THE SECOND REPORT
ON THE STATE
OF THE WORLD'S

FOREST GENETIC RESOURCES

COUNTRY REPORT

GERMANY

This country report was prepared as a contribution to the FAO publication, *The Second Report on the State of the World's Forest Genetic Resources*.

The country reports had two elements: (1) an online questionnaire to gather data and information on forest genetic resources; and (2) a complementary written report. For the written reports, countries were invited to follow the structure of the global report and reporting guidelines adopted by the Commission on Genetic Resources for Food and Agriculture at its Seventeenth Regular Session in 2019.

15 October 2021

National Report
on the Conservation and Sustainable Use of
Forest Genetic Resources
in the Federal Republic of Germany
2020

Table of contents

LIST OF ILLUSTRATIONS

List of tables

LIST OF ABBREVIATIONS AND ACRONYMS

AdaptForClim	Principles and strategies for the procurement of high quality and adaptable forest reproductive material under climate change
AWG	Bayerisches Amt für Waldgenetik (Bavarian Office of Forest Genetics), Teisendorf
AöR	Anstalt öffentlichen Rechts (public-law institution)
BGBl.	Bundesgesetzblatt (Federal Law Gazette)
BLAG-FGR	Bund-Länder-Arbeitsgruppe „Forstliche Genressourcen und Forstsaatgutrecht" (Federal-Länder Working Group on Forest Genetic Resources and Forest Seed Law)
BLE	Bundesanstalt für Landwirtschaft und Ernährung (Federal Office for Agriculture and Food)
BMBF	Bundesministerium für Bildung und Forschung (Federal Ministry of Education and Research)
BMEL	Bundesministerium für Ernährung, Landwirtschaft und Verbraucherschutz (Federal Ministry of Food and Agriculture)
BMU	Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (Federal Ministry for the Environment, Nature Conservation and Nuclear Safety)
BNatSchG	Bundesnaturschutzgesetz (Federal Nature Conservation Act)
BWaldG	Bundeswaldgesetz (Federal Forest Act)
CICES	Common International Classification of Ecosystem Services
CO_2	Carbon dioxide
DAkkS	Deutsche Zertifizierungsstelle (German Accreditation Body)

DendroMax	Research project for the development of biotechnological tools and practical cultivation methods to enhance dendromass production by the breeding and bulk propagation of varieties of selected tree species
DNA	Deoxyribonucleic acid
EEZ	Exclusive economic zone
EU	European Union
EUFGIS	European Information System on Forest Genetic Resources
EUFORGEN	European Forest Genetic Resources Programme
FAO	Food and Agriculture Organization of the United Nations
FastWOOD	Research project for the breeding of rapidly growing tree species of the genera Populus, Robinia and Salix for short-rotation coppice production of renewable resources
FAWF	Forschungsanstalt für Waldökologie und Forstwirtschaft Rheinland-Pfalz (Rhineland-Palatinate Forest Ecology and Forestry Research Institute), Trippstadt
FFV	Verein Forum forstliches Vermehrungsgut e.V.
FFK	Forstliches Forschungs- und Kompetenzzentrum Gotha (ThüringenForst) (Thuringia Forest Research and Competence Centre, Gotha)
FitForClim	Research project for the procurement of highly-productive and suitable forest reproductive material for future forests under climate change
FNR	Fachagentur Nachwachsende Rohstoffe e. V. (Agency for Renewable Resources)
FoVG	Forstvermehrungsgutgesetz (Act on Forest Reproductive Material)
FoZVO	Forstvermehrungsgut-Zulassungsverordnung (Forest

	Reproduction Material Approval Ordinance)
FPNR	Förderprogramm Nachwachsende Rohstoffe (Renewable Resources Funding Programme)
FraxForFuture	Ash conservation demonstration project
FVA	Forstliche Versuchs- und Forschungsanstalt Baden-Württemberg (Baden-Württemberg Forest Experimental and Research Institute)
GenMon	Research project to establish a genetic monitoring network for common beech and Norway spruce in Germany to evaluate the tree species' genetic adaptability to climate change
ha	Hectare
Habitats Directive	Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora
IACS	Integrated Administration and Control System
IBV	Informations- und Koordinationszentrum für Biologische Vielfalt (Information and Coordination Centre for Biodiversity)
ISAP	Inter-SINE Amplified Polymorphism (retrotransposon-based marker system)
IUFRO	International Union of Forest Research Organizations
kg	Kilogramme
km	Kilometre
km^2	Square kilometre
m	Metre

m^2	Square metre
m^3	Cubic metre
MV	Mecklenburg-Vorpommern (Mecklenburg-West Pomerania)
NFI	National Forest Inventory
NFI2	Second National Forest Inventory (as of 2002)
NFI3	Third National Forest Inventory (as of 2012)
NFI4	Fourth National Forest Inventory (as of 2022)
NGS	Next generation sequencing
NRW	Nordrhein-Westfalen (North Rhine-Westphalia)
NW-FVA	Nordwestdeutsche Forstliche Versuchsanstalt (Northwest German Forest Research Institute)
OLD	Other long-lived deciduous trees (primarily ash, maple, European hornbeam, lime, black locust and chestnut)
OSD	Other short-lived deciduous trees (such as birch, alder, poplar, rowan and willow)
SNP	Single Nucleotide Polymorphism
SSR	Simple Sequence Repeats
Thünen Institute	Johann Heinrich von Thünen Institute, German Federal Research Institute for Rural Areas, Forestry and Fisheries
ZüF	Zertifizierungsring für überprüfbare forstliche Herkunft Süddeutschland e.V.

1 Summary

The Federal Republic of Germany is a federal state composed of 16 Länder. Its forests cover a total area of around 11.4 million hectares. That is about 32% of the land area. Forest management today follows the principles of sustainable and semi-natural forestry. This generally fulfils the functions of production, conservation and recreation at the same time. A substantial legal framework governs forest management for the Federal Government and the Länder. Forest management in Germany is more extensive than other land use forms. Sustainable forestry practices – in conjunction with unexploited areas of forest where nature is left to run its course – result in a dynamic mosaic of diverse ecosystems, connecting elements and exceptionally richly structured habitats and refuges for vulnerable and rare animal species.

Conservation of biodiversity and in particular forest genetic resources is a prerequisite for future uses, innovation and breeding progress. Forest conservation and hence also the conservation of forest genetic resources is generally a responsibility of the Länder. These coordinate their measures for the conservation of forest genetic resources among themselves and with the Federal Government in the Federal-Länder Working Group on Forest Genetic Resources and Forest Seed Law (BLAG-FGR).

As of 2017, there were in situ conservation stands covering approximately 34,400 hectares for a total of 127 tree and shrub species. Many in situ conservation measures for forest genetic resources are integrated into normal forestry operations. There are also specific ex situ conservation programmes in Germany for tree and shrub species that are vulnerable or rare at national or regional level. Ex situ conservation measures are also carried out for regionally significant populations of non-vulnerable tree and shrub species if they are regionally threatened or particularly valuable.

Genetic investigations of species and populations of forest tree and shrub species have continued intensively over the last 10 years. Such investigations aim either to describe the status or development of genetic diversity, to describe population structure or to accompany breeding measures:

The growing impacts of climate change and the increasing extent of damage from storms, drought and pests call for a change of thinking with regard to the conservation and use of forest genetic resources. The above management trends and drivers of change harbour opportunities for forest genetic resources. The search for alternatives to what have so far been main tree species together with the increasing importance of the recreational function of forest and of nature conservation have raised interest in previously neglected, in some cases secondary and rare tree species.

Federal and Länder measures for in situ and ex situ conservation of forest genetic resources are coordinated in Germany by BLAG-FGR. As early as in the 1980s, BLAG-FGR presented an initial "Concept for the Conservation of Forest Genetic Resources in the Federal Republic of Germany". That concept has also served as a National Programme since 2010. Research on forest genetic resources is conducted by the Länder member institutions of BLAG-FGR, the Thünen Institute, universities and other institutions of higher education. The Forest Genetics/Forest Tree Breeding section of the German Association of Forest Research Organisations (DVFFA) provides a platform for the exchange of scientific knowledge in all subdisciplines. Research is supported with federal funding programmes.

2 Value and importance of forest genetic resources

Forests are a defining feature of the German natural and cultural landscape. Germany's forests concurrently serve a variety of functions: the supply of timber, as a carbon reservoir, for the local climate, for nature and species conservation, for the supply of water, as a source of income for forest owners and for recreation. The management of forests and of how they develop in Germany is largely guided by an integrative principle of sustainable, multifunctional forestry to safeguard the economic, protective and recreational functions of forest above and beyond the production of timber. Forests have been shaped by human activity for many centuries. Germany no longer has any primary forest. Forests cover 32% of the German land area. The principle of sustainability has a long tradition in German forestry.

Germany has a substantial legal framework governing forests and their management that has continuously evolved on the basis of centuries of experience in forestry and on the part of forest owners. The separation of responsibilities between the Federal Government and the Länder (the sixteen German states) enshrined in the German Basic Law (the German constitution) makes it possible for that legal framework to be adapted to regional circumstances. This leads to a certain diversification of forest law (chapter 2). Federal and Länder laws require all forest owners to manage their forests in an orderly and sustainable manner.

The Federal Act on Forest Conservation and the Promotion of Forestry (Bundeswaldgesetz – also referred to in the following as the Federal Forest Act) is the most important federal-level instrument concerning forest conservation and safeguarding multifunctional and sustainable forest management. It also provides the basis for promoting forestry and balancing the public interest with the interests of forest owners. It is implemented and supplemented by Länder-level forest acts. A further act of special importance to the conservation and sustainable use of forest genetic resources is the Act on Forest Reproductive Material (Forstvermehrungsgutgesetz – FoVG). Its purpose is to conserve and improve forests – with their many beneficial functions – in terms of genetic diversity by providing high-quality source-identified forest reproductive material and to promote forestry and its productivity. The Act governs the production, placing on the market, import and export of forest reproductive material.

Three categories of forest reproductive material are distinguished for forestry use:

- Selected reproductive material: phenotypically selected stands
- Qualified reproductive material: plus tree seed orchards
- Tested reproductive material: basic material or progeny (stands, seed orchards, parents of family, clones or clonal mixtures) tested in scientific field trials and growing trials.

Further stipulations are contained in national and Länder laws on nature conservation, hunting, plant protection and other environmentally relevant sectoral law.

Other strategies of relevance to forests and forestry include the National Strategy on Biological Diversity (BMUB 2007), the German Sustainable Development Strategy (Federal Government 2016, updated Die Bundesregierung 2020), the German Resource Efficiency Programme III (BMU 2020), the Climate Action Plan 2050 (BMU 2016) and the National Bioeconomy Strategy (BMBF 2020).

2.1 The role of forests and of the forestry and timber cluster in the economy

Efforts to convert single-species stands that are unsuited to their location into more natural mixed-species stands with predominantly native tree species must be stepped up considerably in the coming decades. This poses a challenge in terms of technology, especially for the well-established sawmill industry, which is mainly geared towards softwood. The Norway spruce (*Picea abies*) is currently the main source of added value in the forestry and timber sector. Covering 25% of forest land and making up 33% of stock, this species accounted for a disproportionately large 52% of the timber supply in the last decade (NFI3 2012). Value creation in the timber industry has so far heavily relied on softwood (88% of domestic roundwood consumption).

Deciduous species do not match the technological properties of softwood and hardly any mass-manufactured hardwood products are available today for use in building. Most hardwood (63%) is currently still used for energy. Developing new, innovative and marketable hardwood products is currently one of the most important and challenging research and development tasks in the forestry and timber industry.

German forestry was a profitable sector of the economy in the period 2008 to 2018. Net entrepreneurial income reached a high level of over €1 billion per year from 2012. In 2018 it came to no less than €1.9 billion. As recently as 2018, the national forestry and timber industry, which by the EU definition also includes trade, printing and publishing, generated revenue of €187 billion and gross value added of €58 billion. This corresponds to about 1.9% of gross value added in the economy as a whole. In 2018, this sector of the economy provided income for 1.8 million private forest owners and about 1.1 employees in about 120,000 enterprises with their main focus in rural regions. However, forestry in the strict sense accounts for only a small share of this total: With some 78,000 employees, forestry generated annual revenue of around €6.9 billion and gross value added of about €3.8 billion (2018 figures).

The timber market is highly volatile, however. Market prices for timber plummeted between 2018 and 2020 due to drought and heatwaves, storm damage and related impacts.

2.2 Economic, environmental, social and cultural benefits of forest genetic resources (ecosystem services)

Forest management in Germany is more extensive than other land use forms; as a defining feature of the modern cultural landscape, human influence is indeed visible in forests but less so than in other land uses. Sustainable forestry practices – in conjunction with unexploited areas of forest where nature is left to run its course – result in a dynamic mosaic of diverse ecosystems, connecting elements and exceptionally richly structured habitats and refuges for vulnerable and rare animal, plant and fungus species.

The German forestry sector provides numerous services with regard to conservation and recreation in forests, partly to comply with legal requirements and partly on a voluntary basis. In addition to services relating to recreation, forests and forestry provide important ecosystem services such as carbon sequestration, storage of precipitation (flood prevention) and water filtration, protecting against soil erosion, noise and pollution control (including particulates), provision of fresh air and local climate improvement (such as protecting against wind, temperature and humidity). The basis for safeguarding and providing these services is biodiversity. In managed forests, forest services are provided both by actively engaging in management measures and also by deliberately refraining from other measures, such as leaving old growth and deadwood in place and not planting specific tree species. Only a small fraction of forest services can be marketed in niche markets, such as in environmental education and trading in ecopoints.

Forests also provide various cultural functions or services. On the basis of the Common International Classification of Ecosystem Services (CICES), these include forest services that promote recreation, ecotourism, aesthetic experience, intellectual interactions with nature (such as environmental education) and spiritual fulfilment. A further cultural ecosystem service provided by forests is their contribution to the scenic beauty of the countryside. In combination with fields, meadows, hedges and waterbodies, forests shape the characteristic appearance of the natural and cultural landscape in Central Europe.

To the extent that the Federal Government is responsible and involved, any additional material and human resource requirements are met financially and in staffing terms from the relevant section of the federal budget.

2.3 The contribution of forest genetic resources to relevant sustainable development goals

Conservation of biodiversity and in particular forest genetic resources is a prerequisite for future uses, innovation and breeding progress. This is because forestry has certain distinguishing characteristics relative to other sectors. Forestry under Central European conditions is characterised by production periods spanning multiple human generations. The extremely long-term nature of forestry production means that silvicultural decisions reach far into the future and mostly have to be made under conditions of uncertainty about their consequences. The importance of forests for climate change mitigation, biodiversity and preserving cultural heritage is thus reflected in multifunctional forestry producing and exploiting timber as a renewable resource in a manner that is in harmony with nature and sustainable, providing for nature-friendly recreation and creating long-term employment.

2.4 Priorities

The focus is on developing climate-adaptable, semi-natural, sustainably managed mixed forests with site-appropriate, predominantly native tree species that mitigate the risk of large-scale degradation. An additional goal is to further increase the climate change mitigation value of forests, sustainable forest management and efficient timber use. Semi-natural, species-rich mixed forests with predominantly native tree species are more resilient and adaptable to climate change. They are less susceptible to disruption in the production of timber, are particularly effective in terms of soil and water conservation and make an important contribution to the conservation of biodiversity. The prevailing diversity of sites and locations, ownership and management practices fundamentally constitute a good basis for broad risk diversification in German forestry. However, the projected impacts of climate change may necessitate extensive adaptation measures in various areas of forest management. The enabling conditions must be maintained and where necessary created so that forests can adapt to the new environmental conditions in line with the vision set out in the Forest Strategy 2020. "Sustainable management preserves and develops site-appropriate, robust forests with mainly native species of trees that are able to adapt to climate change" (BMEL 2019).

A proven instrument for monitoring the development of genetic diversity in forest ecosystems is the genetic monitoring approach (section 11.4.1). However, high costs stand in the way of establishing further monitoring plots and expanding the system to additional species. A key priority is further assessment of the genetic suitability of native tree species in Germany in terms of their geographical distribution. Practicable and efficient methods are to be further developed in order to provide meaningful results and workable recommendations. Leaf and needle samples are being collected nationwide for genetic analysis for the first time as part of the fourth National Forest Inventory.

2.5 Challenges

The growing impacts of climate change and the increasing extent of damage from storms, drought and pests call for a change of thinking with regard to the conservation and use of genetic resources used in forestry. Set against this are the limited human resources in research and public agencies.

Cooperation between forestry and nature conservation is also highly important to enable adapted seed also to be harvested in protected areas in cases where this is compatible with the applicable conservation objectives.

3 State of forests

Germany's forests are sustainably managed and fulfil diverse economic, protective and recreational functions in rural and urban regions. Forest in Germany is defined as follows in section 2 of the Federal Forest Act (Bundeswaldgesetz – BWaldG):

(1) Forest within the meaning of this Act is any area of ground covered by forest vegetation. Forest also includes cutover or thinned areas, forest tracks, firebreaks, temporarily unstocked land and clearings, forest glades, feeding grounds for game, landings and further areas linked to and serving the forest.

(2) Forest within the meaning of this Act does not include

1. *areas of ground on which tree species are planted with the objective of rapid timber extraction and whose stands have a rotation period not exceeding 20 years (short rotation coppices),*
2. *areas with trees that are also used for the cultivation of agricultural products (agroforestry cultivation),*
3. *areas covered by forest vegetation that on 6 August 2010 are identified as agricultural land in the land parcel identification system referred to in section 3 sentence 1 of the IACS Ordinance of 3 December 2004 (Federal Law Gazette I p. 3194), as last amended by article 2 of the Ordinance of 7 May 2010 (electronic Federal Law Gazette AT51 2010 V1), for as long as the agricultural cultivation continues, and*
4. *smaller areas in open pasture land or in built-up areas with individual groups of trees, rows of trees or hedges or that are used as tree nurseries.*

(3) The Länder may include other areas of ground as forest and exclude Christmas tree and ornamental brushwood plantations and parkland attached to country houses.

The definition of forest is further operationalised in the Survey Instructions for the National Forest Inventory (NFI):

"Forest within the meaning of the NFI is any area of ground covered by forest vegetation, irrespective of the information in the cadastre or similar records. The term forest also refers to cutover or thinned areas, forest tracks, firebreaks, temporarily unstocked land and clearings, forest glades, feeding grounds for game, landings, forest aisles, further areas linked to and serving the forest including areas with recreation facilities, overgrown heaths and moorland, overgrown former pastures, alpine pastures and rough pastures, as well as areas of dwarf pines and green alders. Heaths, moorland, pastures, alpine pastures and rough pastures are considered to be overgrown if the

natural forest cover has reached an average age of five years and if at least 50% of the area is covered by forest.

Areas with forest cover in open pasture land or in built-up areas of under 1000 m², coppices under 10 m wide, Christmas tree and ornamental brushwood plantations, commercial forest-tree nurseries as well as parkland attached to country houses are not forest within the meaning of the NFI. Watercourses up to 5 m wide do not break the continuity of a forest area."

The forest area covered by the NFI thus also includes areas with forest cover of between 0.2 and 0.5 hectares that do not count as forest under the definition of forest applied by the Food and Agriculture Organization of the United Nations (FAO). Areas of dwarf pines and green alders are forest under the national definition. Under the FAO definition, these would come under "other wooded land" as they do not usually attain the minimum height of 5 m. However, these vegetation categories are found only on a small scale in Germany in the Alps and on upland ridges.

3.1 Forest structure parameters

Forests cover 32% of the German land area, or 11.4 million hectares. About 54% of the forest area is covered with conifers and about 43% with deciduous trees. The most common and economically important tree species are Norway spruce *(Picea abies*), Scots pine *(Pinus sylvestris*), common beech *(Fagus sylvatica*) and the two oak species *(Quercus petraea and Q. robur*).

The average age of forest as of the 2012 sample year for NFI3 was 77 years, 4.5 years older than in the 2002 NFI2. Above-average numbers of conifers in particular come under the 41-60 age category. Among other things, and on a regional basis, this is a consequence of reafforestation in the 1950s and 1960s following the Second World War. These reforestations were often established as pure coniferous stands, in particular because Norway spruce (*Picea abies*) and Scots pine (*Pinus sylvestris*) grow well and showed high growth rates in the open-land conditions prevailing on destroyed and clear-cut forest land.

Table 3-1: Distribution of tree species[1] in Germany. NFI3 (2012)

Species groups 2012	Area (ha)	Percentage area (%)	Change[2] (ha)
Beech	1,680,072	16	102,324
OSD[3]	1,147,904	11	42,273
Oak	1,129,706	10	70,221
OLD[4]	769,578	7	99,550
All deciduous trees	**4,727,260**	**43**	**315,368**
Norway spruce	2,763,219	25	– 242,487
Pine	2,429,623	23	– 84,774

Larch	307,050	3	6,296
Douglas fir	217,604	2	35,205
Fir	182,757	2	18,540
All conifers	**5,900,253**	**54**	**– 267,220**
All tree species			**48,148**

1 Reference: Accessible forest, timberland including gaps in cover or in stands

2 Change relative to findings of NFI2 (2002)

3 OSD: other short-lived deciduous (such as birch, alder, poplar, rowan and willow)

4 OLD: other long-lived deciduous (primarily ash, maple, European hornbeam, lime, black locust and chestnut)

3.2 Ownership structure

Ownership structures in Germany are diverse. Private forests account for the largest share. The following table shows the distribution of ownership structures.

Table 3-2: Forest area by type of ownership

Ownership structure	Area (million ha)	Area (%)
Private forest	5.49	48
Länder-owned forest	3.30	29
Communal forest	2.22	19
State forest	0.40	4

There is a wide spread of private forest ownership in Germany with the number of private forest owners estimated at around 1.8 million. Most of these are small and very small private forest owners with an average forest area of just 2.5 hectares. Forest owners are organised in about 3,600 forestry associations with over 430,000 members, who together manage about 3.5 million hectares of forest land.

3.3 Management trends

The Norway spruce (*Picea abies*) was considered until recently as the 'bread-and-butter' tree of German forestry, accounting for 25% of timberland with forest cover, a third of timber stock and over half of timber use. It has consequently long been the commercial backbone of many forestry enterprises and, largely for historical reasons, has been grown well beyond its natural range.

Cultivating pure coniferous stands involves numerous risks, however, attention to which was already being drawn in the late 19th and early 20th centuries (GAYER 1886; WIEDEMANN 1925). Since as early as the mid-1980s, in response to recent and widespread forest dieback, the Federal Government and the Länder launched funding programmes in Germany for the conversion of coniferous forest to mixed forests. Most of the Länder have decreed forest conversion measures in Länder-owned forests and funding measures for forest conversion in non-Länder-owned forests. The forest inventory findings confirm the trend: Recent decades have brought a decrease in the share of Norway spruce and an increase in the share of mixed and deciduous forest. Mixed forest also includes coniferous forest and deciduous forest with more than one coniferous or deciduous tree species respectively. As climate change progresses, conditions are expected to deteriorate in Germany for Norway spruce (*Picea abies*) (BOLTE et al. 2009; BUGMANN & PFISTER 2000; HANEWINKEL et al. 2013). Some areas have seen large-scale dieback. Damage caused by storms, droughts and beetle in 2018, 2019 and 2020 raised awareness of the issue and put it on the political agenda. To a lesser extent, lack of water in conjunction with secondary biotic damage has also affected other tree species such as Scots pine (*Pinus sylvestris*) and common beech (*Fagus sylvatica*). Based on data for the years 2018, 2019 and 2020, the Federal Ministry of Food and Agriculture (BMEL) estimates the volume of fallen timber at about 171 million m^3, comprising 156.5 million m^3 of softwood and 14.1 million m^3 of hardwood. An area of 277,000 hectares currently needs restocking. Aside from the losses of income and stock, dead and dying trees present enormous challenges for forestry enterprises. Dealing with these areas calls for a range of different approaches. Wood decay fungi cause rapid strength loss in timber, for example, with the result that large branches and entire sections of crown can suddenly break off and fall. Challenges on a similar scale relate to ash dieback and to bark beetle outbreaks in Norway spruce.

3.4 Drivers of change

The forestry sector is on the search for alternatives in order to adapt our forests to climate change. Options being explored include the potential suitability of other, heat and drought-adapted provenances of our main native tree species, greater use of rarer native tree species and also the use of non-native tree species. Conversion to deciduous and mixed forest is to be stepped up and softwood cultivation adapted to suitable sites. Sustainable forest conversion will result in a larger supply of hardwood and hence shifts in the commodity timber product range. Developing new, innovative and marketable hardwood products is therefore one of the most important and challenging research and development tasks in the forestry and timber industry. Mainly for technological reasons and with a view to market acceptance, conventional softwood products cannot be simply switched out for products made of hardwood. There is thus a need for innovations that better exploit the potential of hardwood. Forest genetic resources consequently play a key role in the conversion of forests and adaptation to climate change. At the same time, climate change presents challenges precisely for *in situ* conservation of forest genetic resources as it can have negative impacts on the locations of conservation stands.

As well as climate change mitigation and resource conservation, increasing awareness of the environmental problems caused by widespread use of plastics (such as ocean plastic pollution and microplastics) has also become a driver of innovation for the use of timber as a renewable resource. Examples include wood-based artificial fibres, lignin-based adhesives and even wooden coffee capsules. Bark substrates for garden, horticulture and landscaping use and as a substitute for peat have become an important byline in timber milling. This is not without problems of its own, as taking the bark together with timber deprives the forest of valuable nutrients. Work is therefore being done on the development of debarking harvester heads.

3.5 Challenges and opportunities for forest genetic resources

The above management trends and drivers of change are important to the conservation and protection of forest genetic resources. The search for alternatives to what have so far been primary tree species together with the increasing importance of the recreational function of forest and of nature conservation have raised interest in intraspecific genetic variation, both of native tree species and of previously neglected, in some cases secondary and rare tree species. There are also risks, however, relating to climate change and the introduction of invasive pests. These can lead to the loss of genetic resources.

4 State of other wooded lands

Forest and other areas with tree cover outside of forests are defined in Germany in the Federal Forest Act (Bundeswaldgesetz – BWaldG) (chapter 2). This definition differs from that applied by the FAO. The FAO definition refers solely to trees in general, without distinguishing between forest vegetation and other trees. This results in imprecision in transferring and comparing with the situation in Germany.

4.1 Description of the state of other wooded lands

Areas with woody vegetation cover that are not forest within the meaning of the Federal Forest Act include:

- Short rotation coppices
- Agroforestry systems
- Smaller areas in open pasture land or in built-up areas with individual groups of trees, rows of trees or hedges or that are used as tree nurseries
- Areas with forest vegetation cover (such as railways)
- The Länder are permitted to include other areas of ground as forest and exclude Christmas tree and ornamental brushwood plantations and parkland attached to country houses.

In Germany, these areas are agricultural land. The agricultural statistics do not include sparse orchards with fewer than 100 trees per hectare.

Each of the Länder have a Land forest act, some of which restrict the definition of forest by excluding smaller areas in open pasture land or in built-up areas with individual groups of trees, rows of trees or hedges or that are used as tree nurseries, Christmas tree and ornamental brushwood plantations and parkland attached to country houses (an example is section 2 (4) of the Baden-Württemberg Land Forest Act (Landeswaldgesetz)).

Nursery cultivation for forestry and 'open countryside' purposes is carried out by 1,970 enterprises, currently with a total cultivation area of 18,200 hectares (2019). The number of nurseries and their cultivation area has decreased significantly overall. This notably applies to forest nurseries.

Table 4-1: **Nurseries and nursery areas**

Attribute		Unit	Year		
			2008	2017	2019
Enterprises with nursery areas		Number	3,035	1,714	1,970
Total nursery areas		ha	22,597	18,613	18,200
– Ornamental shrubs		ha	12,146	7,975	
– Hedge plants				2,047	
– Conifers for Christmas tree plantations		ha	1,203	684	
– Forest vegetation		ha	2,258	1,829	
of which	conifers (excluding conifers for Christmas tree plantations)	ha	907	684	
	deciduous trees	ha	1,351	1,145	
Other nursery areas		ha	5,537	3,729	

[1] Federal Statistical Office 2019

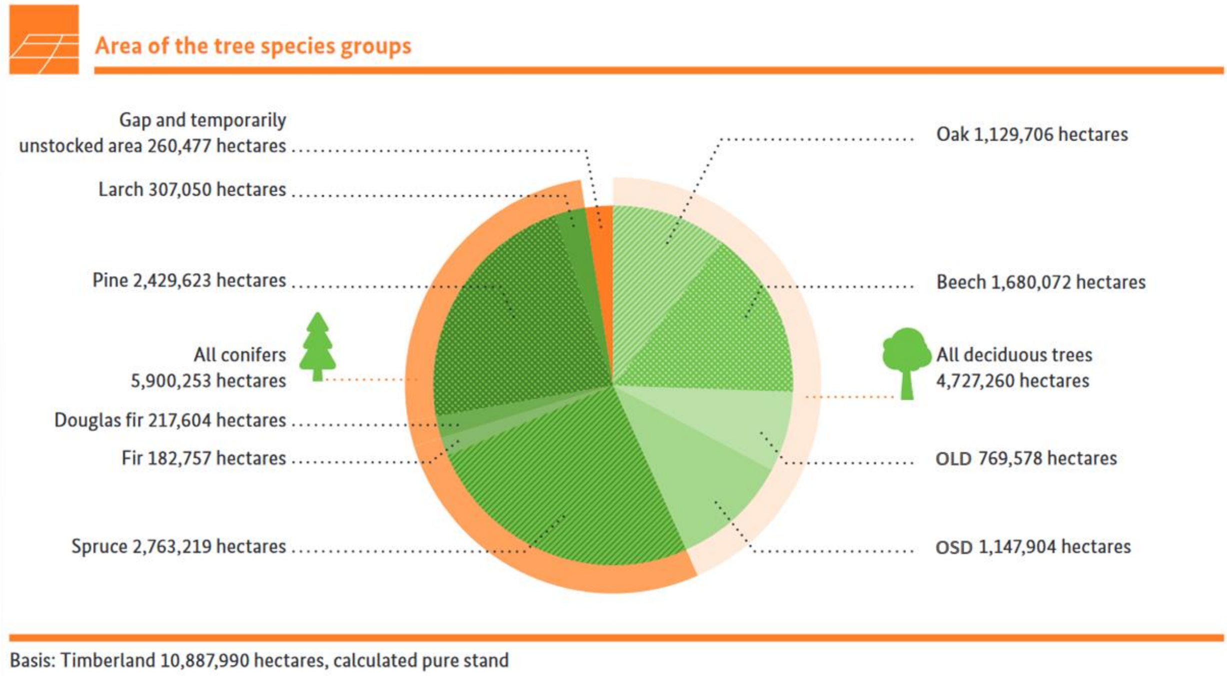
4.2 Impact of areas with woody vegetation cover outside of forests on forest genetic resources

Clearing away forest genetic resources for purposes such as promoting species adapted to open countryside can result in the displacement of vulnerable tree species (as with the mountain pine (*Pinus mugo*) when acidic wet woodland is converted to open bog as a species conservation measure for the moorland clouded yellow (*Colias palaeno*)). Conflicts arise here between different conservation objects or different levels of biodiversity.

5 State of diversity between trees and other woody plant species

First published in 1987, the National Programme for Forest Genetic Resources in Germany (Concept for the Conservation and Sustainable Utilization of Forest Genetic Resources in the Federal Republic of Germany; PAUL et al. 2010) identifies measures for the future conservation of forest genetic resources and thus forests. At subnational level, several of the Länder have also adopted strategies for the conservation and protection of forest genetic resources. Including epiphytes and lianas, 191 tree and shrub species occur in German forests. Of these, 13% are neophytes, meaning species introduced to Germany after 1500 AD (SCHMIDT et al. 2003). Eleven tree species dominate: Norway spruce (*Picea abies*), Scots pine (*Pinus sylvestris*), common beech (*Fagus sylvatica*), sessile oak (*Quercus petraea*) and English oak (*Q. robur*), European birch (*Betula pendula*), common ash (*Fraxinus excelsior*), common alder (*Alnus glutinosa*), European larch (*Larix decidua*), Douglas fir *(Pseudotsuga menziesii*) and sycamore *(Acer pseudoplatanus*). These account for about 90% of the main forest canopy in Germany (NFI3). A further 40 tree species or species groups share about 10% of the forest area. Notwithstanding their limited coverage, these make important contributions to diversity, soil conservation, timber production and potentially as more important tree species in terms of area cover as climate change progresses. In principle, all tree species found in Germany (both native and non-native) have importance as forest genetic resources.

Introduced tree species such as Douglas fir (*Pseudotsuga menziesii*), Japanese larch (*Larix kaempferi*), American red oak (*Quercus rubra*), black locust (*Robinia pseudoacacia*), Sitka spruce (*Picea sitchensis*), black pine (*Pinus nigra*), Weymouth pine (*Pinus strobus*), giant fir (*Abies grandis*) and others account together for just under 5% of the forest area. The most widespread is Douglas fir (*Pseudotsuga menziesii*) with around 218,000 hectares (2%), followed by Japanese larch (*Larix kaempferi*) with about 83,000 hectares (0.8%) and American red oak (*Quercus rubra*) with about 55,000 hectares (0.5%) (NFI3). The introduced species are of interest in terms of timber production and the adaptation of forests to climate change and harbour opportunities for safeguarding forest timber production. Their ecological compatibility must be assessed, however, before introducing them into German forests.



The National Forest Inventory surveyed the trees in the German forests in categories of 51 tree species or tree species groups. For evaluation, they were categorized in nine tree species groups: oak, beech, other deciduous trees with long life expectancy, other deciduous trees with short life expectancy, spruce, fir, Douglas fir, pine, larch.

Other deciduous trees with long life expectancy (OLD):maple, ash, chestnut, lime tree, white beam, service tree, black locust, elm.

Other deciduous trees with short life expectancy (OSD):birch, wild service tree, alder, poplar, bird cherry, rowan tree, wild cherry, willow, forest fruit trees.

Figure 5-1: Area of tree species groups in main stands in relation to timberland (including gaps and unstocked areas). NFI3

Trees and shrubs form populations that are largely untouched by breeding, are subject to anthropogenic influence to a greater or lesser extent and display high phenotypic and genetic variation. In some cases, adaptation to different climatic and other location-specific factors also leads to large genetic differences.

Forest communities that developed naturally in a single place for a long time and whose specific composition corresponds to the natural forest communities listed in the National Forest Inventory are particularly important to the protection and conservation of forest biodiversity. Selection of units for *in situ* conservation of forest genetic resources should therefore also take into account the attributes of the surrounding forest as well as criteria of conservation worthiness, conservation viability and conservation urgency. In the naturalness classification of tree species composition in NFI 2012, 14.5% of forests are very close to natural and 21.3% are close to natural. There is highly favourable potential for the conservation of forest genetic resources of native species in the context of natural biocenosis. By contrast, habitat continuity (MÜLLER et al. 2005) and genetic losses due to forest land take for infrastructure and housing development are frequently more difficult to assess. Instances of primary forest relict species may provide indications here.

5.1 Use of tree and shrub species in the wild

For the conservation of species, their intraspecific genetic variation and geographic differentiation, the introduction of non-autochthonous plants and animals in the wild outside (of) agriculture and forestry requires a permit under article 40 of the Federal Nature Conservation Act (Bundesnaturschutzgesetz – BNatSchG). Implementing these requirements makes it necessary among other things to evaluate suitable seed sources that meet the requirements under the Act. Such sites are then also suitable *in situ* conservation units for the species concerned. It is vital to avoid conflict here with entries in seed stand registers under the Act on Forest Reproductive Material (Forstvermehrungsgutgesetz – FoVG).

In the case of tree species not subject to the Act on Forest Reproductive Material, proper forestry management also includes consideration of genetic aspects for biodiversity conservation and the use of opportunities to conserve genetic resources. There is scope here for synergies with the provisions of the Federal Nature Conservation Act referred to above.

5.1.1 Guidelines on the use of autochthonous tree and shrub species and implementing module as the basis for accreditation

In contrast to the Act on Forest Reproductive Material, the Federal Nature Conservation Act does not stipulate on how autochthonous tree and shrub species are to be grown and placed on the market. Recommendations for uniform implementation in the Länder have been published in guidelines on the use of autochthonous tree and shrub species (Leitfaden zur Verwendung gebietseigener Gehölze, BMU 2012). The guidelines recommend dividing Germany into six provenance regions. These are intended to serve as a basis for the production and use of autochthonous tree and shrub species in the whole of Germany. For tree species that come under the Act on Forest Reproductive Material, the provenance regions specified in that Act apply in addition if they are less finely divided than the provenance regions specified in BMU (2012).

The guidelines additionally lay down minimum requirements for seed sources of autochthonous reproductive material. They also provide a list of naturally occurring tree and shrub taxons for planting in the wild, including information on suitability in each provenance region.

Reliable proof of origin of seed and plant material, as provided for example by certification schemes, is crucial for nature conservation agencies, public agencies publishing calls for tenders, horticultural and landscaping operators and tree nurseries. For this purpose, an implementing module – Fachmodul Gebietseigene Gehölze – specifies requirements for the certification of autochthonous trees and shrubs by certification bodies (BMU 2019). This provides the basis for defining the scope for the German Accreditation Body (Deutsche Zertifizierungsstelle – DAkkS) to accredit certification bodies for autochthonous trees, shrubs and their reproductive material. Among other things, it follows the recommendations of the guidelines with regard to provenance regions and specifies a standard national crop reference number. For tree species that come under the Act on Forest Reproductive Material and are intended to be planted for non-forestry purposes, meaning as autochthonous tree species in the wild, the detailed requirements on labelling and documentation in the module are based on the stipulations of the Act.

5.2 Outlook

The number of tree and shrub species native to Germany is relatively small compared to other regions of the world. Deliberate introduction as part of forestry management and garden escapes have so far only resulted in a small number of additional tree and shrub species. However, few of those are currently known to compete so vigorously with local flora as to prove locally invasive as in the case of the black cherry (*Prunus serotina*). Conversely, habitat loss due to factors such as alluvial woodland being turned into farmland, hydroengineering or the planting of single-species stands led in the past to major losses in individual weakly competitive species. Reversing such impacts is the aim of landscape planning and of habitat conservation and restoration activities. A key part is played here by the reintroduction of vulnerable tree species in their native habitats, for example under species conservation programmes. One example among many is the black poplar (*Populus nigra*) and its reintroduction into softwood and hardwood alluvial forest habitat types listed in the Habitats Directive.

Climate change is affecting competitive relationships between species. It is not yet possible to predict how far these changes will lead to losses in specific species. The changing climate will also cause significant shifts in climatic altitudinal belts, shrinking or even eliminating the habitat range for species adapted to montane and high montane zones. The sole compensatory measures feasible here are the use of ecological networks or assisted migration to boost natural migration in order to promote the establishment of genetically better adapted variants.

6 State of diversity within trees and other woody plants species

Genetic studies of species and populations of forest tree and shrub species have continued intensively over the last 10 years. Such research aims either to describe the status or development of genetic diversity, to describe population structure or to accompany breeding measures:

1. Genetic inventories of selected populations to describe the genetic diversity and structure of a species in the geographic context (sampling-based studies)
2. Comprehensive analysis of populations over multiple generations to describe reproduction and adaptation processes over time, taking into account as many influencing factors as possible (genetic monitoring)
3. Investigation of the progeny of seed orchards, of populations or from harvesting specified Mother Trees in order to verify compliance with the Forest Reproductive Material Act (FoVG)
4. Analysis of single individuals, clone ramets or crossbreeding progeny for identification purposes
5. Study of the carriers of certain phenotypic traits to find correlating gene markers (adaptive markers)

6.1 Characterisation of genetic diversity with neutral gene markers

A number of projects that have contributed or are contributing to the recording and evaluation of genetic diversity in various tree species are presented by way of example in the following.

6.1.1 Genetic inventories

In the course of BMEL-funded activities to inventorise and document genetic resources of rare and vulnerable tree species in Germany, the Federal Office for Agriculture and Food (BLE) has produced findings on genetic variation at population level, on the basis of isozyme and microsatellite analyses, for the species common yew (*Taxus baccata*), wild service tree (*Sorbus torminalis*), field maple (*Acer campestre*), downy oak (*Quercus pubescens*), European bird cherry (*Prunus padus*), green alder (*Alnus viridis*), grey alder (*Alnus incana*), service tree (*Sorbus domestica*), wild apple (*Malus sylvestris*) and wild pear (*Pyrus pyraster*).

Grey alder (*Alnus incana*), for example, shows very little genetic variation and very pronounced clonal structures within populations. There are also few differences between populations in terms of genetic diversity, which is very strongly determined by the most common alleles. However, many populations feature different rare alleles. In green alder, there is significantly greater genetic variation between populations than in grey alder. Two specific gene pools have emerged – in the Alps and in the Black Forest – and should be preserved.

In the case of the European bird cherry (*Prunus padus*), genetic variation and genetic diversity in relation to individual populations are in the middle range. The genetic distance between the investigated populations varies very strongly (2–46%). There are comparatively small genetic distances between the populations in Bavaria and Lower Saxony. However, it was not possible to identify a geographical trend. The number of clones within populations is medium to high.

There are relatively large differences in genetic variation and genetic diversity between wild service tree populations (*Sorbus torminalis*). There is a comparatively high incidence of heterozygosity in all populations, whereas expected heterozygosity varies greatly from population to population. F values vary considerably as a result. There is also strong variation in genetic distance (15–82%). Populations in Bavaria and Brandenburg show the most extreme differences. The genetic distance between populations in southern Germany is smaller (15–30%). The number of clones within populations ranges from low to high. In smaller populations especially, clonal dissemination has a negative impact on genetic variation.

In common yew (*Taxus baccata*), the investigated populations show very large differences in allele frequency. This is important evidence of large genetic variation in common yew in Germany. The fourteen investigated populations also show very different levels of genetic diversity. With few exceptions, the F values are close to zero, meaning that inbreeding effects can be ruled out, as is to be expected for a dioecious species. There are indications of geographical structuring from northern to southern Germany.

Proposals for the designation of gene conservation stands were derived from the findings.

Regional studies followed in a number of Länder on the basis of the nationwide investigations. An example is a model/demonstration project, Conservation of Intraspecific Diversity of Native Wild Fruit Species in Saxony, carried out jointly by Grüne Liga Osterzgebirge e.V. and the Saxony state forestry authority and funded by BLE with funding from BMEL. Populations of the species wild apple (*Malus sylvestris*), wild pear (*Pyrus pyraster*), rowan (*Sorbus aucuparia*), common juniper (*Juniperus communis*) and Alpine currant (*Ribes alpinum*) were surveyed in selected model regions in Saxony, described on the basis of morphological, phenological and genetic parameters and evaluated for suitability as seed sources (ANONYMOUS 2017). The findings on the genetic diversity of the investigated species point to differences in genetic structure between them. Juniper showed no differentiation between populations, whereas the other species showed very major differences. This limits the scope for transferring genetic resource conservation and harvesting strategies from one species to another.

Another example of a regional genetic inventory is the analysis of 70 populations of Norway spruce (*Picea abies*) from stands, seed orchards and progeny tests in Saxony. The work was carried out using isozymes, as findings on genetic diversity based on this marker system are available from numerous studies throughout the range. This recent study confirms for Saxony as elsewhere that there is very large genetic variation within and little difference between populations. It also found the same differentiation according to origin height above sea level as is known from provenance trials. In addition, the study demonstrated very intensive gene flow among local populations. This wind-pollinated tree species is therefore thought to be subject to strong anthropogenic influence on genetic diversity resulting from a long history of movement of forest reproductive material, including from greatly varying geographical conditions. Population adaptability may be adversely affected as a result.

6.1.2 Processes within populations

As part of the National Programme for Forest Genetic Resources in Germany (PAUL et al. 2010), a genetic monitoring system was developed to track the development of genetic diversity in forest ecosystems (KÄTZEL et al. 2005). Its aim is to monitor changes in the genetic structure of tree and shrub species in time and space. So far, in a pilot study, four selected monitoring plots have been established for common beech (*Fagus sylvatica*, MAURER et al. 2008) and five for wild cherry (*Prunus avium*) (DEGEN et al. 2008). An additional, inter-agency project to assess the adaptability of beech and spruce to environmental change, “Establishment of a genetic monitoring network for common beech (*Fagus sylvatica*) and Norway spruce (*Picea abies*) in Germany to evaluate the genetic adaptability to climate change” (GenMon) was launched by BLAG-FGR and funded between 2016 and 2020 by BMU and BMEL through the Forest Climate Fund (FUSSI et al. 2020). Comprehensive studies on the two species were conducted on a total of 24 monitoring plots, with a major focus on microsatellite marker genotyping of old-growth trees, natural regeneration trees and seed. The resulting data can be used for analysis and long-term monitoring of genetic structures in populations and of reproduction processes (section 11.4.1).

6.1.3 Verification of compliance with the Act on Forest Reproductive Material (Forstvermehrungsgutgesetz – FoVG)

Authorities in the states of Bavaria and Baden-Württemberg increasingly use genetic analysis to verify provenance for the two oak species, English oak and sessile oak (*Quercus robur* and *Q. petraea*). Numerous batches have been examined for identification and to verify compliance with the Act on Forest Reproductive Material. The focus is on distinguishing the two oak species, and they have been shown to be wrongly identified in various instances. Additionally, chloroplast haplotypes are used to assign batches and seed stands to post-glacial recolonisation lineages. Naturally recolonised populations and their reproductive material usually exhibit one single haplotype or at most a small number. The presence of several haplotypes, especially from recolonisation lineages from multiple refuges, suggests a blend of reproductive material from more than one population. In a number of cases, batches have been found to exhibit numerous haplotypes that do not match the seed stock. The ongoing refinement of laboratory and statistical methods enables increasingly precise inferences to be made. For example, fully genotyping a population or seed orchard by parental analysis makes it possible to identify a match or mismatch between cutting or seed batches and the seed stand. Alongside checks by the authorities, there are also private-sector schemes (such as ZüF and FFV certification) that have developed and implemented systems for verifying provenance. These are usually based on comparison of supplied forest vegetation with stored reference material (mostly seed).

6.1.4 Identification of breeding material (clones and crossbreeding progeny)

In the two inter-agency projects FitForClim and AdaptForClim, microsatellite marker genotyping was performed in the course of breeding for all selected plus trees (about 5,000 individuals in total) in six tree species and species groups: Norway spruce (*Picea abies*), Scots pine (*Pinus sylvestris*), Douglas fir (*Pseudotsuga menziesii*), larches (*Larix decidua* and *L. kaempferi*), oaks (*Quercus petraea* and *Q. robur)* and sycamore (*Acer pseudoplatanus*). Selected plus trees are characterised in terms of molecular genetics and phytopathology. The information is used for final selection of trees for the establishment of seed orchards. This serves identification and verification purposes in clone propagation and seed orchard planting. It is thus also possible to make inferences about genetic variation at species level, although not at population level. Further breeding projects such as FastWOOD likewise use microsatellite markers for clone identification in poplars, black locust (*Robinia pseudoacacia*) and willows (section 9.1).

It remains to be noted that marker systems with neutral markers (microsatellites or isozymes) are established for numerous tree species in Germany and are routinely used by the various forest genetic laboratories. These marker systems are eminently capable of delivering answers to various questions according to the investigation objective, the type of marker and the material used. However, the specificity of such investigations means that they do not support general inferences as to the genetic diversity of tree and shrub species in Germany.

6.2 Development of markers for phenotypic traits

The development of molecular markers associated with phenotypic traits in forest tree species is a longstanding aim of several research projects. Real prospects of finding such markers have only now emerged, however, with the use of next generation sequencing (NGS) methods. For example, markers linked to sex expression have been developed for poplars of the genus *Populus*. Work is currently being done in two research projects on finding markers for adaptive traits: for leaf flushing date in common beech (*Fagus sylvatica*) and for drought stress tolerance in Norway spruce (*Picea abies*).

6.3 Trends in the genetic diversity of such species and in the state of their populations

As no general inferences can be made as to the genetic diversity of tree and shrub species in Germany, it is also not possible to identify generalised trends in that diversity. However, long-term monitoring and multi-generational comparisons of the kind now conducted for two species in an ongoing genetic monitoring system (FUSSI et al. 2020) provide a basis for such trends to be tracked in the future. Where possible, when adding more monitoring plots and including additional tree species, plots should be selected that are already part of other long-term research and monitoring programmes.

Research on the transmission of genetic diversity from parent generation to progeny (natural regeneration trees and seed) in individual populations or seed stands allows a growing understanding of processes and structures in the space and time dimensions. A proposal arising from that research and warranting further discussion envisages increasing the minimum size of seed stands to 100 trees for stand-forming tree species.

It is too early to assess what effects the recent, locally very severe forest damage could have on the genetic diversity of tree species. However, this can and should be investigated in future on affected genetic monitoring plots (of which there are currently permanent monitoring plots solely for common beech and Norway spruce). The extent of the recent forest damage and the demand for reproductive material must not be allowed to lead to a reduction in the requirements for quality standards for forest reproductive material. The potential of natural regeneration should be exploited where possible and appropriate.

6.4 Current and emerging technologies used for assessing and monitoring genetic diversity

Existing analysis methods for assessing genetic diversity are being refined in various directions. This not only relates to technical advances with regard to gene markers; there is also a need for parallel development in sample design and meaningful parameters and indicators.

6.4.1 Genetic markers

The range of gene markers now used to characterise genetic diversity has become broader in conjunction with a shift from isozymes towards DNA markers. Isozyme markers can still be useful for exploiting the considerable potential of comparative data to assess the diversity of populations or for checking genotypes in seed orchards and experimental facilities. Such questions are mostly addressed today using microsatellite markers, which have advantages over isozymes in terms of significantly greater variability and greater potential for automation. For many species, simple sequence repeat (SSR) markers are available for routine applications and there is growing availability of comparative data for numerous populations with sufficiently large sample sizes.

The use of single nucleotide polymorphisms (SNPs) will continue to increase with ongoing improvements in sequencing techniques. However, SNPs will not be able to replace established SSR marker sets in the short term, as they show significantly less variability per marker and this deficit has to be made up with very much larger numbers of markers. They are expensive to develop and currently also significantly more expensive to use if they are to deliver at least the same information value as SSRs. The potential adaptive markers currently in development would also be SNP markers.

A new retrotransposon-based molecular marker system (ISAP) for genotyping individuals and assigning them to clones has been developed to the point of practical application for the *Populus* genus and is under development for larch species and for Norway spruce (*Picea abies*). Species-specific development here is likewise expensive. Based on current knowledge, ISAP markers have greater application potential in the identification of genotypes rather than in the description of genetic diversity.

6.4.2 Study designs

Genetic inventories with representative samples capture the genetic diversity of a species as a geographical distribution at a given time. Sampling can be population-based (as in most inventories to date) or individual-based (as planned for NFI points).

In genetic monitoring, the spatial and temporal distribution of genetic diversity is analysed in a population-based sample of selected monitoring plots (DEGEN et al. 2008; FUSSI et al. 2020). Due to their broad data base, inventories and monitoring both provide a good basis for research projects with precisely specified objectives.

6.5 Capacity-building and research needs to increase the availability of information on genetic diversity

Genetic diversity is considered vital to the ability of species to adapt to changing conditions. The main current challenges relate to assessing the genetic diversity impacts of climate change and other factors – such as forest management and forest fragmentation – and to translating research findings into recommendations for action and changes in the law. This applies to both native and non-native tree species.

Genetic monitoring is regarded as an important building block here and should therefore be established as an ongoing activity enshrined in legal requirements (and where possible linked into existing monitoring systems). A further focus is on genetic analysis to support forest gene conservation, provenance research and forest conversion, again in order to derive recommendations for action from a genetic standpoint.

Federal Government and Länder institutions involved in forest genetics collaborate intensively both in projects and in specialist working groups, and there are strong international links with projects such as EUFORGEN (http://www.euforgen.org/), Trees4Future Work Package 7: Towards the development of a platform for fingerprinting and traceability of biological material (http://www.trees4future.eu/), Gentree (http://www.gentree-h2020.eu/) and Lifegenmon (http://www.lifegenmon.si/). However, these are unable to counterbalance the present need for permanent staff and related resources for the tasks at hand. Third-party funded research projects and temporary staff are important in terms of initiating and supporting research work but do not enable ongoing long-term research with a comparatively large administrative workload.

7 *In situ* conservation of forest genetic resources

Forest management in Germany today largely follows the principles of semi-natural forestry. Among other things, this means cultivating mostly site-native and a broad selection of site-appropriate tree species and a priority on natural regeneration with the application of long-term regeneration methods, including shelterwood, in order to develop mixed, richly structured forest stands of varied age composition. These principles largely coincide with the requirements for conserving forest genetic resources of predominantly site-native tree species that are present in large populations over a wide geographic range. Specific measures continue to be additionally needed for the targeted conservation of individual, mostly relatively rare tree species and for the conservation of genetic variation within various tree species. Surveying and documenting existing genetic resources across the country and across all forms of forest ownership comprise an essential basis for all conservation measures. After assessing the surveyed resources, the nature and timing of necessary action are decided against the criteria of conservation worthiness, conservation viability and conservation urgency. *In situ* and/or *ex situ* (chapter 7) conservation measures are then initiated according to the outcomes of this evaluation.

7.1 Organisation of *in situ* conservation efforts

Federal and Länder measures for *in situ* conservation of forest genetic resources are coordinated in Germany by a working group, the Federal-Länder Working Group on Forest Genetic Resources and Forest Seed Law (BLAG-FGR) (section 11.1). Coordinating such measures includes agreeing a list of tree and shrub species for which, according to region, various types and degrees of action are needed in order to ensure their conservation. BLAG-FGR has also published recommendations for the designation of gene conservation units based on minimum criteria as a fundamental basis for *in situ* conservation of forest genetic resources (https://www.genres.de/fachgremien/blag-forstliche-genressourcen-forstsaatgutrecht/empfehlungen-und-veroeffentlichungen/?L=0). The purpose of the recommendations is to ensure that the Länder – which are responsible in this regard – follow a uniform approach to identifying and designating *in situ* conservation units. They take into account the recommendations of EUFORGEN, the European forest genetic resources programme. BLAG-FGR coordinates its various tasks according to an action plan whose implementation is the responsibility of the Länder on account of Germany's federal structure. In addition, BLAG-FGR serves as a platform for information and data sharing between the various institutions, for harmonisation and standardisation of genetic analysis methods and techniques and for identifying joint research priorities.

In the Länder, *in situ* conservation units are designated and *in situ* measures carried out in accordance with the joint recommendations and in cooperation with Länder forest administrations and forest owners.

7.2 Approaches used for *in situ* conservation

The basis for all conservation measures is the documentation, characterisation and evaluation of existing forest genetic resources. For this purpose, populations of the target tree and shrub species are mapped, delimited and documented nationwide. The populations that have been precisely defined in this way are then grouped by area into three categories of conservation unit:

a) Small-scale conservation units are small patches of woodland with up to 20 individuals and individual trees of the species to be conserved. If their survival is at risk *in situ*, then *ex situ* measures must be initiated.

b) Gene conservation stands are units with more than 20 individuals of the species to be conserved, with an area of up to 20 hectares.

c) Gene conservation forests are larger – 20 hectares or more – continuous tracts of forest where the species to be conserved is found.

The decision criteria for conservation measures are conservation worthiness, conservation urgency and conservation viability. Populations that are worthy of conservation from an ecological, economic and ethical point of view are valuable populations that are adapted to their location. Attributes of conservation worthiness include adaptation (vitality), adaptability (high genetic variation), autochthony, quality attributes and rarity.

Conservation urgency applies to populations where there is a risk of partial or complete loss of the genetic resource. The degree of vulnerability can be estimated against the following risk factors: susceptibility to disease/storm damage, effective (local) population size, risk of hybridisation with cultivated varieties, impending loss of habitat or forest area, competitive weakness, pollution, other abiotic risk factors and wildlife damage. Recent years have increasingly seen local changes due to climate change as a further threat to genetic resources. The urgency of conservation measures is divided into four categories: Category 1 “Very urgent” to Category 4 “Desirable”.

Conservation viability applies to populations that are able to survive and reproduce for the long term where they grow naturally. The attributes against which it is assessed are abundance, demographic structure, genetic variation, reproductive capacity and vitality.

The fact that *in situ* conservation focuses not only on protection of the selected forest genetic resource but also on the genetic system linking generations. In this regard the minimum age is a particularly important selection criterion. Preference should therefore be given to selecting conservation units that have already reached a reproductive age.

Conservation units identified as worthy of conservation can be designated in the course of forest function mapping by the Länder forest authorities as forest of special genetic conservation function. This assigns conservation units the status of a forest ‘function’. Under the forest acts of each of the Länder, the bodies in charge of public works must take into account the functions of forest in planning and implementation. For Länder-owned and communal forests, forest function maps are a binding basis for planning. Their data must be taken into account in forestry framework planning, periodic forest management planning, annual forest management planning, implementation of planned measures, decisions of forest authorities and all other planning and measures affecting forests. For private forest owners, the Länder forest acts stipulate that forest must be properly managed in such a way that its functions, and hence also its genetic conservation function, are safeguarded at all times and for the long term.

Designation by the competent authorities of the various categories of protected areas – such as national parks, biosphere reserves, nature conservation areas, Natura 2000 sites, nature parks, natural forest reserves and closed forests – also contributes to the conservation of forest genetic resources (Table 6-1).

Protected areas with a priority strategy of minimal intervention may also offer scope for the selection of suitable gene conservation stands, thus also increasing the proportion of genetically valuable populations.

Table 7-1: Selected areas subject to nature conservation in Germany.

Protected area category	National parks	Biosphere reserves	Nature conservation areas	Natura 2000 sites	Nature parks	Natural forest reserves
Number*	16	18	8,878	5,286	103	747
Area (km^2)**	2,057	13,439	13,983	55,429	101,340	360

Legend: * Number of protected areas across all Länder, including protected areas in the EEZ; 16 of the 18 biosphere reserves are recognised by UNESCO.
** The areas for the various categories cannot be added to form a total as some categories overlap. The figures exclude marine parts of protected areas.
Source: BLE 2021, Federal Agency for Nature Conservation 2020

7.3 State of *in situ* conservation

191 tree and shrub species occur naturally in Germany. The tree and shrub species can be grouped into three categories: (1) FoVG tree species, meaning tree species subject to the Act on Forest Reproductive Material (Forstvermehrungsgutgesetz – FoVG); (2) non-FoVG tree species; and (3) shrub species. To date, 156 of these species have been included to a greater or lesser extent in *in situ* conservation measures, meaning in the designation of gene conservation stands and small-scale conservation units (Figure 6-1).

As of 31 December 2017, *in situ* conservation stands with an area of approximately 34,400 hectares had been designated for a total of 127 tree and shrub species. The FoVG tree species category comprises the tree species that are of economic importance to forestry in Germany and are therefore subject to statutory rules on production, placing on the market, import and export. This category consists of 29 tree species and thus a relatively small proportion of the target species range in Germany. In terms of area, however, the FoVG tree species category dominates, with 80% of designated *in situ* conservation stands (Figure 7-2).

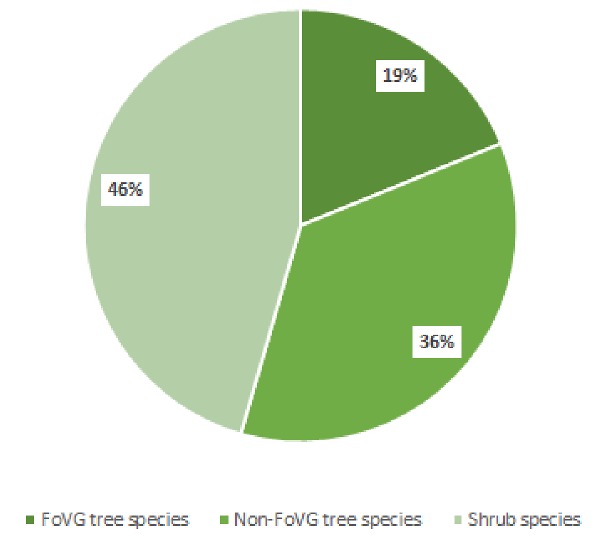


Figure 7-1: Percentage of species in the tree and shrub categories included in *in situ* conservation measures (as of 31 December 2017). BLAG-FGR 2020

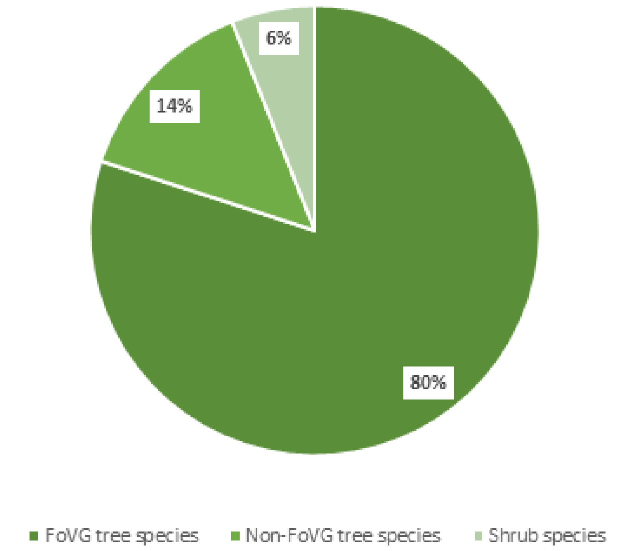


Figure 7-2: Percentage of the area of designated *in situ* conservation stands accounted for by the categories FoVG tree species, non-FoVG tree species and shrub species (as of 31 December 2017). BLAG-FGR 2020

The non-FoVG tree species and shrub species categories have so far been of lesser economic importance to forestry on account of their distribution, cultivation or habit but are particularly important in terms of ecological stability, species diversity and habitat diversity. This group also includes tree species that may become increasingly important in Germany in the wake of climate change. They comprise the majority of species so far included in *in situ* conservation measures (Figure 7-1) but come a distant second in terms of area. In area terms, the 38 non-FoVG tree species included account for 14% or a little more than twice the area accounted for by the 60 shrub species (Figure 7-2).

Among FoVG tree species, the majority of the area of *in situ* conservation stands – some 27,630 hectares of the total – is accounted for by common beech (*Fagus sylvatica*, 33%), the two native oak species English oak and sessile oak (*Quercus robur* and *Q. petraea*, 21%), Scots pine (*Pinus sylvestris*, 10%) and Norway spruce (*Picea abies*, 7%). The remaining 30% by area accounted for by FoVG tree species is spread among a further 24 tree species (Figure 6-3).

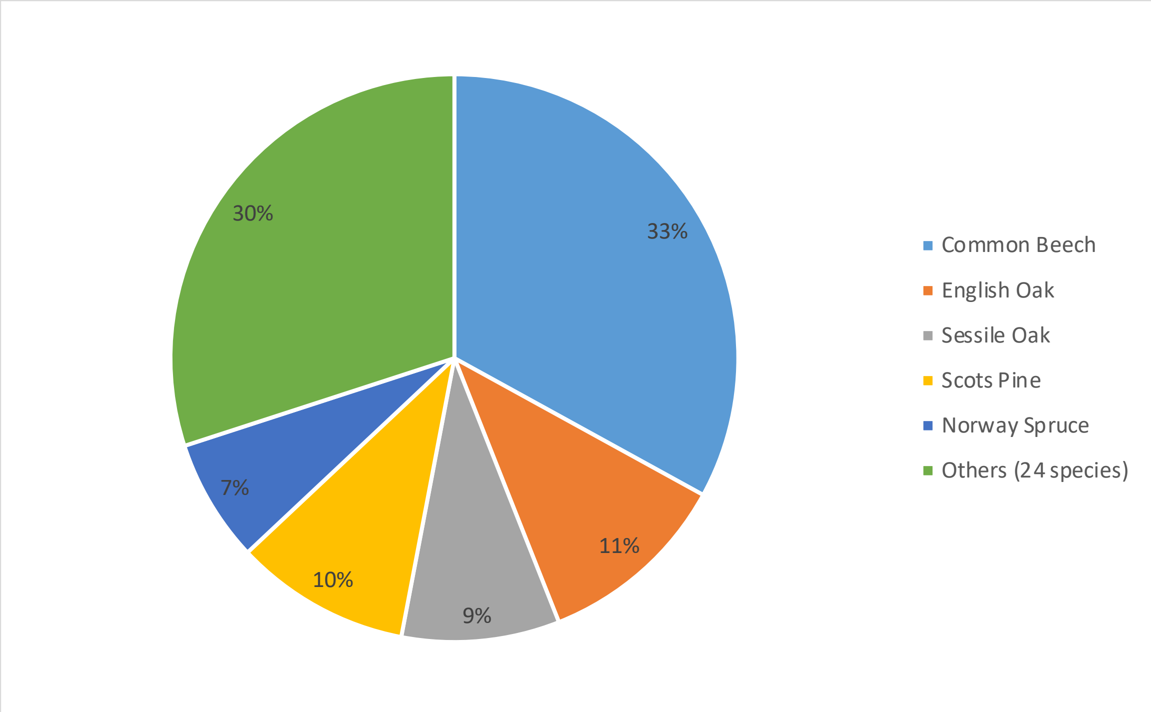


Figure 7-3: Percentage area of in situ gene conservation stands accounted for by selected tree species subject to the Act on Forest Reproductive Material (FoVG) (as of 31 December 2017). BLAG-FGR 2020

The approximately 4,830 hectares comprising the total area of *in situ* conservation stands of the 38 non-FoVG tree species included in the analysis are dominated by the three elm species (*Ulmus glabra*, *U. laevis* and *U. minor*) with 61%, followed by the wild fruit species wild apple (*Malus sylvestris*) and wild pear (*Pyrus pyraster*) with 12%, common yew (*Taxus baccata*) with 10% and field maple (*Acer campestre*) and service tree (*Sorbus domestica*) with 4% each. The remaining 9% is spread across 30 other tree species.

Designated *in situ* conservation stands of shrub species cover a total of approximately 1,940 hectares, mostly comprising common hazel (*Corylus avellana*, 22%), European bird cherry (*Prunus padus*, 12%), three hawthorn species (*Crataegus* sp., 10%), dog rose (*Rosa canina*, 7%), common spindle (*Euonymus europaeus*, 7%), common dogwood (*Cornus sanguinea*, 6%) and common elder (*Sambucus nigra*, 6%). All of the remaining 51 target shrub species included each account for significantly less than 5% of the total designated area.

With regard to small-scale conservation units, over 92,000 individual trees and individual shrubs were designated for *in situ* conservation measures as of 31 December 2017. In contrast to the area distribution among *in situ* conservation stands, the 65 shrub species included in the analysis account for the largest proportion of small-scale conservation units, at 58%. They are followed at a considerable distance by non-FoVG tree species with 26% and FoVG tree species with 15% (Figure 6-4).

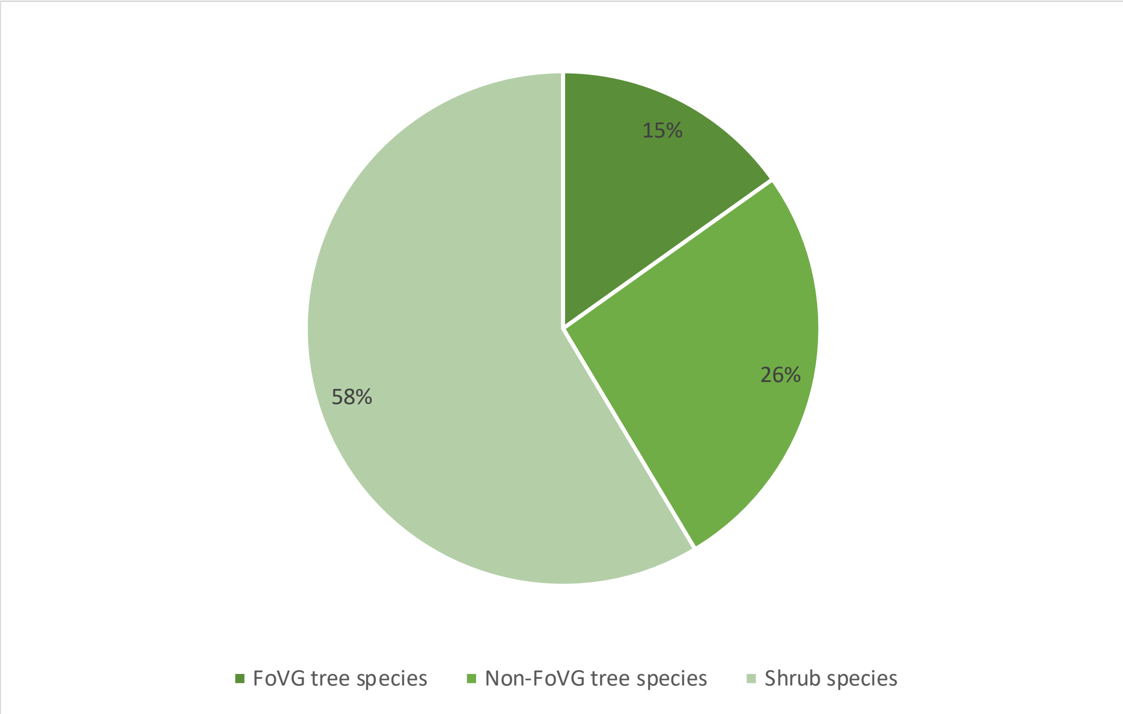


Figure 7-4: Distribution of designated small-scale conservation units among species groups (FoVG tree species, non-FoVG tree species and shrub species, as of 31 December 2017). BLAG-FGR 2020.

Of the 65 target shrub species, small-scale conservation units primarily consisted of the following, with shares between 5% and 17%: European bird cherry (*Prunus padus*), common hazel (*Corylus avellana*), snowy mespilus (*Amelanchier ovalis*), common dogwood (*Cornus sanguinea*), common elder (*Sambucus nigra*), common privet (*Ligustrum vulgare*), common spindle (*Euonymus europaeus*) and wayfaring tree (*Viburnum lantana*).

The main non-FoVG tree species designated as *in situ* small-scale conservation units are common yew (*Taxus baccata*, 29%), Montpellier maple (*Acer monspessulanum*, 21%), the wild fruit species wild apple and wild pear (*Malus sylvestris* and *Pyrus pyraster*, 21%), the three elm species (*Ulmus glabra*, *U. laevis* and *U. minor*, 12%) and service tree (*Sorbus domestica*, 5%).

Among FoVG tree species, which with 15% account for the smallest proportion of individuals included, the highest numbers are accounted for by wild cherry (*Prunus avium*), black poplar (*Populus nigra*), sycamore (*Acer pseudoplatanus*) and European silver fir (*Abies alba*).

As the survey findings across all conservation units show, *in situ* conservation measures mainly focus on the conservation of stands and small-scale conservation units. Conversely, the designation of gene conservation forests is relatively rare because of the relatively small-scale population structures in many regions of Germany.

Based on the findings of all survey work, some 11,000 stands of about 130 tree and shrub species with a total area of about 34,400 hectares and over 92,000 individuals of about 150 tree and shrub species were designated for *in situ* conservation measures as of the end of 2017. In terms of area, the FoVG tree species account for the largest share at 80% (corresponding to 27,700 hectares). The total area of forest stands of all tree and shrub species designated for *in situ* gene conservation purposes is equivalent to 0.3% of Germany's timberland area of 10.9 million hectares (NFI3). Of the total area accounted for by each tree species/tree species group in Germany, the conservation stands of FoVG tree species represent between 0.07% in the case of Norway spruce (*Picea abies*) and 0.5% in the case of common beech (*Fagus sylvatica*) and the oak species (*Quercus* sp.). It should be noted here that the progress of work in this connection varies greatly among the Länder. While some Länder have now completed the survey work, others only just started during the reporting period. The Länder have also opted for different approaches according to available capacities and regional circumstances.

7.4 Challenges for improving *in situ* conservation of forest genetic resources

In situ conservation measures are mainly concentrated on publicly owned forest land. In privately owned forests, *in situ* measures can only be implemented on a voluntary basis. Only one of the Länder (Thuringia) provides forest owners with support for implementing *in situ* conservation measures, which often involve loss of income due to non-use or additional costs of protection and maintenance.

The many different demands placed on forests can be a challenge in carrying out *in situ* conservation measures. It would also be desirable for institutions to adjust their staff planning in line with needs so as to add capacity for this work area, which is important for the future.

There is very little scope for plugging the capacity gap with third-party funded projects or service contracting because of the long-term nature of the measures and limited financial resources.

Climate change is beginning to alter the context for *in situ* conservation of forest genetic resources. This will mainly affect tree and shrub species that are adapted to cooler and wetter locations. Also, various tree species are under threat due to the massive spread of pests, including Norway spruce (*Picea abies*), ash (*Fraxinus excelsior*), wych elm (*Ulmus glabra*) and European field elm (*Ulmus minor*). For the conservation of these tree species, effective and sustainable *in situ* conservation approaches need to be developed and implemented on a long-term basis in conjunction with suitable *ex situ* conservation measures.

The Federal Government and the Länder engage in various activities to promote the conservation of forest genetic resources and specific *in situ* conservation measures. These include:

- Congresses, information and education events; field trips for forestry practitioners, forest owners and nature conservation volunteers
- Courses, seminars and field trips for higher education students and professors of forestry
- Press conferences and articles in popular science print media.

The institutions represented in BLAG-FGR have also long participated in "Tree of the Year" activities focusing on a different species each year. As a result of strong media interest, this is an increasingly successful means of communicating knowledge about the conservation of forest genetic resources, including *in situ* conservation.

7.5 Priorities for capacity building and research in this area

The manifest impacts of climate change on the stability of forests in Germany and on tree species composition lead to widespread uncertainty in the sector, most of all regarding how to approach reafforestation measures and the tree species to select for them. Possible responses range from immediate reafforestation with tree species that have been proven in the past to the exclusive use of alternative tree species, in ignorance or disregard of their suitability. A further issue gaining importance in this connection is the rapid spread of diseases such as ash dieback.

These developments have led to increasing shifts in focus and capacity. This relates both to coordinating the documentation, conservation and utilisation of forest genetic resources and to future research activities. Whereas a major focus has previously been on coordinating conservation programmes for vulnerable, rare species and the conservation of genetic variation in traditional commercial tree species, various new aspects are now coming to the fore.

Firstly, these include identifying the provenance of well-proven tree species from other parts of their range or from particular sites, the provenance of rare native tree species currently of minor importance and the provenance of native European tree species from adjacent regions and of non-European tree species. In 2020, on behalf of Federal Government and Länder silviculture policy officers, BLAG-FGR published a recommendation for the identification of relevant tree species for Germany in the face of climate change and a national approach for the establishment of provenance trials (LIESEBACH et al. 2021). Working from a list of tree species potentially suitable for adapting forests to climate change, BLAG-FGR outlined the main features of an approach for provenance trials to identify tree species suitable for the future. This aims to ensure comparability of experimental findings and make them more useful and representative than would be the case in an uncoordinated approach.

Secondly, impacts of climate change on the conservation and use of existing resources now play a central role in research projects. These include studies on the response of different genetic resources of commercially important tree species to abiotic factors such as drought and frost and on the future usability of forest reproductive material in changing local conditions.

Third, diverse interdisciplinary activities within one inter-agency project focus on the conservation of tree species, such as common ash (*Fraxinus excelsior*), that are endangered by aggressive and rapidly spreading pests. In the same project, knowledge gained from genetic monitoring of common beech (*Fagus sylvatica*) and Norway spruce (*Picea abies*) will be transferred to the establishment of plots for nationwide monitoring of ash dieback in selected stands.

A further focus of activities will be to assess the impacts of climate change on the efficiency and sustainability of *in situ* conservation measures. Various questions will play a central role in this connection: What are the limits of adaptability for specific genetic resources? Have the limits of *in situ* conservation already been reached for certain tree and shrub species in locations where they have traditionally grown? What to do about 'lost species', meaning tree and shrub specifies whose past adaptation history means that they have little or no future chance of survival?

7.6 Priorities for policy development to support *in situ* conservation activities

Neither the general public nor forestry or nature conservation professionals are sufficiently informed about the most important aspects of conserving and using forest genetic resources. Stepping up public relations work in relation to the subject matter and including stakeholders in events have done little to change this finding from the previous National Report. Nevertheless, key aspects relating to the conservation of forest genetic resources did feature in a joint position paper on efficient forest nature conservation recently published by two scientific advisory boards to the Federal Ministry of Food and Agriculture.

7.7 Efforts to improve the coverage, characterisation and sustainability of *in situ* conservation measures

The drafting and publication of recommendations for the designation of *in situ* conservation stands has established a substantial framework for the competent Länder institutions to continue their work on the basis of common criteria. Documentation and genetically characterising eleven rare tree species on uniform criteria throughout the country has provided a further basis for ongoing evaluation and designation of gene conservation units for those species.

The successful establishment of a national network for monitoring changes in the genetic structure of a total of 24 stands of common beech (*Fagus sylvatica*) and Norway spruce (*Picea abies*) on the basis of uniform criteria has demonstrated the feasibility of the approach for genetic monitoring. At the same time, the findings have also pointed to an immediate need for implementation in relation to rare tree species and tosustainable use of genetic resources with respect to the species studied.

The dramatic deterioration in the state of forests due to extreme climatic events and the resulting pest damage have led to activities being stepped up with regard to alternative tree species for the adaptation of forests in the face of climate change. This ultimately led to the recommendations published by the Federal-Länder Working Group on Forest Genetic Resources and Forest Seed Law (BLAG-FGR). A number of Länder have also started projects of their own to systematically localise and record existing stands of alternative tree species.

8 *Ex situ* conservation of forest genetic resources

Ex situ measures to conserve forest genetic resource are those carried out at a location other than the original growth site of the genetic resource. In many cases, activities such as mining and infrastructure works make *in situ* conservation impossible. The material to be conserved is then removed for *ex situ* conservation under conditions as similar as possible to the natural location but with lesser environmental pressure. *Ex situ* conservation can be accomplished by seeding or planting conservation stands and by establishing conservation seed orchards or gene banks.

Rarer tree species tend to occur solely as individual trees or in small groups and only exceptionally in the form of small stands. *In situ* conservation of individual trees or small groups of trees may conserve genetic information for a long time, but that ends with the death of the tree or trees. Isolation also fosters self-pollination, which limits genetic variation, or the formation of full-sibling families and/or, as in the case of wild fruit species, hybridisation with cultivated varieties.

Substantially conserving the genetic variation of rare tree species generally calls for the establishment of conservation seed orchards and clonal collections. Bringing together isolated individuals of a species in reproductive populations also promotes genetic variation and, by means of seed production, paves the way for reintroducing rare tree species into the forest ecosystem cycle. In contrast to seed orchards, which are solely used to produce seed, conservation seed orchards involve a much larger number of clones. Conserving greater numbers of clones reduces the probability of losing genetic information due to random events during recombination.

As with *in situ* conservation, removing suitable material to another natural *ex situ* location is a dynamic conservation method. The advantage of a dynamic method is that evolutionary processes are not suspended and changes in genetic structure are possible, for example by adaptation. However, there is also the risk of losing genetic information due to selection or genetic drift.

Alongside the possibility of removing genetic resources for conservation at a natural location as described above, *ex situ* conservation measures also include conservation under artificial conditions by storing seed, pollen, plants and plant parts and conservation by vegetative propagation. Unlike the previously described *in situ* and *ex situ* conservation measures, storing seed, pollen, plants and plant parts and conservation by vegetative propagation are static conservation methods. Static methods aim to conserve genetic structures as they are. No changes take place as a result of evolutionary processes. However, it is not currently possible to rule out selection processes that alter genetic structures, for example under the storage conditions used for seed. The use of these methods heavily depends on the biology of the tree or shrub species (such as propagability by cuttings and seed storage viability), on the developmental state of the basic material to be conserved (age, fructification, etc.) and on technical capabilities.

Large numbers of genotypes can be conserved by harvesting and storing seed in gene banks like those maintained by institutions in four of the Länder. Seeds can be preserved under controlled conditions and, once cultivated, reused for reforestation. However, this method is only suitable for tree species whose seed can be stored for a relatively long time without significant loss of germination capacity. Storing pollen (DIETZE 1973) makes it possible to conserve large quantities of genetic information in a very small space. Reintroduction of this information into forest ecosystem cycles, however, depends on the availability of suitable female trees.

Genetic information can be conserved beyond the lifetime of a parent individual by vegetative propagation methods. Any number of cuttings can be propagated from one individual. The success of cutting propagation depends on the rooting ability of the individual, which can lead to a further reduction in the genetic variation of the basic material. Conversely, natural ageing processes in the basic material reduce its ability to root. For sustained success, the basic material has to be constantly re-propagated to delay the ageing processes. For these reasons, it is only practicable to propagate a limited number of genotypes. Cutting propagation has developed to the point of practical application for a number of tree species, including Norway spruce (*Picea abies*). With a small number of exceptions, cutting propagation only plays a minor role in practical conservation work.

Vegetative propagation by grafting is traditional method in fruit growing and can generally be applied to all tree species. In various forest tree species, however, there are problems with compatibility between rootstock and graft, especially as the graft gets older, and this can lead to graft rejection even many years later. For tree species with which this problem does not arise, grafting is labour and cost-intensive. This method is therefore mainly used for the conservation of individuals in conservation seed orchards or for establishing constantly monitored clone archives.

Microvegetative propagation or tissue culture can produce large numbers of plants. This method still has the major disadvantage, however, that the number of genotypes to be conserved and propagated cannot be scaled up indefinitely due to the need for continuous propagation. With some exceptions, the method has scarcely been developed for tree species. It is cost and labour-intensive.

8.1 Organisation of *ex situ* conservation efforts

As with *in situ* conservation efforts, Federal Government and Länder efforts for the *ex situ* conservation of forest genetic resources are coordinated by the Federal-Länder Working Group on Forest Genetic Resources and Forest Seed Law (BLAG-FGR). The information in section 6.1 therefore also applies accordingly for *ex situ* conservation efforts.

8.2 State of *ex situ* conservation efforts

There are specific *ex situ* conservation programmes in Germany for tree and shrub species that are vulnerable or rare at national or regional level. *Ex situ* conservation measures are also carried out for regionally significant populations of non-vulnerable tree and shrub species if they are regionally threatened or particularly valuable. These *ex situ* conservation measures so far target about 100 tree and shrub species found in Germany. The conservation measures (Figure 7-1) are more or less evenly spread among FoVG tree species (29%), non-FoVG tree species (36%) and shrub species (35%) (FoVG tree species being species subject to the Act on Forest Reproductive Material – Forstvermehrungsgutgesetz/FoVG).

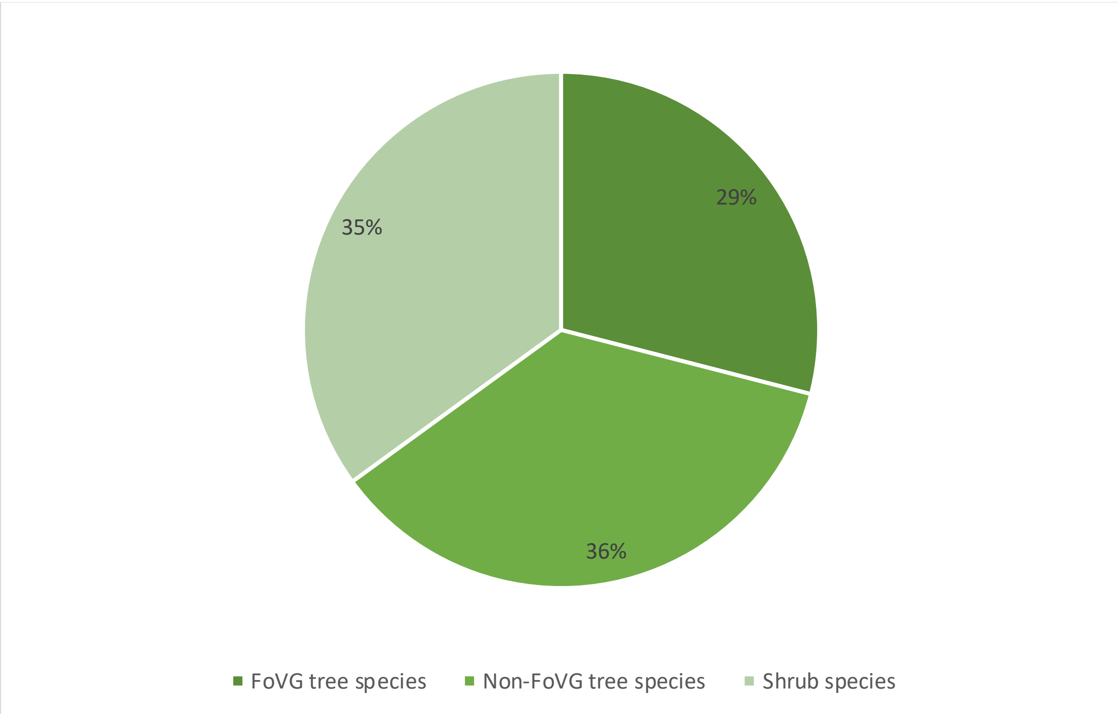


Figure 8-1: **Proportion of species in the tree and shrub categories included in *ex situ* conservation measures (as of 31 December 2017). BLAG-FGR 2020**

A major part of *ex situ* conservation comprises the establishment of *ex situ* conservation stands by seeding or planting, seed orchards and clone archives. FoVG tree species predominate here due to their commercial importance, followed by non-FoVG tree species (Table 7-1). For shrub species, the establishment of *ex situ* conservation stands was not a practice of choice in the reporting period.

Table 8-1: Number of species and number of *ex situ* conservation facilities per species group (as of 31 December 2017). BLAG-FGR 2020

Species	Conservation stands	Seed orchards	Clone archives

group						
	Number of species	Number of stands	Number of species	Number of seed orchards	Number of species	Number of collections
FoVG tree species	28	826	28	398	18	100
Non-FoVG tree species	19	357	20	123	10	30
Shrub species	---	---	33	90	1	2

A little more than half of the 826 *ex situ* conservation stands established for FoVG tree species relate to the tree species Norway spruce (*Picea abies*), Douglas fir (*Pseudotsuga menziesii*), and common beech (*Fagus sylvatica*). A further third is accounted for by deciduous species of the genus maple (*Acer* sp.), ash (*Fraxinus excelsior*) and wild cherry (*Prunus avium*). The remaining 16% of *ex situ* conservation stands are composed of 14 other FoVG tree species (Figure 7-2).

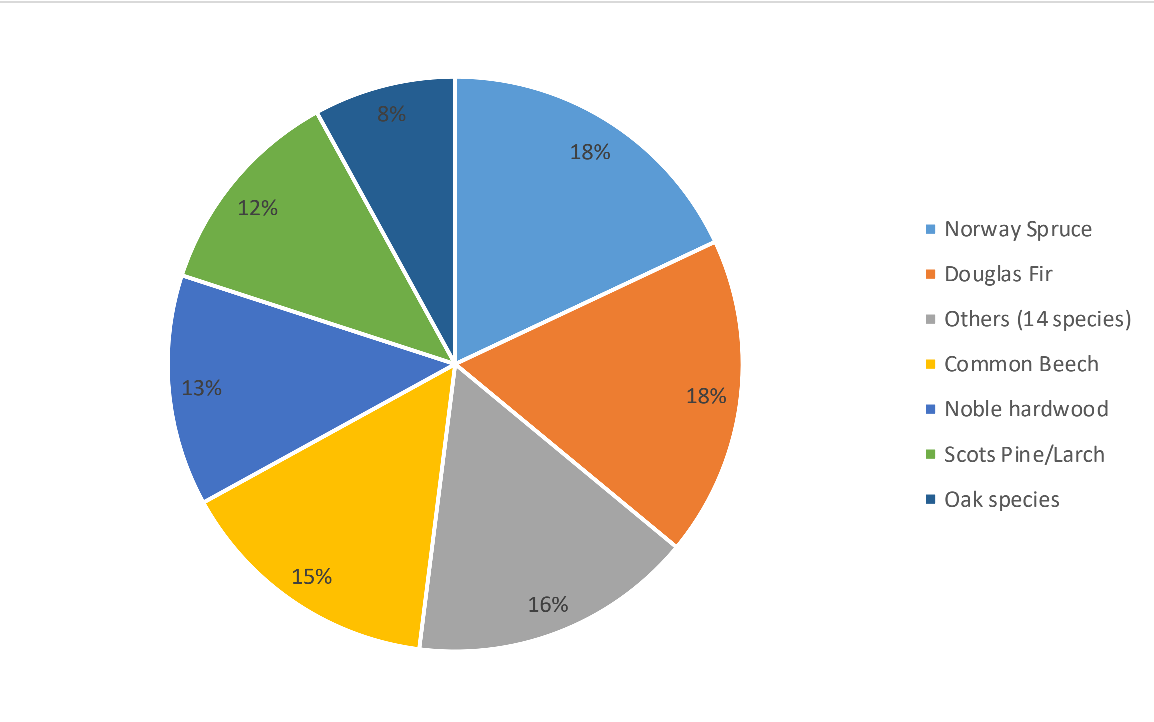


Figure 8-2: **Percentages of selected FoVG tree species among the 826 established *ex situ* conservation stands (as of 31 December 2017). BLAG-FGR 2020.**

Among non-FoVG tree species, the 357 established *ex situ* conservation stands are dominated, with a 90% share, by the tree species common yew (*Taxus baccata*), species of the genera elm (*Ulmus*), *Sorbus* and the wild fruit species wild apple (*Malus sylvestris*) and wild pear (*Pyrus pyraster*). The remaining 10% is accounted for by a further eight non-FoVG tree species (Figure 7-3).

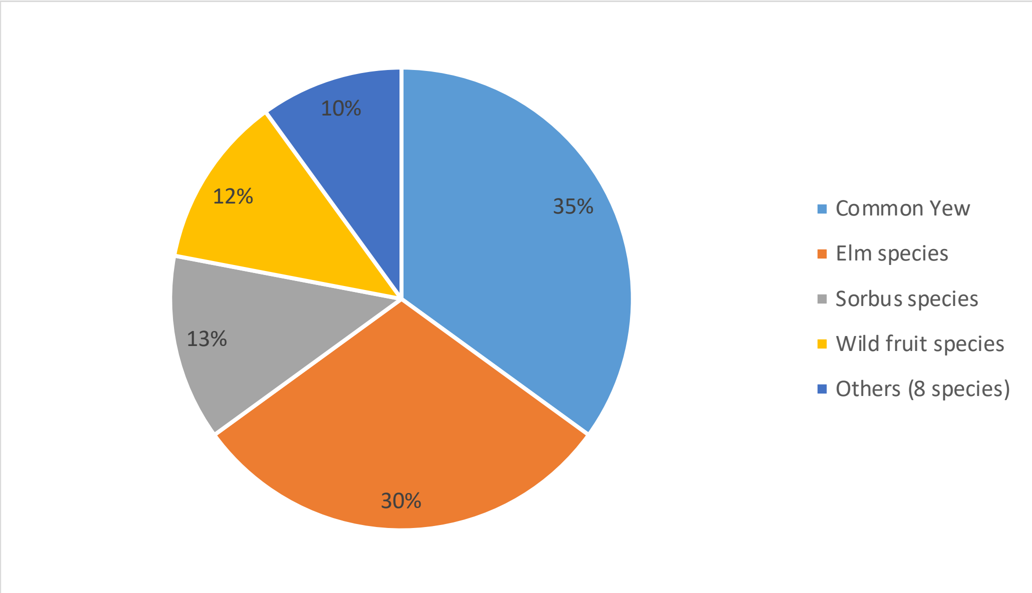


Figure 8-3: Percentages of selected non-FoVG tree species among the 357 established *ex situ* conservation stands (as of 31 December 2017). BLAG-FGR 2020.

The bulk of the 398 approved and non-approved seed orchards for FoVG tree species, which serve the purpose not only of seed production but also of *ex situ* conservation of forest genetic resources, is accounted for by the coniferous species Scots pine (*Pinus sylvestris*) together with the larch species, Norway spruce (*Picea abies*) and Douglas fir (*Pseudotsuga menziesii*). A further disproportionately large share comprises seed orchards for the deciduous species ash (*Fraxinus excelsior*), wild cherry (*Prunus avium*) and maple species. Seed orchards for oak species and common beech (*Fagus sylvatica*) play a relatively minor role. 25% of seed orchards are composed of 14 further FoVG tree species (Figure 7-4).

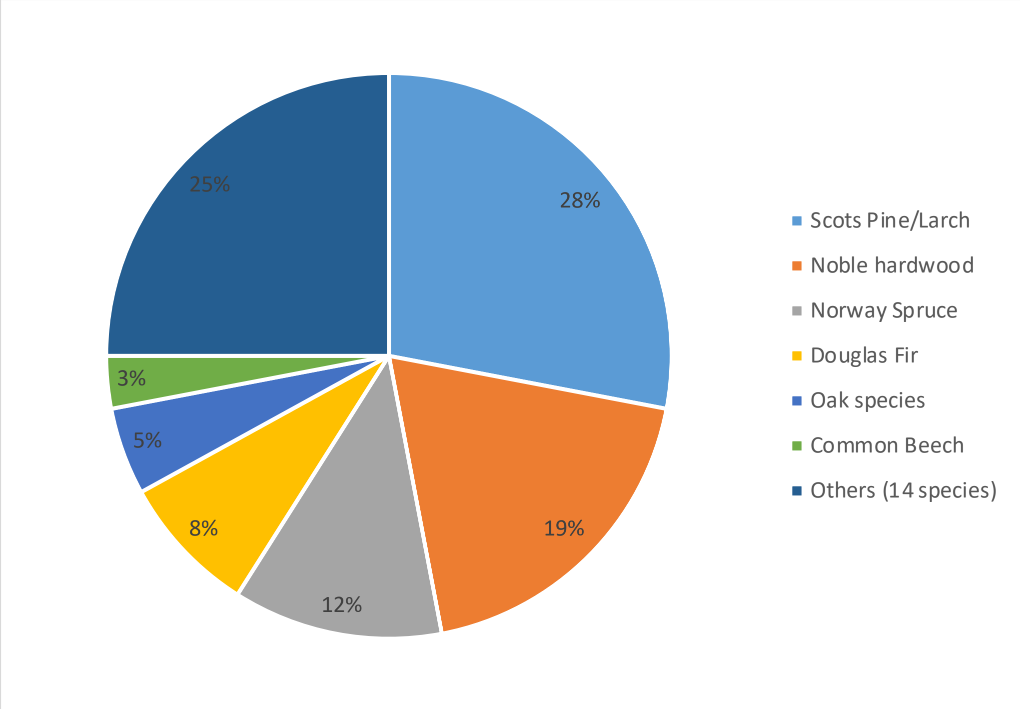


Figure 8-4: Percentages of selected FoVG tree species among the 825 established *ex situ* seed orchards (as of 31 December 2017). BLAG-FGR 2020.

The 123 seed orchards for non-FoVG tree species once again mainly consist of tree species of the genera elm and *Sorbus* and the wild fruit species wild apple (*Malus sylvestris*) and wild pear (*Pyrus pyraster*). Common yew (*Taxus baccata*), with a 4% share, and 11 further non-FoVG tree species with shares totalling 14% play a minor role (Figure 7-5).

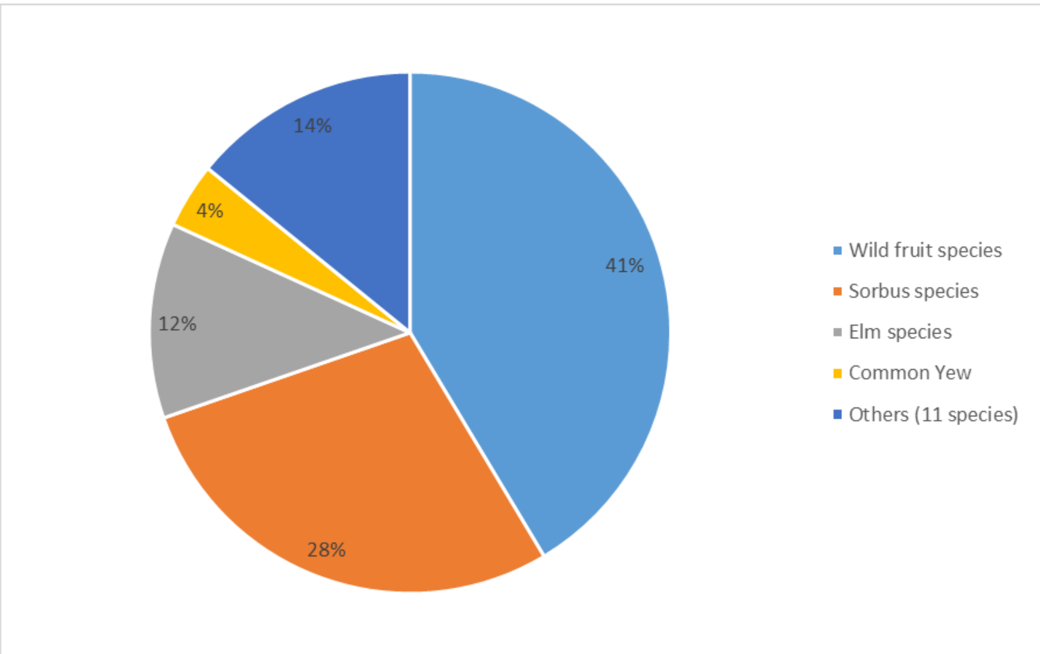


Figure 8-5: Percentages of selected non-FoVG tree species among the 357 established *ex situ* seed orchards (as of 31 December 2017). BLAG-FGR 2020.

Seed orchards for shrub species do not show such clear priorities for the establishment as in the case for tree species. Almost two-thirds of *ex situ* conservation seed orchards are for 28 of the 33 target shrub species; 38% is accounted for by the species common hazel (*Corylus avellana*) and common spindle (*Euonymus europaeus*) with eight seed orchards each and common dogwood (*Cornus sanguinea*), common buckthorn (*Rhamnus cathartica*) and dog rose (*Rosa canina*) with six seed orchards each.

A further *ex situ* conservation measure carried out as a back-up is medium to long-term storage of seed in gene banks. For FoVG tree species, seed is largely stored in storage facilities belonging to state seed extractories, although these mainly serve the needs of Länder forestry operations. Genetically valuable reproductive material is also stored for the long term in state-run gene banks in three of the Länder (Bavaria, North Rhine-Westphalia and Saxony) and in the gene bank belonging to the Northwest German Forest Research Institute. These have storage capacity of about 200 m^3. According to the tree species, the material is stored either as a representative accession for an entire population or for individual trees. As a supplementary measure to *in situ* conservation and as an additional *ex situ* measure for the conservation of forest genetic resources, for example for breeding purposes, various BLAG-FGR institutions also store pollen or tissue cultures in gene banks. The *ex situ* conservation infrastructure maintained by BLAG-FGR institutions is shown in Table 7-2.

Table 8-2: *Ex situ* conservation facilities maintained by BLAG-FGR institutions (2019).

Institution	Seed storage	Gene bank	Genetic laboratory	Physiological laboratory	*In vitro* laboratory	Tree nursery
AWG	x	x	x			x
FAWF	x		x	x		x
FVA	x		x			x
Landesbetrieb Wald und Holz NRW	x	x				x
Landesforst MV	x					x
LFE	x			x		x
NW-FVA	x	x	x		x	x
Sachsenforst	x	x	x	x		x
FFK ThüringenForst AöR	x					x
Thünen Institute	x		x	x	x	x

8.3 Challenges for improving *ex situ* conservation of forest genetic resources

Under the National Programme for Forest Genetic Resources in Germany (PAUL et al. 2010), the priority in the conservation of forest genetic resources is on *in situ* conservation measures (chapter 6). *Ex situ* conservation measures are used for the long-term conservation of forest genetic resources of species and populations for which *in situ* measures are ineffective and unable to ensure conservation. However, climate change is beginning to alter the context for *in situ* conservation of forest genetic resources. This will mainly affect tree and shrub species that are adapted to cooler and wetter locations. Also, various tree species are under threat due to the massive spread of pathogens, including Norway spruce (*Picea abies*), ash (*Fraxinus excelsior*), wych elm (*Ulmus glabra*) and European field elm (*Ulmus minor*). For the conservation of these tree species, effective and sustainable *ex situ* conservation approaches need to be developed and implemented on a long-term basis.

A further difficulty is the structure of forest ownership in Germany, above all with the large share of small private forest holdings distributed among many owners. Necessary activities can only be carried out here with the consent and support of forest owners.

Reintroduction efforts, particularly for vulnerable tree species in their native habitats, in some cases require lengthy consultation between various stakeholders with diverging aims, including farmers, water authorities, flood control authorities and nature conservation professionals.

8.4 Priorities for capacity building and research

This shift in focus due to climate change described in section 6.5 will also affect *ex situ* conservation capacity and research to varying degrees. In general, the ongoing evaluation of genetic resources and the *in situ* and *ex situ* conservation measures for forest genetic resources need to continue.

The emphasis in conservation work has so far been on *in situ* conservation. Suitable conservation methods that go beyond *in situ* conservation therefore need to be developed for a range of tree and shrub species that are increasingly at risk of habitat change due to climate change and biotic pests. This includes further developing and improving measures such as seed storage, cultivation and propagation methods, flowering stimulation, establishment of conservation seed orchards, revitalisation of *in situ* conservation units and *in vitro* propagation. The aim is to develop and implement specific *ex situ* conservation methods for particularly vulnerable tree and shrub species. This work should be accompanied by studies on the representativeness of the chosen conservation approaches in order as far as possible to avoid unnecessary loss of genetic information. The same purpose is also served by basic genetic characterisation of *ex situ* conservation facilities as a complement to *in situ* genetic monitoring.

Generational change in the institutions concerned can cause significant loss of knowledge about *ex situ* conservation at many levels. It is therefore necessary to push rapid development and deployment of knowledge management systems geared to the needs of working with forest genetic resources.

9 Use of forest genetic resources

The explicit aim of forestry in Germany is the establishment, management and use of forests that are site-appropriate, close to nature and stable, with predominantly site-native tree species, in order to ensure that forests remain lastingly healthy and able to perform their many functions. In furtherance of this aim, all of the Länder apply semi-natural, ecologically oriented silvicultural approaches that take into account the diversity of species within their forests. Only in isolated instances are today's forests in Germany the outcome of long-term natural adaptation processes to specific local conditions. The current composition and state of forests in large parts of Germany is a result of human influence. The natural mosaic of diverse forest ecosystems is now superimposed in the various regions by silvicultural measures that have significantly influenced the choice of tree species, stand structure and form of regeneration. Overuse, selection and seed transfer have also caused intensive changes to the genetic structure of many tree species and their populations.

With the exception of poplar, forest tree species have undergone far less breeding than agricultural crop species. Conversely, the natural distribution pattern of forest tree species in many parts of Central Europe and beyond is massively influenced by human intervention. The longevity of most tree species and the genetic nature and heritability of both adaptationally and economically important traits mean that the disruptions referred to have a long-lasting impact. At the same time, the genetic resources that define the forest in its current state and composition are the basic material for the future composition of forests. The application of knowledge of forest history and forest genetics in a silviculture system geared to natural processes is therefore highly important to the establishment of stable, productive and high-quality forests. In this connection, the regeneration of forest stands decides the adaptability, stability, productivity and quality of subsequent stands for up to several centuries. This applies all the more if successor stands are allowed to regenerate naturally.

National Forest Inventory (NFI) statistics show that young forest cover – trees between 0.2 m and 4 m tall – accounted for some 2,656 million hectares (about 23%) of forest in 2012. 85% of this area originated from natural regeneration (NFI3). Natural regeneration is thus the dominant form of forest regeneration in Germany. Regeneration by planting or seeding, with an area of around 354,000 hectares, accounts for only 13% of the total. The remaining area (coppice shoots/unclassified) makes up a mere 2% (NFI3).

In Germany, 15,638 seed stands are approved under the Act on Forest Reproductive Material (Forstvermehrungsgutgesetz – FoVG) as basic material for seeding and planting the 28 main commercial tree species. The great bulk of these, with 98% of approved units and 99% of the area, are seed stands of the category 'selected' (Table 8-4). Common beech (*Fagus sylvatica*), at 16%, accounts for the largest share of approved stands, followed by sessile oak (*Quercus petraea*) and Douglas fir (*Pseudotsuga menziesii*) with 13% each. Shares of between 6% and 10% are accounted for by European silver fir (*Abies alba*), Scots pine (*Pinus sylvestris*), English oak (*Quercus robur*) and Norway spruce (*Picea abies*). The remaining 25% relates to 20 further non-FoVG tree species. Tree species for which there are particularly small numbers of approved seed stands, accounting for less than 1% of the total, are grey alder (*Alnus incana*), downy birch (*Betula pubescens*), Sitka spruce (*Picea sitchensis*), poplar (*Populus*), black locust (*Robinia pseudoacacia*) and large-leaved lime (*Tilia platyphyllos*). The mean area of a seed stand ranges according to tree species from 0.6 hectares (large-leaved lime (*Tilia platyphyllos*)) to 14.2 hectares (common beech (*Fagus sylvatica*)), while the mean area across all species is 7.3 hectares.

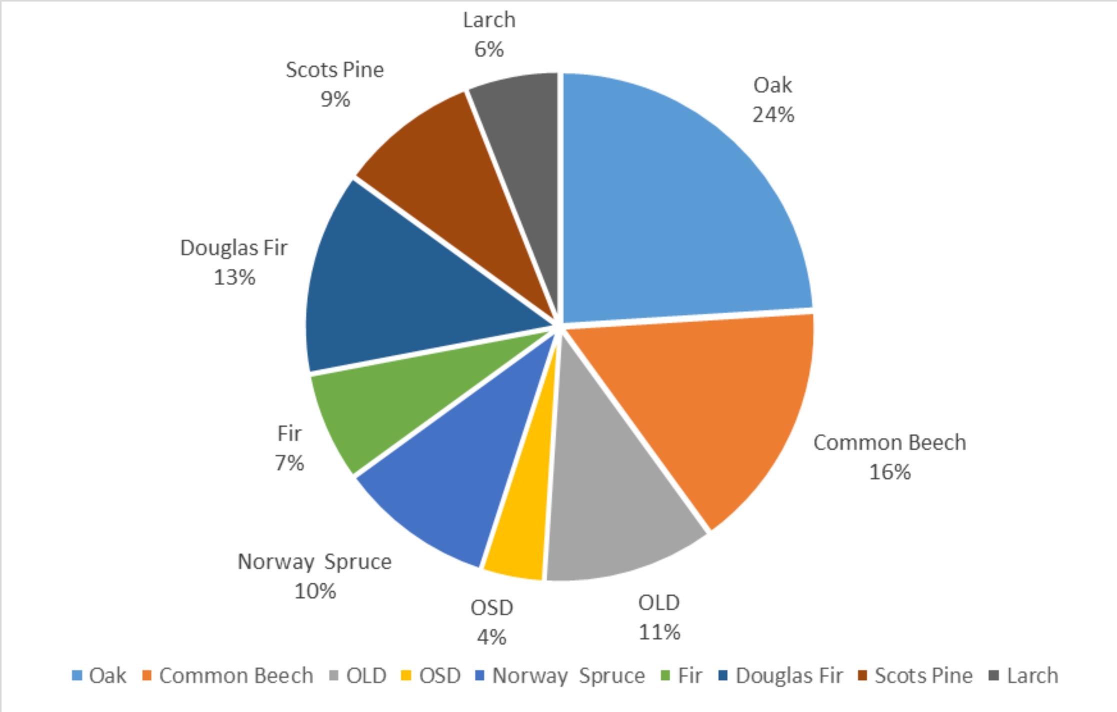


Figure 9-1: Percentage of approved seed stands of main tree species in the category 'selected' (as of 1 July 2019). BLAG-FGR 2020

The remaining 2% of approved basic material for producing forest reproductive material is accounted for by seed orchards in the category 'qualified' and by seed stands, seed orchards, parents of family, clones and clonal mixtures in the category 'tested'. Seed orchards are now approved as basic material for the production of reproductive material for almost all FoVG tree species, either in the category 'qualified' (255 seed orchards; 25 species) or in the category 'tested' (50 seed orchards; 11 species). Likewise for 11 species, 99 seed stands with an area of around 910 hectares are available as basic material in the category 'tested'.

Different minimum requirements for the approval of basic material in each category are laid down in the Act on Forest Reproductive Material. Minimum requirements for the approval of seed stands relate to age, size or number of trees, isolation, uniformity, health (adaptedness), growth and quality. There are no legal requirements for the management or treatment of seed stands. State forestry operations in various Länder, such as Lower Saxony and Thuringia, have instructions or principles for the treatment of seed stands.

There are minimum tree numbers for seed harvesting under the Forest Reproduction Material Approval Ordinance (Forstvermehrungsgut-

Zulassungsverordnung – FoZVO). Seeds may only be harvested in approved units under the supervision of the forest or tree owner or their designee and by a registered forest seed and seedling producer (Table 8-3).

On a ten-year average, 550,708 kg of seed was harvested in Germany in the harvest years 2008/09 to 2017/18. Of this, 92% was accounted for by the heavy-fruited oak species and by common beech (*Fagus sylvatica*) and sweet chestnut (*Castanea sativa*). The remaining 22 FoVG tree species together made up 8% of the harvest volume (Table 8-1).

Table 9-1: Harvest volumes (kg), ten-year average. BLE 2021

Tree species	**Harvest volume (kg) 2008/2009 – 2017/2018**
European silver fir	6,241
Giant fir	657
Norway maple	1,463
Sycamore	8,328
Common alder	250
Grey alder	8
European birch	318
Downy birch	111
European hornbeam	4,472
Sweet chestnut	11,938
Common beech	106,567
Common ash	762
European larch	840
Japanese larch	34
Dunkeld larch	38
Norway spruce	957
Sitka spruce	25
Black pine	67
Scots pine	749
Poplar	76
Wild cherry	15,642
Douglas fir	1,099
Sessile oak	194,483
English oak	121,644
American red oak	71,878

Black locust	377
Little leaf linden	1,419
Large-leaved lime	341

Forest reproductive material of the category 'qualified' was produced for up to 22 tree species. Depending on the species, this category accounted for between 1% and 91% of the reproductive material of each tree species in the 2013 harvest year and up to 98% in the 2019 harvest year. The proportion of qualified reproductive material is generally significant for tree species such as common alder (*Alnus glutinosa*), European larch (*Larix decidua*), Black pine (*Pinus nigra*), Scots pine (*Pinus sylvestris*) and wild cherry (*Prunus avium*) (Figure 8-2). The total volume of reproductive material in the category 'qualified' varied only insignificantly between the two harvest years (10,076 kg versus 10,570 kg). Reproductive material of the category 'tested' was produced on a smaller scale for six species in 2013 (6,284 kg) and seven in 2019 (2,768 kg) (Table 8-2). For pine, the proportion of higher-quality reproductive material (categories 'qualified' and 'tested') in the 2013 and 2019 harvest years was between 67% and 78%.

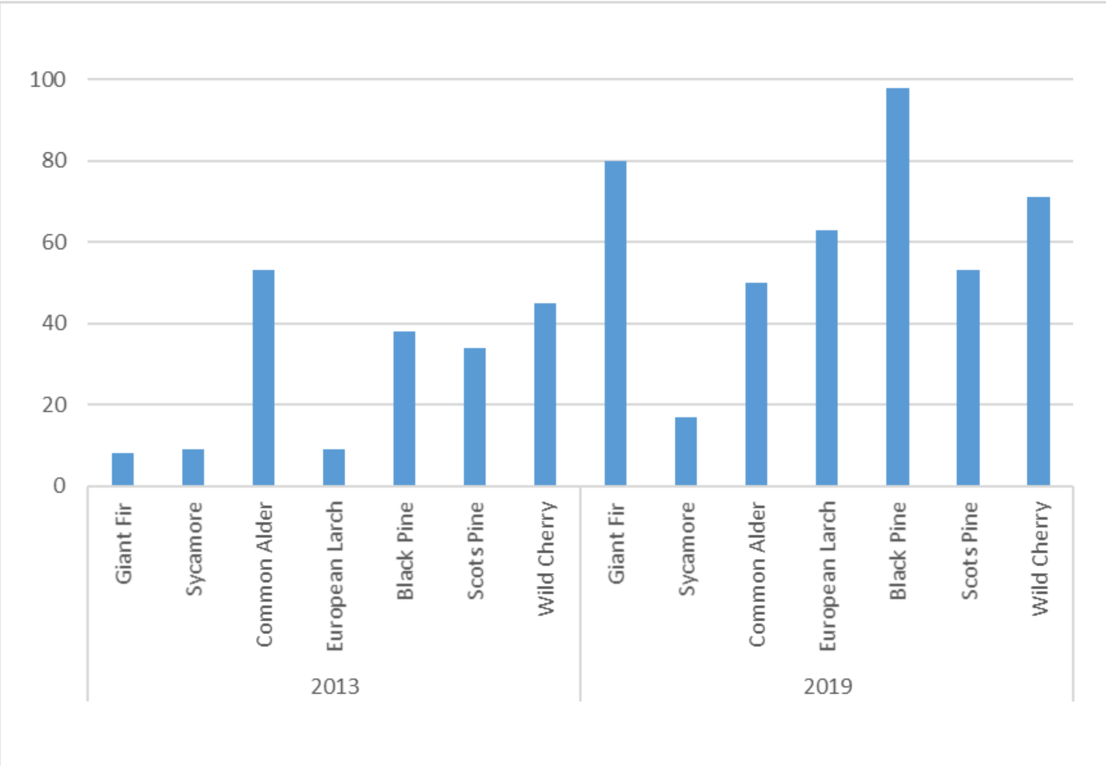


Figure 9-2: Proportion (%) of reproductive material in the category 'qualified' for the harvest of selected tree species in 2013 and 2019 BLE 2021

Table 9-2: Harvest volumes (kg) by FoVG tree species and seed quality category in 2013 and 2019. BLE 2021

Tree species	Harvest year	Seed harvest (kg)			
		Category 'Selected'	Category 'Qualified'	Category 'Tested'	Total volume
European silver fir	2012/2013	14,219	113		14,332
	2018/2019	778	91		869
Giant fir	2012/2013	1,725	159		1,884
	2018/2019	654	2,560		3,214
Norway maple	2012/2013	611			611
	2018/2019	520	203		723
Sycamore	2012/2013	10,576	984		11,560
	2018/2019	3,292	670		3,962
Common alder	2012/2013	118	134	2	254
	2018/2019	110	133	22	265
Grey alder	2012/2013	2	9		11
	2018/2019	5			5
European birch	2012/2013	26			26
	2018/2019	683	96		1,044
Downy birch	2012/2013				
	2018/2019	128			128
European hornbeam	2012/2013	10,360	643		11,003
	2018/2019	10,153	285		10,438
Sweet chestnut	2012/2013	12,212		295	12,507
	2018/2019	13,860	20		13,880
Common beech	2012/2013	11,144			11,144
	2018/2019	114,479	479	2,350	117,308
Common ash	2012/2013		93		93
	2018/2019				
European larch	2012/2013	300	34	33	367

	2018/2019	148	654	233	1,035
Japanese larch	2012/2013	11	1		12
	2018/2019	128	1		129
Dunkeld larch	2012/2013			21	21
	2018/2019			17	17
Norway spruce	2012/2013	27			27
	2018/2019	25	46		71
Sitka spruce	2012/2013	56	3		59
	2018/2019	24	4		28
Black pine	2012/2013	248	153		401
	2018/2019	1	54		55
Scots pine	2012/2013	365	536	673	1,574
	2018/2019	269	430	105	804
Poplar	2012/2013	82		4	86
	2018/2019	1,067			1,067
Wild cherry	2012/2013	7,945	6,372		14,317
	2018/2019	1,825	4,514		6,339
Douglas fir	2012/2013	529			529
	2018/2019	626	238	41	905
Sessile oak	2012/2013	202,230	628	5,256	208,114
	2018/2019	148			148
English oak	2012/2013	187,378			187,378
	2018/2019	175			175
American red oak	2012/2013	61,152			61,152
	2018/2019	178,303			178,303
Black locust	2012/2013	8	79		87
	2018/2019	593			593
Little leaf linden	2012/2013	222	51		273
	2018/2019	368	6		374
Large-leaved lime	2012/2013	289	83		372
	2018/2019	552	84		636

Forest seedlings are cultivated in Germany by about 275 forest nurseries with a total outdoor nursery area of around 1,830 hectares, 4% (71 hectars) of which is used for the cultivation of container plants (Statistisches Bundesamt

2017). As there is no central register of stored reproductive material in Germany, no information can be provided on the availability of seed, pollen or other reproductive material. However, such information is available in some Länder and is continuously maintained. The forest nursery sector produces an average of 150 to 187 million plants per year. If necessary, conclusions about availability can be drawn from the harvest quantities. Pollen extraction does not come under the Act on Forest Reproductive Material and is consequently not included in any statistics. Demand for cones for decorative purposes is negligible.

The approval of basic material, the production of seed and planting material and the placing on the market of non-FoVG tree and shrub species are not regulated by law. No further figures are therefore available on seed sources and seed volumes (see also chapters 6 and 7).

A total of 1,465 nurseries with a total area of about 16,800 hectares are engaged in the cultivation of trees and shrubs for horticulture, fruit growing and landscaping. With about 9% of the area (1,479 ha), container plants account for more than twice as much of the area total than in the forest tree sector (Statistisches Bundesamt 2017).

9.1 Trends in production of and demand for forest reproductive material

Despite a 2002 revision of the Act on Forest Reproductive Material to include a range of additional tree species, both the number and area of approved seed stands have been in continuous decline for somewhat more than 20 years. Regeneration of forest stands, for example, makes seed harvesting difficult or even impossible. The number of approved seed stands thus declined from 43,574 with a total area of 207,817 hectares in 1997 to 15,234 with a total area of 111,771 hectares in 2019. This marks a 65% decrease in number and a 46% decrease in area. Over the same period, the percentage of approved seed stands accounted for by common beech (*Fagus sylvatica*) has almost halved, while that accounted for by other tree species such as European silver fir (*Abies alba*) and Douglas fir (*Pseudotsuga menziesii*) has increased (Figure 8-3 and Table 8-4). It can also be seen that the inclusion of new tree species, most of all in the other long-lived deciduous (OLD) and other short-lived deciduous (OSD) groups, initially led to an increase in the number of approved seed stands, but their percentages of the total stayed more or less the same over the reporting period.

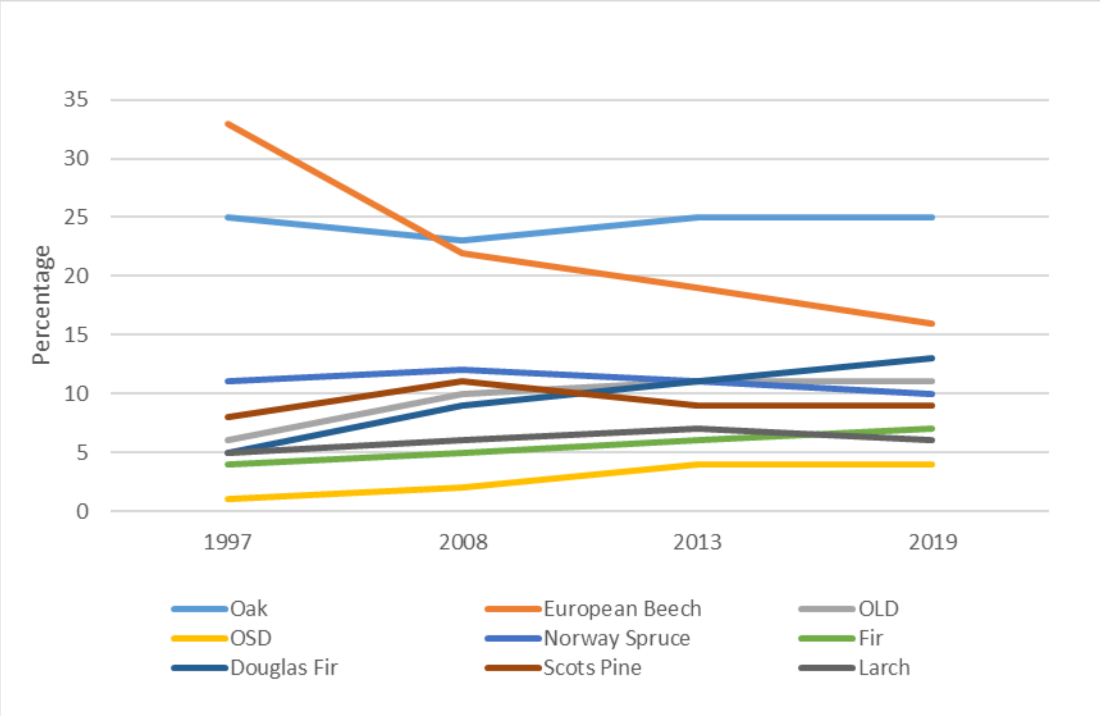


Figure 9-3: Change in the percentage of approved seed stands, 1997 to 2019. BLE 2021

According to BLE statistics, for all species, the category ‘selected’ made up a stable 95% to 97% by volume of seed harvested over the last ten years. The higher-quality categories ‘tested’ and ‘qualified’ each accounted for between 1% and 3%. However, the figures vary significantly from species to species. Particularly for tree species that are hard to harvest in the stand (such as alder, birch or black locust (*Robinia pseudoacacia*)), seed orchards are able to provide most of the supply (category ‘qualified’). Compared with past periods, Germany is also seeing higher demand for reproductive material with enhanced commercial potential (as a result of selection and breeding), including special provenances, reproductive material of the categories ‘qualified’ and ‘tested’, clones and clonal mixtures. This trend is particularly pronounced for forest reproductive material of the category ‘qualified’. The number of species for which reproductive material is produced in seed orchards went up continuously from eight in 2003 to 19 in 2019 (Figure 8-4). Reasons include mostly commercially motivated more selective demand and also a significant increase on the supply side in the number of productive seed orchards.

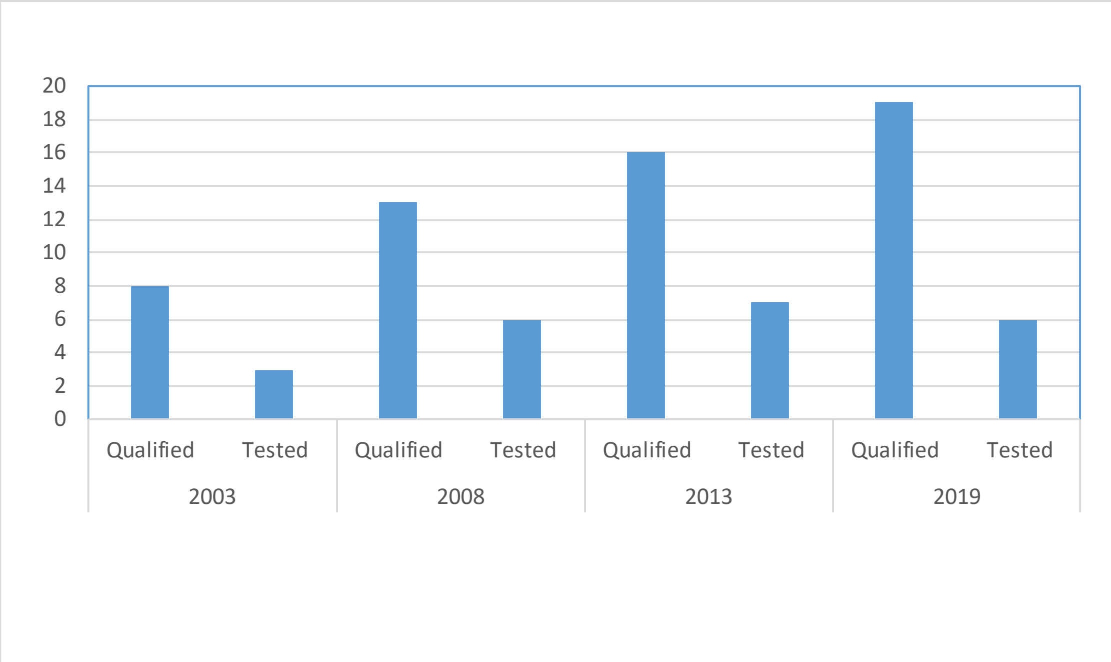


Figure 9-4: Number of tree species from which higher-quality reproductive material was harvested in selected harvest years. BLE 2021

Over the last ten years, the trend to renewed demand for conifer seed continued at least until the onset of the drought and bark beetle years from 2018 to 2020, with Douglas fir (*Pseudotsuga menziesii*), larches (*Larix sp.*) and Norway spruce (*Picea abies*) in particular demand. There is also a trend towards heat and drought-tolerant deciduous species. Based on initial observations, the effects of the damage caused by storms, drought and bark beetle in almost all parts of Germany will further intensify this trend to the point of greater demand for alternative tree species. In the BLE statistics, this is evident in the case of sweet chestnut (*Castanea sativa*). A particularly stable and intense level of activity across many years and also many provenance regions is seen in the harvest of English oak, sessile oak and American red oak acorns. Common beech (*Fagus sylvatica*) harvesting activity also remains at a high level but has dropped significantly since the 1990s. Harvesting of ash (*Fraxinus excelsior*) has virtually stopped due to the effects of ash dieback. This species should therefore be given special attention in the conservation of forest genetic material.

The downward trend in the number of operators in the forest seed/seedling sector accelerated during the reporting period. In addition to the existing trend towards operators exiting the market, the last several years have also seen a decline in nursery cultivation area. This went down from about 2,540 hectares in 2004 to about 1,830 hectares in 2017, a decrease of 28% (Table 4-1). However, comparability with past nursery surveys is limited by changes in various survey parameters (notably the cut-off size for inclusion in survey and the area under high accessible cover) (Statistisches Bundesamt 2017). This is associated with a significant loss of expertise, risk diversification and output capacity in the supply of forest reproductive material. This must also be viewed with concern in connection with the need for forest conversion driven by climate change, as this is totally dependent on a functioning supply of seedlings from nurseries. Supply shortages of forest reproductive material are already visible in certain stock ranges. The downward trend in the number of producers in the forest seed/seedling sector increases the need for separate public-sector harvesting, storage and subsequent provision of selected seed resources for conservation and research purposes.

Table 9-3: Overview of the number of registered forest seed and seedling producers. BLE 2020.

Land	**Number of producers**								
Year	2011	2012	2013	2014	2015	2016	2017	2018	2019
Baden-Württemberg	157	161	163	174	173	183	182	182	194
Bavaria	248	259	267	273	288	297	301	301	314
Berlin	8	8	8	8	8	8	8	8	8
Brandenburg	301	309	309	309	330	330	330	330	324
Bremen									
Hamburg	3	3	3	4	4	4	4	4	5
Hesse	62	62	61	22	32	33	33	33	34
Mecklenburg-Vorpommern	35	33	36	36	37	43	43	43	44
Lower Saxony	135	140	139	139	144	142	137	137	136
Nordrhein-Westfalen	210	220	225	231	240	251	258	258	264
Rhineland-	48	48	49	51	52	34	34	34	30

Palatinate									
Saarland	7	7	7	7	7	7	8	8	8
Saxony	209	208	215	216	222	220	225	225	236
Saxony-Anhalt	144	144	143	143	143	144	144	144	164
Schleswig-Holstein	143	146	142	141	137	135	137	137	135
Thuringia	33	35	35	36	36	39	39	39	35
Germany	**1,743**	**1,783**	**1,802**	**1,802**	**1,853**	**1,870**	**1,883**	**1,883**	**1,931**

The same applies to the operation of seed orchards. Under the prevailing conditions, seed orchards are considered in isolation from the entire forestry value chain. From an economic point of view, they are thus repeatedly questioned critically even though they hold high-quality and mostly diverse genetic resources and hence are of major importance both to practical forestry and to the conservation of forest genetic diversity. They thus make a valuable contribution to the supply of in most cases genetically diverse plant reproductive material with strong potential for future adaptation and high economic productivity. In order to exploit their genetic potential, seed orchards must be continuously maintained and managed in accordance with current genetic science. They are maintained almost exclusively by state forestry operations and administrations. As an important means of conserving and promoting forest genetic resources, these seed orchard activities should continue to be publicly supported by maintaining or establishing the financial resources for their operation.

Demand for container-grown seedlings is increasing throughout the Central European forestry sector. This trend is also relevant from a genetic standpoint. Firstly, it is associated with demand for seed with maximum germination rates, which in turn frequently originates from only a small number of parent units, and secondly, under optimum conditions, container cultivation offers maximum seed yield and seedling survival rates so that a very broad genetic population is available for site-specific selection in cultivation.

The trend in forestry to extremely small numbers of trees per crop appears to have halted or slightly reversed. This is a positive development from a genetic point of view because it also tends to mean a broader genetic base for site-specific and silvicultural selection.

9.2 Certification of forest reproductive material

In principle, the production and placing on the market of forest reproductive material is governed by the Act on Forest Reproductive Material. No additional certification is required by law.

Two mutually independent, private-sector certification schemes have nevertheless been established in Germany, with differing regional focuses. Both of these are fundamentally based on a system of reference samples that can be used as a reference for genetic analysis of the material in question in case of suspected nonconformity. Another scheme for the provision of particularly high-quality forest reproductive material is offered by a further private-sector registered association in cooperation with RAL, the quality marks organisation. The same association also monitors, on a civil-law basis, that quality mark users comply with the quality mark statutes and implementation provisions and undertake to attach the quality mark solely to quality-assured products.

9.3 Needs, challenges and opportunities related to the use of forests

Climate change and global resource demand will mean that growing demands are placed on forests. At the same time, forests (in the form of the forest-timber-paper cluster) are a resource supplier to the world market and, along with the timber processing industry, an important factor in the national economy. Together with the way in which the state of forests has developed in recent years, this underscores the need to identify provenances and tree species that will meet future needs and to assess their suitability for cultivation in Germany in various geographical conditions, taking into account the orignin of provenances and security of supply. Initial steps in this process had been initiated by the end of the reporting period (LIESEBACH et al. 2021).

A key step in the conservation and development of forest genetic resources is the passing on of genetic resources to the next stand generation – in other words, forest regeneration. It is fundamentally important to forest gene conservation for existing genetic resources to be passed on to the next generation as fully as possible and with long-term adaptation potential. This applies regardless of whether regeneration is natural or artificial.

There are various implications for forestry practice with a view to conserving and developing forest genetic resources:

a) Mainly for commercial reasons, seed harvesting concentrates in practice on relatively small numbers of units, most of which are used recurrently from year to year. This means the genetic potential of the total available seed sources is not fully exploited. From a genetics standpoint, active use should be made of as many seed sources as possible.

b) It is necessary to pay attention to provenance, local adaptation and adaptability in the initial stand.

c) Where natural regeneration is not feasible (too few trees of target species in initial stand; site characteristics; initial stand not same as potential natural vegetation (PNV); too much competition from climax species; etc.), active seeding and planting is a practicable alternative.

d) Valuable genetic resources can be conserved by expanding forest areas under minimal intervention.

e) There are deficiencies in the maintenance and regeneration of seed orchards.

An enduring task is ongoing training and professional development for all forestry personnel in all topics relevant to forestry. Awareness of the use of improved reproductive material also needs to be promoted among forestry practitioners. In times of changing environmental conditions and impending resource shortages, the subject of forest genetics and forest species breeding must be retained or reinstated as a central topic of forestry education and training. It must be made clear to the forestry professions that the choice of reproductive material decisively determines the success and hence the survival of forestry enterprises as well as the adaptability of forests as a whole (BLE 2012).

Table 9-4: Overview of approved basic material for forest reproductive material (as of 1 July 2019). BLE 2020

Bundesanstalt für Landwirtschaft und Ernährung

Overview of approved basic material for forest reproductive material in the Federal Republic of Germany

As of 1 July 2019

Tree species		Selected		Qualified		Tested						
		Seed stands (no.)	Seed stands (ha reduced)	Seed orchards (no.)	Seed orchards (ha reduced)	Seed stands (no.)	Seed stands (ha reduced)	Seed orchards (no.)	Seed orchards (ha reduced)	Clones (no.)	Clonal mixtures (no.)	Parents of family (no.)
Abies alba	European silver fir	927	5,802.69	8	19.61							
Abies grandis	Giant fir	171	218.65	2	1.10							
Acer platanoides	Norway maple	96	83.99	4	5.00							
Acer pseudoplatanus	Sycamore	417	763.30	15	25.90							
Alnus glutinosa	Common alder	306	1,061.73	19	33.60	4	11.30	4	7.80			
Alnus incana	Grey alder	10	12.90	2	1.00					6		
Betula pendula	European birch	99	181.43	6	4.90			2	2.00	5		
Betula pubescens	Downy birch	17	55.30	5	3.60							
Carpinus betulus	European hornbeam	185	691.43	2	4.60							
Castanea sativa	Sweet chestnut	60	115.80	1	0.60	1	4.40					
Fagus sylvatica	Common beech	2,466	34,895.12	3	7.40	11	217.60					
Fraxinus excelsior	Common ash	594	1,663.91	7	15.30							
Larix decidua	European larch	590	1,708.64	25	50.31	4	13.10	14	29.70			5
Larix kaempferi	Japanese larch	238	599.40	4	9.40			2	6.20			7
Larix x eurolepis	Dunkeld larch					1	3.80	4	10.17			
Picea abies	Norway spruce	1,471	15,357.00	31	86.41	13	107.20	3	16.60		1	
Picea sitchensis	Sitka spruce	7	17.50	1	1.00							
Pinus nigra	Black pine	90	480.94	4	10.24							
Pinus sylvestris	Scots pine	1,238	12,944.95	37	125.09	19	158.10	17	96.20			
Populus poplar hybrids	Poplar	28	22.70			2	0.20	1	0.10	112	9	12
Prunus avium	Wild cherry	152	155.38	20	37.05					33		
Pseudotsuga menziesii	Douglas fir	1,926	4,288.19	22	83.63	20	52.61	1	2.50	1		4
Quercus petraea	Sessile oak	1,999	21,602.10	1	2.10	19	300.30	1	1.00			
Quercus robur	English oak	1,417	7,384.74	7	15.10	5	38.60					
Quercus rubra	American red oak	402	934.18									
Robinia pseudoacacia	Black locust	37	112.33	4	2.20							
Tilia cordata	Little leaf linden	273	606.24	19	39.05			1	2.00			
Tilia platyphyllos	Large-leaved lime	18	10.80	6	11.00							
Total		**15,234**	**111,771.34**	**255**	**595.19**	**99**	**907.21**	**50**	**174.27**	**157**	**10**	**28**

10 The state of forest tree breeding programmes in Germany

Multifunctional forest management includes the sustainable use of forest genetic resources and safeguarding the economic, protective and recreational functions of forests. Ensuring the greatest possible biodiversity in forests provides the essential foundation for their functional capacity. Most of all, genetic adaptability and adaptedness safeguard the stability of forests for all uses and notably ensure the ability of forests to respond with resistance against biotic and abiotic stress factors. This is taken into account in forest tree breeding.

10.1 Forest tree breeding approaches

Forest tree breeding is particularly dependent on the conservation, utilisation and diversity of forest genetic resources. The objective of forest tree breeding is to provide reproductive material of high adaptability, growth performance and quality. In addition, breeding can provide reproductive material with specific stability and production traits for forestry and other land uses.

An example of the objectives referred to being implemented in practice is provided by FitForClim and AdaptForClim, two inter-agency projects underway since 2014. The projects are based on a strategy published in November 2013 for the medium and long-term supply of high-quality forest reproductive material through breeding in Germany (LIESEBACH et al. 2013). In the strategy, in view of climate change projections, a selection was made of six tree species (sycamore (*Acer pseudoplatanus*), Douglas fir (*Pseudotsuga menziesii*), Norway spruce (*Picea abies*), Scots pine (*Pinus sylvestris*)) and species groups (larches (*Larix* sp.) and native oaks (*Quercus* sp.)) based on the following criteria (Table 10-1).

As the first criterion, tree species were included for which significant breeding progress is expected in the workable timeframe of 15 years. As the second and third criteria, the choice of species was based on the future orientation of silviculture given impacts of climate change and on expected demand for forest products and services. The Federal Government and Länder forest tree breeding institutions involved in the projects rated species for these three criteria in an expert assessment. For each of the identified tree species, the future focus of breeding efforts was set out in relation to past breeding progress. The breeding focus varies according to the species and ranges from stand progeny testing (as for oak) to establishing new high-yield seed orchards (such as for sycamore (*Acer pseudoplatanus*)) to controlled crossings (for example with European larch (*Larix decidua*)). It is estimated that the volume can be increased by 10% to 30% over 15 years of breeding effort, with at least a 50% increase in value.

Table 10-1: Selection matrix for breeding programmes with selected tree species. BLAG-FGR 2014

Tree species	Breeding progress	Silviculture	Utility	Overall	Future breeding focuses			
					Stands	SOs	Families	Clones
Douglas fir	4.5	5	5	4.8	x	x	(x)	-
Larch	4.5	4	4.5	4.3	(x)	x	x	(x)
Sycamore	3.5	4	4.5	4.0	(x)	x	-	-
Norway spruce	2.5	4	5	3.8	-	x	-	(x)
Scots pine	3	3	5	3.7	-	x	-	-
Oak	1	5	5	3.7	x	-	-	-

Legend: Federal Government and Länder forest tree breeding institutions estimated the prospects of genetic improvement (breeding progress), future silvicultural importance (silviculture) and expected demand for forest products and services (utility) (5 = high to 1 = low). An overall value is determined with all three criteria weighted equally. SOs: seed orchards

The two projects FitForClim and AdaptForClim are funded by the Federal Ministry of Food and Agriculture (BMEL) and the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) out of Forest Climate Fund resources on the basis of a resolution of the German Bundestag.

The primary approach in both projects is a review of existing long-term field trials, firstly to identify breeding zones for forest reproductive material that are no longer based on geographic criteria alone but on climate and site variables. Secondly to establish clonal collections with plus trees of the target species that are primarily selected from the existing field trials on the basis of the analysis results and with particular regard to site condititions. The next stage consists of assessing the phenotypic adaptability of the selected basic material to changing climate conditions taking into account adaptive traits, together with thorough genetic characterisation of all selected plus trees. Finally, the characterised plus trees are assigned to breeding populations for the deployment zones for which they each appear best suited on the basis of their characteristics. These breeding populations can then be used for further breeding efforts such as establishing seed orchards for each deployment zone or in crossbreeding.

A further example of the breeding of reproductive material for specific stability and production traits is provided by the FastWOOD inter-agency projects conducted from 2009 to 2018 to breed poplar and willow clones for the production of woodfuel on short rotation coppices. Funded by BMEL on the basis of a resolution of the German Bundestag, the projects started out with a review of former field trials with two objectives: (1) To select clones from existing breeding material, propagate them and test their suitability for short rotation coppice use and (2) to identify further crossbreeding candidates to produce new clones and progeny. In a second stage, controlled crosses were made, experimental trees grown from the resulting seed and trial plots established for nationwide progeny testing. Reliable identification of the planted poplar and willow clones was ensured by genetic studies and morphological descriptions. Accompanying studies were carried out for physiological and anatomical characterisation and to systematically test the resistance of the newly cultivated material to biotic and abiotic stresses.

In their findings, the expert panel recommended 13 poplar clones and three aspen parents of family for approval as basic material for the production of forest reproductive material of the category ‘tested’. This ensures the availability of high-quality planting material that has 50% superior growth performance to poplar clones grown to date and is also more resistant to poplar rust. The newly produced poplar clones are propagated in stoolbeds and protected in clone archives.

A further approach to the breeding of tree species is seen in DendroMax, an inter-agency project conducted from 2012 to 2021 and funded by BMEL on the basis of a resolution by the German Bundestag. In this case, clones of the tree species Dunkeld larch (*Larix × eurolepis*) and Douglas fir (*Pseudotsuga menziesii*) are propagated vegetatively by somatic embryogenesis following controlled crossing of previously approved parents of family. Once the propagated clones have become established, acclimatised and grown, they are tested in field, greenhouse and laboratory trials to select suitable clones in terms of growth, quality and drought-resistance.

In addition to the projects referred to, breeding institutions have conducted various further breeding projects during the reporting period on a more or less regional basis with wild cherry (*Prunus avium*), sycamore (*Acer pseudoplatanus*), common beech (*Fagus sylvatica*) and black locust (*Robinia pseudoacacia*).

10.2 Prioritisation of uses and traits in forest tree breeding

In general, there has been little change in the established prioritisation of traits with regard to growth (such as height and diameter), quality (such as stem straightness and branchiness), resistance (such as survival rate and damage) or phenological traits such as bud burst and shoot growth termination. As climate change progresses, increasing use is now also made of adaptive traits in order to assess the phenotypic adaptability of selected basic material. Among other things, this includes systematically testing of the material to resistance against the abiotic factors drought and frost, using laboratory experiments, greenhouse container trials and field trials.

The potential adaptability of selected breeding material is also assessed by systematic genetic characterisation.

10.3 Organisation of forest tree breeding programmes

Forest tree breeding, including provenance research, is personnel-intensive and cost-intensive. It requires ongoing attention and long-term experimental design due to the long generation cycles of forest tree species. In Germany, forest tree breeding is therefore primarily a matter for the public sector. The long-term nature of tree breeding projects means that, unlike in agriculture, there are no longer any private forest tree breeding operators in Germany. Cooperation-based approaches as in Scandinavia or North America cannot be transferred to the German situation as forest ownership in Germany is separated from timber processing.

Germany currently has eight Federal Government and Länder institutions that carry out forest tree breeding in the broader sense of the term, meaning the selection of plus trees and the establishment of first-generation seed orchards. Of these eight institutions, three – operating at four locations – continue to perform forest tree breeding in the narrower sense, meaning that they also carry out crossbreeding.

The Federal Government and Länder forest tree breeding institutions coordinate their activities and collaborate in the Working Group of Länder Forest Tree Breeding Institutions (ARGE) and the Federal-Länder Working Group on Forest Genetic Resources and Forest Seed Law (BLAG-FGR). This includes designing and establishing provenance trials, progeny and clonal testing, and initiating, preparing and implementing funded inter-agency projects. The various institutions focus on different tree species according to geographical differences across Germany. Preparing and implementing inter-agency projects – funded, among others, by BMEL – increasingly leads to long-term collaboration among institutions from the various Länder, together with the allocation of tasks and responsibilities and the use of standardised methods.

There are various channels for funding forest tree breeding projects in Germany. In addition to BMEL's FPNR renewable resources funding programme launched in 2008 and refocused in 2015, a German Bundestag resolution led in 2010 to the establishment by BMEL and BMU of the Forest Climate Fund as a further programme and source of funding for forest tree breeding projects. An expert workshop resulted in October 2019 in the announcement of a limited-term funding call for forest tree breeding projects under the Forest Climate Fund. This led to 18 outlines being identified as eligible, of which 12 have so far been granted funding.

A research area such as forest tree breeding with its long-term horizons fundamentally requires ongoing funding and support – also with a view to ensuring that trial facilities remain available for as long as possible. Limited-term third-party funded projects can help significantly in kick-starting research. Real progress and the only solution with regard to forest tree breeding, however, lies in relatively substantial institutional support from the Federal Government and the Länder in combination with third-party funded project support through the Forest Climate Fund and the FPNR programme.

10.4 Use of current and emerging technologies in forest tree breeding

Forest tree breeding methods are mainly based on selection and crossbreeding or a combination of the two. Generally speaking, these methods are mature and proven.

The main area where new methods are used is in deployed is in recording of traits of the resulting material as a basis for its evaluation. These include methods to measure drought stress response, for example by measuring chlorophyll fluorescence in leaves and needles, xylem conductance loss, or proline content in plant tissue. Sorbitol-based *in vitro* early testing methods to assess drought stress tolerance also appear promising.

Image acquisition and processing systems are increasingly used in the recording of morphological and anatomical traits. There is considerable development potential in particular in automated detection and measurement, for example of cell wall thickness and cell lumina in the analysis of microscopic preparations.

Thorough characterisation of breeding material with biochemical and molecular genetic testing methods allows an assessment of adaptation potential, guards against the risk of significant genetic narrowing and can serve as a basis for the development of marker-assisted selection methods.

The now largely completed development of methods for *in vitro* propagation of Dunkeld larch and Douglas fir (*Pseudotsuga menziesii*) and true fir species (*Abies* sp.) by somatic embryogenesis opens up new possibilities for producing, selecting and testing high-yield, high-quality and resilient clones of those species.

As before, no use is made of genetic engineering in breeding. Two institutions in Germany apply genetic engineering for forestry research purposes.

10.5 Needs, challenges and opportunities for forest tree breeding

A fundamental goal as climate change progresses is to safeguard the continuity of forest ecosystem services such as raw timber production and climate change mitigation, recreation and nature conservation services. In particular, it is necessary to preserve the carbon storage capacity of forests and their accustomed capacity for meeting social and economic needs.

Forest damage from the combination of storm events, drought and bark beetle very forcefully highlights the need for high-quality, adapted forest reproductive material of future-viable, resilient provenances and tree species for the purposes of restoring and maintaining forest functions. It must be noted here that there also continues to be severe damage to what have so far been primary tree species such as Norway spruce (*Picea abies*), Scots pine (*Pinus sylvestris*) and also common beech (*Fagus sylvatica*). There have been considerable range losses and also range shifts in these species. Superimposed on these developments is the occurrence of biotic pests in deciduous tree species (including sycamore (*Acer pseudoplatanus*), common ash (*Fraxinus excelsior*), European field elm (*Ulmus minor*) and wych elm (*Ulmus glabra*)).

Forest tree breeding therefore plays an important role in increasing the long-term adaptability of forests to climate change by extending the options available, among other things by augmenting the range of provenances and tree species alongside breeding material with improved characteristics.

Greater consideration should be given here to collaboration with the private nursery sector, particularly with regard to reseach and development.

10.6 Priorities for capacity building and research in this area

Forest tree breeding is a key element in the supply of timber as an important, climate-friendly and renewable resource on the world market. It enables the long-term adaptation of forests to climate change, for which purpose high-quality forest reproductive material preferentially of site-native tree species is urgently needed.

This makes it essential to provide long-term structures and funding opportunities for scientific research, with timely application and approval pathways. Stronger institutional support needs to be implemented at Federal Government and Länder level in order to ensure continuity and long-term scientific success in forest tree breeding.

Third-party funded project support both under existing programmes (such as FPNR and the Forest Climate Fund) and under future programmes is an important means of kick-starting research that can subsequently be transferred to institutional structures and pursued on a long-term basis. Funding opportunities for forest breeding research projects have developed encouragingly in general. In the final analysis, what is needed is a combination of the two policy instruments – third-party funding complemented by stronger institutional support at federal and Länder level – rather than focusing on one at the expense of the other.

To make existing breeding methods more efficient and meaningful, it appears necessary to step up the development of serial phenotyping methods for experimental specimens of different ages and also the development of reliable early testing methods. These studies should be supported by the provision of standardised and permanently available reference material such as clones in order to improve the comparability and representativeness of study results.

11 Management of forest genetic resources

Principles for the management of forest genetic resources are set out in the National Programme for Forest Genetic Resources in Germany (PAUL et al. 2010). Maintaining the genetic diversity of forest plants is cited among the possible solutions for sustainable forest management in Germany's Forest Strategy 2020 (BMELV 2011). Efforts are directed towards integrating conservation work into routine forestry practice in order to safeguard the genetic potential and sustainable use of forests.

The term 'forest genetic resources' essentially covers the gene pool of forest tree species. Germany's forests are almost universally shaped by anthropogenic influence and correspond most closely to the international category 'semi-natural forest', as they generally comprise mixed stands with site-native and site-appropriate tree species. Natural forests that have developed without direct or indirect human influence are virtually non-existent. The existing forest gene pool is strongly influenced by centuries of land use. Most tree species are nonetheless assumed to display high genetic variation, the conservation of which can generally be well integrated into semi-natural forest management practices.

In addition, specific genetic resources are designated for conservation value – as conservation stands, for example – and recorded in databases. These resources are taken into account to varying extent in forest planning, forest function mapping and forest management in the various Länder. Implementation of specific management recommendations is not made mandatory and takes place in non-Länder-owned forests on a voluntary basis, in some cases with public funding. In Länder-owned forests, management instructions for forest genetic resources are incorporated into operating plans for each forestry operation that are drawn up and implemented in cooperation with Länder research institutions.

11.1 Consequences for forest genetic resources and their management

Significant present-day factors with a major influence on genetic resources include clearing and fragmentation due to increasing use of forest land for residential and commercial development and for transport infrastructure. The associated mandatory compensation and substitution measures are intended to avoid any absolute loss of forest area, but specific genetic resources are still put at risk.

Other consequences for forest genetic resources are expected in connection with Germany's target of taking five percent of forest out of cultivation by 2020. Free movement in the EU internal market continues to be a challenge for controls to prevent the introduction of unsuitable reproductive material. Finally, the management of forest genetic resources must be viewed in the light of climate change and resulting recent losses in genetic diversity. Extreme events, such as the 2018, 2019 and 2020 drought years, can overwhelm short-term population adaptability, rendering *in situ* conservation no longer possible.

Regionally overabundant game populations continue to pose a major problem, especially for the conservation of rare tree species, which in some parts of Germany requires considerable additional effort and expense.

11.2 Challenges and opportunities for improving the management and use of forest genetic resources

Natural regeneration is currently the predominant form of regeneration in German forests. Natural regeneration can conserve forest genetic resources over long regeneration periods given suitable parent populations with sufficient stem numbers. Otherwise, suitable reproductive material has to be sown or planted. This must be done in accordance with the Act on Forest Reproductive Material (Forstvermehrungsgutgesetz – FoVG), provenance recommendations and recent research findings. When planting, sufficiently large numbers must be planted in order to ensure sufficient genetic variation. Sorting by size can be dispensed with.

Avoidance of overly selective practices and conservation and maintenance of rare tree species are important genetic aspects in stand management. When cutting at exploitable size, it is necessary to ensure that trees have had the opportunity to reproduce before cutting. Some of the Länder actually prohibit exploitable size cutting in seed stands. All measures to improve stand stability and operational safety ultimately also safeguard genetic resources.

In general, every forest owner has a statutory duty to conserve the forest (chapter 2). Public forest administrations additionally have the task of meeting societal demands on forest use. In implementation of the Convention on Biological Diversity (CBD), sustainable timber use becomes an important aspect alongside the conservation of genetic diversity as it involves exploiting genetic potential in terms of growth characteristics and quality. The genetic potential of forests is deliberately exploited to grow productive and high-quality stands. The basic principles touched upon here are mainly set out in mandatory policies and plans for the management of state-owned forests; for non-state owned forests, they serve as recommendations.

A matter of great importance in this connection is knowledge transfer on the appropriate management of genetic resources across all forms of forest ownership. The proper conservation and sustainable use of forest genetic resources are also promoted by various private-sector certification schemes such as those of the Programme for the Endorsement of Forest Certification Schemes (PEFC) or the Forest Stewardship Council (FSC).

An important means of sustainably conserving forest genetic resources is utilisation of the genetic material as forest reproductive material. For the main tree species in Germany, the production and marketing of forest reproductive material is regulated by law. Reproductive material may only be obtained from specially designated and registered stands or populations (section 3.1) (Table 9-4).

Production and distribution are monitored by government agencies. There are also various private-sector schemes for provenance certification of forest reproductive material.

The use of forest reproductive material is not regulated by law. The Länder issue science-based provenance recommendations. These are binding for Länder-owned forests. In non-Länder-owned forests, they have significance as the basis of funding programmes or as requirements under certification schemes. Independently of this, the provenance recommendations are also the subject of training programmes provided for forest owners, enabling them to implement recent scientific findings in their forests on a voluntary basis.

Only registered operators may harvest and cultivate forest reproductive material (Table 9-3). Forest seed is currently processed by 11 public-sector seed extractories and one private-sector seed extractory. The number of nurseries for forest reproductive material is difficult to estimate as there is only limited overlap with registered operators. The figures also include all operators trading in forest reproductive material.

The German forestry sector is undergoing a generational change. This also applies to institutions that specifically deal with forest genetic resources, such as seed extractories, kilns, nurseries, experimental stations and control facilities.

12 Institutional framework for the conservation, use and development of forest genetic resources

12.1 National coordination mechanisms and other institutions dealing with forest genetic resources

Since 1985, on the basis of a Bundestag resolution, national activities in connection with forest genetic resources have been coordinated, on behalf of the Conference of Forest Directors and Federal Government and Länder Silviculture Policy Officers, by the Federal-Länder Working Group on Forest Genetic Resources and Forest Seed Law (BLAG-FGR) (section 6.1). BLAG-FGR is composed of representatives of the Federal Ministry of Food and Agriculture, the Federal Office for Agriculture and Food, the Johann Heinrich von Thünen Institute and nine Länder institutions representing the 13 large Länder (other than the three city states of Berlin, Bremen and Hamburg). It has established three working groups for specific thematic areas (genetic analysis, genetic monitoring and indicators). Management is provided by the Federal Office for Agriculture and Food. The group meets twice yearly.

In addition to the actual coordination of measures for the conservation and use of forest genetic resources, BLAG-FGR is increasingly involved in preparing conceptual frameworks and recommendations of national importance and initiating research and monitoring projects. Examples include a position paper on native trees and shrubs within their natural range 'Gebietseigene Gehölze', recommendations on the establishment of seed orchards for the production of native trees and shrubs within their natural range, and recommendations for the designation of gene conservation units on the basis of minimum criteria (https://www.genres.de/fachgremien/blag-forstliche-genressourcen-forstsaatgutrecht/). BLAG-FGR was also instrumental in advocating genetic investigations as part of the 2021/2022 National Forest Inventory, initiated and supported the establishment of an interdisciplinary research network for conservation of the common ash (*Fraxinus excelsior*) as a commercial tree species (section 11.4.2) and supported national implementation of a conceptual framework for genetic monitoring in Germany of the tree species common beech (*Fagus sylvatica*) and Norway spruce (*Picea abies*) (section 11.4.1).

Through its chair, BLAG-FGR is a member of the Federal Ministry of Food and Agriculture (BMEL) Advisory Board on Biodiversity and Genetic Resources and represents the interests of forests and forestry in the context of biodiversity conservation. The Advisory Board's remit is to advise BMEL on general and fundamental issues relating to the conservation and sustainable use of biodiversity – including genetic resources for food, agriculture and forestry as part of biodiversity – and in related activities at national, EU and international level. Advisory Board publications directly or indirectly relating to forest genetic resources include statements on effective insect protection (jointly with the German Advisory Council on the Environment (SRU), 2018), on pathways to efficient forest nature conservation in Germany (jointly with the Advisory Board on Forest Policy, 2020) and on the policy response to climate change factors affecting biodiversity in the agricultural landscape (2020).

The Working Group of Länder Forest Tree Breeding Institutions (Arbeitsgemeinschaft der Länderinstitutionen für Forstpflanzenzüchtung) coordinates Federal and Länder work on questions of the phenotypic and genotypic characterisation of tree species and their provenances along with broader activities on forest tree breeding. This includes initiating, coordinating and conducting joint provenance trials such as Germany's European silver fir provenance trial Carpathians (2011) and inter-agency projects such as FastWOOD and FitForClim/AdaptForClim (sections 5.1.4 and 9.1). A further major task is the development, coordination and publication of conceptual frameworks, strategies and recommendations. These include the strategy for the medium and long-term supply of high-quality forest reproductive material through breeding in Germany (LIESEBACH et al. 2013) and a manual on experimental design, setup and maintenance of field trials in forest tree breeding (LIESEBACH et al. 2017).

In addition to Federal Government and Länder institutions, various universities are also actively involved in forest genetic resources, including the Technische Universität Dresden Institute of Forest Botany and Forest Zoology, the Georg August University Göttingen Department of Forest Genetics and Forest Tree Breeding and the biology/conservation biology groups at Philipps-Universität Marburg.

The Forest Genetics/Forest Tree Breeding section of the German Association of Forest Research Organisations (DVFFA) provides a platform for the exchange of scientific knowledge in all subdisciplines. It serves the purpose of collaboration among scientists from all relevant institutions in German-speaking countries and of the development of joint research projects. Regular conferences provide the opportunity for knowledge transfer between basic and applied research and between scientists and practitioners. Conferences during the reporting period focused among other things on forest genetic research in climate change (Tries-Karden 2013), forest genetics and nature conservation (Chorin 2016) and forest tree breeding for practice (Dresden 2019).

A further player in the field of forest genetic resources is Gütegemeinschaft für forstliches Vermehrungsgut e.V. (DKV), a private-sector alliance of major forest seed and seedling producers, forest owners and forest administrations. The forest seed and forest nursery sector is a very important element in the production and supply of forest reproductive material and is represented by the German Forest Nurseries Association (Verband Deutscher Forstbaumschulen e.V., or VDF) and the Federation of German Nurseries (Bund deutscher Baumschulen e.V., or BdB).

12.2 Polices and strategies relevant to forest genetic resources

The basis for the long-term conservation and use, research and development of genetic resources of trees and shrubs in Germany is the National Programme for Forest Genetic Resources in Germany. The National Programme was up-dated and published in 2010 (PAUL et al. 2010). It is part of the National Strategy on Biological Diversity alongside national programmes for plant, animal and aquatic genetic resources. Implementation of the national programmes is supported in terms of documentation, information, advice and coordination services by the BLE Information and Coordination Centre for Biological Diversity (IBV).

The German Strategy for Adaptation to Climate Change (DAS) provides a framework for climate change adaptation in Germany. Climate change will have major impacts on biodiversity, on forests and hence on forestry. A conservation of forest genetic resources indicator was included in the strategy in order to track climate change impacts on the conservation of forest genetic resources. The dataset for this indicator is based on *in situ* and *ex situ* conservation measures conducted by the Länder and by Federal Government departmental research (the Thünen Institute). As the plots designated for conservation measures provide only one indicator for the state of conservation of forest genetic resources, the BLAG-FGR Indicators *ad hoc* expert group is developing a more meaningful replacement indicator.

The use of seeds and seedlings for forests and forestry is not regulated by law. An effective instrument for guiding their use and for translating findings on forest reproductive material into forestry practice – in combination with public funding – comprises provenance recommendations issued by the Länder for forest reproductive material. The purpose of the provenance recommendations is to encourage the use of suitable provenances of forest reproductive material when establishing stands, as this is decisive for future forest health, stability and productivity.

12.3 Legislation and/or regulations related to forest genetic resources

The Basic Law of the Federal Republic of Germany – the German constitution – assigns extensive legislative powers to the Länder. Under Article 70, the Länder have the right to legislate wherever the Basic Law does not confer legislative powers on the Federation. Federal legislative powers are exhaustively listed in Articles 71 to 74. All other matters are exclusively in the power of the Länder. The Basic Law notably assigns extensive legislative powers to the Länder in the areas of forest conservation, forest management and nature conservation. Conversely, trade in forestry seed and seedlings is subject to what is called a concurrent federal legislative remit. As the Federation has made use of this remit, the Länder have no leeway to legislate in this regard.

By virtue of its membership in the EU, the Federal Republic of Germany is also bound by European law. European legal acts that do not have direct effect have to be transposed into national law. European law has therefore been transposed in German nature conservation law and in the Act on Forest Reproductive Material.

12.3.1 Federal Forest Act

The Federal Act on Forest Conservation and the Promotion of Forestry (Federal Forest Act – Bundeswaldgesetz, or BWaldG) of 2 May 1975 (BGBl. I p. 1037), as amended, provides a national framework for Länder legislation on forest conservation and forest management (chapter 2). As set out in section 1 of the Act, its purpose is "to preserve, where necessary to enlarge and to safeguard the proper management of forest in view of its commercial utility and of its importance to the environment, including to the maintenance of ecosystem services, the climate, hydrology, clean air, soil fertility, the countryside, the structure of agriculture, infrastructure and public recreation (the protection and recreation function of forest)." The most recent amendments to the Federal Forest Act entered into force on 31 July 2010 (BGBl. I p. 1050). These left the general thrust of this widely accepted and well-proven act unchanged but revised the statutory definition of forest to exclude short rotation coppices and agroforestry systems. The Federal Forest Act does not explicitly refer to the conservation of forest genetic resources. Instead, this is inferred from the general requirements set out in section 1 of the Act.

12.3.2 Act on Forest Reproductive Material

The Act on Forest Reproductive Material (Forstvermehrungsgutgesetz, or FoVG) is the central act relating to forest genetic resources. Its purpose is to conserve and improve forests – with their manifold positive effects – in terms of genetic diversity by providing high-quality and source-identified forest reproductive material and to promote forestry and its performance.

The Act's seven divisions stipulate on the approval, production, placing on the market, import, export, provenance and identification of forest reproductive material. Reproductive material includes seed, plant parts (for vegetative or microvegetative propagation) and planting material (plants grown from seed or from plant parts or obtained from natural regeneration). The law applies to 28 tree species, one hybrid and one genus of significance to forestry in Germany. Detailed implementing provisions are contained in three statutory instruments governing implementation of the Act, the approval of basic material and the delimitation of provenances. The Act does not stipulate on the use of forest reproductive material.

Various bodies support its implementation. These include a Länder joint expert committee to develop recommendations and guidance on procedural matters and Länder joint expert committees to advise Länder bodies on implementation of the approval provisions. The committees comprise representatives of competent Federal Government and Länder authorities together with representatives of forest owners and of the forest seed and forest nursery sector. An expert advisory board advises the Länder bodies on the complex approval of category 'tested' basic material. This comprises one representative each from the Federal Government and Länder forest tree breeding institutions.

12.3.3 Federal Nature Conservation Act

The Federal Nature Conservation Act (Bundesnaturschutzgesetz, or BNatSchG), which most recently underwent major revision in 2017, only stipulates on planting in the wild. It provides that from 1 March 2020 (the end of a ten-year transitional period), native provenances may only be planted in the wild within the natural ranges in which they occur. From then onwards, any planting of non-native flora in the wild requires approval; responsibility lies with the Länder. Cultivation in agriculture and forestry is exempted from these provisions.

The provisions of the Federal Nature Conservation Act also apply to tree species that come under the Act on Forest Reproductive Material when planted in the wild. Depending on the law in the various Länder, this can mean that one and the same tree species – an example is European hornbeam (*Carpinus betulus*) – is subject to different legislation in forests and in the wild. The implementing module on autochthonous trees and shrubs referred to in section 4.1.1 (BMU 2019) therefore contains detailed specifications on how to proceed after certification as an autochthonous tree or shrub (meaning when planting in the wild outside of the forestry context) with regard to the assignment of harvest reference numbers, provenance region classification, identification and documentation.

12.4 State of research and development on forest genetic resources

Institutions involved in research and development on forest genetic resources have worked on a very broad range of topics, primarily with third-party research funding. These are generally practice-oriented research projects with a focus on individual Länder and in some cases across multiple Länder. Especially in projects involving multiple Länder, BLAG-FGR organises cooperation on and coordination of focal tasks between the partner institutions. Examples include the GenMon inter-agency project to establish genetic monitoring for common beech and Norway spruce in Germany and the FraxForFuture demonstration project on conservation of the common ash.

Funding is mainly provided by the European Union, the Federal Ministry of Food and Agriculture (BMEL), the Federal Ministry of Education and Research (BMBF) and the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) on the basis of resolutions of the German Bundestag. In one case, funding was provided by Landwirtschaftliche Rentenbank.

The projects focused on the following topics:

- Development and application of molecular genetic techniques including adaptive markers
- Recording, genetic characterisation and documentation of conservation units of selected tree and shrub species
- Implementation of species conservation programmes
- Establishment of a nationwide network for genetic monitoring of two important commercial tree species
- Genetic characterisation of harvesting units (stands, seed orchards and clone archives) including provenance certification for reproductive material
- Analysis of the impact of legal provisions on forest reproductive material and of silvicultural activities on genetic diversity
- Assessment of the adaptability of trees and shrubs to climate change by tracking phenotypic and genotypic traits
- Breeding of tree species as contributions to the description and use of forest genetic resources

12.4.1 Genetic monitoring for common beech and Norway spruce in Germany (GenMon)

Genetic variability is the basis for the adaptability and survival of tree species under changing environmental conditions. The projected global warming will lead to extreme weather events. A monitoring system for forest genetic resources is urgently needed to provide information about the long-term development of the genetic systems of forest tree populations. Genetic monitoring aims to track genetic variation and the state of the genetic system together with how it changes geographically and over time. It thus makes a vital contribution to estimating and evaluating the impact of factors influencing genetic variation and hence the adaptability of local tree populations.

The GenMon project is based on strategic and methodological foundations of genetic monitoring published in 2004 and 2008 (https://www.genres.de/de/fachgremien/blag-forstliche-genressourcen-forstsaatgutrecht/genetisches-monitoring/). At European level, a EUFORGEN working group with German participation has developed initial recommendations for the development of a European monitoring network.

Approaches and practical experience from Germany provided an important basis for this work (ARAVANOPOULOS et al. 2015).
The aim of the project was to establish a first nationwide monitoring system for two important commercial tree species in order to monitor the current state of genetic variation and the genetic system along with changes over time. For this purpose, a national network comprising 14 stands of common beech (*Fagus sylvatica*) and ten stands of Norway spruce (*Picea abies*) was established to uniform specifications in addition to existing monitoring plots (Figure 12-1). The existing populations were described in terms of morphological, genetic and phenological traits. The monitoring also includes meteorological data. The findings have made it possible to assess the current state of the populations. They also provide base data for monitoring their long-term development.

The phenological observations have shown significant differences in mean flushing date. For common beech (*Fagus sylvatica*), this was earlier in 2018 and 2019 than in 2017; for Norway spruce (*Picea abies*) it was earlier in 2018 than in 2017 and 2019. Late frost damage to foliage during flushing was more frequent in common beech (*Fagus sylvatica*) than in Norway spruce (*Picea abies*). Comparison of genetic variation in common beech (*Fagus sylvatica*) and Norway spruce (*Fagus sylvatica*) shows the almost complete transfer of genetic variation from old growth to new growth in natural regeneration. In the large populations of currently well over 250 adult trees, only about a third reproduced, but the potential loss of alleles is made up for by gene inflow provided that the adult stand is not isolated.

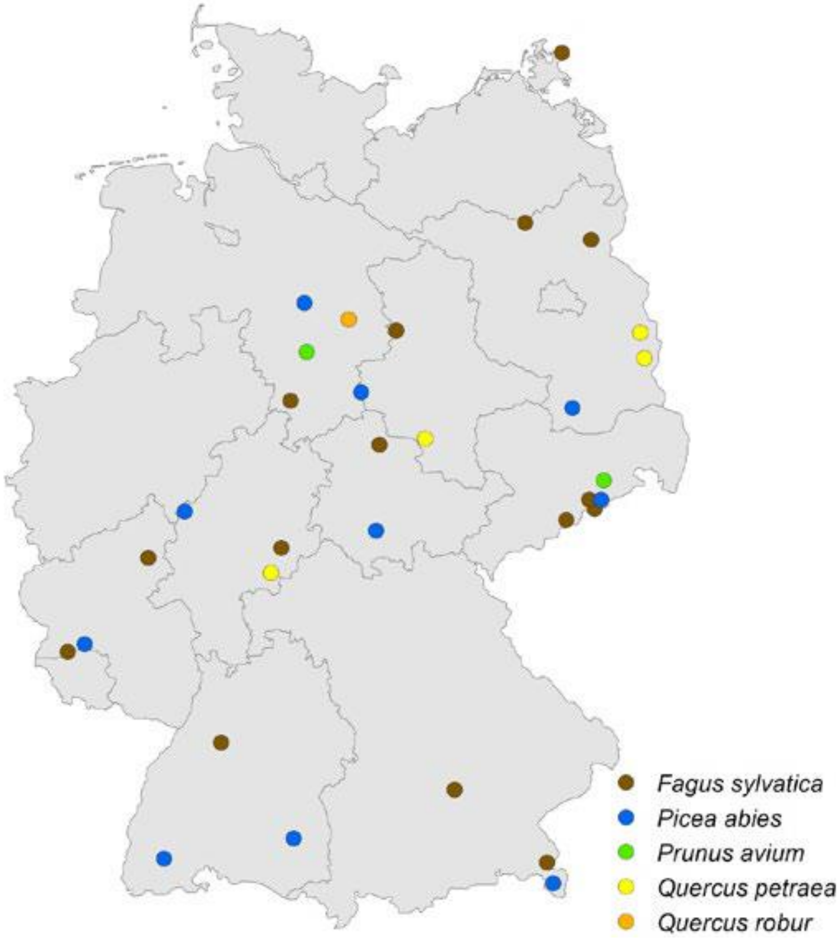


Figure 12-1:Genetic monitoring locations

Regeneration often occurs on a very small scale, but is always combined to a certain degree with pollen and seed dispersal over relatively large distances. Although the contribution of mature trees to progeny varies from individual to individual, diverse combinations of different parents are found that would not be possible to achieve with seed harvesting from just 20 trees. This pattern of reproductive behaviour provides intergenerational stability of genetic diversity and must be considered characteristic of stand-forming, wind-pollinated tree species.

Ongoing maintenance and regular observation of the plots represent a particular challenge for the future but are essential to the monitoring. Genetic analyses need to be repeated after a certain time and additional analyses performed for new-growth parts of the population. A long-term perspective with periodic reassessment of the state of the populations is needed in order to properly monitor and assess genetic processes and to estimate the influence and potential threat of the diverse environmental factors.

12.4.2 Conservation of the common ash (FraxForFuture)

The background to the FraxForFuture demonstration project is a drastic decline in numbers of common ash (*Fraxinus excelsior*) in Central Europe. This is mainly due to infection with a fungus, *Hymenoscyphus fraxineus,* that has been causing ash dieback in Germany and many other parts of Europe since 2002. Forestry operations incur financial losses due to reduced timber quality, tree mortality and increased monitoring and public safety costs. The future of ash in forestry is also highly uncertain, especially in light of current advice against new plantings.

FraxForFuture was launched to safeguard the conservation of the common ash as a native forest tree species together with the conservation of ash-specialist species and ecological communities. Study plots spread throughout the country serve as a common working platform for scientific investigations applying a wide range of approaches. Work on the study plots is conducted by all institutions involved in the project.

The project also includes the development of a national strategy for forest practitioners, policymakers and researchers for effective collaboration to preserve the common ash. In addition, it uses the example of ash dieback to test – for the first time in Germany – a concerted approach to documenting, describing and dealing with a forest disease. This focuses on the conservation of the common ash as a commercial tree species, the occurrence of the disease and the management of infested stands. As well as work on ash dieback itself, FraxForFuture therefore also includes work on preparing for other major forest damage scenarios that may be expected in future in order to establish structures for effective nationwide management of such scenarios. For this purpose, five research sub-networks have been established – on monitoring, genetics of the common ash and of the fungus, pathology, silviculture and coordination/communication. While pursuing their different research focuses, the sub-networks work in close collaboration. Each of them comprises a number of sub-projects that are carried out by various project partners spread all over Germany.

FraxForFuture is designed as a demonstration project. This means that alongside the actual findings on ash dieback and forest management of the disease, other important processes are also studied and evaluated as part of the research. Among other things, this includes the identification of relevant and capable research partners in order to establish a transdisciplinary research network for a complex research issue. This is a challenge that other researchers and research funding bodies are also expected to face. Ash dieback, as a multifaceted forest disease, thus serves as an example for similarly wide-ranging future research challenges.

It is necessary to identify, for example, what specialist capabilities are needed, who possesses them in Germany and how best to divide a complex research challenge into sub-projects. The collaboration process between project partners has to be organised, structured and reviewed, both at the preparatory phase and during the actual research.

Further activities involving research and development on forest genetic resources can be found in chapters 5 and 9 of this report.

12.5 State of education and training (including consultation efforts) related to forest genetic resources

The German education system is divided vertically into several levels: a three-tier school system with one primary and two secondary levels, a tertiary level comprising education at universities and academies, and a quaternary level with all forms of private and vocational continuing education and training.

Constitutional sovereignty over education and therefore responsibility for the schools and higher education system in Germany lies with the Länder. This results in differences in the implementation and naming of parts of the education system, although the system is based on a uniform national framework.

This system is supplemented by the ‘dual’ system of vocational training, which is conducted at two places of learning – a training workplace and a vocational school. In the dual system, responsibility for on-the-job training lies with sectoral public-law entities while the Länder are responsible for the accompanying vocational school-based training.

Biodiversity as a thematic area comes under science at primary level and biology at secondary level. There is no knowledge of specific teaching content in connection with forest genetic resources in school education. In higher education institutions with forestry and forest science degree programmes, forest genetics and forest tree breeding are covered to a greater or lesser extent in bachelor’s and master’s programmes. Bachelor’s degree programmes either include forest genetics, forest tree breeding and the conservation of forest genetic resources as separate subjects or the subject matter is covered in biology, forest botany, forest ecology and silviculture lectures. In-depth modules are offered in master’s degree programmes. Higher education graduates seeking a career in public administration go through a preparatory period (qualifying period, practical period or trainee programme) in a public forest administration. Subject matter relating to forest genetic resources is likewise covered to a greater or lesser extent in this preparatory period. The depth to which it is covered largely depends on the expertise present in the forest administration providing the training.

The three-year vocational training programme to become a forester prepares trainees for the practical work of forestry operations. Training content includes knowledge of tree species and their site requirements, forest reproductive material, silviculture, nature conservation and environment protection. Foresters can continue their education to become master foresters or, at technical schools, forestry technicians.

Alongside higher education institutions, forest administrations also play a major role in private and vocational education and training. This includes training for staff, forest owners and interested members of the public. Partly because of recent forest damage events, the reporting period also saw increasing interest in congresses on issues relating to forest genetic resources staged by forestry-oriented organisations such as the German Forest Society (Deutscher Forestverein) and the German Center for Forest Work and Technology (Kuratorium für Waldarbeit und Forsttechnik).

12.6 Organisation of research, development, education and training at national level, including main players and stakeholders

As with the education sector, the structure of research in forest sciences is shaped by Germany's federal system. At national level, the primary organisation involved in developing the scientific basis for Federal Government policy is the Johann Heinrich von Thünen Institute, the German Federal Research Institute for Rural Areas, Forestry and Fisheries. This is one of four federal research institutes in the BMEL portfolio and actually comprises a total of 14 institutes, including one for forest genetics. The Federal Office for Agriculture and Food (BLE) is another important player and coordinator with regard to education on forest genetic resources, with the Information and Coordination Centre for Biological Diversity (IBV) and the Federal Information Centre for Agriculture (BZL). The Competence and Information Centre Forest and Wood (KIWUH), a civil-law entity established in 2019 under Fachagentur Nachwachsende Rohstoffe e. V. (FNR) (Agency for Renewable Resources), supports FNR on behalf of BMEL as project management agency for the Renewable Resources funding programme. KIWUH is also responsible for professional and consumer information on the topics of forests, sustainable forestry and timber use and their contribution to climate change mitigation.

At Länder level, independent forest research institutes and forestry competence centres tied to public-sector forestry operations address practical research needs that are directly connected with the characterisation, recording, conservation and documentation of forest genetic resources.

Broader research on forest genetic resources is also carried out at Länder-funded universities, including universities of applied sciences – primarily those with departments of forestry and/or forest sciences. These are Technische Universität Dresden (Tharandt site), University of Freiburg, Georg August University Göttingen, Technical University of Munich (Freising site), Eberswalde University for Sustainable Development, Erfurt University of Applied Sciences, Göttingen University of Applied Sciences and Arts, University of Applied Forest Sciences Rottenburg and Weihenstephan-Triesdorf University of Applied Science. Research related to forest genetic resources is also carried out in related departments of other universities (such as departments of botany, biogeography, agriculture and horticulture).

The BMEL Renewable Resources funding programme is coordinated by FNR, which was established in 1993. Among other things, the programme funds projects on the use of wood and its components in the bioeconomy, including genetic and breeding research projects. Under the Forest Climate Fund funding programme established in 2013, BMEL and BMU support projects to unlock the carbon reduction, energy and substitution potential of forests and timber along with projects to adapt German forests to climate change. A number of projects relating to forest genetic resources were funded under this programme during the reporting period, including GenMon, FraxForFuture and FitForClim/AdaptForClim.

12.7 Needs, challenges and opportunities for strengthening the national institutions and policies on forest genetic resources

The conservation and sustainable use of forest genetic resources is subject to various provisions under national and Länder-level forest legislation. Specific reference to it is made in the Land forest acts of some of the Länder (such as Brandenburg, Bavaria and Rhineland-Palatinate). In two Länder (Mecklenburg-Western Pomerania and Thuringia), forests can be designated protected forest for the purpose of conserving forest genetic resources. Due to the increasing importance of biodiversity, including forest genetic resources, as reflected in a wide variety of international agreements, it is desirable for the task of biodiversity conservation to be explicitly addressed in legislation.

Including the conservation and sustainable use of forest genetic resources as a conservation objective in relevant legislation can help ensure that conservation measures are actually implemented following designation of *in situ* gene conservation units. As a matter of principle, sites and units that are important for the conservation of forest genetic resources should be taken into account in forestry framework planning and forest function mapping. It would also be useful in this connection to develop funding instruments to support *in situ* conservation measures for forest genetic resources in privately owned and communal forest. It may be possible for suitable stands to be harvested in protected areas – in some cases including areas under minimal intervention.

Special challenges arise from the increasing and in some cases severe deterioration in the state of forests, in part due to effects of climate change. The extreme natural events since 2018 may well have set changes in motion that challenge the adaptability and productivity of forests to a far greater extent than previously assumed. A fundamental goal as these changes progress is to safeguard the continuity of forest ecosystem services such as raw timber production and climate change mitigation, recreation and nature conservation services. In particular, it is necessary to preserve the carbon storage capacity of forests and their capacity for meeting altered social and economic needs by adhering to comprehensive sustainability principles. Genetic variability in the populations of tree species, in combination with the diversity of species, remains the basic precondition for adaptation processes to environmental change. The conservation and sustainable use of diverse forest genetic resources are thus key elements in the future resilience, semi-natural condition, stability and productivity of forests.

The central task of forestry in the decades ahead – besides dealing with damage already incurred – is to bring about a long-term increase in the adaptability of forests to changing climate conditions. In particular, this requires the establishment of semi-natural mixed forests, for which high-quality seed and planting material is needed from predominantly site-native and adaptable tree species and provenances.

Of the primary and secondary tree species in Germany, nine species are projected to undergo major changes in range, either in the form of range losses/range shifts as in the case of common beech (*Fagus sylvatica*), Norway spruce (*Picea abies*), Scots pine (*Pinus sylvestris*), sessile and English oak (*Quercus petraea* and *Q. robur*), or due to biotic pests as in the case of sycamore (*Acer pseudoplatanus*), common ash (*Fraxinus excelsior*), wych elm (*Ulmus glabra*) and European field elm (*Ulmus minor*). To compensate, the search should be stepped up for other suitable tree species and provenances. Additional provenance trials provide the basis for well-founded cultivation and provenance recommendations. Provenance research identifies variation within and between provenances and their suitability for cultivation in different site conditions together with their plasticity with regard to climate change impacts. Of particular importance here are genotype and phenotype-level studies on the adaptedness and adaptability of tree populations to climatic conditions. It is also necessary to designate suitable sources of reproductive material.

A further urgent need is to extend the existing system of seed orchards to other previously neglected tree species and to ensure ongoing regeneration. Various projects follow this approach at the time of reporting. Here again, the present-day bias towards third-party project funding means that a special challenge is posed by the long-term nature of the work involved – from selecting suitable plus trees, propagating them and establishing a site to actual approval and entry into routine operation.

The increase in tree mortality associated with extreme events reduces genetic diversity (WBGU 2020). Assessment of the risks to forest genetic processes requires genetic monitoring to be transferred from today's temporary project phase to a permanent task of forest environment monitoring. Countering the loss of genetic diversity also requires increased efforts to conserve forest genetic resources, including as a basis for breeding.

12.8 Priorities for capacity building in this area

The conservation and use of forest genetic resources, including forest tree breeding, is a research area with long-term horizons that consequently requires ongoing funding and support – also with a view to ensuring that trial facilities remain available for as long as possible. Limited-term third-party funded projects can help very significantly in kick-starting research. Real progress and the only solution in this regard, however, lies in relatively substantial institutional support from the Federal Government and the Länder in combination with third-party funded project support through the Forest Climate Fund and the FPNR programme.

While limited-term project funding can generate lasting impetus, it also highlights the challenges when it comes to supporting and achieving long-term objectives and solutions in research on forest genetic resources. The following examples are intended to illustrate those challenges in the field of forest tree breeding and the need to combine the two instruments of institutional funding and third-party funded project funding.

It takes time to familiarise staff with the complexities of forest tree breeding, with field trials to be looked after and evaluated over a period of decades. Trained staff cannot be employed on a long-term basis with project funding, which is why this needs to be combined with institutional funding so that acquired knowledge is retained. In the end, investing in staff on limited-term contracts effectively incurs a loss for the research institution. This situation has been exacerbated in Germany by amendments to the Academic Fixed-Term Contracts Act (Wissenschaftszeitvertragsgesetz – WissZeitVG).

There is an increasingly tendency for staff to leave projects early as they are offered permanent positions elsewhere or find follow-up employment. The leftover duration of a project is unattractive for new hires, who are hard to come by in any case in a market with high demand for personnel.

While third-party funded research projects create temporary positions, doing so also ties up existing staff resources. Permission has to be obtained to advertise each post (with outline, application and additional submissions), project management has to be looked after (including recruitment, personnel and expenses planning and funding reallocation submissions), there are formal reporting requirements to comply with and provision must be made for handover at the end of the project. With the establishment of additional long-term structures, a solution approach is to be initiated in order to allocate more of the capacity invested to the institution’s actual research activities.

This makes it essential to provide long-term structures and funding opportunities for scientific research, with timely application and approval pathways. Greater institutional support needs to be implemented at Federal

Government and Länder level in order to ensure continuity and long-term scientific productivity in the field forest genetic resources, including forest tree breeding.

Funding opportunities for research projects on forest genetic resources have developed encouragingly in general. In the final analysis, what is needed is a combination of the two policy instruments – third-party funding complemented by stronger institutional support at federal and Länder level – rather than focusing on one at the expense of the other.

Independently of the above, forest genetic resources should be given greater prominence in degree programmes as a subject area in its own right. In addition, provision should be stepped up for initial training and above all further training on forest genetic resources, including with the use of new learning platforms (such as e-learning).

13 International and regional cooperation on forest genetic resources since 2013

The conservation and sustainable management of forests worldwide – along with the restoration of degraded and destroyed forests – comprise an important global aim and a major challenge for the international community, including for Germany. This is reflected in the importance of the diverse forest ecosystem services for society.

International and regional cooperation in networks and collaborative projects is particularly important for the conservation, sustainable use and development of forest genetic resources.

European Forest Genetic Resources Programme (EUFORGEN)

Germany has been part of the European Forest Genetic Resources Programme (EUFORGEN) from the outset. EUFORGEN aims to promote the conservation and sustainable use of forest genetic resources for the benefit of present and future generations. The EU member states cooperate in EUFORGEN on a voluntary basis in order to promote *in situ* and *ex situ* conservation of forest genetic resources and to coordinate activities, exchange ideas and disseminate information. EUFORGEN is funded by the member states. Until the end of 2017, its secretariat was hosted by Bioversity International in Rome. From January 2018, the secretariat was located at the regional office of the European Forest Institute (EFI) in Bonn. It is now based at the EFI regional office in Barcelona. The programme is overseen by a steering committee composed of national coordinators. The Thünen Institute of Forest Genetics provides Germany's national coordinator.

EVOLTREE

EVOLTREE (http://www.evoltree.eu/) is an excellence network that has remained in place beyond expiry of the EU-funded project phase. Parts of the infrastructure and training capacity developed in the project have been retained permanently or at least for an additional ten years. Significant project outcomes include databases, analysis programmes and training courses. German participants comprise the Thünen Institute, the University of Göttingen and the University of Marburg. The network is funded out of contributions from the 27 member institutions (research institutions and universities) from 18 European countries. Its main objectives are:

- To improve understanding of forest ecosystem structure, dynamics and processes by linking genomics, genetics, ecology and evolutionary studies
- To promote the application of genetics and genomics in breeding and conservation activities and in forestry operations
- To continuously develop initiatives and projects for long-term research

Numerous studies have additionally been carried out on the characterisation and conservation of forest genetic resources as part of various EU research projects with the involvement of German partner institutions. Major projects included the following:

- Trees4Future (2011-2016) => http://www.trees4future.eu/
- ForGer (2012-2016) => https://www.wur.nl/en/show/forger-1.htm
- GenTree (2016-2020) => https://www.gentree-h2020.eu/
- SusTree (2016-2019) => https://www.interreg-central.eu/Content.Node/SUSTREE.html
- LifeGenMon (2014-2020) => http://www.lifegenmon.si/
- TreesForJoules (2011-2015) => http://tfj.lrsv.ups-tlse.fr/

German partner institutions have also been involved in various EU-COST activities (FP0905 Tree Biosafety [http://www.cost-action-fp0905.eu/]; CA15223 iPlanta [https://iplanta.univpm.it/]; CA18111 PlantEd [https://plantgenomeediting.eu/]).

A number of German institutions have additionally been involved over many years in international IUFRO provenance trials, for example on Norway spruce (*Picea abies*), Douglas fir (*Pseudotsuga menziesii*), Scots pine (*Pinus sylvestris*), oaks (*Quercus* sp.) and European silver fir (*Abies alba*). Numerous scientists from Germany also participate in IUFRO working groups on forest genetic issues (http://www.iufro.org).

13.1 Benefits from international and regional cooperation

The natural range of most tree and shrub species spans multiple European countries. European cooperation has contributed significantly to a better understanding of the genetic composition of important tree species, to the identification of regions of high or special genetic diversity of conservation value and to better assessment of the regional cultivation suitability of different provenances. It has also resulted in the large-scale availability of material for breeding programmes. As part of EUFORGEN, gene conservation units have been selected throughout Europe for numerous tree species and incorporated in a geographic information system (EUFGIS). International cooperation has also been highly instrumental in advancing the development of early career researchers. Furthermore, international collaboration is the only feasible option for cost-intensive infrastructure and experiments in genome research and forest tree breeding.

13.2 Needs for improving international and regional cooperation

International and, in the present context, European cooperation has proved highly effective in achieving progress in project-based activities. What are lacking, however, are effective mechanisms to perpetuate international research activities, networks and infrastructure. In the field of forest genetics, the EU has given preference in recent years to funding very large and complex projects, in some cases involving more than 20 partners and multiple work packages. The significantly smaller and thematically focused projects that previously attracted funding were at least as effective but far less costly and far easier to manage. A weakness in many cases was the transfer of research outcomes to forestry practice. There is a substantial need for improvement in such knowledge transfer.

13.3 Priorities for future cooperation

European cooperation on increasing the adaptability of forests to climate change is particularly important. This relates to drawing up recommendations on the cultivation of different provenances of tree species native to Europe, joint projects on cross-border seed transfer – such as the Interreg SUSTREE project ("Conservation and sustainable utilization of forest tree diversity in climate change") – joint breeding programs, Europe-wide genetic monitoring and increased *in situ* and *ex situ* gene conservation activities.

14 Recommended actions for the future

14.1 Availability of information on forest genetic resources

The following national information sources on genetic resources are available:

Table 14-1: Central databases

Database	Link
GENRES genetic resources information system	http://www.genres.de
FGRDEU national inventory of forest genetic resources	http://fgrdeu.genres.de
Data on harvesting and trading of forest reproductive material	https://fgrdeu.genres.de/erntehandel/

Centralised management of the data is the responsibility of the Federal Office for Agriculture and Food (BLE). Work is currently underway on a georeferenced national database of gene conservation units for common beech (*Fagus sylvatica*) and common yew (*Taxus baccata*), including their assignment to transregional genetic conservation zones. Among other things, this work aims to coordinate the representative distribution of genetic conservation units across Länder boundaries. These activities need to be completed and extended to include additional tree species.

14.1.1 Information on genetic monitoring

As part of the GenMon research project (2017-2020), a nationwide genetic monitoring database was developed for the tree species common beech (*Fagus sylvatica*) and Norway spruce (*Picea abies*), with annual data on vitality, phenology, fructification and genetic structure for old-growth stands and natural regeneration for 24 monitoring plots in Germany. The database is currently centrally managed by the office of forest genetics (AWG) in Teisendorf, Bavaria. Future responsibility for maintenance and use of the database needs to be clarified on the continuation of genetic monitoring beyond the end of the project (section 11.4.1).

14.1.2 Reports

Progress reports of the Federal-Länder Working Group on Forest Genetic Resources and Forest Seed Law (BLAG-FGR)

BLAG-FGR presents progress reports (https://www.genres.de/fachgremien/blag-forstliche-genressourcen-forstsaatgutrecht/taetigkeitsberichte) every five years, providing an overview of work carried out in Germany.

Annual survey of the supply situation with forest reproductive material

BLE publishes the findings of the annual survey of the supply situation with forest reproductive material in Germany. The documents are available online (https://www.ble.de/DE/Themen/Wald-Holz/Forstliches-Vermehrungsgut/forstliches-vermehrungsgut_node.html).

This reporting will continue in future years.

14.1.3 Professional publications and public relations

Alongside professional publications, continued use should be made of all information channels. New information offerings need to be provided for specific target audiences such as conservation workers and forest owners lacking a forestry background. This could include experimental plots based on publicly available demonstration sites – Marteloscope sites (http://www.integrateplus.org) – focusing on the conservation of forest genetic resources.

14.2 Conservation of forest genetic resources

The most important climate change adaptation option for forestry consists of broad diversity in tree species selection in order to spread risk. As the impacts of climate change cannot be predicted at local level, forests with a diverse species composition and broad genetic amplitude provide the best basis for adaptable and stable future forest ecosystems and for the breeding of adapted, productive and high-quality trees. Equal attention and effort must therefore be directed at species diversity and intraspecific genetic variability, for example by establishing mixed stands with predominantly site-native tree species.

14.2.1 *In situ* conservation

The basis for all conservation measures is *in situ* documentation, characterisation and assessment of existing forest genetic resources. Many *in situ* conservation units were designated many years ago, since when they have been subject to multiple influences and changes. Ensuring the long-term conservation of such stands requires repeat surveys of vitality and where necessary regeneration. This will become all the more important because increasing abiotic and biotic stresses can have an impact on the potential for *in situ* conservation.

14.2.2 *Ex situ* conservation

Ex situ conservation has so far focused on rare native tree species or populations that are endangered in their natural location. A number of these tree species – such as the wild service tree (*Sorbus torminalis*), Norway maple

(*Acer platanoides*), field maple (*Acer campestre*) and sweet chestnut (*Castanea sativa*) – will gain in silvicultural importance with increasing temperatures and drought conditions. In light of this, *ex situ* conservation of these species needs to be stepped up in terms of area and the number of clones in each genetic conservation zone.

Additionally, stands of non-native species previously rarely cultivated in Germany need to be included in *ex situ* conservation. Examples include Turkish hazel (*Corylus colurna*), downy oak (*Quercus pubescens*) and Turkey oak (*Quercus cerris*).

14.3 Use, development and management of forest genetic resources

Forest management in Germany is extensive compared to other forms of land cultivation and contributes to the conservation of biodiversity typical of Europe's natural forests.

14.3.1 Conservation of forest genetic resources across all ownership forms; public funding

Tree and shrub populations fulfil the function of conserving forest genetic resources in forests under all forms of ownership. In non-state-owned forests, *in situ* conservation can only take place on a voluntary basis. This requires comprehensive information on the background, objectives and activities directed at obtaining the approval of forest owners. *In situ* conservation measures can incur loss of income due to non-use or additional costs of protection and maintenance. This necessitates the development of funding instruments to assist forest owners for such purposes (or the evaluation of such measures in Länder such as Thuringia and Brandenburg where they already exist).

14.3.2 Genetic monitoring

As part of the National Programme for Forest Genetic Resources in Germany (PAUL et al. 2010), a detailed genetic monitoring system with recommendations for practice (ANONYMOUS 2008) was developed to track the development of genetic diversity in forest ecosystems. Using permanent monitoring plots, the aim of this system is to monitor changes in the genetic structure of selected tree species in time and space. It is currently being implemented under a limited-term (to 2020) third-party funded project for the two tree species common beech (*Fagus sylvatica*) and Norway spruce (*Picea abies*) (section 11.4.1). However, one of the main aims of monitoring is to observe genetic processes over as long a period as possible. In other words, the genetic monitoring must (i) be continued for the two tree species beyond the end of the funding period and (ii) be extended to other tree species (such as oak (*Quercus* sp.), Scots pine (*Pinus sylvestris*) and Douglas fir (*Pseudotsuga menziesii*). Detailed approaches need to be developed and implemented for this purpose.

A parallel approach aims to implement aspects of genetic monitoring in the large-scale National Forest Inventory (NFI4, starting in 2022). The objective is to investigate the geographical differentiation of seven commercial tree species – Scots pine (*Pinus sylvestris*), Norway spruce (*Picea abies*), Douglas fir (*Pseudotsuga menziesii*), European silver fir (*Abies alba*), common beech (*Fagus sylvatica*) and sessile and English oak (*Quercus petraea* and *Q. robur*) – based on genetic markers in a grid network covering 4,000 sample points.

14.3.3 Assessment of forest genetic resources on the basis of genetic markers

Most genetic conservation units in Germany have been selected on the basis of phenotypic traits and population biology criteria (such as number of individuals, rarity, vitality and demographic structure) and on the basis of the threat situation (conservation urgency). Work should now be stepped up on characterising these conservation units with genetic markers, especially considering the advancing development of such markers and the emergence of low-cost analysis routines.

Alongside neutral gene markers, further support needs to be provided for the development and use of gene markers to identify adaptive genetic variation.

14.3.4 Incorporating *in situ* conservation measures into forest management

Safeguarding and increasing genetic diversity as the basis for long-term and sustainable forest conservation includes in the entire range of activities from selecting and maintaining seed stands, producing reproductive material, regenerating and thinning strategies through to timber harvesting and designating forest refuges free of forestry intervention.

New research findings in forest genetics need to be incorporated to a greater extent both in the interdisciplinary forest science discourse and in new silviculture guidelines, provenance recommendations and so on. An important platform in this regard is the Forest Genetics and Forest Tree Breeding section of the German Association of Forest Research Organizations (DVFFA, www.dvffa.de).

Knowledge transfer to forestry practice and forest policymakers has been significantly intensified in recent years. Training and education activities, fact sheets, lectures and online resources (such as www.waldwissen.net) help educate the public about the importance of genetic diversity and forest genetic resources.

14.4 Institutions and capacity building

In Germany, the diverse activities for the conservation of forest genetic resources are the responsibility of Länder ministries, which have delegated these tasks to nine Länder-level forest research institutes. Staffing at these departmental research institutions for this activity area is at a stable but low level. Genetic analysis capabilities, for example, are available to only a few of the forest research institutes and to the Thünen Institute.

Conversely, there has been substantial capacity building in funding for limited-term forest genetic research projects (such as the Competence and Information Centre Forest and Wood (KIWUH) via the Forest Climate Fund and FNR). However, the mismatch between temporary and permanent positions in research institutions, the effort required for project administration and the costly administration of invariably limited-term, predominantly specialised, third-party funded staff reduces the necessary innovation thrust and the continuity of the work processes.

In addition, BLAG-FGR is at the limits of its coordinating capabilities in the face of the conflicting priorities, organisational structures and resource provision of the institutions in the various Länder. Centralised, national responsibilities for the conservation of forest genetic resources (such as database hosting and national reporting) need to be assumed by national-level institutions (such as the Thünen Institute), which would also have to be provided with the necessary staffing for the purpose.

15 References

ANONYMOUS (2008): Anleitung zur Durchführung des genetischen Monitorings für bestandsbindende Baumarten. BLAG-FGR Genetic Monitoring Expert Group, 16 p.

ANONYMOUS (2017): Abschlussbericht zum Modell- und Demonstrationsvorhaben „Erhaltung der innerartlichen Vielfalt gebietsheimischer Wildobstarten in Sachsen", project undertaken by Grünen Liga Osterzgebirge e.V. and Staatsbetrieb Sachsenforst, funded by BLE with funding from BMEL.

ARAVANOPOULOS F A, TOLLEFSRUD M M, GRAUDAL L, KOSKELA J, KÄTZEL R, SOTO A, NAGY L, PILIPOVIC A, ZHELEV P, BOŽIC G, BOZZANO M (2015): Development of genetic monitoring. methods for genetic conservation units of forest trees in Europe. European Forest Genetic Resources Programme (EUFORGEN), Bioversity International, Rome, Italy. xvi+46 p

BECHER G (2014) Clusterstatistik Forst und Holz: Tabellen für das Bundesgebiet und die Länder 2000 bis 2012. Hamburg: Johann Heinrich von Thünen-Institut, 105 p, Thünen Working Paper 32

BECHER G, WEIMAR H (2020) Branchen des Clusters entwickeln sich meist positiv. Holz Zentralbl 146(6):132-133

BLE (2012): National Report on the Conservation and Sustainalbe Use of Forest Genetic Resources in the Federal Republic of Germany. Agrobiodiversität Bd. 36. Schriftenreihe des Informations- und Koordinationszentrums für Biologische Vielfalt. BLE (Hrsg.)

BMBF (2020): Nationale Bioökonomiestrategie. BMBF (Eds.)

BMEL (2019): Agenda Anpassung von Land-und Forstwirtschaft sowie Fischerei und Aquakulturan den Klimawandel (Eds.)

BMELV (2011): Waldstrategie 2020. Nachhaltige Waldbewirtschaftung – eine gesellschaftliche Chance und Herausforderung. Bundesministerium für Ernährung, Landwirtschaft und Verbraucherschutz (Eds.)

BMU (2012): Leitfaden zur Verwendung gebietseigener Gehölze. BMU, Berlin.

BMU (2019): Fachmodul „Gebietseigene Gehölze" als Grundlage für einen entsprechenden „Scope" zur Akkreditierung von Zertifizierungsstellen für Gehölze bzw. Gehölzsaatgut gebietseigener Herkunft bei der Deutschen Akkreditierungsstelle (DAkkS), BMU, Berlin.

BMU (2016): Klimaschutzplan 2050, Klimaschutzpolitische Grundsätze und Ziele der Bundesregierung. BMU (Eds.)

BMU (2020): Deutsches Ressourceneffizienzprogramm III 2020 – 2023, Programm zur nachhaltigen Nutzung und zum Schutz der natürlichen Ressourcen, BMU, Berlin.

BMUB (2007): Nationale Strategie zur Biologischen Vielfalt. Bundesministerium für Umwelt, Naturschutz, Bau und Reaktorsicherheit (Eds.)

BOLTE A, EISENHAUER D-R, EHRHART H-P, GROß J, HANEWINKEL M, KÖLLING C, PROFFT I, ROHDE M, RÖHE P, AMERELLER K (2009): Klimawandel und Forstwirtschaft - Übereinstimmungen und Unterschiede bei der Einschätzung der Anpassungsnotwendigkeiten und Anpassungsstrategien der Bundesländer. Landbauforschung -vTI, Agriculture and Forestry Research 4 2009 (59)269-278

BUGMANN H, PFISTER C (2000): "Impacts of interannual climate variability on past and future forest composition." Regional environmental change 1.3-4 112-125.

DEGEN B, JOLIVET C, LIESEBACH H, HOELTKEN A, DOUNAVI A, FLADUNG F, NAUJOKS G, SCHNECK V, STAUBER T, STEINER W, KÖHL M (2008): Abschlussbericht „Erfassung der genetischen Struktur der Vogelkirsche (Prunus avium) als Grundlage für ein genetisches Monitoring wichtiger Waldbaumarten in Deutschland".

Die Bundesregierung (2020): Deutsche Nachhaltigkeitsstratgie. Weiterentwicklung 2021.

DIETZE W (1973): Gefriertrocknung und Lagerung von Pollen verschiedener Waldbaumarten. Silvae Gen. 22: 154-162.

FUSSI B, KUNZ M, TRÖBER U, LEINEMANN L, KÄTZEL R, EUSEMANN P, LIESEBACH H, BECKER F, KUCHMA O, KERSTEN B, VOTH W, KAROPKA M, HÖLTKERN A, ROSE B, WOLF H, KAHLERT K, HOSIUS B (2020): Schlussbericht zum Verbundvorhaben „GenMon – Einrichtung eines genetischen Monitorings für Buche und Fichte in Deutschland zur Bewertung der genetischen Anpassungsfähigkeit der Baumarten gegenüber Umweltveränderungen".

GAYER K (1886), Der Gemischte Wald, Berlin, Verlag Paul Parey.

HANEWINKEL M, CULLMANN D A, SCHELHAAS M J, NABUURS G J, ZIMMERMANN N E (2013): Climate change may cause severe loss in the economic value of European forest land. Nature Climate Change 3.3: 203.

KÄTZEL R, MAURER W D, KONNERT M, SCHOLZ F (2005): Genetisches Monitoring in Wäldern. Forst und Holz 60 (5): 179-183.

LIESEBACH M, WOLF H, BEEZ J, DEGEN B, ERLEY M, HAVERKAMP M, JANßEN A, KÄTZEL R, KAHLERT K, KLEINSCHMIT J, LEMMEN P, PAUL M, VOTH W (2021): Identifizierung von für Deutschland relevanten Baumarten im Klimawandel und länderübergreifendes Konzept zur Anlage von Vergleichsanbauten - Empfehlungen der Bund-Länder-Arbeitsgruppe „Forstliche Genressourcen und Forstsaatgutrecht“ zu den Arbeitsaufträgen der Waldbaureferenten. Braunschweig: Johann Heinrich von Thünen-Institut, 51 p, Thünen Working Paper 172, DOI:10.3220/WP1617712541000

LIESEBACH M, AHRENHÖVEL W, JANßEN A, KAROPKA M, RAU H-M, ROSE B, SCHIRMER R, SCHNECK D, SCHNECK V, STEINER W, SCHÜLER S, WOLF W (2017): Planung, Anlage und Betreuung von Versuchsflächen der Forstpflanzenzüchtung: Handbuch für die Versuchsanstellung. Braunschweig: Johann Heinrich von Thünen-Institut, 80 p, Thünen Rep 49, DOI:10.3220/REP1496222427000

LIESEBACH M, DEGEN B, GROTEHUSMANN H, JANßEN A, KONNERT M, RAU H-M, SCHIRMER R, SCHNECK D, SCHNECK V, STEINER W; WOLF H (2013): Strategie zur mittel- und langfristigen Versorgung mit hochwertigem forstlichem Vermehrungsgut durch Züchtung in Deutschland. Thünen-Report 7, 81 S. DOI:10.3220/REP_7_2013 urn:nbn:de:gbv:253-201311-dn052664-9.

MAURER W, CREMER E, DEGEN B, KONNERT M, TRÖBER U (2008): Abschlussbericht „Erfassung der genetischen Struktur der Rotbuche (Fagus sylvatica) als Grundlage für ein genetisches Monitoring wichtiger Waldbaumarten in Deutschland“.

MÜLLER J, BUßLER H, BENSE U, BRUSTEL H, FLECHTNER G, FOWLES A, KAHLEN M, MÖLLER G, MÜHLE H, SCHMIDL J, ZABRANSKY P (2005). Urwald relict species - Saproxylic beetles indicating structural qualities and habitat tradition. Waldokologie Online. 2. 106-113.

PAUL M, HINRICHS T, JANSSEN A, SCHMIDT H P, SOPPA B, STEPHAN B R, DÖRFLINGER H (2010): Konzept zur Erhaltung und nachhaltigen Nutzung forstlicher Genressourcen in der Bundesrepublik Deutschland. Aktualisierte

Neuauflage, Bundesministerium für Ernährung, Landwirtschaft und Verbraucherschutz; Bund-Länder-Arbeitsgruppe „Forstliche Genressourcen und Forstsaatgutrecht“ (EDS.), BONN, 84 S.

SCHMIDT M, EWALD J, FISCHER A, VON OHEIMB G, KRIEBITZSCH W-U, ELLENBERG H, SCHMIDT W (2003): Liste der Waldgefäßpflanzen Deutschlands. Mitteilungen der Bundesforschungsanstalt für Forst- und Holzwirtschaft, Hamburg 212, 34 p. (with annex).

STATISTISCHES BUNDESAMT (Destatis) 2017: Land- und Forstwirtschaft, Fischerei. Landwirtschaftliche Bodennutzung – Baumschulerhebung.

WBGU – Wissenschaftlicher Beirat der Bundesregierung Globale Umweltveränderungen (2020): Landwende im Anthropozän: Von der Konkurrenz zur Integration. Berlin: WBGU.

WIEDEMANN E (1925): Zuwachsrückgang und Wuchsstockungen der Fichte. Tharandt.

Population genetics and genetic diversity

BAIER R, FUSSI B, KAVALIAUSKAS D, GRUBER K, GÜNZELMANN G, PAULUS A, LANG E, LUCKAS M, WIENERS M, SCHMID R, KONNERT M (2017): Die Elsbeere – Generhaltung und Herkunftsfragen. AFZ/Der Wald 20, 14 – 18.

BLANC-JOLIVET C, DEGEN B (2014) Using simulations to optimize genetic diversity in Prunus avium seed harvests. Tree Genet. Genomes 10(3):503-512

CREMER E, FUSSI B, KONNERT M (2014): Seltene Baum- und Straucharten im forstgenetischen Labor. LWF Wissen 74, 98 – 105

CREMER E, SCHIRMER R, LUCKAS M (2017): Aspekte zur Genetik und zum Vermehrungsgut der Fichte. LWF Wissen 80, 20 – 25.

EUSEMANN P, LIESEBACH M, LIESEBACH H (2017): Mit Drohnen Ernteaussichten in Saatgutbeständen erkunden. AFZ-Der Wald 72 (10):28-30

EUSEMANN P, PREUSS A, LIESEBACH M, LIESEBACH H (2017): Optimierte Saatgutqualität durch einzelbaumweise Beerntung – Eine Untersuchung an Buche (Fagus sylvatica L.). Forstarchiv 88 (1):17-23. doi:10.4432/0300-4112-88-17

EUSEMANN P, PREUSS A, LIESEBACH M, LIESEBACH H (2019): Genetische Diversität im Vermehrungsgut der Rotbuche. AFZ-Der Wald (1):35-37

EWALD J, PAULE J, GREGOR TH, FUSSI, B (2016): Neues Vorkommen von Sorbus x decipiens im Fünfseenland entdeckt. Berichte der Bayerischen Botanischen Gesellschaft 86, 260 – 261.

FALTERMEIER M, MEYER N, GREGOR TH, PAULE J, LEPŠÍ M, FUSSI B, KOUTECKÝ P, SCHÄFER H, EWALD J (2016): Genetische und blattmorphologische Variabilität von Sorbus ratisbonensis. Berichte der Bayerischen Botanischen Gesellschaft 86: 37 – 56.

FAUST K, FUSSI B (2018): Genetik und Vermehrungsgut der Esskastanie. LWF Wissen 81, 14 – 19.

FUSSI B, CREMER E, KONNERT M (2014): Auf der Suche nach anpassungsrelevanten Genen bei Waldbäumen. LWF Wissen 74, 27 – 31.

FUSSI B, KONNERT M, CREMER E (2014): Genfluss in Waldbeständen. LWF Wissen 74, 22 – 26.

FUSSI B, KONNERT M (2014): Genetic analysis of European common ash (Fraxinus excelsior L.) populations affected by ash dieback. Silvae Genetica 63, 198 – 212

FUSSI B, DOUNAVI A, KONNERT M (2013): Identification of varieties and gene flow in Douglas-fir exemplified in artificially established stands in Germany. Annals of Forest Research 56 (2), 249 – 268

DOUNAVI A, NETZER F, CELEPIROVIC N, IVANKOVIĆ M, BURGER J, FIGUEROA A G, SCHÖN S, SIMON J, CREMER E, FUSSI B, KONNERT M, RENNENBERG H (2015): Genetic und physiological differences of common beech provenances (F. sylvatica L.) exposed to drought stress. Forest Ecology and Management 361 (2016), 226-236.

HARTER D, NAGY L, BACKHAUS S, BEIERKUHNLEIN C, FUSSI B, HUBER G, JENTSCH A, KONNERT M, THIEL D, KREYLING J (2015): A comparison of genetic diversity and phenotypic plasticity among European Beech (Fagus sylvatica L.) populations from Bulgaria and Germany under drought and temperature manipulation. Int. J. Plant Sci. 176(3): 232 – 244

HUBER G, WURM A, FUSSI B (2015): Verbreitung und Genetik des Feldahorns in Bayern. LWF Wissen 77, 14 – 21

KAROPKA M, CREMER E, KAVALIAUSKAS D, FORREITER L (2019): Die Spirke in süddeutschen Mooren. AFZ-DerWald 4, 14 – 17.

KELLER F, MEYER N, GREGOR TH, PAULE J, LEPŠI M, KOUTECKY P, FUSSI B, HACKL CH, EWALD J (2015): Hybriden zwischen Mehlbeere (Sorbus aria) und Elsbeere (Sorbus torminalis) im oberbayerischen Fünfseenland. Berichte der Bayerischen Botanischen Gesellschaft 85, 19 – 34.

KONNERT M, CREMER E, FUSSI B (2014): Genetische Variation wichtiger Waldbaumarten in Bayern. LWF Wissen 74, 14 – 21.

LEINEMANN L, KLEINSCHMIT J, FUSSI B, HOSIUS B, KUCHMA O, ARENHÖVEL W, LEMMEN P, KÄTZEL R, ROGGE M, FINKELDEY R (2014): Genetic composition and differentiation of sloe (Prunus spinosa L.) populations in Germany with respect to the tracing of reproductive plant material. Plant Systematics and Evolution 300, online

LEINEMANN L, STEINER W, HOSIUS B, KUCHMA O, ARENHÖVEL W, FUSSI B, HAASE B, KÄTZEL R, ROGGE M, FINKELDEY R (2013): Genetic variation of chloroplast and nuclear markers in natural populations of hazelnut (Corylus avellana L.) in Germany. Plant Syst. Evol. 299: 369 – 378.

LEMKE A, LIESEBACH H (2014): Gebietseigene Gehölze – Zertifizierungssysteme und Herkunftskontrolle. Deutsche Baumschule 66 (2):34-37

LEMKE A, LIESEBACH H (2014): Herkunftskontrolle und Systeme zur Zertifizierung bei Gehölzen. TASPO (3):12

LIESEBACH H (2014): How representative are plots in provenance trials? – An example from beech (Fagus sylvatica L.) genotyped with SSRs. In: 2014 IUFRO Forest Tree Breeding Conference, Prague, Czech Republic, 2014. IUFRO and Faculty of Forestry and Wood Sciences, Czech Univerity of Life Sciences, Prague, Prague, p 57

LIESEBACH H (2014): Sexuelle und asexuelle Fortpflanzungsformen in der Gattung Sorbus L. (Rosaceae) – ein Review unter besonderer Berücksichtigung der Apomixis. Mitt Deutsch Dendrol Ges (MDDG) 99:55-66

LIESEBACH H, EUSEMANN P, LIESEBACH M (2015): Verwandtschaftsbeziehungen innerhalb von Prüfgliedern in Herkunftsversuchen – Beispiel Buche (Fagus sylvatica L.). Forstarchiv 86 (6):174-182. doi:10.4432/0300-4112-86-174

LIESEBACH H, PREUß A, LIESEBACH M, DÖBBELER H, EUSEMANN P (2019): Bereitstellung von genetisch hochwertigem Vermehrungsgut. AFZ-Der Wald (1):38-40

LIESEBACH M, EUSEMANN P, LIESEBACH H (2018): Waldklimafonds-Vorhaben "Buchensaatgut" beendet. Das Amt Aktuelles – Mitteilungen – Termine Niedersächsisches Forstamt Oerrel 21:1-3

NEOPHYTOU CH, FUSSI B, KONNERT M, LUCKAS M (2014): Traubeneiche und Stieleiche – zwei ungleiche Schwestern. LWF Wissen 75, LWF Wissen 75, 14 – 20.

NEOPHYTOU CH, KONNERT M, FUSSI B (2019): Western and eastern post-glacial migration pathways shape the genetic structure of sycamore maple (Acer pseudoplatanus L.) in Germany. Forest Ecology and Management 432, 83 – 93, https://doi.org/10.1016/j.foreco.2018.09.016

ŠEHO M, KAVALIAUSKAS D, KLEINSCHMIT J, KAROPKA M, FUSSI B (2018): Elsbeere – Bedeutung und Anlage von Herkunftsversuchen im Klimawandel. Allg. Forst- und Jagdzeitung 3/4, 41 – 57 (DOI-Nummer: 10.23765/afjz0002020).

TAEGER ST, FUSSI B, KONNERT M, MENZEL A (2013): Large-scale genetic structure and drought-induced effects on European Scots pine (Pinus sylvestris L.) seedlings. European Journal of Forest Research DOI 10.1007/s10342-013-0689-y, published online: 02 February 2013

WOJACKI J, EUSEMANN P, AHNERT D, PAKULL B, LIESEBACH H (2019): Genetic diversity in seeds produced in artificial Douglas-fir (Pseudotsuga menziesii) stands of different size. Forest Ecol Manag 438:18-24. doi:https://doi.org/10.1016/j.foreco.2019.02.012

WURM A, FUSSI B, KONNERT M (2016): Winterlinde – Vermehrungsgut und genetische Aspekte. LWF Wissen 78, 14 – 19.

Fundamentals and marker development

FUSSI B, BELLE C, BLANC-JOLIVET C, LIESEBACH H, BUITEVELD J, PIOTTI A, SPANU I, VENDRAMIN GG, GUICHOUX E, TRÖBER U, JAHN D, MENGL M, HEINZE B (2014): D7.2 – Report on cross-validation of molecular marker identification protocols. Designing Trees for the Future, vol Project no. 284181, Theme INFRA-2011.1.1.13: Research infrastructures for forestry research.

FUSSI B, WESTERGREN M, ARAVANOPOULOS F, BAIER R, KAVALIAUSKAS D, FINZGAR D, ALIZOTI P, BOZIC G, AVRAMIDOU E, KONNERT M, KRAIGHER H (2016): Forest genetic monitoring: an overview of concepts and definitions. Environ Monit Assess 188:493; DOI 10.1007/s10661-016-5489-7.

KAVALIAUSKAS D, FUSSI B, WESTERGREN M, ARAVANOPOULOS F, FINZGAR D, BAIER R, ALIZOTI P, BOZIC G, AVRAMIDOU E, KONNERT M, KRAIGHER H. (2018): The Interplay between Forest Management Practices, Genetic Monitoring, and Other Long-Term Monitoring Systems. Forests, 9, 133; doi:10.3390/f9030133

KERSTEN B, MADER M, MÜLLER NA, FLADUNG M, DEGEN B, LIESEBACH M, LIESEBACH H (2018): Genome-wide scan for diagnostic markers for bud burst in beech. In: Di Filippo A, Madsen P, Matsui T, Pederson N, Piovesan G, Sagheb-Talebi K (eds) 11th International Beech Symposium "Natural and managed beech forests as reference ecosystems for the sustainable management of forest resources and the conservation of biodiversity", Viterbo, Italy, 18-21 September 2018. vol Book of abstracts. IUFRO, p 14

LIESEBACH H, HARTMANN M, LIESEBACH M, BOLTE A (2018): Genetisch verankerte Reaktion der Fichten auf Trockenstress? AFZ-Der Wald 73 (9):13-15

LIESEBACH H, ULRICH K, EWALD D (2015): FDR and SDR processes in meiosis and diploid gamete formation in poplars (Populus L.) detected by centromere-associated microsatellite markers. Tree Genet Genomes 11:801. doi:10.1007/s11295-014-0801-6

MADER M, LIESEBACH H, LIESEBACH M, KERSTEN B (2019): The complete chloroplast genome sequence of Fagus sylvatica L. (Fagaceae). Mitochondrial DNA Part B 4 (1):1818-1819. doi:10.1080/23802359.2019.1612712

MEYER M, ZACHARIAS M, MORGENSTERN K, KRABEL D, LIESEBACH H (2018): Variable genotypes at the cpDNA marker locus trnDT in spontaneous rejuvenation of the species complex around the European black poplar (Populus nigra L.) and its relatives collected in Germany. Landbauforsch Appl Agric Forestry Res 68 (1-2):93-102. doi:10.3220/LBF1544605045000

MOSCA E, CRUZ F, GÒMES-GARRIDO J, BIANCO L, RELLSTAB CH, BRODBECK S, CSILLÈRY K, FADY B, FLADUNG M, FUSSI B, GÖMÖRY D, GONZÀLES-MARTINEZ S, GRIVET D, GUT M, HANSEN O, HEER K, KAYA Z, KRUTOVSKY K, KERSTEN B, LIEPELT S, OPGENOORTH L, SPERISEN CH, ULLRICH K, VENDRAMIN G, WESTERGREN M, ZIEGENHAGEN B, ALIOTO T, GUGERLI F, HEINZE B, HÖHN M, TROGGIO M, NEALE D (2019): A Reference

Genome Sequence for the European Silver Fir (Abies alba Mill.): A Community-Generated Genomic Resource. Genes/Genomes/Genetics, https://www.g3journal.org/content/9/7/2039

SCHRÖDER H, KERSTEN B, FLADUNG M (2018): Identifizierung von 19 verschiedenen Pappelarten mit Hilfe von Chloroplasten- und Kernmarker-Sets. Landbauforsch Appl Agric Forestry Res 68(1-2):27-34

Breeding and characterisation of individual clones

BÄUCKER C, LIESEBACH H (2018): From in vitro clones to high-quality timber production: the Project "Wavy Grain Maple". Thünen Report 62:49-54. doi:10.3220/REP1539855736000

BÄUCKER C, LIESEBACH H (2019): Weiterer DNA-Nachweis für einen monumentalen Solitär: Der Berg-Ahorn (Acer pseudoplatanus L.) im Hamburger Hirschpark. Mitt Deutsch Dendrol Ges (MDDG) 104:122-126

EUSEMANN P, LIESEBACH H (2017): Die „Championbuche“ (Fagus sylvatica L.) von Hoppenrade (Prignitz): Bündelpflanzung oder ein einziger Baum? Mitt Deutsch Dendrol Ges (MDDG) 102:347-352

LIESEBACH H, EWALD E (2015): DNA-Nachweis: Die „tausendjährige“ Linde von Heede (Tilia platyphyllos Scop.) ist ein einziges Individuum. Mitt Deutsch Dendrol Ges (MDDG) 100:229-232

LIESEBACH H, LIESEBACH M (2016): Züchtung von Aspen und Hybridaspen für den Kurzumtrieb - Genotypisierung auf Versuchsflächen zum Nachweis von Wurzelbrut. Journal für Kulturpflanzen - Journal of Cultivated Plants 68 (1):1-6. doi:10.5073/JFK.2016.01.01

LIESEBACH H, NAUJOKS G (2015): Triploide Buchen (Fagus sylvatica L.) am Rande des Verbreitungsgebiets gefunden. Mitt Deutsch Dendrol Ges (MDDG) 100:189-196

ULRICH K, LIESEBACH H, EWALD D (2015): Erzeugung, Nutzung und genetische Charakterisierung polyploider Pappeln. FastWOOD II: Züchtung schnellwachsender Baumarten für die Produktion nachwachsender Rohstoffe im Kurzumtrieb - Erkenntnisse aus 6 Jahren FastWOOD, vol 26. Thünen Institut, Braunschweig. doi:10.3220/REP_26_2015

WALLBRAUN M, LIESEBACH H, MEIER-DINKEL A, JANßEN A, HUTTER I, SCHNEIDER C, MERKLE S (2016): Erarbeitung biotechnologischer Methoden zur Identifizierung, Erhaltung, Vermehrung und Nutzung selektierter Riegelahorn-Bäume für die Wertholzproduktion (Riegelahorn). In: Innovationstage 2016 – Die Zukunft ins Jetzt holen, 25. bis 26. Oktober 2016 in Bonn, Bonn, 2016. Bundesanstalt für Landwirtschaft und Ernährung, Deichmanns Aue 29, 53179 Bonn, pp 44–46