selected provenance. Progeny tests, clone banks and breeding orchards may advantageously be planted within a provenance preserve so long as the material is limited to local origin.

With intolerant pioneer species such as jack pine, provenance conservation in situ is both a practical and effective means of gene pool conservation. In the short term, large quantities of seed of known origin and potential can be provided as needed, a system of provenance preserves provides a framework within ecogeographic regions for testing and selecting populations for future seed supply, and establishes a sound basis for long term improvement. In the absence of direct introduction of non-local or unknown genetic material, and in contrast to other methods for genetic conservation such as special plantations or seed banks, the in situ provenance preserve carries its own insurance. The large, indigenous population retains a resiliency to loss or degradation due to neglect, fire, endemic pests or other natural or induced disasters.

EX SITU CONSERVATION OF WHITE SPRUCE RACES

Silvics

White spruce is a species of considerable economic significance in Canada. Of the total conifers harvested, 44% is spruce (Sutton 1969), and a large proportion of this is white spruce. The species is widely distributed (Fig. 5) from sea level to about 1,500 m (5,000 ft) elevation growing in a broad range of ecological conditions in cool to subarctic climates; it is found on wet to dry habitats with soil pH ranging from 5.0 to 7.0 (Sutton, loc. cit.). It is found in pure stands and in association with a number of deciduous and coniferous species and is particularly prevalent in the boreal forest.

Inadequate natural regeneration following harvesting is attributed to the removal of seed sources and possibly to recent climatic changes such as increasing temperatures and decreasing precipitation (Sutton, loc. cit.). Artificial regeneration, mainly planting, has been conducted on a scale of 26,300 ha. (65,000 acres) per year (Rennie 1972) at an estimated cost of $6,500,000. It is vital that only seed with high inherent value be used to ensure an increased potential for survival and growth of the planted stock.

Genetic Background

Extensive genetic variation has been found among and within provenances (Holst and Teich 1969, Teich and Khalil 1973). Inter-provenance variation is the most useful feature because appreciable quantities of seed can usually be collected from existing stands of known genetic quality. Provenances with high breeding value are therefore a resource worth conserving. Selections from within provenances consist of relatively few trees, which must be propagated for seed production. The propagules do not bear seed in quantity for at least a decade.

Provenances with high breeding value have been found by growing seed from 100 provenances in 25 experimental plantations in eastern and central Canada (Teich 1973) and northeastern and northcentral United States (Nienstaedt 1969). Those which survived the best and grew the most or possess a highly desirable trait with acceptable consistency have been designated as superior races.

Superior white spruce races are being preserved in clonal and seedling orchards and seed banks because the original populations in their native habitat are in danger of extinction. The danger arises from (i) land clearing for urbanization and agriculture, (ii) inability to relocate original stands, and (iii) loss of racial purity resulting from planting mediocre provenances among remnants of superior ones.

Ex Situ Conservation Measures

The races which have been chosen for preservation have shown genetic superiority or possess genetically valuable traits. This evaluation is based on provenance experiments extending as far back as 40 years ago (King and Rudolf 1969) and in as many as 13 plantations located from Newfoundland in the east to Manitoba in central Canada (Teich 1973). Five races have been selected.

1. Cobourg, Ontario This race has grown rapidly (17% above average) in 11 experimental sites from Newfoundland to the Manitoba border and especially on limestone soils (Teich and Holst 1974) where the growth of most provenances is suppressed.

   The original stand could not be located either because it was cleared for agriculture, or because the original location description was inaccurate. There are now few white spruce in the area, and these appear to be planted (and therefore of unknown origin) rather than natural.

   In an experimental plantation, 100 trees were selected for growth rate and stem and crown form. They were propagated by 5 ramets per clone for a seed orchard at the Petawawa Forest Experiment Station. Some of these clones have also been propagated by the British Columbia Forest Service.

2. Renfrew County (Beachburg, Douglas, Ontario). Provenances from this area (Fig. 6) have grown well (14% above average) in central and eastern Canada and northcentral United States on non-limestone sites. The oldest experiment in Wisconsin is now about 40 years old. Ten individuals were selected and cloned from this experiment. Twenty other individuals were selected and cloned from remnants of the original stands (now reduced to a few thousand trees). About 10 ramets of each clone have been established in a clonal orchard at the Petawawa Forest Experiment Station. Clonal orchards have been established in northeastern and northcentral United States as well. Seed is being collected from as many trees in the original stands as possible each year for a seed bank. These individual trees are being progeny tested and the best will be selected for propagation.

3. Winchester, Ontario Precocious flowering (as early as 11 years of age) combined with rapid growth on limestone sites make this provenance outstanding. It is valuable as breeding stock, and perhaps may be useful for planting directly provided heavy cone crops do not unduly reduce its vegetative growth on limestone sites (Teich and Pollard 1973). Increasing urbanization in the vicinity of the provenance necessitates implementation of conservation measures. The present breeding programme at Petawawa Forest Experiment Station has incorporated rapid-growing selections of this provenance in hybrid combination with local plus-trees. Several clones are being propagated by the British Columbia Forest Service.

4. Grand Piles, Quebec Trees from this area grow rapidly on non-limestone soils (15% above average) and produce moderate cone crops precociously. The purity of the original stand is in jeopardy from the nearby Grand Mere experimental plantations which serve as a source of contaminating pollen and seed.

Individual trees of this provenance have been selected, and should now be preserved in clonal orchards to allow continued use. Some hybrids have already been propagated by the Ontario Ministry of Natural Resources and by the Maritimes Forest Research Centre, Canadian Forestry Service, in New Brunswick.

5. Kirkland Lake, Ontario Only a single northern provenance has shown breeding value for growth rate in the North, the Swastika provenance near Kirkland Lake. Its performance has not been consistent; while it grows well in some plantations, it is poor in others. Some seed collections from different stands in this area result in better growth than others and only the best stands merit conservation. One provenance from this area which has grown well in a number of plantations is being conserved in a seedling seed orchard of several acres. Individual trees were selected for growth and early seed production, and the selections hybridized with plus trees. Clonal preservation will follow individual tree progeny testing.

Impact of Dysgenic Selection

Selective cutting is expected to cause relatively little genetic degeneration of white spruce. When a few trees of poor quality are left following a logging operation they often blow over because their root systems are inadequate to withstand the increased exposure to wind. Seed from the survivors is unlikely to produce many viable seedlings unless there has been extensive soil scarification (Sutton loc. cit.) to expose a suitable germination medium. Many of the seedlings would have resulted from self pollination, and would therefore have little chance of survival because of inbreeding depression. The few hybrids which do survive might not differ significantly in breeding value from the previous generation because only a small proportion of individual tree phenotypic variation is heritable (Holst and Teich loc. cit.).

Only a small part of the white spruce range has been provenance-tested. The best provenances are being preserved in clonal orchards, seedling orchards, seed banks and in the experimental plantations. In the untested part of the species' range, seed has been and is being collected and stored for future provenance tests, and as a safety measure against future loss.

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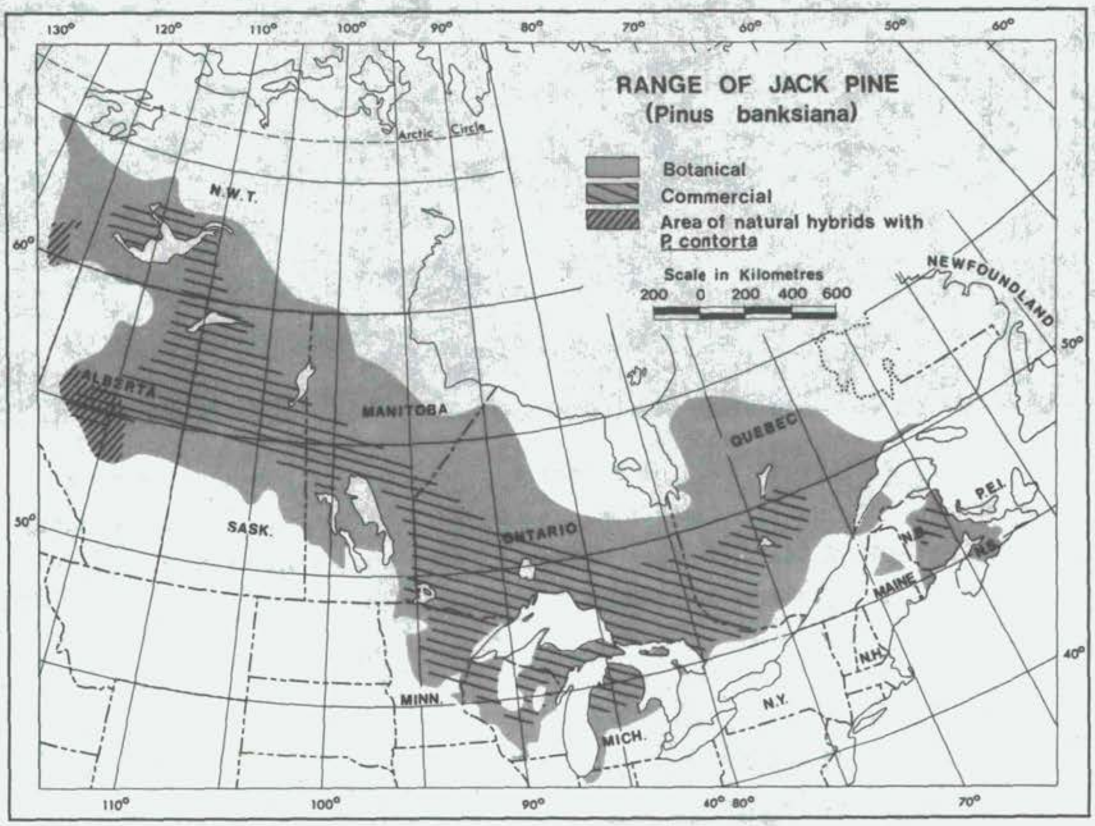

FIGURE 1 Botanical and commercial range of jack pine (Pinus banksiana Lamb.) (Critchfield and Little, 1966; Rudolf, 1958).

Figure 2. Aerial view of a seed production area and strip cut in a natural 50-year-old jack pine stand, western Quebec. (Photo courtesy of H. Bitto, Canadian International Paper Co., Maniwaki, Que.).

Figure 3. Access row (8 m) cut in the seed production area from which thinnings are being harvested to improve the stand and increase cone production. Periodic clear fellings of the stand remaining will be made for seed collection (Photo by H.Bitto)

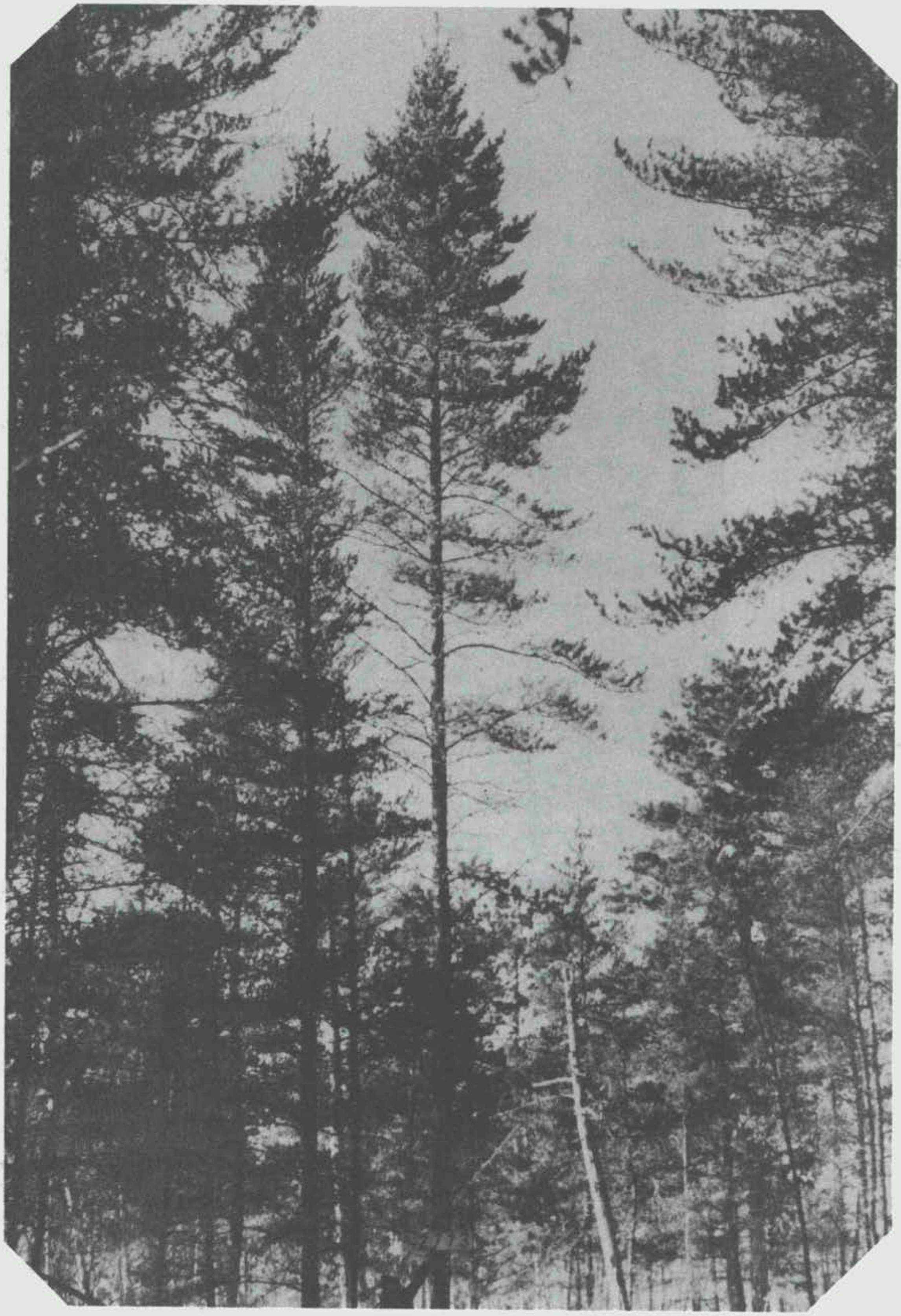

Figure 4. Jack pine plus tree selected for superior growth, straight stem, wide branch angle and uniform branch size.

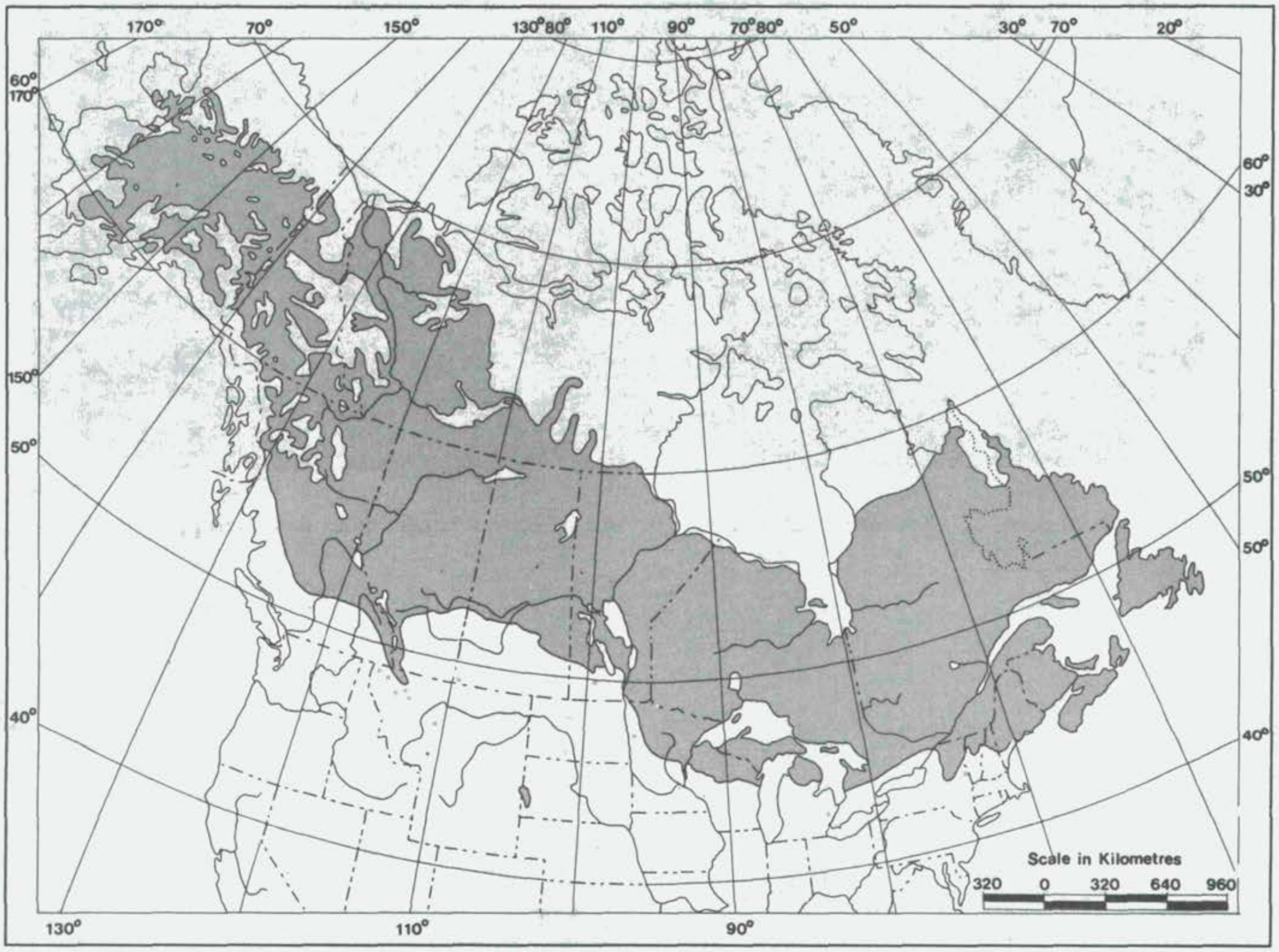

Figure 5 The botanical range of white spruce (after Fowell 1965).

Figure 6. Remnant of a superior white spruce race near Beachburg, Ontario.

4

CALIFORNIA CONIFERS

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THE SIGNIFICANCE OF CALIFORNIA'S FOREST TREE GENE POOLS

Limits of this chapter

This case study has been limited to conifers, partly because the majority of California's native forests are largely coniferous. In addition, while California's native angiosperms, non-coniferous gymnosperms and palms are ecologically and aesthetically important, few are commercially important in California or widely planted elsewhere. Many administrative decisions affecting use, exploitation, and conservation of California's trees are made by the California state government, by Region Five of the United States Forest Service (whose boundaries largely coincide with the state boundaries), and by private industries (most of which operate wholly within California or have semi-autonomous divisions largely restricted to California). However, many of our species are not restricted to California, but (mostly) extend north and northeast into the important forest regions of the Pacific Northwest and Inland Empire. In these cases, we will consider the California populations in the context of the entire species.

California as a timber-growing region

California's north coast combines favourable climate, fertile deep soils, several excellent native tree species, and a broken and steep topography generally unfriendly to urbanization or mechanized agriculture. Trees will be grown commercially for wood and fiber on large areas of this region in the foreseeable future, with the expected site productivity ranking among the highest in the world. The growth conditions and topography of California's north border mountains (Trinity Alps and Siskiyous), Cascades, and the middle elevations of the northern and central Sierra Nevada will probably also make commercial forestry the primary use on extensive areas of these regions.

California as a human environment

Over 20 million people presently reside in California, concentrated mostly in the coastal areas of the southern third of the state, near San Francisco Bay, and in the central valley. Both native and non-native forest trees have been used for urban and amenity plantings in these and other areas, generally on sites which were not previously forested. Much trial-and-error and the beginnings of organized research have been applied in adapting these forest species to their new environments. It is clear that a large base of genetic variation is a useful resource when searching for trees adapted to these new niches.

People are also going to the forests in larger numbers each year. To many of these visitors, it is important that the forest be natural and, to a limited extent, their needs will continue to be served by California's established system of parks, reserves, and wilderness areas. For others, the history of the forest is less important. Planted forests serve some of their needs better than naturally regenerated forests. Plantations of both native and exotic species are being established for these purposes in California's southern mountains. These recreation and watershed forests will also benefit by selection from a broad genetic base.

California populations outside of California

Some of California's conifers are proving to be faster-growing, healthier, and more valuable than most native tree species in other Mediterranean-climate regions of the world. This is particularly true in parts of Australia, New Zealand, the west coasts of South America and South Africa, and around the Mediterranean Sea. The gene conservation measures taken with California's conifers are of interest and importance to the people and forests of these regions.

GENE CONSERVATION STATUS OF CALIFORNIA'S NATIVE CONIFERS

The text which follows explains and amplifies Table I.

1. Importance of California conifers (Table I, Columns 1a-1g)

We have divided this section into seven subcategories; 1a-1e are concerned with cut products, such as lumber, poles, posts, pulp, chips and Christmas trees, while 1f and 1g are concerned with living trees.

1a. Presently of commercial importance in California

Nine species are so designated. Eight of these are of primary importance as timber species, with douglas-fir (*Pseudotsuga menziesii*), ponderosa pine (*Pinus ponderosa*), redwood (*Sequoia sempervirens*), and white fir (*Abies concolor*) being the state's most common and valuable logged species; sugar pine (*Pinus lambertiana*), jeffrey pine (*Pinus jeffreyi*), red fir (*Abies magnifica*), and incense-cedar (*Libocedrus decurrens*) are also significant components of the present annual cut. The ninth species, radiata pine (*Pinus radiata*), is the most important of California's plantation-grown Christmas trees, with *Pseudotsuga menziesii*, *Abies concolor*, and *A. magnifica* also being extensively used, both from natural stands and plantations.

1b. California populations of commercial importance elsewhere

Pinus radiata is presently the most widely-planted tree species in the world, with most of the genes of this rapidly domesticating species having originated in the two northern populations on the central California coast. Its major uses in other regions are for lumber, poles, posts, pulp, and chips, with Christmas trees being only a minor use. In Mediterranean climates, populations of *Pinus ponderosa* and *Pseudotsuga menziesii* from coastal California are performing as well or better than populations of these two species from other origins. In New Zealand, low-elevation populations of shore pine (*Pinus contorta* ssp. *contorta*) from California appear to be the best of this moderately-important species. The good growth rate and excellent wood properties of Monterey cypress (*Cupressus macrocarpa*) encourage commercial planting of this species in several countries, but its continued disease problems caution against its widespread planting.

1c. California populations potentially of commercial importance in California and elsewhere

Having proved themselves elsewhere, it is likely that *Pinus radiata*, *P. contorta* ssp. *contorta*, and possibly its edaphic variety, *P. contorta* ssp. *bolanderi*, will be widely planted in California for timber purposes, especially as California's old growth forests are depleted and management intensified. In Australia and New Zealand, the blue race of *P. muricata* is presently receiving serious attention, based on its fine wood qualities and good growth on sites too cold for P. radiata to perform well. The same pattern could occur in California. Several countries, including France and New Zealand, are presently considering moderate planting of Sequoia sempervirens on appropriate sites. In California, giant sequoia (Sequoiadendron giganteum) is being seriously considered as an important addition to the mixed-conifer forest of California's central and northern mountains, and to the area east of the natural range of Sequoia sempervirens on the north coast. Four other California species, in our opinion, have some chance of being added to the world list of important timber trees. Torrey pine (Pinus torreyana) exhibits fast growth, good form, and large size when planted on good sites in California and New Zealand, contrasting with its short, gnarled appearance in its two native stands on California's south coast and on Santa Rosa Island. Digger pine (P. sabiniana) grows well, although with poor form, on the extensive low-elevation, drier sites in central California. As wood demand increases, these sites and this species may be pressed into more active service. Finally, just as populations of Sitka spruce (Picea sitchensis) and of grand fir (Abies grandis) from north of California have donated most of the genes now used in European exotic plantations of these two species, so may the California populations prove valuable in Mediterranean-climate regions.

1d. Non-California populations of commercial importance outside of California

The 16 species and subspecies indicated in this subcategory are of commercial importance in other parts of North America. Non-California populations of Pseudotsuga menziesii, Picea sitchensis, Pinus ponderosa, and P. contorta ssp. contorta are also important outside of North America as exotics. Only four presently have populations of major commercial importance within California. The remaining twelve are not generally exploited in California, but may be cut and utilized as part of logging operations directed at associated species. The California populations of these 16 species and subspecies may prove useful in augmenting the gene pools of the commercially important populations outside of California.

1e. Close relative of commercially important species

By "close" is meant that interspecific hybridization between these designated species and one or more commercially important species may be accomplished by techniques available today. Twenty-six species and subspecies are thus designated, and cases can probably be made to add several others to this group. Many are themselves commercially important; others are not.

1f. Urban and amenity plantings

We have included trees commonly used for home, street, and park plantings in urban areas, shade and windbreak plantings in agricultural areas, highway landscaping, and soil stabilization for watershed and erosion-control in undeveloped areas. Thirteen California native conifers are indicated as being important for one or more of these uses. Most are used in California, but several (Pinus radiata, Pseudotsuga menziesii, Abies concolor, A. grandis, Sequoia sempervirens, Sequoiadendron giganteum, Chamaecyparis lawsoniana, and Cupressus macrocarpa) are also extensively planted elsewhere 1/.

1g. Aesthetic in native range

Most trees in their native range have some aesthetic appeal to many people for various reasons. In this subcategory we have applied "aesthetic" to those tree species which have some characteristic(s) which especially capture the public interest. We have cited 23 of California's conifers for the following general appeal,

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1/ Although it is not a conifer, we feel we should mention the California native fan palm (Washingtonia filifera) which is widely used for roadside, street, home, and park plantings in California and in many subtropical regions throughout the world. Its limited native distribution and fragile habitat make it a prime candidate for gene conservation efforts in California.

with apologies to the rest: the lovely shapes of Picea breweriana, and the Abies and Pseudotsuga species; the bizarre shapes of Picea sitchensis, Pinus torreyana, P. jeffreyi, P. contorta ssp. bolanderi, Juniperus occidentalis, Cupressus macrocarpa, and C. pygmaea; the massive size of Sequoiadendron giganteum and the great height of Sequoia sempervirens; the great age of Pinus aristata; the beauty of sunlight on mature bark of Pinus ponderosa, Libocedrus decurrens, and Juniperus occidentalis; the spectacular cones of Pinus lambertiana and P. coulteri; the pleasant smell of P. jeffreyi; and finally, the tasty pine nuts from P. monophylla. Few of these are endangered, partly because they are sufficiently common to have attracted public attention, or if of limited distribution, that public interest has increased the probability of their preservation. Perhaps attention should be directed to the blanks in column 1g, such as the high elevation pines (P. albicaulis, P. balfouriana, and P. flexilis), which are clearly of aesthetic value, but mostly to the small portion of the public which encounters them. With this smaller public awareness, there is less demand for their preservation.

2. The adequacy of present in situ reserves (Table I, Column 2)

California has many national, state, and local parks, wilderness areas, and nature reserves. Except for some local parks, most of these are managed under the provision that native ecosystems are to be largely undisturbed. We have attempted to judge the adequacy of in situ preservation of each California conifer species based on the number and size of populations in reserves (Griffin and Critchfield 1972), and the degree to which "important" populations of a species are protected.

There is a tendency for the wilderness areas to be at high elevations and the parks to be at low elevations. Unfortunately, the mid-elevation populations of many of California's most valuable species are included in relatively few reserves. These central populations may be where the best genes (from a timber-growing viewpoint) are concentrated. Consequently, we have debated without satisfactory resolution whether to list Abies concolor, Pinus ponderosa, P. lambertiana, P. jeffreyi, Pseudotsuga menziesii, and Libocedrus decurrens as adequately represented in in situ reserves, even though many of their high- and low-elevation populations appear to be protected (note question marks in Table I, Column 2). Thus, of California's nine commercially important species, only Sequoia sempervirens and Abies magnifica are noted as having adequate in situ protection. Among California's populations commercially important elsewhere, only Cupressus macrocarpa is in adequate reserves, while Pinus contorta ssp. contorta and P. radiata are clearly not adequately protected.

3. Danger of extinction (Table I, Columns 3a and 3b).

A population with a limited distribution is in danger of extinction, whether or not the trees are located in a protected reserve. Fire, disease, pests, or man-related influences are among the many factors which could destroy such populations. If an entire species is composed of just a few small populations, then the entire species is in danger of extinction.

3a. Important populations in danger of extinction

Extinction of small individual populations of most species is a common event, and probably not generally serious from a gene conservation standpoint. It becomes serious when only a few populations of a species remain, or when such extinction is widespread. We have tentatively identified eleven such cases (Table I, Column 3a). Five of these concern extensive populations of Pseudotsuga macrocarpa, Pinus attenuata, P. coulteri, P. jeffreyi and P. ponderosa in the southern California smog (light-reacted hydrocarbon air pollution) belt, where smog has already caused severe damage and mortality. When we run short of fossil fuels, smog concentrations will be so reduced that these populations could again form healthy forests in this region. When that occurs, the populations which were adapted to this region before the smog era will have been significantly altered, or even may have become extinct. Additional populations of P. attenuata are in danger of replacement due to management which excludes fire (important for its reproduction), or physical removal in favour of more valuable species. Coastal populations of P. contorta ssp. contorta and Cupressus pygmaea may be displaced by urbanization. Cupressus goveniana exists in two small native populations, both in reserves, but the largest is underlain by glass-quality sand which puts the reserve status in some danger. Two of the four populations of C. abramsiana are unprotected, very small, and thus subject to loss, as are several of the nine known populations of Pinus washoensis and the Santa Rosa Island population of P. torreyana

3b. Entire species or subspecies in danger of extinction

Most of California's conifer species are in no immediate danger of extinction; we have noted (Griffin and Critchfield 1972) two species and one subspecies which are in danger. Cupressus abramsiana and C. stephensonii are little-known cypresses of limited distribution; C. abramsiana exists in four small populations, while C. stephensonii consists of only one, greatly reduced in the past 25 years as a result of two devastating fires. Pinus contorta ssp. bolanderi exists as an edaphic form of P. contorta on the white plains of coastal central Mendocino County. The nearby harbour is being considered for nuclear dredging to create a deep-water port. The urbanization which would likely follow would displace most of the trees of this subspecies, and urban plantings of other subspecies of P. contorta might complete the genetic obliteration of subspecies bolanderi.

4. Gene pools in danger of contamination

This form of gene loss or unnatural evolution may occur when artificial regeneration is extensively practiced in the species' natural range. It tends to be important, therefore, for our most valuable species and in the most productive parts of their natural ranges. It is now serious in the north-coast stands of Pseudotsuga menziesii, where aerial seeding of non-native seed has been extensive; in the central Sierra Nevada stands of Pinus ponderosa, where many plantations have been established with seedlings of non-local or even unknown origin; and in the Monterey Peninsula stands of P. radiata and Cupressus macrocarpa, where urban and amenity plantings have not always been of local seedlings (UNESCO 1973). Less extensive planting programs with Pinus lambertiana, P. coulteri and P. jeffreyi have probably caused significant contamination in some important areas of these species' ranges. As planting or seeding increases with more intensive forest management in California, several other species will be in danger of significant contamination of natural gene pools (Table I Column 4b). Increased planting is expected soon with Abies concolor, Sequoia sempervirens and Sequoiadendron giganteum, although most planting of S. giganteum will probably not be near native stands.

Species of little economic importance, if in reserves, will generally have these protected samples of their native gene pools maintained. But there exists a problem of some importance relative to in situ reserves of aesthetically or commercially important species. If amenity plantings or active management of valuable species is proceeding near their reserves, the trees in the reserves will repeatedly receive clouds of pollen from these nearby trees. Non-native populations may be used in some commercial forests either because provenance tests have shown non-natives to be more productive, or by mistake. Later, selected domesticated trees will be used, and whether originally native or not, they will be genetically different from the native population samples maintained in the reserves (Libby 1973). The offspring of the "natives" will be increasingly contaminated by genes from these surrounding trees or forests, and the native gene pool will be compromised and finally lost. Thus, gene samples of such populations will have to be preserved ex situ, if extensive man-caused genetic modification of the native stands occurs in important parts of the species range.

SPECIES ON WHICH WORK IS IN PROGRESS FOR EX SITU CONSERVATION

In California we have begun *ex situ* work on three coniferous species: *Pinus radiata*, *Cupressus macrocarpa*, and *Sequoiadendron giganteum*. In the following pages we will outline relevant taxonomic and methodological information on each of the species.

Pinus radiata D. Don

Natural distribution

P. radiata occurs in three mainland populations on the coast of California, and in two island populations near the west coast of Mexico:

Population	Approximate Latitude
Año Nuevo	37°07'N
Monterey	36°30'N
Cambria	35°33'N
Guadalupe Island	29°10'N
Cedros Island	28°15'N

Total area occupied: 8 000 hectares

Status of native populations

Guadalupe Island population: Endangered. Lack of reproduction due to grazing by goats.

Cedros Island and Año Nuevo populations: Not presently endangered. Commercial planting has begun in the Año Nuevo stands.

Monterey and Cambria populations: Genetic integrity endangered. Ornamental plantings in the area have obscured the natural boundaries of the species (Griffin and Critchfield 1972). Many plantings from nonlocal sources have introduced significant genetic contamination. Seed for these plantings is often obtained from New Zealand where *P. radiata* is partially domesticated, originating largely from Año Nuevo (UNESCO 1973)

Ex situ measures already taken

Sampling methods

1. Plant material and time of collection: In 1963, we rooted cuttings from 15 random genotypes (most trees less than nine years old) from each of ten stands in each of the three mainland populations (Libby and Conkle 1966). Thus, the mainland sample was of genotypes which had successfully established themselves under natural conditions. In 1964, cones were collected from 59 and 68 random, and 39 and 9 selected, trees on Cedros and Guadalupe Islands, respectively (Libby, Bannister and Linhart 1968). (Using seed eliminated the problem of bringing green plant material across the border from Mexico. Note, however, that the genotypes obtained had not successfully established in nature, but were the offspring of successful adult genotypes.)

2. Special provisions: A permit from the Mexican government was necessary to collect the seeds, and a permit from the United States government was necessary to import them. A phytosanitary cone inspection was performed at the border.

Packaging of genes

Soon after collection, two replicate gene bank plantations of each sample were established near Berkeley. The trees are now sexually mature, and in 1973 we began a programme of controlled pollinations as a means of preserving the genes now contained in the trees in the gene bank plantations. The controlled pollinations serve two purposes: (a) avoiding contamination by pollen from other populations in the gene bank plantations or by pollen from nearby trees of different or unknown origins; and (b) maintaining accurate pedigrees to better balance the contributions of each founding ancestor in later generations, and to better deal with the problems of inbreeding in later generations. A total of 200 crosses is planned in order to maintain the genetic integrity of this sample. During at least the first several generations, it is anticipated that crosses will be restricted to trees from the same stand. Eight sexually mature trees from each of 50 stands (ten per population) have been designated for use in four pairwise matings per stand. Thus, the genes originating in 400 trees will provide the long-term gene conservation base for radiata pine. We are using a single-pair mating scheme for this project, as it allows the maximum number of contributing parental genotypes per unit of work, with a minimum amount of record keeping.1/ In this scheme, the first year (1973) was used mainly for pollen collection, the second and third years for making the crosses using both fresh and stored pollen. Cones will be collected soon after maturity, and the seed will be extracted and placed in the best available conditions for long-term storage. The cones from the first crosses will be collected in the spring of 1975.

Maintenance

It is difficult to anticipate the advances in seed storage technology. The goal, however, is to keep the genes in seeds as much of the time as possible without loss of germinability and viability. An important consideration is possible adaptation to the storage condition, i.e. selection for those seeds which store well over long periods. If stored too long, some genes may be lost in those seeds which fail to survive under the conditions of storage.

Samples of these unselected natural gene pools should be grown out no more often than is necessary. Controlled crosses can be made soon after the trees attain sexual maturity, and the gene pools will be thus continued. In so doing, each generation will lose a few genes to drift. Additionally, although no overt selection will be used, there will be a tendency for the sample to adapt to the gene bank environment. By lengthening the cycle from seed to seed, thereby reducing the number of times the seeds must be grown out and re-crossed, the sample is given the least opportunity for loss or change of genetic variability. Seed will be stored in Australia and the United States, and perhaps one other country.

Dissemination

No definite guidelines have as yet been established for dissemination of these

1/ Three hundred additional crosses are also being performed using this sample of trees, in order to investigate intrapopulation and interpopulation heterosis, and to create a multipopulation base for future breeding (Libby 1973).

seeds. We propose that the following priorities be used:

(1) First priority is to maintain the genetic integrity of the gene conservation collection.

(2) Extra seeds not needed for (1) may be used by breeders to replenish variability in domesticated radiata pine.

(3) Seeds not needed for (1) and (2) may be available for various types of research on population structure, genetic variability, etc.

Costs

In terms of current outlay, the costs of *ex situ* gene conservation are high. Relative to the long-term value of the resource, they are probably trivial.

It is difficult to assign direct costs within projects with numerous simultaneous objectives. The original mainland collections required approximately 20 days in the field for one scientist and one research assistant. On the expedition to Guadalupe Island, three of us (Libby, Bannister and Linhart 1968) were non-paying guests on the research vessel *Gringa*, arranged by The Scripps Institute of Oceanography. *Gringa* devoted five days to our expedition, and we were informed it required about $1 000 per day to operate such a vessel. The trips to Cedros Island were supported by grants totalling $2 500 from The Associates in Tropical Biogeography and The Wrasse Foundation, plus the time of the scientists and a research assistant. Establishment and early care of the gene banks were accomplished during two grants from The National Science Foundation totalling $83 400 over a four-year period, with additional support in the form of staff salaries, greenhouse facilities, and land from The University of California. During the next several years, the maintenance of the gene banks required several man-weeks of staff time, plus several hundred dollars per year in equipment and supplies. Several other experiments were accomplished or initiated using these population samples and under these grants. But, with the exception of the NSF grant, the costs would probably have been similar had the sole purpose of the work been gene conservation.

The current controlled crossing programme requires several days' attention of a scientist, the half-time attention of a research assistant for six months, plus six people working quarter-time during the three months before, during, and after the pollination season. Equipment and supplies (ladders, climbing belts, syringes, vials, plus expendable pollination bags, etc.) require in excess of $1 000 per season. Facilities and financial support for this project are presently provided by the Departments of Genetics and of Forestry and Conservation, University of California at Berkeley; the Institute of Forest Genetics at Placerville (U.S. Forest Service); and the Australian State and Federal Forest Services via the Standing Committee of the Australian Forestry Council, Canberra.

Cupressus macrocarpa Hartw.

Natural distribution

The entire natural distribution of *C. macrocarpa* consists of two populations on the coast of California: one on the Monterey Peninsula, the other on Point Lobos.

Population	Latitude
Point Cypress	36°34'N
Point Lobos	36°31'N

Total area occupied: about 200 hectares

Status of native populations

Point Cypress: Mostly private estates, with limited natural reproduction. Genetic contamination by ornamental plantings.

Point Lobos: Entire population contained within Point Lobos State Reserve.

Both populations are well protected, but their small size makes them vulnerable to both natural disasters and human impact.

Ex situ measures already taken

A sample of unselected seed has been collected from about 85 trees in each population, part of which is earmarked for *ex situ* preservation of the gene pool.

Sampling methods

1. Plant material and time of collection: Cones were collected in Spring 1973, generally from the upper crowns using a pole pruner and ladder. At Point Lobos, cones were taken from 9 to 15 random trees in each of seven stands. Cones from an additional ten isolated, selected trees were also included in this collection. At Point Cypress, cones were collected from ten to twelve random trees from each of eight stands. An average of 20 to 25 cones per tree was collected. Cones contain an average of about 100 seeds and germination varies between 0 and 40 percent. The serotinous cones remain unopened on the trees for an as yet undetermined number of years, making collection possible at any time of the year. Cones should be at least two growing seasons old at the time of collection.

2. Special provisions: At Point Lobos, a permit from the California State Department of Parks and Recreation was required for collecting seed. At Point Cypress, permission from private property owners was required.

Packaging of genes

Cones were allowed to dry and open in paper bags for approximately four weeks, at which time the released seeds were placed in envelopes and stored at -10°C. Some seeds continued to be released from the cones for several months, and were gathered periodically until all were shed. We plan to begin growing out a sample of this collection in Spring 1975 and later repackaging the genes via controlled crosses.

Maintenance and dissemination

It is our intention to eventually store the seeds in several as yet undetermined places. The priorities for maintenance and dissemination are the same as for *P. radiata* (see above).

Costs

Thus far, direct costs have been only the salary of a graduate student, half-time for approximately three months, plus approximately $1500 for field expenses, supplies, and equipment. Additional costs will be comparable to those of the latter phases of the *Pinus radiata* project, above. Facilities and support for this project are provided by the Departments of Genetics and of Forestry and Conservation, University of California at Berkeley, and by the U.S. Forest Service Pacific Southwest Forest and Range Experiment Station.

Sequoiadendron giganteum (Lindl.) Buchholz

Natural distribution

S. giganteum occurs naturally in about 70 groves on the west slope of the Sierra Nevada in California, occupying approximately 15,200 hectares (Wensel 1971). The most northerly grove (Placer grove), containing only six trees, occurs near the middle fork of the American River at about 39°N. About 500 km south, the most southerly grove occurs at Deer Creek in Tulare County at 35°50'N. Outlying trees within this latitudinal range occur at elevations of 823 meters and 2,683 meters (Griffin and Critchfield 1972). Most grove boundaries have remained fairly stable for many centuries (Rundel 1971).

Status of native populations

Placer grove: Endangered. No natural regeneration. Possible danger of contamination by a nearby plantation suspected to be of non-local origin.

Most of the *S. giganteum* groves are protected in national and state parks and forests. Most of the populations are not presently in danger of extinction. In some parts of its range, where fires have been prevented for many years, accumulation of litter on the forest floor presents an increasing threat to the standing trees in the forest. In addition, reproduction in many of these areas has not significantly occurred for several decades. Changes in park management to include small controlled fires in and near the groves will reduce the fire danger and may provide sites for new reproduction.

Ex situ measures already taken

Sampling methods

1. Plant material and time of collection:

Placer grove: Cones were collected from two of the six trees in 1973 by researchers from the Institute of Forest Genetics, and seedlings from these cones are being grown in their nursery. Excess seed will be added to our gene conservation collection.

Other seed collection: Cones are to be collected from about 600 unselected trees throughout the range. Cones will also be collected from a few selected trees. In Summer of 1973, this collection was begun with cones from 31 trees from six of the northern groves. One cone per tree will be collected, with approximately 240 seeds per cone (Hartesveldt et al 1970). Reported germination varies from less than 1% (Leroy Johnson, Institute of Forest Genetics, personal communication, 1974) to 75% (Hartesveldt et al 1970).

S. giganteum may retain its closed green cones for 22 years or longer, with maximum seed viability reported to occur at five years on the tree (Hartesveldt et al 1970). Fallen branches provide moderate numbers of green cones in Spring and Summer, and cones may also be gathered from the ground during the late Summer and early fall when the chickory squirrels are actively cutting them. As mature trees are generally fairly distant from each other in their natural groves, and usually make up only about 5 percent of the stand, cones may be collected from the ground with reasonable certainty of identification with a particular tree. Groves are frequently inaccessible during the Winter months when heavy snow accumulates.

2. Special provisions: Special collecting permits are required in order to remove plant material from the parks.

Packaging of genes

Cones were (will be) allowed to dry in paper bags (away from direct heat and sunlight) for several weeks until they open and release the seeds. Seeds will be stored in plastic bags at low moisture content at temperatures below freezing.

Maintenance and dissemination

It is our intention to eventually store *S. giganteum* seed in several places, with priorities for maintenance and dissemination the same as for *P. radiata*.

Costs

Thus far, direct costs have been the half-time salary of a graduate student for approximately seven months, plus field expenses, supplies and equipment of approximately $3000. Initial collections will probably consume another three months at this rate. Additional costs will be comparable to those of the latter phases of the *Pinus radiata* project, above. Facilities and support are provided by the Departments of Genetics and of Forestry and Conservation, University of California at Berkeley, and by Region Five of the U.S. Forest Service.

Other species

Many seed collections have been made for purposes other than gene conservation. However, a comprehensive inventory of these collections does not now exist. Stettler and Cummings (1973) have prepared a list of plantations of known source or parentage available in the western United States and Canada. Objections to use of such plantations for *ex situ* gene conservation include: (a) trees are sometimes a selected sample; (b) in general, too few populations are sampled; and (c) the genes are all in growing plantations, which are mortal. For existing collections which are or include stored seed, objections (a) and (b) above generally apply. Additionally, (d) the seeds generally are not stored in conditions favourable for long-term viability; and (e) priority is not given to gene conservation in future seed allocations.

Among California species, we suggest top priority for further *ex situ* gene conservation be given to the north coast populations of *Pseudotsuga menziesii*, Sierra Nevada and southern California populations of *Pinus ponderosa*, plus smog-belt populations of other southern California species. Work on the other populations and species in columns 4a and 4b of Table I should be begun within a decade, as circumstances warrant.

Miller (1973) reviewed the general problem of genetic erosion, and general lack of support for gene conservation. She described a major effort by the Rockefeller Foundation supporting gene conservation, but Rockefeller is concentrating on food-related genes, to the exclusion of forest-tree genes (personal communication, L.M. Roberts, Associate Director, The Rockefeller Foundation, 25 January 1974). The U.S. Forest Service, while actively participating in designating *in situ* reserves (Franklin, Jenkins and Romancier 1972; Romancier 1974), has not yet begun an effective *ex situ* programme (personal communication, S. L. Krugman, Programme Leader, Genetics and Related Projects USFS, 13 September 1972). FAO begun active work, particularly in Mexico and Australia, but its funds are limited relative to the urgency and extent of the work that needs to be done soon (personal communication, R. L. Willan, FAO Forest Resources Division, 29 November 1973). Clearly, the problem demands greater organization and support.

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Table I

Family, Genus, Species a/	(1) Importance							(2)	(3)		(4) Gene Pools in Danger of Contamination	
	Cut Products					Standing Trees			Danger of Extinction			
	Present Commercial Importance in California	California Populations of Commercial Importance Elsewhere	Potential Commercial Importance	Non-California Populations of Commercial Importance	Close Relative of Commercially Important Species	Urban and Amenity	Aesthetic in Native Range	Adequate or Near-Adequate <u>in-situ</u> Reserves	Important Populations	Entire Species or Subspecies	Now or Soon	Potentially
	1a	1b	1c	1d	1e	1f	1g	2	3a	3b	4a	4b
CUPRESSACEAE												
Chamaecyparis												
lawsoniana				X		X						
nootkatensis				X	X							
Cupressus												
abramsiana									X	X		
bakeri												
forbesii												
goveniana								X	X			
macnabiana												
macrocarpa		X				X	X	X			X	
nevadensis												
pygmaea							X	X	X			
sargentii												
stephensonii										X		
Juniperus												
californica												
communis												
occidentalis							X	X				
osteosperma												
Libocedrus (Calocedrus)												
decurrens	X					X	X	?				X
Thuja												
plicata				X	X							

a/ Adapted from Leroy C. Johnson's 8 Feb. 1974 revised list, California conifers available from LCJ at The Institute of Forest Genetics, 2480 Carson Road, Placerville, California 95667.

	1a	1b	1c	1d	1e	1f	1g	2	3a	3b	4a	4b
PINACEAE												
Abies												
amabilis				X	X		X	X				
bracteata						X		X				
concolor	X			X	X	X	X	?				X
grandis			X	X	X	X	X	X				
lasiocarpa					X		X					
magnifica	X				X		X	X				X
procera				X	X							
Picea												
breweriana							X					
engelmanii				X	X							
sitchensis			X	X	X		X	X				X
Pinus subgenus Haploxylon												
albicaulis								X				
aristata							X	X				
balfouriana								X				
flexilis								X				
lambertiana	X			X			X	?			X	
monophylla							X					
monticola				X	X			X				
quadrifolia												
subgenus Diploxylon												
attenuata					X				X			
contorta												
ssp. contorta		X	X	X	X				X			X
ssp. bolanderi			X		X		X	X		X		X
ssp. murrayana				X	X			X				X
coulteri					X	X	X		X		X	
jeffreyi	X				X		X	?	X		X	
muricata												
blue race			X		X	X		X				X
green races					X							
ponderosa	X	X		X	X	X	X	?	X		X	
radiata	X	X	X			X					X	
sabiniana			X		X							
torreyana			X		X		X	X	X			
washoensis					X			X	X			
Pseudotsuga												
macrocarpa					X		X		X			
menziesii	X	X		X		X	X	?			X	

	1a	1b	1c	1d	1e	1f	1g	2	3a	3b	4a	4b
Tsuga												
heterophylla				X	X			X				
mertensiana					X			X				
TAXODIACEAE												
Sequoia sempervirens	X		X			X	X	X				X
Sequoiadendron giganteum			X			X	X	X				X

5

CENTRAL AMERICAN PINES

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INTRODUCTION

The Central American pines are a case study of particular interest and significance in the context of international responsibility for conservation of genetic resources. There are four main reasons for this:

1) The two principal species (*Pinus caribaea* Mor and *P. oocarpa* Schiede) are of the greatest importance for the creation of man-made forests in tropical countries, and hence for future world timber supplies. For ecological as well as technological reasons their value is likely to be even greater in the future.

2) There is great variation both between and within populations in the natural range of both species. The systematic investigation of this variation by means of international provenance research has only recently begun and many years will be needed to complete the process of exploration and evaluation.

3) Destruction of the natural pine forests in Central America has been progressively intensified during the last twenty to thirty years and many populations have been severely depleted; some are threatened with extinction.

4) The Central American countries have very limited resources of funds and skilled manpower. In the context of their pressing economic and social problems the conservation of genetic resources in their forests has low priority despite its undoubted importance for the world as a whole.

The technological reasons for the importance of these pines stem from their wood qualities and rates of growth. The wood is suitable for use in a great variety of ways, either directly as timber or after undergoing various treatments and processes. This versatility, combined with high rates of production under intensive management of the forests, is likely to be most valuable in the future. Their ecological importance lies in their ability to grow productively on relatively infertile and seasonally dry sites in the tropical lowlands. As the competing demands for land continue to rise the need to make better use of the large areas of unproductive land in the tropics, while conserving the existing forests, becomes ever more urgent. For this reason, and because the technological requirements for wood in the distant future cannot be predicted with certainty, it is vital to conserve as much as possible of the genetic variation in these wild populations, which have evolved under severe environmental pressures.

The main centre of diversity of the pines in this area of the Americas lies in Mexico, where about 30 species and many varieties are found, mainly at higher altitudes. Moving southwards the number of species is progressively reduced, to 10 in Guatemala, the majority still in the highlands, and finally to only three in Nicaragua, which is the southern limit of the natural pine forests in the American continent. These three are the most important elements of this case study.

THE RESOURCE

P. caribaea Mor var hondurensis Barr and Golf

The natural stands of this variety occur most extensively on the Atlantic coastal plain of Central America, extending in a generally narrow band from about 12°13'N at the most southerly limit in Nicaragua almost as far as the northern border of Belize, at about 18°N. At the southern extremity of its range the pine is in small, scattered stands, separated by broad areas of open swampy ground carrying only grass and sedge, and isolated from the more extensive stands of the species, further north, by dense broadleaf forest. The mean annual rainfall at this end of the range is about 3,800 mm but the grasses dry out sufficiently during the three driest months to burn fiercely, especially in very dry years, and the existence of the pine stands may be attributed to periodic fires in the strips of grassland between the perenially wet swamp and the evergreen rainforest. Northwards up the coastal range there is a progressive decrease in annual rainfall to about 1,600 mm in northern Belize. There are some major discontinuities in the coastal stands, particularly along the northern coast of Honduras Republic, where the mountain ranges approach quite closely to the sea, without the broad coastal plain on which P. caribaea is characteristically found.

Whereas the coastal stands are little above sea level the species also occurs inland at elevations up to about 800 m, and at distances up to 300 km from the Atlantic coast. The inland distribution, now at least, is markedly discontinuous, being restricted to valleys and foothills where it has been subject to human interference. The climatic conditions in some of the inland stands are in marked contrast to those on the coast, with a generally longer and more severe dry season. The driest occurrences are found in the broad upper valley of the Rio Choluteca, in the Republic of Honduras, between low rocky hills at about 700 m above sea level. The main annual rainfall here is between 650 and 900 mm, with a continuous period of six months during which the mean monthly rainfall is less than 30 mm. The populations in this area are of great interest for seasonally arid sites but they have been heavily depleted in recent years by intensive exploitation followed by fire.

P. caribaea var hondurensis is already being extensively planted in many tropical countries and the annual rate of planting is expected to reach 20,000 hectares in 1975 (Lamb, 1973). Almost all of the existing plantations are derived from the most northerly sources in Belize and Guatemala, since these were the only ones readily available. The present demand for seed from the natural stands greatly exceeds the supply.

P. oocarpa Schiede

The natural range of this species extends from about 28°N in Mexico as far south as 12°N in Nicaragua. Until recently very little was known of the populations in Central America and particular interest attaches to these most tropical provenances as seed sources for plantations in seasonally dry tropical countries. Since 1969 comprehensive collections of seed and botanical material have been made in Central America in the current programme of provenance research on this species and there is undoubtedly great variation both within and between populations in this part of the range.

In the dry mountainous interior of Central America it is found more or less continuously at elevations between 700 m and 2,000 m, with mean annual rainfall commonly between 700 mm and 1,500 mm, and with a severe and prolonged dry season. Below 800 m elevation it may be found in mixture with P. caribaea. A comparison of the distribution of the two species in some areas where they overlap suggests that P. oocarpa is the more drought resistant, although the different adaptations of the two in withstanding ground fires may also influence their relative distribution (Kemp, 1973). P. oocarpa occurs characteristically on steep slopes, where the soil is shallow and drainage free to excessive. Because the stands were less accessible, they were less heavily exploited until the more accessible P. caribaea forests had been exhausted. The timber of both species is now in great demand for export to the U.S.A. and Europe and exploitation has been greatly intensified.

P. pseudostrobus Lindl

This species (including the closely related P. tenuifolia Benth, considered by some botanists to be a variety of P. pseudostrobus) has a latitudinal range equal to that of P. oocarpa, from about 27°N to about 12°45'N. It is rarely found below 1,200 m elevation and it occurs characteristically on more favourable sites than the other two species, being apparently less resistant to seasonal drought and/or fire. For this reason its potential value for tropical plantations is more limited. However some at least of the few provenances which have so far been tried exhibit very rapid rates of growth in plantations. The most tropical occurrences in Nicaragua and Honduras have yet to be properly explored and evaluated. Many of these populations are now severely reduced and isolated and some are rapidly being destroyed.

THE DESTRUCTIVE INFLUENCES

1. Exploitation

Large scale export of pine timber from Central America began more than thirty years ago in the most accessible areas adjacent to the Atlantic coast. The early operations were selective, removing only the largest and best formed sound trees, but cutting has been progressively intensified as the resource diminished and has been extended to all accessible inland forests also. Many areas have been cut twice or three times, so that only a few of the poorest quality trees remain. The need to regenerate the areas has been generally disregarded. The result has been not only the extinction of the best genotypes in the stands, as observed under similar conditions elsewhere (Zobel, 1970) but also the destruction of the forest over large areas as a result of fire following excessive felling.

2. Land clearance

The remaining natural forests of P. caribaea and P. oocarpa in Central America are almost entirely restricted to sites too poor for profitable agricultural crops. Subsistence farming by methods of shifting cultivation continues to destroy pine forest in the areas less accessible to timber exploitation. P. pseudostrobus now suffers more heavily from this than the other two species, since it occurs under more favourable climatic and soil conditions, and the shifting cultivation has almost certainly been responsible for the destruction of the natural forests of this species over large areas in the highlands of Honduras Republic and Guatemala. Land clearance to provide cattle pasture has extended progressively into the pine forests as a by product of their exploitation for timber, despite the very low quality of the pastures that can be produced on the poor soils. The regular grass burning practised in conjunction with cattle raising is severely destructive to young regeneration of pine.

3. Fire

The Central American forests of P. caribaea and P. oocarpa are generally accepted to be a fire induced disclimax (Johannessen, 1959; Denevan, 1960; Taylor, 1963; Hunt, 1970) but the introduction of intensive exploitation of the forest, and of cattle raising, has brought fire regimes severely destructive to pine regeneration. Logging is most active in the dry season and fires are commonly associated with the felling operations. Only the poorest trees remain to take advantage of the cleared land in the following fruiting season. Even if deliberate burning of the area is not carried out in the following year the spread of fire from neighbouring areas is very probable. When cattle are introduced annual burning is usually practised. The introduction of the African grass Hyparrhenia rufa (Nees) Stapf. as a pasture grass has almost certainly increased the severity of grass fires over large areas of the Central American pine forests (Kemp, 1973). This species grows much taller than the native grasses and produces dense patches of inflammable material.

4. Bark beetle

Several Dendroctonus spp are endemic to the Central American pine forests and periodic explosions in population have caused severe destruction of pine over large areas. When severe attack causes heavy mortality in well stocked stands dense regeneration of the pine often follows, so that despite serious loss of standing volume of timber the genetic resources are maintained. However when the attack spreads to stands severely reduced by exploitation, with many damaged or unhealthy trees, and frequent fires destructive to regeneration, it is a further agent of destruction of the entire population.

5. Seed collection and resin collection

The international demand for seed of P. caribaea has led to destructive activities in a few areas as a result of intensive and repeated seed collection. The practice of breaking off all branchlets bearing cones has contributed to the death of trees in those areas where seed collection is not properly controlled. Similarly the use of crude methods of resin tapping, involving the excavation of large holes in the trunk, has killed many trees of P. oocarpa in some areas. These activities can only assist in destroying the genetic resources when allied to the major agencies of exploitation, land clearance and fire.

THE PROTECTIVE INFLUENCES

1. Ecological

Although severely reduced by exploitation in recent years the natural populations of P. caribaea and P. oocarpa are likely to continue existence for a long time to come in the centre of their ecological range, i.e. on the broad Atlantic coastal plain and on the seasonally arid, steep and infertile mountain slopes respectively. In these areas sustained interference by man is unlikely to be so widespread as to eliminate the pine completely, and pockets at least of the originally continuous forests will survive. Although individual genotypes will vanish the gene pool will continue to exist. However there is more need for concern over the probably more specialised populations at the fringes of the ecological or geographical range of each species, where the remaining stands are already isolated from the main areas in the centre of the range, and where a sudden intensification of the destructive influences could eliminate them entirely. This situation is seen at the southern limit of both species and also in the most severely dry inland occurrences of P. caribaea. Many of the southern populations of P. pseudostrobus are now endangered since they are unable to survive under such unfavourable conditions as the other two species.

2. Managerial

The economic importance of the pine forests is now more fully appreciated in Central America and greater control over exploitation is being exercised. Schemes of fire control to ensure regeneration of the pine have been introduced in some areas with spectacular success, as in the Mountain Pine Ridge of Belize and in the N.E. of Nicaragua. In addition to these governmental schemes a few private landowners are also managing their pine forests to encourage natural regeneration. However these schemes only operate to conserve commercial timber resources and they do not extend to the populations which, as a result of severe depletion or isolation, are most in danger. Although the legal framework may be available to protect such stands the practical means to do so are not.

In a few areas the protective value of the forest over water catchments is likely to ensure its conservation for this reason alone, but these conditions are exceptional.

3. International

The interest of countries outside Central America in the pine resources has resulted in widespread establishment of trial plots and plantations. Most of these are restricted in origin to the same few seed sources. Range wide seed collections for provenance research began in Central America in 1969 under international auspices and the collection of seed for establishment of *ex situ* gene conservation stands is now in progress. This is at present the only effective means of conserving the genetic resources of those populations most endangered in the natural forests. *Ex situ* conservation need not necessarily be international in regard to the siting of the conservation stands, since some at least may well be sited within the country of origin. However a large part of the cost of such operations must be borne internationally.

GENE POOL CONSERVATION IN SITU

Limitations

The main factors limiting the present use of *in situ* gene conservation in the Central American pine forests are social, political and economic, rather than technical in nature. *In situ* conservation can only be attempted where a sufficient level of protection against the main destructive influences can be assured for a sufficient length of time to safeguard the resource. To attempt conservation without adequate control would be counter productive. The majority of the people in the rural areas in Central America live at subsistence level with little more than the natural resources immediately available to maintain them. An area of forested land which is set aside by an outside authority for conservation is certain to be the focus for resentment and even more intensive interference, unless special incentives and/or protective measures are provided. In most areas the administrative problems and the overhead costs in providing adequate protection are too great. It is necessary to rely on the ecological influences for protection, assisted where necessary by *ex situ* conservation.

The exceptions to this are, of course, the areas in which some management is being practised to ensure natural regeneration of the forest. To the extent that this is successful it will ensure continuation of the gene pool but there may be a danger that artificial regeneration may later be introduced, using seed from elsewhere. In order to establish the principles and techniques for *in situ* conservation, some pilot schemes are desirable, in the hope that they may later be applicable more widely. Then pilot gene conservation areas must be located within the larger management schemes.

Selection of pilot areas

The largest and most soundly based management schemes at present are in N.E. Nicaragua (*P. caribaea*) and in the Mountain Pine Ridge of Belize (*P. caribaea* and *P. oocarpa*). These are situated at opposite ends of the latitudinal and climatic range of the species on the coast, although the important stands at the southern extreme of the range are outside the presently controlled area in Nicaragua. Some fire control is also practised on the coastal plain in Belize and there are plans to extend the area under protection here to include a further 26,000 hectares of coastal stands of *P. caribaea*. In the Mountain Pine Ridge gene conservation seems fairly well assured, since part at least is likely to be maintained as a national park, in addition to the large areas naturally regenerated for wood and resin production. Moreover the *P. caribaea* populations from the Mountain Pine Ridge are the most widely represented in the 50,000 hectares of plantations already planted in other countries. The two most appropriate areas for the pilot studies are therefore N.E. Nicaragua, where more than 330,000 hectares are already under protection, and on the coastal plain of Belize.

It would also be desirable to include the other extreme of the ecological range of the species, namely the dry inland stands in the upper valley of the Rio Choluteca in Honduras Republic. This would have the added advantage of providing a pilot scheme in that country. Similar considerations apply to the interesting and isolated stands near Poptun, in Guatemala. However there are many additional problems involved in attempting in situ conservation in these areas and for the pilot scheme there are advantages in concentrating the effort in Belize and Nicaragua.

The size of the area needed depends partly on the initial stocking of mature breeding individuals and partly on the need to explore and demonstrate suitable methods of management. If fire is entirely excluded for a complete rotation period (perhaps 40 to 50 years) the pine is unlikely to regenerate itself adequately in the face of competition from broadleaf species. For this reason, and also to reduce fire risk and protection costs, controlled burning is desirable once the pine regeneration is sufficiently well established to permit it. Some experimentation is needed, and the area should be sufficiently large to accommodate this, and to provide areas of pine forest at different stages of development from young regeneration upwards. For all of this individual areas of about 100 hectares will be required. Average stocking of 200-300 stems per hectare of breeding individuals can be assumed in stands 15 years old or more. Thus a total area of 100 ha should contain 8,000 - 12,000 breeding individuals on 40 ha at any one time, while allowing for 60 ha of immature or regenerating stands.

Selection of the actual sites must be done in consultation with the local forestry authorities and a visit of about 3 months duration by a consultant from an international organization will be needed to complete the selection and other arrangements with the authorities concerned. Two or three sites may be selected in each of the main management schemes. The possibility of extending the pilot schemes to other areas, perhaps in other countries, could also be explored at this time.

Costs

As proposed here the pilot schemes would be a part of larger management schemes, with common overhead expenses and sharing in the normal operations of protection of the forest. It is important that the gene conservation scheme should be thoroughly integrated, and be regarded by the forestry authorities as part of their own project. Clearly there are long-term benefits for the country concerned and it may be considered that the costs of the conservation area are a part of the normal expenses of the larger scheme. However, in addition to the initial expenses concerned with selection and demarcation of the areas, the greater intensity of operations that is desirable in the conservation area, to give a high degree of protection and to provide for different burning regimes in different sections, will certainly incur somewhat higher annual costs.

The initial direct expenses to be borne entirely by the international agency sponsoring the pilot scheme consist of the salary, subsistence and travelling expenses of the consultant. Allowing for the increased costs of air travel these may amount to a total of US$ 10,000.

The cost of the field operations for demarcation, access roads, fire breaks and for the maintenance of the capability to detect and control fires within or threatening the area can only be determined in discussion with the authorities concerned. However some estimate can be made as the basis for such discussions.

An F.A.O. report on fire control in the relevant area of Nicaragua (FAO, 1973) gives an estimated annual cost for the proposed area of the project extension amounting to approximately US$ 237,000 during the first three years. This does not include some overhead expenses shared with other projects. It amounts to a charge of about US$ 1.8 for each hectare under protection. The total area for the new scheme of fire control proposed in Belize is much smaller and accurate estimates of cost are not yet available. Allowing for depreciation of vehicles and plant over a period of 10 years, and of buildings over a period of up to 50 years, and assuming that salaries of supervisory staff are only attributable to the protection scheme for about $3\frac{1}{2}$ months in the year, the annual cost per hectare may be approximately US\$ 4.00. If this figure is taken as the basis for calculation the annual cost of protection of a gene conservation area of 100 hectares would be US\$ 400.00, if it is treated on an equal basis with the rest of the larger scheme.

During the first year the cost of providing access roads and boundary fire breaks for the conservation stands will be somewhat higher than the overall average and extra expenses on demarcation and enumeration may also be incurred. At the same time the roads and the information will be of value to the larger management scheme. As the basis for discussion therefore it is suggested that the initial contribution to field operations in the first year should be US\$ 1,000 in respect of each conservation site of 100 hectares, and that the annual contribution to protection measures during the first 10 years should be US\$ 500 per site. Alternatively the estimated contribution for a period of ten years to all conservation sites within a management scheme might be treated as a single contribution to the initial costs of purchase of equipment.

The long term security of the conservation areas will depend on the sustained interest of the local officials responsible. The provision of funds for local officials to travel to other countries where gene conservation areas are maintained is desirable and an additional sum of US\$ 10,000 may be provided for this purpose.

The total cost over a period of ten years, involving initial consultant visits to four countries, and the selection and management of six pilot gene conservation schemes in two countries, with provision for travelling fellowships for local staff, would amount to approximately US\$ 53,000. This small outlay should be seen against the background of the needed international contribution to the cost of gene conservation ex situ, which is essential to safeguard the populations in the most immediate danger.

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TROPICAL HARDWOODS

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INTRODUCTION

The number of species of tropical hardwoods is vast and their ecosystems, though greatly fragmented, occur throughout the tropics. The majority are known only taxonomically, and very little is known of their ecology and genetics. Their distribution is continually being reduced, and the remaining ecosystems in which they occur massively disrupted. The need for conservation measures for tropical hardwood ecosystems is more pressing than for any of the other forest ecosystems of the world. Except for an insignificant number, these species are not cultivated and occur only in the wild form. Hence for the most part, their continued existence depends on the continued integrity of the ecosystems in which they occur.

The inadequacy of available information and the scope of the problem prevent a detailed treatment of the methodology of tropical hardwoods for each of the three major regions in which they occur. For these reasons, the case study is confined to Africa with special reference to Nigeria, though it is placed in the context of the problem on a world-wide basis.

In most countries in tropical Africa the forest estate, which comprises a large part of the remaining closed forests, is controlled by Government departments of Forestry. In some countries significant areas of forest are controlled by the National Parks Administrations. Effective measures for conservation of tropical forest ecosystems and the genetic resources of their constituent hardwood species can therefore be implemented only through the agency of these Government departments. Any proposed methodology of conservation must recognise this fact.

Since many tropical forest ecosystems are also the habitats of a variety of rare wild life the conservation of these ecosystems is also the concern of zoologists, ecologists and wildlife managers. Furthermore, ensuring the integrity of many of these endangered ecosystems will also ensure the integrity of important water catchment areas and prevent erosion. For these reasons there is clearly a need for a co-operative effort and close contact between foresters and others engaged in conservation of Africa's forest heritage and the resources it contains.

TROPICAL HARDWOOD ECOSYSTEMS

Distribution, Structure and Composition

Tropical hardwood ecosystems are found in three regions of the world. These are the forest areas of Africa, South-east Asia and Central and South America which lie between the tropics of Cancer and Capricorn.

Three broad formations, Wet Evergreen Rain Forests, Moist Deciduous Forests, and Dry Deciduous Forests, are recognized and it is within these three formations, but particularly the first two, that tropical hardwoods are found in commercial quantities.

Almost all the species and many of the families are different in each of the three geographic regions. Despite this, the structure of primary forest ecosystems, and the successional stages in their development in each of the regions are very much alike, and generally there are no tropical hardwood ecosystems which possess synusiae not found elsewhere (Richards 1952).

In each region tropical forest ecosystems typically possess large numbers of species no one of which is dominant in frequency, and of which the great majority are represented by very few individuals per hectare (Table 2, Fig. 1). This latter characteristic may be adaptive and based on host-parasite relations (Connell 1970).

Ecosystems with many species and great stability are generally found in environments which have optimum conditions for growth and which have remained stable for a long time. Such environments have prevailed especially in the ecosystems of the humid tropics and sub-tropics (Stern and Roche, 1974).

Despite their apparent ecological uniformity, a multitude of niches is provided in tropical forest ecosystems, and these niches may be partly filled by chance but predominantly by niche specialization. Niche specialization may result in differences in a few characters only, e.g. mature height, growth rate, life span, shade tolerance, reproduction strategy, type of dispersal mechanism, phenology of leafing, flowering, and fruiting (see Richards 1969). In addition, there may be zones with different frequencies of niches, such as zones of unlike soil type, or trends in mean values of climate along mountain slopes, leading to zonation in distribution of the species or to trends in species frequencies. Increasing complexity of structure in time provides further opportunities for specialization. Therefore, the wealth of species in tropical forests is not only the result of environmental stability and optimum growth conditions which allow extreme specialization in narrow niches, but is also a product of the age of these systems. Every evolutionary process takes time. The more time that is available in a constant milieu the greater the number of species that evolve (Stern and Roche 1974).

EFFECTS OF MAN

The effects of man on tropical forest ecosystems have recently been discussed by Stern and Roche (1974) and a summary of the relevant parts of that discussion is given in this section.

So much of the original plant cover of Africa has been changed as a result of man's activities that it is difficult, if not impossible, to map its vegetation on climatic climax concepts, and many workers have preferred to map the natural vegetations as it exists (Shantz and Turner, 1958). Richards (1952) has stated that, unless determined efforts are made to halt the destruction, the entire tropical rain forest may disappear within the present generation, except for a few inaccessible areas and forest reserves artificially maintained as sources of timber.

It has been estimated (Schantz 1948) that the then area of closed forests of tropical Africa was about 530 million hectares. The adjacent savanna and grasslands, derived primarily from the destruction of forests, was about 900 million hectares, most, if not all, of which is capable of producing forest under proper management. Shantz (1948) concluded that the closed forests of tropical Africa had already at that time been reduced to a third of what they probably were originally, and were still shrinking rapidly. This general disruption of forest ecosystems has resulted in the depletion of the gene resources of many tropical hardwoods, and threatened the existence of entire species. A detailed account of the present conservation status of the natural vegetation of Africa is contained in the publication "Conservation of the Vegetation South of Sahara" (Hedberg and Hedberg 1968).

The remnants of tropical forest ecosystems are now confined to state forest reserves in many parts of the world. This, however, does not mean that the indigenous species within the reserves are regenerated for future use. Logging continues, and the logged areas are sometimes planted with fast growing exotic tree species such as Tectona grandis, Gmelina arborea, Pinus and Eucalyptus spp. Almost everywhere in Africa it has been found easier to establish plantations of exotic tree species than to manage natural, species rich, heterogeneous high forest ecosystems. Thus, modern forestry practice in many parts of the tropics, and certainly in Africa, is aimed at replacing natural forest ecosystems with extensive tracts of single-species plantations of exotic origin.

Despite the smallness of the reserved forest estate in many tropical countries (less than 2% of the land mass is under high forest reserves in Nigeria), there is intense pressure for dereservation of forest land. Since the second world war, and with increasing population density, large tracts of reserved forest land have been turned over to agriculture, or are occupied by farming communities migrating from areas of impoverished soil on the periphery of the reserves.

Natural forest ecosystems in the tropics are being permanently eliminated or massively disrupted at an increasing rate. Furthermore, it appears that there has been relatively little increase in ecological and genetic studies within these systems during the past thirty years, the period during which they have been subjected to the most intensive exploitation. The risk of further permanent loss of many tropical ecosystems and their constituent species over broad geographic regions is high. Furthermore, this loss may occur before these ecosystems have been subjected to any detailed biological investigations to determine their present and future use to man.

GENETIC RESOURCES OF TROPICAL HARDWOODS

Genetics

Pollen and seed distribution are of importance in the initiation and maintenance of species diversity. They determine the effective population size of species, as well as genetic drift and related effects. Pollination is determined by distance, presence of vectors, and time of flowering. Seed distribution is generally limited and regeneration in clumps is not uncommon. Thus, though low population density and autogamy are characteristic features of species of many tropical ecosystems, the presence of small clumps of trees facilitates cross pollination. Furthermore, dioecy, i.e. obligatory cross pollination, may be common in some tropical ecosystems. In a rain forest in Sarawak 26% of 711 tree species exceeding one foot in circumference were dioecious compared with an estimated 2% of British flora and 5% of the seed plants of the world. Most of the dioecious species were found in the lower strata. Pollination by wind is rare and insects, birds, bats and small animals are the principal vectors. Only one out of 760 tree species on 100 acres in Brunei was a wind pollinator. Characteristically, it grew on mountain tops. Wind pollination is more frequent on extreme sites such as river banks, heath areas and mountain tops (Ashton 1964, 1969 - see Poore 1968 for complementary studies in the Malaysian Rain Forest).

The interdependence of flora and fauna of tropical ecosystems is frequently the result of co-adaptation. For example, it has been shown that, of 40 species of Ficus studied in Central America, every one had its own pollen vector; only one species had two. Of the two broad taxa of Ficus studied each possessed its own growth related pollinator species of wasp (Agaonidae). Introduced species of Ficus did not produce seed if the pollinator was missing (Ramirez 1970). This interdependence of vector and tree species would indicate that, if the ecosystem is so disrupted that the vector is no longer present in sufficient numbers to ensure pollination, seed set would be reduced and the species eventually eliminated if no change in the mating system occurred. There is evidence, however, that change in the mating system can occur if such a change favours the survival of the species.

The dispersal of seed is a more effective mechanism for migration than the dispersal of pollen. Here again, light, wind-distributed seed is rare in tropical forest ecosystems, though there are exceptions, e.g. Bombax buonopozense and Ceiba pentandra (Hall 1974). Heavy fruits with large food reserves predominate, allowing seed establishment in shade. Distribution by animals is frequent. Osmaston (1965) has suggested that the fruit bat (Eidolon helvum) can consume over 500 seeds of Chlorophora excelsa, a dioecious, commercial hardwood, in the course of a single night's feeding on the fruit, and subsequently disseminate the seeds in droppings.

The demands upon a population in regard to adaptation change with the position of a species in succession. Succession begins with pioneer species and ends with the prevalence of climax species or with a subclimax vegetation. Both types of species colonize or recolonize respectively in different ways and with different requirements on their respective environments (Stern and Roche 1974).

Climax forest ecosystems are periodically subjected to natural catastrophies which result in large gaps being created in the forest. The natural processes of aging and death result in smaller gaps, which also provide opportunities for the regeneration of the ecosystem. Pioneering species, usually light demanding, rapid growing, and short lived, colonize the larger gaps. Thus, Cecropia and Ochroma spp. are found in primary forest gaps in South America; Musanga cecropioides and Maesopsis eminii respectively in West and East Africa; Macaranga in Malaysia; and species of Adinandra, Mallotus, Melochia and Trema in South-east Asia (Richards 1971). These pioneering species are in turn succeeded through various seral stages of succession. Furthermore, there is considerable evidence that the combination of species of a climax ecosystem, at a given place and time, is succeeded, following the establishment of gaps, not by the same combination, but by a different one; however, over an extensive area of mixed forest all combinations would be represented. Therefore, the dynamic equilibrium of species combinations in climax ecosystems, though fluctuating in space and time, is constant over a large area. The smaller gaps, caused for example by the death of an emergent, may be filled by shade tolerant saplings which assume rapid growth following removal of the heavy canopy under which they had become established. Thus the gap is filled by a species randomly present and able to respond to increased sunlight (Richards 1971, Baker 1959).

Genetically based, habitat correlated variation has been demonstrated for almost all tree species of the north temperate zone which have been studied. The extent to which the same phenomenon exists in tropical hardwoods is unknown. However, it is very likely that tropical hardwood species which have a wide distribution through a range of environments, for example Khaya grandifoliola in Nigeria, will also exhibit intraspecific variation. Those important commercial species of tropical and subtropical environments such as Tectona grandis and a number of Eucalyptus spp. which have been studied confirm this conclusion.

Limits of Conservation

Though fragmented and sparse, the information on the ecology and genetics of African tropical forest ecosystems illustrates the interdependence of the flora and fauna of these ecosystems, and the difficulties that would be encountered in developing a methodology of conservation of species independently of their ecosystems. In the absence of adequate information on the biology and silviculture of the vast majority of tropical hardwoods, these difficulties are compounded, and in the short run insurmountable.

At the low densities in which they occur, and in the absence of adequate information on what constitutes an effective breeding population, questions of correct size of area to ensure conservation in situ of the genetic resources of a particular species in tropical forests are even more difficult to determine than elsewhere (cf. discussion in chapter 10). Frequently all that can be done at the present time is to ensure that the endangered species is represented by as many stems as possible in the forest ecosystems scheduled for allocation to Strict Natural Reserves, or National Parks.

Similarly the lack of silvicultural information limits the possibilities of ex situ conservation of many tropical hardwoods.

Frequently, it is not known whether populations of a species, limited in distribution and occupying a unique habitat, are increasing or decreasing in a given ecosystem. It is possible, therefore, that in time desirable populations will be eliminated from a conserved ecosystem. In such instances, and with appropriate management techniques, an ecosystem can be maintained in a subclimax stage to favour the perpetuation of a particular species. "However, there are natural and economic limits to conservation, and completeness of coverage is less realistic and relevant than the biological soundness of systems of conservation, whatever biota they are designed to protect. If extinction of a protected species occurs at some time in the future, it should be due to natural evolutionary causes, and not to an inadequate reserve" (UNESCO 1973).

Conservation in situ

State forestry departments in the tropics are aware of the need to conserve remnants of the natural forest in different vegetation zones, and many African countries have put aside tracts of forest which are referred to as Nature Reserves, Strict Natural Reserves, or Inviolable Plots. The term Strict Natural Reserve (SNR) is that used, endorsed and defined by the Organization of African Unity (O.A.U. 1968) whose stated policy on the conservation of nature and natural resources is clear. A Strict Natural Reserve is defined by the O.A.U. as follows:

(i) Under state control and the boundaries of which may not be altered nor any portion alienated except by the competent legislative authority.

(ii) Throughout, any undertaking connected with forestry, agriculture or mining, any grazing, and excavation or prospecting, drilling, levelling of the ground or construction, any work tending to alter the configuration of the soil or the character of the vegetation, any water pollution and generally any act likely to harm or disturb the fauna or flora, including introduction of zoological or botanical species, whether indigenous or imported, wild or domesticated, are strictly forbidden.

(iii) Where it shall be forbidden to reside, enter, traverse or camp, and where it shall be forbidden to fly over at low altitude, without a special written permit from the competent authority, and in which scientific investigations (including removal of animals and plants in order to maintain an ecosystem) may only be undertaken by permission of the competent authority.

As previously indicated, Departments of Forestry of a number of African countries already have a well defined programme of conservation of their major forest types, which, though implemented prior to the O.A.U. agreement on conservation of natural resources, conforms closely with its recommendation and definitions. For example, Kenya has 4 Strict Natural Reserves, Uganda has 10 and Nigeria 7, and each of these countries has demarcated other areas for reservation. Some of these Strict Natural Reserves were established in the late thirties and early forties, and have been instrumental in maintaining the habitat of a number of important animals, for example Gorilla gorilla in the Bwindi Forest Reserve in Uganda.

The legal status of Strict Natural Reserves in Nigeria and Uganda is identical to that of Forest Reserves; hence they continue to be vulnerable to the traditional rights of local people. In Kenya on the other hand a Strict Natural Reserve has a legal status which gives it greater protection than a Forest Reserve. The appropiate section of the Kenyan Forest Law is as follows:

(i) The Minister may, by notice in the Gazette declare any forest area or any central forest or any part thereof.to be a nature reserve for the purpose of preserving the natural amenities thereof and the flora and fauna therein, and may in like manner declare that any nature reserve shall cease to be a nature reserve.

(ii) In any nature reserve, no cutting, grazing, removal of forest produce or disturbance of the flora shall be allowed except with the permission of the Chief Conservator, and such permission shall only be given with the object of conserving the natural flora and amenities of the reserve.

(iii) Hunting, fishing and the disturbance of the fauna shall be prohibited except in so far as may be permitted by the Chief Conservator in consultation with the Chief Game Warden, and such permission shall only be given in cases where the Chief Conservator in consultation with the Chief Game Warden considers it necessary or desirable to take or kill any species.

There is then available, for African states, a clearly stated policy and an equally clear definition of a Strict Natural Reserve. Based on this policy, and a refinement of the methodology already implemented in a number of countries, a programme of action for conservation of the genetic resources of tropical hardwoods can be developed. It is emphasized, however, that the programmes proposed will require support from international agencies, and that they must be developed through existing government departments already concerned with forest genetic resources conservation.

When African nations have established sufficient plantations to meet national requirements, the rate of conversion of high forest to plantations will considerably decrease. Even so the forest reserves will continue to be subjected to great pressure from local farming populations. It is certain, therefore, that an increase in the reserved forest estate cannot be anticipated in African countries, but on the contrary, it is highly probable that it will decrease as a result of dereservation, hence the pressing need for the further establishment of Strict Natural Reserves.

Guidelines for <u>in situ</u> conservation have been given in Chapter 10 and will not be repeated here. However, it is perhaps desirable to reemphasize the necessity of providing rigorous criteria for the setting up of Strict Natural Reserves, and for the subsequent management of these reserves. As indicated in Chapter 10, areas of forest land set aside, merely with the stated purpose of forest genetic resources conservation, are unlikely to remain inviolate, and furthermore will not provide information about these resources which would result if conservation objectives were incorporated in forest management plans.

<u>Conservation ex situ</u>

A methodology for the conservation of tropical hardwoods must result from a synthesis of all available information on the composition, ecology and genetics of their ecosystems, and the extent to which these ecosystems have been disrupted by man. This information must be incorporated in practical proposals for the demarcation and management of S.N.R. by state agencies. However, if the establishment of S.N.R. is not possible in an area where unique populations of a species are endangered, then it will be necessary to devise methods for <u>ex situ</u> conservation.

Such populations should be propagated either vegetatively in clone banks or from seed in order to ensure their perpetuation. Seed should be harvested as often as possible from the original stands and planted either locally or in another country willing to co-operate in conserving the genetic resources of the species. On occasion when endangered populations of a species cannot be propagated locally because of chronic attacks by pathogens, e.g. <u>Lovoa swynnertonii</u> in Kenya, it is necessary to seek assistance in having plantations established in another country where the pathogens are absent or less virulent.

A relatively small number of tropical and subtropical hardwoods are sufficiently known silviculturally to allow the successful establishment of plantations both within and outside the countries of their origin. Of these by far the most important internationally are Tectona grandis, Gmelina arborea and certain Eucalyptus spp. These species have been planted throughout the tropics and ex situ conservation measures have been taken particularly for Tectona grandis and Eucalyptus spp.

Chapter 8 indicates a methodology for ex situ conservation, and outlines the major factors that must be considered in developing such a programme. There is little doubt that similar methods of ex situ conservation will prove to be necessary for a number of tropical hardwoods for which at the present time appropriate techniques of seed storage, plantation establishment and vegetative propagation have not yet been worked out. For these reasons priority must be given to research programmes that will supply this information. It is important to note, however, that many commercially important tropical hardwoods are species of climax forest ecosystems, and will prove extremely difficult or impossible to establish in pure plantations. The species that lend themselves best to ex situ conservation are the light demanding, colonizing species which generally do not pose a conservation problem.

Research needs

The on-going programmes of conservation of tropical hardwoods by State Departments of Forestry could be given scientific support by relevant research programmes conducted by national committees composed of scientists from appropriate University Departments and Government agencies. These research programmes could be concerned with ecosystem survey and classification, and the genetics and ecology of endangered or impoverished species. Particular emphasis should be placed on studies within the reserves to determine such factors as mature height, growth rate, life span, shade tolerance, reproductive strategy, type of dispersal mechanisms, and phenology of flowering and fruiting. They would also be concerned with problems of harvesting, storage, and testing of tropical hardwood seed.

The results of these research programmes will have a direct bearing on conservation, for only when such results are available is it possible to manage scientifically the remnants of reserved high forest which surround the Strict Natural Reserves and for which conversion to plantations of exotic species is not planned. The development of silvicultural techniques for individual hardwood species, and the eventual domestication of these species must, of course, also depend on the results of these research programmes.

THE SITUATION IN NIGERIA

Since it is not possible to deal in detail with the methodology of conservation of all tropical hardwoods in the countries of the world in which they occur or even for Africa, it is proposed instead to describe, in some detail, the on-going programme in one country where a methodology is developed and where the need for conservation is clearly evident.

Though a nation of possibly 80 million people, Nigeria has only two per cent of its land mass in reserved high forest (Table 1). Formerly attempts were made to manage these forests under tropical shelter wood systems (TSS), but to a very large extent these attempts have now been abandoned and emphasis is placed on converting high forest ecosystems into man-made plantations of exotic species. Conversion is usually by the Taungya system, that is, local farmers are invited into the reserves to clear logged-over, though still heavily wooded areas, and in return they are allowed to plant their crops on the cleared land until the planted tree crop closes canopy. When this occurs they are moved to another area.

Though Nigeria does not have the large number of tree species found in some tropical countries, it nevertheless contains some very important commercial hardwoods and hence there has been an intensive exploitation of a number of these species to the extent that they are increasingly in short supply. Furthermore, they are not being planted on any significant scale (Table 3). Logging continues to be intensive and is likely to increase with the rapid growth of the home market. Exploitation combined with conversion of high forest to plantations, dereservation, agricultural encroachment in forest reserves, and past disruption, have resulted in the virtual elimination of undisturbed primary high forest ecosystems. Present conservation efforts, therefore, are aimed at arresting a rapidly deteriorating situation, for at the present time there are no parks or game reserves gazetted in the high forest areas most heavily affected.

In situ conservation

A vegetation map for the country is in preparation and seven Strict Natural Reserves have been established in a number of major forest formations. Details of the location and size of these Strict Natural Reserves are given in Table 1. A detailed description of one of these reserves is given in Table 4. Similar records are kept for each of the other reserves. The criteria used in selecting the areas to be constituted as Strict Natural Reserves are:

(i) Areas which contain adequate samples of typical major ecological formations which exhibit no major disturbance.

(ii) Areas which support species of plants of outstanding interest or great rarity.

(iii) Areas containing endangered species or species undergoing genetic impoverishment.

(iv) The areas must be accessible but not too close to highways, plantations, and settlements.

(v) Their size must be sufficient to prevent the vegetation type from being disrupted by change in the vegetation surrounding it.

In selecting and establishing a Strict Natural Reserve, the following steps are taken:

(i) Potential areas are demarcated on aerial photographs.

(ii) A reconnaissance survey is carried out in the area demarcated in order to locate the particular area suited for constitution as a Strict Natural Reserve.

(iii) Approval is sought from the Chief Conservator of Forests of the state concerned to constitute the selected portion of the forest reserve as a Strict Natural Reserve.

(iv) When approval is given, the area is surveyed and its boundaries demarcated by cement pillars.

(v) The vegetation is described and a detailed list of the flora of the reserve is made. A profile diagram of the forest structure is drawn, and the soil type determined.

(vi) A file is opened for the reserve and all subsequent records are maintained in this file.

The boundaries of the Strict Natural Reserves, which are not fenced, are cleared annually by personnel of State and Federal Forestry Departments, and inspection is carried out in the Reserve. To date, it is clear that the legal status of the Strict Natural Reserves in Nigeria is not satisfactory, for unlike the situation in other African countries, such as Kenya, traditional rights still prevail in forest reserves in Nigeria, and hence local people continue to hunt, and to collect firewood and forest produce of various kinds. Considerable disruption has resulted in a number of reserves because of this.

It is recognized that there is not a sufficient number of Strict Natural Reserves in Nigeria, and that many forest formations containing important populations of hardwoods are not represented. Hence proposals have been made for the establishment of other reserves. A list of vegetation types and forest reserves in which it is proposed to establish further Strict Natural Reserves is given by Charter (1968).

The entire programme of *in situ* conservation is the responsibility of the Federal Department of Forest Research working in close cooperation with the forestry departments of each of the 12 states.

Ex situ conservation

Seed is harvested for a number of major hardwood species and those species for which a methodology of storage has been developed are retained in cold storage indefinitely. Seed of a number of hardwoods is supplied both to the states within the Federation and to other countries. A major research programme has been developed to determine the biology and silviculture of two major hardwood species, *Triplochiton scleroxylon* and *Terminalia ivorensis* which will ensure in the long run the perpetuation of these species in plantations, and their eventual domestication. These programmes are being conducted by the Federal Department of Forest Research with financial and technical support from outside agencies.

Supporting Research Programmes

The Federal Department of Forest Research has initiated a programme of research and development for tropical hardwoods which is centred on the seven SNR already established. The Department has also drawn up proposals for the establishment of more SNR and a related research programme to ensure the conservation of gene resources presently unprotected (Iyamabo and Adams 1974).

A programme of genecological studies on tropical hardwoods is being conducted at the Department of Forest Resources Management, University of Ibadan, and stand tables and distribution maps are being prepared for the major hardwood species (Hall and Redhead 1974, Redhead 1971).

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Table 1: Area of Reserved Forest Estate in Nigeria by Vegetation Types, and areas in Strict Natural Reserves

Vegetation Zone	Area (km^2)	Percentage of Land Area	Area of Forest Reserve (km^2)	Percentage of Land Area	No. of Strict Natural Reserve	Total Area (ha)
Sahel	31,463	3	2,571	0.3	-	-
Sudan Savanna	342,158	35	31,247	3.2	1	142
Guinea Savanna (inc. Bauchi Plateau)	400,168	40	38,271	3.9	1	170
Derived Savanna*	75,707	8	3,208	0.3	1	145
Lowland Rain** Forest	95,372	10	19,986	2.0	4	620
Freshwater Swamp Communities	25,563	3	256	-	-	-
Mangrove Forest and Coastal Vegetation	12,782	1	522	0.1	-	-
TOTAL	983,213	100	96,061	9.8	7	1,077

* includes moist semi-deciduous forest outliers
** includes a small proportion of moist semi-deciduous forest

Table 2: Nigerian High Forest Species: The Thirty Most Frequently Occurring Species (Hall and Redhead 1974)

Rank	Species	Stems per Hectare (over 60 cm girth)	Rank	Species	Stems per Hectare (over 60 cm girth)
1	Strombosia pustulata	6.65	16	Pausinystalia Talbotii	1.66
2	Celtis zenkeri	3.46	17	Brachystegia spp.	1.61
3	Diospyros suaveolens	3.29	18	Pausinystalia macroceras	1.53
4	Scottellia coreacea	3.11	19	Combretodendron macrocarpum	1.51
5	Anonnidium mannii	2.72	20	Hylodendron gabunense	1.43
6	Elaeis guineensis	2.52	21	Bosqueia angolensis	1.43
*7	Triplochiton scleroxylon	2.48	22	Mansonia altissima	1.16
8	Ricinodendron heudelotii	2.47	23	Alstonia boonei	1.14
9	Sterculia rhinopetala	2.13	24	Celtis mildbraedii	1.11
10	Cola gigantea	2.03	25	Pentaclethra macrophylla	1.09
11	Celtis brownea	2.00	26	Strombosia grandifolia	1.04
12	Hunteria umbellata	1.85	27	Diospyros alboflavescens	0.99
13	Anthostema aubryanum	1.83	28	Xylopia quintasii	0.99
14	Uapaca spp.	1.75	29	Diospyros piscatoria	0.96
15	Terminalia superba	1.71	30	Berlinia spp.	0.91

* The only species presently of major economic timber importance (see Redhead 1971)

Table 3: Species Planted in the West and Mid-Western State of Nigeria (Redhead 1971)

Western State-up to 1968

Species	Area (acres)
Cedrela odorata	30
Gmelina arborea	4,672
Entandrophragma utile	20
Khaya ivorensis	29
Lovoa trichilioides	10
Mansonia altissima	20
Nauclea diderrichii	533
Tectona grandis	12,919
Terminalia ivorensis	966
Triplochiton scleroxylon	293
	19,492

Mid-Western State-up to 1969

Species	Area (acres)
Pure planting	
Cedrela odorata	187
Eucalyptus spp.	25
Gmelina arborea	5,225
Meliaceae	1,645
Mitragyna ciliata	16
Nauclea diderrichii	5,601
Tectona grandis	4,987
Terminalia ivorensis	5,903
Terminalia spp.	1,638
Triplochiton scleroxylon	809
Others	3
Mixtures	
Nauclea/Meliaceae	14,269
Nauclea/Mel/Term.	2,401
Nauclea/Triplochiton	30
Miscellaneous	996
	43,735

Table 4: Location, Size and Composition of a SNR in Nigeria

STRICT NATURAL RESERVE NO. 2 FOREST RESERVE: AKURE

1. ECOLOGICAL ZONE: Moist Lowland semi-deciduous forest.

2. LOCATION: North of Akure, 1.2 km before the Pilot Sawmill (7 - 7.5°N, 5 - 5.5°E), Western State.

3. AREA: 32 hectares

4. ELEVATION: 250 m.

5. SOIL AND PARENT MATERIAL: The area as a whole overlies crystalline rocks, mainly gneisses, varying considerably in mineral composition, while the inselbergs are either granite or hard quartz-rich granitoid gneiss.

6. TOPOGRAPHY: The plot is fairly even, with one small stream valley running more or less north and south through it. Topographically the whole plot occupies a high level site with the exception of the colluvial valley sides.

7. RAINFALL: Mean annual rainfall is 1500 mm.

8. BIOTIC FACTORS: Bush pigs, antelopes and duikers are common. Occasionally hunters set traps along the boundaries of the plot.

9. HISTORY: Little is known of the history of the area. Artefacts, including sculptures and figures, and fragments of domestic pottery have been unearthed from several parts of the Akure forest reserve, particularly during the excavation of the mill-site and the construction of the feeder roads.

   Pot fragments were found in one of the soil pits on the plot itself and all the soil profiles appear to be old farmed soils. This, together with the high density of emergents and large upper storey species per acre, would seem to indicate that the area has been part of a farming mosaic at some not very distant period, and most probably about 150-200 years ago.

10. VEGETATION: About 70% of the area is under high forest, 30% is under gaps, windbreaks and broken forest of various densities. The emergents totalling 160 (made up of 20 species) consist mainly of Triplochiton scleroxylon, Klainedoxa gabonensis, Terminalia superba, Entandrophragma utile, E. angolense, Alstonia congensis, Khaya grandifoliola, Cylicodiscus gabonensis, Piptadeniastrum africanum and Amphimas pterocarpoides.

    These emergents occur over both high forest and the broken derivatives.

    In the high forest patches there are large numbers of big middle storey trees totalling 1000 (made up of 32 species) consisting mainly of Hexalobus crispiflorus, Strombosia pustulata, Sterculia rhinopetala, Cola gigantea, Scottellia coriacea, Nesogordonia papaverifera, Celtis mildbraedii, Diospyros piscatoria, Pterygota macrocarpa and Chrysophyllum delevoyi.

    The lower storey is fairly well developed. There are 1105 trees made up of 30 species, consisting mainly of Annonidium mannii, Anthonotha macrophylla, Lychnodiscus reticulatus, Hunteria umbellata, Diospyros dendo,

Table 4 (Contd.)

Fagara macrophylla, Trichilia heudelotii and Desplatzia subericarpa.

Occasional seedlings, 2-5 feet high of Mansonia altissima, Nesogordonia papaverifera, Celtis mildbraedii, Entandrophragma utile, Cola lateritia and Sterculia rhinopetala are found confined to gap edges and open places. There is fairly dense herb layer under broken and high forest (Jones 1948).

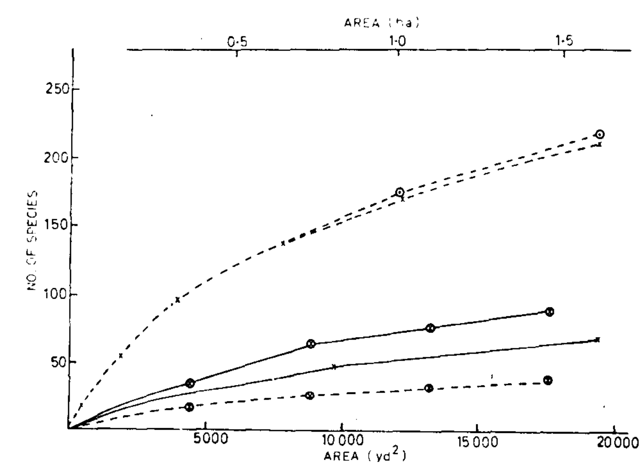

FIG. 1. Species/area curves from Tropical Rain forest. (a) Trees over 4 in. (10 cm) diameter in mixed forest, British Guiana (⊗——⊙); (b) Trees over 12 in. (30 cm) diameter in mixed forest, British Guiana (⊗– – –⊗); (c) Trees over 4 in. (10 cm) diameter, Bukit Lagong, Malaya (○– – –○); (d) Trees over 4 in. (10 cm) diameter, Sungei Menyala, Malaya (×– – –×); (e) Trees over 11·5 in. (28 cm) diameter, Sungei Menyala, Malaya (×——×); (a) and (b) after Richards (1952); (c), (d) and (e) based on Wyatt-Smith (unpublished data) (Poore 1974).

7

EUCALYPTS

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INTRODUCTION

The eucalypts are confined to Australia except for one species found in Timor and adjoining Indonesian Islands and another in Papua New Guinea, the Celebes and Mindanao. Half a dozen species, which otherwise occur in Papua, are shared with North Australia and are closely similar in both places. As it happens, although the two species which occur indigenously outside Australia, but not within it, are of special importance, the large number of species in the genus which occur almost entirely in Australia also provide an enormous interest for silviculture. Some are widespread and some are restricted in geographic range (Blakely 1965, Forestry and Timber Bureau 1953, Pryor and Johnson 1971). In the widely distributed species there is usually a great deal of diversity associated with their occurrence in different places within the country.

Since European settlement, there have been great changes in Australian vegetation, many eucalypt populations having been largely reduced, even though it is unlikely that any single species, or any significant provenance, has been lost. On the other hand, as land use is changing rapidly, there are cases in which, unless positive action is taken to conserve some of the genotypes, they may well be lost. Many species are, of course, small trees such as the mallees which have importance for soil conservation and amenity planting rather than as forest plantations. Others form extensive woodlands, many of which likewise are only marginally significant for wood-production forestry. The preservation of these is by no means guaranteed and in some of the woodland species there have been massive reductions of populations because it is in these areas that food growing is largely centred, either by direct cropping, such as with wheat, or by the production of pasture for grazing sheep and cattle. On the other hand, the species which are the principal timber producers are amply represented in State Forests, since most of the timber producing forest in Australia is part of the Public Estate which, in each case, is under the management of a Government Forestry Service. For these latter species there is no need for any specific action in conservation.

1. EUCALYPTUS "UROPHYLLA" (PAU PRETO)

This tree does not occur in Australia but is found in natural stands over a fairly extensive area on non-calcareous soil in Portuguese Timor. It also occurs, although more sparingly, in Indonesian Timor and also in several other Indonesian islands. It has been reported that the stands on Solor have completely vanished but there are stands still on the islands of Flores, Wetar and Alor. Information concerning the species on these islands is sketchy and the first step in conservation would be to assess by an exploration visit the current status of the stands, make collections of seed for provenance trials and undertake an assessment of the conservation status of the species in each island as a prerequisite to suggesting the most appropriate method of conservation. The occurrence in Portuguese Timor is of particular importance because it is the most extensive population. It occurs over a wide range of habitats from an altitude of about 500 metres in the vicinity of Dili to the summit of the highest peak in the country, Mt. Tatamalau, at about 3000 metres.

This, therefore, is by far the greatest altitudinal range covered by a single eucalypt species. E. "urophylla" is a species of great potential significance in tropical forestry. Small trials in recent years indicate that it is particularly suitable for plantations producing industrial wood and other wood products in tropical areas of moderate to high rainfall. There are a few small, but particularly promising, trial plantations of the species in Brazil in latitude 23^{o} S and at an altitude of 1000 metres and at 100 metres altitude in latitude 17^{o}S (Pryor 1971).

It is also evident that it is one of the relatively few species of eucalypt which can be extended in plantation form at low altitude into low latitudes in the tropics, although the precise limits to which it may be successfully introduced are not yet clear. E. "urophylla" is a species which shows wide provenance variation. For most of its distributional range in Portuguese Timor it is the only eucalypt present, although in the lower zone up to 1000 metres in altitude, there is a mosaic in some degree of stands of this species and E. alba. Rarely, hybrids are found between them. For the most part the E. "urophylla" occurs as the sole species on all topographic aspects and through the whole altitudinal range. This situation is unusual in Eucalyptus since, where more species are available instead of the solitary pair found in Timor, similar altitudinal and aspect variations would give sites occupied by a substantial range of species, ten to twelve in number being common in Australia. In the biological sense, it seems that the occupation of the eucalypt zone in Timor largely by E. "urophylla" results from the existence in the island of a limited gene pool. That is to say, there have been only two species of eucalypt in the area and only one species has occupied most of the sites. As a result, there are wide variations in the populations in different localities as might be expected. Assessment of genetic make-up by growing seedlings collected from different stands shows that there are strongly inherited differences between them. Indeed, the level of distinction between the more extreme forms approaches that characteristic of sub-species in other situations. But if one were to make sub-species out of the easily recognizable forms alone, these would be numerous and at the same time difficult to separate, since there are stands of intermediate features between them.

In a broad sense, there are three kinds of habitat in Timor. First, there are the steep slopes on the north coast, particularly to the south of Dili from about 500 metres elevation to 2000 metres elevation, much of which is in an evident mist belt. This clearly affects the character of the stand and is expressed in the genetic make-up of the population. Secondly there is a middle montane zone extending roughly from Aileu to Hato Builico and to areas east and west of this line and thirdly, a subalpine zone from Hato Builico at about 2000 metres to the summit of Mt. Tatamalau at 3000 metres.

It is evident from the studies based on open pollinated progenies that in the mist belt the trees are better adapted to the wet lowland tropics than those from elsewhere and that they are fast growing and of reasonably good form when planted on low altitude - low latitude sites in the moderately wet to wet tropics. In the middle montane zone trees of the best form are probably found and this is reproduced in plantations grown from them. The sites in this zone are probably more subject to drought between monsoons and no doubt this will be reflected in the physiology of material taken from these areas. At the higher altitudes above 2000 metres, the tree becomes smaller in stature with a different bark character and with differences in the morphology of leaves and fruit but it is in no way cut off by a sharp boundary. There is a general morphological gradation in accordance with altitude but there remains a high level of variation in any one particular site indicating the incomplete genetic isolation of the different stands and the incomplete adaptation of the natural stands to each site. At the summit of Mt. Tatamalau the trees are mere shrubs of two or three metres height and are burnt from time to time. Even if fire were excluded, it is unlikely they would ever reach a height greater than four or five metres.

Needless to say, all of the populations are of considerable silvicultural value and they are of value to the local residents in Timor. As is inevitable from the population pressure there, as in other parts of the world, the areas subject to clearing and cultivation are forever increasing to make way first for a transient crop such as potatoes, and then for grazing. Recently, ring barked trees near Hato Builico are much in evidence. Over quite extensive areas, too, the stands existing at present are patchy regrowth resulting from similar operations in the past. The stage of economic development of Portuguese Timor, the application of the laws with regard to the preservation of forest, and the facilities for the management of it, are such that the surviving stands, although still fairly extensive, are for the most part very substantially modified and are in a precarious situation. It cannot be claimed that the species as a whole is yet very seriously threatened with extinction but particular provenances of it are so limited that they may be almost eliminated, if not entirely so, by the slow attrition in the course of ordinary life in the country.

They may perhaps be faced with a disaster, such as an over zealous seed collecting expedition directed solely to the economic end of establishment of large-scale plantations of plantations of a particular provenance of the species in countries outside Portuguese Timor. While a well planned operation might achieve without lasting damage significant seed collection by lopping branches only, the temptation to fell trees would always be great and if this were done legally or illegally the likelihood of added damage in some localities would be heightened. This would follow because of the needs of people for fuel. Also some areas carrying particular provenances of E. "urophylla" at present could provide agricultural cropping land, the urge to use which would weaken any protective arrangements.

The main needs in a conservation programme for this species would be first a detailed survey followed by provenance testing, so that stands which represent provenances of particular value might be set aside and protected in Timor itself, as far as this is practicable within the social context of the country. It may be said that such setting aside has already been done in terms of current legislation in Timor, but the policing and protecting of the stands is a vital part of an effective system which the present financial and other resources are scarcely adequate to meet. Secondly, the establishment of seed producing areas of selected provenances outside Timor becomes of vital importance. Such stands should have identity records and be given suitable breeding isolation to ensure the retention of their genetic integrity. Thirdly, it should be accepted that, while carefully controlled collection of seed for provenance trials and ex situ conservation stands is to be encouraged, felling for massive collection of seed from Timor for industrial plantations should not be countenanced at the present time.

A tentative estimate of costs for conservation of E. "urophylla" appears in the appendix on p. 79.

2. EUCALYPTUS CAMALDULENSIS

This species is perhaps the most widely planted eucalypt and it is the most wide-spread species in the natural Australian habitat. It occurs in all States of Australia with the exception of Tasmania, being found from the south coast in Victoria and South Australia to almost the north coast in Queensland, Western Australia, and near Darwin. A very characteristic site for E. camaldulensis is along the sandy transient water courses of the inland drainage systems in Australia which run with water only at widely separated intervals when seasonal conditions produce flood rains. The intensity of land use through much of the range of E. camaldulensis is light and there is no foreseeable change which would significantly affect the survival of E. camaldulensis over the vast areas through which it occurs. Some of the occurrences too are on dedicated State Forests which provide the guarantee for continuing survival of the populations which is sought.

As with other widespread species, there are in different parts of its range, distinct differences in the genetic make-up of the species (Karschon 1967, Pryor and Byrne 1969, Turnbull 1973). At the broadest scale there are a northern and a southern sub-species meeting at about latitude 26° S. As with E. "urophylla", within each of these two major groups there are many genetically based variants. One of the matters of particular interest with this species is its capacity to withstand calcareous soil. This for the most part is relatively slight and most natural stands do not occur on soils with a high pH.

Here and there, however, small stands of E. camaldulensis, such as near Port Lincoln in South Australia, are found growing on massive occurrences of Miocene limestone. In such circumstances it is likely that the population is adapted to some extent to calcareous conditions, and there is some evidence of physiological adaptation. Special stands of this kind may be on privately owned property or land under local government control and, if so, there is no certainty that an owner will continue to preserve them. This will often depend on local economic pressures and there is no guarantee of continuity of preservation in such conditions.

To know what stands of this kind exist, or others adapted to different but special kinds of site, would require more survey than at present, so that particular sites of special importance can be identified. The best means for preservation then would be to arrange for the setting aside of appropriate areas attached to a Government Authority, so that a government sponsored management programme aimed at conserving the resource would be put into effect. In many cases this would simply mean ensuring that there was no tree clearing in the future and that the site was recognized as one devoted to the retention of the resource for occasional seed collection as required. Reservation as a National Park, from which seed could be collected under prescribed conditions, would suffice. The need for preservation is generated mainly by the importance of the species for use as an exotic outside Australia.

3. EUCALYPTUS PARVIFOLIA

The situation with this species is different from the foregoing. It is a small round-headed tree of woodland rather than forest form, seldom exceeding 10 metres in height. It has been found, as a result of plantings for shelter belts mainly in the United Kingdom, to be one of the few species capable of surviving low temperatures in the higher latitudes with an Atlantic type climate characteristic of sites in Western Britain on which it has been planted. It has unusual physiological capacity to resist low temperature, and this might be incorporated in hybrids to produce cold resistant trees to extend the range of Eucalyptus planting for timber production or other use to higher latitudes than is commonly feasible at present in the Northern Hemisphere. This possibility has attracted attention and it is the quality of the gene resource which makes it valuable.

E. parvifolia occurs as scattered groups of trees in a very restricted area in the south east of New South Wales, extending over a distance of less than 100 km in a north-south direction in a narrow strip a kilometer or two wide on the coastal scarp. Most of the known occurrences are on land privately owned in lots of 500 ha to 1000 ha which are devoted to cattle and sheep grazing. Some clearing on such properties has been carried out in the past to develop either rough pasture or even substantially improved pasture. As a result a good many of the trees have already been lost. There remain probably only a few hundred individuals. They often occur on the edge of swampy ground. In current land use practice these are not likely to be cleared, but pressure for land development to improve production, if it were associated with drainage, could eliminate major parts of the remaining population. The full distribution of the species is not known from any published work and a survey would be necessary to establish this. Such a survey might disclose that some small stands exist on State Forest but, if not, the preservation of the species in its natural habitat could be assured if a grazing property, at present privately owned, were purchased and attached to State Forest under the control of the Government of New South Wales. A survey might disclose that two or three properties would merit purchase and such attachment to the government authority, especially so that there would be some insurance against losses by storm or fire from the resultant dispersion of the resource, as well as to include some separate stands which might extend the range of genetic diversity thus preserved, even though at this stage no assessment has been carried out to indicate whether there is significant genetic variation or not. The preservation of the species would be the prime purpose of management of this land and its survival would then be assured.

E. parvifolia is certainly not unique in this regard and is in a position similar to that of a number of other eucalypt species in south eastern Australia which have relatively little importance in their natural habitat but, because of their genetic make-up, may have very considerable future breeding value and therefore merit preservation as a gene resource. For example E. neglecta in Victoria and E. morrisbyi in Tasmania are similar cases and in every Australian state there is a comparable position. Effective preservation of natural stands generally means provision of finance to return ownership of the land to a public authority, together with the adoption of a management policy to maintain the stands of the species in the conservation interest. When use of the gene resource is sought, the preserved area could provide the small quantity of seed needed to set up a seed-producing stand for more extensive use outside Australia.

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APPENDIX

DRAFT BUDGET FOR CONSERVATION OF E. "UROPHYLLA"

PHASE I		$US
Survey in Timor and Indonesia Biological Assessment and Seed Collection		
1 Forester (specialist) 1 Field Assistant	6 months	18,000
Administrative Assessment		
The development of in situ plans in Timor (Portuguese speaker with legal and forestry experience)	3 months	6,000

PHASE II

Similar Programme in Indonesian Islands for Administrative Assessment.	3 months	6,000

PHASE III

Conservation *ex situ*

100 hectares of plantation with isolation belts of *E. citriodora*	50,000

Host country where there is well developed forestry practice in the lowland wet in a suitable tropical country such as Malaysia, New Guinea or Brazil, or perhaps two countries.

Australia is not feasible because preliminary seedlings of material from Timor show it to be very susceptible to insect attack from nearby *Eucalyptus* within Australia.

Hopefully this could be done in conjunction with some forestry operator and with supervision from the technical side by a suitably subsidized forester. The cost of 100 hectares of experimental work like this would need the attention about half time of a research forester, say $US 7,000 p.a.

8

EX SITU CONSERVATION STANDS IN THE TROPICS

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INTRODUCTION

For some years it has been realized that conservation of forest genetic resources is an urgent and important task from two view points:

1) Security of seed supply of promising exotic species and provenances is imperative for tree breeding and plantation programmes.

2) Due to expanding exploitation of natural resources, the genetic potential of many species is in danger of being eroded.

In the present paper an attempt is made briefly to elucidate factors to be considered in planning *ex situ* conservation schemes as well as the possible utilization of such schemes. An example of one region suitable for establishment of conservation stands, the Savanna Zone of Nigeria, is briefly mentioned.

THE NEED FOR ESTABLISHMENT OF EX SITU CONSERVATION STANDS IN THE TROPICS

The need to ensure seed production of species and provenances showing promise as exotics in tropical plantation forestry

The rate of establishment of tropical forest plantations has increased rapidly over the last two decades, a fact of great importance for the economy of developing countries and for the long term global timber supply. In most cases choice of species and provenances has been based on small scale species and provenance trials or pilot plantings representing only small fractions of the total genetic variation available. Nevertheless there has been a surprising coincidence in choice of species for plantation establishment throughout the tropical belt. Species such as *Pinus caribaea*, *P. oocarpa*, *P. kesiya*, *P. patula*, *Euc. grandis*, *E. tereticornis*, *Tectona grandis* and *Gmelina arborea* are widely and successfully distributed in tropical plantations.

In recognition of the relatively narrow genetic base on which the choice of provenances in the successful species was made, there has been, and is, considerable activity at national and particularly at international level to widen this base. Successful seed collection schemes and establishment of high quality international provenance trials have been accomplished. Several hundred provenances are now established in replicated trials throughout the tropical belt and a flow of data and information on provenances has started to emerge. Very distinct differences between provenances have been found, e.g. in a provenance trial of *E. camaldulensis* in the savanna zone of Nigeria the best provenances have produced three times as much (volume) as the poorest (4 years of age). But only for a very limited number of provenances is it possible to reprocure seed for plantation establishment and tree breeding.

International action to ensure seed procurement of promising provenances is a logical and necessary follow-up of the international provenance trials, if the economic potential of the genetically superior provenances demonstrated in the trials is to be utilised. The safest and most effective means to ensure long term seed procurement is often the establishment of ex situ conservation stands within the countries which have the most active planting programmes.

The universal need for conservation of genes and gene pools in danger of extinction

Beside the urgent and well defined need for conservation of provenances promising for the tropics, the universal need for conservation of genes and gene pools in danger of extinction needs to be considered. For this purpose ex situ conservation may be relevant in those cases where in situ conservation of ecosystems proves impracticable.

BASIC GENETIC CONSIDERATIONS IN DETERMINING STRATEGIES IN EX SITU CONSERVATION

Four alternative objectives for ex situ conservation of a population (provenance) are considered below:

A. To establish and maintain conservation stands characterised as far as possible by the same genotype frequencies as the original population (provenance) - static conservation (geno-types).

B. To establish and maintain conservation stands characterised as far as possible by the same gene frequencies as the original population (and thus avoid total loss of any allele) static conservation (gene pools).

C. To establish conservation stands where gene frequencies are allowed to change freely according to natural selective forces - evolutionary conservation.

D. To establish conservation stands, in which gene frequencies are deliberately changed by man in order to conserve characteristics important for plantation economy in a region and at the same time eliminate undesirable characteristics - selective conservation.

Objective A - expressing the "highest degree of conservation" - is theoretically possible to fulfil by means of vegetative propagation of individual clones. This is the normal method of propagation in Populus, Salix and Cryptomeria and promising results have been obtained with Triplochiton in Nigeria. Nevertheless, for many tropical species, technical and quarantine problems are likely to make seed the most practicable method of propagation. Fulfilment of objective B would mean that no genetic information would be lost, and that any genotype found in the original population in principle could be reproduced, even though genotype frequency in the first generation ex situ stands might be different from that in the original population. Transfer of genes by means of seed from the original population to the conservation stand aims to fulfil objective B rather than A, but in practice an appreciable change in gene frequencies is likely to be caused by uncontrollable factors such as those described below under "The Maintenance of genetic integrity ...."

Action according to objective C implies creation of artificial platforms for initiation of "new natural evolution".

Objective D In effect, this is "Evolution at the will of man" as Vavilov phrased plant breeding. Conservation of genes and gene complexes controlling economically important characters is of imperative importance for tree breeding and plantation programmes as already mentioned above. Two general problems in selective conservation are:

a) Definition of economically important characters may change with time. Characters such as straight stem form, high volume production, small branch diameter, broad environmental adaptability and disease resistance are as likely to be important in the future as slow growing crooked trees are unlikely to be of interest. Still the comparative weighting of such properties may change and the demand for breeding properties not studied so far (new disease resistance, wood properties) may occur in the future. As long as a reasonably broad genetic variation is maintained and characters demanded in the future are not strongly correlated with characters undesirable at present, it should be possible to maintain the potential for future genetic improvement.

b) Strong genotype/environment interaction may cause a disastrous decrease of the genetic potential for future plantation establishment in environments different from the environment in which a conservation stand is established. If selective conservation alone is used, it becomes necessary to replicate the stands in different potential plantation environments.

In using selective conservation the immediate demands for seed for tree breeding and plantation establishment can be met to a great extent. In the long term, methods of selective conservation face the same problems (maintenance of genetic variation, avoidance of inbreeding) as met in planning long term breeding programmes.

THE MAINTENANCE OF GENETIC INTEGRITY IN EX SITU CONSERVATION

The practical problems in pursuing objectives in conservation are many. In this context basic practical problems result from the three main stages in the conservation operation:

1) The sampling of genotypes (seed) in the original population

2) The survival and growth of sampled genotypes - *ex situ*

3) The mating between sampled genotypes - *ex situ*

Sampling of genotypes from the original population (provenance)

It is most realistic to expect initial conservation schemes for tropical plantation species to be based on international provenance collections (seed) as carried out by international seed centres. Briefly described, the normal method of sampling conifers is to collect 10 to 50 litres of cones from each of 15-25 random, but not suppressed, trees per stand. Collection areas are chosen in various ways (e.g. grid system, parallel to environmental gradients such as elevation, rainfall etc.) all of which aim to sample suspected or known genetic diversity.

Although the standard of the international collection methods applied over the last decade is, from a practical forestry point of view, very satisfactory, the sampling error from a population genetic point of view may be high:

1) A collection area may not be representative of the population (subpopulation) in which it occurs.

2) The number of trees being sampled per stand is very low, giving rise to high sampling errors. If e.g. a specific gene is available from 500 out of one million seed bearers, the probability of including this gene is only one per cent when collecting seed from 20 randomly chosen trees.

3) Collection can only be made from fruiting genotypes.

4) The percentage of half sibs within a seed lot collected from 20 trees will be at least 5 per cent and a small percentage of full sibs may be present also.

Collection schemes can be organized specifically for conservation programmes, but even so a considerable sampling error is to be expected. (In the example above the probability of collecting the gene mentioned increases from one to five per cent when collecting from 100 trees instead of 20). The gene frequencies in the seed sample may thus differ considerably from gene frequencies in the original population.

At the present stage where no genes are fully defined in the tropical plantation species in question and where any information on genotypes is only demonstrated in plantation environments outside the natural distribution, the possibility of controlling the initial sampling procedure is very small. The relatively high sampling errors to be expected must be taken into account when considering the successive steps in a conservation scheme. It may be inappropriate to spend much funds and effort in order to maintain gene frequencies in conservation stands if the gene frequencies have been already considerably changed during the initial sampling phase. On the other hand it can be argued that genetic variation is valuable *per se* and that all possible precautions should be taken in order to maintain gene frequencies found in the seed sample. Long time storage or maltreatment of seed are other factors that may influence gene frequencies.

Survival and growth of sampled genotypes - ex situ

The gene frequencies present in the seed samples can be conserved in living trees for 30 - 50 years or more (depending on species), provided that survival and a reasonable growth rate can be ensured. For successful tropical plantation species, it is now possible to combine the selection of suitable sites with efficient nursery and establishment techniques so as to ensure almost 100 per cent survival in the field, a first condition for static conservation. Competition may operate against the less fit genotypes as the stand matures. If the conservation stand is laid out at seed orchard spacing (e.g. 9 x 9 m) or mechanical thinning is carried out, the effect of competition can to a large extent be avoided.

In selective conservation the definition of selection criteria is of decisive importance. It may be desirable to give special attention to important economic characters of low heritability (narrow sense) such as vigour, which are generally more difficult to improve through individual selection and breeding than characters of high heritability such as stem form.

Mating between sampled genotypes, ex situ

The long term conservation of genes and gene frequencies is the most difficult part of a conservation programme. By appropriate techniques, conservation can be ensured for some 30 - 50 years, but beyond this point a series of problems occur of which only a few can be dealt with in the establishment phase. Accurate passing on of genetic information from a first generation *ex situ* conservation stand to the next depends on the factors: type of mating, size of "population" (genetic drift, inbreeding), and migration.

If all individuals are flowering, *random mating* (the probability of all mating combinations is equal) can theoretically be ensured by means of controlled pollination, but in practice this may be too costly. Apart from selecting environments which stimulate seed production, avoiding suppression of individuals with poor seeding characteristics and securing a reasonable size of conservation stand, little can be done to secure random mating. *Migration* in terms of pollen contamination can be minimised by adequate isolation.

By establishing "reasonably big" conservation stands the influence of genetic drift and inbreeding can be diminished. It is presumed that genetic drift and inbreeding will be of little importance, at least for the first 2-3 generations (60 - 90 years), in well managed conservation stands of 10 - 30 ha. in size, based on the international provenance collection schemes.

Despite the relatively high proportion of sibs and half sibs in such collections, mating in *ex situ* stands is often considered to be out-crossing, relative to the conditions in a natural stand, because of the mixing of seed from well scattered mother trees in the original population. This phenomenon is probably part of the often surprisingly high improvement in terms of vigour in second generation *ex situ* plantations.

Control of genetic parameters in ex situ conservation

The study of forestry population genetics has developed strongly in recent years, as have the methods to identify genotypes and genes (particularly the chemotaxonomic methods; iso-enzymes, volatile oils, flavonoid derivatives etc.). It is likely that the possibilities for checking and controlling the population genetic parameters of conservation programmes will increase significantly in the next few decades. At the present stage the above mentioned methods are considered too complicated and costly to apply to conservation schemes in general.

Retention of single tree offspring identity is a valuable method of control, particularly in selective conservation. In cases of strong genotype/environmental interaction, a conservation stand based on seed from 15 trees might accidentally end up with only 3 - 5 families. This type of control will require mapping of each single tree in the conservation stand. Although demanding in the lay out, the method is practicable. Single tree lay out would further give possibilities to avoid sib mating, (polycross designs, decrease inbreeding).

The above methods of controlling genetic identity should be considered in planning conservation schemes. Still it should be stressed that, in the present urgent situation, virtually any *ex situ* establishment of a promising provenance that survives is likely to be beneficial.

CRITERIA FOR SELECTING SPECIES AND PROVENANCES FOR EX SITU CONSERVATION

In forming a priority list of species and provenances to be established in *ex situ* conservation stands, the economic potential, difficulty in reprocurement of seed and danger of extinction should be the main criteria. On the basis of these criteria the recently sampled tropical pines of *P. caribaea* and *P. oocarpa* (Kemp 1973) should be put high on the priority list. Most of the provenance trials of these species are young and the economic potential is difficult to judge, but some indications are now becoming available from young trials.

In cases of sufficient seed supply, but limited finance for establishment, it would be possible to establish 5 - 10 provenances spread in a single tree lay out in one stand and to remove all provenances but the single most promising when information on provenance potentials is available. The stand would thus constitute a provenance trial of single tree plots for the first part of the rotation, and would then be converted to a conservation stand of the best provenance.

Beside the main criteria mentioned, provenances not in danger of extinction and possible to reprocure could be included at lower priority, in order to establish a broad representation of the provenance variation *ex situ*. This could be useful for tree breeding studies and future breeding programmes in a region.

SELECTION OF REGIONS TO "HOST" CONSERVATION STANDS

Seeds for establishment of conservation stands are in general likely to be scarce and expensive, while the necessary high standards of establishment and maintenance are also expensive. In many cases conservation stands can only be established by considerable financial support from international aid agencies. An imperative condition for establishment of conservation stands in a region is that sufficient technical expertise is available as well as organizational stability, in order to ensure a high standard of long term management. Intensive regional interest in the provenances concerned, both from tree breeding and plantation points of view, is likely to increase the benefit and security of a scheme. Adequate environmental conditions must be available.

Regional conservation projects should be considered in relation to an overall global conservation plan for the species in question.

SELECTION OF SITES FOR EX SITU CONSERVATION

The general criteria for selection of sites for seed orchard establishment apply to site selection for conservation stands (environment for high seed production, free from pollen contamination, protected against damage from man, animals, fire, erosion, flooding etc., accessible, close to labour force, suited for mechanical maintenance).

Knowledge of potential seed production is limited in many tropical plantation areas, plantings being still young. Although some confidence in prediction of seed production on the basis of general information on provenances is possible, a certain degree of risk is likely to be involved. But even in the worst case (little or no seed production) a conservation stand is likely to be beneficial in other respects (see below: Utilisation of Conservation Stands).

Static conservation stands should be established under optimal environmental conditions in order to ensure survival of as many different genotypes as possible. Selective conservation stands may be established in more extreme environments, but these should be representative of potential plantation areas. Several tropical plantation schemes have been initiated in the very best environments of a region. Expanding agriculture may force forest plantation development onto the poorer soils, calling for selective conservation in such areas.

ESTABLISHMENT AND TREATMENT OF EX SITU CONSERVATION STANDS

Lay out

As several species and provenances are likely to be involved in a regional conservation scheme, isolation between provenances and hybridizing species may cause problems. A possibility is to place the blocks of provenances in a row at right angles to the direction of prevailing winds in the flowering season, and to avoid contiguous borders between hybridizing provenances (species). Adjacent provenances should preferably be of comparable rotation ages.

Nursery treatment

Direct sowing, one seed per pot, as practised in some tropical nurseries, is considered ideal to avoid losses. If possible, single tree offspring should be kept separate in the nursery in order to check: number of offspring per sample tree, accidental hybridization, possible inbreeding depression and between family variation.

Outplanting and later treatment

Methods should as far as possible be standardized and laid down in control plans. Thinning schedules should be given special attantion.

UTILIZATION OF CONSERVATION STANDS

Beside the long term benefits of conserving provenances of known genetic characteristics, conservation stands have valuable possibilities for short-term utilization.

Seed production from conservation stands

Seed for plantation establishment, seed for seed stand establishment, seed for seedling seed orchards (from selected trees), seed for standards in provenance, progeny and other trials.

Selection pools

Conservation stands will form pools for individual selection for establishment of clonal seed orchards, tree shows and clonal banks. Although relatively small (10 - 30 ha., initially 10.000 - 30.000 trees) considerable genetic gains can be expected in breeding highly heritable characters such as stem form.

Conservation stands will finally form a valuable source for general provenance studies (heritability, flower, seed and production characteristics, etc. as well as for general population genetic studies).

INTERNATIONAL AGREEMENTS

Control plans for international *ex situ* conservation stands should include agreements on establishment, treatment and management. A fixed proportion of the seed harvest should be made available to other countries, as well as possibilities for procurement of vegetative propagules and pollen. The proportion of seed harvest made available for international distribution could be set in relation to the proportion of international financial resources invested in a scheme.

CONSERVATION STANDS IN THE SAVANNA ZONE OF NIGERIA

In *E. camaldulensis* seed supply has for several years been inadequate. The provenances of Katherine and Petford are estimated to yield 30 - 50 per cent higher returns than the provenance commonly used, but seed has not been available in sufficient quantity for large-scale plantation establishment. In the tropical pines, *P. oocarpa* and *P. caribaea* have shown great promise in provenance trials, and plantation establishment is being planned. Supply of seed of promising provenances in big quantities is a difficult problem.

As there is good technical expertise and intense interest in the region, the establishment of conservation stands of the above species is recommended. Because of the severe dry season conditions, the conservation should be selective, not static. It is recommended to establish 20 ha. stands of two provenances of *E. camaldulensis*, and three provenances each of *P. oocarpa* and *P. caribaea* in the eastern part of Afaka F.R. near Kaduna, where criteria for site selection enumerated above are sufficiently met. Estimated establishment costs, including nursery work and tending over a 5 year period, are $US 400 per hectare. It is recommended that selection in the conservation stands should be for health and vigour (adaptability) only in the first instance. Individuals showing extra-ordinary characteristics other than vigour could be preserved in clonal banks if marked for thinning. At later stages, selection could be for single characters of high heritability e.g. stem form.

Decision on what pine provenances to be conserved should be considered just before establishment (or supplementary seed collections), in order to obtain the most accurate up-to-date information from provenance trials. At present the provenances of Petford and Katherine in *E. camaldulensis* seem unbeatable candidates.

Replication of conservation stands in other areas should be considered in the near future, if only for reasons of security, with a view to eventual plantation establishment.

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9

TREE SEED AND POLLEN STORAGE FOR GENETIC CONSERVATION: POSSIBILITIES AND LIMITATIONS

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INTRODUCTION

There is a growing realization by geneticists, breeders, pathologists, evolutionists and others that in many areas of the world forest gene resources are being drastically reduced and that protective measures are urgently needed (Jasso 1971).

Because forest trees are widely distributed, long-lived and wild species, conservation of forest gene resources is considered most effective in their natural environments (Bouvarel 1970, Frankel 1970, Yeatman 1971).

With the present knowledge of seed physiology and biochemistry, preservation of forest gene resources in the form of seed, pollen or tissue culture storage under controlled conditions can be effective when it is used as a short- to long-term alternative and as a supplement to conservation *in situ* or *ex situ* (Wang 1971)

For some tree species (e.g. many *Acacia*, *Eucalyptus* and *Pinus* spp.) seed storage for long periods (more than 15 years) is possible; for others (a majority of conifers and hardwoods) only short- (0-3 years) to intermediate-term (4-15 years) storage can be successful.

In genetic conservation, the purpose of seed, pollen or tissue culture storage is to provide the preserved materials for future use in genepool plantations, and to conserve the materials under optimum conditions so that the original germinability, vigour and genetic integrity can be retained. However, specified quantities of the stored genetic materials can be distributed for breeding research or seed production during the storage period.

Storage of tissue culture for genetic resource conservation is an interesting prospect but not practical with the present knowledge (Frankel 1970, Lata 1971, Nag and Street 1973). Pollen storage is valuable for short- to intermediate-term preservation but not as long and reliable as seed storage.

This chapter reviews the present knowledge of seed and pollen storage, and discusses the possibilities and limitations of such storage as a means of genetic resource conservation with emphasis on seed storage.

WAYS OF STORING GENETIC MATERIALS

Gene conservation by seed or pollen storage becomes desirable when it is not possible to preserve designated forest populations *in situ*, or establishment of clone archives or seed orchards is to be delayed, or important, untested natural stands are threatened by extinction. Storage can be used as a safety measure for untested populations or populations of which progeny testing is in progress as in the case of *Picea glauca* (Moench) Voss (see chapter 3 above). Storage in this case is to ensure against partial or total loss of conserved plantations (Schreiner 1968).

In view of the unpredictable fertility, pollen storage is a useful technique for short- to intermediate-period storage in tree breeding and genetic research, but cannot be relied upon heavily for genetic resource conservation.

LONGEVITY OF GENETIC MATERIALS IN STORAGE

Longevity of Seed in Storage

The length of time that a given seed will remain germinable varies widely with tree species, initial seed quality and storage conditions. Increased knowledge and modern methods permit extended storage of many tree species previously thought to have short-lived seed. Seed of many pines, spruces and many small-seeded hardwoods can tolerate a high degree of drying, sealing and subfreezing temperatures, and thus can retain their germinability for over 40 years. Seeds of *Acacia* spp., *Gleditsia triacanthos* L., some *Pinus* spp. and *Robinia pseudoacacia* L. have hard, impermeable seedcoats and can maintain their germinability for up to 50 years (Barton 1961, Harrington 1972). For seed of the latter group, storage conditions are not critical (Harrington 1972). For seeds that can only tolerate a medium degree of drying (a majority of conifers and hardwoods), storage life is only 4 to 15 years in sealed containers at 0° to -18°C (Wang 1974).

However, the main problem in seed storage lies with the short-lived seed of *Acer macrophyllum* Pursh, *A. saccharinum* L., *A. negundo* L., *A. plantanoides* L., *Araucaria angustifolia* (Bert.) O. Kuntze, *A. heterophylla* (Salib.) Franco, *A. hunsteinii* K. Schumann, *Castanea* spp., *Cedrela odorata* L., *Chamaecyparis obtusa* (Sieb. & Zucc.) Endl., *Cryptomeria japonica* (L.f.) D. Don., *Fagus* spp., *Juglans nigra* L., *Libocedrus decurrens* Torr., *Populus deltoides* Bartr., *P. trichocarpa* Torr. & Gray, *P. nigra* L., *Quercus* spp. and *Salix* ssp. Seed of this group can tolerate only a very low-degree drying but cannot endure subfreezing temperature and sealing, and consequently can only be stored for short periods of a few weeks up to 3 years with decreasing germinability.

Dormancy, both internal and external, is a significant contributing factor to the extension of storage life of seed (Barton 1961, Harrington 1970). Thus it is of paramount importance to protect the seedcoat and other characteristics affecting dormancy from harvesting too early, mechanical injury during seed dewinging and unfavourable environments, in order to gain the maximum advantage of seed dormancy in stored seed.

Initial Quality of Seed

All seeds collected from designated populations require careful control of original quality through all the phases of collection, handling, extracting and cleaning, testing and storage (Wang 1971). This includes (1) verification of the origin of selected stands, supervision of cone or fruit harvesting, lot identification and labelling of harvested cones or fruits; (2) checking of cone or fruit maturity and timing of collection in abundantly flowering years; (3) proper packaging, shipping, curing, extracting and cleaning of the collected cones or fruits; and (4) effective and reliable testing of the extracted seeds.

Seed collected before natural maturity is liable to have a low rate of seed germination, a rapid deterioration in storage and further injury during seed extraction and cleaning (Allen 1956, 1957, 1958; Ching and Ching 1962, Huss 1956). Harrington (1970) suggested that the more rapid decline in germinability in immature seed compared with mature seeds in storage may be due to incomplete seed development. In immature seeds certain compounds (including dormancy-inducing compounds, lipid antioxidants and energy compounds) may not have formed, or certain proteins may not have reached a final structural form.

Storing the collected cones or fruits in a cool, well-ventilated place to prevent heating, fermentation and fungal growth is the key to successful seed extraction and cleaning. For some tree species (e.g. Abies procera Rehd.) even mature cones will not produce seeds of maximum germinability unless the seed is allowed to after-ripen in the cones for a period after collection during which organic compounds are transferred from the cones to the seed (Rediske and Nicholson 1965).

In seed extraction and cleaning, high temperature and relative humidity in the kiln and mechanical de-winging are the most frequent sources of seed injury (Allen 1957, Eliason and Heit 1940, Gordon et al. 1972). Injured seeds are not fit even for short-term storage as they have a high respiration rate and undergo spontaneous heating (Holmes and Buszewicz 1958, Kamra 1967, Zeleny 1954). To avoid such injury, it is essential to employ more conservative seed extraction schedules as well as hand or wet de-winging techniques (Wang 1974).

Moisture content of seed is one of the two most critical factors influencing seed longevity (Harrington 1972). Seed of some tree species (e.g. Abies and most hardwoods) only require air drying to reduce the moisture content down to safe levels, while others, especially those requiring wet de-winging or cleaning, need further moisture reduction by artificial drying. Although there is a risk of increasing seed dormancy and of loss by rodents or insects, Wakeley (1954) considered drying pine seed under direct sunlight a better method than artificial heat for reducing the moisture content of extracted seed; it never causes injury. However, since seeds are hygroscopic, it should be realized that the success of air-drying seeds is affected by differences in atmospheric relative humidity which varies with locality and time of year (Barton 1961, Heit 1967b.)

Because the chemical composition of seeds varies with tree species, some (e.g. Abies alba Mill. and southern pines) can withstand slow drying at low temperatures better than fast drying at high temperatures (Magini and Cappelli 1964, Wakeley 1954). Furthermore, Harrington (1972) pointed out that seeds of different species do not attain the same equilibrium moisture content when exposed to the same relative humidity of the air. For example, at a given air temperature and moisture content, seeds with a high level of protein or starch and low oil content will absorb more moisture from the air than those with a high oil content. Wakeley (1954) considered that a knowledge of the equilibrium moisture content percentages of various tree species in different combinations of air temperature and humidity will have a wide practical application in seed drying and storage.

Wang (1974) reviewed the critical moisture content (above or below which there is a rapid deterioration in seed germinability) of different species, and considered it as a useful guide for safe storage. The importance of positive fluctuation in moisture content of stored seeds has been demonstrated by Barton (1961).

To illustrate the relationship of moisture content and storage life of seeds, Harrington's (1972) rule of thumb for most agricultural seeds may be applicable to tree seed. He described that when moisture content is between 5 and 14 per cent, the storage life of the seeds is doubled for each percent reduction of moisture content. In tree seeds that can endure a medium- to high-degree drying, moisture content should be reduced to below 8 per cent (fresh weight) at temperatures of 20° to 35°C. The application of the freeze-drying technique to tree seed in recent years has produced some promising results. Surber *et al.* (1973) reported that seed of *Picea abies* Karst. with an initial moisture content of 10 to 12 per cent was dried directly to 2.4 per cent by the freeze-drying method and stored successfully for 6 years in sealed glass containers at -25°C. They found that seeds with an initial moisture content more than 12 per cent have to be predried to that level in order to be dried directly by this technique without injury (e.g. *Abies* spp.)

Excessive drying of seeds can be detrimental to seed germinability and storage capacity (Barton 1961, Harrington 1972, Roberts 1972). Roberts (1972) suggested that drying seeds to lower than 2 per cent moisture content may be deleterious to some species.

Although high moisture content has proved to be harmful to stored seeds that can tolerate drying, it is a physiological requirement for retaining germinability and vigour of many large hardwood seeds. Seeds of these hardwoods need 25 to 79 per cent moisture content to keep their germinability in storage from a few months to 3 years. Thus, the opportunity for genetic conservation by seed storage of this group is limited.

Storage Conditions

Storage conditions involve both storage method and storage temperature. The proper storage method for a given tree seed varies with seed characteristics, initial seed quality and the period of storage. Although there are two types of storage method, dry and wet, only the former is important to storage of seed for genetic conservation. In dry storage germinability can be retained best in sealed containers and at low temperatures.

Sealing maintains a constant moisture content of the seeds, reduces respiration as carbon dioxide increases and oxygen decreases, and protects seeds from insects and diseases (Harrington 1970, Wang 1974). To prevent fluctuation in moisture content of stored seeds, the seal of containers should not be broken until the time of use. If withdrawal of stored seeds is necessary, sealed containers removed from cold storage should be allowed to reach the temperature of the surrounding environment before being opened to avoid condensation of water within the container and on the seed (Wang 1974).

On the other hand, seeds requiring a high moisture content can be injured by prolonged storage in sealed containers (Wang 1974). Acorns of *Quercus robur* L. and *Q. borealis* Michx. f. stored without any aeration lost their germinability (Korneeva 1966, Serenkov and Kuznetsova 1952, Suszka 1974, Yevreinova and Yerofeyev 1956). Seeds of this group apparently require some gas exchange for maintaining their germinability in storage.

Storage temperature is the other critical factor influencing longevity of seed. The importance of storage temperature in maintaining the quality of tree seeds has been thoroughly reviewed (Barton 1961, Harrington 1972, Holmes and Buszewicz 1958, Heit 1967a, 1967b, Wang 1974). In general, within the acceptable limits of a given seed species, the lower the storage temperature the longer the storage life of the seed. According to Harrington's (1972) rule of thumb, the effect of storage temperature on stored seeds is that, between 0° and 50°C the storage life of the seeds is doubled by lowering every 5°C of storage temperature. For short- or intermediate-term storage of tree seeds, the storage temperature appears to be 0° to 5°C (Huss 1967, Wakeley 1954). For long-term storage of tree seeds, however, especially those tolerant of low storage temperature (e.g. *Abies* and *Populus* spp.), subfreezing temperatures (to - 25°C) have been proven to be superior to above-freezing temperatures (Surber *et al.* 1973, Wang 1974). Furthermore, it has been demonstrated that the lower the subfreezing temperature (- 4° to - 18°C) the better the retention of germinability of the stored seeds (Barton 1961). However, it should be pointed out that not all tree seed can benefit from subfreezing storage. Seed that can endure little or no drying (e.g. most large-seeded hardwoods) can tolerate neither subfreezing storage temperature nor sealing although acorns of *Quercus robur* and *Q. borealis* of 40 to 45 per cent moisture content suffered no injury at – 3°C for a storage period of 33 to 40 months in closed but unsealed containers in mixture with air-dried sand or peat (Suszka 1974, and personal communication). Apparently seeds of some species in this group can tolerate some degree of subfreezing storage.

Despite the short-term storage of seeds of this group in controlled conditions, such storage would be especially useful in areas where the winter climate is relatively warm or fluctuating.

Storage of Pollen

The life-span of tree pollen is shorter than most of the tree seed under the presently known drying techniques and storage conditions. As for seed, pollen of many tree species has been stored satisfactorily at temperature of 5° to -23°C and relative humidity of 0 to 50 per cent from a few months to 13 years depending upon species and initial quality (Alam and Grant 1971, Barber and Stewart 1957, Bingham and Wise 1968, Bingham et al. 1971, Callaham and Steinhoff 1966, Duffield and Callaham 1959, King 1965, Popnikola 1971, C.W. Yeatman, personal communication). In recent years deep-freezing and freeze-drying (lyophilization) techniques have proved effective in extending the period for pollen storage (Ching 1969, Duffield and Callaham 1959, Ichikawa and Shidei 1971, 1972b; King 1965).

At Petawawa Forest Experiment Station pollen of *Picea abies*, *P. glauca*, *P. mariana* (Mill.) B.S.P., *P. rubens* Sarg., and *P. mariana* x *P. rubens* was stored with some success for 11 to 13 years in cotton-stoppered containers over dry silica gel in desiccators (relative humidity 0 to 1%) in a deep freeze at -18°C (C.W. Yeatman, personal communication). However, when the stored pollen was used for pollination, seed yield was low (from 10% to 14.3%) and variable, and some pollen lots lost their germinability completely over the years. A similar technique was used for storing pine pollen for 10 months with good results (Duffield and Callaham 1959).

King (1965) experimented with the freeze-dried technique for pollen storage and successfully stored pollen of many tree species in a vacuum or nitrogen gas in sealed containers for up to 3 years under uncontrolled room temperatures. This method is unique because the sealing facilitates long-distance shipping and pollen so stored can withstand freezing and dehydration (Harrington 1970).

Ichikawa and Shidei (1972b) stored 30 coniferous and hardwood pollens in liquid nitrogen at -196°C and found many of them retained their germinability for 5 to 7 years with moisture contents between 10 and 23%.

No adverse effects of deep-freezing were detected from an artificial pollination test in the field for *Cryptomeria japonica*, several *Pinus* spp. and *Larix leptolepis* Henry. They suggested that the critical moisture content for long-term storage of tree pollen in liquid nitrogen at -196°C is about 10%, above which pollen will be injured by intracellular freezing (Ichikawa and Shidei 1972a).

Possible causes of pollen deterioration in storage are (1) exhaustion of respiratory substrate, (2) inactivation of enzymes, growth hormones and pantothenic acid, (3) desiccation injury, (4) accumulation of secondary metabolic products, and (5) changes in lipids of the exine of the pollen membrane and lipid autoxidation (Harrington 1970, King 1965).

QUALITY TESTING OF STORED MATERIALS

Careful storage of poor quality or dead seed or pollen is futile. Therefore it is essential to assess the initial moisture content and germinability of the genetic materials by official standard methods and reliable germination criteria before and during the storage period. This ensures the value of the preserved materials, and detects any changes in germinability or moisture content.

It is an advantage in long-term storage to establish an acceptable level of germinability for stored material at the beginning of the storage, and seed and pollen stocks should be replenished or rejuvenated when germinability of the stored materials falls below the acceptable level (Wang 1971).

LIMITATIONS OF STORING GENETIC RESERVED MATERIALS

Aging of seed and pollen is a natural process. According to Helmer *et al.* (1962), seed and pollen reach the highest quality at their physiological maturity, and from that point onwards the quality decreases. The rate of degeneration depends upon the degree of deviation from the optimum genetic and environmental conditions.

Because the aging is an inevitable process, there is always the fear that stored seed or pollen will undergo genetic, physiological or biochemical changes with time even under optimal environments, especially during prolonged storage. Such changes are usually losses in seed germinability and vigour, although Abdul-Baki and Anderson (1972) found that the first detectable decrease in germinability does not coincide with the onset of deterioration (in terms of carbohydrates and protein synthesis).

Effect of Storage on Genetic Change

One of the strong arguments against long-term storage as a means of conserving genetic resources is the fear shared by geneticists and tree breeders that even in ideal storage conditions there will be genetic changes in stored seeds or pollen, and that the resulting populations will be genetically different from the original ones after many years (Frankel 1970, Harrington 1970, 1972). Such genetic change can be caused by (1) differential survival of various genotypes within a stored seedlot through a considerable loss of the original germinability, or (2) by an increase in the proportion of mutations (Allard 1970, Bouvarel 1970, Harrington, 1972). Both forms of genetic change, however, can be prevented or minimized by meeting all requirements from harvesting through all stages of handling, extraction and cleaning to storage (Harrington 1972). Although there is abundant evidence to substantiate the occurrence of chromosome aberrations in aged agricultural seeds, results from long-term storage studies at Petawawa Forest Experiment Station and elsewhere have indicated that such genetic change is not common in tree seeds (Barnett 1972, Heit 1967a, Eliason and Heit 1973, Wang 1974). Figure 1 demonstrates the germinability and vigour of stored, aged seeds compared with those of fresh seeds of several pines and spruces.

On the other hand, it should be borne in mind that some seeds are sensitive to storage (e.g. *Pinus lambertiana* Dougl.) For instance Stone (1957) reported that the retarding effect of 30-month storage (2°C) on germination and embryo elongation vigour of *Pinus lambertiana* could not be completely removed by chilling treatment although the retarding effect of 6-month storage was overcome by chilling.

Another example is the noticeable decline in the rate of germination and the resulting seedling vigour of several chestnuts after storage at 1 to 2°C for 2 1/2 to 3 1/2 years (Jaynes 1969).

Short-lived Seeds

Short-lived seeds (e.g. *Quercus*, *Salix* spp.) are difficult to store for prolonged periods even under ideal storage conditions. Evidence has shown that seeds of this group, due to their special requirements for high moisture and gas exchange, and intolerance to sub-freezing temperature, invariably deteriorate as duration of storage increases (Suszka 1974, and personal communication).

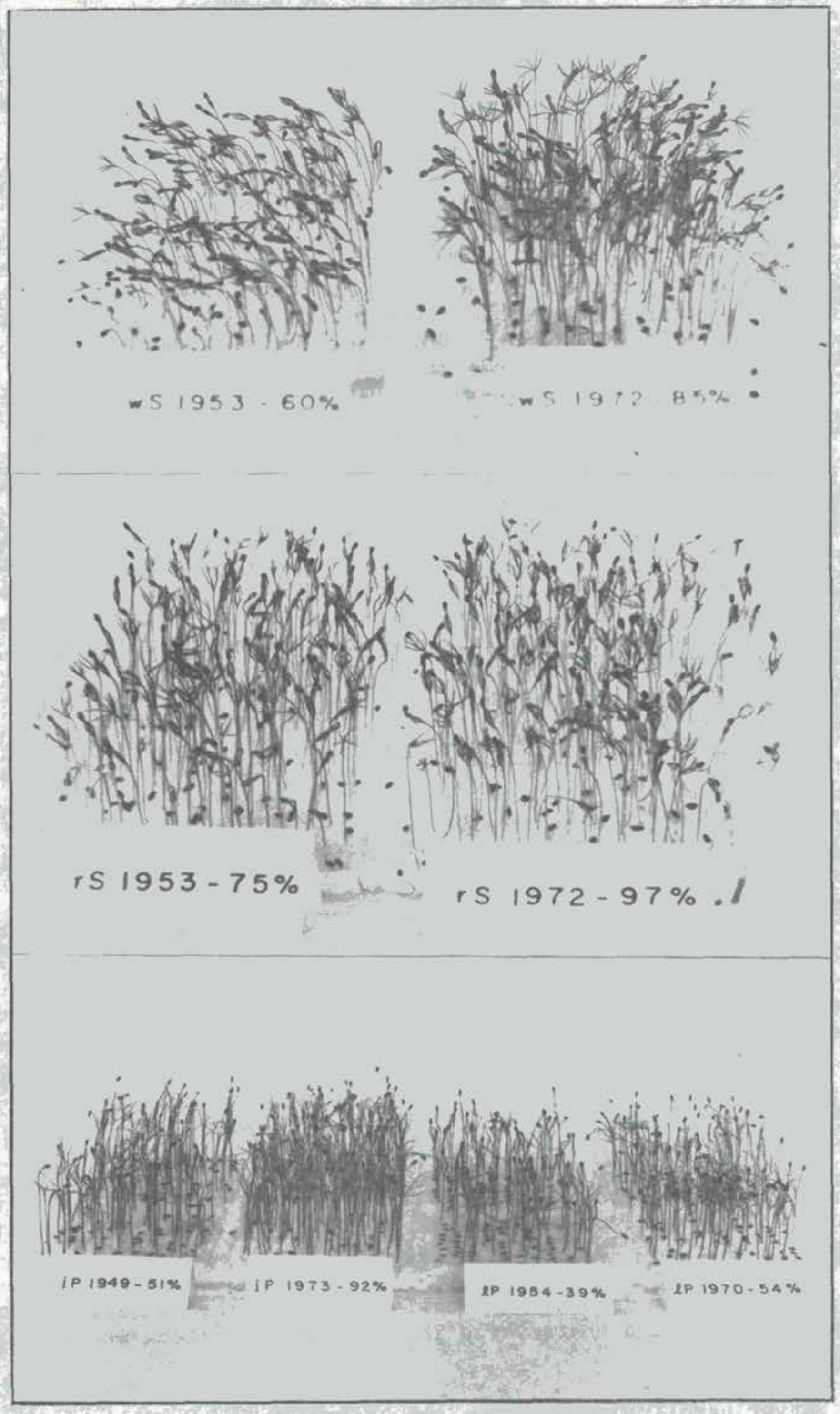

FIGURE 1. Although there are differences in total germination %, there is little or no difference in germination vigour between old, stored seeds (7.2 to 8.9% moisture content by fresh weight) and fresh or relatively fresh seeds (4.5 to 7.7% moisture content) of <u>Picea</u> <u>glauca</u> (wS), <u>P.</u> <u>rubens</u> (rS), <u>Pinus</u> <u>banksiana</u> (jP) and <u>P.</u> <u>contorta</u> Dougl. (lP). The numbers indicate year of seed collection and total germination % after 2 weeks. All seeds were stored in air-tight containers at 1 to 2°C.

At present, the available information suggests that the maximum storage life of these short-lived seeds is less than 3 years (Bonner 1971, Harrington 1970, Suszka 1974 and personal communication, Wang 1974). Therefore, preservation of genetic resources by means of storage of this group is limited.

Rejuvenation

Unlike agricultural seeds, tree seed stock is much more difficult to be replenished by rejuvenation, as most trees require a decade to reach sexual maturity and at least two decades to produce abundantly fertile seeds. For this very reason, seeds or pollen should be collected only in years of abundant flowering when a high proportion of the genes of the designated populations is represented.

Unreliable Testing and Erratic Post-Storage Germination of Pollen

It is essential that pollen is (1) viable and capable of fertilization, and (2) able to perform physiological and chemical processes until seed is developed (Ching 1969). However, the testing of pollen viability *in vitro* does not provide a reliable assessment of the true pollen quality *in vivo*, as viable pollen is not necessarily fertile (Callaham and Steinhoff 1966, Cumming and Righter 1948, King 1965, C.W. Yeatman, personal communication). In view of these discrepancies, pollen storage is a useful technique for short-period storage in tree breeding and genetic research, but cannot be relied upon heavily for genetic resources conservation.

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PART III

G U I D E L I N E S

AND

R E C O M M E N D A T I O N S

10

GUIDELINES FOR THE METHODOLOGY OF CONSERVATION OF FOREST GENETIC RESOURCES

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INTRODUCTION

Conservation of forest genetic resources is best understood as "wise use of resources for the good of the greatest number of people for the longest possible time" (G. Pinchot, quoted by New Zealand Journal of Forestry 1973). Conservation in this sense has had a long and distinguished history in a number of countries where forestry is important, and continues to form the basis of programmes of natural and artificial regeneration in these countries.

The introduction of shelterwood systems of natural regeneration into tropical forests, however, has not proved an efficient instrument in conservation terms, for both practical and biological reasons, and there is now clearly a need of a conservation methodology compatible with the increasing demands of the market for tropical wood products. However, modern methods of renewable natural resources management which emphasize conservation as a dynamic element in management plans have yet to be applied in many tropical and sub-tropical forest ecosystems of the world.

A single method of forest genetic resources conservation cannot have universal application. The forest ecosystems of the world are too diverse, and the practical constraints vary so much from country to country, that local solutions to local problems will often take precedence over theoretical principles. A second factor of importance is that biological and other information with a direct bearing on local conservation priorities and methodology, e.g. inventory data and information on the extent of conservation requirements, are frequently lacking, or not available in a form easily accessible to forest managers.

Yet it is clear that, despite the above considerations, it is desirable that some general guidelines be formulated which will assist the development of local programmes. The seven case studies in Part II indicate in varying detail the kinds of solutions possible for given species and ecosystems, and the applicability to other species of the methods there presented should be determined before planning local programmes.

The summary of general guidelines in this chapter attempts to synthesise experience from the case studies and elsewhere, for the benefit of conservation planners, but needs to be interpreted flexibly in the light of local conditions.

SURVEY AND ASSESSMENT

The first stage in any programme of conservation of forest gene resources is to determine the extent to which representative samples of forest ecosystems and their constituent species are already conserved in existing National Parks or Strict Natural Reserves (SNR) and then to determine those which are not so protected, though presently endangered. Forest inventory data, vegetation maps, distribution maps for particular species, herbarium records and maps delineating forest reserves and national parks are the principal sources of information on which conservation decisions for particular species and ecosystems can be based. Where national committees of the Man and Biosphere (MAB) programme exist, much of this essential preliminary work could be done through them.

The assessment of current conservation status will often indicate not only the need for, but also the kind of, conservation measures most appropriate for the species. If an endangered species is a major constituent of climax forest ecosystems, does not regenerate adequately after logging and is not cultivated, or not easily cultivated with present knowledge, it is likely that *in situ* conservation will prove the most immediately appropriate. *In situ* conservation is understood in this context to mean the exclusion of commercial felling and the conservation of the climax ecosystem of which the endangered species is a component.

A species which regenerates naturally after logging or can be readily planted may also be suitable for *in situ* conservation. In this case exploitation is permissible and conservation can be ensured by normal silvicultural practices, either by natural or artificial regeneration. In the case of the latter, plants must originate from seed collected from the local population.

For a species which can be cultivated but cannot readily be regenerated in the area in which it occurs naturally, *ex situ* conservation is most appropriate. *Ex situ* conservation is the only possible method when natural populations face destruction from overwhelming social or economic pressures for development of the land for non-forestry purposes. Since resources for *ex situ* conservation are limited, priority must be given to species of proven economic importance. Storage as seed may be effective for several decades in many important species and provides an invaluable method of interim conservation, giving time for research on cultivation methods of difficult species and for the training of staff in the management of *ex situ* conservation stands. For other species, however, the short period of seed viability severely limits the value of seed bank conservation.

CONSERVATION IN SITU IN STRICT NATURAL RESERVES

Exclusion of felling and conservation *in situ* of representative samples of ecosystems in their natural state can best be done by establishing Strict Natural Reserves (SNR) within the larger units of Forest Reserves or National Parks.

Legislation

If there are no adequate legal procedures for the establishment and protection of SNRs, then Forestry Departments should solicit the support of appropriate government Departments in having such laws promulgated. In this regard national committees of the UNESCO programme on Man and the Biosphere (MAB) can play an important role. In some cases, SNRs may qualify for inclusion in the international network of MAB Biosphere Reserves (UNESCO 1974).

Size of SNRs

Chapter 1 presented "guesstimates" of the minimum area likely to be needed for long-term conservation of samples of forest ecosystems. The range quoted is from 100 to 1000 ha. It is necessary to consider to what extent areas of this order, protected in SNRs, would be adequate to conserve a viable local gene-pool of the constituent species.

When forest inventory data are available it is possible to determine both the general distribution of a species and its frequency of occurrence (see Chapter 6, table 2). Thus for a given region and ecosystem the number of stems present on a given area of land can be estimated and compared with the theoretical figure considered adequate.

The minimum number of stems of an endangered population needed to form a viable gene-pool will vary with the species. For example it is likely that this number will be relatively large for coniferous species of the north temperate zone, which are wind-pollinated and strongly outbreeding. A figure of 10,000 individuals has been suggested by Toda (1965). In other species a breeding population of much fewer individuals may be adequate. Dyson (1974) suggests 200 individuals, a figure based on experience in animal breeding. However, in view of lack of experimental data from forest trees, it would be prudent to double Dyson's figures in practice. It is likely, in any case, that the number required for tropical hardwood species, which are predominantly pollinated by insects, birds or bats and many of which are capable of self-fertilization, will be considerably less than for the northern anemophilous conifers.

However, because of the considerable differences in stocking, the area required to embrace a minimum effective breeding population may be large for a tropical hardwood and relatively small for a coniferous species of the north temperate zone. In the latter case the forest is composed of only a small number of tree species, e.g. the *Picea engelmannii* and *Abies lasiocarpa* associations of the subalpine forest regions of Canada or the *Pinus sylvestris* and *Picea excelsa* associations in Scandinavia, therefore the minimum area required to ensure the perpetuation of a viable genepool within the ecosystem is likely to be less than 100 ha. If the ecosystem is composed of large numbers of species, e.g. tropical hardwood ecosystems, then the minimum area required to ensure the perpetuation of a diversity of species within the ecosystem is likely to be considerably greater. Reference to Chapter 6, table 2, shows that an area of 60 ha would be sufficient to contain 400 stems of *Strombosia pustulata*, whereas 160 ha would be needed for the same number of *Triplochiton scleroxylon* and 440 ha for *Berlinia* spp.

The range of areas required for conservation of the minimum effective breeding population of a particular species with known frequency of distribution thus corresponds reasonably well with the range of areas (100 to 1000 ha) quoted above for ecosystem conservation. In making these rough assessments it is assumed that there is no marked clustering of stems.

It is clear, however, that it is impossible to generalise concerning either the number of stems constituting a minimum effective breeding population or concerning the minimum area required to conserve a particular ecosystem. In each case for consideration, whether single species or ecosystem, it will be necessary to consider all the available inventory and biological data as well as practical constraints before coming to a decision. The above figures are given merely to indicate a possible approach to the problem.

Distribution of SNRs

If a species is widely distributed through a range of environments, then it is likely that intraspecific variation is present, and therefore it may be necessary to set up a number of SNRs spanning the extremes and the centre of the distribution of the species. In the absence of genecological data, decisions concerning the number of SNRs to ensure conservation of valuable gene resources of a particular species can be based on data obtained from inventory records and distribution maps of the species. If it is confined to one vegetation type in a relatively homogeneous environment, then one SNR may be sufficient. On the other hand a species distributed through a wide range of latitudinal environments (e.g. Pinus contorta) is likely to require at least three SNRs to ensure an adequate sample of its gene resources. These SNRs should be so distributed that one is at the ecological centre of the species distribution and the others at the extremes.

If the environment varies rapidly within a relatively short distance, e.g. from valley bottom to ridge top, it may be possible to ensure the conservation of a range of ecological and genetic variation by establishing one large SNR comprising the whole watershed. Another reason for using a large SNR is to conserve seral stages in the succession, as well as the climax vegetation. SNRs should not be confined to undisturbed primary forest. It is of equal importance to establish them in disturbed secondary forest containing valuable gene resources, which makes up the bulk of the forest estate in many countries.

Buffer zones

SNRs are normally established in forest reserves in Africa, though a number have been established in national parks. Whatever the location of a SNR, it should be surrounded by a buffer zone of indigenous forest subjected to sustained yield management but not to clear-felling and replacement by plantations. In Nigeria, Kenya and Uganda SNRs are established well inside forest reserves and often in remote areas far from roads. They are thus surrounded on all sides by large tracts of reserved forest. This is the ideal situation. If on the other hand forest gene resources scheduled for conservation are close to the boundary of the forest reserve then every effort must be made to ensure that a buffer zone of at least 300 meters is established around the SNR.

More than one buffer zone may be required, as proposed for MAB Biosphere Reserves (UNESCO 1974). Gene pools must be managed and utilized as well as conserved and this implies periodic seed collection. An inviolate core area, from which human interference other than scientific observation is excluded, could be surrounded by an inner buffer zone of gene-pool reserve, with outer buffer zones for tourism and commercial forest management.

Combined objectives

The setting up of a Strict Natural Reserve to achieve specific objectives of forest genetic resources only may not be possible. For this reason it is always desirable to combine these objectives with others of concern to wildlife managers and land and water conservationists. It may be possible both to determine these other objectives and to combine them in a common plan of management, thus providing a stronger case for in situ conservation of all the resources in the area. In such instances the size and shape of a single large reserve will be determined by land forms, the presence of water catchment areas etc., as well as by the exigencies of genetic resources conservation.

A large reserved area with multiple objectives such as that referred to above would qualify as a Biosphere Reserve under the MAB programme (UNESCO 1974). Such a reserve, say on a tropical mountain top, would have in order of decreasing altitude Nival, Alpine, Ericaceous, Montane forests, and savanna belts occurring in both an inviolate core area and in buffer zones of reserved forest land. An area for education and tourism would also be set aside.

Need for management

It cannot be too strongly emphasized that if Strict Natural Reserves are to play an important part in forest genetic resources conservation every attempt must be made to provide rigorous criteria both for their establishment and subsequent management. Areas of forest land set aside merely with the stated purpose of forest genetic resources conservation, and without clearly stated objectives incorporated in management plans are unlikely to remain inviolate. Furthermore, such static forms of conservation of forest genetic resources will not result in the accumulation of information about these resources as would result from dynamic conservation measures forming part of a forest management plan. In the long run, and if appropriately managed and studied, SNRs should not only conserve forest genetic resources but should generate a continuous flow of information about these resources which will allow their eventual domestication, and in the case of tropical hardwoods the development of plans for the management of natural ecosystems of the species.

The maintenance of specific genetic resources within a SNR will require intervention in the ecosystem if the species concerned are seral forms which decrease or disappear as the ecosystem approaches a climax condition. For reasons such as these, management plans must be prepared if the conservation objectives within SNRs are to be achieved. These management plans are best incorporated in the overall management plan for the forest reserve in which the SNRs are located.

Controlled visits to Strict Natural Reserves by school children and others should in many instances be seriously considered in management plans. "... Human impact on reserved areas, unless widespread and severe, should not interfere so seriously with the population structure of the great majority of species in a reserved area as to have genetic consequences. The essence is to keep the impact in reasonable bounds. Infringement of ecological and genetic integrity must be balanced against long-term security of tenure: conservation is, and is likely to remain, uncertainly poised at the will of any generation, community or government. Moderate access for our dominant human species may result in exchanging a bearable loss in biological integrity for a gain in size, diversity and security of reserved areas"(UNESCO 1972b).

CONSERVATION EX SITU

In situ conservation will not always be possible or even desirable. Where there is no system of forest reserves and pressure is high for massive clearance of natural forests in favour of agriculture, genetic resources of certain populations are endangered with complete destruction. Elsewhere genetic integrity may be threatened by pollen invasion from nearby large-scale plantations of alien provenance. Populations of forest trees endangered in these ways can frequently be conserved only by *ex situ* conservation measures, i.e. by establishing artificial stands on new sites removed from the natural origin, where intensive management can ensure protection, or by storage as seed in seed banks where conditions of e.g. temperature and humidity are carefully controlled.

Ex situ conservation stands are expensive to plant and to maintain, so they are normally confined to species of proven or potential economic value. Within those species material of all endangered populations should be conserved as possible sources of useful genes, such as for drought or cold resistance, which may be present in isolated or peripheral populations. *Ex situ* conservation stands should be established in introducing countries as well as in the country of origin. Every effort should be made to ensure that the new environment is as similar as possible to that at the place of origin, and that seeds of different provenances from diverse environments are not bulked.

An area of 10-30 ha per provenance or population on each site is appropriate. As an insurance against catastrophe, each population should be planted on at least two sites. Impeccable standards of planting, tending and protection are essential. Isolation from hybridising provenances should be provided where possible, but practical considerations may render this difficult. In such cases, vegetative propagation or controlled pollination provide means of conserving a high degree of genetic integrity in the next generation.

A number of developing countries have a great interest in testing and conserving genetic variation of exotic species, e.g. of tropical pines, but lack the finance required.

This provides a wonderful apportunity for international cooperation. International agencies should finance the establishment of gene pool conservation stands over a period of five years and in return the "host" countries would undertake to make half the eventual seed harvest from the stands available to other countries.

CONSERVATION AS SEED

If seed storage facilities are available, and if the storage requirements for the seed of endangered species or populations are known, then seed from these stands should be harvested as often as possible, and stored until required for the establishment of conservation stands *ex situ*. The technical problems of storage as seed have been fully covered in Chapter 9. Its advantages in economy of space are self-evident. It already plays an important role in conservation of genetic resources in some countries and will play a far greater one when more is learnt of the storage needs of species in the tropics, which until now have been little studied.

CONSERVATION OF INFORMATION

Conservation measures for forest genetic resources must be accompanied in all instances by the conservation of information about these resources, and it is, therefore, essential for each agency to develop a system of gathering, storing and retrieving genetic resources information. Such a system must be accompanied by the introduction of standard procedures of naming and registering gene resources and, in the long run, by seed certification.

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11

PRIORITIES FOR RESEARCH AND ACTION

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ZONES

The present world programme of research on the genetics and ecology of tree species in temperate zones is sufficiently developed to allow the implementation of a methodology for the conservation of the genetic resources of many of these species. Furthermore, the institutions necessary for the formation and application of this methodology are well developed. The programme in Finland for both softwood and hardwood species, and those described in Chapters 3 and 4 for North American conifers are typical of the progress made to date in this field, and further rapid progress can be confidently expected.

This does not mean, of course, that there are no major problems of conservation in temperate regions. On the contrary, workers in many parts of the world outside the tropics are faced with continued threats to unique populations of many tree species. However, in most instances action is being taken, as for example in regard to the unique *Picea glauca* populations in the Ottawa valley described in Chapter 3, and those for the Californian conifers in Chapter 4. The priorities for research and international action therefore relate predominantly, though not exclusively, to the genetic resources of tree species of value in tropical, subtropical, Mediterranean and arid zones.

SPECIES

At the present time research on the genetics and ecology of tropical and subtropical tree species is concentrated on a very small number of species presently of major commercial importance as plantation trees e.g. *Tectona grandis*, certain *Eucalyptus* and *Pinus* spp., *Cedrela odorata* and *Gmelina arborea*. The important work presently underway for the plantation species listed above must be further developed and extended to other species.

The importance and vulnerability of the genetic resources of the Central American pines have been described in Chapter 5. A methodology of *in situ* conservation for these resources is described in that Chapter and their *ex situ* conservation is described in Chapter 8. These species have high priority for research and international action, as do the tropical and subtropical pines of South and South East Asia.

In regard to Chapter 7 on *Eucalyptus* spp., it is necessary to emphasize the fact that the genetic resources of many of these species are of major interest throughout the tropics and subtropics and savanna regions of the world, though the centre of diversity of the genus is confined to Australia. Two species of major importance in tropical forestry do, however, occur outside Australia, and their genetic resources are endangered. The conservation of the genetic resources of *Eucalyptus* species must continue to receive high priority.

The rehabilitation of deforested lands in arid zones and round the Mediterranean basin deserves high priority. As pressure increases on land in the moister areas of the tropics and sub-tropics, so will the need for a higher productivity from the marginal lands of the sub-arid and arid zones. Study of genetic variation and its conservation in dry areas has been generally neglected and more work is needed on both indigenous and exotic genera such as _Acacia_, _Tamarix_, _Zizyphus_, _Conocarpus_, _Prosopis_, _Callitris_, _Casuarina_, _Eucalyptus_ and _Pinus_.

A more detailed listing of species arranged by priorities can be found in the reports of the FAO panel on forest gene resources (FAO 1969, 1972, 1974b).

ACTIVITIES

Both _in situ_ conservation of natural ecosystems in Strict Natural Reserves and _ex situ_ conservation of individual populations of economically important species in planted conservation stands have an important role to play in the conservation of forest genetic resources on the global scale and both merit substantial financing from international agencies. The same applies to storage in seed banks which for some species provides a reliable and space-saving method of conserving genetic resources. The relative importance of these methods will, however, vary greatly from country to country. All three have been included for financing in FAO's proposed global programme for forest genetic resources (FAO 1974a).

Practical constraints to forest genetic resources conservation will frequently be greater than biological constraints. These practical constraints result from lack of trained personnel and finance, and often simply from lack of information on both the need for conservation measures and the methodology of conservation. Other practical constraints, which result from low public interest and consequently negligible political support, are the lack of any official policy and legislation for conservation of forest genetic resources in some countries. These, however, are frequently based on lack of information which in turn can be traced to lack of personnel with professional expertise in this field in government agencies with responsibility for the management of the forest resource. Thus priority needs to be given to the training and financing of specialist staff in developing countries, who, in turn, could develop a better informed consciousness of the importance of genetic conservation among government officials and the general public. At the same time, more attention must be given to the dissemination of information, in several languages, on the methods available.

There are several publications which underline the need for urgent conservation measures for the forest genetic resources of tropical species and ecosystems. It is exceptional, however, to find a publication which gives quantitative data on a methodology of conservation. Questions as to how the genetic resources of a particular species or ecosystem are to be conserved are left unanswered. The principal reason for this is that basic data are not available, or are not available in a form that has a bearing on conservation measures. Synthesis and codification of existing local information relevant to conservation of genetic resources deserve high priority.

The literature which has a bearing on methodologies of conservation of forest genetic resources is frequently not available to forest managers in tropical countries where it is most needed. A handbook which would deal with the subject in a readable and practical manner, giving specific examples for the tropics, is needed. The present report could form the basis of such a handbook, which should be modified and improved as information accumulates.

In order to decide on the most appropriate methods for conservation under local conditions, there is need for a great increase in research and the acquisition of field data, especially in the tropics and sub-tropics. Priority should be given to the acquisition of precise and up-to-date inventory data, as a basis for determining the conservation status of ecosystems and the extent of genetic impoverishment of species undergoing intensive exploitation or conversion and to long-term ecological and genetic and physiological research on important species. This should include research on seed physiology and storage and the development of common standards of international seed certification.

A greater emphasis on conservation methodology in forestry curricula at both a university and technical level is required. Furthermore, there is a need for international support and encouragement for meetings and symposia on forest genetic resources conservation in tropical countries where the problems related to this work are evident but solutions are not. At the present time most such meetings and symposia are being held, frequently with international financial support, outside the tropics.

Those Government departments and other institutions in the tropics concerned with the management of the forest estate need to be encouraged by financial support, by technical assistance, and by the supply of appropriate information to incorporate a methodology of forest genetic resources conservation into forest management plans, and to build up indigenous expertise in this field. Institutions engaged in related research in the tropics should be encouraged by financial support to direct their interests more specifically to problems of conservation of forest genetic resources. Those institutions outside the tropics concerned with practical and theoretical problems of forest genetic resources conservation should be encouraged by financial support to broaden their activities into tropical forest ecosystems.

INTERNATIONAL ASPECTS

Priorities between both species and conservation methods will vary greatly from country to country. At the same time the fact that many species are indigenous to a number of countries and have been introduced to many others makes international coordination essential. The best way of ensuring coordination is by the adoption of a global programme for forest genetic resources such as that proposed by the FAO Panel of Experts on Forest Gene Resources (FAO 1974a). Such a programme should ensure the integration of conservation measures with the equally important activities of exploration, collection and utilization. At the same time it should improve efficiency through coordinating the efforts not only of the many countries but also of the several international agencies concerned with genetic resources. A further need is for close coordination of any forest genetic resources programme with similar programmes for crop plants. This can be ensured by the overall direction of the recently established International Board on Plant Genetic Resources which is financed by and responsible to the Consultative Group on International Agricultural Research.

Proposals for a global programme are considered further in Chapter 12.

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12

RECOMMENDATIONS

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GENERAL RECOMMENDATIONS

1. The conservation of forest genetic resources should be an integral part of forest management, and provision for it should be included in forest management plans.

2. *In situ* conservation is the ideal form of conservation of whole ecosystems and should be implemented wherever practicable. It is not always possible in practice; in such instances *ex situ* conservation measures should be developed for species of potential economic importance.

3. A methodology of *in situ* conservation of forest genetic resources in Strict Natural Reserves has been developed by State Departments of Forestry in some countries, and forms an integral part of their forest management plans. This methodology should be extended to many ecosystems presently endangered, and particularly to tropical hardwood ecosystems.

4. In some countries Strict Natural Reserves have a legal status which ensures their inviolability; others do not and consequently the areas set aside are prone to varying degrees of disturbance and not infrequently total destruction. Therefore, countries which do not have forest laws ensuring the inviolability of endangered forest ecosystems should take steps to promulgate appropriate legislation. Action in this matter should be given every encouragement by international agencies.

5. Conservation of forest genetic resources should whenever possible be combined with other conservation objectives, such as wildlife and watershed conservation and National Parks.

6. The conservation of forest genetic resources depends not only on the conservation of endangered populations in Strict Natural Reserves, but also on their eventual cultivation and domestication. At the present time research programmes designed to provide data allowing the cultivation and domestication of important tropical and sub-tropical species are wholly inadequate and they should be expanded.

7. In developing countries the introduction of private forestry based on plantations of fast growing exotic species, to take the place of bush fallow outside forest reserves, could result in a lessening of pressure for the conversion of the reserved high forest to plantations. Such a development could in the long run have a major beneficial effect on conservation of forest genetic resources and, therefore, should be encouraged.

8. Programmes of research in the testing and storage of the seed of tropical tree species should be developed. At the same time standards for testing and certification and a concomitant nomenclature to ensure repeatability of genetic material should be developed.

9. In a number of countries the work of maintaining existing Strict Natural Reserves and establishing new ones, and of planting and maintaining ex situ conservation stands, should justify the appointment of a full-time forest officer to take responsibility for all activities for conservation of forest genetic resources. In appropriate cases in developing countries his work should be financially supported from international funds.

10. Information from all sources e.g. the literature, forest inventories, and herbarium records on endangered species should be documented in a manner similar to that being done in the IUCN Data Book on Angiosperms and by the IUFRO Working Party on Gene Resource Conservation. However, it is of equal importance that this information be brought to the attention of personnel in State Departments of Forestry who are responsible for conservation measures. Financial support should, therefore, be given for the publication and dissemination of information.

11. Principles of conservation of forest genetic resources should be an integral part of courses in forest management given in universities and schools of forestry. Conferences and symposia on this subject should be encouraged and given financial support.

12. Conservation measures for forest genetic resources must be accompanied by the conservation of information about these resources and it is, therefore, essential for each institution to develop a system of gathering, storing and retrieving information. Such systems have already been developed and could be emulated with appropriate modification for local needs. Initially, however, a pilot project should be established in an institution already engaged in this work, and having computer facilities.

PROPOSALS FOR INTERNATIONAL ACTION

The global programme for forest genetic resources proposed by FAO's Panel of Experts at its third session (FAO 1974a) constitutes a comprehensive and balanced programme covering a five year period, in which conservation forms an integral part, together with other essential operations such as exploration, collection, utilization and documentation. It is recommended that it be adopted as the basis for international action over the next five years and financed to the extent possible.

It is imperative that plans for action in forest genetic resources be closely coordinated with complementary plans in crop plants. The recently established International Board for Plant Genetic Resources, which is financed by and responsible to the Consultative Group on International Agricultural Research, provides the means for overall coordination and direction.

For many tree species, the development of a sure methodology of gene resource conservation still awaits information from research. Yet the urgency of the problem requires immediate action. The global programme proposed for implementation in 1975-79 should therefore be considered as a pilot phase leading to a greatly expanded long-term programme. Progress should be assessed towards the end of the five year period and the results achieved used as a basis for further planning.

The proposals for action in conservation included in the global programme are here summarised in two groups:

A. Proposals for action to be directly financed by UNEP

B. Proposals for action related to conservation which could be financed by UNEP or by other international or bilateral agencies.

A. Proposals for action to be directly financed by UNEP

		Total cost ($ 000) over 5 years
(1)	Seed collection for conservation *ex situ*	125
(2)	Establishment costs of *ex situ* conservation stands of two *Pinus* spp. and two *Eucalyptus* spp., ten provenances in eleven developing countries	356
(3)	Development of pilot projects for *in situ* conservation in Central America, Brazil, India, West and East Africa	310
(4)	Dissemination of information on conservation of forest genetic resources	60
	Total	851

B. Proposals for action in conservation for financing by UNEP or other agencies

(1)	Research on seed storage and handling	250
(2)	Research on data/storage and retrieval	250
(3)	Establishment of prototype conservation/selection stands *ex situ*	63
(4)	Appraisal of the need for international forest gene centres	50
	Total	613

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ADAPTATION. The process of evolutionary (genetic) adjustments fitting biological groups to their environment. Often the changed structure or function itself is referred to as an adaptation.

AGRI-SILVICULTURE. See Taungya.

ALLELE. One of an array of genes possible at a certain position (locus) on a given chromosome. Alternative (Mendelian) effects on the same character are produced by different alleles, e.g., as met in green or albino seedlings. If the array contains more than two, the genes are called "multiple alleles". These arise by repeated mutations of a gene, each with different effects. No more than two alleles can be present in a given diploid organism.

ANEMOPHILOUS. Plants pollinated by wind.

ASEXUAL REPRODUCTION. Reproduction without fertilization, from vegetative parts such as tubers, bulbs, rooted stems, or from sexual parts such as unfertilized eggs or other cells in the ovule.

AUTOGAMOUS. Plants which are self-fertilized.

AUTOGAMY. Self-fertilization.

BREEDING ARBORETUM. An area where selected trees or species are established for breeding. If the collection is preserved vegetatively, it is sometimes known as a clone bank. Spacing, culture, and protection practices are designed to stimulate early and prolific flowering for controlled pollination and seed harvest.

BREEDING SYSTEM. Any of a number of schemes by which individuals are assorted in pairs leading to sexual reproduction. Random: assortment of pairs is by chance. Genetic assortative mating: mating together of individuals more closely related than individuals mating at random. Genetic disassortative mating: mating together of individuals less closely related than individuals mating at random. Phenotypic assortative mating: mating of individuals more alike in appearance than the average. Phenotypic disassortative mating: mating of individuals less alike in appearance than individuals mating at random.

CERTIFIED. Of commercial seed or propagules produced under conditions satisfying specified standards guaranteed by a certificate from an official agency.

CHARACTER (trait). A distinctive but not necessarily invariable feature of all individuals of a group that can be described or measured, e.g. colour, size, performance. A character of a given individual will have a certain phenotype (state) as determined by the individual's genotype and environment.

CLIMAX. The culminating, highly stable, stage in plant succession for a given environment.

CLINE. A geographical gradient of phenotype or genotype within the species range. Detection of a genotypic cline requires a test in a single environment. Usually clinal variation results from an environmental gradient. Portions of populations exhibiting such continuous (clinal) change from one area to another should not be designated as ecotypes, races, or taxa.

CHROMOSOME. A microscopic, usually rod-like body carrying the genes. Their number, size, and form are usually constant for each species.

CROSS-POLLINATION. Pollination of a plant with pollen from a genetically different plant.

DEGREE-DAY. A number of degrees above a threshold, e.g., of 10°C. per day times the number of days taken to produce a given biological effect.

DIOECIOUS. Plants in which staminate and pistillate flowers occur on different individuals.

DYSGENIC. Detrimental to the genetic qualities of future generations. The term applies especially to man-made deterioration, such as losses resulting from "high-grading" a forest stand.

ECOSYSTEM. A self regulatory system of inter-acting populations of plants and animals and their environments. Increasingly used in place of biocoenose.

ECOTYPE. A race adapted to the selective action of a particular environment. Most differences among ecotypes show up only when different ecotypes are tested in a uniform environment. Ecotypes are described as climatic, edaphic, etc.

ENDOGENOUS. Arising from within the organism.

ENTOMOPHILOUS. Plants pollinated by insects.

ENVIRONMENT. The sum total of the external conditions which affect growth and development of an organism.

EPIPHYTES. Plants which germinate on other plants and grow without obtaining nutriment at a cost of a substance of the host.

FERTILIZATION. Union of the nucleus and other cellular constituents of a male gamete (sperm) with those of a female gamete (egg) to form a zygote. In some species, fertilization may occur months after pollination.

FOREST TREE BREEDING. Applying knowledge of genetics to produce trees with specific characteristics. In the narrow sense, it refers to propagation by artificial pollination. In the broad sense, it refers to systems of breeding varying from harvesting seed from only the best trees or seed sources (mass selection) to sophisticated multiphase, multi-generation controlled-pollination programs.

GAMETES. Mature sex cells, either sperm or eggs.

GENE. The smallest transmissible unit of genetic material consistently associated with a single primary genetic effect. The genes are ultra-microscopic and act as if linearly arranged at fixed places (loci) on a chromosome. Each gene, by interacting with other genes and the environment, governs a certain physiological effect in the cell and is expressed as one or more characters.

GENECOLOGY. The study of genetically-based, habitat-correlated variation within species.

GENE FREQUENCY. The proportion in which alternative alleles of the gene occur in a population.

GENE POOL. The total genetic information possessed by the reproductive members of a population of sexually reproducing organisms.

GENOTYPE. The entire genetic constitution of an organism.

GENOTYPE-ENVIRONMENT INTERACTION. The failure of different populations to maintain the same relative ranks and level of differences when tested in different environments. It is tested for by planting at more than one location or under more than one cultural condition.

GEOGRAPHIC VARIATION. The phenotypic differences among native trees of a species growing in different portions of its range. If the differences are largely genetic rather than environmental, the variation is usually specified as racial, ecotypic, clinal, etc.

HETEROGENEITY. Dissimilarity among members of a group.

HETEROSIS. Hybrid vigour exhibited when the mean F1 hybrid phenotype falls outside the range of the parents. Statistically: An increase over the mean of the parents. Usually applied to traits such as size or general thriftiness.

HETEROZYGOUS. Having one or more sets of unlike alleles, e.g., the dominant with the recessive gene. Thus, an <u>Aa</u> cell or plant is heterozygous whereas the <u>AA</u>'s and <u>aa</u>'s are homozygous. Refers also to differences in the arrangement of genes on the chromosomes. A heterozygous organism (heterozygote) does not generally breed true and is known as a hybrid with respect to the genes in question.

HOMOZYGOUS. Having like alleles at corresponding loci on homologous chromosomes. An organism can be homozygous at one, several, or all loci.

HYBRID. The product of a cross between genetically unlike parents.

ISOENZYME. Multiple forms of a single enzyme. The assessment of presence or absence of isoenzymes can give an indication of genetic variability. Increasingly used in the assessment of intraspecific variation in tree species.

LIFE FORM. The characteristic vegetation form of a plant species such as trees, shrubs, herbs, grass, vines etc.

MONOECIOUS. Staminate and pistillate flowers occurring separately on the same plant.

MUTATION. Sudden heritable change in the gene or in chromosome structure.

NICHE. A localized environment where the ecological factors combine to favour the permanent survival of some particular population. Such a habitat may be discontinuous or be part of a gradient. Unique niches may favour hybrids, mutants, etc., that are at a disadvantage in other environments.

PHENOLOGY. The study of relations between plant development and seasonal climatic changes, such as temperature or day length, especially as such changes affect periodic phenomena like leafing, flowering, and dormancy.

PHENOTYPE. The plant or character as we see it; state, description, or degree of expression of a character; the product of the interaction of the genes of an organism (genotype) with the environment.

POPULATION. Genetically, a group of similar individuals related by descent and so delimited in range by environmental or endogenous factors as to be considered a unit. In cross-bred organisms the population is often defined as the interbreeding group.

PROPAGULE. A plant part such as a bud, tuber, root, or shoot, used to propagate an individual vegetatively.

PROVENANCE. The original geographic source of seed, pollen, or propagules.

RACE. A population within a species which exhibits general genetic characteristics discontinuous and distinct from other populations. It is usually an interbreeding unit. When the distinguishing characteristics of a race are adaptive, the term is synonymous with ecotype, and the race is described similarly i.e., climatic, edaphic, etc.

SECONDARY FOREST. Forests arising as a result of interference of man in primary forest.

SEED COLLECTION ZONE. Zone defined for seed collection purposes and occupied by trees with relatively uniform genetic (racial) composition as determined by progeny testing various seed sources. The encompassed area usually has definite geographic bounds, climate, and growing conditions, e.g., a range of altitude. A single geographic race may be divided into several zones.

SELECTION. Often synonymous with artificial selection which is the choice by the breeder of individuals for propagation from a larger population. Artificial selection may be for one or more desired characteristics and based on the tree itself, (phenotypic) or genotypically, on the tree's progeny or other relatives.

SELF-FERTILITY. Capability of producing seed from self fertilization.

SELF-FERTILIZATION. Fusion of male and female gametes from the same individuals.

SELF-INCOMPATIBILITY. Genetically controlled physiological hindrance to self-fertilization.

SIBS. Progeny of the same parents derived from different gametes. Half-sibs, progeny with one parent in common.

SPECIES. The unit of taxonomic classification in which genera are sub-divided. A group of similar individuals different from other similar arrays of individuals. In sexually reproducing organisms, the maximum inter-breeding group isolated from other species by barriers of sterility or reproductive capacity.

SUCCESSION. The gradual supplanting of one community of plants by another.

SYNGAMY. The union of the nuclei of two gametes following fertilization to produce a zygote nucleus.

SYNUSIUM. A natural community of species belonging to the same life-form groups and with uniform ecological requirements.

TAUNGYA. Farming system allowing the establishment of a tree crop at the same time as food crops. When the tree crop closes canopy, agricultural activities cease in the area until the tree crop is harvested and the cycle is established once again.

ZYGOTE. The fertilized egg; sometimes also the individual developing from it. The zygotic chromosome number is normally diploid (2n).