CONSERVATION OF TROPICAL FOREST GENETIC RESOURCES: IPGRI'S EFFORTS AND EXPERIENCES

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Introduction

Long-term conservation of forest genetic resources (FGR) is a cornerstone of sustainable forest management. Through conservation and proper forest management, it is possible to maintain the evolutionary processes of species and the diversity of their genepools for use now and in the future. Traditionally, forest conservation has often been understood as a steady-state process, whose goal is to preserve natural forests in their original state. Forests, however, are dynamic systems. Human activities have modified forests and their biodiversity for millennia, even in seemingly pristine tropical forests (see review by McNeely 1994).

Among the different components of biodiversity, genetic diversity is the building block of the evolutionary process. Conservation of FGR, therefore, should accommodate evolutionary concepts to ensure continuous adaptation under changing environments (Eriksson *et al*. 1993). Several global and regional threats to forest ecosystems are contributing to profound changes in the patterns of distribution of tree genetic diversity. Global climate change is modifying the prevailing environmental conditions to which forests have adapted. Forest fragmentation, the introduction of invasive species and atmospheric pollution also are having adverse effects on forests. It has been predicted, however, that changes in land use will have a greater impact on biodiversity in the tropical terrestrial biome in the next 100 years than will changes in climate, nitrogen deposition, biotic exchange or atmospheric carbon dioxide (Sala *et al*. 2000).

As tropical deforestation is still continuing (Geist & Lambin 2002), it is clear that many conservation efforts in the tropics have not been effective. This lack of success can be attributed partly to inadequate participation by various stakeholders in natural resources management and conservation. Conservation strategies should take into account the needs of different stakeholders, as well as non-environmental policies that can indirectly affect the use of forests. Recent efforts to promote sustainable forest management in tropical forests are welcome, but may not be enough to safeguard biodiversity in these forests. It is difficult to achieve sustained timber yields from natural forests without degradation of habitats and subsequent loss of biodiversity (e.g. Bawa & Seidler 1998). However, sustainable forest management may indirectly support FGR conservation efforts in natural tropical forests.

This paper gives an overview of the conservation of FGR and some of the related activities of the International Plant Genetic Resources Institute (IPGRI) and its partners. We discuss priority setting, locating genetic variation, conservation methods, implementation and the role of sustainable forest management in maintaining genetic diversity in tropical forests. Lastly

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we highlight some issues that are important for better conservation of FGR, particularly in a regional context.

Conservation of forest genetic resources as a process

Conservation of FGR is a multiphase process (Figure 1). Existing forest resources and the genetic diversity they contain provide a basis for conservation measures. The selection of priority species is one of the most important phases of the conservation process because future activities will be based on priorities set in the planning phase. As soon as priority setting has been completed, genetic diversity must be assessed and located for subsequent conservation activities. The selection of conservation measures depends on how the objectives of a conservation programme are defined. These measures then provide a framework to implement practical conservation work.

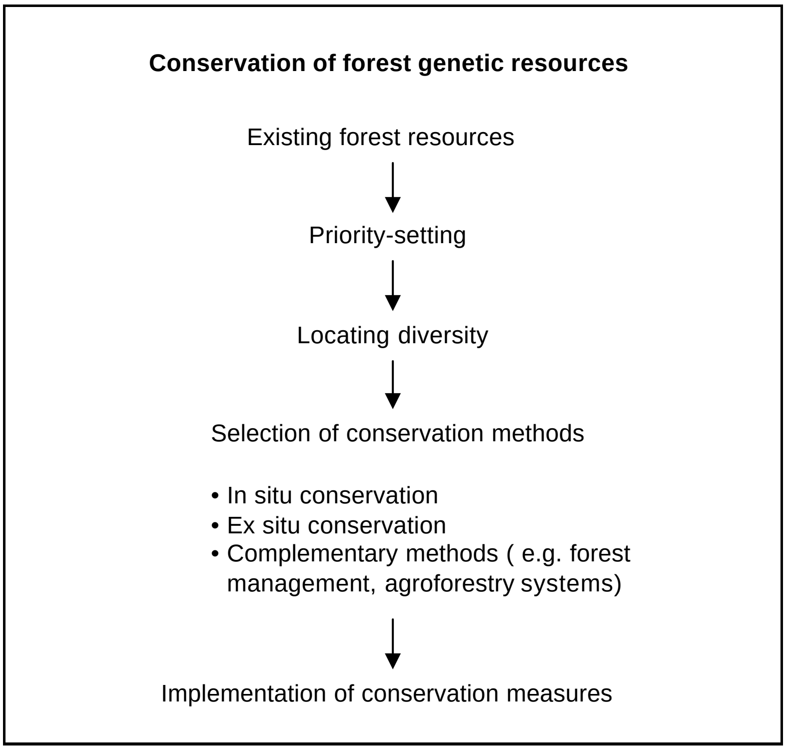

Figure 1. *Simplified schematic representation of the conservation process*

Setting priorities for conserving forest genetic resources

Only a small number (fewer than 140) of the world's 50,000 or more tree species is being used in forestry, and current gene conservation or breeding efforts cover even fewer species (National Research Council 1991). Yet many more tree species are useful to man in terms of their non-wood products or environmental services. Hence long-term FGR conservation efforts, especially for tropical and subtropical tree species, should be strengthened (National Research Council 1991; Palmberg-Lerche 1999). In practice, however, conservation needs far outweigh the available human and financial resources, and relatively little is known of even the basic biology of most tree species. These constraints make priority-setting one of the most important tasks not only of conservation work but also of research.

The need to develop decision strategies for setting priorities is particularly urgent for countries that are trying to identify priority tree species and populations for inclusion in regional and national conservation programmes. The University of British Columbia in Canada has been developing a framework for prioritizing species, populations and conservation methods under an IPGRI-supported research project. In addition to developing this framework, the project aims to develop a general procedure to support more comprehensive strategies for conservation and management of FGR (IPGRI 1999, 2000).

The framework attempts to prioritize species or populations in a rational manner, on the basis of threats, potential or present values, and the means that are available for conservation (see IPGRI 2000). The framework requires basic information on the status and dynamics of genetic diversity, as well as its values, threats and potential for conservation management. This range of information is rarely, if ever, available, but the framework provides a tool for compiling existing information and identifying research needs. This process produces a priority ranking or classification of species into priority groups that can be used by managers to select and implement necessary measures.

Testing the decision-making framework in the field

The framework has been tested at two sites in São Paulo, Brazil: a 2000ha forest reserve with 267 tree species, and a park of more than 35,000ha with about 300 tree species (Koshy *et al*. 2002). Field data for these two sites are readily available from permanent sample plots. The two-step prioritization process starts with specifying tree species and identifying their potential threats and values. Subsequently the species are ranked for further management options. The second step involves acquiring additional information and estimating how much this information costs.

In the first step, tree species are given a score of 1–5 based on threat and value evaluations by various stakeholders. In the field test, for example, the threat evaluation was based on exploitation intensity, fragmentation and fire. The value evaluation combines economic and biological factors. Economic factors include present and potential commercial values of wood, non-wood products and social and cultural values. Biological factors consist of the ecological functions of a species and its contribution to phylogenetic diversity. Both the threat and value scores are given a relative weight indicating the importance of a species to different stakeholders and a probability that reflects the certainty of a given score. The final threat and value scores are calculated as a sum of the three components, i.e. initial score, weight and probability, and the species are ranked for priority. The higher the score, the higher the priority for management.

In the second step, additional information is collected for high-ranked species at i) demographic, ii) non-genetic (phenology, pollination, seed dispersal, etc.) and iii) genetic levels. Additional information will either increase or decrease the probability of managing (i.e. whether conservation is needed or not). More precise information reduces the likelihood of making a ‘wrong’ decision because the range of probability distributions can be narrowed. The increased costs of obtaining additional information at the different levels are estimated and included in the analysis while a decision tree is being constructed.

Koshy *et al*. (2002) conclude that the decision-tree approach is an effective tool for rational decision-making in gene conservation, provided that the necessary information can be estimated (if it is not available), and that monetary values can be assigned with reasonable accuracy. The main challenge is accurately estimating population parameters, which increase the probability of making ‘correct’ management decisions. It is likely that further research on new methodologies and results will alleviate this problem in the future, thus making the developed framework more useful. Other advantages of the framework are that the collection costs of additional information can be compared directly with the expected returns of such a choice, and that the framework is amenable to sensitivity analysis to identify influential factors in decision-making.

Locating genetic diversity

The process of decision-making for conservation of FGR highlights the importance of information on the amount and location of genetic diversity. No matter how useful the decision-making framework is in practice, no conservation effort can be effective without adequate information on genetic diversity. At present, however, this kind of information is extremely scarce, especially in the case of tropical forests, and cannot be produced rapidly. Thus different layers of information, i.e. patterns of species and forest ecosystem distribution, threats and the amount and spatial distribution of genetic diversity, must be combined to assess adequately the state of genetic diversity in forest ecosystems.

Combining information produces a spatially explicit framework for conservation efforts by identifying areas to be ranked according to the level of threats and the genetic diversity they hold (Boffa *et al*. 2000). Once species distribution has been identified, more efforts can be made to evaluate genetic diversity. Detailed information on genetic diversity and threats is essential to designing effective conservation areas, which will safeguard intra-specific diversity and maintain evolutionary processes. Several conservation areas, hosting a considerable portion of a species' genetic variation, may be needed. Modern tools, such as remote sensing and geographic information systems, can greatly facilitate this work.

Locating genetic diversity in Vietnam

The Research Centre for Forest Tree Improvement (RCFTI), under the Forest Science Institute of Vietnam, has been locating the genetic diversity of the threatened timber tree species *Pterocarpus macrocarpus*, *Xylia xylocarpa* and *Dalbergia oliveri* (Le & Nguyen 1999). The work carried out so far has focused on assessing tree species composition and natural regeneration potential, and the relations between the target species and other dominant species in the remaining forests. Land-use changes from 1973 to 1995 have also been evaluated in selected locations, and socio-economic surveys have been carried out to assess the importance of forests to local livelihoods.

This work has revealed that the species are found only in some national parks and nature conservation areas, and that they occur independently of each other (Le & Nguyen 1999). *P. macrocarpus* and *X. xylocarpa* occur in semi-deciduous or deciduous forests, whereas *D. oliveri* grows mainly in evergreen forests. All of the species are light-demanding and the potential for natural regeneration, except in *P. macrocarpus*, seems to be high. Over-exploitation, however, still endangers these species and conservation efforts must be further developed.

Remote sensing studies have found that forest cover in some areas decreased markedly (20–35%) between 1973 and 1995. Other areas saw only small reductions of 3–7%. Most of these changes were caused by the conversion of forest land into agricultural and residential land. A similar pattern has been observed in many neighbouring countries (FAO 1999). Socio-economic studies have shown that, although paddy and milpa cultivation is the main source of employment for local people, forests are also important to livelihoods. For example, farmers surveyed around the distribution areas of *P. macrocarpus* use wood extensively for house building and cooking.

Socio-economic factors are sometimes neglected or seen as irrelevant when focusing on the conservation of forest genetic diversity. However, the success or failure of any conservation project depends heavily on how the needs of local people are taken into account during planning and implementation (Enters 2000; Isager *et al*. in these proceedings).

RCFTI is currently assessing the distribution of intra-specific genetic variation in *P. macrocarpus* using isozyme studies. These will provide information on genetic diversity within selected populations (located mainly in the Central Highlands of Vietnam) and enable sound planning of future conservation efforts. This work is also regionally important. To date the genetic diversity of *P. macrocarpus* has been assessed only in Thailand, where a west-east geographic pattern in genetic variation has been found (Liengsiri *et al*. 1995). For regional gene conservation purposes, it is important to know whether this pattern extends to neighbouring countries, i.e. Myanmar, Lao PDR and Vietnam (Liengsiri *et al*. 1995; Coles & Boyle 1999).

Methods for conserving forest genetic resources

A wide range of methods, from protected reserves to intensive management of breeding populations for production systems, can be used to conserve FGR. The choice of methods depends on available genetic material, selected time scale and specified aims. The method selected and the subsequent implementation of a conservation strategy also depend on the availability of both human and financial resources.

The two most commonly considered methods for conserving FGR are *in situ* and *ex situ* conservation. The term *in situ* refers to the continued maintenance of tree populations at their natural sites, in the environment to which they have adapted. *Ex situ* conservation takes place outside the natural habitat of a tree species, and may consist of activities such as establishing live collections or *ex situ* conservation stands, or storing seeds, pollen or tissue.

FGR can also be conserved and maintained by using tree species in forestry or other land-use systems such as agroforestry. It is likely, however, that forest management interventions reduce genetic variation in tree populations (Savolainen & Kärkkäinen 1992). Not even carefully planned and implemented forest management activities, therefore, can replace more active conservation measures with clearly specified objectives. The same caveat also applies to tree domestication and the use of trees in agroforestry systems.

In situ conservation

There is a general consensus among scientists and practitioners that no single conservation method is adequate, and that different methods should be applied in a complementary manner (e.g. Palmberg-Lerche 1999; Boffa *et al*. 2000). *In situ* conservation, however, has a number of benefits and so often forms the basis of conservation programmes. It allows evolutionary processes to be maintained, including the adaptation of tree populations to changing environmental conditions. This is particularly important for breeding programmes, since future human needs and environmental conditions are difficult to predict.

The reproductive biology and overall survival of many tropical forest species are dependent on complex ecological interactions. Thus long-term genetic conservation of such species is difficult, if not impossible, without *in situ* conservation. In addition, recalcitrant seed behaviour (i.e. inability to tolerate desiccation) also complicates long-term *ex situ* conservation efforts for many tropical tree species (see below). *In situ* conservation can also contribute to the conservation of biological diversity at higher levels, i.e. species and ecosystems.

Protected areas have often been established on the basis of ecosystem or species conservation, rather than gene conservation. Thus the design of *in situ* conservation programmes has been considered primitive (National Research Council 1991). In tropical forests in particular, the complexity of interactions and lack of scientific information have hampered the development of *in situ* conservation strategies. Uncertainty surrounds the adequate size of *in situ* conservation areas, the number of individuals to be included, how to select locations, and how genetic variation is distributed within selected areas (Palmberg-Lerche 1999).

Undisturbed tropical forest ecosystems are often taken as a starting point when planning *in situ* conservation programmes. Today, however, rural landscapes are a mosaic of disturbed and less disturbed patches of forest, ranging from seemingly natural and secondary forests to seriously degraded forests and other wooded fragments. The most obvious genetic effects of fragmentation are a loss of genetic diversity at both population and species levels, changes in the genetic structure of a population and increased inbreeding (Young & Boyle 2000). Clearly, *in situ* efforts cannot always rely on intact natural forests, and so it is essential to understand how the processes of genetic drift, gene flow, selection and mating affect genetic diversity in fragmented forests (Young & Boyle 2000).

IPGRI's partners at the Universities of Costa Rica, Alberta and Massachusetts have been studying the effects of fragmentation on the genetic diversity of *Enterolobium cyclocarpum* in Costa Rica. Studies of the reproductive biology of *E. cyclocarpum*, a tropical dry forest species, in continuous forests and forest fragments in pastures indicate that pasture trees are less likely to receive pollen and set fruit, and that their fruits bear less seed, than trees located in continuous forests (see IPGRI 2000). Also, outcrossing rates within the two groups of trees have been found to be similar, but progeny vigour among seedlings in continuous forest is higher than in pastures.

These results have immediate implications for the conservation and management of *E. cyclocarpum* and other species in similar habitats. Trees in pastures can aid the movement of pollinators between intact forest fragments and so contribute to gene flow and maintenance of genetic diversity among forest fragments. However, because seedlings in pastures have less vigour, seeds from these areas cannot be recommended for establishing plantations or rehabilitating degraded natural forests.

In southern India, sandal (*Santalum album*) forests have long been exposed to selective logging, poaching and changes in land use. The effects of disturbance on the genetic diversity of sandal have been investigated by the University of Boston, together with the Ashoka Trust for Research in Ecology and the University of Agricultural Sciences in Bangalore (IPGRI 1999, 2000). Results from two protected areas indicate that genetic diversity of sandal is highest in the core undisturbed park zone, whereas allelic diversity is reduced in the outer buffer and disturbed zones. These findings suggest that present protection measures are adequate and that excessive logging will cause genetic deterioration in natural sandal populations. Allelic diversity, however, is similar in the two disturbed zones, which suggests that, contrary to general assumptions, no significant genetic segregation has resulted from different degrees of disturbance. This finding can be attributed to the fact that sandal is insectpollinated and animal-dispersed, i.e. substantial gene flow still occurs despite varying degrees of disturbance.

Ex situ conservation

As mentioned earlier, *in situ* and *ex situ* conservation should be used in a complementary fashion to conserve FGR. Both are an integral part of the conservation process, and both can only be effective after genetic diversity has been located and conservation priorities have been set. The main purpose of *ex situ* conservation is to capture and maintain a representative sample of the existing genetic diversity of a species. For highly endangered tree species, *ex situ* conservation may be the only approach in the short to medium term. The main pitfalls of collecting germplasm samples for *ex situ* conservation are: i) limited coverage of genetic variation; ii) biases in the collected plant material; and iii) samples that are too large to deal with (Brown & Hardner 2000). Because *ex situ* conservation is more costly than *in situ* conservation, it is particularly important that sampling of populations and germplasm within populations is given special attention to maximize the use of limited financial and human resources.

The traditional approach to *ex situ* conservation of FGR is to establish conservation stands of a species outside its native habitat to facilitate gene management. However, long-term maintenance of the collected genetic variation in *ex situ* stands tends to be complicated by genetic drift and potential contamination by external gene flow. Another commonly used method of *ex situ* conservation is to store seeds collected from a range of natural populations. In the case of many tropical tree species, however, this method is limited by recalcitrant seed behaviour.

More than 70% of commercially valuable tropical tree species are estimated to have recalcitrant or intermediate seeds (Ouédraogo *et al.* 1999). In recent years, therefore, considerable effort has been expended in developing *in vitro* techniques for *ex situ* conservation of recalcitrant tree species. A notable example is cryopreservation (Benson 1998; Marzalina *et al.* 1999). Cryopreservation, the storage of cells or tissue at ultra-low temperatures, offers great opportunities for longer-term *ex situ* gene preservation. Its applicability, however, has been limited by difficulties in identifying protocols to reduce the water content of tissue before freezing. Tissue water content must be reduced to avoid lethal ice formation in cells. Different results from different laboratories engaged in drying the same species of seed are an additional obstacle (Walters 1999). Although it is likely that further research will ease these problems, the main application of cryopreservation seems to be in supporting tree improvement programmes and conserving biotechnically derived germplasm (Benson 1998), rather than as a widely applied *ex situ* conservation method to support *in situ* conservation of FGR.

Micropropagation, the use of tissue and organ cultures for organogenesis and somatic embryogenesis, can also be applied to maintain genetic variation in germplasm collected for *ex situ* conservation. Practical propagation applications are already available for several tropical trees, based on shoot tissue culture in broadleaved tree species and on somatic embryogenesis in conifers (see Luukkanen 1998 for a review of biotechnology in tropical forestry). Micropropagation does not necessarily require expensive laboratory facilities, and can therefore be used in less-developed conditions. Maintaining juvenile material, however, can be problematic. At present, the technology used in somatic embryogenesis is in most cases too expensive for cost-effective *ex situ* conservation.

Since 1997, the Danida Forest Seed Centre (DFSC) and IPGRI have cooperated in enhancing *ex situ* conservation methods for recalcitrant tropical forest trees. Project activities have focused on determining whether seeds are recalcitrant, intermediate or orthodox, and have included seed development research to assess optimal conditions for seed collecting, germination and storage. An international Forest Tree Seed Research Network has been established under the project to facilitate information exchange among scientists developing protocols for collecting, handling, testing and screening of tolerance to desiccation and optimal storage conditions. At present more than 20 countries worldwide are involved in the project. More than 50 tropical forest species have been screened so far. Activities also include publications and training workshops to increase research capacity, particularly in developing countries.

Implementation of *in situ* conservation at an operational level

Putting FGR conservation strategies into practice at an operational level is a major challenge. Three important aspects of implementing *in situ* conservation must be considered, i.e. how to establish a network of *in situ* conservation areas, how to improve the usefulness of protected areas for FGR conservation, and how sustainable forest management can promote FGR conservation (see FAO/DFSC/IPGRI 2002).

Networks of in situ conservation areas

The key variables in planning and establishing a network of *in situ* conservation areas are location, number of areas and their size or the number of individuals they contain. The factors that should be considered when selecting areas for an *in situ* gene conservation programme can be summarized as follows (FAO/DFSC/IPGRI 2002):

- Abundance of priority species;
- Low risk and threat levels (including land tenure issues);
- Efficient management agency in terms of commitment and resources;
- Support from local people;
- Compact in shape and presence of forest buffer zone; and
- Opportunities to conserve other priority species.

Even if governments implement a conservation programme for FGR in state-owned forests, they must rely heavily on local people’s participation to make conservation efforts successful. In many countries, local people have traditional or customary rights to use public lands for subsistence purposes, and any efforts that might prevent them from exercising these rights are likely to cause conflicts. Conservation efforts can only be successful if local people see such efforts as important to their livelihood and as a source of benefit.

The factors listed above are important in terms of practical implementation of *in situ* conservation efforts, but should not replace the original ideal of gene conservation. Populations for conservation programmes should be selected on the basis of known or expected distribution of genetic variation, so that conservation areas contain the maximum genetic diversity of a priority species. However, detailed data on the distribution of genetic diversity in forest ecosystems are often unavailable, especially in the tropics. In such cases, the populations of a species can be selected systematically across its distribution range. Alternatively, the distribution range can be divided into different ecological zones, and representative populations selected from each zone (FAO/DFSC/IPGRI 2002).

FAO/DFSC/IPGRI (2002) suggest, as a general guideline for the number of gene conservation areas required for any species, that between one and three areas in each major ecological zone are likely be adequate for widespread and highly outcrossing species. This figure reflects the fact that such species often have more or less continuous patterns of variation, and that a considerable amount of their genetic variation is found within populations. For inbreeding species or outcrossing species with scattered and discontinuous ranges, more than three conservation areas in each ecological zone are likely to be needed. The number of areas will also depend on the level of threat facing a given population, what resources are available to manage the areas, and the present or expected importance of a variant, i.e. its economic value and genetic distinctiveness (FAO/DFSC/IPGRI 2002).

How large should an *in situ* conservation area be? For many tropical tree species, it is difficult to estimate the minimum viable population size that will ensure long-term maintenance of adequate genetic diversity. For most tropical tree species, we lack detailed biological information on sexual systems, incompatibility mechanisms, flowering patterns, pollination vectors and gene flow. However, general guidelines based on current scientific understanding do exist.

Kageyama and Reis (1993) offer guidelines for Brazil based on different abundance categories. For common tree species with high abundance (>5 trees per hectare) and a wide natural distribution range, a large number (20) of smaller gene reserves (500ha) is likely to capture most of the genetic variation within the species. For rare species (2–5 trees per 100ha), it is estimated that a very large area (5000–10,000ha) is required to maintain a viable population. In comparison, the guidelines of FAO/DFSC/IPGRI (2002) are based on population size, and recommend that each gene conservation reserve should include a minimum of 300 adult interbreeding trees.

The guidelines include assumptions, such as low threat levels and undisturbed ecological interactions (e.g. pollinators and seed dispersers), and so should not be adopted without further consideration. These assumptions may not hold in a given country or situation, and the actual number of individuals or the size of a conservation area may vary. Depending on the frequency of different genes in a population and the type of genes (i.e. dominant or recessive), the number of trees required to conserve adequate genetic diversity is likely to range from several hundreds to several thousands (FAO/DFSC/IPGRI 2002).

The role of sustainable forest management in gene conservation

Sustainable management of forests has received a great deal of attention during the past decade. Major developments took place after the Convention on Biological Diversity (CBD) was signed at the United Nations Conference on Environment and Development (UNCED) in 1992. Before this, the concept of sustainability in forest management was commonly considered in terms of sustained wood production. Now it is also understood to cover biodiversity at all levels. Sustainable forest management has been defined as “a process of managing permanent forest land to achieve multiple objectives to produce desired forest products and services without undue reduction of future productivity, and without undue undesirable effects on the physical and social environment” (ITTO 1992).

Several international agencies have been actively developing guidelines to enhance sustainable forest management. The International Timber Trade Organization (ITTO) has published guidelines for sustainable forest management of natural tropical forests, for the conservation of biological diversity in tropical production forests, and criteria and indicators for sustainable forest management of natural tropical forests (ITTO 1990, 1992, 1993, 1998). The Centre for International Forestry Research (CIFOR) has also been active in promoting the formulation of criteria and indicators for sustainable forest management (Prabhu *et al*. 1999). Field testing of various criteria and indicators is taking place in many countries. Recently, criteria and indicators have been developed for the conservation of genetic diversity in forest ecosystems (see Boyle 2000 for a review).

Conservation of FGR is an integral part of sustainable use of forests because it maintains short-term viability of individuals and populations, and their evolutionary potential, and ensures the present and future use of FGR (see Boyle 2000). Because only a tiny proportion of tree species and their germplasm is actively and adequately conserved, the maintenance of genetic diversity in most tree species depends on how natural production forests are managed to meet human needs. It is often suggested that accelerating the establishment of tree plantations and other tree-based production systems would alleviate the pressure on natural forests, especially in developing countries. However, the present and probable future use of FGR depend heavily on tropical natural forests as only 2% of tropical forests are plantations (FAO 1999).

There is a growing consensus among scientists and practitioners that sustainable management of natural tropical forests is technically feasible, but constrained by economic, social and political factors (e.g. Reid & Rice 1997; Bawa & Seidler 1998). Commercial logging has a major impact on FGR, not only by reducing population size, but also by causing structural alterations that are likely to affect the complex ecological interactions between trees and the various animals that maintain genetic processes (Bawa & Seidler 1998; Wickneswari & Boyle 2000). Logging also reduces regeneration potential by physically damaging remaining trees and seedlings. Collection of non-wood forest products can also have dramatic genetic effects, especially if it focuses on reproductive parts such as flowers and fruits (Wickneswari & Boyle 2000).

The concept of low or reduced-impact logging has evolved in response to the need to reduce damage to the residual stand. It incorporates a number of additional measures such as pre-cutting of climbers, comprehensive timber harvest planning, directional felling, increased supervision, reduced roadside clearing and more careful road construction. The viability of low-impact logging as a standard forestry practice depends on how many additional, cost-increasing measures are included, and in what kinds of stands and sites they are applied (Ahmad *et al*. 1999; Hamzani *et al*. 1999). The concept has been developed mainly to meet carbon management, rather than gene conservation, objectives, although practices that maintain carbon stocks in natural tropical forests generally help to maintain FGR as well. Low-impact logging may not be the best way to conserve FGR in tropical production forests, but it is better than current concession-based logging practices which drastically reduce seed production and regeneration (Curran *et al*. 1999).

High-intensity logging is likely to cause an immediate reduction in genetic diversity and so lead to inbreeding. In a ridge forest in Peninsular Malaysia, a 56% reduction in basal area due to logging reduced genetic diversity by 5–23.4% (measured less than one year after logging) in five species with different life histories (Wickneswari & Boyle 2000). The long-term genetic consequences of logging, however, may not always be as dramatic because ample seed or seedling banks and gene flow from undisturbed areas may compensate for immediate losses in genetic diversity. Compared with an unlogged site in lowland dipterocarp forest in Peninsular Malaysia, no adverse changes in the genetic diversity of six species were detected in sites logged over 40 years ago with a reduction in basal area of 13.5% and 40.7%

(Wickneswari & Boyle 2000). These findings suggest that low-impact logging has the potential to promote the conservation of FGR in tropical production forests, even though natural forest management often has a simplifying effect on biodiversity at higher levels (Bawa & Seidler 1998). More studies on the genetic aspects of sustainable forest management are urgently needed.

Networking and conservation of forest genetic resources in Asia and the Pacific

As we have discussed above, the conservation and management of FGR require information on complex phenomena and processes. This underscores the need for more holistic approaches, both regionally and at the national level. In addition, a lack of human and financial resources to integrate new research results into practical forest management is an obstacle in many countries. Research is often duplicated because previous results remain localized; their dissemination prevented not by selfish motives but by the lack of a suitable channel for distribution.

Through networking, it is possible to avoid duplicating research efforts and create synergies among collaborating institutions and other stakeholders. Networking promotes partnerships and more efficient use of limited resources. It can also enhance the dialogue between scientists, managers, policy makers and users, and increase interaction between different sectors at a national level. This is a precondition for sustainable forest management. A network with a holistic approach, therefore, has the potential to enhance conservation and management of FGR in the Asia-Pacific region.

The concept of networking on FGR is not new to the Asia-Pacific region. A number of species-specific networks already operate in the region. These include the International Neem Network, TEAKNET, the International Network on Leucaena Research and Development (LEUCANET), the International Network on Bamboo and Rattan (INBAR) and the International Centre for Research and Training on Seabuckthorn (ICRTS) (see Sigaud *et al*. 2000 for a review). In addition to these, there is the South Pacific Regional Initiative on Forest Genetic Resources (SPRIG), a network for several island states. The global Tropical Montane Cloud Forest Initiative, which focuses on biodiversity conservation, also operates in the region.

Most of these networks try to promote better management of the genetic resources of a single species or group of species. They frequently emphasize tree improvement. Improved management of the genetic resources of economically important species is important, but existing network activity mainly focuses on plantation forestry or agroforestry. The management of genetic resources in natural forests has received little networking attention.

This lack of attention is surprising, given that natural forests in Asia and the Pacific provide raw materials for many economically valuable goods and products, as well as many important environmental services. Dipterocarps are a good example of this negligence. Timber and non-timber products derived from dipterocarps provide substantial revenues for many countries, particularly in Southeast Asia. Their importance at the local level is also considerable—lowland tropical rainforests, commonly dominated by dipterocarps, support a huge array of biodiversity and support the livelihood of rural people in numerous ways. Several institutions have been conducting research on dipterocarps and their genetic resources, but the main constraint to progress has been a lack of coordinated action with well-defined objectives and priorities (Bawa 1998).

In a recent regional seminar (26–27 March 1999), the member institutions of the Asia Pacific Association of Forestry Research Institutions (APAFRI) presented their visions and country-based research needs (APAFRI 1999a, 1999b; Hoon & Awang 2000). The seminar's recommendations on networking can be summarized as follows (APAFRI 1999b):

- Information support services at national and institutional levels should be upgraded so that the national, regional and global knowledge pool can be better utilized.
- Area and skills-based regional and global networking efforts should be strengthened.
- APAFRI should promote information exchange in rapidly developing areas of science such as biodiversity assessment and conservation, and biotechnology.
- APAFRI should also support the establishment of research networks to meet the needs of its members and to strengthen cooperation among researchers.

In addition to these recommendations, many papers and country reports presented at the seminar identified other needs for research and development closely related to conservation and use of FGR, for example sustainable management of natural forests, tree improvement and tree domestication (Hoon & Awang 2000). A need exists, therefore, to enhance information exchange and cooperation for more efficient conservation and sustainable use of FGR in the Asia-Pacific region. A formal FGR network could fulfil this need and APAFRI has the potential to facilitate any networking effort in cooperation with relevant international and regional institutions.

Conclusions

Conservation of FGR aims to maintain the evolutionary processes of forests and the diverse genepools they contain for present and future use. Conservation of FGR is a cornerstone of truly sustainable use of forests. It is widely recognized that conservation or sustainable forest management cannot be successful without a broad planning process involving different actors within and outside the forest sector, as well as an inter-sectoral policy dialogue. The capacity of national institutions to carry out FGR conservation should be strengthened, and FGR conservation programmes should be included in national plans for forestry and biodiversity conservation (National Research Council 1991; Palmberg-Lerche 2000).

Conservation of FGR should be viewed as a continuous process, which begins by selecting priority species. Priority setting should be done in consultation with various stakeholders, and should be based on threats, present or potential values, and the resources that are available for conservation. The subsequent selection of populations for conservation requires information on the amount and distribution of genetic diversity if conservation activities are to be targeted effectively. Compared with *ex situ* conservation, *in situ* conservation has certain benefits, but different conservation methods should be applied in a mutually supportive manner, and in accordance with the costs and objectives of conservation. Sustainable forest management appears to have the potential to support conservation of FGR, but the impacts of various new management guidelines on genetic diversity in forest ecosystems require further study. In addition, several attempts are being made to use genetic criteria in forest management and forest certification schemes, but empirical evidence of their impact is currently limited.

A number of species-specific networks already exist, but research institutions in the region have indicated that cooperation on many FGR-related issues should be integrated and strengthened. There is a need, therefore, to enhance the exchange of information to facilitate conservation and wise use of FGR in the Asia-Pacific region. Regional networking is the primary means of strengthening the capacity of national institutions to plan and implement FGR conservation programmes.

References

Ahmad, S., Brodie, J. D. & Sessions, J. (1999) Analysis of two alternative harvesting systems in Peninsular Malaysia: sensitivity analysis of costs, logging damages and buffers. *Journal of Tropical Forest Science* **11**: 809–821.

APAFRI (1999a) *Regional research priorities workshop, 26–27 March 1999, Kuala Lumpur, Malaysia*. Asia Pacific Association of Forestry Research Institutions, Serdang.

APAFRI (1999b) *Regional seminar on Asia Pacific forestry research – conclusions and recommendations, 26–27 March 1999, Kuala Lumpur, Malaysia*. Asia Pacific Association of Forestry Research Institutions, Serdang.

Bawa, K. S. (1998) Conservation of genetic resources in the Dipterocarpaceae. In Appanah, S. & Turnbull, J. M. (eds.), *A review of Dipterocarps: Taxonomy, ecology and silviculture*. Centre for International Forestry Research, Bogor.

Bawa, K. S. & Seidler, R. (1998) Natural forest management and conservation of biodiversity in tropical forests. *Conservation Biology* **12 (1)**: 46–55.

Benson, E. E. (1998) Development of plant cryopreservation technology applications in agroforestry and forestry. *In International Foundation for Science (IFS), Recent advances in Biotechnology for tree conservation and management, Proceedings of an IFS workshop*. International Foundation for Science, Stockholm.

Boffa, J.-M., Petri, L. & Amaral, W. (2000) In situ conservation, genetic management and sustainable use of tropical forests: IPGRI's research agenda. In Krishnapillay, B. *et al*. (eds.), *Forests and Society: the role of research: XXI IUFRO World Congress, 7–12 August 2000 Kuala Lumpur Malaysia, Vol. 1. Sub-Plenary Sessions*. International Union of Forest Research Organizations, Vienna.

Boyle, T. J. (2000) Criteria and indicators for the conservation of genetic diversity. In Young, A., Boshier, D. & Boyle, T. (eds.), *Forest conservation genetics: principles and practice*. CSIRO Publishing, Collingwood.

Brown, A. H. D. & Hardner, C. M. (2000) Sampling the gene pools of forest trees for *ex situ* conservation. In Young, A., Boshier, D. & Boyle, T. (eds.), *Forest conservation genetics: principles and practice*. CSIRO Publishing, Collingwood.

Coles, J. F. & Boyle, T. J. B. (eds.) (1999) *Pterocarpus macrocarpus. Genetics, seed biology and nursery production*. Centre for International Forestry Research, Bogor.

Curran, L. M., Caniago, I., Paoli, G. D., Astianti, D., Kusneti, M., Leighton, M., Nirarita, C. E. & Haeruman, H. (1999) Impact of El Niño and logging on canopy tree recruitment in Borneo. *Science* **286**: 2184–2188.

Enters, T. (2000) Rethinking stakeholders involvement in biodiversity conservation projects. In Young, A., Boshier, D. & Boyle, T. (eds.), *Forest conservation genetics: principles and practice*. CSIRO Publishing, Collingwood.

Eriksson, G., Namkoong, G. & Roberts, J. H. (1993) Dynamic gene conservation for uncertain futures. *Forest Ecology and Management* **62**: 15–37.

FAO (1999) *State of the World's Forests 1999*. Food and Agriculture Organization of the United Nations, Rome.

FAO/DFSC/IPGRI (2002) *Conservation and management of forest genetic resources. Volume 2: Forest genetic resources conservation and management: In managed natural forests and protected areas (in situ)*. International Plant Genetic Resources Institute, Rome.

Geist, H. J. & Lambin, E. F. (2002) Proximate causes and underlying driving forces of tropical deforestation. *BioScience* **53**: 143–150.

Hamzani, A. M., de Chavez, A. G. & Udarbe, T. (1999) *Reduced impact logging and its implications on carbon balance*. Paper presented at the National Workshop on Forest and Carbon Sequestration, 17–18 May 1999, Melaka, Malaysia.

Hoon, T. B. & Awang, K. (eds.) (2000) *Asia Pacific Forestry Research – Vision 2010. Proceedings of a regional seminar, 26–27 March 1999, Kuala Lumpur, Malaysia*. APAFRI Publication Series No. 7, Asia Pacific Association of Forestry Research Institutions, Serdang.

IPGRI (1999) *FORGEN News. Research Update on IPGRI's Forest Genetic Resources Projects.* International Plant Genetic Resources Institute, Rome.

IPGRI (2000). *FGR Research Highlights. Research Update on IPGRI's Forest Genetic Resources Projects.* International Plant Genetic Resources Institute, Rome.

ITTO (1990) ITTO *Guidelines for the sustainable management of natural tropical forest*. ITTO Policy Development Series No. 1, International Tropical Timber Organization, Yokohama.

ITTO (1992) *Criteria for the measurement of sustainable tropical forest management*. ITTO Policy Development Series No. 3, International Tropical Timber Organization, Yokohama.

ITTO (1993) *ITTO Guidelines on the conservation of biological diversity in tropical production forests.* ITTO Policy Development Series No. 5, International Tropical Timber Organization, Yokohama.

ITTO (1998) *Criteria and Indicators for Sustainable Management of Natural Tropical Forests.* Policy Development Series No. 7, International Tropical Timber Organization, Yokohama.

Kageyama, P. Y. & Reis, A. (1993) Areas of secondary vegetation in the Itajai Valley, Santa Catarina, Brazil: perspectives for management and conservation. *Forest Genetic Resources Information* **21**: 37–39.

Koshy, M. P., Namkoong, G., Kageyama, P., Stella, A., Gandara, F. & Neves do Amaral, W. A. (2002) Decision-making strategies for conservation and use of forest genetic resources. In Engels, J. M. M., Ramantha Rao, V., Brown, A. H. D. & Jackson, M. T.

(eds.), *Managing Plant Genetic Diversity.* International Plant Genetic Resources Institute, Rome, and CABI, Wallingford.

Le, D. K. & Nguyen, H. S. (1999) *Effective conservation and sustainable use and management of tropical forest genetic resources in Vietnam*. IPGRI project progress report. International Plant Genetic Resources Institute, Rome.

Liengsiri, C., Yeh, F. C. & Boyle, T. J. B. (1995) Isozyme analysis of a tropical forest tree, *Pterocarpus macrocarpus* Kurz. in Thailand. *Forest Ecology and Management* **74**: 13–22.

Luukkanen, O. (1998) Seedling biotechnology of tropical trees: a forester's view. In International Foundation for Science (IFS), *Recent advances in Biotechnology for tree conservation and management, Proceedings of an IFS workshop*. International Foundation for Science, Stockholm.

McNeely, J. A. (1994) Lessons from the past: forests and biodiversity. *Biodiversity and Conservation* **3**: 3–20.

Marzalina, M., Khoo, K. C., Jayanthi, N. & Krishnapillay, B. (eds.) (1999) *IUFRO Seed Symposium 1998 "Recalcitrant seeds", Proceedings of the Conference, 12–15 October 1998, Kuala Lumpur, Malaysia*. Forest Research Institute Malaysia, Kuala Lumpur.

National Research Council (1991) *Managing global genetic resources: Forest trees*. Committee on Managing Global Genetic Resources: Agricultural Imperatives, Board on Agriculture. National Academy Press, Washington, DC.

Ouédraogo, A. S., Thompsen, K., Engels, J. M. M. & Engelmann, F. (1999) Challenges and opportunities for enhanced use of recalcitrant and intermediate tropical forest tree seeds through improved handling and storage. In Marzalina, M., Khoo, K. C., Jayanthi, N. & Krishnapillay, B. (eds.), *IUFRO Seed Symposium 1998 "Recalcitrant seeds", Proceedings of the Conference, 12–15 October 1998, Kuala Lumpur, Malaysia*. Forest Research Institute Malaysia, Kuala Lumpur.

Palmberg-Lerche, C. (1999) Conservation and management of forest genetic resources. *Journal of Tropical Forest Science* **11 (1)**: 286–302.

Palmberg-Lerche, C. (2000) *International action in the management of forest genetic resources: status and challenges*. Paper presented at Symposium on In situ Conservation of Tropical Arboreous Species, 46th National Genetics Conference, Simposio 11, 19–23 September 2000, Águas de Lindóia, São Paulo, Brazil.

Prabhu, R., Colfer, C. J. P. & Dudley, R. G. (1999) *Guidelines for developing, testing and selecting criteria and indicators for sustainable forest management*. The Criteria & Indicators Toolbox Series No. 1, Centre for International Forestry Research, Bogor.

Reid, J. W. & Rice, R. E. (1997) Assessing natural forest management as a tool for tropical forest conservation. *Ambio* **26 (6)**: 382–386.

Sala, O. E., Chapin, F. S., Armesto, J. J., Berlow, E., Bloomfield, J., Dirzo, R., Huber-Sanwald, E., Huenneke, L. F., Jackson, R. B., Kinzig, A., Leemans, R., Lodge, D. M., Mooney, H. A., Oesterheld, M., Poff, N. L., Sykes, M. T, Walker, B. H., Walker, M. &

Wall, D. H. (2000) Global Biodiversity Scenarios for the Year 2100. *Science* **287**: 1770–1774.

Savolainen, O. & Kärkkäinen, K. (1992) Effect of forest management on gene pools. *New Forests* **6**: 329–345.

Sigaud, P., Palmberg-Lerche, C. & Hald, S. (2000) International action in the management of forest genetic resources: status and challenges. In Krishnapillay, B. *et al*. (eds.), *Forests and Society: the role of research: XXI IUFRO World Congress, 7–12 August 2000 Kuala Lumpur Malaysia, Vol. 1. Sub-Plenary Sessions*. International Union of Forest Research Organizations, Vienna.

Walters, C. (1999) Levels of recalcitrance in seeds. In Marzalina, M., Khoo, K. C., Jayanthi, N. & Krishnapillay, B. (eds.), *IUFRO Seed Symposium 1998 'Recalcitrant seeds', Proceedings of the Conference, 12–15 October 1998, Kuala Lumpur, Malaysia*. Forest Research Institute Malaysia, Kuala Lumpur.

Wickneswari, R. & Boyle, T. J. B. (2000) Effects of logging and other forms of harvesting on genetic diversity in humid tropical forests. In Young, A., Boshier, D. & Boyle, T. (eds.), *Forest conservation genetics: principles and practice*. CSIRO Publishing, Collingwood.

Young, A. G. & Boyle, T. J. (2000) Forest fragmentation. In Young, A., Boshier, D. & Boyle, T. (eds.), *Forest conservation genetics: principles and practice.* CSIRO Publishing, Collingwood.