

CONSERVATION OF FOREST GENETIC RESOURCES UNDER CLIMATE CHANGE: THE CASE OF FRANCE

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Introduction

Forest gene conservation programmes aim at preserving genetic diversity in the long term to maintain the capacity of forests to respond to societal demands in the context of environmental change. National conservation strategies for forest genetic resources contribute to the collective effort towards sustainable management of European forests. Since 1994, international coordination of these efforts has been strengthened by the European Forest Genetic Resources Programme (EUFORGEN) as part of the Ministerial Conference on the Protection of Forests in Europe (MCPFE) process. These conservation strategies are generally developed at species level and combine *ex situ* and *in situ* approaches in a complementary way. The *ex situ* approach (germplasm collections) can be used for any species that is vegetatively or generatively propagated, but it becomes time consuming and costly when the objective is to achieve dynamic gene conservation. The *in situ* approach is a dynamic gene conservation strategy based on natural regeneration, but it is

classically limited to those species that form large populations in a reasonably manageable area, and suitable methodologies for scattered or pioneer species have not yet been developed. Beside specific conservation networks, other activities such as silvicultural practices and natural reserves also have a significant impact on long-term evolution of genetic resources.

In this perspective, climate change is a challenge because of the magnitude and time scale of the environmental shift, which was not expected when conservation programmes were initiated in the 1980s. Will the current forests withstand the change that is occurring within one or two generations of trees? Will the forests have time to evolve and adapt genetically to new conditions? Will the tree species have the capacity to migrate in latitude or elevation and follow the shift of their potential distribution range?

In this paper, the French forest genetic resources conservation programme is used as a case study. Its aims, principles

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and achievements are reviewed with a focus on each decision step. Then, basic principles for gene conservation are re-considered in the context of rapid climate change. Finally, recommendations are made in terms of the definition of the objectives for genetic resources conservation, as well as for conservation methodologies.

Aims, principles and achievements of the current forest genetic resources conservation programme in France

The French forest genetic resources conservation programme is 20 years old (Teissier du Cros et al. 2001). A first working group on forest genetic resources (FGR) was initiated by scientists (M. Arbez and G. Steinmetz) in 1985. Four years later, in 1989, the National Commission of Forest Genetic Resources was created by the Ministry in charge of agriculture, with the objective of maintaining a large resource of genetic diversity for priority species in the long term, by implementing specific conservation networks at national level, to preserve the adaptive capacity of the resources. Five pilot species were selected to develop a conservation strategy based on conservation networks (beech (*Fagus sylvatica*), silver fir (*Abies alba*), wild cherry (*Prunus avium*), elm (*Ulmus laevis*) and black poplar (*Populus nigra*)). In 1991, the first *in situ* conservation networks for beech and silver fir were officially established by the Ministry. In 1997, a charter for the conservation of FGR was prepared by

the Commission, and signed by all partners of the 'FGR chain': the public forest service, representatives of the private sector, research and development organizations, and forestry schools. Today (in 2006), 11 specific conservation networks are operational (the five initial pilot species plus sessile oak (*Quercus petraea*), maritime pine (*Pinus pinaster*), Norway spruce (*Picea abies*), service tree (*Sorbus domestica*), wild service tree (*S. torminalis*) and walnut (*Juglans regia*)) (Balsemin and Collin 2004). Priority is given to *in situ* conservation as a dynamic strategy that allows the evolution of genetic diversity in response to environmental changes. *Ex situ* conservation is reserved for the most threatened species or when an *in situ* approach is not applicable.

Besides the conservation networks, the Commission has two plenary meetings each year, and four working groups have been established: (1) definition of criteria and indicators for *in situ* conservation networks (chairs: B. Fady and A. Valadon); (2) dissemination and use of FGR maintained in the national *ex situ* collection (chairs: E. Collin and M. Villar); (3) development of new approaches for the dynamic conservation of scattered tree species (chairs: N. Frascaria-Lacoste and B. Musch); and (4) coordination among network managers (chairs: A. Ducouso and A. Valadon).

The national strategy developed by the Commission includes the following decision-making steps:

- selection of a range of pilot tree species for which conservation strategies are specifically adapted (*in situ* or *ex situ* or both) and strategies that can be extended further to any other species having the same biological or ecological characteristics;
- establishment and management of *in situ* conservation networks:
 - › selection of the conservation units that will contribute to the network,
 - › definition of the management plan for each conservation unit, and
 - › definition of criteria and indicators for monitoring the conservation units and the network;
- establishment and management of *ex situ* collections:
 - › definition of a sampling strategy to establish and regularly update the collection, and
 - › definition of the conservation methodology (*in vivo* or *in vitro*) and procedures;
- definition of a strategy for the valuation of conserved genetic resources; and
- public awareness.

As an illustration, I will briefly review the decision steps for *in situ* conservation.

It is considered that a network of 30 gene conservation units offers a good compromise with sufficient diversity in a still manageable organization. The objective assigned by the French Commission to the network of *in situ* conservation units is to represent the adaptive

diversity existing in the main distribution range of the species, including some marginal populations, all material being autochthonous. Of course, the information available for the establishment of the network varies among species. The first conservation networks for beech and silver fir have been extended several years after their initial establishment, to account for the most recent results on the structure of genetic diversity, whereas, by contrast, much more detailed information was initially available when establishing the conservation network for sessile oak. Legal status and ownership of the land is also important information for the selection of conservation units. In the case of silver fir, we are facing a situation where a potentially original resource in the western part of the country only occurs on private land, and the question is how to ensure long-term conservation of such conservation units.

Each conservation unit has a common structure with a core area, where the target species must be autochthonous and be represented by more than 500 seed trees, with a minimum density of 60 trees/ha, and a peripheral zone where no alien origin of the target species is allowed. Management plans of the conservation units allow any silvicultural treatment, but the following three objectives should be met: (1) natural regeneration is sufficient in quantity (it can be assisted by using local seed from the core); (2) good genetic quality of the regenerated seedlings is ensured (enough diversity and reduced

consanguinity); and (3) local phenotypic identity is maintained (mainly adaptation to local conditions). In particular, in even-aged silviculture, regeneration of the core must be conducted prior to the peripheral area, applying given critical values for the number and density of seed trees. Natural regeneration is preferred, but assisted regeneration from local seed sources is an alternative when the three previous requirements can not be met.

As previously mentioned, this species-based approach cannot be applied to all forest tree species. Moreover, classical *in situ* methodology is not readily applicable to highly scattered species that do not form obvious populations or stands, nor to strictly pioneer species in which regeneration dynamics is governed by extinction versus colonization processes not related to silvicultural management (e.g. in riparian forests). *Ex situ* strategies are preferable in such cases. This also emphasizes the need to develop criteria and indicators for monitoring the evolution of genetic resources under 'normal silviculture' outside specific conservation networks, and the need for enhanced coordination between genetic resources conservation and habitat conservation programmes.

How does climate change influence forest genetic resources conservation programmes?

Various climate change scenarios have been predicted on a regional basis (see

<http://www.ipcc.ch>). Although the predictions still vary from one scenario to another, it is likely that once changes start occurring, they will be rapid (within a time scale of one tree generation) and differ among geographical zones. For example, in Europe, the Mediterranean area will experience a decrease in annual rainfall, whereas northern areas might rather experience seasonal fluctuations within each year, not necessarily accompanied with total annual deficit. Climate change might also result in higher frequency of exceptional weather events, beyond biological thresholds, leading to catastrophic damage to the present forests. In practice, climatic events have already affected our forest genetic resources: the big storm of 1999 destroyed large parts of *in situ* conservation units of beech in north-east France and the severe drought of 2003 led to die-back of silver fir in south-eastern parts of the country, and the mortality of silver fir in 2006 was still increasing as an after effect. Experimentally, these situations also provide an excellent opportunity to evaluate the robustness of our genetic resources conservation networks, but this evaluation has not yet been done.

Theoretically, climate change can influence each of the decision steps listed above. Firstly, it should be incorporated within risk assessment more explicitly than before: what are the areas of higher risk due to climate change (drought, temperature, catastrophes)? What are the species or habitats most susceptible

to climate change? These considerations will affect the choice of priority species and priority areas for gene conservation. One problem is that the real impact of climate change on forest genetic resources results from complex processes and is not yet predictable. Therefore, we must reconsider our objectives and make them evolve from the preservation of existing genetic diversity to the conservation of the capacity of forest genetic resources to 'keep on running'. It is clear that we have to manage adaptive capacity in the long term. Genetic resources must be considered from a dynamic perspective and exposed to constant evolution. The current values of diversity parameter estimates should not be simply considered as an objective for management, but rather as indicators of evolutionary processes. For sustainable management of forests in the context of rapid environmental change, three conditions are required: (1) existing resources do not completely disappear; (2) remaining trees are able to regenerate and produce a new generation better adapted to the new conditions (examples of transplantations have shown that genetic changes in adaptive potential can occur in just one generation (Skrøppa and Kohmann 1997; Rehfeldt et al. 2001)); and (3) the migration process allows trees to follow a geographical shift in their potential distributional range.

Rather than just genetic diversity, gene conservation strategies should focus more directly on adaptive capac-

ity, which includes three components: (1) plasticity, i.e. the capacity of existing trees to respond differently to different environmental conditions; (2) adaptation, which includes adaptive genetic diversity and the occurrence of natural selection in a dynamic management system; and (3) migration potential through natural dissemination of seeds or artificial seed transfer, or both. In other words, forest genetic resources conservation programmes must evolve from a perspective with a focus on population management, to the management of evolutionary trajectories. This must be seen as an adjustment of our objectives, not a complete shift.

From a scientific point of view, information on climate change scenarios, as well as on the biological processes underlying adaptive capacity, is rapidly increasing. However, the knowledge of biological processes has increased for so-called model species, but little effort has been made to transfer this knowledge to non-model species, which represent the vast majority of the genetic resources of interest. Therefore, the challenge is to develop dynamic forest genetic resources conservation programmes and permanently integrate the most recent research results into these programmes to improve their effectiveness.

Conclusions and recommendations

We have to improve the conservation programmes of forest genetic resour-

es in a context of rapid environmental change, i.e. conservation plans will probably need to be evaluated in a context that differs from when these were initially elaborated. More than ever, it is clear that we must develop process-based conservation strategies rather than just diversity-based strategies, i.e. move from the management of genetic diversity to the management of the evolutionary processes that shape the diversity. Research priorities should be to study plasticity, adaptation and migration processes. Applied conservation strategies should benefit from the most recent research developments in biology and modelling. This requires specific efforts by the scientific community towards vertical integration (from the molecular to the ecosystem scale) and horizontal transfer (from model species to broader biodiversity) of biological knowledge.

The development of genetic criteria and indicators for *in situ* management is an urgent need. Some lists have recently been proposed at the level of the population, but they are still rarely used (Namkoong et al. 1996; Brown et al. 1997; Koski et al. 1997; Lefèvre et al. 2001; Eriksson et al. 1993). However, the context of climate change has not really been taken into account yet. This work is favoured by the emergence of new process-oriented rather than species-oriented working groups as part of Phase III of EUFORGEN. Furthermore, effective coordination among all programmes and

activities that directly or indirectly contribute to the conservation of genetic resources is urgently needed, including *in situ* and *ex situ* conservation networks, nature reserves and protected habitats. This could require the development of new criteria and indicators for the management of genetic resources at ecosystem level, although the proposed frameworks for genetic criteria and indicators are probably acceptable. The problem lies in their practical implementation. Furthermore, MCPFE has adopted a decision that the ecosystem approach and sustainable forest management are consistent one with the other.

Since climate change scenarios vary geographically, international coordination for monitoring the impact of climate change on forest health at regional scale is also needed for prioritizing areas, habitats and species for conservation.

Scientific knowledge should be continuously assimilated into FGR conservation strategies. However, a common trend in research is to increase scientific knowledge vertically, based on a limited range of biological models, with little horizontal transfer across species. It will become a challenge to apply research results from a large diversity of organisms in a diversity of local contexts. Therefore, two priorities emerge for research: (1) the integration of the various disciplines and approaches that address the questions of plasticity, adaptation and migration, such as integrative

biology, demo-genetic modelling or the study of biotic interactions at ecosystem level; and (2) the transfer of scientific knowledge based on model species to a broader biodiversity. The Network of Excellence EVOLTREE (<http://www.evoltree.org>) should provide a major contribution to these efforts.

Finally, we can conclude that existing conservation networks in France were based on objectives and principles that remain valid in the context of climate change. However, they need to be extended, as follows:

- the objective should be extended from genetic diversity alone to plasticity, adaptation and migration potential;
- process-based rather than diversity-based criteria and indicators should be developed, which consider processes at all scales;
- there is a need for coordination between habitat and FGR conservation programmes;
- priority areas, priority ecosystems and priority species should be identified in relation to climate change scenarios;
- European forest genetic resources conservation programmes should pay attention to the situation outside Europe, in particular in the Mediterranean and boreal zones; and
- robustness of existing networks regarding climatic hazard should be monitored whenever singular climatic events occur.

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