Tree Improvement & Forest Genetic Resources

- The case of Germany -

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Summary
This report investigates the organisation and level of forest genetic resources (FGR) and tree improvement knowledge and implementation in Germany. It explores the emphasis of policies and the focal points of research and forest management.

The genetic composition, such as structure and diversity determine the aptitude of forests and trees to adapt to changes in site factors. Maintaining and increasing genetic variation within populations is *the* key measure to adapt our forests to changes in climate and increasing their resilience (Brang et al., 2014; Kavaliauskas et al., 2018).

It is found that *in situ* measures (FGR) are prioritised over *ex situ* measures (tree improvement) in German policies, however *ex situ* measures are gaining momentum and importance as the recent launch of a national genetic monitoring program (GenMon) shows.

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1 Introduction

1.1 Forestry resources and organisation

Germany is a well afforested country with a third (11.4 million. ha) under forest cover. Average stocking is 336m³ per ha and the average increment is 11.1m³ per ha/yr, resulting in an overall stock of 3.4 billion m³ and therefore the highest total stock in Europe (BWI3, 2012; (FAO, 2011). Main species are Norway spruce (*Picea abies*) in southern Germany and Scots pine (*Pinus sylvestris*) in the north followed by common beech (*Fagus sylvatica*) and Oak (*Quercus petraea and robur*). Almost 60% of German forests are coniferous with the rest allocated to deciduous trees and open ground. Nearly all forests (99%) are managed as high forest. Almost half of the German forest area is private forests (47%) with the rest being publicly owned. The identification and documentation of genetic resources is carried out across all forest ownerships (FAO, 2011).

To comprehend the main strategy of forest genetics and tree improvement in Germany it requires an understanding of the organisation of the forestry sector first. Germany is a federal state and as such the 16 states (Länder) have partial sovereignty (Paul et al., 2010). Forestry policies and management are the task of the states. Some states, such as Baden-Württemberg, are divided into four regional governmental districts (Regierungsbezirke) that share between them the tasks of forest law, hunting, forest policies, funding, timber marketing, forest labour law, silviculture and climate change. The forestry commission (LandesforstverwaltungBW) which is divided into 46 lower forestry commissions (Untere Forstbehörden) reports back to the regional governments and manages the state, corporate and private forests in Baden-Württemberg – view figure 1 (LandesforstverwaltungBW, 2020). The largest forest enterprise is ForstBW with 21 lower forestry commissions and 300.000 ha states forest under management (ForstBW,2020).

In 2020 the forestry and timber supply chain was reorganised resulting among other things in a merger of the forestry and timber marketing sector under the forestry commission's responsibility, while in the past forestry and timber marketing were separate industries (ForstBW, 2020). Similar to the UK, a lot of private forests are not under management in Germany mainly due to inheritance laws (which split forest ownerships to a degree where people don't even know that they own a small forest holding). Private forest owners are subsidised and financially encouraged from the forestry commission to make use of their expertise and take their forest resources under management.

While forest policies are state specific, national policies are in place which are then altered by each state's specific ministries on agriculture, forestry and rural affairs. These ministries report back to the Federal Ministry of Food and Agriculture (BMEL), which serves as a kind of umbrella organisation but has only limited competencies. At first the organisation and structure of the forestry and timber sector in Germany sounds confusing while actually it results in a less fragmented sector compared to the UK, which enables a regional and nationwide collaboration through the BMEL very easily.

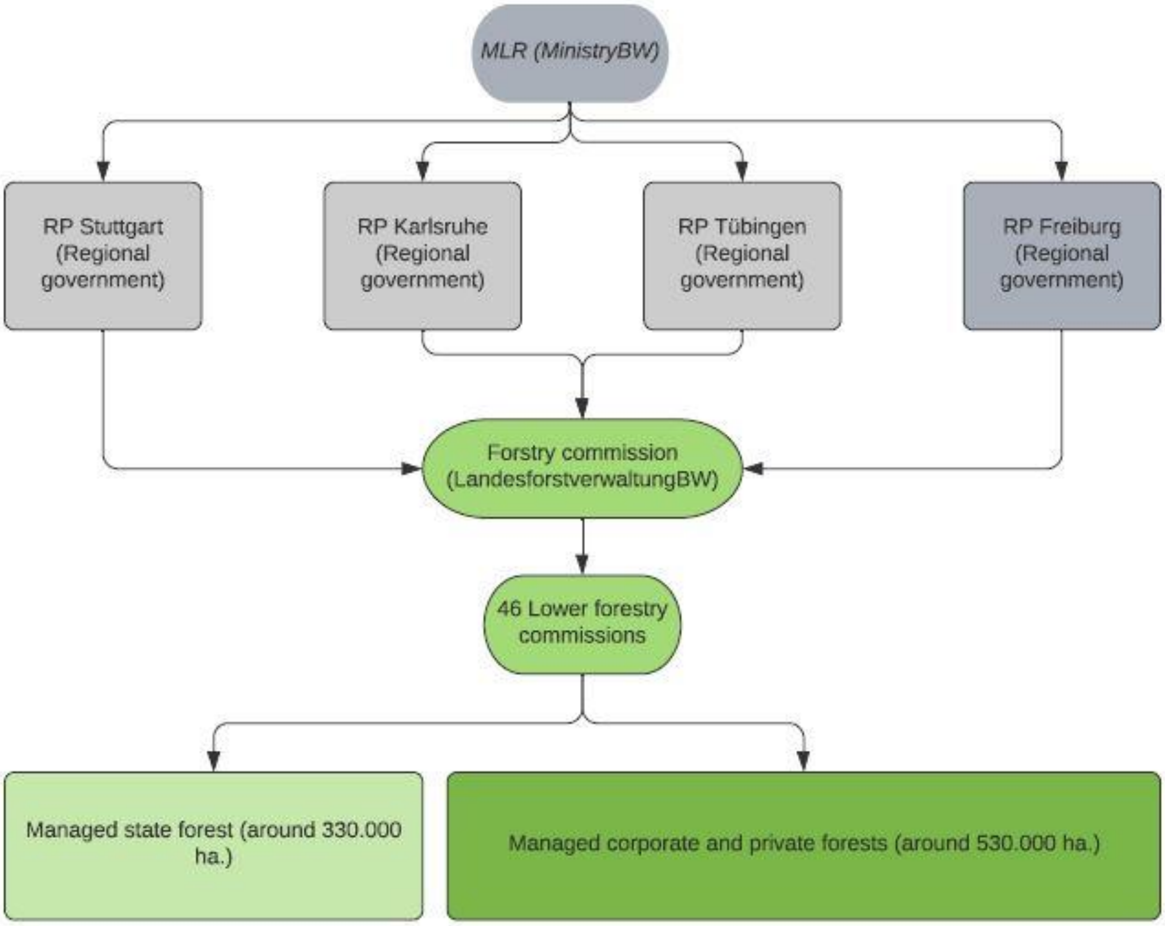

Figure 1 shows the organisation of the Forestry sector in Baden-Württemberg in south-west Germany with the states Ministry (MLR), the four regional governments (RP's) and the 46 Forestry Commissions (FVA, 2016).

1.2 Marketing and funding

The annual turnover of the German forestry and timber sector is around 170 billion euros and the forest and timber sector contributes 3 to 4% of the gross domestic product (FAO, 2011). 1.2 million people are employed in the sectors of forestry and timber. Germany is one of the leading importing and exporting countries of timber products in the European Union (UNCE, 2019). Imports increased significantly in recent years making Germany the second largest importer of industrial softwood roundwood in Europe behind only Austria and in front of the UK. This is likely to be related to the devasting effects of the bark beetle (*Ips typographus*) in central Europe, which led to a loss of 140million m^3 of timber in central Europe. Next to the bark beetle, storms and changes in climate are the greatest threat to the forestry economy in Germany and central Europe (UNCE, 2019). Germany is one of the top five producers of sawn hardwood in Europe and thus special emphasis should be given to the improvement of hardwoods (UNCE, 2019).

While forestry is mainly a task of each state, the federal government supports the states through legal frameworks and promotes research with funding through specific funding schemes (FAO, 2011). The Federal Office for Agriculture and Food (BLE) provides technical and administrative support e.g. the development and maintenance of a web page and financial management of research programmes. The Waldklimafond, for instance, funds all relevant nationwide projects that aim to mitigate or adapt to climate change, with a strong focus on forestry. Funding is bound to specific guidelines, for example, on provenance choice (FAO, 2011). Facilities and infrastructure, such as laboratories are provided by the states, while the private sector for genetic studies is growing (FAO, 2011).

2 Genetic Resources & Improvement

2.1 Forest Genetic Resources - in situ

Forest Genetic Resources refers to the genetic structure and diversity that allows the adaptability of forests and trees to changes in site factors and also to deliver forestry objectives (Euforgen, 2020). The genetic composition determines the phenology of the individual such as fructification behaviour, vitality, form and growth. Changes in flowering within a population and within a single species over time can have significant effects on the genetic diversity and adaptability of future generations (GenMon, 2018).

The "Concept for the Conservation and Sustainable Utilization of Forest Genetic Resources in the Federal Republic of Germany" is the most important nationwide policy for forest genetic resources (Euforgen, 2020; Paul et al., 2010) The document was published by the "Forest Genetic Resources and Legislation on Forest Reproductive Material (BLAG-FGR)" Working Group in 1987, an expert group represented by members from all 16 states of Germany and was reviewed in 2000 and 2010. This policy is implemented in each state with different priorities focussing more on either the forestry objective of timber quality, resilience or conservation.

In Germany *in situ* measures are prioritised and more widely supported and implemented than *ex situ* measures (FAO, 2011). *In situ* measures are measures carried out on the site where the genetic resource occurs, while *ex situ* measures involve the relocation of genetic resources from their place of origin, for instance, through the creation of seed orchards. (FAO, 2011). Over 7,080 ha in Germany are specifically marked as sites of *in situ* measures, containing over 170 tree and shrub species, while only 1,250 ha are designated as *ex situ* measures. Common practise is to designate whole forest stands as genetic resources, with seed orchards taking mainly the role of conserving seeds from rare species (FAO, 2011).

The main concept to achieve sound genetic diversity is through sophisticated silviculture on the principles of close-to-nature forestry with a focus on selecting future trees (Zukunfts Bäume or Z-Bäume) already at juvenile or pole stage that will build the future canopy with their phenotypic attributes for timber quality, resilience and biodiversity criteria. Indications of resilience are assessed after signs of tree health as a result of drought or pests, such as discoloration of leaves and on monitoring sites after timing of flowering or the degree of fructification (Schmiedel et al., 2018). Some individuals must be marked and selected by foresters for their biodiversity value and will be left standing until natural decay. Characteristics such as rot, holes and age determine whether individuals qualify as biodiversity trees. In order to weigh the economic, resilience and biodiversity value of trees against each other, foresters are nowadays trained in Marteloscope plots (permanent plots where every tree was subject to an in-depth inventory and the data is linked to a software) so that they can directly assess their tree selection against sound data.

In addition, German forestry has a very strong focus on natural regeneration especially on sites where the selection of future trees has occurred for a significant time and parent material is seen as suitable and plentiful (FAO, 2011). The fundamental assumption in the German forest genetic resource program or rather in general forest management is that through the selection of a sufficient number of tree crops as future parent material, through small silvicultural harvesting systems (clear fell larger than 0.5 ha are forbidden in most circumstances) and through a focus on natural regeneration (and shade tolerant species) the genetic variation and diversity is sustained and increased adequately to evolve adaptable forests (Kavaliauskas et al., 2018; Brag et al., 2014). In practise, however, contemporary German silviculture can leave as little as 80 - 50 final crop trees per ha standing, to contribute to the next generation. It is argued that so few parent trees per ha are an insufficient gene resource for future generations. Probably a paradigm shift towards more final crop trees (or rather parent material) is necessary here to sustain resilient forest stands.

Another possibility would be to increase the genetic diversity through more artificial planting. While results from studies are contradictory there is evidence that enrichment planting with improved material from seed orchards increases the genetic diversity within stands and thus increases their adaptability (Kavaliauskas et al., 2018; Brag et al., 2014). But planting is often restricted to stands were forest conversion is the main aim, usually from coniferous monocultures to uneven-aged, mixed stands. Planting material is sourced from "selected" stands and according to the act on forest reproductive material (FoVG Forstvermehrungsgesetz) for the use of reproductive material in state owned forests and in private forests it is controlled via support guidelines.

2.2 Tree improvement – *ex situ*

A national breeding or seed quality improvement programme doesn't exist in Germany, though the national strategy on forest genetic resources touches on a lot of *ex situ* measures and provides some guidelines (Paul et al., 2010). Individual forest research institutes investigate and handle tree improvement in Germany, while the states provide the harvest, processing and longer-term storage of seed in gene banks. The focal point lies on the selection and testing of whole forest stands. Stands must fulfil a number of requirements to qualify as seed crop stands. There is regulation on the number of trees and that the harvesting system is carried out by only registered forest seed and plant enterprises which are either private or state owned and of which there are 1,662 in Germany. In the past, parent material from plus trees used to be selected for growth, quality and resistance to pests, but today the focus lies on resilience and adaptability to changes in site factors (FAO, 2011). Thus, individuals are assessed not just after their stem form and vigour but also on their phenology (timing of budburst, fructification behaviour), overall health, and vitality.

Seed stands and seed orchards are governed by the FoVG. They are recorded in the Crop Authorization registers of the states (FAO, 2011). Every year the Federal Ministry BLE (Bundesanwaltschaft für Landwirtschaft und Ernährung) in Bonn conducts a survey for the 28 main commercial tree species in collaboration with the states. The seed harvest amounts are recorded separately according to regions of provenance and the seed is recorded according to the categories "source identified", "selected", "qualified" and "tested" (FoVG). By far the largest category is "selected" compromising 98% of all material (FAO, 2011). Material from the categories "qualified" and "tested" are rare due to the lower number of approvals and the limited funding opportunities to cover the higher costs of producing these higher categories. Table 1 gives an overview of the categories after tree species and seed source type.

Table 1 Approved basic material for forest reproductive material as from 2008 (FAO, 2011)

Category		Selected		Qualified		Tested							Source identified			
Type of basic material		Stands		Seed orchards		Stands		Seed orchards		Clones	Clonal mixtures	Parents of Family	Seed sources		Stands	
Tree species		number	reduced area [ha]	number	reduced area [ha]	number	reduced area [ha]	number	reduced area [ha]	number	number	number	number	reduced area [ha]	number	reduced area [ha]
Scientific name	Common Name															
Abies alba	European Silver Fir	1,195	7,973	2	8											
Abies grandis	Giant Fir	52	43	2	2											
Acer platanoides	Norway Maple	80	60	1	3								5	1	1	1
Acer pseudoplatanus	Sycamore Maple	726	1,083	13	22			1	3							
Alnus glutinosa	Common Alder	484	1,400	17	28	5	14	5	15							
Alnus incana	Grey Alder	6	4	2	1											
Betula pendula	European Birch	96	183	1	0,1											
Betula pubescens	Downy Birch	19	44	1	2											
Carpinus betulus	European Hornbeam	212	508	1	4								2	2	2	5
Castanea sativa	Sweet Chestnut	17	33													
Fagus sylvatica	Common Beech	5,643	76,201	4	9	12	134									
Fraxinus excelsior	Common Ash	1,162	2,769	9	19											
Larix decidua	European Larch	1,226	2,378	23	49	8	14	15	17							
Larix kaempferi	Japanese Larch	344	683	4	7			2	6							
Larix x eurolepis	Dunkeld Larch			1	4			3	8							
Picea abies	Norway Spruce	3,113	34,154	31	86	19	185	1	10							
Picea sitchensis	Sitka Spruce	7	28	1	1											
Pinus nigra	Austrian Pine	162	551	4	10											
Pinus sylvestris	Scots Pine	2,629	18,012	44	173	12	92	10	30							
Populus spec.	Poplars	6	7							58	8	6				
Prunus avium	Wild Cherry	121	131	11	22						3		22	21	6	4
Pseudotsuga menziesii	Douglas Fir	2,293	3,271	9	40	4	15	1	3			2				
Quercus petraea	Sessile Oak	3,306	31,890			13	250	1	1							
Quercus robur	English Oak	2,058	8,854	5	11	5	29									
Quercus rubra	American Red Oak	443	774													
Robinia pseudoacacia	Black Locust	42	109	1	1											
Tilia cordata	Little Leaf Linden	425	837	14	26			1	2							
Tilia platyphyllos	Large-Leaved Lime	18	11	1	2								1	0,3		
Total		25,885	191,989	202	527	78	733	40	95	58	11	8	30	24	9	10

3 Case Studies

3.1 GenMon Project

In Germany most forest data are collected during the National Forest Inventory (NFI) which provides the main data on tree species performance such as growing stock, increment and on timber resources (BWI 3, 2012). Because most of the data isn't transferable to a genetic monitoring program a national genetic monitoring program (GenMon) was launched and implemented jointly between research institutes of the different states (GenMon, 2018). The projects' main aim is the creation of an early warning system for changes in climate, stability, vitality and adaptation of forests stands, so that forest managers can adjust their strategy, for instance, in terms of marking criteria. A genetic long-term monitoring system for 14 beech (*Fagus sylvatica*) and 10 Spruce (*Picea abies*) research plots has been established across Germany (GenMon, 2018).

Subjects for monitoring include parent material, progeny and seeds. Using DNA-marker and microsatellites or simple sequence repeats (SSRs) their current genetic state (structure, diversity) are analysed against changes in time and space. Some individuals are assessed further after their phenological type, such as budburst, health, fructification behaviour and growth rate (GenMon, 2018).

Beech is chosen due to its wide distribution, its economic importance, biodiversity value and its occurrence on a wide variety of sites and thus its wide genetic spectrum and range of adaptability (GenMon, 2018).

Spruce was chosen for its high economic importance (spruce is called the "bread tree" in German) and its wide application on sites outside its natural geographical range (it is only native to altitudes from around 1000 m in the Alps and to slightly lower altitudes in more easterly, continental areas of Germany) (GenMon, 2018). Spruce has, in the past, shown to adapt well to different sites; however, it is highly sensitive to increasing temperatures and moisture deficit, thus it is supposed to be suitable as an even earlier warning indicator species than beech to changes in climate. Furthermore, the project will elicit on which sites Spruce stands and mixed stands with Spruce have a future (GenMon, 2018).

3.1.1 Sample plot Design & Method

The GenMon project design is based on a pilot study by Konnert et al., which investigated beech and wild cherry (*Prunus avium*) (2011). During this study isozyme gene markers, molecular genetic markers including microsatellites (SSRs) and amplified fragment length polymorphisms (AFLPs) were used (Konnert et al., 2011). Every research plot is 4 ha and has a fenced core section of 50 x 50m, enclosed by an intensive section of 100 x 100m and an extensive section of 200 x 200m. At least 1050 samples are collected per plot and utilised for genetic analysis (view table 2).. The level of genetic variation is assessed through gene frequencies like genetic diversity, number of polymorphic loci, and mean number of alleles per locus. Twenty plus or dominant trees are chosen as seed trees and investigated for flowering phenology, leaf flushing and the degree of fructification and vitality (Schmiedel et al., 2018).

Table 2: Sampling procedure for example plot (Schmiedel et al., 2018).

Development state	Intensive section including core section	Extensive section
Genetic studies		
Adult trees	All individuals present	Additional individuals up to 250
Natural regeneration	200 young plants representative for overall plot	
	4 clusters of natural regenerations comprising 50 individuals each	
Seeds	Single tree collections of seeds from 20 adult trees	
Qualitiy structure of seeds		
Seeds	Seed mixture from entire stand area	

3.1.2 Results

The data provides information within and across plots within different age classes and it might be possible to correlate molecular findings with phenotypic attributes. Specific software (GDA-NT, GSED, SGS) allows spatial structures and family structures to be investigated.

3.2 Other Key Projects

In the past *ex situ* projects in Germany were focused around short rotation forestry and biomass production, hence mostly poplar and willow species were genetically improved. Most prominent projects on short rotation forestry and biomass production were / are Fastwood and Weidenzüchtung. Other relevant German/European forest genetics and tree improvement projects are:

- FraxForFuture is a project around Ash (*Fraxinus excelsior*) and the fungus *Hymenoscyphus fraxineus* which leads to ash dieback. The project aims to find practical applications that help to maintain ash stands in Germany through an interdisciplinary approach. Researchers and foresters work together in the areas of forest genetics and tree improvement (FraxGen), phytopathology (FraxPath), biosecurity and silviculture (FraxSilva). The project was launched at the beginning of 2020 and runs for four years. Funding for the first year is €9.16m. through the Waldklimafond. For FraxGen, plus trees are selected from 10 core stands or 20 monitoring sites across Germany (Waldklimafond, 2020). Using gene-marker and phenotypical traits the most resilient and resistant trees are selected for seed collection and further tree improvement in seed orchards (Waldklimafond, 2020). Trees are investigated on the molecular scale for signs of genetic resistance against ash dieback *Hymenoscyphus fraxineus*. Organisations involved in the project are the Fachagentur Nachwachsende Rohstoffe (FNR) and the Forstliche Versuchsanstallt (FVA).
- EUFORGEN is the European Forest Genetic Resource Programme of which Germany joined in 1994. The program focusses on *in situ* measures and the maintaining of forest genetic resources to maintain forests that can evolve to changes in site conditions.
- Germany is a member of the European Evolution of Trees as drivers of terrestrial biodiversity (Evoltree) network, from the European Forest Institute (EFI) which aims to promote genetics and breeding programs through an interdisciplinary study of genomics, genetics, ecology and evolutionary studies.
- TreeBreedex is a Europe wide database of forest genetic resources and tree breeding programs.
- GenTree aims to provide the European forestry sector with better methods and tools to assess and understand forest genetic resources.

4 Key Players

While literature suggests that private institutes conduct research on forest genetics, the key organisations with the most influence appear to be government and states organisations. Policy guidelines are provided by the federal governmental ministries Federal Ministry of Food and Agriculture (BMEL) and the federal office for agriculture and food (BLE) which are informed by the advisory BLAG FGR group. The best and leading state institute (in my view) appears to be the Bavarian office for forest seeding and planting AWG Bayrisches Amt für Waldgenetik (AWG). It is in charge of the forestry propagation material (Forstliches Vermehrungsgut) and is a special commission that is designed especially for research on forest genetic resources and tree improvement and is a unique status in Germany. A strong collaboration between field trials and laboratory research, the size of the institution and its unique status makes the AWG probably the number one research facility on forest genetics and tree improvement in Germany.

Other relevant players are:

- The Forstliche Versuchs- und Forschungsanstallt (FVA) is the Baden-Württemberg equivalent to the Bavarian AWG but it focusses on a much wider range of disciplines and only one sub department collaborates closely with the AWG on forest genetic resources.

- The Fachagentur Nachwachsende Rohstoffe (FNR) is advising and collaborating with the federal Ministry BMEL on the organisation, promotion and funding of nationwide projects around Natural Resources.
- The Waldklimafond funds all relevant nationwide projects that aim to mitigate or adapt to climate change, with a strong focus on forestry. The fund is part of the federal ministries BMEL and BNU.
- ISOGEN is a company that aims to bridge the gap between research and practical application in the area of forest genetics and tree breeding.
- Genres is an information system for (forest-) genetic resources by the federal ministry BLE.
- The Thünen Institute researches a wide spectrum of topics related to renewable resources and also has a Department for Forest Genetics.
- The Department of Forest Genetics and Forest Tree Breeding at the der Georg-August-University of Göttingen investigates population and ecological genetics of forest organisms with a focus on molecular genetics to research genetic variation.
- The Faculty of Environment and Natural Resources of the University of Freiburg is a leading institute in forest research in Germany and worldwide, however, they don't hold a specific forest genetics and tree improvement chair. The institute of forest sciences is currently inviting applications for a Full Professorship for Forest Genetics.

5 Conclusion and thoughts

Germany's strategy to create adaptive and resilient forests is focussed on *in situ* measures and professional forest management, which results in profound selection of parent material which is genetically suitable for current and future site factors and progeny that hold the desired genetic variation. *Ex situ* measures are in place and embedded in forestry guidelines and law, however, the application of seed from seed stands and especially from seed orchards and the criteria "qualified" and "tested" are sparse due to the policy focus on *in situ* measures, the management focus on natural regeneration and a lack of funding incentives for the more elaborative improvement measures.

An increasing number of scientific literature and newspaper articles suggests that German forests struggle with diseases and drought nationwide and that they are in a "bad state". Hence, *in situ* measures and silvicultural practises need to adapt as well as *ex situ* measures needing to be funded and integrated into forest management to a greater extent to increase the resilience of German forests to changes in climate. For instance, more parent material should be left as means to increase the genetic diversity among the progeny and more "qualified" and "tested" planting stock should be provided and planted to ensure the future genetic diversity and resilience of German forests. Since evidence suggests that a combination of natural and artificial regeneration is a good strategy to develop a sound genetic variation within stands, a wider implementation of enrichment plantings in Germany would seem a sensible way forward.

Tree improvement and genetic monitoring strategies with a focus on adaptability and resilience are gaining momentum but are still in their infancy in Germany. While many challenges remain, Germany's forests can maintain and improve their genetic diversity in the future, however *ex situ* measures must continue to gain importance.

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