In situ conservation methods

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Introduction

Basic principles of conservation of genetic variation are essentially the same for all living organisms. The methods, however, may vary according to the specific objectives of conservation and the distribution and biological nature of the material to be conserved (FAO 1989). The term 'method' is often used to denote different concepts such as *in situ* conservation, *ex situ* conservation, ecosystem conservation, species conservation, static conservation, dynamic conservation and others. Here species, ecosystems, populations and individuals are considered objects of conservation and the term 'method' will be used to distinguish between basically different ways to conserve genetic resources like *ex situ* or *in situ*, dynamic or static, active or passive conservation.

Definition of *in situ* conservation is not very clear and the term has been used in different ways. The lack of clarity is in part due to *in situ* conservation being applied to wild species on the one hand and to domesticates on the other hand (MAXTED *et al.* 1997b). *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 associated with wild, naturally regenerating populations in protected areas. However, *in situ* conservation has also been integrated into managed and multiple-use forests. In its essence, *in situ* conservation focuses on conserving a genetic resource in its original ecosystem, irrespective of whether such ecosystems have been subject to human interference. It simply means that the germplasm is conserved in the locality where it is currently found, either where it is naturally located or where it has developed distinctive traits under cultivation. *In situ* genetic conservation thus involves the saving of appropriate populations over generations, in order to maintain their potential for future evolution given by the adaptively or randomly developed genetic structures within the species (KOSKI *et al.* 1997).

The *in situ* method has several advantages. It is a dynamic method of conservation, allowing for natural selection processes, *i.e.* further evolutionary potential of the gene pool and the adaptive capacity of the population. This is important since no species is

Th. Geburek & J. Turok (eds.)
Conservation and Management of Forest Genetic Resources in Europe
Arbora Publishers, Zvolen, 2005, 535–565, ISBN 80-967088-1-3

static but is continually interacting with its physical environment and is competing with other species in the ecosystem. For a species to be viable in the future, it must be able to compete and it will only maintain its competitive ability if the evolutionary process is allowed to continue. This aspect is of particular importance today in the light of the worldwide climate changes which are taking place as a result of global warming. In addition, the *in situ* conservation method has the general advantage of conserving the functions of an ecosystem rather than a population or a species which means that it normally includes a great number of associated animal and plant species including all interactions among them. Finally, another advantage of *in situ* conservation, which is most important to the evolutionary development of a species, is that it is much easier, more secure and financially more efficient to conserve a viable population of a species in its natural habitat than in an *ex situ* situation. This is particularly true for tree species, since they require a lot of area to conserve thousands of individuals (MAXTED *et al.* 1997b).

It is commonly agreed today that the big challenge in using and developing *in situ* methods, however, is to expand our vision of protected areas to include multiple use reserves (see p. 513 ff., this volume) and even to integrate conservation of genetic resources into the production system of modern forestry (ALLEGRETTI *et al.* 1996, KANOWSKI & BOSHIER 1997). An integration of conservation and utilization would be highly effective both in terms of inputs and outputs. However, there may be important constraints to this goal. In forestry, uncontrolled and undocumented movement of forest reproductive material (see p. 75 ff., this volume) or the use of genetically modified material may pose a serious threat to the maintenance of genetic identity of local populations. Use in itself may therefore pose a threat to the possible future use of certain resources. Hence, for certain species it may be essential, independent of *in situ* conservation activities, to better control commercial use and movement of reproductive material. This may for example be the case for some economically important and common species such as *Picea abies* (L.) Karst. or *Fagus sylvatica L.* In spite of such constraints, conservation of genetic resources within protected areas need to be complemented by actions outside the reserves such as forests which are sustainably managed for multiple use. According to the World Conservation Union and the World Resources Institute, the total expanse of protected areas needs to be increased by a factor of three in order to maintain the earth's biotic resources (MCNEELY *et al.* 1990). The establishment or improvement of *in situ* conservation programmes thus will remain an important task in the future.

The following sections provide guidance in developing *in situ* conservation programmes. Since most of the theoretical aspects have been presented and discussed in this book, only practical aspects will be outlined. Furthermore, since objectives, conditions, prerequisites and many other factors vary for different species and situations, there exists not one but many different possible strategies for an *in situ* conservation. The following sections discuss the relevant criteria and principles which are important for developing species- and situation-specific *in situ* means. Even if *in situ* conservation of forest genetic resources should be integrated into the overall framework of sustainable forest management, this aspect will not be discussed here any further (readers are kindly referred to FAO, DFSC, IPGRI 2001 or ROTACH 1999, 2000).

Programmes to conserve genetic resources *in situ* are best undertaken and coordinated by a designated national agency, working in cooperation with regional and local agencies, landowners and other interested or concerned parties. Conserving and managing genetic resources in practice will also have to be incorporated into more general land use planning and management, because large reserves are unlikely to be designated only for the purpose of genetic resources conservation.

In summary, *in situ* conservation is a complex activity, requiring the integration of many disciplines and different groups of people. A good understanding of the different tasks to be done, and their necessary integration into a strategy are essential, calling for a systematic approach.

A systematic approach to develop *in situ* conservation programmes

Basically, a systematic approach requires an initial phase where necessary information is collected and priorities are discussed based on known and anticipated threats to the genetic resources in question. In a second phase, species and populations to be conserved are then selected, clear objectives are defined and management plans are drawn. Finally, a monitoring system needs to be put in place which will guarantee that objectives are reached and management activities are adapted in accordance with the observed development.

The process of developing and implementing an adapted, species- and situation-specific *in situ* conservation programme may thus be divided into the following seven activities which need to be accomplished:

- collection of relevant information;
- selection of target species and setting of priorities;
- establishment of basic conservation method (active, passive, dynamic, static);
- identification and selection of populations to be conserved;
- definition of conservation objectives and specific targets;
- definition of management guidelines (if any); and
- establishment of a monitoring system.

These activities will be outlined in the following sections. It has to be kept in mind, however, that this outline cannot serve as a recipe to simply go through step by step. It rather presents how such a complex tasks may be approached in a systematic way. It is far from being exhaustive and needs to be adapted to any given situation.

Collection of relevant information

Conserving species and their genetic resources *in situ* basically means maintaining their habitats and processes in the ecosystem as natural and functioning as possible. It is obvious that this can be accomplished only if all relevant information regarding the species and its natural environment is available. Species life history traits, important natural processes and their spatial and temporal dynamics need to be understood. Demography, eco-geography and genetic structure of the species should be ideally known as well as their habitat requirements. In order to be able to decide on conservation priorities and measures, threats and human impacts on the species or its natural environment need to be known. Finally, information on socio-economic values, current conservation status, existing relevant protected areas, ownership, stakeholders and many other practical or political factors are essential for efficient, well integrated, and realistic solutions.

In practice, however, very limited information is usually available, because resources for research are limited and the potential number of species to investigate is vast. Since threats to genetic resources may have severe, long-lasting and irreversible effects, it is unwise in most cases to delay conservation activities, although relevant information is incomplete. In such a situation, an approach based on systematic and robust principles and relying on best possible guesses may be more appropriate than waiting for elusive research data (FAO, DFSC, IPGRI 2001).

The overall objective of an *in situ* conservation programme is to ensure that the maximum possible range of genetic diversity is represented within the minimum number and size of reserves, established and run with a minimum of costs (MAXTED *et al.* 1997b). Since genetic conservation is a long term task for the benefit of future generations, reserve sites as well as site conditions should be sustainable for the foreseeable future. In order to minimize the need for interventions and thus running costs, populations selected as *in situ* reserves should possibly be growing under optimal habitat conditions, in sufficiently large, viable populations and in ecosystems with a maximum of intact natural processes and functions. In order to achieve these rather complex objectives, detailed information is required, especially on:

- population structure with its spatial and temporal dynamics,
- eco-geographic distribution of the species and its genetic structure;
- autochthony of populations, value and potential of the genetic resources;
- habitat requirements and habitat breadth of the species, availability and quality of habitats;
- life history traits – biological and ecological characteristics of the species;
- relevant biotic and abiotic factors of the natural ecosystem, including interactions and natural processes, dynamics of relevant processes, their sensibility to human impact and their actual status;
- threats to the species and its environment, causes and intensities, current conservation status;
- socio-economic value, importance of resources from an international perspective;
- existing protected areas, ownership, stakeholders, land use planning, legal and financial factors and other relevant information.

Table 1 presents an overview over this information, how it relates to the outlined activities in developing an *in situ* conservation programme and what sources may be used to collect the information. The details are discussed in the following sections.

Table 1. Basic information needed for the establishment of a network of *in situ* conservation areas.

Information on	Used for assessing	Source of information
Abundance Population structure Demography Dynamic	Endangerment: • demographic, environmental and genetic uncertainty, risks • natural vs. artificial distribution, fragmentation, declining populations, isolation, human impact • rarity, endemism (threat, priority species) Identification and selection of potential populations: • hot spots, core, outlier, peripheral populations • fragmentation, linkage, gene flow • GAP analysis Definition of conservation objectives	Inventories Inquiries (forest service, experts) Other sources of information (old distribution maps, flora's, vegetation databases, *etc.*) Combined GIS layers of distribution maps and maps of protected areas
Eco-geographic distribution Genetic structure	Identification and selection of potential populations: • differentiation, distinct populations • most diverse populations • range of environments to cover • number and distribution of reserves Design of reserve network Definition of conservation objectives	Combined GIS layers of distribution maps, vegetation maps, maps on geology and soil types, maps of eco-geographic zones, elevation models Genetic inventories or other genetic information (provenance trials)
Autochthony Value of genetic resources	Identification and selection of potential populations • valuable wild gene pools • valuable landraces • special resources of interest (morphotypes-genotypes, ecotypes) • exclusion criteria	Forest history Planning and management documents

Table 1. (continued).

Information on	Used for assessing	Source of information
Habitat requirements Habitat quality and availability	Identification and selection of potential populations: • viable populations with best ecological chances for future development Endangerment and risks: • human impacts • status of natural processes Definition of basic conservation methods Definition of management guidelines	Vegetation and soil maps Ecological, botanical, silvicultural literature Research results Disturbance indicators, present *versus* natural vegetation, history Field work
Life history traits Biological, ecological characteristics	Identification and selection of potential populations: • design of reserve network • viable, most self sustained populations Endangerment and risks: • breeding system, gene flow, migration • competitiveness • sustained regeneration • demographic and environmental uncertainty Definition of basic conservation methods Definition of conservation objectives Definition of management guidelines	Ecological, botanical, silvicultural literature Research results Observation Field work
Biotic factors, natural processes, actual status	Identification and selection of potential populations: • viable, most self sustained populations Definition of basic conservation methods Definition of conservation objectives Definition of management guidelines	Ecological, botanical, silvicultural literature Research results Observation Field work

Table 1. (continued).

Information on	Used for assessing	Source of information
Threats Conservation status	Endangerment and risks: • Selection target and priority species Definition of basic conservation method Definition of conservation objectives Definition of management guidelines	Compiled from different information above Map of protected areas
Socio-economic value International perspective	Selection of target and priority species	Markets, stakeholders, species distribution and density maps
Political, financial and practical frame	Identification and selection of potential populations: • coordination, integration in land use planning • sustainability and protection in the long run • exclusion of conflicts Selection of target and priority species Design of reserve network	Link with other governmental and non-governmental organizations Overall national conservation objectives Diverse sources

Selection of target species and setting of priorities

Setting priorities for forest genetic resources conservation and use is essential for the efficient allocation of limited resources of time, funds and personal (BAWA & KRUGMANN 1991, KEMP 1993). Therefore, in a first step, target species and their order of priority need to be carefully evaluated. The identification of genetic resources of priority on the species level is a cost/benefit consideration which may be based on the following criteria.

Current conservation status:
- number of populations and area which are already protected;
- range of eco-geographic distribution covered with protected areas;
- status and quality of protected areas, integrity;
- sustainability of target species within protected areas;
- *ex situ* measures.

Threatened species:
- rare species *i.e.* species occurring in highly fragmented populations, few locations only, small populations only, low density only;
- declining species (abundance, area, number of populations)[1];
- species with narrow habitat requirements (specialists);
- highly utilized or overexploited species;

[1] see also http://www.redlist.org/info/categories_criteria.html.

- species restricted to habitats strongly influenced by human activities;
- species which are experiencing other decisive negative impacts (biotic or abiotic factors, declining or insufficient habitat quantity or quality, grazing, burning ..).

Socio-economic value:
- economic value;
- potential value, intrinsic value;
- biological value (keystone-species, species supporting high biodiversity ..);
- cultural value.

Responsibility from an overall (international) perspective:
- endemic species;
- center of distribution;
- large remaining populations, important gene pools;
- high eco-geographic differentiation.

Distinctiveness of gene pools:
- gene pools existing under extreme situations, at the limit of distribution;
- different migration events, glacial refuges;
- old centers of diversity.

If sufficient genetic diversity is already safely and sustainably conserved from the full range of ecological habitats and geographical locations, then further active conservation may not be necessary. This may for example be the case for wide-spread, common species such as *Picea abies* or *Fagus sylvatica*. Care must be taken, however, when assessing information on current protected areas since in most cases these areas were not primarily dedicated to the objective of genetic conservation (see p. 513 ff., this volume). The fact, that a species is occurring within a reserve, does not necessarily mean that it is safely protected, since the number of individuals may be declining due to the natural dynamic, lack of management or inappropriate management for the sake of genetic conservation. The natural dynamics of the ecosystem in question thus need to be carefully analyzed, requirements and life history traits of the target species thoroughly reviewed, potential and likely developments of the system evaluated and compared to existing management plans. This will finally allow to decide if existing reserves are suitable for the sustainable protection of the genetic resources of the target species as such, with additional measures or with an adapted management plan. This will further be discussed in section 'Establishment of basic conservation method'. The contribution of protected areas to the conservation of genetic diversity also depends on some additional factors (BOYLE & SAWYER 1995, MACKINNON *et al.* 1986). Important factors that need to be considered when the conservation status of a species is evaluated are, for example, the optimal distribution of protected areas across the landscape and an adequate representation of eco-geographic zones, sufficient size and suitable design of the reserves (little edge effects, buffer zones) and sufficient integrity of the reserves, including levels of protection and extent of acceptance and respect of owners and other stakeholders.

Clearly, certain species are in more danger of genetic erosion, *i.e.* loss of genetic diversity or even of complete extinction than others. Evaluation of such risks is a rather complex task, however, which requires a lot of profound information. This is especially true regarding the demography of the species and its dynamic over time and space since biological, demographic and genetic stochasticities and risks largely depend on the population structure and the changes made through human activities. Even if the relationship between rarity and endangerment is influenced by a lot of different factors (life history traits, mating system, natural *versus* artificial population structure, habitat availability and quality and many others), and rarity occurs in different forms (RABINOWITZ 1981), rare species clearly have a higher risk to face genetic erosion or even extinction than common and widespread species. The IUCN Red List categories (IUCN 2001) are based on important demographic indicators for different forms of rarity and may be useful to assess the threat. In order to qualify for a category of threat, one of the following evidence is needed: (a) population is seriously declining or is expected to decline at a specified rate, (b) population is localized, fragmented and declining at an unspecified rate, (c) population is small and declining and either fragmented or localized, (d) population is very small or localized, and (e) quantitative analysis shows a specific probability of extinction.

Habitat requirements are another decisive factor regarding endangerment. Species with narrow habitat requirements (specialists) are likely more threatened than generalists. Degradation of habitats through human impact may mean a high level of threat for some species while other species may profit from such a situation (for example pioneer species). A thorough evaluation of threats and their causes may not only help to select and prioritize species for conservation programmes; results already indicate reasonable conservation activities which need to be undertaken. As an illustration, consider the case of a species that is naturally restricted to narrow habitat conditions, like *Populus nigra* L. which is occurring naturally only in dynamic floodplains. In order to conserve black poplar, which is threatened in many European countries, it will not suffice to protect a number of *in situ* populations. In many cases the conditions of the river systems and its dynamic have been altered by human activities to such an extent that *P. nigra* is no longer regenerating naturally (LEFÈVRE *et al.* 2001). In such situation, conservation activities first need to improve or even restore the original habitat, *i.e.* to allow for flooding events or alternatively to create suitable conditions for natural regeneration by technical measures. Otherwise, conservation efforts will neither be efficient nor successful in the long run.

Assigning socio-economic values to species or its genetic resources is a complex, highly debatable and controversial task (see p. 89 ff., this volume). Depending on the perspective, value assigned to one and the same species will differ enormously. Defining socio-economic values is mainly a social or ethical problem. In spite of this, the choice of target species should be as objective as possible, based on logical scientific and economic principles related to the perceived values of the species (GIVEN 1994, MCNEELY 1988, PEARCE & TURNER 1990). Because perceptions and weights which are assigned to the different criteria generally are highly controversial, it is important that any selection based on socio-economic values of species is not only transparent but also widely supported by various stakeholders (GOs and NGOs). It also has to be kept in mind, that traditions, cultural importance, use and other factors (even mystic perception) associated with species may be equally important than economic or biological values; decisions and activities may otherwise not be sufficiently accepted and respected by certain groups. Finally, it has been argued by several authors (GIVEN 1993, PEARCE & MORGAN 1994) that biodiversity is more prone to depletion if a species has little or no perceived value to humans because it is less likely to be given high conservation priority. From this it follows that each plant species is ascribed a comparative value and that the value given will have a marked effect on commitment of conservation; therefore it is important that overall value is ascribed as objectively as possible.

For highly valued, commercialized species, information on economic value is easily available. It is more difficult, however, to assess the potential of highly valuable species, which may contribute only little to overall economy simply because they are rare. The same is true for non wood products. Intrinsic values *i.e.* values that may arise in the future are another complex problem. Past experience has often shown that wild species once considered commercially 'useless' have proved on further examination to be 'useful', because they contain resistance genes (HAWKES 1990) or pharmaceutically active compounds. A nice example is Pacific yew (*Taxus brevifolia* Nutt.) which had no 'economic' interest (no value) until the substance *'taxol'* was discovered to be highly effective in cancer treatment (GOODMAN & WALSH 2001). All species certainly have intrinsic values that might become important in one or the other way for human benefits. Consequently, it could be argued that all species are equally important for conservation. However, as a selection of target species for a conservation programme is required, it is necessary to assign different weights to the different criteria and to rate existing socio-economic values higher than intrinsic values. Species value should be used with caution and may need to be revised periodically, since appreciations may change radically in the future, especially in the light of the drastic changes of the environment.

A species may be of little economic but high biological value if many associated species depend on it (CARTER *et al.* 1979, ROTACH 2003). For species occurring in sensitive, important ecosystems, or important flagship or keystone species, biological values may be given more weight than the other criteria.

Since value assignment is a complex task it may be useful to develop a system of points and weights to determine overall values of target species and in order to set priorities in an objective and as transparent way as possible.

Distribution of species does not respect national boundaries. Within the distribution area, the species and its genetic resources are not evenly distributed, due to both natural differences and human influence. Consequently, values, threats and priorities assigned to species are unequal within the distribution area. From this it clearly follows that different national *in situ* programmes do not need to select the same target species nor assign the same priorities. The responsibility for conserving any given species are surely not the same for all countries. Most countries have species for which they have a higher responsibility than other countries. National responsibilities from an overall perspective need to be defined through international cooperation between national programmes for conservation of genetic resources , such as the European Forest Genetic Resources Programme (EUFORGEN). At present, this task still has to be accomplished. It would be highly efficient in terms of costs and benefits, if the criteria of overall responsibility were considered when selecting target species and setting priorities for national conservation programmes.

It is rather evident that the highest responsibility and conservation priority for a national conservation programme has to be assigned to endemic species. High priorities and thus prime candidates for target species are also species which have (1) large remaining populations compared to other countries, (2) high environmental diversity which most likely translates into high adaptive diversity of the species, (3) their center of distribution *i.e.* their major occurrence in the country. As an illustration, let us consider the cases of stone pine (*Pinus cembra* L.) and yew (*Taxus baccata* L.) in Europe. Since stone pine is restricted to the Alpine arch, Austria, Switzerland and France clearly have a high responsibility for the conservation of this species. Yew, on the other hand, is rare and endangered in most European countries, except in Switzerland and in several East European countries. Even if the status of rarity and endangerment of yew makes it a prime target species for conservation programmes in many other countries, it may be more effective in terms of costs and benefits to concentrate conservation efforts in those countries with large remaining populations. However, such an approach faces diverse obstacles, the most important being a strong belief in the advantage of autochthonous genetic resources *i.e.* the opinion that local gene pools are both optimally adapted and adaptable to local conditions, consequently are the most valuable one and need to be conserved locally. Although there are strong arguments and results which question this view (HEYBROEK 1990, STETTLER 1986 and 1987, WILKINSON 2001). The importance of autochthonous populations for genetic conservation will further be discussed in the section on 'Identification and selection of populations to be conserved'. Local gene pools certainly may be valuable for conservation, but not because they are autochthonous but because they may be distinct compared to the overall genetic resources (see below). From this it follows, that in such situation, the species may be of lower priority, because not all the genetic resources need to be conserved through a national programme but only those parts which are distinct compared to the overall gene pool.

As already mentioned, distinctiveness of the gene pool is a criteria to be considered for the selection of target species or setting of priorities in certain situations. It may be an important criteria for borderline situations (limit of occurrence, edge of the distribution) where unique genetic resources exist that need to be conserved from both a national and overall perspective. This may be a reason to select a species for a national conservation programme, although it is both rare and has no economic nor other values. Distinct gene pools especially from the limit of the distribution area of a species (horizontally as well as vertically) most likely will play an important role in the future, given the environmental changes that are predicted.

Establishment of basic conservation method

MAXTED *et al.* (1997b) made the distinction between 'active' and 'passive' *in situ* conservation. Plant species are conserved in numerous environments unlikely to be considered genetic reserves, such as national parks, regional parks, natural reserves, landscape parks and many more; in each of these reserves the existence of particular species is coincidental, therefore passive, and not the result of active conservation management. These populations or particular species are not actively monitored and thus are more vulnerable to loss or even extinction, because unfavorable environmental or biological trends would not be noted and measures to counter not adopted. In this sense, active conservation requires positive action to promote the conservation of the target species and the maintenance of the natural, semi-natural or artificially created ecosystems which contain them, including the need for associated habitat monitoring, restoration, management and protection. While conservation of genetic resources is a primary objective of most types of protected areas (McKinnon *et al.* 1986), the general inadequacy of existing protected areas for genetic resource conservation is well recognized (IUCN 1993, *loc. cit.* pp. 175–176). Several reasons are responsible for this fact. Current protected areas commonly do not have an optimal location for conservation of genetic resources, because they do not sample all the species or the genetic variation within a target species. Moreover, the fact that an area is protected does not necessarily mean that a species occurring within the area is safely protected, since the population size may decline due to the natural dynamic, lack of management or inappropriate management for the species in question. Hence, for many target species additional conservation efforts *i.e.* active conservation in managed populations is required (FAO, DFSC, IPGRI 2001). Nevertheless, current protected areas do provide important conservation of many species, and thus are important pinpoints for the establishment of a network of *in situ* conservation areas. Their value for genetic conservation, however, needs to be carefully evaluated case by case.

For this reason, the basic conservation method *i.e.* active or passive *in situ* conservation needs to be established for each target species and given situation. While certain species may be conserved *in situ* without the necessity for active management, other species will need various protective and management measures to ensure the continued existence of the species, habitat conditions, ecosystem functions or associated species. Species thus generally differ in their basic conservation method. Highly competitive species such as the climax species *Picea abies* or *Fagus sylvatica* do not need active conservation in most cases because they are dominant and regenerate easily without any intervention. Other species such as pioneer species (*Betula* spp., *Salix* spp.) or specialists tolerating extreme site conditions (such as *Populus nigra* L., *Quercus pubescens* Willd., *Sorbus torminalis* [L.] Crantz) are week competitors; they either occupy a site only for a limited time, are restricted to very narrow habitat conditions, are highly dispersed or occur in highly influenced or man-made environments. Tree species with a metapopulation structure in which local subpopulations become periodically extinct with re-colonization from neighbouring subpopulations are at high risk of being permanently lost from small reserves. In strict reserves, such species are prone to disappear without active intervention in favor of them.

The basic method for a species may, however, partly depend on the environmental situation or the specific habitat conditions since both influence the competitive ability of the species and the natural dynamic of a given plant community. This means that, even if a general basic method applies to a given species, it may differ for each situation depending on the specific site conditions, the plant community and other factors such as former treatment or the naturalness of the ecosystem.

Consequently, for each case, the natural dynamic of the plant community in question needs to be carefully analyzed, requirements and life history traits of the target species thoroughly studied, potential developments of the system evaluated and then compared to the objectives and targets of conservation. Results will help to decide if passive conservation is sufficient or if active conservation is needed and what kind of management will be suitable for the objectives of *in situ* conservation of the target species. Finally, findings will allow to decide if the existing protected areas are suitable for the continued conservation of the genetic resources of the target species, which areas are best suited for this purpose, what kind of interventions, if any, are indispensable and whether conflicts between the different objectives exist, in what form and if and how they can be resolved.

In situations where passive conservation is compatible with the conservation objectives and targets, existing reserves may be included in the network of *in situ* conservation areas, as long as they fulfill other important criteria such as sufficient size, adequate value of the genetic resource, suitable design and sufficient protection. It is obvious that the network of existing protected areas should form the core of any *in situ* conservation system since costs may be kept as low as possible; additional conservation areas need to be established only in locations or environmental conditions which are under-represented in the network. Hence, to qualify as a potential new reserve, an area ideally should cover identified gaps and suffice other criteria such as sufficient size, adequate conservation value of the resource, the possibility for adequate long term protection or the lack of conflicts with other objectives. For certain species which allow for passive conservation such as the common widespread climax species *Picea*, *Fagus* or *Abies*, *in situ* conservation of genetic resources may in fact already exist to a large extent with only few new conservation units.

For species that ask for active conservation, long-term development of the stand and of its biotic and abiotic environment need to be analyzed in the light of the current management regime in order to project the likely development of the target species and on potential changes in the management.

For any given target species, a pragmatic approach could comprise the following steps:

(1) establish the basic conservation method based on relevant life history traits, silvicultural knowledge of the species and stands, the natural environment and dynamic of the system;

(2) review the network of existing reserves with respect to the occurrence (abundance, population structure) of the target species; collate all relevant information on the species in each reserve;

(3) in each reserve, reflect the basic conservation method of the target species with the specific habitat conditions, status of protection, recent and potential development, existing management regime, and determine the need for area specific protective and management measures;

(4) for each reserve, compare the new conservation objectives and protective and management measures with the already existing objectives and management regime, identify conflicts and evaluate possible solutions;

(5) retain reserves which are suitable for *in situ* conservation of target species; review them in the light of other important factors (size, restrictions, *etc.*) make final decision on suitability of existing reserves;

(6) establish, review or refine the distribution map of the target species and identify

'core populations' 'peripheral populations' or 'outlier populations';

(7) overlay distribution map of target species and map of selected reserves and identify potential gaps, if needed, list potential new areas or populations;

(8) if needed, rank potential new areas or populations according to other important factors such as size, ownership, distinctness of genetic resource, occurrence of other target species, naturalness, habitat conditions (see next section);

(9) if needed, select and establish additional conservation areas in order to complete the network of *in situ* conservation areas.

This pragmatic approach involves rather complex multi-criteria evaluations which ideally are supported by GIS (PRESSEY *et al.* 2000). Practically, the process involves finding criteria to evaluate existing protected areas (*e.g.*, the number and size of 'core',' outlying' or 'peripheral' populations it contains, the uniqueness or redundancy of genotypes it covers, its size and species composition) and potential new reserves. Selection criteria for the identification and location of new reserves are discussed in more detail in the following section.

Identification and selection of populations to be conserved

Many different criteria are associated with the selection of *in situ* conservation areas. In addition, weights and importance of the different criteria vary among species and specific situations and depend on the overall objectives of *in situ* conservation and the financial means which are available for conservation. Hence, selection of populations for *in situ* conservation is a rather complex task which is not only guided by pure scientific considerations but also by national and local priorities, strategic considerations and higher-level objectives of different kinds (*e.g.*, land use, conservation policy, forest policy, silvicultural management, legislation). For the identification and selection of populations as *in situ* conservation areas, the following criteria are useful:

- conservation value of resource population;
- distribution of genetic variation or eco-geographic distribution of target species;
- population structure of target species *i.e.* abundance, pattern of distribution, population size, core populations, outlier populations, peripheral populations;
- areas of special interest (*e.g.*, suitable existing reserves, areas with high species diversity, populations at risk in need of immediate attention);
- integrity of stand, ecosystem and habitat conditions, natural dynamic;
- land use planning, acceptance, ownership, conflicts with other land use, available finances.

Regarding the value of genetic resources, highly contrasting views exist. These questions, however, are very fundamental and should be answered and agreed upon from the very beginning of any conservation activity. It is rather astonishing to note, however, that in many existing conservation programmes it has not been clearly stated which genetic resources are valuable for what reasons and what priorities are applied when selecting them. Even on an international level, organizations dealing with genetic conservation such as EUFORGEN have not yet agreed upon criteria and priorities that may be used to assess the value of genetic resources.

The values of genetic resources depend on the objectives of genetic conservation and the priorities among them. There has however been considerable confusion over the issue of genetic conservation being for utilitarian purposes or to maintain natural evolutionary processes (YANCHUK 2001). In addition, there are opposing views regarding the question if conservation for most of the ecological concerns is met at the same time when objectives for utilitarian objectives are fulfilled. The different goals of *in situ* conservation that have been proposed and discussed in the literature (see for example KRUGMANN 1984, LEDIG 1986, ZIEHE *et al.* 1989) can be summarized in three major conservation objectives:

(1) conservation of economically important phenotypes or genes;
(2) conservation of adaptedness to given environments;
(3) conservation of genetic diversity and genetic adaptability.

Conservation of the genetic basis for certain desirable traits is the most common and traditional objective. Specifically, high frequencies of certain traits or certain trait combinations, *i.e.* the underlying genes or gene complexes are the object of conservation. Commonly, seed stands, plus tree collections, clonal archives, seed orchards, provenance trials or progeny tests serve as basic material for conservation. Neither origin nor integrity of a genetic resource is important; autochthonous populations, imported foreign provenances, landraces or selected and tested material from breeding programmes may serve as conservation populations (see p. 567 ff., this volume). According to NAMKOONG (1997), breeding populations are important components in conservation and, if properly structured, may be all that is needed.

Conservation of a population's adaptedness to a given environment is a common objective in nature protection. Because the genetic structure of a population is seen as the result of long lasting selection driven by environmental factors, local genetic resources are believed to be adapted to current habitat conditions and therefore are viewed as the most valuable resources. This may especially be the case for populations occurring under extreme habitat conditions. Object of conservation are therefore autochthonous gene pools while other genetic resources are of inferior value from this perspective.

A third approach is focussing on the conservation of genetic adaptability of a given species or the conservation of a maximum of genetic diversity within that species. Both objectives are largely identical, since genetic diversity is the basis for adaptation and evolution in a changing environment and an important buffer against pathogens and climatic extremes. Genetic diversity is thus highly valuable as such and needs to be conserved (LEDIG 1986). In addition, phenotypic (genetic) variation is also important for both improvement of economically important traits in the future and protection of these products by breeding for resistance traits against all kinds of pathogens. In order to capture as many genes as possible, especially rare or unique genes, populations to be conserved for this third objective are commonly selected among autochthonous gene pools which possibly sample a variety of different environments and have experienced little human influence. The conservation of rare genes requires large populations while conserving a maximum of genes and unique genes requires many populations from a maximum of different environments. Information on the genetic structure of the target species is needed to solve this dilemma of better selecting few but large populations or many but small populations.

Since target species differ with respect to their value for timber production, their range and pattern of distribution, their genetic structures, risks and threats to their gene pools and human impact on their gene pools, it follows that objectives of conservation differ considerably among species, especially regarding the priorities among the three major objectives. Hence, in a first step, objectives and priorities need to be clarified and decided on for each target species. Then, in a second step, values can be assigned to genetic resources and priorities among them can be defined. For species with a high economic importance, phenotypically selected and tested genetic resources certainly will have higher priority than autochthonous genetic resources, while it may be the opposite for species with little economic importance. Clearly defined priorities among the three major conservation objectives are a necessity for the establishment of any effective, cost efficient network of *in situ* conservation populations. Clear objectives and clearly assigned values to genetic resources are needed because number, size and distribution of the conservation populations depend on it. For the conservation of economically important genes, for example, a smaller population size is acceptable than for the conservation of genetic diversity or rare genes. In most cases, a combination of all three major objectives is needed, however, with different priorities among them, depending on the target species and specific situation. Assignment of values to genetic resources will help to come up with a suitable, cost efficient and highly effective network of different *in situ* genetic conservation areas.

Genetic conservation of forest tree species often concentrates on autochthonous resources (FINKELDEY *et al.* 2000, FRANK & MÜLLER 2003, KOSKI *et al.* 1997). In most cases, it remains unclear, however, why only autochthonous populations are selected as genetic reserves. The example of Norway spruce may serve as an illustration. The 'Technical guidelines for genetic conservation of Norway spruce (*Picea abies* (L.) Karst)' issued by EUFORGEN (KOSKI *et al.* 1997) does neither state conservation objectives and priorities nor does it assign values to the different genetic resources. Autochthony and an area greater than 100 ha are the only requirements for a genetic reserve. For an economically important species such as Norway spruce, one would however rather expect an emphasis on the conservation of the economically important genetic resources (including the results of breeding programmes) in combination with the preservation of the genetic diversity of the species. The importance for the conservation of genetic adaptability within the distribution area of Norway spruce differs of course; it clearly deserves a higher importance in areas with distinct environmental gradients as in Scandinavia or alpine regions, while it is less important in other areas of its natural range. Accordingly, objectives and values of genetic resources are expected to differ, and autochthony of populations is expected to be of more or less importance. In fact, rather different objectives and values for genetic resources than the ones recommended in the technical guidelines have been adopted by east European countries (PAULE *et al.* 2000) where seed stands and plus tree selections are considered as principle resources for genetic conservation. Accordingly, genetic reserves are established within the most valuable and approved seed stands which are used for production forestry and are more than 100 ha in size. A well balanced approach regarding the objectives and different values of genetic resources has been adopted by Germany (PAUL *et al.* 2000).

The selection of stands and populations for inclusion in a network of *in situ* conservation areas for a given target species ought to be based on the distribution of genetic variation, within and between geographic regions. All major gene pools should be conserved, but the number of conservation units on the other hand needs to be limited to a manageable, affordable level (GRAUDAL *et al.* 1997). Genetic variation can be assessed by different techniques. It is possible to study morphological and metric traits in field trials, biochemical and molecular markers or to guess on possible variation patterns from ecogeographic variation (see p. 275 ff. and p. 337, this volume). Unfortunately, genetic studies are only rarely or partially available, and even when data exist there are some difficulties in readily using such information for identifying conservation stands. However, populations of known superiority or distinctness (for example populations with high genetic diversity or differentiation, unique alleles, special traits, representing various migration routes) should be given special attention. The same holds true 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, a suitable approach would be to include different sites of the species biogeographic distribution area and selecting conservation areas more or less uniformly throughout the species range, together with any disjunct or unusual populations (LEDIG 1986). A somewhat more refined method is to apply a genecological[2] approach (GRAUDAL *et al.* 1995, 1997), which leads to the identification of different genecological zones. It is generally assumed that similarity of ecological conditions implies similarity of genetic constitution (FRANKEL 1970). This is based on the assumption that local adaptation through natural selection is the overriding force in the process of genetic differentiation between populations. In a landscape level analysis of genetic resources for *in situ* conservation we may then assume that genetic differentiation has tracked geographic and ecological variation (YANCHUCK & LESTER 1996) and that by providing spatial coverage for eco-geographic variation genetic variation will automatically be covered as well. Even if this may not be 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. However, unusual genotypes or rare genetic variants may be located in outlying populations or at the edge of the species range. Depending on the objectives of conservation, these populations may be of special interest. These populations are likely to fall through the 'coarse filter' based on eco-geographic zones and an additional effort must be made, if possible, to identify such genetic resources.

A comparison of the species distribution with well defined ecological zones will provide a good basis for the initial selection of conservation populations. Genecological zonation consists in identifying areas with uniform ecological conditions. Ecological zones can be derived from existing data and maps of vegetation, topography, climate and soil. Natural vegetation reflects the combined effects of the most important ecological factors and site conditions, topography or land form influences climate and soils and thereby vegetation while different aspects of climate are the most decisive factors for the distribution of plant communities. Fairly elaborate examples of practical

[2] Editors' remark: The word 'genecological' is here not used in its original meaning (see p. 279, this volume)

application of genecological zonation are found in GRAUDAL *et al.* (1995, 1997, 1999) and THEILADE *et al.* (2000, 2001).

Depending on the number and size of genecological zones, more than one population per zone should be selected, if possible. Especially for widespread, highly outcrossing species such as trees which often exhibit a semi-continuous pattern of genetic variation, more than one population may be necessary to sufficiently sample genetic structure (FAO, DFSC, IPGRI 2001). For species with scattered and disjunct distribution patterns many more perhaps smaller conservation areas are likely to be needed. In practice, the number of populations that needs to be selected as *in situ* conservation areas also depends on the levels of risks or threats at the population level, especially for rare and threatened species, the resources available to manage and maintain them, the values of existing genetic resources and the genetic distinctiveness found within the area and species. Hence, there does not exist such thing as a recommended number of *in situ* reserves; the number of reserves needs to be determined for each species and given situation separately.

The evaluation of potential populations based on genetic variation and/or eco-geographic distribution of the target species may result in a first overall idea for a network of *in situ* reserves. In several following steps, this 'backbone' of reserves needs to be modified and completed:

(1) existing suitable protected areas are designated and missing or under-represented areas (eco-geographic zones) are identified;

(2) potential populations occurring in the missing areas are identified and evaluated based on additional criteria such as population structure of target species, size of populations, type of populations (core, outlier, peripheral), populations of specials interests (threatened populations, important populations (gene flow, linkage, stepping stones), populations containing other target species, genetic or morphologic distinct population and possibly other criteria;

(3) the practical (ownership, legal status) and financial context needs to be reviewed because the final solution should be widely accepted and integrated in land use practices and be cost efficient and manageable.

Some of the mentioned criteria for the evaluation of *in situ* reserves will be discussed in more detail in the following paragraphs.

Knowledge about the population structure and demography of the target species is important in many different ways. From the pattern of species' distribution, risks and threatened populations may be inferred, core populations and outlier populations can be identified, and an adequate number of conservation areas (genecological zones, core and outlier populations, *etc.*) may be derived. Information on the demography of the species will help to identify areas of increased risks and threats that may need special attention. Moreover, isolated populations, gaps and existing barriers to gene flow which can be bridged or populations which are essential to link other populations need to be identified because such populations are of special interest as *in situ* reserves. Core and outlier populations are other focal points of special interest. Core populations are especially valuable for conservation, since they are the largest and most likely also the most viable populations that exist, growing under the best possible conditions. Outlier populations, on the other hand, may contain unique genes or different adaptive traits.

Empirical and theoretical studies show that peripheral populations are often genetically and morphologically different from more central populations, and that their conservation may be beneficial to the dynamic conservation of a target species (LESICA & ALLENDORF 1995). Peripheral populations, given their edge of range conditions and possibility of harboring rare genes, are of particular importance in providing the capacity to adapt to future climate change (*e.g.*, GUNTER *et al.* 2000). Hence, if maintaining genetic diversity and conserving adaptability and rare genes is an objective of *in situ* conservation, outlier and relict populations as well as populations at the edge of species distribution should even be over-represented in a network of *in situ* reserves because such populations not only have a higher chance of containing rare genes and gene combinations, but also may have an increased risk of losing them (FRANK & MÜLLER 2003).

As genetic diversity can be continuously eroded in small populations, conservation populations need to be large enough to conserve the existing genetic variation over generation. While low-frequency genes will be lost quite quickly from small populations, a large proportion of the genetic variation can be conserved by relatively few individuals, at least over few generations. If the objective of conservation is the maintenance of economically important genes, even rather small populations may be selected as conservation populations (NAMKOONG 1997, YANCHUK 2001). If, however, the major objective of conservation is the maintenance of genetic diversity and the conservation of low frequency genes, this leads to much larger population size requirements (see p. 413 ff., this volume). Again, the objectives of *in situ* conservation are decisive. In practice, the size of conservation stands will be highly variable, although too small populations are best avoided whenever possible.

For the maintenance of normal adaptive potential in quantitative traits (steady state of mutation and drift), LYNCH (1996) has suggested that 1,000 individuals would be an adequate effective populations size. For the conservation of genetic diversity 2,000 to 3,000 individuals are recommended (KRUSCHE & GEBUREK 1991), and for the maintenance of rare genes (< 1 %) a census number of 5,000 or more appears to be adequate for *in situ* populations in natural or wild situations for most types of low-frequency alleles (LANDE 1995, LAWRENCE & MARSHALL 1997). In the most ambitious case where recessive alleles at frequencies below 1 % should be conserved for future selection of traits, approximately 300,000 individuals are required (YANCHUK 2001). Of course, various other non-genetic considerations such as threats including the chance of catastrophic events, management requirements and others may necessitate larger populations than the 1,000 individuals. Rare species with low densities (25 individuals per100 ha) will require larger areas for *in situ* reserves than species with high densities (100 individuals per ha). Area requirements to capture the genetic variation of a 'population' may thus be in the range of 5 to 10,000 ha or more. The identification of core populations with high densities of the target species is thus important because higher effective populations sizes may be conserved on smaller areas.

It is obvious that the decision on reserve size is also linked to decisions of reserve design since a given number of 'conserved' individuals of a target species may be selected in few large populations or alternatively in many small ones. Large reserves are better able to maintain genetic and species and population diversity because of their greater species and population numbers and internal range of habitats (ABELE & CONNER

1979). Alternatively, a network of many reserves situated in distinct environments, *i.e.* many populations in different eco-geographic zones would better enable conservation of extreme ecotypes, unique genotypes and higher genetic and adaptive diversity. Hence, the conservation value of multiple reserves may be greater than the sum of its individual components (MAXTED *et al.* 1997b). However, if reserves are too small or too isolated the populations may become unviable in the long run. Smaller reserves will generally require more intensive management and monitoring to maintain the same population levels and diversity because of their inherently artificial nature (HAWKES *et al.* 1997). On the other hand, the extreme importance of the demography of populations in determining their minimum viable size has been emphasized by LANDE (1988). His point of view that environmental and demographic uncertainties may be of more immediate importance than genetic uncertainty suggest that it is wiser to 'replicate' conservation population, *i.e.* to have multiple conservation populations which consist of adequate reproductive and ecological units (GRAUDAL *et al.* 1995). Again, there is no optimal number and size for *in situ* reserves (NUNNEY & CAMPBELL 1993) because reserve design depends on the objectives of conservation and the target species. Factors such as the characteristic of the species, the population structure and demography, risks and threats, genetic structure or eco-geographic distribution need to be considered. Unmanaged populations may require larger numbers of individuals than managed, as the extrinsic factors in such populations will be under no control (SIEGISMUND 1994).

Establishing and managing an *in situ* reserve is expensive and therefore both the taxon and the reserve must be sustainable over an extended period of time or the investment will be forfeit. Therefore, the integrity of stand, ecosystem and habitat should be guaranteed for the time period. Human impact on the reserve and conflicts with other forms of land use should be as minimal as possible in the foreseeable future. Ownership and acceptance thus is an important factor. Legislation ensuring that once reserves are designated they are maintained and not developed for other uses may assist with the security and sustainability. In this sense, the selection of multiple reserves is advantageous since the eventual destruction of any one reserve will obviously have less overall impact. Moreover, if a species is extremely rare and restricted, *ex situ* techniques must have greater importance; they are in fact absolutely essential if the population size of the species has become so low that survival *in situ* cannot be guaranteed or where ecosystems in which the species occurs are so degraded that survival of the target species is doubtful. In any case, ecosystem and habitat conditions and natural processes should be as optimal as possible for *in situ* reserves in order to provide ideal conditions for the survival of the target species and to minimize the necessity for management interventions or other protective measures. This has of course a positive effect on running costs of conservation.

Definition of conservation objectives and specific targets

For each *in situ* reserve a practical management plan must be formulated and a monitoring system put in place to ensure that the objectives of conservation are met in the long run. Both successful management and monitoring require the formulation of

precise objectives and specific targets, especially regarding:
- major conservation objectives and priorities among them;
- target species and possible priorities among them in case of several species;
- precise boundaries and area of reserve where objectives and targets should be realized;
- if needed, zones with special objectives or priorities (*e.g.*, strictly reserved zone, managed zone, buffer zone), zones with special management regimes, zones with special priorities for certain target species, *etc.*;
- current and planned ideal population size of sexually reproductive individuals for each of the target species (or possibly zone);
- limits for populations size of sexually reproductive individuals (minimum) beyond which management regime needs to be revised and possibly changed, for each target species (or possibly zone);
- current and desired age class distribution of target species, family structure;
- current and desired area of regeneration needed for long-term sustainability (in a given period);
- special targets for regeneration *i.e.* conditions that allow artificial regeneration; in case of artificial regeneration, genetic resource used as planting material, minimal number of mother trees which need to be represented in planting material, *etc.*;
- detailed objectives and targets of tending interventions (minimum final stocking density, selection criteria, thinning from above or below, schematic thinning, *etc.*);
- isolation of reserve if needed , size of buffer zones and required distances;
- possibly additional objectives or targets (for example sex ratio for dioecious species).

Objectives and targets need to be as detailed and precise as possible such that criteria may be derived which can be used for monitoring purposes. For example, it is not sufficient to state that the target species should remain at the current frequency; a census number is needed. Because changes in population levels and density are a natural component of community dynamics, the objectives must allow for natural fluctuations due to stochastic, cyclical or successional changes as long as they do not threaten the long term viability of the target species. Hence, the objectives should rather define optimal and minimal census numbers, *i.e.* a frame the population of the target species is allowed to fluctuate in before other actions are taken. Regeneration is an essential prerequisite for the sustainability of the species and its gene pool over time. Hence, it is an important objective to ensure that the target species is continuously regenerating and that an adequate amount of regeneration (area, number) is constantly available either by way of natural regeneration or by way of planting. If artificial regeneration is indispensable, then the planting material needs to originate from within the reserve population and should be collected from a minimal number of individuals (50 or more trees). All these objectives and targets have to be precisely stated such that they can be checked periodically for success or failure. A monitoring system needs to be set up for this reason.

Definition of management guidelines

Once clear conservation objectives for a reserve have been formulated, a management plan for the selected reserve needs to be drawn. Management plans should be comprehensive but with all activities clearly documented, including timetables and responsibilities. It is preferable that management plans are kept simple with a minimum of technical jargon. Generally, a management plan should include:

- basic information on the conservation area, including maps, extent and boundaries, tenure status, ownership, history, forest inventory (species composition, volume, size classes, *etc.*);
- target species, conservation objectives and targets, reasons for selection of reserve, role of reserve in overall conservation strategy for target species;
- key reference documents on the area and target species, including any biological inventories, especially census, ecological or genetic studies of target species;
- description of target species (taxonomy (classification, identification aid, *etc.*), wider distribution, habitat preferences and limits, phenology, breeding system, phenotypic and genetic variation, biotic interactions (*e.g.*, pollinators, dispersal agents, herbivores, pests, pathogens, symbionts), local name, uses, overall threats, conservation status, *etc.*;
- evaluation of the site (reserve sustainability, factors influencing management such as legal constraints and access, obligations to local people or communities, *etc.*);
- description of the site (physical description such as geology, geomorphology, hydrology, climate, soils, land use and land tenure, biotic and abiotic description, vegetation, potential and limits of habitat related to target species, most critical factors and special risks for target species, site and population history, natural dynamic of the system, *etc.*);
- status of the target species in the reserve (distribution, abundance, demography, genetic structure and diversity – if known – autecology within reserve, interactions with associated fauna and flora, specific threats to populations, *etc.*);
- prescriptions (decisive factors that influence management, objectives of interventions and priorities among them, detailed management prescriptions with timing, frequency, duration, including selection criteria, volume, remaining cover, *etc.*, programme of interventions for planning period);
- organization (description of roles, responsibilities and rights of all those involved in management and use of the reserve, including permitted and prohibited activities and uses);
- monitoring including which criteria to be assessed and how to asses them, schedule;
- budget and human resources needed.

As the specific focus of establishing an *in situ* reserve is the maintenance of a specific target species or several target species, the management plan requires details associated with the target species being conserved, both at the general level describing the species (taxonomy, phenology, habitat preference, limits for habitat conditions, most decisive habitat conditions and factors, growth, competitive ability, breeding system, regenerative ability, conditions for regeneration, *etc.*) and the description of the target population at the given site (map of populations, density within site, autecology within reserve, synecology with associated fauna and flora, current situation of regeneration, age class distribution and others).

The objective of management is to ensure the continued existence of the target populations. Thus, firstly, management should aim to protect the population against risks and calamities. According to HELLAWELL (1991), communities are intrinsically dynamic with basically three kinds of natural changes: stochastic, successional and cyclical. Stochastic changes are unpredictable; they result from natural catastrophes such as fire, windstorms, avalanches and others. Populations and communities have different levels of resilience to, or abilities to recover from, such events. In some cases a natural catastrophe may even be necessary for the maintenance of the population or community (*e.g.* need of fire as a breaker of seed dormancy). Management can only partly influence resilience against catastrophes (for example through improvement of individual tree stability); however it can mimic catastrophes in order to guarantee the continuance of the population, if needed. Successional change is directional and passes through predictable stages. It naturally involves the extinction of species. If the target species occurs only in certain stages of succession, successional change may have to be halted in a given stage by management interventions. Cyclical changes are usually associated with site dependent interactions such as competition. In the short term they may be quite dramatic but by there very nature, their effects do not persist, however. Therefore, extinction is unlikely, but genetic drift and founder effects may be important factors if populations persist at low levels for lengthy periods. If populations of the target species in the reserve are undergoing such cyclical change, intervention thus may or may not be necessary, depending on the level of fluctuation in population size. Hence, the management plan should include upper and lower limits for populations of the target species, beyond which management action is triggered. The formulation of a minimal census in the definitions of objectives clearly helps to decide if and when interventions are needed to counteract such cyclical changes.

Secondly, management should aim to create conditions which are favorable both for growth and vitality of the target species and for its natural regeneration. For this reason, in most cases thinning is not only permissible but necessary to ensure continued stability, vigor and regeneration of the stand. Although thinning is a form of unnatural selection which can modify the genetic composition of populations (see p. 651 ff., this volume), in most cases thinning is necessary to guarantee the continued existence of the target species. Of course the need for tending will depend on the species and site conditions and needs to be carefully evaluated. It is not possible to give detailed tending prescriptions for *in situ* reserves since the target species, the specific objectives and targets, possible risks and site conditions have a decisive influence. However, in order to avoid overstocked stands with all its negative effects on heath, vigor, stability and seed production, timely thinning is important. Usually, in order to maintain the genetic composition of the stand, either systematic thinning or thinning from below is recommended (KOSKI *et al.* 1997, GRAUDAL *et al.* 1997). Systematic thinning may however counteract natural selection while thinning from below may not lead to sufficient stability and vitality of remaining individuals, especially in older stands. Moreover, the initiation and development of natural regeneration may require stronger interventions with the removal of dominant trees in order to promote seed production and to create sufficient light conditions for the germination, installation and development of seedlings. Thinning does not have strong selective effects as long as selection criteria are similar to those of natural selection. For example, if trees are selected only based on their social status and not on quality traits, the selective effects of thinning are expected to be small (ROTACH 1994).

Regeneration is the most critical aspect of *in situ* conservation because the genetic structure of the next generation strongly depends on it. Natural regeneration is the preferred method. It is, however, not always reliable or possible. Natural regeneration certainly is the most desirable, efficient and economic method which commonly is also advantageous from a genetic point of view. However, even natural regeneration needs management expertise. The interventions need to be adapted to local circumstances, especially to the site and stand conditions. It is especially challenging and needs profound silvicultural knowledge to control the light conditions such that the seedlings of the target species will find optimal conditions while competitors and weeds are discriminated. Universally applicable instructions cannot be given, only few general principles. Since each generation has a specific genetic composition, it is good practice to continuously regenerate the stand on small patches and simultaneously in different areas. This kind of regeneration will allow multiple mating events to be transmitted to the next generation. Moreover, long regeneration periods should be used; individuals of the original stand should be removed gradually over time. The longer the regeneration period and the larger the proportion of trees that are involved in seeding, the higher is the probability of genetic information of the population to be sufficiently represented in the next generation. For this reason it is also advisable to keep a maximum of remaining trees during the phase of regeneration. Hence, it is advantageous (but more costly) to remove trees from the old stand in the course of several interventions in order to keep a maximum number of seeding trees while allowing for sufficient light conditions for the establishment and growth of the seedlings. With continuous small scale regeneration and long regeneration periods, a mosaic of stands with different age classes and genetic compositions is created and genetic diversity is best conserved and transmitted to the next generation (ROTACH 1994). The management plan thus should detail all the necessary intervention, including both temporal and spatial elements for the regeneration of the reserve during a given time period. For the planning period, detailed prescriptions should be given for each regeneration surface, especially on the location, size, number of interventions and duration, volumes to be removed or percentage of cover that remains, social status of trees to be cut and other important information (direction of cuts, risk to avoid, *etc.*).

Prior to the intervention, site preparation may be needed to favor natural regeneration. In addition, weed control frequently is necessary during the seedling stage. Later on, tending may be necessary to control for competition and to enhance abundance and vitality of the target species. In certain conditions, planting or direct seeding may be indispensable to guarantee sufficient regeneration of the target species. Planting is a fully acceptable method of regeneration for *in situ* reserves, provided that the reproductive materials used are of local origin and representative for the population *i.e.* that seed is collected within the reserve itself from a sufficient amount of individuals. Seed is to be collected from approximately 50 unrelated, widely spaced trees, preferably from the central parts of the reserve. If possible, bulked seed lots, representing as many trees in the stand as possible, should be used. To create high genetic diversity, mixing of different seed years from the stand is advisable. It is recommended to collect this kind of bulked seed during abundant seed years and to store it for future use if possible. The management plan should of course give all the necessary information and prescription regarding all questions related to artificial regeneration and planting material.

Establishment of a monitoring system

It is unlikely that the ideal management regime will be known from the beginning. Objectives and targets thus may not be reached with the first management plan. Therefore, the population or populations of the target species in the reserve (and possibly also competitors and associated species) will need to be assessed regularly in terms of the objectives and targets in order to detect unwanted changes. If a change is indeed detected, the management prescriptions will need to be reviewed. Management may or may not be amended, depending on the nature of the change and the difference from the targets that were defined.

The monitoring process will likely involve the following decisions:

- key and associated taxa;
- method of sampling;
- observations and measurements (variables);
- periodicity of monitoring;
- data accumulation and statistics;
- feedback to management plan.

It is not possible (and not necessary) to record and monitor every species or individual occurring within the reserve. Monitoring thus involves the taking of samples of data that, if effectively selected, will reflect the overall picture of the reserve. Key species and sites within the reserve thus need to be selected for monitoring on a regular basis. The target species, which is the reason for establishing the reserve in the first place, will clearly need to be followed over time. It is likely that any taxonomically related species which may exchange genes with the target species will also be included in the monitoring programme. In addition, the abundance of other species may be directly related to or affect the abundance or diversity of the target species; these include parasites, pollinators, symbionts and competitors. Depending on the resources available, some of these associated species should also be included in the monitoring programme.

There are three main strategies for sampling a reserve: random, systematic or stratified random. In random sampling, every point in the reserve has an equal chance of being sampled. Locations may for example be determined using a random number generator to produce sets of coordinates. Random sampling is the most robust and statistically safe form of sampling. Systematic sampling means that samples are taken at regular intervals, for example along a transect or in a grid pattern. Because many biological phenomena are spatially auto-correlated, this has the advantage over random sampling of avoiding over sampling of 'uninteresting' areas at the expense of more interesting ones (MAXTED *et al.* 1997a). Stratified random sampling involves dividing the reserve into different but internally homogeneous zones (stratums) and taking samples at random independently within each zone in proportion to the areas of the zones. For example, zones could be areas of different vegetation or soil types. This would assure that all habitats are sampled and well represented. Stratified random is the most common sampling strategy applied in ecological research. However, in case of strong environmental gradients within the reserve (elevation, temperature, water flow, *etc.*), sampling at regular intervals along a transects which parallels the gradients will more appropriate.

Numerous methods may be used for assessing species abundance or diversity for example density, frequency or cover. Density is the number of individuals per unit area. Frequency is the proportion of samples within which the target species occurs. Cover, finally, is the percentage of the ground occupied by the projection of the aerial parts (crown) of the species. Absolute measures of density may be assessed in the form of number of individuals, demographic structure, distribution pattern and biomass or volume. It may well be that abundance of different species will be recorded in different ways, depending on the accuracy required and the importance of the species to the conservation objectives of the reserve. The target species for which the reserve has been established most likely is assessed as density. In addition, estimates on age or vigor may be recorded for each individual that is counted (girth at breast height). Moreover, the area of existing regeneration may be recorded as it is encountered at or within a certain radius from the sampling point. For other species, however, a fairly rapid visual assessment of cover may be sufficient. Again for others, there presence or absence at or within a certain radius from the sampling point may be sufficient. If information on the genetic structure and diversity of the target species is wanted, genetic marker studies are required. There are various methods for sampling of individuals for genetic information (VON BOTHMER & SEBERG 1995). If all individuals within the sampling area have been tagged and labeled, numbers could be used to randomly select individuals for the genetic survey.

At a sampling point, two different ways of sampling may be applied: plot or intercept sampling: plot sampling involves taking observations at the sampling point within a usually circular or quadratic area of standardized size. Observation are made by systematically going through the area counting and perhaps measuring and even tagging each individual of the target species encountered. In the intercept sampling method, a measuring tape is laid out in a random direction at the sampling point and observations and measurements are taken on those individuals which intersect the tape.

If plot sampling is used, sampling may be done on temporary or permanent plots. Using temporary plots, *i.e.* sampling new plots each time is statistically more manageable since the assumption of observations being independent of each other is basic to most statistical procedures. However, ways exist of analyzing repeated observations such as time-series data from a set of fixed sampling units, and using permanent plots is certainly easier and more efficient. Today, it may be easy, accurate and efficient to map plot locations, boundaries and even individuals with the help of a Geographic Positioning System (GPS). Problems of accuracy and measurements in dense forests have been largely overcome today. GPS thus may be an excellent instrument for monitoring purposes.

There exist no simple rules regarding the number and size of sampling plots required, but generally the greater the number the more reliable the result (GOLDSMITH 1991). However, the information each new plot provides needs to be balanced against additional resources required to record the observations because the extra information gained from each newly recorded plot will diminish as the total number of plots rises. One way of finding the optimal number of plots is to graph the variance of the data against the number of plots; a useful guide to find the minimum number of plots is the point where the oscillations of the graph damp down (GOLDSMITH *et al.* 1986). Another method for determining the appropriate number of samples was proposed by POOLE (1974). He suggests that variance (s^2), resolution (L) and number of samples (n) are related as:

$$n = 4\, s^2 / L^2.$$

In our case L would refer to the difference or the change in the numbers of individuals of the target species between years at a given site which the project is willing to consider unimportant (*e.g.*, the acceptable error rate). In most cases, size and number of samples taken from the reserve will be a practical compromise between the numbers that are required to produce statistically meaningful results with an acceptable error rate and the resources available for monitoring.

Regarding the periodicity, in case of long lived plants such as trees it will be in the range of several years, *i.e.* each 10 or even 20 years will be sufficient. However, in newly established reserves in which it is unlikely that the most appropriate management prescriptions are already known, intervals should likely be shorter than in well established reserves. As changes or adjustments to the management prescriptions become less necessary, intervals of monitoring may be extended.

After collecting the necessary observations in a monitoring event, results are compared to those of former events. Population characteristics are compared to those recorded in previous surveys to see if any significant changes have occurred in the intervening period. When interpreting the results of monitoring it is important to distinguish between effects due to management and effects caused by other, natural causes. Is the observed change the result of normal, natural cycles or processes, or an inappropriate management regime? The two causes are often difficult to separate. Natural factors influencing population characteristics may for example be climate change, long-term habitat alterations or successional or cyclical changes. In order to separate management related from natural causes, it may be necessary to monitor populations within the reserve, which are subjected to the management plan and populations that are left unmanaged. The establishment of different zones within the reserve may thus be advantageous from a monitoring perspective.

Monitoring should reveal trends in the observed population parameters for the target species. If these trends are interpreted as reflecting a deterioration of the conservation objectives for the target species, then the management plan and especially the prescriptions need to be reviewed and possibly altered. It is only by such a monitoring process that the need for changes in the management plan can be recognized. The monitoring process acts as a feedback mechanism, triggering changes in the management of the reserve if necessary and ensuring that the genetic resources of the target species are safely conserved.

Conclusions

At first glance, *in situ* conservation seems an easy way of conserving species and their genetic resources. This general overview should illustrate, however, that the establishment of effective and efficient networks of *in situ* reserves is far from being trivial. It is a highly complex and demanding task which needs a lot of knowledge, information or good guessing. Only a systematic approach will guarantee that all important genetic resources may be conserved in a minimum number of reserves and with a minimum of costs. Finally, two important things have to be kept in mind. Firstly, there does not exist an optimal standard solution for *in situ* conservation; solutions need always be related and adapted to the species, the demographic and eco-geographic situation, the conservation objectives and the national, social and political context. Secondly, this overview is not complete; there may be other important things that need to be included or considered which were not discussed here.

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