

Forest genetic resources conservation and management:

In managed natural forests
and protected areas (*in situ*)

2

Forest genetic resources



Danida Forest
Seed Centre



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This volume is one in a set of three guides to the conservation and management of forest genetic resources. These include:

Volume 1. Forest genetic resources conservation and management: Overview, concepts and some systematic approaches

Volume 2. Forest genetic resources conservation and management: In managed natural forests and protected areas (*in situ*)

Volume 3. Forest genetic resources conservation and management: In plantations and genebanks (*ex situ*)

The document has been prepared as a common effort between FAO, the Danida Forest Tree Seed Centre (DFSC) and IPGRI (International Plant Genetic Resources Institute), and draws on inputs of a great number of national, regional and international partner institutions throughout the world.

Danida Forest Seed Centre (DFSC) is a Danish non-profit institute, which has been working with development and transfer of know-how in management of tree genetic resources since 1969. The development objective of DFSC is to contribute to improving the benefits of growing trees for the well-being of people in developing countries. The programme of DFSC is financed by the Danish International Development Assistance.

The Food and Agriculture Organization of the United Nations (FAO) is the specialized UN agency in agriculture, forestry, fisheries and rural development. FAO provides information and technical support to member countries, covering all aspects of the conservation, sustainable use and management of forest genetic resources.

The International Plant Genetic Resources Institute (IPGRI) is a member of the Consultative Group on International Agricultural Research (CGIAR). IPGRI fulfils its mandate by encouraging, supporting and undertaking activities to improve the management of genetic resources worldwide so as to help eradicate poverty, increase food security and protect the environment. IPGRI focuses on the conservation and use of genetic resources important to developing countries and has an explicit commitment to specific crops.

Many staff members of FAO, DFSC and IPGRI have been involved in the preparation of this guide. Special thanks are due to Dr Alvin Yanchuk of Canada, who undertook the difficult task of reviewing and harmonizing the many different contributions to the publication. Overall guidance, inputs and the continued encouragement of the members of the FAO Panel of Experts on Forest Gene Resources are also acknowledged with thanks.

While staff of all three main partner institutions have been involved in each of the chapters in the three volumes, taking full institutional responsibility for the contents, lead authors are shown against each of the chapters. These lead authors are responsible for the final contents, and provide focal points for those readers seeking additional information or clarification of points discussed.

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Cover photo: Parkland dominated by the imposing features of baobab trees (*Adansonia digitata*) in Arusha National Park, Arusha, Tanzania
(Pierre Sigaud)

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PREFACE

Forests are the single most important repositories of terrestrial biological diversity. They provide a wide range of products and services to people throughout the world. Forest trees and other woody plants help support many other organisms, and have developed complex mechanisms to maintain high levels of genetic diversity. This genetic variation, both inter and intra specific, of trees and shrubs serves a number of fundamentally important purposes. It allows them to react against changes in the environment, including those brought about by pests, diseases and climatic change. It provides the building blocks for future evolution, selection and human use in breeding for a wide range of sites and uses. And, at different levels, it supports the aesthetic, ethical and spiritual values of humans.

Forest management for productive and protective purposes can and should be rendered compatible with conservation through sound planning and coordination of activities at national, local and ecoregional levels. Conservation of forest biological diversity, which comprises forest genetic resources, is essential for sustaining the productive value of forests, for maintaining the health and vitality of forest ecosystems and, thereby, for maintaining their protective, environmental and cultural roles. This guide highlights the major role that managed natural production forests and protected areas play in programmes aimed at the conservation of forest genetic resources and intraspecific variation in socioeconomically important species.

A major threat to forest ecosystems is the conversion of forests into other land uses. Increasing pressure from human populations who aspire to higher standards of living, without due concern for the sustainability of resource utilization underpinning such developments, raises concerns in this regard. While it is inevitable that land-use changes will occur in the future, such changes should be planned to help ensure that the complementary goals of conservation and development are achieved. This can be done by including concerns for conservation as a major component in land-use planning and resource management strategies.

The main problem in achieving conservation goals currently is actually the lack of adequate institutional and political frameworks under which land-use and operational management choices, fair to all stakeholders, can be considered, efficiently implemented, monitored and regularly adjusted to meet new and emerging needs. Therefore forest genetic resources conservation decisions should not be made in isolation but as an integral component of national development plans and national conservation programmes.

The key to success will therefore lie in the development of programmes that harmonize conservation and sustainable utilization of biological diversity and forest genetic resources within a mosaic of land-use options. Sustainability of action over time will be based on genuine efforts to meet the needs and aspirations of all interested parties. It will require close and continuing collaboration, dialogue and involvement of stakeholders in the planning and execution of related programmes.

There are in principle no fundamental technical obstacles to meeting conservation objectives that cannot be solved. In recent years, a number of activities have been initiated furthering conservation and sustainable use of genetic resources. Practical experience, however, has been insufficiently documented, and 'lessons learned' from it have received

little attention and have only seldom been applied on a larger scale. The evidence of experience is that prudent and timely measures and programmes based on the best available knowledge can make a vital contribution to the conservation of forest genetic resources. It is therefore considered of utmost importance that this experience coupled with current knowledge of conservation theory is made widely available in the form of generalized guidelines and procedures to serve as inspiration for others engaged in such conservation activities.

This guide is the second volume of a series of three that deals with the conservation of forest (tree and shrub) genetic resources. It is focused on the conservation of forest genetic resources *in situ*. Its main aim is to demonstrate the benefits attainable through genetic conservation, and to provide practical guidance on *in situ* conservation strategies and methodologies for planners, decision-makers and professionals involved in forest conservation and forest management. Examples and case studies illustrate some of the differences and complementarities between genetic resources and ecosystem conservation, and the compatibility of conservation and sustainable resource utilization.

Therefore we hope that this guide will contribute to fulfilling this purpose.



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CONSERVATION OF GENETIC RESOURCES IN THEIR NATURAL ENVIRONMENT

by Lex Thomson, Lars Graudal and Erik Kjær

1.1 Introduction

Conserving genetic resources in their natural environment, whether in production forests or in protected areas, is called *in situ* conservation. *In situ* conservation implies that a given population is maintained within the community of which it forms a part, in the environment in which it has developed (Frankel 1976). The term is frequently applied to naturally regenerating wild populations in protected areas, and can be integrated into managed production and multiple-use forests. *In situ* conservation thus focuses on conserving the genetic resource in their original ecosystem, irrespective of whether such ecosystems have been subject to human interference (see Vol. 1, Chap. 2).

In situ conservation in general has the advantage of conserving the function of an ecosystem rather than just species. This means that *in situ* programmes for conservation of selected target species often result in valuable conservation of a number of associated animal and plant species. The majority of tree species cannot be conserved *ex situ* in plantations or genebanks because of biological, technical and resource limitations (see Vol. 1, Chap. 2 and Vol. 3, Chap. 6). Therefore, conservation of the majority of the world's plant genetic resources will rely on *in situ* conservation, which underlines its importance. Because the conservation of genetic resources can be included in managed natural production forests and protected areas, *in situ* conservation will usually be a low-cost option.

Planting of indigenous tree species based on local seed sources is sometimes considered as *in situ* conservation, because it involves growing trees in their original environment. However, artificial regeneration and establishment of plantations can expose trees to conditions that are very different from those under which they develop in natural forest. This volume therefore deals almost exclusively with natural forests, whereas Volume 3 deals with management and conservation of forest genetic resources in tree plantings.

Ideally, in order to be undertaken efficiently, *in situ* conservation programmes ought to be based on substantial knowledge of species. However, in practice very limited information is usually available. The resources available for research are limited, especially in developing countries, and the potential number of species to investigate is vast. In addition, threats to forest genetic resources are of a major, immediate and continuing nature. Therefore in many cases, it is unwise to delay taking conservation action because all relevant information is not available.¹

Fortunately, understanding of various theoretical aspects of *in situ* conservation can contribute to the formulation of some general recommendations. Furthermore, practical experience gained from *in situ* conservation over the years in different parts of the world can serve as valuable experience for anyone dealing with conservation of tree genetic resources. However this valuable information is not often available to people dealing with forest conservation and management, whether government officials from Forestry and Environment Departments, or NGOs and local communities.

This guide focuses on practical aspects of *in situ* conservation based on lessons learned from a number of conservation programmes throughout the world. Given the huge diversity

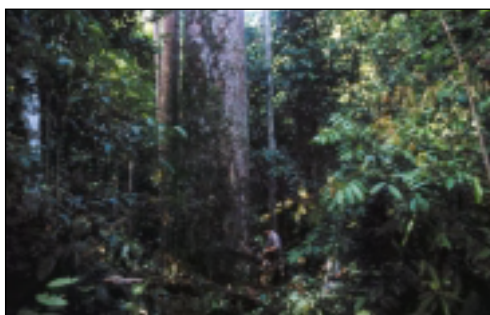
¹ See also Vol. 1, Chap. 4, where the role of timely research is discussed.

of species, ecosystems, countries and patterns of use, it is obvious that every conservation plan must be unique. The intent of this guide is not to outline an easy 'turn-key' conservation programme. Conservation efforts must be built on the specific challenges and options in a given area, country or region. However, the guide presents selected examples from different gene conservation programmes, and combines these with theoretical knowledge to provide general guidelines that can assist the development and implementation of effective conservation activities.

1.2 *In situ* gene conservation in managed natural forest and protected areas

In situ conservation in natural forests often comprises ecosystem functions and species interactions, rather than individual tree species. In addition forests have a number of natural trees and shrubs that may be of minor interest to forest managers, but may be highly valuable in terms of genetic resources and future use. However their conservation may require specific management measures, which could be ensured through the establishment of genetic conservation areas. From a theoretical point of view, a network of genetic resource conservation areas should be an efficient way to conserve the genetic resources of target species, if they follow the patterns of distribution of genetic variation (Eriksson *et al.* 1995).

Practical experience suggests that sound management of genetic resources must include conservation efforts based on two overlapping strategies: management of natural forests with due respect to their genetic resources, and the establishment of networks of smaller gene conservation areas. This does not mean that we need to include conservation of genetic resources of all species in all native production forests or all protected forest areas. The challenge is to find the balance and synergism between these two approaches. This will in turn depend upon biological factors (species composition, distribution and ecology) as well as the present and future forest uses. This guide therefore provides information and alternatives on how to protect and manage forest genetic resources in managed natural forest and protected areas. Specific managed genetic resource areas may be established in both types of areas. The process of selecting such areas is discussed in Chapter 2. In addition, general management of natural production forests as well as protected areas should take genetic resource conservation into consideration.



Natural forest in Sabah with many commercial, as well as non-commercial, species. Such complex ecosystems are best conserved in situ.

(K. Holsting/BAM)

1. Sustainable management practices in natural forests that lead to *in situ* gene conservation (Chap. 3). The majority of forest genetic resources can be conserved in managed natural forests, specifically designated genetic conservation areas. Hence it is vital that forest owners and managers are well informed about how they can conserve, manage and benefit from forest genetic resources in areas of natural forest under their control. Chapter 3 provides guidelines on how genetic resources can be maintained in relation to logging, harvesting of non-wood forest products and forest rehabilitation.

2. Protected areas (Chap. 4) as a vital component of programmes to conserve forest genetic resources. Fortunately, most countries have established networks of protected areas. However, the protected areas do not automatically provide conservation of the forest genetic resources. First, there can be a lack of appropriate representation of important populations. Second, viable populations may not be present and, without adequate management interventions, normal successional changes in forests may affect a given species targeted for gene conservation. Protected areas often form a 'backbone' from which more specific networks of designated *in situ* conservation stands of priority species, including non-commercial ones, can be developed. Chapter 4 provides suggestions on how to assess and improve the value of protected areas for conservation of forest genetic resources.

1.3 Use of the guide

This guide on *in situ* conservation, used in concert with Volumes 1 and 3, will provide the conservation officer and the forest manager with valuable information and the overview required to develop and customize a conservation programme for target species or a 'set' of species, based on local conditions and specific objectives.

This volume also includes and relies heavily on selected examples and case studies for different tree species from various parts of the globe; however, more examples can be found in Volumes 1 and 3 that support the technical discussions on the various aspects of *in situ* conservation. These case studies demonstrate that long-term conservation of forest genetic resources *in situ* is far from a straightforward process, but one whose success depends on:

- appropriate social, economic and political conditions
- relevant biological information
- commitment and appropriate resourcing
- active participation of and benefits to local communities.

Furthermore, the examples illustrate the need for complementary *ex situ* conservation measures. We hope with these examples to show that it is possible to plan and implement activities that contribute significantly to the safeguarding of the genetic resources of forest trees despite limited resources and knowledge.



SELECTION AND MANAGEMENT OF *IN SITU* GENE CONSERVATION AREAS FOR TARGET SPECIES

by Lex Thomson, Lars Grael and Erik Kjær

2.1 Steps in planning the *in situ* conservation of a species' genetic resources

In its most planned form, the conservation of forest genetic resources entails the scientific management of identified target or priority species in a carefully planned network of designated gene conservation areas.² While the primary objective, and focus of management, in gene conservation areas will be to conserve the genetic resources of target species, they may be used for other compatible purposes.

Programmes to conserve genetic resources of particular tree species are best undertaken and coordinated by a designated national agency, working in collaboration with various state/provincial agencies, landholders and any other interested or concerned parties (see Vol. 1, Chap. 3). However the conservation of the genetic resources of species that naturally occur in more than one country often requires additional effective collaboration at regional and international levels (see Vol. 1, Chap. 6).

The main steps in planning a programme to conserve the genetic resources of a particular tree species (described in Vol. 1, Chap. 3) are:

1. Set overall priorities, i.e. identification of genetic resources at the species level based on their present or potential socioeconomic value and their conservation status.
2. Determine or infer the genetic structure of the priority species at the landscape level.
3. Assess the conservation status of the target species and their populations.
4. Identify specific conservation requirements or priorities, typically at the population level for single species and at the ecosystem level for groups of species, i.e. identify geographical distribution and number of populations to be conserved.
5. Identify the specific populations to be included in the network of *in situ* conservation stands.
6. Choose conservation strategies or identify conservation measures.
7. Organize and plan specific conservation activities.
8. Provide management guidelines.

The identification of populations to be conserved is done in Steps 4 and 5. These populations will then constitute the network of stands required to cover sufficient genetic variation of the species in question. Some populations will typically be located in managed natural forests while others will occur in protected areas. The majority of such populations will usually be considered for conservation *in situ* while some may be considered for conservation *ex situ*. Thus, it is imperative to provide forest and protected area managers with relevant guidelines to properly manage genetic resources (Step 8).

Usually such networks will only be established for species of high national priority. Nevertheless, the integration of genetic resource conservation concerns is highly relevant in any managed natural forest, a fact for consideration by any manager of natural forests.

² Gene conservation areas have been variously termed gene conservation forests or reserves, genetic conservation reserves, gene management zones, gene resource management units and evolutionary conservation stands.

Selection and management of *in situ* gene conservation areas address the following questions:

- How many conservation areas are required?
- How large does each conservation area need to be?
- How are individual populations and stands selected for inclusion?
- How is a management plan for the gene conservation area prepared?

Foresters and managers of protected areas will find below a brief introduction to a few important criteria for selecting conservation areas on the basis of number, size, composition and protection status.

2.2 How many conservation areas are required?

The selection of stands and populations for inclusion in a network of gene conservation areas for a particular species ought to be based on the known or expected distribution of genetic variation. Unfortunately, only rarely are genetic studies available, and even when data exist there are difficulties in readily using such information for identifying conservation stands.³ However, populations of known superiority should of course be given special attention, even if their genetic make-up is inadequately known. The same goes for any geographic variants or ecotypes (including subspecies) that may have been taxonomically identified.

In the absence of data on the distribution of genetic variation, one can at least include different sites of the species' biogeographical distribution area by spacing conservation stands more or less uniformly throughout the species' natural range, together with any extreme, disjunct or unusual populations (Ledig 1986). A somewhat more refined method, whether or not genetic information on population structure is present, is to apply a genecological approach (Graudal *et al.* 1995, 1997), which leads to identification of different genecological zones. The assumption used is that genetic variation follows some of the patterns of ecological variation. Even if this is not true, such an approach could provide an effective 'random' sample of populations across the species' range of distribution. Therefore, populations should be sampled in order to cover all genecological zones.

Genecological zonation criteria are based on:

- any information from genetic studies that may be available for the species in question or other similar species
- local distribution of forest ecosystems
- information from climatic stations and climatic surfaces
- physiographic maps
- geological or soil surveys.

The above set of information constitutes very important inputs, and such information should be compiled and thoroughly analysed as part of the zonation process (see Vol. 1, Chap. 3). Fairly elaborate examples of practical application of genecological zonation are found in Graudal *et al.* (1995, 1997, 1999) and Theilade *et al.* (2000, 2001).

In practice it is recommended that more than one population per genecological zone be conserved. Widespread and highly outcrossing species often exhibit a semi-continuous pattern of genetic variation which may be relatively easy to sample by genecological zones. For such species, establishment of 1–3 gene conservation areas in each major zone is likely to be sufficient. For species with mix-mating systems and higher percentage of selfing and outcrossing species with scattered and disjunct distribution patterns, even for species with high levels of endemism, many more and perhaps smaller conservation areas are likely to be

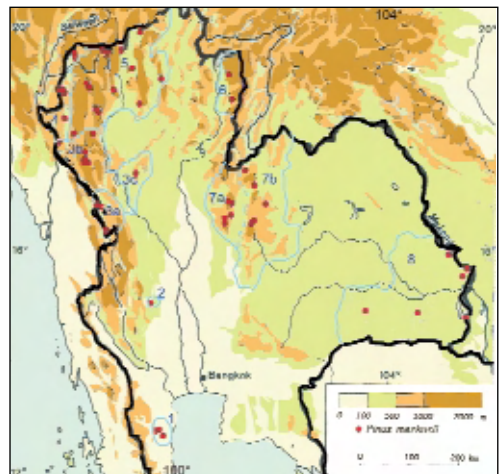
³ See detailed discussion in Vol. 1, Chap. 4.

needed. In practice, the number of populations selected for conservation also depends on the levels of risks or threats at the population level, resources available to manage and maintain them, and expected importance of variant, e.g. economic value and genetic distinctiveness.

In many cases relatively few gene conservation populations will suffice for each species, although more areas will undoubtedly provide a greater degree of long-term security.

In Thailand a total of 15 conservation stands distributed in 6 genecological zones were considered desirable for teak (*Tectona grandis*) (Graudal *et al.* 1999), while for *Pinus merkusii* 10–15 stands in 8 zones have been proposed (Theilade *et al.* 2000). In Zambia 7–10 stands in 7 zones have been suggested for Zambesi teak (*Baikiaea plurijuga*) (Theilade *et al.* 2001). A range of 2–30 stands in 11 zones have been proposed for each of 22 woody species in the Sudan (Graudal *et al.* 1997). In Denmark a range of 2–15 stands in 4 zones are planned for each of 75 woody species (Graudal *et al.* 1995).

Where highly threatened tree populations are identified for conservation of the genetic resources, *ex situ* conservation may constitute either the only or the best approach at least in short to medium terms.⁴



Genecological zonation for *Pinus merkusii* in Thailand. Occurrences of *P. merkusii* are indicated in red, and numbers refer to the 8 genecological zones (after Theilade *et al.* 2000).

2.3 How large does each conservation area need to be?

As genetic diversity can be continuously eroded in small populations, conservation stands need to be of a minimum size to conserve these genotypes. While low-frequency genes will be lost quite quickly from small populations, a large proportion of the genetic variation can be conserved by a relatively few individuals, at least over a few generations. Some conservation programmes place a priority on targeting low-frequency genes, and this leads to a much larger population size requirement (see Yanchuk 2000). In practice, the size of conservation stands is therefore highly variable, although small populations are best avoided whenever possible.

The area required for a conservation stand will therefore depend on the density of reproducing trees of the target species. Given that the conservation objectives are focused on conserving adaptive quantitative genetic variation, conservation populations should preferably include at least 150 and ideally more than 500 interbreeding individuals (see Vol. 3, Chap. 3, where the required size is discussed). Of course, various other non-genetic considerations – threats including likelihood of catastrophic events, management requirements, maintenance of key associated species (notably mammalian or avian pollinators and seed dispersers) – may necessitate much larger populations.

Species with a density of 2–5 individuals/100 ha will require larger areas than species with a density of more than 100 individuals/ha. Area requirements to capture the genetic variation of a population may thus be in the range of 5–10 000 ha or even more. In one *Tectona grandis* gene resource conservation stand in Mai Yom, Thailand, the presence of teak was estimated to be approximately 37 reproductive trees/ha in the areas of high density

⁴ See Vol. 3 for information on approaches and methods.

Box 2.1 *In situ* conservation of Norway spruce (*Picea abies*) in Finland (including guidelines for gene reserve forests)

Norway spruce (*Picea abies*) is a major timber species of the boreal forests of northern Europe. Koski (1996) has proposed a system of gene reserve forests for *in situ* conservation of this ecologically and economically important species. The objective of the programme is to conserve a genetically representative selection of populations that can continue to evolve in their native habitats. Essential elements of the gene reserve system are:

- a reserve network that covers the spatial variation in genetic diversity
- the number of genotypes (individual trees) in each population must be sufficient to ensure that most of the common alleles (frequency >0.01) are represented
- regeneration by stock that must have predominantly originated from matings within the respective population and at levels that maintain the population.

In situ conservation of forest genetic resources in Finland can occur in two broad categories of land use and management: protected areas and managed forests. Protected areas, including national parks, nature parks and reserves, have several major limitations for conservation of forest genetic resources. First, their geographical coverage will usually be inadequate, including siting in extreme environments not especially representative of the range of forest ecosystems. Second, the continued existence of any given species/population in a particular protected area is not assured because management intervention is minimal, e.g. in the face of a new threat. Finally, access to genetic resources in protected areas may be restricted.

Managed *in situ* gene reserve forests do not have the same constraints as strictly protected areas. The main requirements are as follows:

- Secure land tenure with the area designated to be managed in perpetuity as forest.
- All gene reserve forest stands shall be of local origin, but may include other forest tree species (i.e. no requirement for pure stands). Small stands of non-local or introduced sources of Norway spruce may need to be removed from adjacent areas to prevent contamination or pollution of local genepool.
- The target area shall normally be >100 ha, with the shortest diameter being at least 400 m. Smaller areas, especially those with potential for enlargement, might be considered in areas where spruce forest is very limited and as part of special 'gene rescuing' cases. Stands <2 ha would normally be deemed ineligible and the target area allowing enlargement by means of cultivation should be at least 10 ha.

Information on the location, characteristics, ownership, etc. of the gene reserve forest should be supplied to the national registering authority. Prior to registering the area the owner/manager of the gene reserve forest should have formally agreed to follow a set of guidelines for its tending and management or a management plan (also to be held by national registering authority). The area needs to be clearly defined and depicted on a map.

(Based on Koski 1996)

Box 2.2 *In situ* conservation of jatoba (*Hymenaea courbaril*)

Hymenaea courbaril L. is a large tree in the family Leguminosae–Caesalpinoideae, reaching heights of 25–40 m and a dbh of 120 cm. Jatoba has an extensive geographical distribution from southern Mexico, through Central America and the Caribbean (Greater and Lesser Antilles) and into South America. *H. courbaril* produces a heavy, hard and moderately durable timber suitable for many structural uses, production of pulp, and for firewood and charcoal. In addition, ‘jutaicaica’ or copal resin can be extracted from the trunk, branches and roots. This resin is useful for manufacturing varnish and has medicinal properties. The Xingu Indians chew the resin to alleviate stomach pain and burn it to produce smoke that combats bronchitis and tuberculosis (Carvalho 1994). Other parts of the plant, such as the fruit pulp and the roots, also have medicinal uses (diuretic, anti-cough and vermifuge).

Reproductive biology, seed dispersal and regeneration

H. courbaril flowers appear to be mainly pollinated by bats and hummingbirds. There is evidence of self-incompatibility, in which case cross-pollination is required in order to produce viable seed (Crestana *et al.* 1985). Most trees flower annually, but heavy fruiting occurs only at irregular intervals, varying from 2 to 4 years (Lewinsohn 1980). Seed pods mature about nine months after flowering and fall over a period of about three months. Three to four large seeds are held within a powdery pulp inside the large, very hard, seed pods. There are many reports of seed predation. Seed dispersal is effected by gravity and animals, especially large mammals. The very hard, outer shell of the pod does not open by itself, and the majority of seeds in unopened pods will rot (Francis 1990). *H. courbaril* grows slowly under light shade and can persist under fairly heavy shade for a few years. However, full or nearly full overhead light is required for its continued growth (Francis 1990).

Genetic variation

There has been very limited investigation of genetic variation within *H. courbaril*. Variation in the species is associated with differences in geographic distribution and habitat. Presently there are five varieties recognized: var. *courbaril* occupies most of the range, with the other four varieties (vars. *altissima*, *longifolia*, *stilbocarpa* and *villosa*) confined to central and south-central Brazil.

Genetic conservation

H. courbaril has a low relative frequency in natural populations and in many places may be classified as a rare species. Owing to the high value of its timber, the species has been extensively cut. In the Amazon region, timber extraction is now minimal and the tree is approaching commercial extinction. Because of the high value of its products (including fruits and resins) a programme of *in situ* conservation is highly desirable and should be implemented before further populations are lost.

However, the demographic patterns and ecology of *H. courbaril* make it difficult to develop an effective *in situ* genetic conservation programme. Because of its low density, large areas are necessary to maintain the minimum effective population sizes. *H. courbaril* seed dispersers are primarily large mammals (such as tapir and paca) and these animals can only survive in large forested areas. They are also the most pursued

continued

by hunters. In forests without these dispersers, most seedlings develop near the mother-tree.

Recommendations for *in situ* conservation of the genetic resources of *H. courbaril* include:

- establishment of specific gene conservation areas, within large areas of managed forests
- possible reintroduction of large mammals (tapir and paca), responsible for seed dispersal, in forests from which these have disappeared
- reintroduction of *H. courbaril* plants of wide genetic base in depleted forests and forest fragments
- regulations to control *H. courbaril* exploitation in native forests
- research to provide guidance on how best to sustainably manage and utilize the species.

[Based on information provided by H.M. Maltez (University of Campinas, Campinas-SP, Brazil) and L.M. Inglez de Souza (University of São Paulo, Piracicaba – SP, Brazil)]

but much lower in other parts (Mahidol University and RFD 1995). Core conservation areas of 4–40 ha should therefore be targeted in order to obtain 150–1500 mature teak trees. In practice, a larger area may be protected in order to assure an appropriate reproduction unit (see Graudal *et al.* 1997).

In Burkina Faso plans for conservation of the genetic resources of *A. senegal* are underway where 393 stands of *A. senegal* have been identified. The density of 133 of these stands investigated in more detail varied between 25 and 200 trees per hectare. Stands varying in size from around 5 ha to some 40 ha will thus be required to conserve specific populations.

For *A. senegal* in Sudan, the normal density of mature trees in plantations is estimated to be approximately 200 trees/ha. However, the individuals may be much more scattered in natural populations, where fewer than two mature trees/ha were found in a study in the southern part of the Blue Nile Province (CIDA quoted in TSP/DFSC 1996). Here, more than 70 ha would be required just to include 150 mature individuals (Graudal *et al.* 1997).

For many tree species in Denmark, conservation stands as small as 3–5 ha have been considered sufficient (Graudal *et al.* 1995) (see Vol. 1, Chap. 3). In Finland, Koski (1996) has recommended conservation areas of 10–100 ha for *Picea abies* (see Box 2.1).

For example many large-seeded tree species are dependent on vertebrate seed dispersal, and it is likely that the area needed to maintain such species will be large, unless linked through vegetation corridors (see Box 2.2).



Natural stand of *Acacia senegal* at Tamasgo near Kaya in Burkina Faso. (L. Graudal/DFSC)



Tapping of 'gum arabic' in the Sudan. Gum arabic has been used and traded for centuries in the Sahel. (H. Keiding/DFSC)

Managing the genetic resources of very widespread species will in practice have to be incorporated into more general land use planning and management, as large reserves are unlikely to be designated solely for the purpose of genetic resources conservation of one or a few tree species. Please refer to Volume 1, Chapter 2 for a detailed discussion.

2.4 How to select individual populations: which specific stands within each genecological zone?

By their very nature, *in situ* conservation programmes are undertaken and implemented by the responsible landowner or management authority. These may be either government departments and agencies (national, state-provincial and/or local-municipal) or private landholders. Private landholders may include private corporations, individuals and communal landowner groups. Forests and trees under private ownership would normally be considered less secure and suitable for conservation purposes, although this is not always the case. For example, in situations where there is traditional or customary communal ownership, coupled with a dependence on the products and services provided by the forest, there are strong incentives for such forests to be sustainably managed. Furthermore, in many developing countries, such as those in the South Pacific, as well as large areas of the Brazilian Amazon, where the vast majority of forested land is under traditional ownership, *in situ* conservation can only be undertaken in close consultation and with the full support of private landowners, local and indigenous communities. In some developed countries, private landholders are taking strong measures to conserve in perpetuity the forests and tree populations on their land, through the use of legal covenants to prevent future land changes.

Particularly in the State of Acre, Brazil, where large areas of the Amazon forest were classified as Extractive Reserves areas and land tenure given to rubber tappers ('seringueiros'), gene conservation efforts are being carried out for a few selected species, such as *Hevea brasiliensis* and *Bertholletia excelsa*.

Ideally, gene conservation areas are best located on land under secure long-term tenure, principally in appropriately designated public lands, and under the control of agencies with the mandate, commitment, trained personnel and resources to properly manage and protect them. The main factors that favour the inclusion of a particular stand or area in an *in situ* gene conservation reserve system include:

- abundance of target species and presence of key associated species
- low level of risk/threats (including secure land tenure)
- committed and adequately resourced management agency
- support from local people, owners and users of the area
- compact shape and presence of forest buffer zone
- possible opportunities to conserve other priority species.



If the species is already represented in protected areas, these should be identified first and assessed for their likely level of protection in both the short and long terms (see Chap. 4). In most situations conservation

Teak leaves from the 'teli' variety *Tectona grandis* (teak). A teak variety only found in SW India, distinguished by its hairy leaves which are valuable for gene conservation selection.
(H. Keiding/DFSC, 1971)

in situ of species populations outside protected areas will be required to achieve adequate representation. It is therefore important to identify and select populations to fill the critical gaps. Moreover, selecting stands outside protected areas can be particularly efficient for conservation of the genetic resources of a particular species in which active management interventions are desirable but less likely to be permitted or undertaken within protected areas.

Of the 15 conservation stands considered for teak (*Tectona grandis*) in Thailand, 6 are located in protected areas (Graudal *et al.* 1999). Similarly for *Pinus merkusii* in Thailand, 5 out of 10–15 proposed conservation stands are located in protected areas (Theilade *et al.* 2000). For Zambesi teak (*Baikiaea plurijuga*) in Zambia, 7 out of 7–10 conservation stands are in protected areas (Theilade *et al.* 2001) (see also Boxes 4.2 and 4.5 in Chap. 4).

2.5 Formulating a management plan for each conservation stand

A designated *in situ* genetic resource conservation stand of a priority species will ideally be part of a network of conservation stands. Each stand will require its own separate management plan, each of which will form part of the overall plan to manage and conserve the species' genetic resources. Furthermore, each stand will normally be part of a larger forest area, which may be a managed natural production forest or a larger protected area such as a national park. The management plan for the gene conservation stand will thus constitute one element of the overall management plan for the forest or the protected area in which the stand is located.

Such stand-level management plans are best developed through consultative processes involving all concerned parties, notably owners, managers and users of the area involved, including neighbours, and preferably a forest geneticist contributing to the overall planning and implementation of the particular species' gene conservation programme.

Each management plan needs to be comprehensive with all activities clearly documented, including timetable and responsibilities. It is preferable that management plans are written in simple, everyday language with a minimum of technical jargon. In some regions such plans, or key parts thereof, may need to be translated into local dialects or languages. These plans should include:

- Basic information on the conservation area, including maps, extent and boundaries, tenure status, owners, its history, forest inventory (species composition, size classes, etc.) and environmental characteristics (climate and soils).
- Key reference documents of the area and target species, including any biological inventories, especially census, ecological or genetic studies of target species being conserved.
- Description of roles, responsibilities and rights of all those involved in management and use of the reserve area and its resources, including permitted and prohibited activities and uses.
- Programme, timetable and budget for monitoring and management of tree populations being conserved.
- Assessment of potential risks and hazards to the species, and a contingency plan to deal with these, including possible complementary *ex situ* conservation measures.

General management issues and options for natural production forest and protected areas are discussed further in the following two chapters.



MANAGEMENT OF NATURAL FORESTS FOR CONSERVATION OF FOREST GENETIC RESOURCES

by Lex Thomson

In this chapter, sustainable forest management practices are discussed in relation to the conservation of forest genetic resources and how multiple objectives could be achieved through better management programmes.

3.1 What is sustainable forest management and how is it related to conservation of forest genetic resources?

Sustainable forest management is the multipurpose management of a forest to ensure that its capacity to provide goods and services is not diminished over time (FAO 1993). It entails the application of forest management practices that allow the timber and other resources in forests to be sustainably utilized for the development of nations, and for the benefit of human communities living in or close to the forests. The methods adopted must be appropriate to the physical, socioeconomic and institutional contexts in which they will be implemented, and may differ considerably both within and between countries (FAO 1998).

The sustainable management of forests and conservation of forest genetic resources are interdependent. Many target species are not adequately represented in protected areas (see Chap. 4), nor included in plantation and domestication programmes (Vol. 3, Chap. 4). Accordingly, harmonizing conservation and management objectives and practices in production-oriented or multiple-use native forests is essential for conservation of forest genetic resources of these species.

Although many tree species have extensive natural distributions with relatively high levels of geneflow between populations, large areas may still be required to maintain viable populations for many tropical species. These factors further underscore the central role of managed, economically productive forest ecosystems in the conservation of forest genetic resources. Large-scale and lasting conservation of forest genetic resources likely will only be achieved if gene conservation concerns are included in the management practices for production forests, including reservation of areas as gene conservation stands.

Detailed planning and good management, including special attention to basic silvicultural principles, can ensure compatibility among the sustainable productive, protective and social functions of forests (see e.g. FAO 1989; Kemp 1992). Management interventions may then be developed that will better ensure genetic conservation considerations are properly integrated into forest management practices.

A key objective of sustainable forest management will be the maintenance of viable breeding populations of the main commercial timber species, as well as species which provide non-wood forest products (NWFP) for local communities. Sustainable forest management must also take into consideration associated animal pollinators and seed dispersers of commercial and non-commercial tree species (especially keystone species)⁵.

⁵ A keystone species is considered to be one whose impact on its ecosystem is large, and disproportionately large relative to its abundance. Examples include plant species that provide the food resources necessary to sustain different animal populations during periods of scarcity, e.g. figs (*Ficus* spp.), Annonaceous climbers and several species of Myristicaceae and Meliaceae in SE Asia (Peters 1996) and trees which provide unique structural and habitat elements, e.g. desert ironwood (*Olneya tesota*) in the Sonoran desert, Mexico/USA (Nabhan and Suzan 1994) and kauri (*Agathis* spp.) in the SW Pacific region.

The recommended actions for conserving forest genetic resources in managed production forests provided here complement earlier guidelines formulated for conserving biological diversity in forests managed for timber (see Blockhus *et al.* 1992).

3.2 Silvicultural practices and conservation of tree genetic resources in different forest types

Temperate and boreal production forests: during final harvesting most of the mature trees are cut. This is possible because of the generally high proportion of commercial tree species in these forest types, especially those under long-term management. Conifer forests are generally clear-felled, while in mixed or broadleaf forests there is an increasing tendency to carry out selective or successive felling. Tree species that have evolved to regenerate en masse following forest destruction, e.g. ash-type eucalypts following wildfire, have biological characteristics compatible with clear-felling. Most gene conservation criteria are easily met if local regeneration is allowed to dominate, with adequate consideration for population sizes and geneflow to adjacent improved plantations.

Tropical forests: practical management interventions in tropical forests are fairly limited at present as there are various biological, technical, social, economic, institutional and legal obstacles in the way for application of sustainable yield management practices. These obstacles include:

- Biological
 - rapid and luxuriant growth of vines, creepers, woody weeds and Imperata grass in the open spaces created by felling, and difficulties in inducing natural regeneration
 - limited knowledge on silvicultural requirements of many, different species
 - dependency on animals for pollination and dispersal.
- Social
 - poorly educated landholders, lacking information on the various logging options and their longer-term economic and environmental impacts.
- Technical/economic
 - large number of tree species, many of which are non-commercial
 - generally fragile soils, and their vulnerability if fully exposed
 - difficulties of access and constraints of timing of harvest (due to wet weather).
- Institutional
 - inadequately resourced and trained Forestry Departments.
- Legal
 - prevalence of short-term concessions that fail to provide an incentive for logging concessionaires to follow best practice
 - sometimes overlapping or ill-defined concessions have been granted, also encouraging more rapid, exploitative forms of logging
 - lack of or poorly defined land tenure.

Conservation of forest genetic resources in managed production forests in tropical countries can be best achieved through a combination of:

- capacity-building, of both Forestry Departments and communities (see Vol. 1, Chap. 5)
- an enabling policy/legal framework including Logging Codes of Practice, variable silvicultural prescriptions, and Reduced Impact Logging (RIL) guidelines (see Table 3.1) which are backed by legislation and enforcement
- appropriate specific conservation measures (see Box 3.1)
- more appropriate investments and directions of the research agendas of international, regional and national institutions.

Table 3.1 Purpose, elements and benefits of Code of Logging Practice, silvicultural prescriptions and Reduced Impact Logging Guidelines

	Code of Logging Practice	Silvicultural prescriptions	Reduced Impact Logging Guidelines
Purpose	• Establish minimum operating standards • Act as a reference source • Legal document	• State the suggested harvesting intensities (by varying diameter cutting limits) so as to better reflect the existing stand characteristics and ensure that a viable forest is maintained after logging	• Provide a practical mechanism for implementing the Code of Logging Practice • Reduce the adverse impacts and damage levels of logging
Key elements	• Responsibilities of the various stakeholders • Planning requirements (at strategic and operational levels) • Roading requirements • Harvesting requirements • Post-logging restoration methods • Log scaling and presentation requirements	• Define broad 'Silvicultural Forest Harvesting Types' based on forest types which have similar ecological characteristics in order to make more practical operational prescriptions • Variable 'silvicultural diameter' limits to enable all species to be harvested at their optimum size. Diameter limits can be manipulated to ensure sufficient residual stock of each species remaining after harvest	• Construction methods and requirements for roads, skid trails and landings • Tree selection and marking requirements • Directional felling methods • Post-logging damage • Post-logging restoration
Benefits	• Defines minimum set of common harvesting standards • Reference source for what is to be done in relation to forest harvesting	• More flexible prescriptions, with variable cutting limits, which allow the forest to regenerate well	• Provides a practical method to implement a coupe/timber harvesting plan • Flexible guidelines that can evolve and be modified as industry progresses toward their effective adoption

(Adapted from Applegate and Andrewartha 1999)

In different tropical forest types the management objective of forest genetic resources conservation essentially remains the same: ensuring an adequate level of regeneration and recruitment of local seed sources in appropriate genetic or ecological variants.

3.3 How might genetic resource considerations be better taken into account in forest management?

This section focuses on those forest management practices that are most important in the context of conservation of forest genetic resources. FAO (1998) provides more general and detailed guidance on how to plan and undertake the sustainable management of moist tropical forests, especially with reference to timber production.

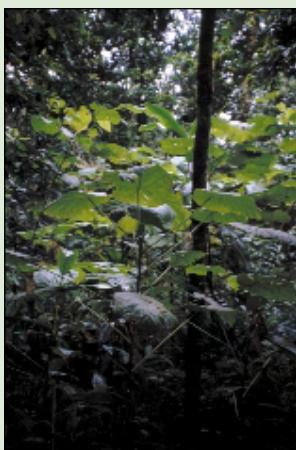
3.3.1 Information needs and planning

A detailed management plan requires a considerable amount of information such as an inventory of the standing stock and its condition, age or size composition, as well as an assessment of soils, slopes and other factors that affect the way silvicultural and logging operations are to be carried out.

Box 3.1 *In situ* conservation of *Endospermum medullosum* (whitewood) in Vanuatu through sustainable forest management



Whitewood (Endospermum medullosum) in Lorum Conservation Area, Santo, Vanuatu. Seed collected and planted in ex situ conservation area, subsequently this tree was illegally logged. (Lex Thomson/CSIRO)



Natural regeneration of whitewood (Endospermum medullosum) following reduced impact logging at Forari, Efate, Vanuatu.

Endospermum medullosum (whitewood) is a fast-growing tree in the family Euphorbiaceae, with a natural range from Irian Jaya (Indonesia) in the west, through Papua New Guinea and the Solomon Islands to Vanuatu in the SW Pacific (Thomson and Uwamariya 1998). In Vanuatu, whitewood is the most important native timber tree, accounting for between 40 and 60% of timber harvest. The species is shade-intolerant and can only grow when sizeable gaps are created and maintained (Whitmore 1966; Siwatibau *et al.* 1998). Whitewood is favoured by periodic disturbance, such as provided by tropical cyclones and shifting cultivation, and is able to regenerate well following appropriate logging practices. However, the species is threatened at population level throughout most its natural range in Vanuatu. Major threats to whitewood's genetic resources come from unsustainable, poorly planned and executed logging practices and conversion of forest land to various forms of agriculture.

Capacity-building and research and development

The Vanuatu Sustainable Forest Project (VSFUP) was a 6-year project (1995–2000) which provided training to forestry staff and forestry industry operators in various areas related to the sustainable forest utilization. The project also assisted in development of a National Forest Policy (officially endorsed in 1998), a Code of Logging Practice (effective from 2000), silvicultural prescriptions for different forest types and allied Reduced Impact Logging (RIL) guidelines. In 1997, the Department/VSFUP established the Forari Demonstration Area (Efate) to demonstrate RIL. A key objective is to keep felling gaps below about 400 m with directional felling into such gaps (i.e. placing 2–3 trees into the same gap where possible). This is to ensure that the rampant, native climber *Merremia peltata* does not invade. *Merremia* quickly smothers regeneration and will overtop and shade residual trees. Following the Forari logging operation, prolific regeneration of whitewood has taken place. In small gaps, whitewood seedlings are usually out-competed by advance growth of more shade-tolerant species. Selective weeding to remove or cut back *Macaranga* saplings and other pioneer species, in direct competition with whitewood sapling regeneration, would be highly desirable and ensure much greater recruitment of whitewood into larger size classes.

continued

Conservation and management plan

As a first step in the planned conservation of whitewood's genetic resources, the Forest Conservation Unit of the Vanuatu's Department of Forests has developed a conservation and management strategy for the species (Corrigan *et al.* 1999b). An essential element in the process has been consultation with key stakeholders, including village communities, industry and NGOs. This conservation strategy details all relevant known information on the species, including biology, distribution, utilization, threats and 10 recommended conservation and management measures involving *in situ*, *ex situ*, research and development and extension.

The key recommendations related to *in situ* conservation of whitewood were:

1. All future logging operations follow the Code of Logging Practice (COLP) with the use of Reduced Impact Logging (RIL) guidelines and silvicultural prescriptions for the harvesting of whitewood and its associated species. The COLP specifies retention of buffer zones along watercourses/drainages, restriction of logging to slopes <30° and use of appropriate roading and machinery. Diameter cutting limits are currently being revised.
2. The Department of Forests works with management, custom owners, other Government Departments, NGOs (where appropriate) and project partners of existing Conservation Areas on strengthening whitewood conservation efforts within them through development of appropriate management strategies and plans. The Department of Forests has worked with communities and custom landowners to establish three new whitewood *in situ* conservation areas on northwest Malekula, east Santo and north Efate.

Sustainability of logging

Major concerns exist for the future security of this resource as the majority of eastern Santo has been logged and only a small uncut area remains in the more central, elevated parts of Santo. Given current rates of utilization, it is predicted that the east Santo forests will be effectively exhausted within 10–14 years. Sawmillers argue that most of lowland East Santo will be converted to agriculture and that the future of conserving and developing whitewood in such areas will be through establishment of commercial plantations.

Sustainable timber production of *Endospermum* in native forests is possible provided adequate seed trees are retained (both males and females) during logging operations, e.g. 2–4 trees/ha, and that logging creates gaps of sufficient size favourable for this light-demanding species. However, following logging there are no legal impediments to the landowner clearing the area for agriculture and removing trees that had been kept as buffers.



In situ conservation in protected areas

All land in Vanuatu is under customary ownership, hence any protected areas need to be established in close consultation with the landowners and managed for their benefit. There are currently only two designated protected

Aftermath of conventional logging of whitewood forest on the east coast of Santo, Vanuatu. Any regeneration is smothered by the native vine, big leaf (Merremia peltata). (Lex Thomson/CSIRO)

continued

areas that contain whitewood. These are the Vatthe Conservation Area established in 1995 at Big Bay, Santo (3000 ha). This CA is managed by local communities and the Environment Department with support from SPREP. There has been no forest inventory of this area and there is no estimate of the number of whitewood trees it contains. Whitewood is mainly found near the NE border and is vulnerable to illegal logging. Lorum Protected Area was established at Khole, Santo in 1995. Lorum is managed by a management committee and strict limitations have been placed on access and use of the area. Vanuatu Protected Areas Initiatives (VPAI), a British-registered NGO, has provided both technical and financial assistance to the area. A portion of a small whitewood population in the area was illegally logged in 1999. Fortunately seed had been previously collected from some of the logged trees by the Department/SPRIG in 1998 and planted in field trials/gene conservation plantings at the nearby Shark Bay Field research Station.

(Based on the work of the Vanuatu Department of Forests and Corrigan *et al.* 1999)

Detailed information on forest composition and growth is vital for both sustainable production and genetic conservation. Information is required from broadly based inventories including botanical surveys, pre-harvest inventory, regeneration surveys and information on non-wood forest products. There is extensive literature on methodologies for botanical surveys for various purposes (see Mueller-Dombois and Ellenberg 1974; Campbell 1989; Peters 1994; Kent and Coker 1996), and accordingly the following discussion will focus on pre-harvest, forest and regeneration inventories, management plans and the selection of an appropriate silviculture system.

The pre-harvest inventory should include a survey and assessment of the adequacy of existing levels of seedlings, saplings and advanced growth of the marketable or preferred timber species as the basis for the future crop following logging. This inventory will usually involve a detailed sampling within small plots either evenly or systematically distributed throughout the compartment. The percentage area sampled will vary depending on factors such as the level of resources available, site heterogeneity, category of regeneration (whether saplings or larger advanced growth) but will normally be in the range of 1–5%. For example, the sampling might consist of one sampling plot of 20 x 20 m/ha in which advanced growth (e.g. 30–60 cm dbh) is identified and measured, with an internal core plot of 10 x 10 m in which all saplings/small trees (e.g. 10–30 cm dbh) are identified and counted. Thorough seedling surveys are more time-consuming and difficult to conduct in tropical forests. A simple approach may be a qualitative or subjective assessment (rough classes which may correspond to a certain seedling density) of seedling regeneration of the most commercially important and easily recognizable species within the inner core plot. Alternatively, assessment could be undertaken along evenly spaced parallel transects, e.g. advanced growth assessed 2 m on either side of line transects spaced 100 m apart (i.e. 4% sampling).

In addition to enabling an assessment to be made of the allowable cut and sustainable yield of timber, a forest and regeneration inventory should be planned and designed to provide baseline data for the continuous monitoring of the forest's growth, and the implications for conservation of forest genetic resources. This will include the establishment of permanent sample or continuous forest inventory plots. Therefore it should include an accurate assessment of the growing stock, its distribution by species, size classes and location. This information can be used to explore the implications and impact of different harvesting and silvicultural treatments.

An important step is to draw up a management plan to achieve the desired objectives and goals. Genetic conservation objectives ought to be an important element in management plans for production and multiple-use forests in order to ensure their future productivity (Box 3.2) They become an essential consideration where the particular forest has been designated as part of a network of gene conservation stands for high-priority species targeted for conservation (see Chap. 2). In many situations, local people will have traditional entitlements to access and use of the forest's resources, and it will be essential to actively involve them in all steps of planning, implementing and monitoring management plans (see also Vol. 1, Chap. 5, and Tuxill and Nabhan 1998).

The management plan also ought to lay down the conditions that logging concessionaires are expected to follow. The number, species and size of trees as well as the methods of felling and extraction are specified to limit damage to the remaining forest.

Sustainable wood production with conservation will be dependent on selection of an appropriate silvicultural system. In particular the mode and intensity of tree harvesting, e.g. single trees, patches or group selection, clear felling, will need to match the regeneration requirements of the principal commercial species. Table 3.2 provides some examples of various species of trees in moist tropical forests grouped by these several factors that need to be considered.

Choice of an appropriate silvicultural system and practices that will ensure regeneration and regrowth of the main timber species requires a good understanding of the autoecology of each species. Where such information is lacking or where commercial species in mixed stands differ in their requirements, one approach that will promote diversity is to manage different compartments of the forest differently. Furthermore, the use of diverse management systems can increase the variation between management units.

3.3.2 How can logging and conservation of forest genetic resources be made more compatible?

Management for timber production carries with it a risk of extinction of local endemics and species particularly vulnerable to physical disruption of their habitats (Whitmore and Sawyer 1992). Logging is at present the only major management intervention in many tropical forests. The most common impact of logging is to reduce the range of species of economic value, especially those of very high value. In tropical conditions logging generally favours faster-growing species, with low- to medium-density timbers. Zonation within managed forests, within which different management regimes and measures are adopted, can greatly diminish the impacts of timber management on forest biological diversity.

A single cycle of selective logging need not reduce species richness among the tree populations (e.g. Johns 1992b), provided adequate regrowth is present and not severely damaged during logging, or seed for subsequent regeneration is available in the soil seed bank or adjacent areas. The impact of logging on a forest's genetic resources will depend on several key factors:

- A. Intensity, frequency and timing of logging
- B. Procedures for determining which trees (both by species and individual specimens) will be cut or retained
- C. Level of planning, including use of reduced impact logging guidelines and incorporation of specific conservation measures
- D. Conduct of logging operations
- E. Regeneration system, protection and management of regeneration
- F. Post-logging management.

Box 3.2 Checklist of forest genetic conservation considerations and steps for forest management planning

1. Identify genetic resources present in the forest, including:
 - major and minor commercial timber species
 - species important for production of NWFP
 - endangered or threatened species
 - keystone plant and animal species, i.e. species critical for ecosystem function.
2. For priority species undertake an inventory or survey to establish:
 - location of stands (and habitats)
 - frequency or numbers
 - age class distribution.
3. For priority species gather important ecological and silvicultural information, including:
 - seeding (periodicity/season, quantity, dispersal, longevity) regeneration ecology, e.g. mortality rates of new seedlings, successional stage/shade tolerant or intolerant, number of years before it is 'free to grow'
 - response to environmental disturbances (fire, cyclones, flooding, pests, diseases, etc.)
 - response to silvicultural and management treatments, such as thinning, release from competing vegetation, control burning
 - reproductive biology (pollination/pollinators, mating system)
 - important ecological associations, especially associated fauna.
4. Assess potential impact of external human and environmental threats on the forest and its genetic resources:
 - fragmentation or loss/modification of surrounding forest ecosystems
 - possible climate change (declining rainfall; increasing temperatures)
 - weed invasion
 - fire.
5. Develop prescriptions in management plans that will:
 - ensure satisfactory regeneration and recruitment
 - ensure that rates of production are commensurate with rates of extraction
 - avoid negative (dysgenic) silvicultural selection, and wherever possible practise positive silvicultural selection (e.g. the average diameter of the trees in the stand should remain the same, or increase)
 - minimize inbreeding by retaining sufficient numbers of healthy, vigorous parent trees for abundant pollen and ovule formation
 - include appropriate protection strategies to counter known threats.

Table 3.2 Successional stage and gap requirements for regeneration of some example tree species in moist, tropical forests

Successional stage/light requirements of dominants	Harvesting pattern/gap size	Examples of forest type	Species	Americas/Neo-tropics	Asia/Pacific
Pioneer/light demanding	Clear felling/ large gaps	Following major disturbance, e.g. volcanic activity, forest fire, large clearings	<i>Musanga cecropioides</i> <i>Macaranga</i> spp. <i>Trema</i> spp.	<i>Cecropia</i> spp. <i>Heliocarpus</i> spp. <i>Jacaranda copaia</i> <i>Ochroma lagopus</i> <i>Vismia</i> spp. <i>Trema</i> spp.	<i>Acacia</i> spp. <i>Eucalyptus deglupta</i> <i>Macaranga</i> spp. <i>Ocoteles sumatrana</i> <i>Paraserianthes falcata</i> <i>Parasponia</i> and <i>Trema</i> spp.
Early secondary/moderate light	Extensive gaps e.g. 0.5–3 ha	Early secondary forest, e.g. following shifting cultivation or cyclone damage	<i>Aucoumea</i> sp. <i>Alstonia boonei</i> <i>Canarium schweinfurthii</i> <i>Maesopsis eminii</i> <i>Olea welwitschii</i> <i>Terminalia superba</i> <i>Triplachiton scleroxylon</i>	<i>Bertholletia excelsa</i> <i>Cedrelinga catenaeformis</i> <i>Cedrella odorata</i> <i>Goupia glabra</i> <i>Hymenaea</i> sp. <i>Swietenia macrophylla</i>	<i>Agathis</i> spp. <i>Endospermum</i> spp. <i>Gmelina</i> spp. <i>Parashorea</i> sp. <i>Pterocarpus indicus</i> <i>Shorea johorensis</i> <i>Tectona grandis</i>
Late secondary/intermediate light	Harvest small groups of trees/ intermediate gaps, e.g. 0.05–0.5 ha	Late secondary forest types	<i>Entandrophragma</i> spp. <i>Guarea cedrata</i> <i>Khaya</i> spp. <i>Lovoa trichilioides</i> <i>Lophira alata</i> <i>Pausinystalia johimbe</i> <i>Piptadeniastrum africanum</i>	<i>Cedrella fissilis</i> <i>Dalbergia nigra</i> <i>Licania alba</i> <i>Ocotea</i> sp.	<i>Calophyllum peekelii</i> <i>Dipterocarpus</i> spp. <i>Hopea nervosa</i> <i>Intsia bijuga</i> <i>Pometia pinnata</i> <i>Toona ciliata</i>
Climax or primary/shade bearing when young	Harvest 1 or 2 trees e.g. 0.05 ha	Late successional climax forest types	<i>Cycnometra alexandri</i> <i>Parinari excelsa</i>	<i>Carapa guianensis</i> <i>Eschweilera</i> spp. <i>Manilkara huberi</i> <i>Protium tenuifolium</i>	<i>Decussocarpus</i> spp. <i>Dillenia salomonensis</i> <i>Palaquium</i> spp. <i>Parinari papuanum</i> <i>Podocarpus</i> spp.

(Source: L. Thomson and F. Castaneda, unpublished)

A. Intensity, frequency and timing of logging

The two broad categories of harvesting systems are monocyclic and polycyclic. In monocyclic harvesting systems the crop trees are harvested all at once, at the end of the rotation. One or more thinnings may be undertaken to remove trees that are not intended for the final crop. Long-term productivity and conservation of the genetic resources in such forests will be dependent on how they are regenerated. The essential components are that:

1. Local seed sources are used as sources of next crop (see also Box 3.3).
2. Level of genetic variation is maintained, through ensuring that an adequate number of trees contribute to regeneration (either by ensuring retention of a sufficient number of seed trees, or by direct seeding with a bulked seed collected from a very large number of individuals).
3. Regeneration processes attempt to avoid the development of 'neighbourhoods' of related trees (which might otherwise result in inbreeding and associated growth depression in subsequent generations in species with mixed mating systems).

In most cases harvesting operations in production forests should aim to mimic gap formation associated with regeneration of target species (see Table 3.1 and Box 3.3 *Swietenia macrophylla* case study).

Box 3.3 *In situ* conservation of *Swietenia macrophylla* (big-leaf mahogany)

Swietenia macrophylla King or big-leaf mahogany, hereafter referred to as mahogany, is one of the world's best-known furniture timbers. The species regenerates naturally in extensive even-aged stands following major environmental disturbances, including hurricanes, fire and flooding, and human disturbances such as shifting agriculture (Snook 1993, 1996). In many parts of its range, selective logging has removed most seed trees, while failing to create the conditions necessary for mahogany regeneration (large canopy openings, removal of competing vegetation and soil disturbance) (Snook 1996; Dickinson and Whigham 1999). This has resulted in the extinction of some local populations, reduction to a small number of relict trees in others, and in some cases a marked reduction in mahogany densities across whole regions. In this case study, modifications to existing harvesting and silvicultural practices are proposed to make these interventions compatible with the conservation *in situ* of the genetic resources of *S. macrophylla*.



Mahogany (Swietenia macrophylla) leaves turn red before dropping, Mexico.
(Laura Snook)

Swietenia macrophylla occurs over a large geographic area, from Mexico through Central America, and in an arc to the southern Amazon region in Bolivia and Brazil. It is typically found as an emergent in seasonally dry tropical forests, where it occurs at low densities, averaging 1–2 commercial-sized trees/ha, in a mixture with ≥ 60 other tree species which are of lower or no commercial value. Mahogany trees are long-lived and resist fire, hurricanes and flooding more successfully than associated species (Snook 1993, 1996).

History of utilization and conservation status

Mahogany from Mexico has been utilized for timber and internationally traded for more than 400 years. The earliest logging was highly selective, leaving behind many large trees that did not meet export standards. In more recent times, changes in technology and high domestic demand have led to the utilization of smaller trees (down to 55–60 cm dbh) and re-logging to remove large trees which had previously been left behind (Snook 1998).

S. macrophylla currently dominates international trade in true mahogany timber, but is considered vulnerable in many parts of its range because of overexploitation (Palmberg 1987). Brazil recently placed a 2-year ban on logging of mahogany, excluding sustainable management areas and planted forests. *S. macrophylla* is presently listed on Appendix III of CITES (the Convention on International Trade in Endangered Species of Flora and Fauna) for populations in Mexico, Costa Rica (since 1995), Bolivia and Brazil (since 1998). Such action puts in place certain requirements supportive of record-keeping of trade in the species, including a certificate of origin, and ensures that the timber has been legally obtained.

continued

Ecology

Reproductive biology, breeding system, seed production and dispersal

Swietenia are known to be monoecious, with separate male and female flowers, but little is known about their incompatibility systems other than that they are generally outbreeding, with the possibility of self-pollination (Styles and Khosla 1976). Pollination is effected by insects including bees and moths (Styles and Khosla 1976). M. Loveless (pers. comm.) has found 100% outcrossing in *S. macrophylla* in the Chimanes forest in Bolivia prior to logging, but this decreased to 85% outcrossing following intensive logging. Fruits take about one year to reach maturity. Mahogany produces winged seeds that are shed during the dry season when the tree is leafless. Dispersal is mainly by wind, and during windy conditions the seeds may be dispersed over distances of several hundred metres.

Regeneration

In nature, mahogany regenerates over patches of landscape from <1 to several thousand hectares in size, usually after various disturbances (Gullison and Hubbell 1992; Snook 1993, 1996). While in the pole stage, these stands may include several thousand mahoganies/ha; at 50 cm diameter, they have self-thinned to a density of about 50 mahoganies/ha, representing approximately 10% of all canopy tree stems (Snook 1993).

Mahogany seeds germinate early in the rainy season, in either full sun or shade. Those failing to germinate lose viability within a few months. *S. macrophylla* is a light-

demanding species; under a full canopy the seedlings die out. Therefore, the mahogany has neither a soil seed bank nor a seedling bank to provide a source of regeneration in the absence of seed trees (Snook 1993, 1996).



Leafless mahogany (Swietenia macrophylla) with fruits before seeds disperse, Mexico.
(Laura Snook)

Mahogany trees fruit from a young age and pre-commercial trees in the smaller diameter classes are able to act as seed sources. However, it seems that significant quantities of seed are not produced until trees reach sizes of >85 cm dbh (Gullison *et al.* 1996). Since mahogany regenerates in essentially even-aged cohorts, all trees in a particular forest or area are likely to reach commercial size at roughly the same time.

As a consequence, they are typically all harvested during a single cut, depleting seed sources over a relatively large area. Other factors that limit seed for regeneration are harvesting of trees before they have shed their seeds (Snook 1996) and irregular fruit production.

Whereas mahogany typically regenerates in large clearings produced by the destruction of most trees of other species, selective logging or single-tree felling of mahogany produces small canopy gaps which do not allow sufficient light penetration for mahogany seedlings to effectively compete with other pre-existing vegetation. Selective logging also reduces the availability of mahogany seed through removal of all or nearly all reproductively mature trees (Gullison and Hubbell 1992; Snook 1993, 1996; Verissimo *et al.* 1995; Dickinson and Whigham 1999).

continued

Genetic variation

Despite its commercial importance, remarkably little is known of the extent and patterns of genetic variation in *S. macrophylla* (Patiño 1997). Small-scale provenance trials have been undertaken in Puerto Rico, Cuba, Fiji and Vanuatu and these have shown variation in economically important characters. Diploid ($2n=54$) and tetraploid ($2n=108$) races are known (Styles and Khosla 1976), and this has important implications for conservation and improvement of the species. Given its wide geographic and ecological range and its disjunct distribution pattern it is likely that there is appreciable genetic differentiation between populations. Further research is urgently needed to elucidate the patterns of genetic diversity both within and between populations (see Helgason *et al.* 1996; Newton *et al.* 1996; Patiño 1997).

Conservation

Enhancing mahogany regeneration in commercial forests

Mahogany regeneration can be assisted through changes to the calendar of harvesting as follows:

1. Harvesting mahogany a few months later in the year than is presently done, and after its seeds have matured and been dispersed.
2. Harvesting other less commercially valuable tree species first, before mahogany seeds fall, to create large gaps/disturbances which favour mahogany regeneration. (Note: this would require development of markets for these less preferred species) (Snook 1993, 1998).

For example, at the Rio Bravo Conservation and Management area in northern Belize, regeneration of mahogany is being encouraged through patch cuts downwind of fruiting trees. Silvicultural practices to enhance mahogany regeneration include the girdling of non-commercial species to open up the canopy, and understorey clearing.

In Costa Rica, limited enrichment planting – involving transplanting of mahogany wildlings into more suitable regeneration niches – is being practised. Line planting coupled with poisoning of the overstorey and careful tending has been successful outside the native range in Fiji where about 45 000 ha have been established (Oliver 1999) and in Puerto Rico (Bauer 1991), but unsuccessful in the Latin American tropics.



continued

Fruit of big-leaf mahogany (Swietenia macrophylla).
(Kron Aken/CSIRO)

Incentives for in situ conservation

Key elements of sustainable use forestry and *in situ* conservation of the genetic resources of mahogany are involvement of local people in management and protection of the forest area, security of land tenure and appropriate silviculture (Sullivan 1993). Forest-owning communities are involved in the management and utilization of forests containing mahogany through the Plan Piloto Forestal in Quintana Roo, Mexico (Snook 1991, 1998). However, across much of its natural range, mahogany trees are at high risk from illegal and uncontrolled logging, even in designated protected areas, and illegal logging of mahogany has been reported from biosphere and Indian reserves in Mexico, Guatemala, Bolivia and Brazil (Snook 1996).

Management plans have been prepared for the mahogany forests along the Atlantic coast of Honduras (see Mayhew and Newton 1998). Mahogany conservation aspects of these plans include utilization of all merchantable species, not solely mahogany; a minimum cutting diameter limit of 50 cm dbh for mahogany; replanting of mahogany in well-lit clearings in the absence of insufficient natural regeneration (<167 stems/ha), and approximately 30% of the area under protection for environmental reasons.

In 1986 the National Forestry Institute of Peru with support from FAO/UNEP established an *in situ* conservation reserve in the von Humboldt National Forest which identified approximately 100 mature mahogany trees as seed trees. Subsequently, illegal loggers took advantage of a weakened forest administration and neglect of forestry control, associated with terrorist insurgency and other problems, and logged all selected seed trees. This example highlights one of the potential risks to *in situ* conservation measures, and the need to undertake complementary *ex situ* conservation for populations at risk.

Ex situ conservation

Options for *ex situ* conservation of *S. macrophylla* face a number of constraints. Seed is bulky and usually rather short-lived (only several years) under refrigeration and low moisture contents (e.g. 3–4°C and 3–7% MC). For longer-term conservation, lower moisture contents (down to 2%) and very low temperatures (-13°C or less) are desirable (Tompsett and Kemp 1996). These requirements are not easily met in developing countries, and seedlots decline in viability over time. Advanced storage techniques, including embryo cryopreservation and encapsulation-dehydration, have been successfully developed for the species (Mansor 1999) and would be technically possible for long-term storage. Given the requirement for specialist expertise and facilities, and the fact that *in vitro* techniques in general allow conservation of only a few genotypes, such techniques will probably be of limited conservation value (see Vol. 1, Chap. 2, and also Vol. 3 for more discussion). However, given the very high value of *S. macrophylla*, gene banks may play a role for intermediate storage of seed from unique populations until such seed can be used for conservation plantings.

In most countries, including those of its natural range, mahogany is subject to severe attack from shoot borer (*Hypsipyla* sp.) when planted in monospecific stands: this problem has deterred interest in planting the species. Nevertheless, given the severe threats to certain native populations it is highly desirable that *ex situ* gene conservation stands be established in well-protected sites, preferably free from *Hypsipyla*, such as Fiji and Samoa, as a safety measure to minimize the likelihood that mahogany genetic resources might be lost. New source-identified collections with sampling strategies aimed specifically at *ex situ* conservation will be required for the establishment of such stands.

(Based mainly on the work of Laura Snook, formerly Duke University, North Carolina, USA, now CIFOR, and Fernando Patiño 1997; INIFAP, Mexico)

Broad-scale clear felling in mixed species tropical forests generally has major adverse environmental impacts, including erosion and degradation of the typically fragile soils, proliferation of weeds and vines which hamper forest regeneration, and increased susceptibility to fire. In other forest types around the world, this may not be the case and each situation has to be evaluated on its own. Accordingly in tropical forests, polycyclic or selection harvesting systems are generally preferred as crop trees can be cut on a cycle of harvests that occur more frequently than the length of the rotation.

In summary, while it is sometimes impractical, logging operations are best timed to occur shortly after fruit crops have matured and seed has been shed. This is especially true of timber species with recalcitrant seeds, and where pre-harvest surveys have indicated a low frequency of seedling and/or advanced growth.

B. Procedures for determining which trees will be harvested

The prime determinate of the allowable cut for any given harvest is that the wood harvested is balanced by the forest growth. Procedures for assessing forest growth and yields in native forests are given in FAO (1998). The actual cut will be based on sustainable yield, and will comprise a variable proportion of available merchantable volume of timber, e.g. 50–60%. In most logging operations the standard procedures for determining which individual trees are to be cut will be:

1. Designated commercial species.
2. Diameter cut-off limits – these will vary with species (and be determined by factors such as the size at which growth starts to taper and heart rot forms).
3. Location of trees within a stand such that the most economical harvest plan will be followed.
4. Need to create regeneration gaps of appropriate size and distribution.

The impact on the genetic quality of the next and subsequent timber harvests also needs to be taken into account when developing procedures and guidelines for selecting individual trees for harvesting. At one end of the selection spectrum is positive silvicultural selection, which involves the deliberate removal of slower-growing, poorly formed, diseased or insect-damaged trees so that the healthiest, most well-adapted individuals are the parents for the next generation. Positive silvicultural selection has sometimes been practised in temperate forests and will be more effective in even-aged stands consisting of one or a small number of species.

Selective logging practices, such as high-grading or diameter-limit cutting in even-aged stands, which leave behind the poorest trees to produce the next generation, have been termed negative silvicultural selection. Such practices are likely to have negative (dysgenic) effects on future generations through increasing the frequency of less-desirable genes. They are likely to have a relatively greater impact on the genetic quality of subsequent generations than practising positive silvicultural selection, because of asymmetry of response to directed selection (see Falconer 1981).

The following guidelines for individual tree selection during harvesting operations will help to ensure long-term productivity, while at the same time conserving forest genetic resources:

- Wherever possible, practise positive silvicultural selection. In mixed tropical forests, and where economic considerations allow, retain better phenotypes of most sought-after species during first harvest.
- Avoid negative silvicultural selection and all forms of high-grading, including (a) highly selective harvesting or 'creaming' operations which entail only cutting of all suitably sized trees of the most highly sought timber species, and (b) in even-aged

forests avoid basing selection of trees for cutting on a diameter cutoff limit, for those species in which the residual smaller trees would comprise the main parent population for the next crop.

- In cases where phenotypically superior individuals of highly sought species are logged in the first harvest, take special care to ensure that their progeny is adequately represented in the existing regeneration or soil seed bank.
- Quarantine rare and highly threatened species from logging, especially those of high commercial value. Aside from helping to conserve biological diversity and genetic resources, the objective of such a measure is to increase the frequency of such species such that in future they may once again be economically utilized.
- Minimize cutting and indirect logging damage to keystone plant and animal species, to ensure that adequate numbers of mature individuals of each species will be present following logging.

C. Planning of harvesting operations and use of Reduced Impact Logging (RIL) guidelines

Maintenance of forest genetic resources entails minimizing logging damage to residual stems and regeneration through a high level of planning and exercise of care by appropriately trained operators. Poorly planned and supervised logging operations in tropical forests cause damage to between 30 and 60% of residual stems (Andrewartha and Applegate 1998). Logging damage is also closely related to the intensity of the harvesting operation. Research in Fiji has found that logging damage to stems in the 10–25 cm dbh overbark class rises from 8 to 20% damage in light and medium-level logging (19–34% of available volume removed) to 35% damage from conventional, unplanned and intensive logging (77% of available volume removed) (Liebau *et al.* 1994).

RIL guidelines aim to reduce the adverse impacts of logging on residual stems and regeneration, and damage to soil (Andrewartha and Applegate 1998). Key features of RIL include practical guidelines in relation to:

- road, skid track and landing construction methods and restrictions
- tree selection and marking requirements
- directional felling methods
- post-logging damage assessment.

Planning of logging operations requires more attention to detail, in order that forest genetic resources are utilized in a sustainable manner. Silvicultural prescriptions and RIL guidelines will need to specify:

- timing of logging such that regeneration is maximized, e.g. logging after fruiting for mahogany (Box 3.3)
- target size of felling gaps to create niches for regeneration of preferred commercial species (the main focus of management)
- numbers of reproductive trees to be retained for different commercial species
- identification and protection of regeneration and advanced growth
- guidelines on artificial regeneration, when natural regeneration is inadequate.

Specific wildlife conservation measures in logging plans for a particular management unit or coupe should include identification and protection of:

- Specialized animal pollinators and seed dispersers including key habitat elements. Overmature, hollow-bearing trees are usually very important habitats for wildlife and an adequate number need to be retained.
- Wildlife harvesting in logged tropical forests directly threatens sustainability of tropical forestry because of the important ecological roles played by larger animals, birds and

reptiles. Logging companies have a major role to play in reducing wildlife harvest on their concessions through measures including provision of domestic animal protein to workers, trade ban in their concessions, prohibition of hunting by workers including a ban on transport of wild meat in company vehicles (Robinson *et al.* 1999).

- Setting aside unlogged areas for conservation, including reserves and drainage lines to protect special and fragile habitats. Retention of unlogged areas amounting to 5% of an intensively logged forest may be adequate to conserve populations of vertebrate species regarded as intolerant of logging (Johns 1992a), while the Forest Stewardship Council requires 10% of any management unit to be set aside for conservation in order to achieve certification as sustainable. As a general guideline it has been recommended that undisturbed riparian strips be established on each side of rivers and around water bodies: these should be a minimum of 20 m wide along perennial streams of less than 20 m width, and 50 m wide along larger streams, rivers and lakes (Blockhus *et al.* 1992).

D. Conduct of harvesting operations

In order to meet its objectives, detailed logging plans must be prepared by well-trained forestry professionals and technicians and such plans implemented by well-trained and appropriately supervised operators. Careful monitoring of individual operators will be especially important during the transition period from 'conventional' practices to those specified under a code of logging practice and associated RIL guidelines, as it is during such times that they may lapse into previous bad habits, such as lowering the bulldozer blade and causing excessive soil disturbance. A high level of care needs to be exercised during falling and snagging operations to minimize environmental damage, especially to advanced growth and seedling regeneration of preferred commercial species.

E. What is the preferred regeneration method for conserving a forest's genetic resources?

Natural regeneration

As a general rule, natural regeneration is the preferred, and in any case the least expensive regeneration approach that meets genetic conservation objectives. In addition to helping ensure that an adequate number of individuals is available to replace trees which have been harvested, greater seedling regeneration will provide more opportunity for elimination of inbreds and other forms of genetic load (accumulation of deleterious genes) at different stages of the tree life cycle, especially at seedling and sapling stages in which natural selection occurs.

The two most important factors for encouraging natural regeneration of preferred timber species, especially in moist tropical forests, are:

- Create favourable light regimes or gaps. Operationally, the creation of suitable regeneration niches/gaps will be achieved mainly through appropriate logging regimes.
- Plan and conduct logging carefully to avoid damage to the seedling bank on the forest floor: this is especially important for species with recalcitrant seeds such as most dipterocarps, and including the majority of primary or climax species.

Other measures to enhance conservation of forest genetic resources during the regeneration phase include:

- Where silviculturally feasible, regenerate stands during good seed years prior to harvesting. Pre-harvest site preparation for regeneration purposes can be done prior to good seed years, when most parents are contributing to the genepool, and when pollen and ovule production ensures maximum outcrossing and minimum inbreeding.

Box 3.4 How many seed trees should be retained during logging in moist tropical forests?

The purpose of retaining seed trees during logging operations is to promote good regeneration of the main commercial timber species. Failure to retain an adequate number of seed trees might contribute to increased inbreeding, e.g. as found for *Shorea megistophylla* (Murawski *et al.* 1994) and/or lead to the forest becoming dominated by less desirable, non-commercial species. For example in Uganda, *Entandrophragma angolense* (an African mahogany and one of the main commercial species), only fruits heavily on older and larger trees (>80 cm dbh). With a cutting limit of 70 cm dbh there is a risk that insufficient seed will be produced for recruitment, unless adequate numbers of larger, reproductively mature trees are retained during logging (Plumptre 1995). In some cases retention of specific seed trees for a given species will be unnecessary, e.g. if there is a reasonable population of reproductively mature trees which are to be retained in any case or there is sufficient advanced growth in different age/size classes.

It is desirable that selected seed trees be of average or better stem form to minimize the risk of dysgenic selection. Clearly there will be a reluctance to retain such trees as it will reduce the returns during the first cycle of logging. It should be noted, however, that seed trees become available for logging in second and subsequent cuts, and failure to maintain adequate seed trees of good genetic quality will jeopardize prospects for future timber production. Long-term logging rights to a particular concession or forest will be vital if companies are to follow best practice.

Moist tropical forests typically contain a large number of commercial timber and other ecologically important species, which need to be regenerated after logging. In most cases, retention of only 2–6 well-formed, reproductively mature trees of the most commercially desirable specie(s) (or a total of 6–10 seed trees/ha) will probably be sufficient to enhance regeneration of the desired species. Where the objective is to conserve and maintain a number of different high-priority tree species in a particular forest, it is suggested that seed trees of preferred species be differentially retained in different forest compartments. The total number of trees within an larger areas should always be kept at a fairly large level, e.g. >150 (see also Chapter 2), whenever possible.

For species such as *Tectona grandis*, which dominates the natural forests in many parts of its natural distribution area, more seed trees/ha will in general be advisable in order to produce more seed, to have seed distributed more evenly over the area (in the case of *Tectona* the seeds are heavy and without wings) and to reduce the family structure that may otherwise be developed owing to the low number of seed trees/ha. This does, however, depend on the amount of viable seed on the forest ground prior to logging.



Natural teak forest at Ban Cham Pui, Lampang District.
(E. Kjær/DFSC)

continued

The developed regeneration should always be assessed a few years after the logging operation, and the result from this inventory be used to modify guidelines for a number of seed trees.

Factors influencing the number (or density) of seed trees retained during logging in moist, tropical forests

Greater number of seed trees

Preferred commercial species

Seed mainly produced on large trees (i.e. those subject to logging)

Abundant or formerly abundant species

Prospective seed trees of average or better phenotypes

Limited regeneration or soil seed bank dominated by non-commercial species

Outcrossing or mixed mating system

Pollen and/or seed dispersed over short distances

Lesser number of seed trees

Less preferred commercial species

Adequate seed crops produced on smaller trees (below minimum harvest size)

Uncommon, but widespread species

Prospective seed trees of poor phenotype (residuals from highly selective logging)

Adequate existing regeneration or soil seed bank including commercial species

Reproduction by selfing or apomixis

Pollen and/or seed dispersed over long distance

- Retention of an adequate number of seed trees of the preferred commercial species. Seed trees are reproductively mature individuals, preferably of large canopy, and high seed production potential, and of better than average stem form. Seed trees need to be fairly uniformly distributed for best results: the number of trees to be retained will vary markedly with species but is typically 20–25/ha for temperate conifers, such as *Abies*, *Picea* and *Pinus*. Guidelines for numbers of seed trees to be retained in tropical moist forests during logging are given in Box 3.4.
- Protect regeneration from browsing by excluding domestic livestock. Considerable tree regeneration is destroyed by grazing livestock, including cattle in tropical seasonal forests, and goats, camels and sheep in woodlands. The adverse impacts of grazing on trees extend to other ecosystems and threaten important forest genetic resources. For example, in parts of southeastern Australia, regeneration of riverine populations of *Eucalyptus camaldulensis* is prevented by browsing of seedlings by sheep and cattle. In Vanuatu, the Epule population (north Efate) of *Endospermum medullosum* is failing to regenerate in a remnant tropical lowland forest patch owing to browsing of young plants by cattle despite the expressed desire of the landowners to conserve the population. In most cases physical measures alone will not be sufficient and it will be essential to consult and negotiate with local people to ensure that wandering livestock are prevented from causing excessive damage to forest regeneration.

Artificial regeneration

In some cases stands may need to be artificially regenerated or natural regeneration may need to be assisted through enrichment planting using local seeds or wildlings/seedlings. It is of course not possible to give precise guidance on how best to undertake such operations as species and situations will differ substantially. This issue is discussed in more detail in Volume 3 in relation to seed collection for conservation in planted stands (Vol. 3, Chap. 3).

Some broad, general guidelines are as follows:

- Collect seed/seedlings from a reasonable number of trees, preferably more than 50, which are dispersed throughout the area to be regenerated (or in adjoining areas with similar environmental characteristics).
- Collect fairly equal amounts from each tree, or at least avoid that a few trees contribute the majority of the seed. Keep the seed separate by tree during collection and transport, and mix the seed only just prior to sowing in order to ensure a reasonable representation of seed trees (see Vol. 3, Chap. 3 for details). Sometimes seedlings of each adult tree need to be propagated separately and only mixed prior to planting.
- Collect seed during years of intense or mass flowering and fruiting, thus enhancing the likelihood of high levels of outcrossing and greater representation of trees comprising the parental population.
- For tree species that flower and fruit sporadically throughout the year or over an extended period, collect seeds at several different times to ensure greater representation of trees comprising the parental population.
- If there are a large number of candidate trees available for seed collection, then it may be possible to introduce a degree of phenotypic selection, and collect seed from better phenotypes, e.g. better stem form, absence of spiral grain. This will, however, depend upon the objectives of the conservation strategy (see Vol. 1, Chap. 2).

F. Post-logging management

Various post-logging measures are often needed to ensure that the logged-over forest can return to its former condition. Such measures may include:

- revegetation of log dumps
- closure of logging roads to reduce likelihood of human encroachment
- post-harvest stand assessment and regeneration surveys
- supplementary regeneration measures
- liberation thinning (gradual removal of pioneer weedy/early secondary species crowding or shading regeneration of preferred species).

In summary, well-planned and carefully implemented logging can be used to maintain a balance between the various stages of ecological succession, and to allow for maximum genetic diversity and conservation of the genetic resources of tree species of different successional stages.

3.3.3 How can silvicultural operations increase the commercial timber values of a forest and contribute to conservation of its forest genetic resources?

Early identification of final harvest trees and release from competition

Management may aim to increase the yield of valuable species and identified final crop trees through elimination, usually by poisoning or girdling, of unwanted and competing trees. Such operations usually have minimal adverse impact on overall biological diversity: they may in fact increase diversity of canopy species by favouring the development of preferred timber species and/or those targeted for *in situ* conservation, which have been reduced by previous logging operations.

Decisions on which tree species to target for release from competition will depend mainly on two factors: their relative value as timber species as may be indicated by royalty category, and their response to different levels of release from overhead shade and competition (from both logging and silvicultural treatments).

Control and management of fire

Forest managers are becoming increasingly aware of fire (presence/absence, intensity, frequency) as a vital component in the maintenance of ecosystem health and diversity. Tropical, moist forests that have been opened up through poor logging practice are highly susceptible to further damage from fire and cyclones. Such forests need total protection from fire if they are to become productive again. Current examples of extensive fires in the Amazon show the importance of such practices (Moreira and Nepstad 2000). Fire protection must involve a range of active and passive measures, including consultation and education of local people, buffer zones of green firebreaks (especially comprising species valued by the local people), and systems for early detection and suppression. Useful references on forest fire, including its prevention and control, include Luke and McArthur (1978), Chandler *et al.* (1983), Pyne *et al.* (1996) and Tolhurst and Cheney (1999).

In many drier forest types, fire is a frequent natural phenomenon and important for the regeneration of fire-adapted species. Routine suppression of fire in such ecosystems can and often does have adverse consequences, such as an eventual uncontrolled and fierce wildfire that can burn out large contiguous areas owing to fuel build-up⁶ and/or the disappearance of fire-dependent species.

Control or prescribed burning can be used to protect forests, including their genetic resources, from damaging wildfire or excessively hot late-season fires. An example is Zambia's teak (*Baikiaea plurijuga*) forest, which is located within designated Concentrated Fire Protection Areas (Theilade *et al.* 2001). Experiments on controlled burning showed that burning in the early part of the dry season (March and April) reduced the damage caused by late fires. Accordingly the new policy was to burn areas with low-intensity fire at a time when the trees are becoming dormant and when *Baikiaea* regeneration will not be adversely affected. Another example is for *Eucalyptus crenulata*, a highly endangered species, in Buxton Silver Gum Reserve (Jelinek 1991). The original management regime had been to protect the reserve from fire, but this has resulted in no regeneration and mature trees becoming unthrifty and infested with coarse dodder-laurel (a parasitic vine). In this case a once-off medium-intensity prescribed burn⁷ was recommended for part of the reserve to:

- encourage regeneration from seedlings and lignotubers, and regenerate the canopy through epicormic buds
- remove competing weedy groundcover vegetation
- kill all coarse dodder-laurel and its seed.

Ecological burning entails the use of the fire as a tool in ecological management, conservation of biological diversity and forest genetic resources. Guidelines for ecological burning are being developed in Victoria, Australia (see Box 3.5). It is evident that ecological burning will normally need to be integrated into existing control burning programmes (whose principal aim is asset protection). Controlled burning ought to, as far as possible, mimic the natural fire regimes, especially in its timing. For maintenance of diversity the management objective will be to create a mosaic of areas at various stages of regrowth through burning different forest patches in different years.

⁶ This occurred in parts of northern Australia when Aborigines were relocated into missions, and stopped their traditional burning-off or fire-stick farming.

⁷ Medium intensity prescribed burn is defined as having a fire intensity of 500–1000 kW/m, a rate of spread of 2–2.5 m/min, a maximum flame height of 2 m and a maximum scorch height of 10 m.

Box 3.5 Developing guidelines for ecological burning

Forest associations in the state of Victoria, Australia have evolved with fire as a major ecological factor. The relevant government authorities are in the process of developing a more comprehensive approach to fire management, which includes undertaking burning for biodiversity conservation. Guidelines for ecological burning are being developed which will cover:

Principles

- The ecological basis for using fire to manage ecosystems.
- The type and minimum amount of biological information needed on which to base an ecological burning regime, in particular:
 - the concept of vital attributes for different species and derivation of key fire response species
 - appropriate scales for mapping and monitoring vegetation.
- The concept of the 'fire cycle' and idealized age distribution for a community type and their use with fire-age distribution curves for developing appropriate fire regimes.
- The basis for prioritizing ecological burning programmes and for monitoring the achievement of outcomes.

Planning processes

- The key steps needed to develop an ecologically based fire regime for an area, in particular the need for clearly stated and agreed objectives, together with a structured input of information regarding:
 - vital attributes and the derivation of key fire response species
 - fire history data and the development of fire-age distribution curves and fire cycles for particular community types.
- The relationship between fire protection planning and planning for ecological burning, and the need to recognize where joint objectives can be achieved.

Standards

- The minimum levels (amount and type) of biological, fire history, and planning and monitoring information required to develop ecological burning prescriptions for various vegetation types.
- The setting of agreed standards and procedures for gathering and analysing data and for monitoring the outcomes from ecological burning.

Responsibilities

- Clear and agreed statement on responsibilities of different agencies involved in ecological burning.

(Adapted from Friend *et al.* 1999)

3.3.4 How can the impact of management on a forest's genetic resources be monitored and evaluated simply?

Careful supervision and follow-up monitoring of forest operations need to be undertaken to ensure that prescribed management practices are being followed and achieving the desired outcomes in species composition and age/class structure, and levels of genetic variation in tree species which are the focus of management.

With respect to conservation of genetic resources, Namkoong *et al.* (1996, 1997) have proposed "conservation of the processes that maintain genetic variation" as the sole criterion for sustainability in forest management. These authors identified different genetic indicators as being necessary for sustainability and provided two types of verifiers for each indicator. Demographic (including ecological) verifiers require various field studies, including population studies (number of individuals in various age/size or reproductive classes) and studies of reproductive biology and ecology. Genetic verifiers will often require molecular marker studies, but can also involve longer-term field/glasshouse studies of quantitative, adaptive traits.

Demographic verifiers are more likely to be used by forest managers, because they provide essential information in relation to their management options. Also, they do not require access to geneticists, trained technicians and specialist laboratory facilities. On the basis of their resources and requirements, forest managers need to select the most appropriate demographic verifiers.⁸ Of those provided by Namkoong *et al.* (1996, 1997), the most readily assessed verifiers would appear to be:

- number of sexually mature individuals
- age/size class shift over time
- seed germination (viability tests which can give an indication of increased inbreeding).

A key measure of reproductive and ecological success is recruitment or progression into different size classes, especially regeneration. The analysis of size-class distributions is a simple, reliable method to monitor the status of a population of forest trees (Peters 1996). Such analyses require periodic monitoring, and comparison with earlier surveys in the same stand and nearby or other reference populations of the same species. It is strongly recommended that forest managers closely study regeneration processes in species targeted for active management, identifying those environmental conditions and other factors necessary for successful regeneration, and ensuring that these continue to be met. An absence of adequate, vigorous regeneration under suitable environmental conditions is a



Alloxylon branchycarpum, a rainforest Proteaceae tree from Western Province, Papua New Guinea. Useful timber being conserved through sustainable utilization by local villagers.
(Maurice McDonald/CSIRO)

⁸ For more discussion and information on indicators and verifiers of conservation of forest genetic diversity in sustainable forest management, users are referred to Namkoong *et al.* (1996), Lindgren *et al.* (1996), Stork *et al.* (1997) and Boyle (1999).

clear indicator that something is wrong and requires further in-depth study, and possibly a revision of current management practice.

Collected demographic, genetic and ecological data need to be examined and it must be ascertained whether any observed changes are within acceptable limits, part of a natural cycle or whether management practices need to be modified to better ensure conservation of genetic resources of managed species. This review and analysis is best undertaken with specialist forest geneticist input and advice.

The following process may be used to determine the sustainability of management in terms of conservation of genetic resources:

Step 1

The types of interventions within the forest management unit (FMU, or stand) are recorded and mapped.

Step 2

With advice from forest ecologists, identify those species which are likely to be most susceptible to the negative impacts of the interventions taking place in the FMU. These species should be identified on a regional basis to promote ease of comparison among FMUs.

Step 3

The most susceptible species for each intervention are assessed, initially using demographic verifiers, and subsequently by genetic verifiers if greater precision is required.

Step 4

Information from the preceding steps is combined to obtain an overall assessment of sustainability. Even if juvenile trees of target species are present, the manager may need to consider a possible lack of sustainability associated with:

- Directional change: does selection take place, e.g. in favour of trees with poor stem form, early flowering or other characters?
- Population size: is the new generation based on the progeny of only a few trees?
- Migration: are pollen and/or seed (still) dispersed over a large area, or does the management result in severe restriction of geneflow?
- Reproductive system: are the trees (still) flowering and producing viable seed?

Step 5

If for any species the conclusion in Step 4 was unsustainable, a modified practice and increased monitoring should be adopted.

3.4 Management of non-wood forest products (NWFPs)

Non-wood forest products (NWFPs) have been defined as goods of biological origin other than wood, derived from forests, other wooded land and trees outside forests (FAO 1999). They include a vast range of products, e.g. plants for food and medicinal purposes, fungi, fibres, dyes, gums and resins, rubber, bamboos and rattans, animal fodder and other necessities. Harvesting of NWFPs can strengthen sustainable management and conservation of forest genetic resources through the provision of direct benefits to people living in or close to the forest (FAO 1993). However, the issues involved are complex, often including very different socioeconomic and ecological considerations, and the impacts and outcomes will vary accordingly (see Nepstad and Schwartzman 1992; Peters 1996; de Jong 1999; Wilkie 1999).

When well-planned and carefully integrated, the traditional harvesting of NWFP by local people is usually compatible with management of the forest for timber production and conservation of forest genetic resources, and vice versa. For example, in Sinharaja Forest Reserve in Sri Lanka the most popularly collected NWFPs (*Calamus* species/rattans, *Caryota urens*/kithul palm used for jaggery production, wild cardamom and a medicinal herb, *Coscinium fenestratum*) all performed better in selectively logged-over forest than in undisturbed forest, where they were either absent or showed poor growth (Gunatilleke *et al.* 1995). There are exceptions, however, e.g. resin tapping of important commercial timber species including many dipterocarps in SE Asia (Shiva and Jantan 1998) and *Agathis macrophylla* in Fiji, may considerably weaken or kill trees. Thus, resin tapping has been banned in some countries. In Cameroon, several localized, high-value timber species (*Baillonella toxisperma*, *Milicia excelsa* and *Pterocarpus soyauxii*) are also important sources of valuable and irreplaceable NWFP. As these species may be heavily depleted by logging, there is a high conflict between their utilization for timber and their potential to provide NWFP (Laird 1999).

Furthermore, extraction of NWFP and other non-timber wood products can have major ecological impacts, including adverse consequences for forest genetic resources. Such situations usually involve commercial extraction, including export to areas remote from the production area, rather than subsistence/traditional uses. Overexploitation may be associated with identification of new medicines, e.g. taxol and taxine from *Taxus baccata* (Himalayan yew) (Sharma 1999), or new markets for traditional NWFP, e.g. yohimbine from *Pausinystalia johimbe* (yohimbe) (Sunderland *et al.* 1999). Reductions in forest area, and associated reductions in availability and access to traditional NWFP, coupled with increased human pressure are factors often associated with unsustainable extraction rates for NWFP.

Threats to forest genetic resources associated with NWFP utilization can develop very rapidly. In SE Asia, trees in the genus *Aquilaria* (eagle wood or aloes wood) may produce small pockets of highly aromatic heartwood, much prized for incense and traditional medicines, and fetching up to several hundred \$US per kg. Populations of eight *Aquilaria* species have already declined to the point where they are considered threatened and are included in the 2000 IUCN Red List. Of these, six species are considered at risk from overexploitation. With the *Aquilaria* resource now highly depleted in traditional source countries, such as Thailand, Malaysia and Indonesia, buyers have targeted Papua New Guinea as a new supply source. In the late 1990s traders established eaglewood (*A. filaria*) harvesting operations in Sandaun and East Sepik Provinces of Papua New Guinea. The species is presently being utilized in an uncontrolled, often illegal and unsustainable manner. The extremely high prices paid for high-quality agar wood and for the essential oil produced from it encouraged the practice of excessive and indiscriminate cutting of both diseased and healthy trees, thereby posing a very real threat to PNG populations of *A. filaria*.

Genetic impacts of harvesting of NWFP have been discussed by Peters (1996) Namkoong *et al.* (1997) and Boyle (1999). In cases where whole plants are harvested the effects of reduced population size may be genetically significant. For a small number of especially valuable species, entire populations have already been lost or severely depleted through overexploitation of NWFP. Examples include aquaje palm in Peru (Vasquez and Gentry 1989), sandalwood species in the SW Pacific (Corrigan *et al.* 1999a; Tuisese *et al.* 2000) and rattan species in parts of SE Asia (Dransfield 1989).

Harvesting of reproductive structures – flowers, fruits and seeds – will directly reduce the effective size of the pool of reproductive parents and reduce genetic diversity in subsequent generations. In situations where fruit and seed of trees are harvested very intensively then the genetic impacts may be severe (e.g. *Phyllanthus emblica* fruit harvesting in southern India; Murali *et al.* 1996). Selective commercial harvesting of fruits, nuts and oilseeds can also adversely affect the genetic composition of the tree species and populations being

Box 3.6 Sustainable production and *in situ* conservation of *Euterpe edulis* (heart-of-palm tree or palmito)

Palmito is the edible shoot or heart from several palms in the genus *Euterpe* (Arecaceae). *E. edulis* Martius occurs naturally in the understorey of the tropical rainforests of southern Brazil and was the original basis for the Brazilian 'Palmito' industry. It has been substantially depleted by uncontrolled cutting, and the industry is now dependent on the Amazonian species, *E. oleracea*. *E. edulis* would appear to have high potential for sustainable yield management and production of palmito in its native habitats. Some of its favourable characteristics include:

1. Extensive natural distribution: from 15 to 30°S in southern and southeastern Brazil. It is also found in Argentina and Paraguay.
2. Ability to be grown in dense stands: in its natural stands it may grow at high densities, including a seedling bank of 12 000–15 000 plants/ha, a population of individuals liable to exploitation of 600/ha, and population of 50–60 reproductive adult plants/ha.
3. Significant economical value and easy exploitation: there is a strong market for 'palmito' both in and outside of Brazil. The 'palmito' of *E. edulis* obtains much higher prices than any other in the Brazilian internal market and is therefore not available for export. Palmito can be extracted and processed by small rural communities with low-input technology.
4. Abundant seed production: unexploited natural stands produce about 35 kg fruits or 350 000 seeds/ha each year, which is ample for natural regeneration of the species.
5. Harvesting and regeneration are environmentally benign: *E. edulis* requires shade during the juvenile phase. Accordingly its regeneration does not require an open forest canopy. Harvesting of the straight stems causes minimal damage to other plants.
6. Compatibility of income generation and conservation: if managed in a sustainable way, and especially if actively reintroduced in secondary forests where highest productivity rates are found, its culture presents a viable economic alternative for landowners. At low discount rates managed extraction has been found to be more attractive than the present unmanaged extraction (Orlande *et al.* 1996). The species has biological attributes that enable it to contribute to a more rapid recovery of these forests.
7. Wildlife value: its fruits are eaten by mammals, reptiles and birds which in turn aid in its dispersal.

Genetic variation and reproductive biology

Isozyme studies on intraspecific genetic diversity indicate high levels of diversity including a high number of alleles per locus (average 3.9) and high heterozygosity levels (both from seedling progenies: $H_e=0.436$ and $H_o=0.403$, and from mature plants: $H_e=0.452$ and $H_o=0.467$). These studies detected limited genetic divergence between populations in allozymes. However, no studies are available on variation in quantitative traits, and given the large distribution area it is likely that substantial genetic differentiation exist in adaptive traits (see discussion in Vol. 1, Chap. 2).

A pronounced dichogamy in the inflorescence and insect pollination contribute to high outcrossing rates. Geneflow estimates were high and implied an effective

continued

population/panmictic unit of 67 individuals. Maintenance of an average of 60 reproductive individuals/ha in managed populations will help maintain high levels of heterozygosity and ensure *in situ* conservation of the species and its genetic diversity.

***In situ* conservation**

The lack of knowledge on the genetic differentiation in important adaptive traits suggests that representative populations from throughout the range, including outlier populations, should be conserved. A genecological approach will be valuable in identifying the conservation need in terms of populations within the natural range of distribution (see Chap. 2 above, and more detailed discussion in Vol. 1, Chap. 3). Fairly large reserves are desirable in order to ensure the maintenance of its associated fauna (especially pollinators and seed dispersers).

While the current situation remains one of illegal and exploitative extraction in many parts of its natural range, there is now a sound knowledge base for palmito production to be sustainably undertaken by small rural communities in its native range, and thereby assuring the *in situ* conservation of the species and its associated ecosystems.

(Based on information provided by Ademir Reis and Maurício Sedrez dos Reis, Núcleo de Pesquisas em Florestas Tropicais, Federal University of Sta Catarina, Florianopolis, Brazil)

utilized (Peters 1990, 1996). In such cases harvesting from mainly better fruit genotypes may result in a population dominated by trees of marginal economic value with much less value as a genetic resource. Of course, in cases where a high proportion of flowers and/or fruits of a particular species are harvested on a regular basis, the most important long-term ecological and genetic impact will be a reduction in seedling regeneration and recruitment, possibly leading to eventual extinction of the population.

One approach to management and utilization of non-timber forest products in the Brazilian Amazonia has been the establishment of specific 'extractive reserves'. Such reserves are managed by the local communities that are dependent on the forest for a significant component of their livelihood. It was anticipated that their establishment would result in sustainable management of the natural resources in the reserve, e.g. rubber (*Hevea brasiliensis*) or Brazil nuts (*Bertholletia excelsa*), with concomitant conservation of forest genetic resources and biological diversity. However, such export commodities are very susceptible to external market forces. When the price of natural rubber was more than halved in the 1990s, production from Amazon forests collapsed (Assies 1997). In more recent times competition from cheaper Bolivian rainforest sources has contributed to a sharp decline in export of shelled Brazil nuts from Brazil (Assies 1999). Peters (1992) has suggested that where market-orientated extraction of NWFP is the objective, then it would be best to concentrate such activities on tropical forests dominated by only one or two useful species (oligarchic forests), rather than species-rich ecosystems, and gives a number of examples, mainly palm species, from Amazonia (see Box 3.6, *Euterpe edulis* case study).

A number of lessons can be drawn from the above and many other examples in relation to the extraction of non-timber forest products from multiple-use forests:

1. Local participation: utilization of NWFP from forest areas needs to be negotiated with local peoples through a participatory, consultative process (see also Vol. 1, Chap. 5). This will include determining which products are allowed to be extracted (including by whom, when, how and in what quantity) and those which are to be protected. Sustainable management practices need to be actively promoted amongst user groups and agreed conservation measures strictly enforced.

2. Focus on NWFP which can be produced on a sustainable basis from native forests, i.e. products that do not require destruction of the whole plant, vital organs (such as bark and apical buds of monopodial palms), or overharvesting of reproductive structures. Monitoring needs to be undertaken to ensure that harvest levels are sustainable, using the method of successive approximation as elaborated in Peters (1996).
3. Focus on diverse NWFP for local use: for a given forest area the most sustainable NWFP utilization is likely to involve traditional harvesting, perhaps with some intensification for local sale, of a wide range of products from many species.
4. For market-orientated NWFP utilization, focus on species that can be most efficiently produced and managed in native forests: the biological characteristics which contribute to making tree species more easily and sustainably managed in native forests are detailed in Peters (1996). It needs to be borne in mind that these same characteristics will make them more amenable and attractive to domestication and commercial plantation development. NWFP utilization from native forests which is based on easily managed species may eventually be supplemented or surpassed by those from planted sources, unless the former have a comparative advantage, e.g. Nipa palm being adapted to very specific sites and occurring naturally in dense, near-monospecific stands.
5. Implement monitoring and management measures to ensure sustainability, i.e. to increase, or at least maintain, the density of selected NWFP. This applies to both timber species and NWFP, and such activities ought to involve and be focused in forest areas near to user groups.

Peters (1994) has listed six steps to sustainability in NWFP utilization involving species selection, forest inventory, yield studies, regeneration surveys, harvest assessments and harvest adjustments and gives details on each step (Fig. 3.1). The three main active interventions are enrichment planting, selective weeding and liberation thinning. Such activities may be traditionally practised to varying extents by local people involved in management of NWFP, but often in an opportunistic and seemingly casual manner.

For a more comprehensive treatment of the general principles and approaches for the sustainable management and utilization of non-wood forest products, the reader is referred to FAO (1995) and Peters (1994, 1996).

3.5 Forest restoration and rehabilitation

Increasingly efforts are being made to rehabilitate degraded lands in various parts of the world. Often the preliminary objective is to re-establish tree cover for environmental purposes, especially for control of soil erosion and for watershed protection. In many situations, once the trees have been established and productive capacity of the land restored, there is the possibility to sustainably harvest a range of wood and non-wood forest products from such areas. There is an especially strong case for using local or indigenous tree species in such circumstances. First, they are adapted to the prevailing environmental conditions and second, they are well known to the local human populations who can then more readily make use of them. An additional benefit is that they can make a contribution to conservation of biological diversity, and if local genetic material is used they can contribute to *in situ* conservation of important forest genetic resources. Unfortunately in the past a number of 'regreening' projects have paid scant attention to the source of planting materials used and their biological requirements, and have failed because of poor species choice. Use of non-local seed sources of indigenous species can result in the contamination of genepools of nearby populations.

In Boxes 3.7 and 3.8, respectively, some examples of assisted natural regeneration and restoration of degraded forest ecosystems are given, considering the source of genetic material and using native or indigenous species.

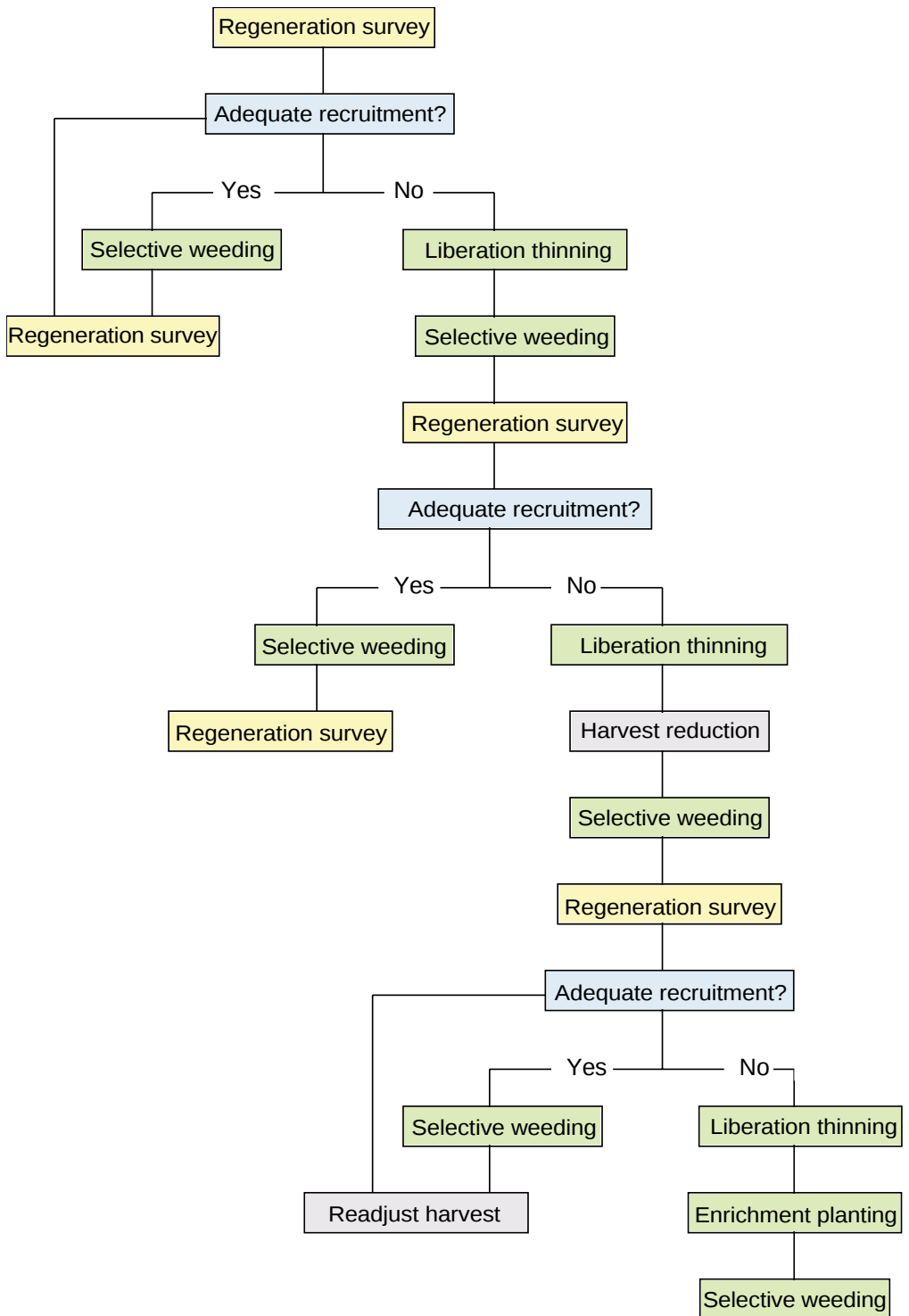


Fig. 3.1. Proposed sequence of silvicultural operations for enhancing the regeneration and productivity of non-timber tropical forest resources (Peters 1996).

Box 3.7 Assisted natural regeneration: cost-effective method of reforestation with conservation of local forest genetic resources

In many cases a policy and practice of protecting and encouraging existing regrowth, or assisted natural regeneration (ANR) may be the most cost-effective approach. Such silvicultural practices have been used in Europe for some time and have been applied more recently to tropical forests.

ANR is a method of reforestation promoted in the Philippines. It exploits the natural processes of vegetation recovery through enhanced protection practices, facilitation of the growth of existing woody species through liberation cutting and inhibition of the grass layer, and may include some enrichment planting (especially of more desired species). ANR has proven to be a cost-effective and ecologically sound reforestation approach, especially for protection forests, and has been recognized and promoted by the Department of Environment and Natural Resources. In one study at Bamban, Tarlac the cost of ANR reforestation was found to be 62% lower than conventional reforestation (Guillermo 1992). A strong participatory approach with involvement of local people in planning and implementation of ANR is essential to the success of such programmes.

Examples of how ANR can contribute to conservation of forest genetic resources include:

1. Samoa: a combination of intensive logging followed by devastating cyclones in the early 1990s has left Samoa's lowland forests in a highly degraded condition where natural recovery will be a slow and uncertain process. Research by the Forestry Division has shown that regular removal of overtopping vines and climbers can liberate secondary tree growth, and direct forest succession. This technique has most potential in degraded forests containing high concentrations of the important commercial timber, tava or Pacific lychee (*Pometia pinnata*).
2. Niger, Sahelian zone of West Africa: the Maradi Integrated Development Project (SIM International) has encouraged farmers to protect coppice regeneration of indigenous trees by retaining at least three coppice shoots on each regenerating tree when the fields are being cleared for planting millet. This has led to good recovery of tree cover (several million trees) over large areas of the district, including populations of important forest genetic resources, such as *Faidherbia albida*. Surplus stems are cut for use or sale as small poles and fuelwood. It is noted that re-establishment of tree cover by planted seedlings is technically difficult in the Sahel and often beyond the resources of poor farmers.
3. Chir Pine plantings in Nepal: in the case of highly degraded lands, including bare, stony slopes and some Imperata grasslands it may be necessary to plant pioneer or early succession tree species, such as *Acacia*, *Casuarina*, *Eucalyptus* and



*Farmer assisted natural regeneration in the Maradi Integrated Development Project, Niger.
(Tony Rinaudo/SIM)*

continued

Pinus to reclaim such sites. In Nepal, the indigenous Chir Pine (*Pinus roxburghii*) has been used for this purpose in the Nepal–Australia Forestry Project. After some years, various indigenous broadleaf species began to volunteer into these plantings, in response to the physical protection and changed microclimate afforded by the pine stands. The broadleaf species are highly regarded by local people for provision of a wide range of products, especially animal fodder, and constitute valuable local forest genetic resources. It has proven very difficult to establish these species directly on degraded, barren sites.

Box 3.8 Restoring northern Thailand's degraded forest ecosystems

The forests of northern Thailand are one of the Kingdom's most important natural resources, protecting extensive mountainous watersheds that feed the Chao Phraya River, and providing water to irrigate the rice fields of the central plains and for the nation's capital, Bangkok. Local villagers rely on these forests for diverse products including firewood, bamboo, edible fruits, mushrooms, medicinal plants and honey to meet basic needs. They are habitat for 150 mammals, 383 birds and at least 3450 vascular plants, including 1116 tree species.

Despite their importance, these forests have been widely degraded or destroyed in recent years. The consequences of deforestation are particularly serious in the mountainous north. As watersheds become eroded, flash floods occur in the rainy season, streams dry up in the dry season and rivers become choked with silt. Rural poverty increases when villagers have to buy products in the market that they formerly collected from forests. Large mammals such as elephants, tigers, bears and wild cattle have disappeared and populations of smaller animals such as gibbons and hornbills have been greatly reduced and fragmented.

Since 1993, Thai people have become involved in tree-planting projects aimed at restoring the nation's forests. However, the success of such projects is limited by a lack of skills and knowledge concerning propagation and establishment of native forest trees.



Rainforest regeneration by FORRU using framework tree species method at Doi Inthanon National Park, North Thailand. (Lex Thomson/FORGENMAP)

continued

The Forest Restoration Research Unit (FORRU) and Framework Species

In 1994 the FORRU was established to investigate technical aspects of tree planting in Northern Thailand. FORRU is a joint initiative between Chiang Mai University (CMU) and Doi Suthep-Pui National Park (part of the Royal Forest Department). The main unit comprises a research tree nursery and office at the National Park's Headquarters. In addition the unit has established a community tree nursery and demonstration plots at Ban Mae Sa Mai, an Hmong hill tribe village in the north of the national park. The aim of the unit is to develop effective methods to complement and accelerate natural forest regeneration on deforested sites within conservation areas, to increase biodiversity and protect watersheds.

FORRU's initial priority was to gather basic ecological data about the vast number of tree species which grow in northern Thailand: this information was to be used to determine which ones might be useful for restoring damaged forest ecosystems. With more than 600 tree species growing on Doi Suthep, it was difficult to make sensible choices as to which tree species to use in forest restoration projects, other than a few known commercially valuable ones. It was decided to employ the framework species method of forest restoration. This method was first developed in Queensland, Australia where it was found that planting of 20–30 carefully selected 'framework' species resulted in a rapidly regenerating forest accumulating up to 80 tree species after 6–10 years (Goosem and Tucker 1995; Lamb *et al.* 1997; Tucker and Murphy 1997). Framework species are fast-growing with dense shading crowns that rapidly shade out competing weeds, and are attractive to seed-dispersing wildlife, especially bats and birds.

Framework species must also be easy to propagate. Accordingly, FORRU collected and germinated the seeds of as many species as possible and developed criteria to assess their potential to restore damaged forest ecosystems.

Research on seed production, collection and germination

To determine when ripe seeds can be collected, FORRU's researchers recorded the abundance of flowers and fruits of 94 native tree species in the forests of Doi Suthep, every 3 weeks, over 4 years. Data on the characteristics of fruits and seeds of different species have been entered into a computer database to help identify species and to provide clues as to their dispersal mechanisms. Some are more likely to attract wildlife into planted sites than others, so it is important that fruit and seed characteristics are considered among the criteria used to select tree species for planting.

Research is being undertaken to identify superior parent trees for seed collection. However, maintaining genetic diversity and integrity of local population structure is an essential element of any tree-planting programme with conservation objectives. Therefore, in collaboration with Horticulture Research International in the UK, genetic variation within selected tree species is being assessed to ensure that genetic diversity is maintained among the seedlings grown for planting.

Seed germination trials have been carried out on nearly 400 tree species to provide basic data on germination rates, dormancy and effective pretreatments. The results enable nursery managers to estimate how many seeds to sow for production of a given number of seedlings. Initially, experiments compared seed germination in partial shade (similar to that in deforested gaps) and deep shade (similar to that beneath a forest canopy). These trials indicated that many so-called primary or climax forest tree species could germinate and grow well in the sunny conditions and had good potential for forest restoration.

continued

Seedling growth in the nursery

Producing a wide range of native forest tree species for forest restoration is beset with nursery scheduling problems. Different species produce seeds at different times of the year and have different seedling growth rates, yet all the trees must reach a suitable size by the planting season in June. Research on seedling growth rates is helping to develop production schedules that will enable nursery managers to better plan their operations.

Tree-planting experiments

FORRU has established experimental field trials in the degraded upper watershed above Ban Mae Sa Mai. These trials have three main objectives:

- to assess the relative performance of different tree species
- to determine the most appropriate treatments to enhance tree performance
- to assess whether tree planting encourages the return of biodiversity to degraded areas.

Plots are planted with 20–30 different tree species and then subjected to different treatments including fertilizer application, weeding and mulching. In addition, trees are planted at different densities and seedlings raised using different nursery methods are compared with wildlings. In addition, the attractiveness of the planted trees to seed-dispersing birds is monitored, as well as the species diversity of the ground flora and the establishment and subsequent performance of volunteer tree seedlings. These experiments have identified several excellent tree species for forest restoration, including *Erythrina subumbrans*, *Ficus altissima*, *Gmelina arborea*, *Hovenia dulcis*, *Melia toosendan*, *Prunus cerasoides*, *Sapindus rarak* and *Spondias axillaris*.

Working with a local community

FORRU aims to provide technical advice to all those wishing to restore Thailand's forests. One such community is Ban Mae Sa Mai whose villagers wanted to restore forest on abandoned agricultural land to protect the watershed and celebrate the King's Golden Jubilee. However, their initial attempts at tree planting were disappointing, so in 1996 Doi Suthep-Pui National Park HQ asked FORRU staff to provide the villagers with technical assistance. The Ban Mae Sa Mai community tree nursery now produces most of the trees needed for the villagers' tree-planting activities as well as some for experimental plots. It is also used to test the feasibility of new techniques developed at FORRU's research nursery within a local community. It has become a focal point for the village conservation group that organizes tree planting, cutting of firebreaks and manning of fire lookouts to protect the planted areas.

Sharing and disseminating results

In addition to hosting many visits from a wide range of different organizations throughout the year, FORRU organizes workshops to share information generated by the project and has produced several papers and publications (Elliot *et al.* 1997, 1998).

(Based on information supplied by Dr Stephen Elliot, Herbarium, Chiang Mai University)



PROTECTED AREAS AND THEIR ROLE IN CONSERVATION OF FOREST GENETIC RESOURCES

by Lex Thomson and Ida Theilade

4.1 Introduction

Protected areas are “areas especially dedicated to the protection and maintenance of biological diversity and associated cultural resources, and managed through legal or other effective means” (IUCN 1994). They cover various situations, ranging from managed resource areas, protected watersheds, national parks and strictly protected reserves, to sacred forest groves.

At a global level about 30 350 protected areas have been established; they cover 8.8% of the Earth’s land area (IUCN 1998). These figures appear impressive, but probably overestimate the extent to which forest ecosystems and forest genetic resources are being conserved in protected areas. A recent survey of 10 developing countries with major forest resources has found that only 1% of forest protected areas are secure, with more than 20% suffering from degradation, and 60% currently secure but with threats likely in the near future (Dudley and Stolton 1999). The threats to protected areas are various and include agriculture and overgrazing, illegal forestry operations, wildlife and plant poaching, encroachment by human settlements, mining, fire, pollution and climate change, and invasive species. Illegal forestry operations are responsible for removing valuable tree species and causing overall impoverishment of the ecology of many protected areas. WWF has reported evidence of illegal logging in over 70 countries, including many operations in protected areas, which are particularly targeted (Carey *et al.* 2000).

Reserves established in the framework of international instruments include the World Heritage Areas, designated under the 1972 Convention for the Protection of the World Cultural and Natural Heritage, and the World Network of Biosphere Reserves, operated within the framework of UNESCO’s Man and the Biosphere (MAB) Programme. Both World Heritage Areas and Biosphere Reserves are proposed for international recognition by the countries in which they are located. Countries themselves are responsible for protecting and managing the Reserves under their own national legal and administrative arrangements.

The contribution of protected areas to maintenance of biological diversity and genetic resources is very much dependent on the following (MacKinnon *et al.* 1986; Boyle and Sawyer 1995):

- An optimal distribution across the landscape, with protected areas linked by vegetation corridors and to other conservation elements in the landscape such as managed forests.
- Size of the areas, which should be as large as possible with good design in relation to shape, infrastructure, zoning, boundary features and edge effects, and buffer zones.
- Integrity including levels of protection and the extent to which they are respected by local people.

Current protected areas do not have an optimal location for conservation of forest genetic resources, because they do not sample all species or the genetic variation within target species. The management regimes of existing protected areas are typically designed for conservation of forest ecosystems, which, as demonstrated by many of the boxed examples in this publication, is often compatible with conservation of genetic resources *in situ* – but not



Acacia midgleyi – promising, fast-growing tree conserved in network of protected areas on Cape York Peninsula, Queensland, Australia. McIlwraith Ranges. (Maurice McDonald/CSIRO)

always so. Additional conservation efforts, such as those discussed in the previous chapters, is therefore required for many target species. Nevertheless, the current protected areas do provide important conservation of many species, and effectively conserved forest ecosystems can maintain a reservoir of continually evolving tree species and populations, including species whose economic and other values have yet to be recognized (McNeely and Vorhies 2000).

In order to enhance biodiversity conservation, Blockhus *et al.* (1992) have recommended that protected area systems be established that cover:

- representative areas of all forest types
- examples of forests having high species diversity and/or high levels of endemism
- forest habitats of rare and endangered species or species associations.

Article 8 of the 1993 Convention on Biological Diversity (CBD), which deals with *in situ* conservation, calls on each Contracting Party to establish a system of protected areas or areas in which special measures are undertaken to conserve biological diversity.

It is also highly desirable that new protected areas be located in areas that will enhance their contribution to conservation of forest genetic resources. Increasingly, simulation models – which take into account both species composition and ecosystem function – are becoming available to aid in optimizing selection of new protected areas to complement existing ones. The aim is to direct the

limited resources for protection and management of particular species (Araújo and Williams 2000; Williams and Araújo 2000a, 2000b). However, a poor or inadequate knowledge of the distribution and abundance of individual species is a serious limitation in use of such models (Gentry 1992). Furthermore, in most developing countries the areas and sites available for protected forest areas are limited and fixed for various reasons, including extent of past forest alienation, land tenure and intense competition for land.

Many protected areas are small, less than 100–1000 ha in extent, and will require active management at ecosystem and species levels if they are to fulfil long-term conservation objectives (Frankel *et al.* 1995). Tree species with a metapopulation structure in which local 'subpopulations' become periodically extinct with recolonization from neighbouring 'subpopulations', are at high risk of being permanently lost from small reserves. Greater attention needs to be given to active management of forest and tree genetic resources in existing protected areas, especially in smaller areas. Little published information is available on management of genetic resources in protected areas, a reflection of the limited amount of activities in this area. This may be attributable to a general lack of awareness among managers about gene-conservation functions of protected forests. Recently, however, this situation is being redressed through a growing literature on the subject (Gadgil 1983; Prescott-Allen and Prescott-Allen 1984; MacKinnon *et al.* 1986; Oldfield 1989; Frankel *et al.* 1995; Maxted *et al.* 1997; Tuxill and Nabhan 1998; McNeely and Vorhies 2000).

While conservation of genetic resources is a primary objective of most types of protected area (MacKinnon *et al.* 1986), the general inadequacy of current protected areas for genetic resources conservation is well recognized (IUCN 1993). The current IUCN categories of

protected areas are given in Box 4.1. A case can be made for designation of *in situ* gene conservation areas as a special category of protected area on the basis that:

- they have conservation of within-species genetic variation as the major objective
- the genepools of concern are primarily of economic species
- provision is made for the use of the genepool by researchers, tree breeders and for *ex situ* conservation purposes (Prescott-Allen and Prescott-Allen 1984).

The objectives of this chapter are to raise awareness of the role of protected areas in conservation of forest genetic resources and to suggest ways in which this may be enhanced. Section 4.2 provides information on the present role and contribution of protected areas to conservation of forest genetic resources and endangered tree species. Next, a process or a sequence of steps is elaborated in Section 4.3 which could enable more effective conservation of forest genetic resources in existing protected areas. In Section 4.4 the critical importance of working effectively with, and involving, local people in protected area conservation measures is discussed (see also Vol. 1, Chap. 5; McNeely *et al.* 1990; Brown and Brown 1992; Tuxill and Nabhan 1998). Finally, in Section 4.5, various specific suggestions are made on how to strengthen the role of protected areas in forest genetic resources conservation.

Box 4.1 IUCN categories of protected areas

Category I. Strict Protection – sometimes called strict nature reserve/wilderness areas. Protected areas managed mainly for science or wilderness protection. Generally smaller areas where the preservation of important natural values with minimum human disturbance is emphasized.

Category II. Ecosystem Conservation and Tourism – frequently referred to as national parks. Generally larger areas with a range of outstanding features and ecosystems that people may visit for education, recreation and inspiration as long as they do not threaten the area's values.

Category III. Conservation of Natural Features – sometimes called natural monuments. Similar to national parks, but usually smaller areas protecting a single spectacular natural feature or historic site.

Category IV. Conservation through Active Management – sometimes called habitat and wildlife (species) management areas. Areas subject to active management in order to ensure the maintenance of specific habitats and/or species.

Category V. Landscape/Seascape Conservation and Recreation – sometimes called protected landscapes/seascapes.

Category VI. Sustainable Use of Natural Ecosystems – protected areas managed mainly for the sustainable use of natural ecosystems. Sometimes called managed resource protected areas, and often an important category within biosphere reserves.

Source: IUCN (1994)

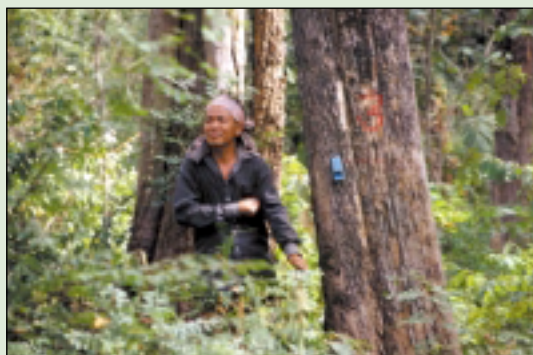
4.2 Current role of protected areas in the conservation of forest genetic resources

In the majority of developing countries it will be possible to conserve the genetic resources of only a relatively small proportion of socioeconomically important tree species within protected areas. An exception is Thailand, a country with an extensive protected area network and one that apparently has the potential to conserve a high proportion of the country's forest genetic resources (Box 4.2). A number of other tropical countries have the basis for substantial and/or useful networks of protected areas for *in situ* conservation of forest and tree genetic resources, including:

- Africa (Botswana, Burkina Faso, Namibia, Seychelles, Tanzania, Uganda, Zambia, Zimbabwe)
- Middle East (Saudi Arabia)
- Asia/Pacific (Australia, Bhutan, Brunei Darussalam, Indonesia)
- Americas (Belize, Brazil, Costa Rica, Colombia, Cuba, Ecuador, Panama, Venezuela).

Box 4.2 *In situ* conservation of forest genetic resources in protected areas in Thailand

Thailand is in the process of developing an extensive protected area network (Bhadharajaya Rajani 1999). The total protected area either declared or in process of being declared in 2000 was 15.7 million ha (30.6% of total area), including 96 national parks, 47 wildlife sanctuaries and 54 non-hunting areas and a substantial watershed conservation zone (5.1 million ha). Trees are very important in the livelihoods of Thai rural communities, with at least 400 species in regular use or providing important environmental services in different regions (Pedersen 2000).



Field assessment of natural mixed deciduous teak forest in Mae Yom National Park, Phrae Province in Northern Thailand. Mae Yom is the largest remaining teak forest. (A. Larsen/DFSC)

In order to evaluate the contribution of protected areas (PAs) to *in situ* conservation of forest genetic resources the Royal Forest Department (RFD)/FORGENMAP undertook a survey to obtain information on conservation of 35 high-priority tree species in the existing network of protected areas. Questionnaires were distributed to each field station of the three main Divisions of RFD's Natural Forest Resources Conservation Office: National Parks, Wildlife Sanctuary and Watershed Management. Replies received from more than 100 stations revealed that most of the 35 species were represented in PAs by viable populations (>100–1000 trees with satisfactory regeneration) throughout their natural ranges in Thailand (FORGENMAP 2000).

continued

The top five priority tree species, all major timber species which have been extensively harvested from native forests in the past, were very well represented in PAs as follows:

- *Azelia xylocarpa* was recorded from 57 PAs in 31 provinces
- *Dipterocarpus alatus* was recorded from 53 PAs in 40 provinces
- *Hopea odorata* was recorded from 60 PAs in 42 provinces
- *Pterocarpus macrocarpus* was recorded from 66 PAs in 33 provinces
- *Tectona grandis* (teak) was recorded from 29 PAs in 12 provinces.

The tree species least well represented in PAs was *Cotylelobium melanoxydon*, a dipterocarp producing valuable timber. This species was reported from only 4 PAs in 4 provinces in southern Thailand, with it being reported under threat from illegal logging in two of these areas. Accordingly it is appropriate that RFD and IPGRI have focused their *in situ* conservation work on this endangered and ecological keystone species (e.g. Chaisurisri *et al.* unpublished). A number of other priority tree species were also less well represented in PAs as follows:

- *Aquilaria crassna* was recorded from 25 PAs in 22 provinces – 5 of these populations were reported to be highly threatened by illegal harvesting to obtain the precious agar wood
- *Azadirachta excelsa*, a relative of neem (*A. indica*), was recorded from 12 PAs in 14 provinces
- *Durio mansonii*, a close relative and rootstock for durian (*D. zibethinus*), was recorded from 13 PAs in 11 provinces, with two populations being highly threatened
- *Intsia palembanica*, a valuable durable timber, was recorded from 13 PAs in 14 provinces, with two populations being highly threatened
- *Mansonia gagei*, a scented timber, was recorded from only 7 PAs in 6 provinces. Outside of PAs this species is highly threatened by limestone quarrying
- *Shorea henryana*, a valuable dipterocarp timber, was recorded in only 9 PAs in 10 provinces. The main threats are illegal logging coupled with inadequate regeneration, with fewer than half of populations reported to be regenerating satisfactorily.

While the RFD/FORGENMAP survey findings must be treated as preliminary, and in need of verification, they are overall reassuring. They indicate that the major challenge facing the RFDs *in situ* forest genetic resources conservation programme is to ensure that trees within protected areas remain protected from illegal activities, in particular timber harvesting and clearing for agriculture.

(Based on the work of RFD/FORGENMAP – Forest Genetic Resources Conservation and Management Project, supported by DANCED, Government of Denmark)

However, lack of political support and funding, low institutional capacity and population pressures often mean that protected areas lack adequate protection (as reported in country case studies in Blockhus *et al.* 1992).

Although protected areas ought to have high potential for protection of rare and endangered tree species, Strahm (1999) has reported that only 12% of the 8750 tree species threatened with extinction are recorded in protected areas. Nevertheless in some regions, protected areas may play a critical role in conservation of forest genetic resources and rare species; one such example is the Sinharaja Forest Reserve, a biosphere reserve in Sri Lanka (Box 4.3).

Box 4.3 Sinharaja Forest Reserve: biosphere reserve vital for conservation of Sri Lankan forest genetic resources

Sinharaja Forest Reserve includes the last viable remnant of tropical lowland rainforest in Sri Lanka. Over time the area has gone from being a wilderness associated with traditional mysticism, protected by its inaccessibility, to supporting a regime of timber exploitation during the 1970s to a fully protected conservation area (Gunatilleke *et al.* 1995). In 1978 the Forest Reserve was gazetted as a biosphere reserve and listed as a world heritage site in 1988 (UNESCO 1988). It now covers an area of 11 187 ha, including submontane and secondary forest, and is administered by the Forest Department. The area serves as an outdoor laboratory for all levels of education and is Sri Lanka's most popular lowland forest for ecotourism (Gunatilleke *et al.* 1995).

At least 184 tree species are present with more than half of these being endemic to Sri Lanka (Gunatilleke and Gunatilleke 1980; de Zoysa and Raheem 1990). The WCMC tree conservation database includes about 30 tree species either now found or previously reported from the Sinharaja Forest Reserve. These include several tree species in economically important genera, and used to varying extents locally including *Adenanthera bicolor*, *Diospyros oppositifolia* and *D. thwaitesii*, *Garcinia hermonii*, *Loxococcus rupicola*, *Myristica dactyloides* and *Palaquium petiolare*. Evidently Sinharaja has enormous significance for the conservation of Sri Lanka's lowland forest genetic resources. However, there is now a concern that several tree species have either disappeared or become extremely rare in Sinharaja, because they were not detected during the extensive forest surveys of 1991 and 1996 for the National Conservation Review. These include a number of economically valuable dipterocarps: *Shorea affinis*, *S. congestiflora*, *S. megistophylla* and *S. trapezifolia*.

The major issue threatening the integrity of Sinharaja Forest Reserve remains that of resource conflict. Even though maximum legal protection has been afforded to the area through its declaration as a national heritage area, in practice protection is difficult owing to the remote, inaccessible boundaries and lack of resources for effective management and policing (McDermott *et al.* 1990). The total population of people living in or adjacent to the reserve is about 5000 and many are keen to continue to utilize wood and diverse NWFPs from the forest, for both income-generation and subsistence purposes. Previously the most important income-generating activity in the forest was production of jaggery from the kithul palm, *Caryota urens*, but this is now restricted to forest surrounding the reserve. Fuelwood gathering for home use is also a major activity. Harvesting of rattan (*Calamus* spp.), for sale and for domestic usage, is reported to constitute the most destructive use of the forest (McDermott *et al.* 1990). Proposed long-term solutions to resource use conflicts in Sinharaja include:

- Allow regulated, traditional, non-destructive forms of forest exploitation including kithul, cardamom, medicinal plants and forest foods (McDermott *et al.* 1990)
- In the buffer zones, practise intensive participatory forest management and develop agroforestry in deforested parts (McDermott *et al.* 1990)
- Eliminate resource dependency on the reserve by relocating villages to areas outside the reserve (Ishwaran and Erdelen 1990)
- Shift the dependency for food and income from the forest to home gardens and cash crop cultivation through development of efficient agroforestry systems (Caron 1995).

continued

There is also a need to more actively protect and regenerate important forest genetic resources that have become scarce in the Sinharaja Forest Reserve. This includes both degraded areas within the reserve and buffer areas. In this context an encouraging piece of research has found that the exotic *Pinus caribaea*, originally established as a live border for the reserve, can be a very suitable nurse crop for facilitating the establishment of site-sensitive tropical forest tree species, including dipterocarps (Ashton *et al.* 1997).

The WCMC Tree Conservation database includes about 40 critically endangered tree species that are found almost exclusively within protected areas (some examples are given in Table 4.1). The entire genetic variation of species which have restricted natural distributions – those found at only one or two locations within existing protected areas – may also be conserved *in situ* in protected areas. Two well-known examples include the coco-de-mer (*Lodoicea maldivica*) in the Seychelles (Vallée de Mai National Park, Praslin Island and Curieuse Island) and the wollemi pine (*Wollemia nobilis*) in the Wollemi National park in New South Wales, Australia (Box 4.4).

Protected areas also can play a vital role in the conservation of forest genetic resources, complementing those populations which are conserved in managed, production forests, e.g. *Endospermum medullosum* (whitewood) in Vanuatu (Box 3.1). *Eucalyptus nitens*⁹ (shining gum), originating from moist, temperate forests in eastern Australia, is an example of another economically important tree species whose genetic resources are being conserved by a combination of production forests and protected areas. The more extensive southeastern Australian populations of *E. nitens* are mainly conserved and managed within designated production forests on state-owned land in Victoria and New South Wales. The morphologically distinctive Errinundra Plateau populations of *E. nitens* in eastern Victoria, now referred to as *E. denticulata*, are protected within the Errinundra National Park, while the two extreme northern outliers and genetically distinct populations, at Ebor and Barrington Tops in northern New South Wales, and of particular interest for summer rainfall areas, are also protected within national parks.

Baikiaea plurijuga (Zambezi teak) is an example of a valuable timber species whose genetic resources, at least at a national level in Zambia, can be largely conserved within the existing protected area network (Theilade *et al.* 2001; Box 4.5).



Shining Gum (Eucalyptus nitens) the distinctive Errinundra population, sometimes referred to as E. denticulata, is very well conserved within Errinundra National Park, Victoria, Australia.
(Ken Eldridge/CSIRO)

⁹*Eucalyptus nitens* is very widely planted in the southern hemisphere (including Chile, Republic of South Africa, New Zealand and Australia), mainly for pulp production.

Table 4.1 Examples of some critically endangered tree species being conserved in protected areas, and threats[†]

Species and family	Protected area	Notes and threats
<i>Aglaia heterotricha</i> (Meliaceae)	'Eua National Park, 'Eua, Tonga	Threatened by illegal encroachment and agricultural activities.
<i>Aubreginia taiensis</i> (Sapotaceae)	Tai National Park, Côte d'Ivoire	A large tree which is threatened by habitat loss, associated with logging and agricultural encroachment, and poor regeneration. Monotypic genus.
<i>Caesalpineae echinata</i> (Caesalpinaceae)	Pau-Brasil Reserve and Monte Pascoal National Park, Brazil	Highly threatened species, and exploited since the first Portuguese settlers arrived in Brazil in the 1500s. Later, coffee farms and the expansion of urban areas reduced this species' occurrence to a very few areas along the Atlantic rainforest.
<i>Cordia leslieae</i> (Boraginaceae)	Chagres National Park, Panama	Very restricted natural distribution. Threatened by encroaching settlement and tourist activities.
<i>Dacrydium guillauminii</i> (Podocarpaceae)	Chûtes de la Madeleine Botanical Reserve, Grand Terre, New Caledonia	A highly unusual conifer growing partially submerged. Extremely localized and vulnerable to any environmental change, including sedimentation from mining.
<i>Dypsis ovobontsira</i> (Palmae)	Mananara Biosphere Reserve, Madagascar	A Madagascan endemic palm known from fewer than 10 individuals. One of many palm species threatened globally.
<i>Hibiscadelphus woodii</i> (Malvaceae)	Napali Coast State Park, Kauai, Hawaii, USA	Fewer than 10 plants remain. Threatened by feral goats, pigs and invasive plants. All four species in this Hawaiian endemic genus are either endangered or extinct.
<i>Inga jaunehensis</i> (Leguminosae)	Jauneche Reserve, Los Rios Province, Ecuador	A small leguminous tree found over less than 100 ha and severely threatened by fire and encroachment.
<i>Maillardia pendula</i> (Moraceae)	Aldabara Strict Nature Reserve, Seychelles	Known only from a few individuals on Grand Terre, and threatened by natural changes in vegetation communities.
<i>Parsania formosana</i> (Fagaceae)	Kenting National Park, Hengchun Peninsula, Taiwan	Single population of fewer than 50 individuals. Threatened by limited regeneration, associated with poor seed crops which are heavily predated by squirrels.
<i>Pittosporum coriaceum</i> (Pittosporaceae)	National Park of Madeira, Portugal	Only about 30 trees remain. Threats include fire, grazing and lack of seedling regeneration.
<i>Quercus hinckleyi</i> (Fagaceae)	Big Bend Ranch State Natural Area, Texas, USA	Major threats include hybridization with other <i>Quercus</i> species, road construction, seed collection by horticulturists, drought and grazing.
<i>Rhododendron protistum</i> var. <i>giganteum</i> (Ericaceae)	Nature Reserve, Gaoligongshan, Yunnan Province, China	Fewer than 100 individuals remain. Now under cultivation as an ornamental.
<i>Shorea bakoensis</i> (Dipterocarpaceae)	Sarawak, Malaysia	Extremely small population; one of the many threatened dipterocarp species in S and SE Asia

[†] These species have been reduced to very small and geographically restricted populations, often with limited genetic diversity, and most are at high risk of loss of sexual reproduction function, reduced fitness due to inbreeding and genetic drift, and being decimated by any catastrophic event, including climate change.

Box 4.4 Conservation of endangered tree species in protected areas

CASE 1: *Lodoicea maldivica* (coco-de-mer) in Seychelles

The coco-de-mer, famous for its large, unusual, female pelvis-shaped nuts, is synonymous with the Seychelles. Male and female flowers are borne on separate plants, with the nuts taking about 7 years to attain maturity. Long-term overexploitation of the highly prized nuts has been a major factor in restricting natural regeneration. About half of the palm population is protected in the Vallé de Mai Nature Reserve, a world heritage site, within Praslin National Park (Praslin Island), and on Curieuse Island, within the Curieuse Marine National Park. The other half is distributed within Praslin NP, Fond Ferdinand and private land on Praslin.

In 1771 pirates collected as many nuts as they could from Curieuse Island: in an attempt to increase the value of their harvest they tried to destroy the palms by burning the island. The palms regrew but are in poor health due to exposure and degradation caused by the fire. The Division of Environment has planted *Acacia auriculiformis* on Curieuse island in an endeavour to ameliorate the microclimate and improve soil fertility for the remaining palms. One of the most viable coco-de-mer population is found within the Vallé de Mai Nature Reserve, a small strictly protected forest area (19.5 ha) of exceptionally high conservation value. This Reserve also protects four other endemic palms, each belonging to a monospecific genera. The Vallé de Mai is located entirely within the Praslin National Park (324 ha), a multiple-use management area, and well protected by a regularly maintained fire break. Environmental damage is minimized by keeping visitors to defined trails, and exotic plants are being gradually removed and replaced by endemics. Park management is mainly funded by admission charges to the reserve. The Division of Environment is in the process of extending Praslin NP by 134 ha, to ensure the protection of the



Individual tree of 'coco de mer'
(*Lodoicea maldivica*).

habitat of this unique species. The nut trade is legally controlled by the coco-de-mer Management Decree of 1978 and amended in 1994.

Very few coco-de-mer have been cultivated outside of the Seychelles, and the palm is an important tourist attraction and economic asset for the country. The conservation of this palm *in situ* is a tribute to the effective conservation policies by successive Seychelles Government in recent decades, and their effective implementation by the Division of Environment and the Seychelles Island Foundation.

(Sources: Lionnet 1974; Wilson 1980; Savage and Ashton 1983; WCMC Tree Conservation Data base and Ms Frauke Fleischer-Dogley (pers. comm. 2001), National Park Unit /Forestry Section, Seychelles Ministry of Environment and Transport)

continued

CASE 2: *Wollemia nobilis* (wollemi pine) in Australia

Wollemi pine came to world attention in 1994 when it was discovered growing in a deep, secluded canyon in the vast 0.5 million ha Wollemi National Park, about 150 km NW from Sydney, Australia. A relictual conifer, known previously only from fossils, it was placed in a new monospecific genus in the family Araucariaceae, which also includes



Vegetative propagation of wollemi pine (Wollemia nobilis) by Queensland Forest Research Institute.
(Mark Hunt/QFRI)

the important forestry genera *Agathis* and *Araucaria*. Wollemi pine grows to 35 m tall and may live for 500–1000 years. It is known only from three populations about 3 km apart, totalling <50 mature specimens and many seedlings and/or clonal root suckers, and is categorized as critically endangered.

Since its discovery the New South Wales State Government has taken strong measures to ensure its survival including the development of a species-recovery plan. The major threats are likely to come from humans (illegal poaching, damage to the site by

trampling) or the arrival of a pathogenic fungus such as *Phytophthora cinnamomi*. Measures taken to conserve the plant include:

- Keeping the location of stands secret from the public and imposing harsh penalties on anyone found interfering with or damaging the trees.
- Additional *in situ* conservation measures include fungicidal foot baths for researchers visiting the site to prevent accidental introduction of pathogenic fungi, and keeping one Wollemi pine stand free from any human interference, to allow use for reference purposes in future
- A major research programme to investigate the species' ecological and propagation requirements, and its genetic variation
- Maintenance of *ex situ* collections at several locations (to minimize the risk of a disease epidemic or other calamity wiping out the entire collection)
- Vegetatively propagating the species by Queensland Forest Research Institute for large-scale commercial release to the public, both to provide funds for further work on the species and to diminish the risk of potentially devastating illegal poaching and trade.

Remarkably, a thorough genetic survey of Wollemi Pine, including 800 AFLP loci and 13 allozyme loci on adults from two populations and progeny from one site, found no variation. It is possible that the species has persisted for millions of years despite this lack of genetic variation. Wollemi pine reproduces asexually by root suckering, but also produces viable seed (about 5% viability). The lack of genetic variation is thought to be due to a combination of clonal behaviour and/or many generations of inbreeding.

The future of the species now seems reasonably well assured in the Wollemi National Park. In the event of a catastrophe wiping out of the wild populations, a protocol has been developed for a re-introduction programme. The species would only be re-introduced into its wild habitats if its disappearance was due to human-related causes, and these causes had been effectively reduced prior to any re-introduction.

(Sources: Woodford 2000; Hogbin *et al.* 2000)

Box 4.5 Planned conservation of the genetic resources of *Baikiaea plurijuga*: the contribution of protected areas in Zambia

Baikiaea plurijuga or Zambezi teak forests are found throughout southwestern Zambia and neighbouring parts of Angola, Botswana, Namibia and Zimbabwe. Zambezi teak, known locally as mukusi, produces one of the world's finest commercial timbers, and is one of the most important high-value timbers of Zambia. It is used for furniture, flooring and railway sleepers. Major closed canopy forests occur in the Senanga and Sesheke District, while large patches of an open and degraded form of *Baikiaea* forest are found throughout the Western and Southern provinces.

Baikiaea forest is under pressure throughout most of its range. Increased human pressure – clearing for agriculture, fire and logging – has caused its disappearance over much of its former range. *B. plurijuga* is a priority species for conservation in Zambia and Botanical Reserves were established within Malavwe and Kataba Forest Reserves in Shesheke District (FAO 1985). More recently, the Zambian Forest Department, in collaboration and with technical advice from Danida Forest Seed Centre and FAO Forestry Department, has prepared a comprehensive plan for conserving the remaining genetic resources. This includes *in situ* conservation within protected areas as part of a wider strategy to conserve the species' genetic resources.

Potential populations for a gene conservation network were identified through comparison of the species' geographic distribution with geneecological zones (see Vol. 1, Chap. 3). Whenever possible, more than one population per zone was identified in order to minimize the risk of loss. Stands within protected areas were preferred as these were considered to be more secure in the long term. Many of the *B. plurijuga* stands are found within existing national parks and form a good starting point for a network of conservation stands.

Important stands are found within the national parks of Kafue, Sioma Ngwezi, Liuwa Plain and Mosi-Oa-Tunya. The prevailing conservation situation in Zambia's protected areas is variable, and often uncertain owing to human pressures associated with poor local economies, coupled with a lack of economic measures to encourage protection. The fact that a *B. plurijuga* stand is present within a legally protected area is by no means an assurance of its long-term survival. The situation in four national parks containing Zambezi teak illustrates this point.

1. *Kafue NP*: The central part of Ngoma forest, situated in the south of the park, is dominated by Zambezi teak. This area contains a large and reasonably stable elephant population. Zambezi teak is likely to benefit from the presence of elephants as they clear the competing thicket and thereby also reduce the fire risk. Furthermore, elephants and other large game might assist regeneration of Zambezi teak by trampling the seeds into the ground. Some elephant poaching does take place in the park, but not to an extent that significantly affects the population. Fire management is carried out, and there is a good natural regeneration in the forest, although uncontrolled bush fires sometimes occur. Nonetheless, the Zambezi teak forest within Kafue NP is considered one of the best protected in Zambia.

continued

2. *Sioma Ngwezi NP*: This park contains patches of mixed forest with Zambezi teak, but these are poorly protected. A string of villages is located within and along the southwest boundary of the park, and illegal cutting of Zambezi teak and uncontrolled bush fires are not uncommon. The location of the park management office some 45 km from the park adds to the difficulties in controlling illegal activities within the park. Likewise, bush fires, grazing by domestic animals and settlements inside the park boundary threaten the Zambezi teak forests in *Liuwa Plain NP*.
3. *Mosi-Oa-Tunya NP* is the home of the world-renowned Victoria Falls. Extensive developments prior to the park's establishment contributed to the loss of some *Baikiaea* stands. In addition, cattle grazing and gradual encroachment by small-scale farmers together with the expanding town of Livingstone pose threats to remaining stands.

Despite these constraints to effective conservation in many protected areas in Zambia, their legal status makes conservation efforts in them more likely to succeed than if undertaken elsewhere. Therefore, a key element in the plan to conserve the genetic resources of *B. plurijuga* ought to be to strengthen conservation measures for stands within existing NPs. In addition, a number of stands within the important production forests in Senanga and Shesheke District need to be protected and managed. There is potential to gazette some of these forests reserves as 'Joint Forest Management Areas' to allow local communities to both take responsibility for and to benefit from greater involvement in their management.

(Based on Theilade *et al.* 2001)

4.3 A process for enhancing conservation of forest genetic resources in protected areas

Generally speaking, the majority of protected areas have traditionally been subjected to fairly minimal management, other than protection, either because of lack of resources, especially in developing countries, or a deliberate hands-off approach to management in more strictly protected areas. However, in a few examples protected areas are being deliberately and actively managed to conserve forest genetic resources (Box 4.6). These include reserves established specifically for the conservation of particular, often highly endangered, tree species and populations, mainly in developed countries. Examples include:

- Riserva Integrale Quacella in Sicily, Italy to protect an outlying population of *Abies nebrodensis*
- Buxton Silver Gum Reserve in Victoria, Australia established to conserve the endangered *Eucalyptus crenulata*, an important amenity tree species (Jelinek 1991)
- Erromango Kauri Reserve (for *Agathis macrophylla*) on Erromango, Vanuatu (Gillison and Neil 1987)
- Pau Brazil Reserve in the State of Bahia, Brazil (for *Caesalpinea echinata*).

In such cases, species management and recovery plans may be developed. These will include various protective and management measures that need to be employed to ensure the continued existence of the target species and associated plant communities. Many protected areas are at the small end of being useful for long-term conservation, and considerable effort and resources may be required to manage the target species. The sequence of steps that can be followed to enhance management of FGR in protected areas is given in Fig. 4.1, with more details on each step in Table 4.2.

Box 4.6 Conservation of forest remnants of the Atlantic Rain Forest in Brazil with participation of local communities

The protection and the use of natural resources are rivals in the densely populated areas of the Atlantic Rain Forest in Brazil. This tropical forest ecosystem used to be the second largest forest area of the country after the Amazon Basin, and served not only as an important water reservoir but also accommodated an enormous wealth of unique animal and plant species. However, logging, agriculture, mining and urbanization have destroyed 92% of the original forest cover since the first Portuguese settlers arrived. Today, the Atlantic Forest, or Mata Atlântica, ranks among the top five biodiversity hotspots in the world.

In order to save some unique remaining areas of such an important forest ecosystem, the 'Serra do Brigadeiro' national park in the State of Minas Gerais was set up in 1996, comprising around 13 500 hectares of little disturbed forest. The park resources include several endemic tree and animal species. The park's sole existence derived from the demand of local communities, which are integrated within the protected area and are themselves caring for the conservation of the park, and therefore enhancing the capacity of this area to achieve a combined role of conserving both the ecosystem and forest genetic resources of selected tree species such as *Cedrela fissilis* and *Cariniana legalis*.



*Atlantic Rain Forest fragment in an agricultural landscape, Brazil.
(Weber Amaral/IPGRI)*

(Based on Nogueira-Neto 1997)

4.4 Planning to harmonize protected areas conservation and human needs

Traditional emphasis on complete protection of parks and forest reserves from external influences has often led to policies that fail to pay appropriate attention to the needs of local people. Protected area managers are increasingly being required to consider ways in which local communities can continue to utilize the biological resources within protected areas. The general approach to protected area management now emerging in many countries is based on a three-part strategy (Anon. 1996; Boxes 4.1 and 4.7):

1. Broadening the range of categories of protected areas, by extending beyond the traditional focus on strict protection and national parks to include those areas in which people live and use natural resources sustainably.
2. Broadening the approach to planning and management of protected areas by: treating them as part of the larger landscape (see Davey 1998), and better addressing the needs of local people (see Beltrán 2000).
3. Broadening the number of partners involved in the establishment and management of protected areas, so that the role of national governments is complemented by the involvement of regional and local governments, indigenous peoples, community groups, NGOs and the private sector.

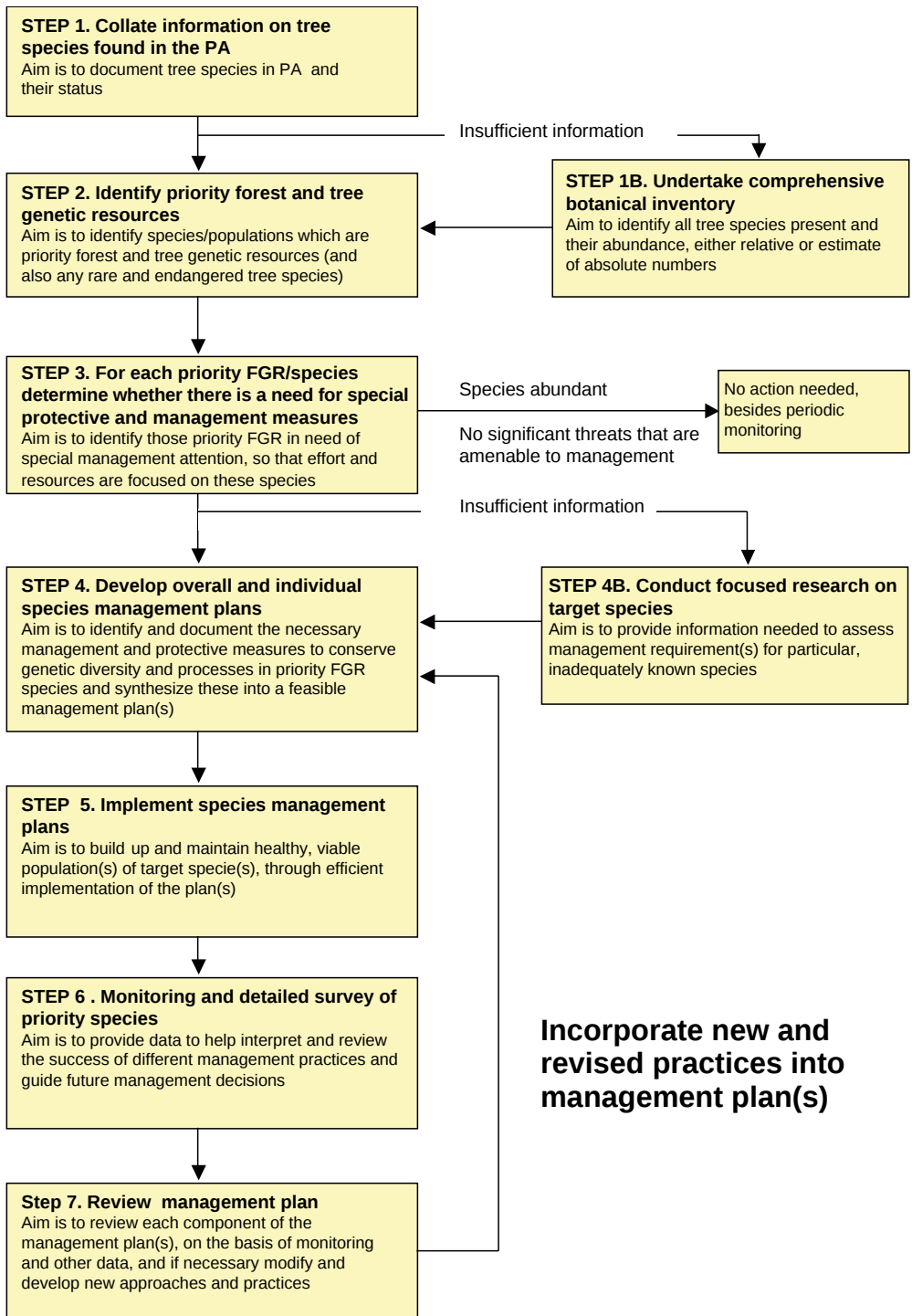


Fig. 4.1 Schematic diagram showing sequence of steps to enhance forest genetic resources conservation role of existing protected areas

In areas of high population pressure a primary focus of planning *in situ* conservation programmes should be to reconcile conservation activities with immediate human needs. In areas of high resource-use conflict, planning of protected area conservation measures must include formulation of local participatory development schemes for the management, production and protection of renewable forest resources. The five elements identified by Poffenberger (1990) for effective community forestry are equally applicable to securing community participation and support for protected areas:

1. Establishing an environment that supports experimentation and learning within forest agencies.
2. Assisting communities to develop local forest management organizations.
3. Collecting information and creating dialogues to improve mutual understanding and to generate joint management priorities.
4. Enhancing the authority and tenure security of forest communities.
5. Developing productive and sustainable agroforestry systems.

The importance of local participation in conservation of forest genetic resources is discussed in Volume 1, Chapter 5 of this series. That chapter provides good examples of how local people have become successful co-managers of protected areas and even national parks.

4.5 Summary: strengthening the role of protected areas for forest genetic resources conservation

A number of specific measures that can be undertaken to strengthen the role of protected areas in FGR conservation are summarized below:

1. Take conservation of forest genetic resources into greater consideration in the planning of new protected areas.

A greater focus ought to be placed on conserving priority forest genetic resources in the planning of Protected Area networks, both in the identification of new areas and zoning in existing protected areas. Protected areas in category IV (conservation through active management) will be very appropriate for maintaining the genetic diversity of many tree species.

2. Improve linkages and coordination between government departments involved in conservation and management of forest genetic resources.

Forestry and Conservation/Environment Departments need to develop closer working relations in order to help identify, monitor and better conserve FGR within protected areas. In countries with a Federal system of Government there may be a need for greater coordination between the National Government (and any national programme of FGR conservation) and State or Provincial Governments which may have responsibility for managing protected areas. The responsibility ought to be on Forestry Departments to make protected area managers aware of any significant FGR under their control.

3. Undertake inventory of forest tree species.

Thorough inventories need to be undertaken of forest tree species present in each protected area and their status. Information also ought to be gathered on each population including its extent and size, with detailed location. Observations on habitat, associated species and flowering and fruiting biology should be documented (MacKinnon *et al.* 1986). This information can then be used for planning purposes in managed categories of protected areas, and more widely in planning conservation programmes for particular tree species.

Table 4.2 Notes on steps to enhance the FGR conservation role of existing protected areas

Step	Description	Notes	Responsibility	References
1	Collate information on tree species present in PA	Review published and unpublished literature and consult local botanical experts (including herbaria and local people), local flora, forestry and botanical surveys, lists of trees, ethnobotanical surveys	PA Management Authority and/or Forestry Department/National Programme of FGR Conservation	Maxted <i>et al.</i> (1997)
1B	Comprehensive botanical inventory	- Many botanical survey techniques available (see references). - Survey should aim to sample all different forest types and associations (area can be stratified on the basis of existing maps, or aerial photo interpretation). - Gather information on species, abundance, regeneration. - Essential to involve taxonomic experts, preferably directly in survey or otherwise through verification of herbarium voucher specimens. - Involve local ethnobotanical collectors – will lead to more species collected/folklore varieties being sampled and identified.	PA Management Authority and/or Herbarium, Forestry Department, University Botany and/or Forestry sections, local people with specialist botanical knowledge	Martin <i>et al.</i> (1998)
2	Identify priority forest and tree genetic resources	Aim is to identify species/populations which are priority forest and tree genetic resources, including: - major and minor commercial timber species - species important for production of non-wood forest products - rare and endangered species - keystone species critical for ecosystem function.	PA Management Authority and Forestry Department/National Programme of FGR Conservation	
3	For each priority species determine whether there is a need for special protective and management measures	Species in need of active management and protection may include those which: - have populations that are approaching or below minimum viable population size, or subject to large fluctuations between generations - are threatened by factors which can be influenced by management intervention and protection - have particular regeneration requirements - are specialized associates for pollination and dispersal, especially if these are larger mammals and birds that require large areas.	PA Management Authority and Forestry Department/National Programme of FGR Conservation	
4	Develop overall and individual species management plans	- Management plans need to be based on both scientific and traditional knowledge. It is vital to identify relevant traditional conservation measures of local peoples and incorporate these into the plans and wherever possible build on these. - Individual species management plans ought to be developed and harmonized with and incorporated into the overall management plan for the PA (and its FGR). Individual species plans may vary considerably, depending on species and PA. - Measures adopted will depend on whether the species is widespread within the PA or whether it is highly localized: in the latter case a special protective/management zone (<i>in situ</i> gene conservation zone) may need to be established. - More thorough inventory may be required during development of the management plan including: location of stands (and habitats), presence of any different varieties or ecotypes, frequency or numbers and age class distribution, including regeneration - Pioneer and secondary species may require intermittent disturbance. Primary or climax species will benefit from complete protection from disturbance.	PA Management Authority, (in consultation and collaboration with Forestry Department/National Programme of FGR Conservation and local communities	Tuxill and Nabhan (1998); Cropper (1993); Tapisuwe <i>et al.</i> (1998); Action Statements of Threatened Flora and Fauna Programme of Victorian Department of Natural Resources and Environment

Step	Description	Notes	Responsibility	References
4B	Conduct focused research on target species	The ecology of many tree species is very inadequately known. For these species carefully focused research is needed to provide information essential to the development of scientifically sound management plans. This may include information on: • regeneration requirements • fire regime • key associated species • threatening processes including impacts of exploitation, pests and diseases and invasive species.	Research Units of Management Authority and other relevant research institutions (including Forestry Research Institutes, Botany and Forestry Departments of Universities)	
5	Implement species management plans	• For very rare species, i.e. where numbers have dropped below the minimum viable population size, and for species in which the number of mature individuals is of the same order as minimum viable population size, specific regeneration measures using local germplasm will be required, or if genetic variation or plant numbers have become very low then germplasm from neighbouring areas with the same environmental conditions should be used. This may include replanting in appropriate, degraded parts of the PA and in buffer zones (including incorporation into agroforestry systems and green firebreaks). • Some species may have particular regeneration requirements involving active management, e.g. – associated species which need to be maintained for pollination and dispersal – periodic disturbance/canopy gaps with certain characteristics – fire dependency.	PA Management Authority and local communities	
6	Monitoring and detailed survey of priority species	• Frequency of monitoring will depend on degree of threat and resources available, typically at 5–10 year intervals (including more frequent monitoring of impact of any more radical management techniques). • Essential information includes an estimate of population numbers, recruitment and mortality, and details of any threatening processes. • Use direct counts for small, compact populations. • Estimate numbers for larger and more dispersed populations using appropriate survey techniques.	PA Management Authority and local communities	Cropper (1993)
7	Review management plan(s) and revise if necessary	• Each measure in the management plan needs to be considered both separately and in conjunction with other measures, and its impact on conservation of the species/population. • Where management is failing, i.e. population is declining in numbers and health or failing to regenerate, then new measures may need to be developed and tested.	PA Management Authority (in consultation and collaboration with Forestry Department/ National Programme of FGR Conservation and local communities)	

Box 4.7 Conserving biological diversity and genetic resources in community-managed conservation areas in the South Pacific: the South Pacific Biodiversity Conservation Programme

The South Pacific Biodiversity Conservation Program (SPBCP)[†] facilitates efforts by local communities, governments and NGOs to conserve biological diversity in 14 countries in the South Pacific region (Reti 1996). Its main aim is to identify, establish and manage a series of conservation areas in which human activities are guided to enable sustainable use of the area's resources, while at the same time protecting their important ecological features and processes. The programme is based on two premises:

1. Local participation is an essential part of the initiation process, and accordingly only areas nominated by their traditional owners are included.
2. Conservation area projects are community driven and owned, and must fully reflect the communities' wishes and desires.

Some key issues to be addressed in the development of conservation areas are:

- the need to deliver tangible benefits, including financial returns through sustainable development activities
- an appreciation of sustainable development as a gradual and ongoing process
- a recognition that communities will need to become dependent on their own resources to carry out the conservation measures necessary to ensure the maintenance of natural resources
- a lack of awareness and management skills among local landowners who have a direct interest in conserving the environment.



Natural stands of Zambezi teak (Baikiaea plurijuga) in Zambia. The stand on the left-hand side is part of a proposed in situ conservation network.
(A.B. Larsen/DFSC, 1998)



Logs of Zambezi teak (Baikiaea plurijuga).

continued

In the past, protected area development in the South Pacific failed for two main reasons:

1. Governments owned very little of the areas and resources targeted for protection.
2. The people who own and use the biological resources, and whose support is vital, were not involved in plans by governments for the protection of these resources.

In order to address these issues, the SPBCP approach has been to establish coordinating committees that include all interest groups: representatives of the relevant agencies (Agriculture, Forestry, Fisheries, Environment, Tourism), NGOs and the local communities. The land-owning groups are the key decision-makers, with other committee members providing technical and policy advice to facilitate better decision-making.

In many parts of the South Pacific, forests have become scarce and precious resources. They need to be managed to provide both immediate economic benefits for the local communities, and a broader range of essential environmental services. The establishment of coordinating committees has helped to build more effective partnerships between government departments involved in forestry and the environment, and the communities. Such partnerships are viewed as essential for sustainable forest management and the conservation of forest ecosystems and their genetic resources.

Conservation areas established thus far under the SPBCP include a number of priority forest and tree genetic resources, e.g. *Calophyllum inophyllum*, *C. neo-ebudicum* and *Santalum yasi*, in the Ha'apai Conservation Area (Tonga), *Intsia bijuga*, *Endospermum medullosum* and *Canarium indicum* (Vathe Conservation Area, Vanuatu)

and *I. bijuga* and *Terminalia richii* (Uafato Conservation Area, Samoa). The case of *I. bijuga* at Uafato is a good example of a local community being provided with appropriate scientific data on which to base management decisions. Production of wooden handicrafts from *I. bijuga* provides the major village economic activity. According to a 1998 inventory of *I. bijuga* in the Uafato Conservation Area, the harvest level was about twice the level deemed sustainable (Martel and Atherton 1998). The village subsequently decided to reduce the harvest of *I. bijuga* trees as part of a resource management plan drawn up with the help of a local NGO, O le Siosiomaga Society (Taulealo and Ale 1998).

Further development and extension of the conservation area approach can make a major contribution to *in situ* conservation of forest genetic resources in the South Pacific, where nearly all land remains under traditional ownership.



Sandalwood (*Santalum yasi*) population being conserved on private-lease land on Foa Island, Ha'apai, Tonga.

The entire Ha'apai group has been declared a conservation area.



Malili (*Terminalia richii*) – an important, endangered endemic timber tree being conserved in Uafato Conservation Area, Samoa. (Lex Thomson/CSIRO)

[†] SPBCP is managed by the South Pacific Regional Environmental Programme (SPREP).

4. Institute effective protection of forest genetic resources.

Develop and enforce legal and other protection measures to ensure that utilization of tree resources within protected areas is only undertaken in a legal, managed and controlled manner. This includes conducting appropriate awareness and education programmes among local populations who are living within or near the protected area. It may also involve sharing of responsibilities and benefits with local people.

5. Actively manage forest genetic resources.

Where necessary, initiate appropriate management regimes within both the protected area and its buffer zones, to ensure that priority forest genetic resources are not inadvertently lost or degraded. This may involve active management and/or manipulation of fire regimes and other measures to ensure adequate regeneration (see Chap. 3). Uses that conflict with the gene conservation function of protected areas will need to be controlled or excluded (Prescott-Allen and Prescott-Allen 1984).

6. Restore degraded areas within protected areas and buffer zones.

Many protected areas contain areas of degraded habitats, including areas that were formerly forested and have been reduced to bush/scrub, shrub lands and grasslands. A high priority ought to be to restore such areas to something approaching their former forest cover. This can be done through catalysing forest succession and return of biological diversity. Such methods of 'assisted natural regeneration' and 'framework species' are presented in Boxes 3.7 and 3.8. Forest rehabilitation can be coupled with planting/regeneration of priority forest genetic resources and rare and endangered tree species using local germplasm sources.

7. Develop and implement a comprehensive bio-regional conservation plan which includes establishment of forested corridors to link protected areas with other forested parts of the landscape.

Conservation of genetic resources in protected areas may be substantially enhanced if they are linked to other areas of modified forest habitats (buffer zones, transition zones and managed forests). This is especially critical for smaller protected areas that are at a very high risk of losing their biological diversity and genetic resources when occurring as 'islands' of natural vegetation in otherwise cleared agro-ecosystems. Corridors may facilitate genetic interchange between otherwise isolated and fragmented populations including movement of key associated fauna, especially pollinators and seed dispersers. Forested corridors may enable protected areas to more effectively act as sources of genes (seed and pollen) for tree species in managed forests and trees in farming systems and vice versa.

8. Establish additional protected areas in managed categories.

Shift emphasis from strictly protected areas to broader, multi-purpose protected areas, such as managed species reserves (category IV) and managed resource protected areas (category VI), which pay greater heed to the needs of local human communities and particular genetic resources.

9. Ensure that forest genetic resources within protected areas remain available for scientific, conservation and other appropriate purposes.

Rules and regulations governing the collection of reproductive material (for conservation and research purposes) of priority forest genetic resources from strictly protected areas must be carefully reviewed, in collaboration with competent authorities, to maximize benefits to all concerned. Protected areas established with an *in situ* genebank function should have as explicit management objectives the provision of information on and access to those genetic

resources by persons engaged in their conservation and research and development (including bona fide researchers, breeders and managers of *ex situ* genebanks) (MacKinnon *et al.* 1986).

10. Identify national and international priorities.

Conduct national reviews of protected area systems, propose immediate and long-term action to establish and strengthen protected areas, undertake an international assessment of present and future protected area needs, provide incentives for establishing private protected areas, and promote international co-operation on protected area management.

11. Ensure the sustainability of protected areas.

A range of measures may need to be implemented in different situations to ensure the long-term viability of protected areas. These might include:

- broadening participation in design of protected area management plans and expanding the range of issues addressed by those plans
- elaborating the management objectives to include the full scope of conservation of biological diversity and genetic resources
- improving management and monitoring of PAs (see also Hockings *et al.* 2000)
- enhancing the ecological and social value of protected areas through land purchase and zoning outside the protected area
- identifying, securing and developing new sources of financing for protection and management (see WCPA 2000 for information on financing PAs)
- providing financial incentives for conservation on adjacent private lands.



EXPERIENCES AND FUTURE PROSPECTS

Conservation of forest genetic resources in their natural habitats

The majority of plant species growing in the forests around the world will be dependent on conservation *in situ* as they are not currently planted, and the majority probably never will be, at least in the foreseeable future. The previous chapters have outlined and discussed some general considerations and show practical experience from forest conservation and management programmes in different parts of the world. It is difficult, and perhaps counterproductive, to try to draw any general conclusions from such work: each particular conservation plan will need to reflect local conditions and requirements. Nevertheless, several principles are important to consider in all conservation activities and are summarized below.

The value of a systematic approach

The previous chapters have presented several examples of important tree species that are critically endangered at either species or population level. Many tree species of less known ecological or human value are at risk of extinction in a near future. For most of these species very little is known about their genetics and ecology.

Facing the overwhelming conservation needs and the lack of knowledge, one may ask where to start. In this guide, the authors have suggested that action, based on systematic and robust principles, may be a more effective approach than waiting for elusive research data. A systematic approach requires an initial phase where priorities are discussed based on the known and anticipated threats on the forest genetic resources. It also includes evaluating the different existing options in order to develop an effective conservation and use strategy. Sometimes the solution may lie in using the resource in a different way, or by giving it greater value, which may paradoxically entail even higher levels of utilization.

Potential conservation populations will have to be identified, surveyed and conservation efforts implemented in a systematic approach in the field. Such an approach may further lead to identification of needed adjustments in institutional structures and necessary involvement of local people in order to facilitate effective conservation. It is therefore important to involve all relevant organizations and stakeholders in the process. Only very rarely should or can conservation of genetic resources of trees be the sole effort of a single organization or government department.

The important role of sustainable management of trees and forests

Conservation of vigorous and productive populations of trees is a basic requirement for the management of forest genetic resources. This is particularly important when considering normal biotic and abiotic threats to forest trees over decades, and especially important if rapid climatic change and global warming occur as is currently being widely predicted. We argue that an *in situ* conservation plan should be, whenever possible, integrated with natural forest management. All management guidelines should assist the forest manager in

recognizing the value of genetic diversity as an important resource for sustainable production. At the same time, the extensive areas with managed forest will help conserve genetic resources that may not be sampled in the network of protected areas.

The importance of protected areas

Sustainable management cannot by itself ensure conservation of all forest genetic resources. There are species and populations that require special and immediate attention, as well as many species of no or little current utilitarian value that the forest manager probably will not be able to attend to. Some of these lesser-known or less economically important species may depend on complicated ecological interaction and may suffer from what at present is believed to be gentle utilization of the forest resources. Therefore, an integrated approach encompassing management of natural stands and establishment of specific conservation populations is advocated. The existing national protected area systems are often a valuable starting point for a network of conservation stands of a particular species.

Knowledge of the species

The reproductive ecology and population dynamics remain unknown or poorly understood for the majority of tree species. This is especially true for tropical tree species, and it would be unsatisfactory to wait for this knowledge to become available before enacting conservation measures. However, there is a definite need to improve our understanding of the species and their ecology. As key information becomes available this can help us to develop better conservation plans. It will also help to identify how species can be better utilized in a more sustainable way. This will not only improve their conservation status, but also benefit the people or countries utilizing the resource.

Integrate use and conservation

In almost all cases local people have an interest in adjacent forested areas, and protection should consider these people's rights and local history. Conservation planning therefore requires a thorough understanding of "Who are the users of the area?", and "For what purpose do they use it?". Conservation without local peoples' involvement is almost invariably not a viable option. However, it can be difficult to develop sustainable use systems in a social environment where tenure and user rights are poorly defined, or when dealing with complex ecosystems. Nevertheless, a combined conservation and sustainable use approach has the greatest larger potential to provide substantial, ongoing benefits to people both near and remote from such forest resources.

Complementarity of conservation methods

While this volume primarily focuses on issues necessary for the conservation of genetic resources in their natural habitats, it should be remembered that *in situ* conservation is only a technical option in a broader approach to conservation of the diversity between species and within species. In several cases, conserving forest trees *in situ* may be the only method that is socially and economically possible. In other cases, a combination of protected areas, managed reserves, clone banks, research plantations and breeding programmes may be better suited to different conditions and objectives. The technical options regarding *ex situ* conservation programmes are detailed in Volume 3.



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ACRONYMS

AFLP	amplified fragment length polymorphism
ANR	assisted natural regeneration
CA	conservation area
CBD	Convention on Biological Diversity
CGIAR	Consultative Group on International Agricultural Research
CIFOR	Centre for International Forestry Research, Indonesia
CIDA	Canadian International Development Agency
CITES	Convention on the International Trade in Endangered Species
CNSF	Centre National de Semences Forestieres, Burkina Faso
CMU	Chiang Mai University
COLP	Code of Logging Practice
Danida	Danish International Development Assistance
dbh	diameter at breast height
DFSC	Danida Forest Seed Centre
FAO	Food and Agriculture Organization of the United Nations
FGR	forest genetic resources
FMU	forest management unit
FORRU	Forest Restoration Research Unit, Thailand
INIFAP	Instituto Nacional de Investigaciones Forestales y Agropecuarias
IPGRI	International Plant Genetic Resources Institute
IUCN	World Conservation Union
MAB	UNESCO's Man and the Biosphere Programme
NGO	non-governmental organization
NP	national park
NWFT	non-wood forest products
PA	protected area
PNG	Papua New Guinea
R&D	research and development
RIL	Reduced Impact Logging
SIM International	Christian Missions International
SPBCP	South Pacific Biodiversity Conservation Program
SPREP	South Pacific Regional Environmental Program
SPRIG	South Pacific Regional Initiative on Forest Genetic Resources
TSP	Tree Seed Programme, Sudan
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
VPAI	Vanuatu Protected Areas Initiatives
VSFUP	Vanuatu Sustainable Forest Project
WCMC	World Conservation Monitoring Centre
WCPA	World Commission on Protected Areas
WWF	World Wildlife Fund



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GLOSSARY of technical terms

AGROFORESTRY A natural resources management system that, through the integration of trees on farms and in the agricultural landscape, diversifies and sustains production for increased social, economic and environmental benefits for land users at all levels.

ALLELE An alternative form of a gene. Alleles are located on corresponding loci of homologous chromosomes. They have different effects on the same trait or development processes and can mutate, one to the other. They may affect the phenotype quantitatively and/or qualitatively.

ALLOZYME Isozymes (proteins) whose synthesis is usually controlled by co-dominant alleles inherited by monogenic Medelian ratios and which show up as banding patterns in electrophoresis.

APOMIXIS A substitution for sexual reproduction, by type of asexual reproduction. Various types exist, namely, diploid- and haploid apomixis, apogamy, apospory, nucellar embryony and parthenogenesis.

AUTOECOLOGY The ecology of individual species.

BIOLOGICAL DIVERSITY The variety of life forms, the ecological roles they perform and the genetic diversity they contain (sometimes abbreviated to biodiversity).

BREEDING SYSTEM The system by which a species reproduces. There are several natural systems in plants: (i) out-breeding (exogamy, cross breeding) is a mating system in which mating is between individuals less closely related than average pairs chosen from the population at random. (ii) Inbreeding (endogamy, self breeding) is the crossing of individuals that are more closely related genetically, than individuals mating at random, especially when repeated for several successive generations. (iii) Clonal reproduction. A species may use one or more of these systems.

BUFFER ZONES The region near the border of a protected area; a transition zone between areas managed for different objectives. Isolation area/strip around seed production areas to minimize contamination by pollen from undesirable trees.

CLIMAX The period of equilibrium that is reached as a result of the gradual slowing down of the rate of continual development in a plant community. It is distinguished by the fact that it maintains itself. The conditions it creates are stable only for the offspring of its own kind. Terminal stage in ecological succession for a given environment.

CONSERVATION (of a resource) The actions and policies that assure its continued availability and existence.

CONSERVATION (of genetic resources) The management of human use of genetic resources so that they may yield the greatest sustainable benefit to present generations, while maintaining their potential to meet the needs and aspirations of future generations.

CRYOPRESERVATION The preservation or storage in very cold temperatures; usually in liquid nitrogen. It is a form of conservation for some seeds and tissues.

DICHOGAMY Maturation of male and female flowers or parts of flowers at different times, and fostering cross-pollination.

DNA MARKER A distinctive, readily identifiable segment of DNA.

DYSGENIC Detrimental to the genetic qualities of future generations. The term applies especially to human-induced deterioration such as may occur through removal of the best phenotypes.

ECOSYSTEM A dynamic complex of plants, animal and micro-organisms communities and their non-living environment interacting as a functional unit.

ECOTYPE Race or infraspecific group having distinctive characters which result from the selective pressures of the local environment.

EFFECTIVE POPULATION SIZE The number of individuals in an ideal population which has the same level of genetic drift and inbreeding as the population from which it is drawn.

ENCAPSULATION The process of enclosing fragile organic material in a protective, nutritive casing, usually of a semi-solid nature. It is used for planting or moving somatic embryos, either individually or in rows.

ENDEMISM A taxonomic category, the natural occurrence of which is confined to a certain region and the distribution of which is relatively limited.

EPICORMIC BUDS Buds, produced under bark, which might develop into branches stemming from the main trunk of a tree.

EX SITU (CONSERVATION) The conservation of components of biological diversity outside their natural habitats.

FIREBREAKS A natural or artificial barrier usually created by removing vegetation to prevent or retard the spread of fire.

FOREST COMPARTMENT A permanent, geographically recognizable unit of forest land forming the basis of prescription and permanent record of all forest operations.

FOREST MANAGEMENT OR WORKING PLAN A plan for regulating all forestry activities for a set period of time through the application of prescriptions that specify targets, action and control arrangements.

FRAGMENTATION The process of transforming large continuous forest patches into one or more smaller patches creating areas of geographical discontinuity.

GENE In the genome of an organism, a sequence of nucleotides (DNA sequence) to which a specific function can be assigned.

GENE BANKS A facility where germplasm is stored in the form of seeds, pollen or *in vitro* culture, or in the case of a field gene banks, as plants growing in the field.

GENE FLOW Exchange of genes between populations owing to the dispersal of gametes or zygotes.

GENE POOL The total sum of genetic material of an interbreeding population.

GENEALOGICAL ZONES Population genetics in relation to habitats.

GENE(TIC) CONSERVATION All actions aimed at ensuring the continued existence, evolution and availability of genetic resources.

GENETIC DIVERSITY The sum total of genetic differences between species and within species.

GENETIC EROSION Gradual loss of genetic diversity.

GENETIC LOAD Accumulation of deleterious genes.

GENETIC RESOURCES The economic, scientific or societal value of the heritable materials contained within and among species.

GENETIC VARIATION Variation due to the contribution of segregating genes and gene interactions.

GENOTYPE The sum total of the genetic information contained in an organism or the genetic constitution of an organism with respect to one or a few gene loci under consideration.

GIRDLING Physical cutting or disruption of the cambial sap flow within a tree. It often kills the tree.

GMZ Gene management zone.

HAPLOID Having a single complement of chromosomes, which is the same as a gamete (pollen or egg cell).

HETEROZYGOSITY The proportion of heterozygous individuals at a locus or of heterozygous loci in an individual. H_e – expected heterozygosity; H_o – observed heterozygosity.

HETEROZYGOUS An individual is heterozygous for a particular locus when two different alleles are present at that locus.

INFLORESCENCE A cluster of flowers generated on the same stalk.

IN SITU (CONSERVATION) The conservation of ecosystems and natural habitats and the maintenance and recovery of viable populations of species in their natural surroundings and, in the case of domesticated or cultivated species, in the surroundings where they have developed their distinctive properties.

IN VITRO 'In glass'. This term refers to an experiment performed in an artificial environment such as a test tube or culture media.

INDIGENOUS SPECIES Species existing in, and having originated naturally in, a particular region or environment.

INTRASPECIFIC GENETIC VARIATION Genetic variation within a species.

ISOZYME Multiple forms of a single enzyme.

KEYSTONE SPECIES A species having major influences on ecosystem structure and function, which are not replaceable by another member of the community.

LIGNOTUBERS Mass of vegetative buds and associated vascular tissue and contains substantial food reserves.

METAPOPULATION A group of populations of the same species coexisting in time but not space.

MOLECULAR MARKER A gene or DNA sequence that can be used to identify an organism, species, or strain or phenotypic trait(s) associated with it.

MONOCYCLIC In monocyclic harvesting systems the crop trees are harvested simultaneously at the end of the rotation period.

OLIGARCHIC FORESTS Forests dominated by only one or two main species.

ORTHODOX SEED Seed which is desiccation tolerant.

OUTCROSSING RATE Proportion of seed derived by crossing between unrelated individuals.

OUTCROSS Cross-pollination between plants of different genotypes.

PANMICTIC UNIT A local population in which there is completely random mating.

PARENT TREES A pollen donor and/or ovules producer.

PHENOTYPE The observable characteristics of an individual, resulting from the interaction between the genotype and the environment in which development occurs.

PIONEER SPECIES The first species or community to colonize or re-colonize a barren or disturbed area, thereby initiating a new ecological succession (used synonymously with colonizing species).

POLLINATORS A living organism transferring pollen, e.g. insect bird or bat.

POLYCYCLIC Crop trees that are partially harvested at the end of the rotation period. Some trees remain for several rotations.

POLYPLOID An organism is considered to be polyploid if it has more than two sets of chromosomes, in other words, if it has homologous triplets or quadruplets instead of pairs. One quarter to one half of all plants are polyploid.

POPULATION A group of individuals of the same species occupying a defined area and genetically isolated to some degree from other similar groups

POPULATION DYNAMICS Changes taking place during a population life.

PRESCRIBED BURNING Applying fire to predetermined areas under conditions that the intensity and spread of the fire are controlled.

RECALCITRANT SEED Seed which is desiccation-sensitive, with a short hydrated life-span in storage typically ranging from a few days to several months. Recalcitrant seed behaviour is most prevalent in tree species with larger seeds (>3-5 g) from tropical, humid zones.

SELF-INCOMPATIBLE Individuals that are unable to produce viable offspring by self-pollination because of a genetically controlled, physiological mechanism (barrier) that prevents self-fertilization or seed development.

SELF(ING) Fertilization with pollen from the same flower or plant.

THINNING gradual removal of trees crowding or shading the preferred species or trees.

VEGETATION CORRIDORS a band of vegetation, which serves to connect distinct patches of the landscape. Through corridors, geneflow is possible between what would otherwise be isolated populations.



**Danida Forest
Seed Centre**



This guide is the second volume in a series of three booklets that deals with the conservation of forest (tree and shrub) genetic resources. This volume is focused on the conservation of forest genetic resources *in situ*. Its main aim is to demonstrate the long- and short-term benefits attainable through genetic conservation, and to provide practical guidance to *in situ* conservation strategies and methodologies to planners, decision-makers and professionals involved in day-to-day field activities in forest conservation and forest management. Through examples and case studies, this guide also seeks to illustrate: the differences and complementarities of ecosystem conservation and conservation *in situ* of genetic variation within and between species targeted for conservation; the compatibility of conservation and sound resource utilization; and the long- and short-term benefits attainable through genetic conservation.