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Conifer Forest Site © LinkTree team

POLICY BRIEF

Adaptation of trees and forests to climate change: the importance of genetic variability

Forests cover approximately 25% of Europe, roughly 117 million hectares. They play a critical role in wood production, the conservation of forest biodiversity, maintenance of carbon sinks and the provision of many ecosystem services. They thus have great ecological, economic and cultural value. Natural forests are also reservoirs of genetic diversity for tree species, essential to the adaptation of forests - and thus of the forestry sector - to climate change.

Trees are long-lived, and maintaining resilient forest ecosystems requires more than planting new tree varieties and species. Persistence will largely depend on the ability of existing trees and populations to adapt locally. In particular, the existence of a high level of genetic diversity within stands is a key prerequisite for forest trees to adapt and be resilient to the unpredictable effects of climate change.

The BiodivERsA-funded project LinkTree examined genetic variation within forest tree populations in five European countries, and assessed how this variability and its management could help forests adapt to environmental changes. This policy brief presents some results and recommendations on how forest policy and management strategies in Europe can be improved.

Main findings

- Tree species within (semi-)natural forests contain significant genetic variation.
- Variable environmental conditions, such as temperature, light availability and drought intensity maintain and promote genetic diversity within and between (semi-)natural forests, even at short spatial scales.
- High genetic variation in forest tree populations allows for more rapid adaptation to climate change.
- Genes associated with key adaptive traits (such as trees' resistance to drought, cold or forest fires) can vary in their frequency spatially and geographically; this type of information is now easily accessible and should be included, along with neutral genetic diversity, in the adaptive forest management toolkit.
- Forestry practices can significantly modify the genetic composition and structure of forest trees and the evolution of their genetic diversity.

Key policy recommendations

- It is advised that conservation of genetic resources is promoted in the implementation of the **EU Forest Strategy** at all levels.
- Forest management plans as set out in the **EU Biodiversity Strategy** (target 3b) would benefit from incorporating measures to maintain and if necessary increase genetic variation within tree populations and stands to ensure the ability of forests to adapt to climate change. The conservation of tree genetic resources should be promoted accordingly.
- Management of the **Natura2000 *network*** should take into account that protected forests can act as gene banks.
- **Implementation of the EU Strategy for Adaptation to Climate Change could be improved by** inclusion and promotion of practical guidance on adaptive forest management using genetic diversity and resources.
- The **1999 EU Directive on marketing of forest reproductive material** should be improved with requirements on how to maintain high genetic diversity within traded seed lots. Requirements include the minimum number of seed trees to collect from a natural stand, the necessity to sample seed trees from ecologically variable micro-environments within stands, and the importance of mixing seed lots within a region of provenance.

The context

Forest trees are long-lived species that are genetically very diverse. Trees have developed natural mechanisms to maintain high levels of genetic variation and reduce inbreeding, e.g. through long-distance dispersal of pollen and reproduction among unrelated distant individuals. Because native tree individuals with a particular genetic make-up occupy very diverse environments, these mechanisms have maintained high levels of genetic variability within forest trees despite strong selection.

Climate change is expected to have a significant impact on European forests, causing changes in the geographic distribution of species, ecosystem functioning and interactions between species. Given the long lifespan of trees, fast local adaptation will largely depend on the genetic variability available within and among tree stands and populations, rather than on new variability caused by mutations. High levels of genetic diversity are thus beneficial as they allow individual trees and populations to adapt more easily to environmental changes.

New knowledge from molecular genetics provides insights into the processes through which forests adapt to changing conditions. Such knowledge is important for guiding forest management decisions, and thus avoiding costly mistakes.

The LinkTree project examined genetic variation within forest tree populations in natural and well-studied forests in Spain, France, Italy, Germany and Sweden, and evaluated the role of genetic variation in response to stressors such as extreme climate and fire. While other research projects have typically focused on large geographic scales, LinkTree examined the genetic diversity of keystone forest tree species both within individual forests with steep ecological gradients, and across their geographic ranges in Europe.

Key results

Genetic variability and adaptation to environmental changes at local spatial scales

Results from the LinkTree project confirmed earlier research that within-species genetic diversity can be very high with significant differentiation even among neighboring trees within the same forest. The project also illustrated that with sufficient genetic variation, trees in forests can adapt rapidly to environmental change.

Researchers identified genes associated with individual tree response to major environmental threats such as drought, cold, heat, and recurrent forest fires. Within populations, genes associated with the seasonality of new leaf emergence in spring, flowering time, and resistance to drought and cold varied significantly along environmental gradients at small spatial scales, such as in the European Silver fir in south-eastern France (Figure 1). They showed experimentally that the variability found for these genes is associated not just with migration and population foundation, but also with varying environmental conditions, such as altitudinal and latitudinal gradients, and is thus affected by natural selection. They also found that up to 80-90% of the genetic diversity underlying adaptive genes remains within populations, suggesting that local environmental conditions can promote and maintain genetic diversity within and among tree populations. Finally, they found that genetic diversity for key traits can evolve within just a few generations, allowing rapid adaptation to a changing environment. Knowledge of how genetic variability is partitioned in space for such important genes can thus help improve models of future range distributions, and better inform the choice of trees in reforestation projects.

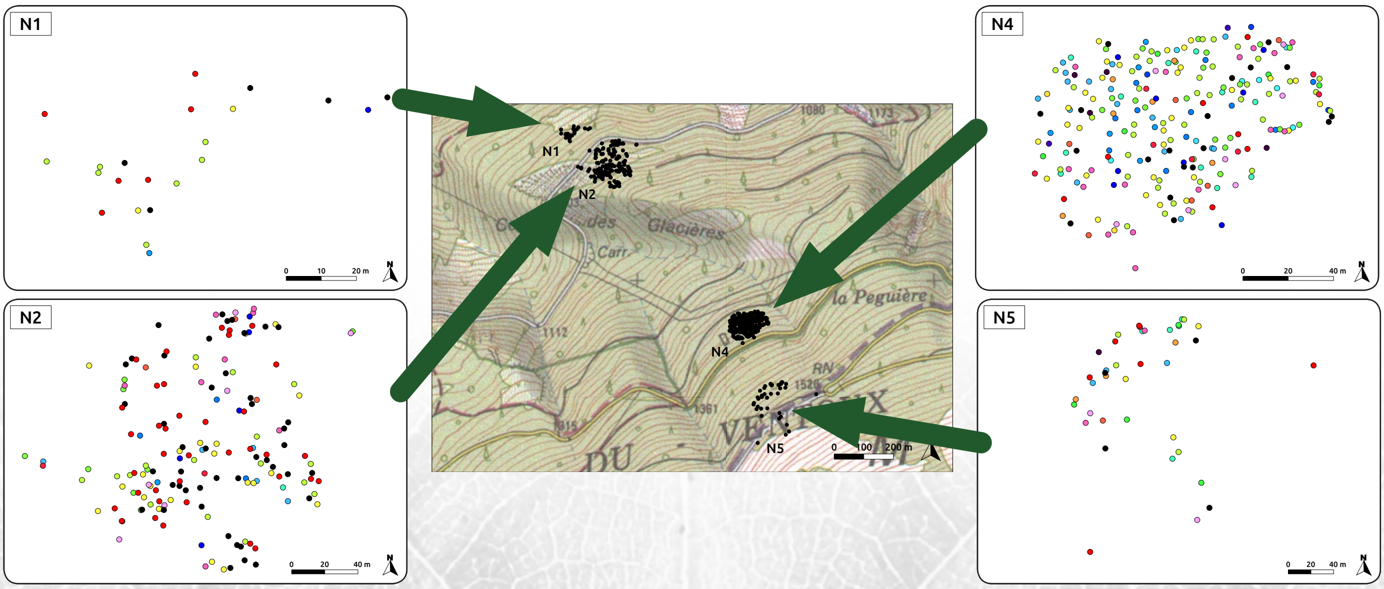

Figure 1: Map showing the distribution of different European Silver fir trees within and among four plots (N1, N2, N4 and N5) located along an elevation transect in Mont Ventoux, south eastern French Alps. The plots show the distribution of individuals with a particular genetic make-up at four different genes (one genotype per color, 47 genotypes in total) involved in resistance to environmental stress. Although differentiation among populations in frequencies of adaptive genes is significant at the landscape scale, genetic variability is at maximum at the micro-environmental scale, among individuals within the same population. This high genetic variability is crucial for local adaptation under climate change.

Other results from LinkTree point to the existence of significant genetic variability affecting tree survival and reproductive output (fitness) in small forests of European temperate oaks. These studies revealed that the pollen output of male trees is highly dependent on the micro-environment in which each tree is growing (e.g. soil humidity and texture). Similarly, studies of three maritime pine forests located in the Mediterranean region indicate that altitude has a measurable effect on genetic diversity at the scale of a few hectares. They also showed that the local environment is very important for the survival of transplanted trees. When trees were transplanted between two locations in Spain, their ability to adapt to the new environment differed; indigenous trees showed a higher fitness than transplanted trees only under certain micro-environmental conditions. This suggests that the difference in fitness between populations depends strongly on the environmental context, and that it is affected not only by regional climate but also by the local environment at very small scales. Consequently, local genetic resources are not always best for all environmental conditions, such as in sites with full sun exposure (Figure 2).

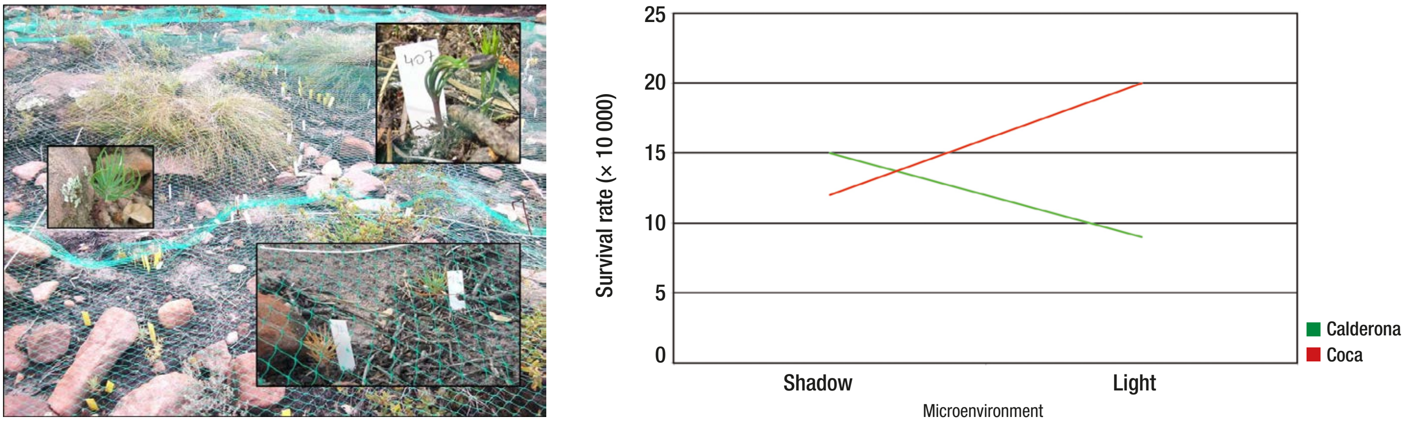

Figure 2: (Left) One of the semi-natural sowing reciprocal experiments for the Calderona site in Spain. Each inset shows different growing conditions for seedlings. (Right) Seedlings from the indigenous maritime pine population (Calderona, in green) survive better in their own site only when sown in a shaded environment, while on sunny spots seedlings from a foreign population (Coca, in red) do better. From *Vizcaíno-Palomar* et al. 2014 (PLoS ONE)

Genetic resources for forest management in a changing environment

LinkTree also demonstrated that management practices can significantly affect the genetic composition of populations, potentially providing forest managers with a strategy to maintain or make forests more resilient to an unpredictable future. The project contributed significantly to the development of highly efficient sequencing and genotyping methods previously restricted to model organisms. These methods can provide forest managers and other stakeholders with better information on the genetic make-up of trees and their adaptative potential, thus helping them to sustainably manage forests in a changing environment. As a short term perspective, it is conceivable that foresters will target the collection of reproductive material for conservation, direct use and breeding programs for trees carrying particular gene variants of interest for managed forests. In the longer term, surveying changes in occurrence of different genotypes will considerably improve monitoring, allowing predictions of whether or not particular stands have a good ability to withstand strong environmental changes.

Policy recommendations

Although LinkTree did not directly address current policies, the new knowledge highlights the key role of genetic diversity of trees in determining forest resilience. Wise use of genetic diversity can improve the implementation of relevant policies, such as national forest management programmes and climate-change adaptation strategies, and current forest management practices. The EUFORGEN programme is well placed for useful discussions and to provide necessary expert advice.

The **EU Forest Strategy**'s strategic orientations (p. 10) state that Member States should strengthen forest genetics conservation with support through the **Rural Development Programmes**. However, the conservation of genetic resources currently does not seem sufficiently emphasized to ensure that agreed biodiversity targets (such as the international **Aichi Targets** 13-15) are met.

Genetic adaptation of forest trees to climate change ultimately depends on specific genes, which underlines the importance of studying and valuing the genetic variability stored in trees and to identify genes involved in local adaptation. Both **the EU and National Climate Change Adaptation Strategies** would benefit from including such knowledge in models forecasting climate-induced range shifts. In fact, the inclusion of genetic diversity in such models may considerably modify the expected range shift of forest tree species.

It is also advised that maintaining genetic diversity of trees should be routinely promoted in forest and land planning and in management, e.g. as part of the **EU Biodiversity Strategy**'s Action 9b. The Strategy aims at increasing the contribution of agriculture and forestry to maintenance and enhancement of biodiversity (target 3b), and stipulates that by 2020, Forest Management Plans should be in place throughout the EU. Increasing the genetic diversity of trees increases the species diversity of the forest community they harbour, thus benefiting overall biodiversity in forests.

The **1999 EU Directive on marketing of Forest Reproductive Materials** should be improved with requirements on how to maintain a high level of genetic diversity within traded seed lots. Requirements should address the minimum number of seed trees to collect from a natural stand (typically more than 100), the necessity to sample seed trees from ecologically variable micro-environments within stands, and the importance of mixing seed lots collected within a region of provenance. Traded seed lots should eventually be made of collections sampled from hundreds of seed trees. It is suggested that such recommendations go beyond reforestation and afforestation projects and address all ecological restoration efforts.

Forest management practices that maintain evolutionary processes in naturally regenerated forests should be promoted. If needed, forest adaptation potential can be accelerated through tree breeding practices and transfer of suitable forest reproductive material. Given the high genetic variation among forest trees occurring in protected areas, such forests should also be considered as gene banks, for example in adaptive management of the **Natura2000 network**. Connectivity between protected areas (the **EU Habitats Directive** and **Strategy on Green Infrastructure**) facilitates gene flow and is important for the maintenance of genetic variation and adaptive potential of species (see also Articles 3 and 10 of the Habitats Directive).

Because forest trees are generally long-lived, **creating and maintaining effective long-term research and monitoring** is highly recommended in order to deliver reliable information, generate meaningful indicators for sustainable management of forest habitats under climate change, and to detect early signs of lack of adaptative capacity in forest trees. This is relevant also in the context of the EU Habitats Directive (e.g. Articles 1a, 1e, 1i, 3.1, 10, 11 and 18).

Links to sources

LINKTREE information on project website
Scientific publications on project website

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About this Policy Brief

This Policy Brief is part of a series aiming to inform policy-makers on the key results of the biodiversity research projects funded by BiodivERsA and provide recommendations to policy-makers based on research results.

The series of BiodivERsA Policy Briefs can be found at www.biodiversa.org/policybriefs.

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