Protection of genetic variability in forest tree populations: an overview

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Abstract

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Forest ecosystems are important components of the European natural environment and provide substantial services and benefits to human society. They are under severe threat due to pollution and human-induced effects; and these pose severe challenges for the adaptation and survival of tree populations. The special nature of tree poplations is considered, and the need to protect adequate amounts of genetic variability in them is discussed. Both *in situ* and *ex situ* approaches play a role in conserving genetic variation of forest tree populations, with the former given high priority.

Forest and woodlands

Tree populations are significant components of ecosystems in many parts of the world. About 30% of the ice-free land surface of the globe is covered by forests or woodlands. The corresponding value for Europe is 38 %, which consists of 31 % closed forests and 7 % woodlands (NRC 1991).

Tree populations provide substantial benefits for the human society, e.g. by protecting landscapes against soil erosion and floods, by harbouring a large variety of plant and animals species, by offering various social functions and services, and by supplying construction materials, fuelwood, food and materials for many industrial products. The absorption of carbon dioxide and the release of oxygen via photosynthesis is mandatory for the maintenance of life and helps to counterbalance fluctuation of global temperatures following greenhouse effects.

In Europe, most of the tree populations are part of long-lived and heterogeneous forest ecosystems. Within these systems, trees are ecologically significant species and contribute essentially to the diversity and the ecological stability of landscapes. Particularly in Central Europe, forest ecosystems are increasingly threatened with decline following air pollution and other abiotic and biotic stress factors. In addition, forest ecosystems are subjected considerably to forest management and modifications of land use.

The deterioration to which forest ecosystems are exposed, severely challenges the potential of tree populations to adapt to and to survive under changing environmental conditions. Genetic variability determines the adaptive potential of species and is an essential component of the stability of ecosystems (see for example. Scholz & al. 1989, Müller-Starck & Ziehe 1991, Baradat & al. 1995). Global warming can be expected to increase the complexity of environmental stress conditions and to furthermore provoke the adaptive abilities of forest tree populations. Preservation of genetic variability *in situ* is crucial in order to maintain adaptive processes and to generally support dynamics of genetic variation within and among tree populations.

Pecularities of tree populations

Tree populations are exposed to highly complex environmental conditions and commonly respond to this ecological complexity by a build up of remarkably wide intrapopulational genetic variation:

(a) Heterogeneity of environmental conditions is considerable in time and space: the predominant indigeneous tree species in Europe are outstandingly long-lived and are usually managed within rotation periods of 60 to 120 years up to 200 or 300 years (Central European oak stands). Tree populations grow in natural environments which reveal complex and highly variable site conditions. Generation cycles of trees and parasites deviate very greatly from one another.

(b) In contrast to agriculture, the complexity of environmental stress conditions at forest sites cannot efficiently be controlled: prophylactic pest control is not possible, fertilization and other measures to improve site conditions are strictly limited in their efficiency, and impacts of stress components like frost events or long term exposure to air pollution cannot be excluded. Furthermore, severe economic limitations are evident.

(c) Forecasting of environmental constellations is strictly limited or not possible: future environmental stress can deviate substantially from the present conditions because of the long term complexity of environmental stress, of interactions among stress components, and because of its non-predictable dynamics. Global warming will interfere with abiotic and biotic stress conditions and possibly further increase environmental variability and dynamics.

(d) Tree populations usually reveal outstandingly large genetic variation within populations. This was demonstrated by comparing results from genetic inventories in populations of European forest tree species and of various dicotyledonous and monocotyledonous reference species (Müller-Starck 1995, 1997, this volume, p. 47). Based on isozyme gene markers, the average proportion of heterozygotes was 24.25 % in tree species (gymnosperms 25.1 %, angiosperms 23.4 %), compared to 13.9 % in the reference species (dicotyledons 11.3 %, monocotyledons 16.5 %). Consequently, the observed heterozygosity in trees exceeds the corresponding value for the reference species by 74 %.

With regard to the average number of alleles per locus, trees exceeds the reference species by 58 % (2.45 for trees, 1.55 for the reference species). This difference in the average number of alleles means much larger amounts of genotypes in tree populations compared to the reference species.

For example, if 18 polymoorphic gene loci are involved, the maximum potential genotype multiplicity theoretically possible is 9.9×10^{10} for tree species, compared with 5.9×10^{4} genotypes for the reference species. The relation is 1 677 966 : 1 in favour of the tree species. Deviations from even distribution may reduce substantially the given values. These data can only illustrate trends because the summarized studies include different gene loci, number of loci, sample sizes, materials and ontogenetic stages. Furthermore, breeding systems vary considerably among species. For instance, obligatory self-fertilized species like certain monocotyledons and dicotyledons will reveal lower heterozygosities than facultatively self-fertilized or obligatorily cross-fertilized species such as trees.

The need for protection of genetic variability in forest tree populations

The presence of a wide genetic variability is a predominant characteristic of tree populations as compared to populations of other plant species. A larger proportion of polymorphic genes – and a larger number of alleles per locus – in the populations means an exponentially greater potential to form genetically different multilocus-genotypes in the next generation and thus to respond to environmental challenges by means of genetically variable offspring populations.

Consequently, preservation of genetic variability is crucial for adaptation and survival of forest tree species and the entire forest ecosystems under changing environmental conditions. Environmental dynamics and anthropogenic impacts can alter the genetic variability to such an extent that the adaptive potential of species and ecosystems could seriously be impaired. Measures to increase genetic variability will increase the chances of survival and will contribute to ecological stability and thus to sustainable development.

Any conservation practices have to take into account the large genetic heterogeneity of tree populations under natural conditions. In forest management, sylvicultural practices are required which maintain genetic variability in any long-lived forest ecosystem, that systematically protect genetic resources and increase genetic variability in case of genetic erosion.

These are the basic requirements of a genetically sustainable forestry. Among the sylvicultural practices, particularly the mode of regeneration, the choice of reproductive material and the mode of thinning are particularly important.

Based on the peculiarities of tree populations with respect to environmental conditions and genetic variability the following proposals can be made:

(a) Maintenance of the wide genetic variability characteristic of forest tree populations is essential for the preservatioon of the adaptability of forest ecosystems to their complex environments.

(b) In genetically impoverished populations, increase of the genetic variability will contribute to sustainable ecological development.

(c) Additional measures of gene conservation such as gene reserve areas *in situ* or *ex situ*, or conservation via "gene banks" will help to preserve extremely rare alleles.

Initiatives

Genetic resources of forest tree populations became part of research programmes that were originally concerned with agricultural crops. During the last six years, various initiatives have been started in order to combine efforts in the conservation and management of environment and natural habitats such as the the Council of Europe 1989 'Colloquy on the Conservation of Wild Progenitors of Cultivated Plants' mentioned in the Introduction to this volume. An essential part of such efforts is the assessment of genetic variation and its dynamics under changing environmental conditions and the utilization of genetic criteria for gene conservation in forest tree populations.

Conclusions

Preservation of genetic variability in forest tree populations is a new and challenging task. In the conservation and management of natural habitats interdisciplinary efforts are required. Tree populations are carriers of significant ecosystems in many parts of the world and provide substantial ecological and economical benefits. Tree species need to be integrated in conservation programmes that take into account the large genetic variation present in tree populations and their complex environments.

Various problems and initiatives are addressed by the papers on forest tree populations included here and in discussion at the workshops the main emphasis was put on the following research needs:

- Universal methods for the assessment of genetic variation and its dynamics under changing environmental conditions, e.g. mode of sampling, choice and verification of gene markers, appropriate methods for quantification of intra- and inter-populational variation with inclusion of gene flow and hybridization.
- Definition of genetic and phenotypic criteria for the choice of populations or individuals in conservation programmes: the characterization of gene resources and the description of high risk situations with respect to genetic loads and genetic erosion are essential
- Definition of environmental criteria needs to be an important element of conservation programmes, especially in case of natural populations. Particularly in forestry, populations in heterogeneous environmental situations may be preferred, due to the expected diversifying effects (preference of mosaic structures).
- Conservation *in situ* vs. *ex situ*: in natural populations, *in situ* methods deserve high priority. Limitations are particularly evident in case of rare species and restrictions in gene flow. Conservation *ex situ* (e.g. via gene banks or seed orchards) will help to counterbalance inbreeding and genetic erosion.
- Conservation management regimes are essential and need to be further developed in order to realize genetically sustainable development in forestry and thus to contribute to the preservation of adaptability of complex forest ecosystems.

Generally it is concluded that experiences in the management of long-lived forest tree populations in natural habitats could be useful also for conservation programes in the fields of agriculture and horticulture.

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