THE SECOND REPORT
ON THE STATE
OF THE WORLD'S
FOREST GENETIC RESOURCES

COUNTRY REPORT

UNITED KINGDOM OF GREAT BRITAIN AND NORTHERN IRELAND (THE)

Department for Environment Food & Rural Affairs

The State of Forest Genetic Resources in the United Kingdom

June 2024

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The complementary report has been structured in line with FAO recommendations. The report considers the United Kingdom of Great Britain and Northern Ireland only and makes no attempt to report on British Overseas Territories.

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The UK lost two leaders in forest genetic resources during the period (October 2021-March 2022) in which this report was first in preparation, both of whom led the Tree Improvement branch at Forest Research.

- Chapter 8 is dedicated to Dr C.J.A. “Sam” Samuel.
- Chapter 9 is dedicated to Dr. Gustavo A. Lopez.

Abbreviation list

BIHIP	British and Irish Hardwoods Improvement Programme
CBC	Conifer Breeding Cooperative
EMBL	European Molecular Biology Laboratory
EUFGIS	European Information System on Forest Genetic Resources
EUFORGEN	European Forest Genetic Resources Programme
FAO	Food and Agricultural Organisation of the United Nations
FERA	Food and Environment Research Agency
FGR	Forest Genetic Resources
FRM	Forest Reproductive Materials
FSC	Forest Stewardship Council
FTT	Future Trees Trust
GCU	Gene Conservation Unit
GFG	Global Forest Goals
ICCP	International Conifer Conservation programme
IUCN	International Union for Conservation of Nature
IUFRO	International Union of Forest Research Organisations
MSBP	Millenium Seed Bank Partnership
NGO	Non-Government organisations
NIAB-EMR	National Institute of Agricultural Botany - East Malling Research Station
NOLTFOX	Northern European Database of Long-term Forest Experiments
NTIS	National Tree Improvement Strategy
OECD	Organisation for Economic Co-operation and Development
PEFC	Programme for the Endorsement of Forest Certification
RBG	Royal Botanic Garden
UKFS	UK Forestry Standard
UKNTSP	UK National Tree Seed Project
UKWAS	UK Woodland Assurance standard
UNSPF	United Nations Strategic Plan for Forests

Executive summary

Genetic diversity is the foundation of all biodiversity. Trees are keystone species in that they are large and habitat-forming and are characterised by very large population sizes. Long lifespans with enormous reproductive output involving distant dispersal of pollen and seed mean that trees hold very high levels of within-species genetic diversity, the sum total of which is known as the 'genetic resource'. Forest Genetic Resources (FGR) are formalised by Food and Agricultural Organisation of the United Nations (FAO) as "*the heritable materials maintained within and among tree and other woody plant species that are of actual or potential economic, environmental, scientific or societal value*."

This report has been prepared according to FAO reporting guidelines for the second assessment of the "State of the World's Forest Genetic Resources" and aims to summarise the State of FGR in the United Kingdom (UK).

Key figures from a technical questionnaire into the "State of Conservation, Use and Development of Forest Genetic Resources" UK are that:

- 78 species are regarded as UK FGR, 48 of which are native to the UK
- 39 UK FGR species have undergone phenotypic evaluation in experimental trials and 25 have had some molecular characterisation
- 17 in situ *gene* conservation units (GCUs) for 7 species, covering 600 hectares have been designated
- At least 4700 genotypes covering 18 UK FGR species have accessions in clone banks
- 15 million seeds, covering 1200 populations of 45 UK FGR species are conserved in seed banks
- There are 421 registered seed stands covering over 18000 hectares of land for 35 species of UK FGR. There are 55 registered seed orchards covering over 160 hectares of land for 12 species.
- 16 tree species have been the subject of tree improvement programmes

This report is complementary to, and elaborates on, the findings of the previously submitted technical questionnaire.

State of diversity in trees and woodlands

Deciding what qualifies as UK FGR is complicated by the UK's history of introducing non-native tree species. 115 species were assessed and 77 of these have some level of FGR infrastructure.

Climate change and pests and diseases threaten tree populations, and there is increasing awareness that the forestry sector needs to increase diversity at all levels.

We have a limited understanding of genetic diversity in native tree species and better information is required to characterise FGR which will inform conservation, use, management, and development.

State of forest genetic resources conservation

Although a significant proportion of the UK's most important woodland habitats are under protection, those explicitly designated as in situ GCUs are few. However, the concept is gaining traction and the number of GCUs could be increased rapidly. Ex situ genetic conservation comprises seed banking and living collections of known genotypes (clone banking), activities which currently proceed separately.

State of use, development, and management of forest genetic resources

FGR are used in woodland creation programmes and use is expected to increase in line with ambitious national targets. A system of documenting exchange of Forest Reproductive Materials (FRM) is in place and could be further enhanced to provide greater support to end-users and quality assurance to enable better forestry outcomes.

The forestry sector enjoys substantial genetic gains in important commercial species delivered through decades of tree improvement. Tree improvement has become more diffuse in recent years with a larger number of organisations involved. Progress is being made on a range of species and opportunities are available to adopt new technologies and apply selection to variation in traits associated with resilience.

State of capacities and policies

Recent efforts have started to consolidate governance of FGR in the UK, but further work is required to deliver impact and synergies. Research and development in FGR are mostly publicly funded and carried out by research institutes, Non-Government Organisations (NGOs) and independent consultants with a relatively peripheral role for universities at present. The UK benefits from participation in international and regional networks in FGR and should seek to maintain and strengthen cooperation.

Challenges and opportunities

The need to improve the characterisation of FGR is a priority. A strategic approach in which conservation, use, management, and development are integrated under a clearly defined governance framework is set out as the main recommendation from this report.

Chapter 1. Value and importance of forest genetic resources

1.1 The role of the forest sector in the national economy

The UK has an economy largely dependent upon secondary and non-industrial sectors, notably service and financial. It is one of the largest net importers in the world of wood and wood-based products, reflecting the relatively low proportion of land covered by forests and a long tradition of relying on wood supplies from elsewhere. The forest sector makes a small but important contribution to the land-based economy but this is dwarfed by agriculture.

A substantial wood-processing sector has developed to make use of the growing domestic wood production which has grown from approximately 4% to 20% of the timber, pulp and panel production in the last 70 years. In 2021 the Gross Value Added (GVA) of the forest sector was estimated at £0.76 billion, and that of the primary wood processing sector, to be £2.09 billion (Forest Research, 2023a). Forestry employs approximately 20000, sawmilling 8000, and panel mills 5000 full-time equivalents.

Forestry policy is devolved to the four nations (England, Scotland, Wales, and Northern Ireland) and support for the forest sector and priorities reflect the different character and aspirations of the countries, and the differing needs for forestry to contribute to the national economy. Forest land values have risen substantially in recent years, reflecting increased interest in land-owning, perceptions of strengthening demand for domestic supply, and possibilities of new markets, including for carbon.

1.2 The main roles of forests in the UK

Forests provide multiple roles across the UK, encouraged through the adoption of the sustainable forest management principles in forestry policy and practice, as set out in the UK Forestry Standard (UKFS). Locally, the roles fulfilled by forests reflect the constraints and opportunities of location, site and climate conditions and owners' interests. Building on the initial twentieth century focus on timber production and a strategic reserve of timber, there has been a broadening of perspectives on the role of forests to sustain rural employment, encourage multi-purpose woodlands, contribute to the conservation and enhancement of biodiversity, and to provide multiple ecosystem services. In recent years, there has been growing interest in the design and management of forests to contribute to climate change mitigation (e.g. carbon sequestration), flood mitigation and natural flood management, biodiversity and nature recovery, and human well-being. Contributions of woodlands and other greenspaces, and time spent in them, have recently attracted attention for providing mental and physical health benefits. It is estimated that 74% of the UK population visited woodland recently (Forest Research, 2023b).

1.3 Economic, environmental, social and cultural values of forest genetic resources in the UK

Economic values, as represented by timber production and forest investment, predominated during the twentieth century and have shaped the current forest resource, driven by the need to establish a strategic reserve of timber. The need to enhance domestic production has placed a high value on the improvement of a small number of coniferous tree species (typically non-native). The route to enhanced economic value has been through improved growth rates and timber properties. More recently, rates of carbon sequestration and pathways to long-term carbon storage (for example in durable wood products) plus a wider set of values associated with resilience to future environmental change have attracted interest.

Environmental values have been strongly associated with the woodlands of largely native tree species with various levels of nature conservation designation being used to protect them from further losses. There have also been considerable programmes of habitat restoration. The biodiversity values of non-native production forests remain under-researched (Barsoum et al. 2024). Considerable value is placed upon the social and cultural aspects of native tree species, many of which are broadleaved, for their association with national history, particular folklore and the provision of habitats for biodiversity (Independent Panel on Forestry 2012). Values have been amplified given widespread losses in populations of some species (e.g. ash (*Fraxinus)* and elm (*Ulmus)*) to disease, prompting concerted efforts to highlight the value of species such as oak (*Quercus petrea* and *Quercus robur*). Social and cultural values differ regionally; for example, Scots pine (*Pinus sylvestris*) is currently not regarded as native in England and Wales but has strong cultural associations in Scotland with notable heritage values for the remnants of the Caledonian pinewoods.

1.4 Contributions of forest genetic resources to sustainable development

Forests are increasingly regarded as important in the societal response to the climate and biodiversity crises, and as an under-developed resource for economic activity and improved well-being. Locally they are seen as an important source of employment whether directly through jobs in forest management, indirectly through the development of leisure and tourism-related businesses (e.g. for ecotourism, mountain-biking), or new models for land use (e.g. community woodland, agroforestry). The UK supports the United Nations Strategic Plan for Forests (UNSPF) 2017-2030 and is committed to contributing to the achievement of the Global Forest Goals (GFGs) nationally and internationally, emphasising these in a Voluntary National Contribution to the United Nations Forest Forum in 2022.

1.5 Priorities and needs to enhance these contributions

Each of the UK nations has its own ambitious targets to expand woodland cover and, in England, a statutory target to increase tree canopy and woodland cover to 16.5% of land area has recently entered legislation. The UK Climate Change Committee has recommended that woodland cover is expanded by at least 30,000 ha/year from 2025 until 2050, increasing woodland cover from 13 to at least 16%. This priority is seen as contributing to a pathway to Net Zero and with careful planning also leading to improvements in nature recovery. In addition, there is interest in enhancing the area under sustainable forest management and improving woodland management in existing forest area to broaden the ecosystem services and increase their natural capital. Much lowland broadleaved woodland remains under-managed and offers prospects of enhanced contribution whether in the form of increased quality hardwood, or better habitat.

1.6 Perception of stakeholders on the importance of forest genetic resources

According to the recent Public Opinion of Forestry survey, there is broad-based public interest in forests and support for their expansion in area with 92% considering them important places for wildlife and 84% agreeing that more trees were needed in the response to the threat of climate chance (Forest Research, 2023b).

Stakeholders hold various perceptions with some more supportive of intensive breeding and tree improvement programmes to deliver economic returns and others more supportive of conservation and longevity of the forests and the preservation of native genetic resources. The rate of environmental change (for example, projections of frequency of extreme drought events) and threat of pests and diseases has drawn attention to the importance of species and within-species diversity and the need for resilience to be factored into choices.

Some insights into the specific motivations of owners likely to shape their perceptions on genetic resources can be gleaned from the British Woodlands Survey (Hemery et al. 2020). The survey suggested that the most important motive was protecting/improving nature or biological diversity followed by personal pleasure, wood products (timber, bioenergy, woodfuel, etc.) and finally non-timber forest products and hunting/shooting. Other publications suggest that reasons to diversify the range of tree species in woodlands can include biodiversity and forest health, carbon capture and storage, and timber yield (Reid et al. 2021).

1.7. Constraints to increasing awareness on the value and importance of forest genetic resources

Much of the UK population is urban and not very familiar with land use and land management decisions. The major constraint is the relatively low profile of forests, forest resources, and associated genetic resources. The relatively low woodland cover, low proportion of Gross Domestic Product related to forests, and relatively small numbers of people engaged in owning or managing woodlands all impact on perceptions of value and importance. Nevertheless, there is a strong interest in tree planting, and in woodlands, their conservation, and availability as a location for recreation.

Chapter 2 State of UK Forests

2.1. State of UK forests

No primary woodland remains in the UK with all forest being impacted to varying degrees by anthropogenic influences. Following the last Ice Age, trees recolonised from refugia in Europe, until the land bridge was severed by rising sea levels. The extensive post-glacial woodland cover was lost over millennia due to clearance, grazing, and changing climatic conditions. Introduction of new tree species is thought to have commenced as early as Roman times, and a substantial trade in timber importation from continental Europe developed from late Medieval times. Ancient woodland (defined as present since 1600 in England & Wales, 1750 in Scotland) covers about 2.5% of the land area, with other ancient and veteran trees found outside woodland. Ancient woodland cover varies between nations from 0.2% in Northern Ireland to 4.6% land cover in Wales (Reid et al. 2021).

Forest cover was less than 5% at the start of the twentieth century, expanded to just over 12% by the start of the 21st Century and is currently 13.4%. The UK average masks national differences – for example, woodland cover is 19% in Scotland, 15% in Wales, 10% in England, and 9% in Northern Ireland. The rate of woodland expansion slowed from a peak of more than 42,000 ha in 1971 to as little as 5,440ha in 2010 (Forest Research, 2023c) but is a topic of renewed attention. An additional 12,960 ha were created in 2022/23 and each nation has its own ambitious woodland expansion targets.

Approximately half the total woodland area in Great Britain (equivalent figures not available for Northern Ireland) is composed of native tree species, varying from two-thirds in England, approximately a half in Wales and one third in Scotland (Forest Research, 2020a). The coniferous proportion varies from 71% of woodland area in Scotland, 53% in Northern Ireland, 45% in Wales and 23% in England according to the 2023 Forestry Statistics (Forest Research, 2023c).

These broad statistics and those shown in Figure 2.1.2 mask substantial variations in character across the UK. Large coniferous forests are often planted in uplands as a financial investment and managed for timber production. Mixed and broadleaved forests of lowland UK are often managed as part of farming or other land-based enterprises, a proportion of which remain unmanaged or ‘neglected’. Approximately 44% of UK woodland area is certified by management schemes (to Forest Stewardship Council (FSC), Grown in Britain (GiB) or Programme for the Endorsement of Forest Certification (PEFC) schemes) reflecting 100% of public sector woodland and 24% of private sector woodland, 1.44 million hectares in all. Only 7% of native woodland is regarded as being in good ecological condition (Ditchburn et al. 2020), the remainder being affected by a range of pressures discussed further below. The urban forest is increasingly recognised as an important component of overall forest cover, which varies substantially between conurbations (Doick et al. 2020).

Trees outside of woodland make a substantial contribution to total tree and woodland canopy cover in Britain – estimated in 2016 at 19.4% and cover an equivalent of 3.2% of land area (including small woods below defined thresholds, linear rows of trees (e.g. in hedgerows and along roadsides), and isolated trees in agricultural settings; however, these are out with the scope of this review. The category of 'Other Woodland' which in the UK is largely composed of wood pasture is covered in chapter 3.

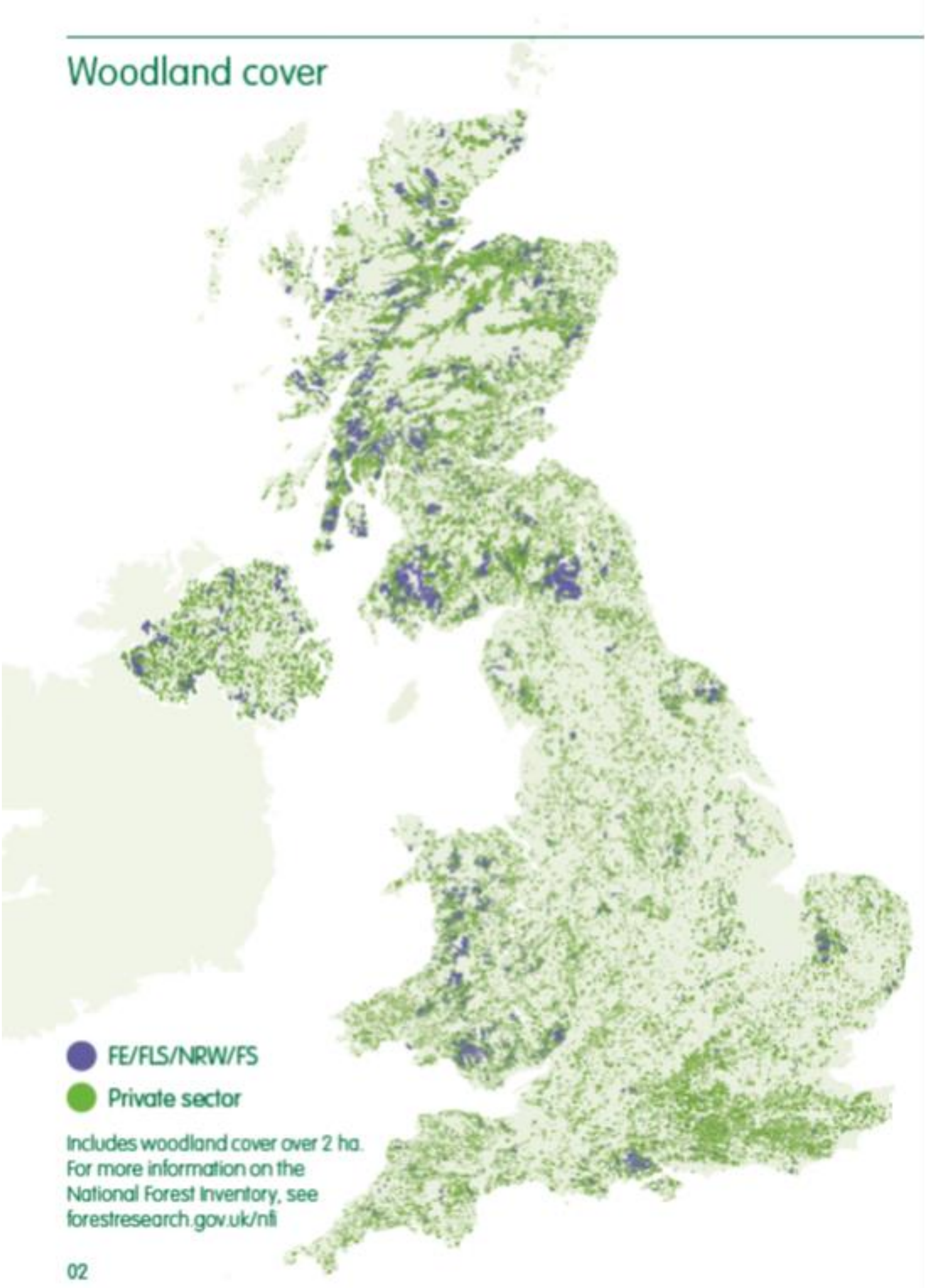
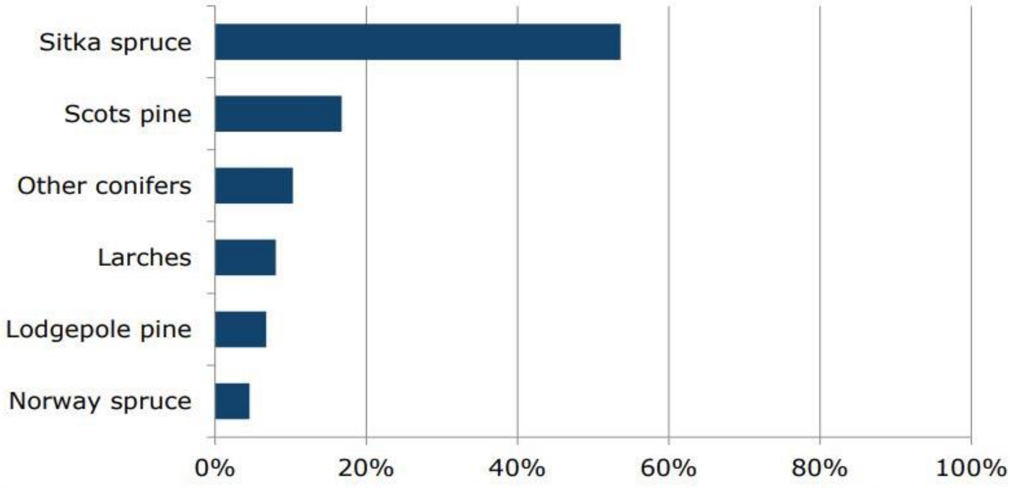
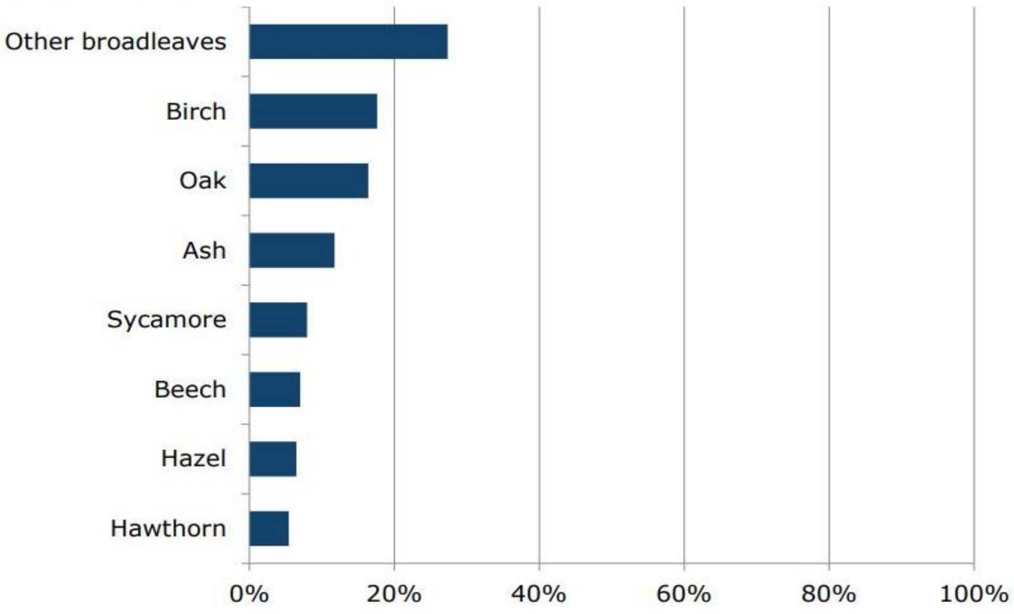


Figure 2.1.1 Map of woodland cover from the Forestry Facts and Figures report 2023 (Forest Research, 2023a)



Source: National Forest Inventory: 25-year forecast of softwood timber availability (Forest Research, 2022).

Figure 2.1.2a Stocked woodland area by principal conifer species, Great Britain, 2021. Figure from Chapter 1: Woodland Area and Planting, *Forestry statistics 2023*. (Forest Research, 2023c).



Source: National Forest Inventory: 50-year forecast of hardwood availability (Forestry Commission, 2014).

Figure 2.1.2b Stocked woodland area by principal broadleaf species, Great Britain, 2012. Figure from Chapter 1: Woodland Area and Planting, *Forestry statistics 2023*. (Forest Research, 2023c).

2.2. Trends affecting forests and their management

As outlined in section 2.1 there has been an enduring but slow increase in woodland area in the UK reflecting a sustained commitment to reforestation and an interest in expanding the multiple benefits which woodlands can provide (Quine et al. 2011). Timber production from UK woodlands had increased in recent decades but is levelling off due to changes in the nature and rate of afforestation during the twentieth century, with annual production influenced by prevailing market conditions and occasionally weather (Forest Research 2019, 2020a). There is increased attention to diversification of tree species and age structure for existing forests (Forest Research, 2023c). The 25-year timber availability forecast (Forestry Commission, 2022) indicates that availability will increase up to the late 2030s but then decline through the 2040s.

As outlined in section 4.4 climate change and pests and diseases are impacting forests and their management.

Grazing and herbivory remains a challenge to woodland expansion and diversification (Spake et al. 2020; Forestry Commission Scotland, 2014).

Some measures of biodiversity are showing declining trends – for example, in the population of certain rare woodland species e.g. Woodland Bird Indicator (BTO, 2023). Long term monitoring suggests woodland composition trending towards fewer, older trees and shadier conditions with some overall decline in species richness on the forest floor although trends vary by species. Herbivory is a common problem impacting tree regeneration (Kirby et al. 2005; Smart et al. in prep). Fragmentation and loss of trees outside woodland have been implicated in losses of woodland wildlife (Reid et al. 2021) as has cessation of traditional management (such as coppicing) and lack of thinning. Priority habitats and protected woodlands are generally seen to be in unfavourable condition (40-60% by nation), although in some instances this is qualified as 'recovering' (Reid et al. 2021).

2.3. Drivers of change, challenges and opportunities in the forest sector and their consequences for forest genetic resources

Drivers for change include environmental, socio-political, and endogenous factors (UK National ecosystems assessment, 2011). A range of future drivers have recently been scoped (Tew et al. 2023). The complex mix of drivers, and a wide variety of views on the nature of future forests, provide a substantial challenge for prioritising and resourcing FGR activities.

Some examples of drivers of change include:

- Climate change (further discussed in section 4.4.)
- Pests and diseases (further discussed in section 4.4) and biosecurity concerns have led to focus on domestic production of planting stock (Reid et al. 2021).

Breeding for disease resistance is of interest (Woodcock et al. 2018) and under active exploration.

- Herbivory pressure, which restricts or prevents natural regeneration, especially of more palatable species, thus restricting dynamic conservation of genetic resources.
- Government support for woodland expansion and for sustainable forest management which has driven changes in the woodland area and is likely to change the character of the resource going forward.
- The ability of wood processors and existing mills to process different species.
- Competition for land and the relative merits of food and timber security.
- Voluntary markets in carbon, payments for ecosystem services, and interest in natural capital
- Increased concern for environmental protection, which has driven an increase in regulation (e.g. use of chemicals, release of organisms into the environment)
- Relaxation of some aspects of new genetic techniques, which may create new opportunities for use and development of FGR. The regulatory position varies across the four nations of the UK.
- The age structure of UK woodlands which reflects large-scale wartime felling in first and second World Wars, and the evolving rate and character of subsequent reforestation and which drives the forecasted production of timber and/or carbon and impacts the habitat qualities of the woodland.
- New uses of domestic wood stocks, greater penetration of wood into domestic markets, and use of woody plants in providing biomass are seen as an opportunity (Defra, 2023a; DESNEZ, 2023).

Chapter 3. State of other wooded lands

3.1. State of other wooded lands

The Food and Agriculture Organisation (FAO) define 'Other Wooded Land' as land with a canopy cover of 5-10% of trees able to reach a height of 5 m in situ; or a canopy cover of more than 10 percent when smaller trees, shrubs and bushes are included (FAO, 2000). This category of land is rare in the UK, with the most recent Forest Resources Assessment (2020) suggesting only 20,000 ha present in the UK (Forest Research, 2020a). Much of this area is wood pasture and parkland, reflecting past management practices blending use of woodland cover and grazing. Many of these are highly valued now for the mosaic habitat and rare microhabitats, notably deadwood, provided for a range of rare invertebrate, lichen and fungi species. For example, a quarter of the registered notable veteran trees (The Ancient Tree Inventory; Nolan et al. 2020)) are found in this form of other woodland (Reid et al. 2021).

The resource may be underestimated due to the variable definitions used by authorities characterising it. One study has suggested there may be ten times the reported area in England alone and further resource characterisation has been recommended (Reid et al. 2021). Agroforestry as a form of other woodland (where it meets the canopy cover definitional thresholds) is underrepresented in UK compared to many other European countries (Reid et al. 2021; den Herder et al. 2019), although all four nations have policy initiatives that aim to increase uptake of agroforestry.

3.2. Trends affecting other wooded lands and their management

Wood pasture is seen as a threatened habitat likely to decline though neglect and development (Natural England, 2020). An Ancient Tree Inventory has been established to enable volunteers to record presence of notable individual trees. Remote-sensing is increasingly being used to monitor the trees outside woodlands and wood pasture resource and how it is changing over time.

3.3. Drivers of change, challenges and opportunities in other wooded lands

The main drivers are thought to be changing land use practices, incentive regimes, and lack of knowledge. Key concerns relate to damage due to grazing animals and to soil compaction, herbicide drift and changing nutrient status of sites. Many wood pasture and parkland environments reflect a form of land use no longer practised or thought economical to modern agriculture; support in conservation grants attempts to incentivise continued care. Without this support, there is a continued risk of long-term decline in this form of woodland with unknown effects upon FGR as the uniqueness of the trees (as opposed to the dependent biodiversity) is largely unknown.

The key challenge is characterising and defining the resource – in terms of its extent, trends in its condition, and whether the trees provide a unique genetic resource.

Other wooded lands could provide an important source of genetic diversity – for example to explore disease resistance. Conversely, rapid development of agroforestry and parkland restoration through importation of semi-mature trees for instant visual effects, could give rise to biosecurity risks.

Chapter 4. State of diversity between trees and other woody plant species

4.1. Tree and woody plant species considered ‘forest genetic resources’

Defining the number of tree and woody plant species considered as FGR is complicated by the fact that the UK has a rich history of introducing non-native species for forestry purposes (Macdonald et al. 1957). Based on the FAO’s definition that FGR are “the heritable materials maintained within and among tree and other woody plant species that are of actual or potential economic, environmental, scientific or societal value”, the authors took a pragmatic decision to constrain the number of species considered to a list of 115 which are considered native to Great Britain, and/or controlled or certified voluntarily under Forest Reproductive Material (FRM) regulations (Forestry Commission, 2019). From this list, 63 are regarded as native to the UK. This does not include subdivision of cryptic taxa such as *Sorbus aria s.l.,* ericaceous shrubs (such as *Calluna, Erica*) and lianas (such as *Lonicera* and *Hedera*) and these have not been considered as FGR despite playing important roles in forest ecosystems.

As outlined in the Appendix, the existence of FGR infrastructure was considered for each of the 115 species by assessing whether there has been molecular or phenotypic characterisation, in situ or ex situ Gene conservation units (GCUs) or collections and registered seed sources or improvement effort. Based on this assessment, the list of species considered ‘FGR’ for reporting to the ‘State of Conservation, Use and Development of Forest Genetic Resources’ consists of 49 native species and 29 non-native species.

Species which have four or more existing, distinct forms of FGR infrastructure are summarised in table 4.1.

Table 4.1. Species with four or more categories of genetic resource infrastructure in the UK. Cells in blue are native species, cells in yellow are non-native species. (described in depth in the Appendix).

Species	Native/Non-native	Molecular studies	Common garden experiments	Gene conservation units	Ex situ (germplasm)	Ex situ (living)	Seed stands	Seed orchards	Breeding programme	Sum
Fraxinus excelsior	Native	1	1	1	1	1	1	1	1	8
Pinus sylvestris	Native	1	1	1	1	1	1	1	1	8
Betula pendula	Native	1	1	1	1	1	1	1	1	8
Quercus robur	Native	1	1	1	1	1	1	0	1	7
Prunus avium	Native	1	1	0	1	1	0	1	1	6
Quercus petraea	Native	1	1	1	0	1	1	0	1	6
Sorbus aucuparia	Native	1	1	1	1	0	1	0	0	5
Fagus sylvatica	Native	1	1	0	1	0	1	0	0	4
Betula pubescens	Native	1	1	0	1	0	1	0	0	4
Crataegus monogyna	Native	1	1	0	1	0	1	0	0	4
Alnus glutinosa	Native	1	1	0	1	0	1	0	0	4
Populus tremula	Native	1	1	0	1	1	0	0	0	4
Picea sitchensis	Non-native	1	1	NA	NA	1	1	1	1	6
Larix kaempferi	Non-native	0	1	NA	NA	1	1	1	1	5
Larix decidua	Non-native	0	1	NA	NA	1	1	1	1	5
Pinus nigra	Non-native	0	1	NA	NA	1	1	1	1	5
Pseudotsuga menziesii	Non-native	0	1	NA	NA	1	1	1	1	5
Acer pseudoplatanus	Non-native	0	1	NA	NA	1	1	1	1	5
Pinus contorta	Non-native	0	1	NA	NA	1	1	1	1	5

Castanea sativa	Non-native	1	1	NA	NA	1	1	0	1	5
Thuja plicata	Non-native	0	1	NA	NA	1	1	1	0	4
Larix x eurolepis	Non-native	0	1	NA	NA	1	1	0	1	4

4.2. Threatened species

Three species regarded as FGR have an International Union for Conservation of Nature (IUCN) status of ‘vulnerable’ or ‘endangered’, all of which are *Salix* spp. These, along with several others, appear on national and subnational biodiversity lists as priority species (Table 4.2.). *Sorbus aria* has been treated sensu lato (in the broadest sense) for the purposes of reporting on FGR but it is worth noting that the British Isles (Great Britain and Ireland) have many endemic *Sorbus* apomicts (Rich et al. 2010).

Table 4.2. Protected UK FGR species in the United Kingdom. *National and subnational designations are based on the following lists: a) England (Biodiversity Lists - England, England NERC S.41, 2006; A Vascular Plant for England, 2014), b) Scotland (Scottish Biodiversity List, 2020), c) Wales (Biodiversity Lists - Wales, Wales NERC S.42, 2006) d) Northern Ireland (Northern Ireland Priority Species List, 2010); e) GB (The Vascular Plant Red Data List for Great Britain, 2005), f) UK (UK list of Priority Habitats and Species, 2007).

Species with protected/priority status	IUCN	National/subnational designation*
Juniperus communis	Least concern	England, Scotland, Wales, Northern Ireland
Populus nigra	Least concern	Scotland
Salix lanata	Vulnerable	Scotland, GB, UK
Salix lapponum	Vulnerable	England, Scotland, GB, UK
Salix myrsinites	Endangered	Scotland, GB, UK
Frangula alnus	Least concern	Northern Ireland

Betula nana	Least concern	England
Salix repens	Least concern	England

4.3. Trends in the number of species

As a relatively species-poor island country on the margin of a continent with recent glacial history, the number of species available for forestry in the UK is largely driven by introduction of non-native species. There are currently high levels of interest in identifying alternative species for use in UK forestry, driven by environmental change and the dominance of a small number of species used in commercial forestry. Many species are under evaluation at plot-stage or in comparative species trials in a programme of research to diversify forests (Willoughby et al. 2007; Mason et al. 2018; Reynolds et al. 2020).

4.4. Drivers of change, threats and opportunities affecting forest genetic resources

Climate change and pests and diseases are both perceived as major threats to the future of UK forests (Sturrock et al. 2011; Tew et al. 2023).

The changing climate is a challenge for forest planning and management in the UK because the projected increases in temperature, changes in the seasonality of rainfall, and an increased frequency of extreme events add complexity to species selection, provenance selection, and silvicultural practice. Uncertainties accompany the magnitude and speed of these predicted changes, but climate projections indicate that winters will be increasingly milder and wetter and summers will become hotter and drier in an unpredictable and non-linear way. There will also be colder spells as the climate gradually warms. More frequent and severe weather events, such as intense periods of drought, flooding events, wildfires and catastrophic windstorms will also occur and are already being experienced. These extreme events are more likely to have a significant impact on FGR than the more gradual warming of the climate.

The future climate may also lead to an increase in the incidence and distribution of pests and diseases, which already cause serious damage in UK woodlands (Table 4.4). For example, pest and disease modelling under future climatic conditions shows changes in the spread and population dynamics of bark beetles, such as *Ips typographus*, and *Phytopthora* species over coming decades.

Furthermore, changes in temperature and rainfall fluctuations may lead to pest and disease range shifts, facilitating the spread of new pests and diseases to the UK. For example, the pine processionary moth, a priority quarantine pest for the UK, has been increasing its geographic range and gradually moving north in France (Boer and Harvey, 2020). Increased globalisation of travel and trade also contribute to a marked increase in the arrival of exotic pests and diseases some of which have already had a devastating effect on some of the tree species in the UK.

Pest and disease threats to UK trees are listed and assessed in the UK Plant Health Risk Register to help determine the level to which changes could affect the likelihood of entry, establishment and impact in the UK and what mitigations could be put in place to reduce these changing risks.

These abiotic and biotic threats have resulted in an increased focus on building resilient treescapes. This ambition has been reflected in government priorities across the UK as laid out in the 2023 Environmental Improvement Plan (Defra, 2023b), the third National Adaptation Programme (Defra, 2023c), the 2018 Tree Health Resilience Strategy for England (Defra, 2018), 2018 Woodlands for Wales (Welsh government, 2018), and Scotland’s Forestry Strategy 2019-2029 (Scottish Government, 2019). This objective to increase the environmental resilience of our forests is also reflected in the UKFS which is the standard for sustainable forestry practice in all four countries.

There is an increasing awareness of the vulnerability of single species stands and forests to both the impacts of climate change and the rising incidence of damaging pests and pathogens. The risks of growing conifer plantations under monocultural clear-fell systems have been highlighted and landscapes composed of more age and species diversity are being encouraged instead. For this reason, the fifth edition of the UKFS has reduced the maximum allowable planting of single species from 75% to 65% of the total area of a woodland. The potential of alternative exotic species to broaden the range of species grown in the UK is being examined and high yielding species mixtures are also being explored. There is an awareness that the susceptibility of these alternative species to pests and diseases has to be elucidated before deployment in commercial forestry in the UK (Ennos et al., 2019) as is consideration of their potential to become invasive.

Table 4.4. Selected pest and disease threats to UK trees

Pest and disease binomial name	Pest and disease common name	Tree species	Current status in UK	Year of first appearance in UK
Hymenoscyphus fraxineus	Ash dieback	*Fraxinus excelsior*	Present, widespread in the UK.	First identified in the UK in 2004.
Agrilus planipennis	Emerald Ash Borer	*Fraxinus excelsior*	Not present in the UK. GB and Northern Ireland quarantine pest.	
A complex disease caused by a combination of factors	Acute oak decline	*Quercus* spp.	Present, Southern England and Wales.	Observed in UK over the last 20 years.
Thaumetopoea processionea	Oak processionary moth	*Quercus* spp.	Present, Greater London and surrounding counties in the South East of England. GB quarantine pest. Northern Ireland is a Protected Zone.	First identified in the UK in 2006.

Pest and disease binomial name	Pest and disease common name	Tree species	Current status in UK	Year of first appearance in UK
Cryphonectria parasitica	Sweet Chestnut Blight	*Castanea* spp.	Present, low numbers of symptomatic trees in England. GB quarantine pest. Northern Ireland is a protected zone.	First identified in the UK in 2016.
Dryocosmus kuriphilus	Oriental Chestnut Gall Wasp	*Castanea* spp.	Present. Northern Ireland is a protected zone.	First identified in the UK in 2015.
Phytophthora ramorum		*Larix* spp.	Present, widespread in the UK. GB quarantine pest. Non-EU isolates are quarantine pest in Northern Ireland, EU isolates are a regulated non-quarantine pest (RNQP).	First identified in the UK in 2009.
Xylella fastidiosa		*Platanus occidentalis*, *Quercus* spp. and many other hosts	Not present in the UK. GB and Northern Ireland quarantine pest.	
Phytophthora pluvialis		*Tsuga heterophylla* and *Pseudotsuga menziesii*	Present, primarily in the west of GB. GB quarantine pest. Not present in Northern Ireland and not listed under EU regulation.	First identified in the UK in 2021.
Ophiostoma novo-ulmi	Dutch Elm Disease	*Ulmus* spp.	Present, widespread in the UK.	First identified in the UK in the 1920s
Dothistroma septosporum	Dothistroma needle blight	*Pinus* spp.	Present, widespread in the UK. GB and Northern Ireland regulated non-quarantine pest (RNQP).	First identified in the UK in the 1990s.
Ips typographus	Eight toothed spruce bark beetle	*Picea* spp.	Present, South-East England. GB quarantine pest. Northern Ireland is a protected zone.	First identified in the UK in 2018.
Phytophthora austrocedri		*Juniperus* spp.	Present, mostly confined to Northern England and Scotland. GB regulated non-quarantine pest. Not regulated in Northern Ireland.	First identified in the UK in the early 2000's.

Chapter 5. State of diversity within trees and other woody plants species

5.1. Non-molecular characterisation of genetic diversity

5.1.1. Provenance testing (1926-1985)

The Forestry Commission (as state forestry organisation) began exploring variation among seed origins of trees in the 1920s, focussing on evaluating the best geographical regions from which to source seed of conifers with potential for commercial forestry in Great Britain. As Scots Pine is the only native conifer suitable for producing construction timber, all other conifers under evaluation were non-native, a significant portion of which were from the Pacific Northwest of North America. Early experiments tended to be established pragmatically, based on exchange of commercial seed lots on the open market, and at times suffered from weak statistical designs (Samuel, 2007). From the late 1960s, the International Union of Forest Research Organisations (IUFRO) began to sponsor campaigns to comprehensively sample populations from native ranges for multinational provenance trials using robust statistical methods (Samuel, 2007). Great Britain benefitted greatly from involvement in IUFRO programmes and British scientists played a leading role in establishing collections of several species. Over four hundred provenance trials were established between 1926 and 1986, during which time provenance was considered a silvicultural, rather than a genetic concern. The results of these trials have been summarised with recommendations made by Lines (1987).

A summary of the most commercially-important species is provided in table 5.1.1, although trials were set up for many other species of lower commercial importance to the UK, including *Abies alba, Abies amabilis*, *Abies concolor*, *Alnus rubra*, *Cryptomeria japonica*, *Eucalyptus* spp., *Metasequoia glyptostroboides*, *Nothofagus obliqua*, *Nothofagus procera*, *Picea engelmannii, Pinus muricata, Pinus pinaster, Pinus ponderosa, Pinus peuce, Pinus jeffreyi, Quercus rubra* and *Sequoia sempervirens*. Some of these older trials are the subject of current attention by Forest Research under an initiative to re-evaluate alternative species for future forestry, the results of which are being summarised on a rolling basis (Jinks and Kerr, 2016a; 2016b Kerr et al. 2015; 2016a; 2016b; 2018; Kerr and McMinn, 2018; Kerr, 2019; Kerr and Trimble, 2020).

Table 5.1.1. Summary of provenance testing of twelve commercially-important non-native conifers in Great Britain (Samuel, 2007). Series denotes the number of years in which experiments were set up (typically identical replicates on multiple sites), sites is the total number of experiments established, IUFRO indicates those established with support and standards set by IUFRO.

Species	Series	Sites	IUFRO
Abies grandis	3	16	11
Abies procera	2	11	10
Larix decidua	14	35	-
Larix kaempferi	7	14	-
Larix x eurolepis	6	7	-
Picea abies	10	18	3
Picea sitchensis	13	53	20
Pinus contorta	23	79	5
Pinus nigra	6	14	-
Pseudotsuga menziesii	8	21	5
Thuja plicata	1	4	-
Tsuga heterophylla	4	17	-

5.1.2. Provenance testing (1985-present)

Research seeking to evaluate variation among UK populations of native species did not begin until the 1990s, when native woodland creation and interest in artificial regeneration with hardwoods became more common. Trials of native and naturalised species have been established, sometimes as part of larger international collaborations for the purposes of comparing seed sources and to characterise natural patterns of variation. More recent trial evaluations are incorporating assessment of a greater diversity of traits, alongside traditional performance measures (Table 5.1.2). Examples include timber properties, disease responses, phenology, and measures to understand water use efficiency. Evaluation of trials by terrestrial and aerial LIDAR scanning is developing.

Table 5.1.2. Examples of provenance trials established to evaluate traits other than survival and growth.

Species	Native/Non-native	Series	Years established	Sites	Traits evaluated	References
Betula pendula	Native	2	1998; 2003	9	Phenology, Form, Leaf Morphology, Disease Response	Worrell (1992); Worrell et al. (2000); De Silva (2007); Lee et al. (2015); Rosique-Esplugas (2018)
Crataegus monogyna	Native	1	1995	2	Disease resistance, Branching, Thorns	Jones et al. (2001)
Fagus sylvatica	Native	2	1996; 1999	2	Form, Carbon isotope ratio, Dendrochronology	Robson et al. (2018)
Fraxinus excelsior	Native	4	1992; 2007; 2009;2013	34	Form, Phenology, Disease resistance	Cundall et al. (2003); Clark (2013); Stocks et al. (2017); Rosique-Esplugas et al. (2022)
Juniperus communis	Native	1	2016	1	Form	
Populus tremula (clonal trial)	Native	1	1995	1	Form	
Prunus avium	Native	1	2011	1	Budburst, Form	
Quercus petraea; Q. robur	Native	4	1990; 1992; 1993; 2006	17	Budburst, Form, Squirrel damage, Carbon isotope ratio, Dendrochronology	Deans and Harvey (1995; 1996); Hubert (2005); Saenz-Romero et al. (2017); Wilkinson et al. (2017)
*Pinus sylvestris** (mostly glasshouse trials)	Native	Many	1995, 2007	Many	Stem form, Seeding morphology, Root condition, Root frost hardiness, Bud dry matter, Bud burst, Susceptibility to Dothistroma inoculation, Chlorophyll fluorescence, Needle anatomy traits	Perks and McKay (1997); Perks and Ennos (1999); Salmela et al. (2011; 2013); Donnelly et al. (2016; 2018); Perry et al. (2016a:2016b)
Sorbus aucuparia	Native	1	2006	4	Bud break, Leaf senescence, Stomatal size, Stomatal density, Leaf morphology, Fruiting	Rosique-Esplugas (2018)
Acer platanoides	Non-native	1	1989	2	Branching	Kerr and Niles (1998)
Acer pseudoplatanus	Non-native	1	1992	5	Form, Budburst	Cundall et al. (1998); Whittet et al. (2021)
Juglans nigra	Non-native	1	2003	2	Form	Clark et al. (2005); Clark and Hemery (2009); Clark and Brocklehurst (2011)

Species	Native/Non-native	Series	Years established	Sites	Traits evaluated	References
Quercus rubra	Non-native	1	1992	5	Form, Squirrel damage	Hubert and Cundall (2006); Kerr et al. (2022)

5.2. Biochemical and molecular characterisation of genetic diversity

Biochemical methods were first used in UK forestry research in the 1970s with early efforts to study variation among native Scots pine populations (e.g. Forrest, 1980). Molecular DNA-based approaches started being used in the mid-1990s, particularly within European research programmes studying postglacial migration routes of oak and other species (e.g. Cottrell et al. 2002; Kremer et al. 2002; Petit et al. 2002a; 2002b). Genomic resources are now commonplace in UK forest science following the rapid development of techniques in DNA sequencing and bioinformatics.

An overview of molecular characterisation of UK FGR is presented in Table 5.2. This is largely based on existing summaries such as that of Cavers and Cottrell (2015) and searches of resources such as Kew's genetic risk assessments (Gargiulo., 2019) and the genetic flora of the British Isles (Ruhsam et al. 2021). It includes UK studies and certain range-wide studies containing multiple UK populations. Approaches to characterisation have included; population genetics, phylogeography, species limits (hybridisation, introgression and systematics), Genotype-environment association (GEA) and Genotype-phenotype association (GPA) (genomics studies where associations are made between genetic variation and environment and/or phenotype, the latter of which commonly involves genome wide association studies), local processes (fine scale genetic structure, local gene flow) and utilities (demonstration of genomic tools, fingerprinting). Many studies, such as molecular taxonomic treatment of cryptic taxa such as *Sorbus aria s.l.* and *Ulmus* have not been included and require a separate treatment. True molecular characterisation, where a comprehensive sample of populations across their UK range have been analysed (e.g. Sutherland et al. 2010), are relatively rare. However, a substantial effort to assess genetic diversity in the woody flora of Northern Ireland has resulted in assessments of eight species (Beatty et al. 2015a; 2015b; 2016; Brown et al. 2016a; 2016b; 2022; Provan et al. 2008).

Table 5.2. Summary of molecular studies in UK FGR grouped by interpreted research purpose (as of March 2022).

Taxon	Population genetics	Phylo-geography	Species limits	Genotype-environment association (GEA)/Genotype-phenotype association (GPA)	Local processes	Utilities	Total
Alnus glutinosa	1	1					2
Betula nana	1			1			2

Taxon	Population genetics	Phylo-geography	Species limits	Genotype-environment association (GEA)/Genotype-phenotype association (GPA)	Local processes	Utilities	Total
Betula pendula		1					1
Betula spp.			3	1			4
Castanea sativa		1					1
Corylus avellana	1	1					2
Crataegus monogyna	1						1
Fagus sylvatica		1					1
Fraxinus excelsior	2	5		1	1		10
Ilex aquifolium		1					1
Juniperus communis	1	1					2
Malus sylvestris			1				1
Picea sitchensis				2		1	3
Pinus spp	1					1	2
Pinus sylvestris	2	2				2	6
Populus nigra	1	1					2
Populus tremula	1		1				2
Prunus avium					2		2
Prunus spinosa	1						1
Quercus robur; Quercus petraea	3	2	1		2	1	9
Sorbus aucuparia					1		1
Taxus baccata				1		1	2
Tilia spp.	1		1				2
Ulmus minor	1						1

Taxon	Population genetics	Phylo-geography	Species limits	Genotype-environment association (GEA)/Genotype-phenotype association (GPA)	Local processes	Utilities	Total
Total	**19**	**17**	**7**	**6**	**6**	**6**	**61**

Microsatellite or simple sequence repeats (SSR) markers are still the staple method for population genetics of both wild and improved populations. Since 2002, SSR markers have been developed and used for studying 22 species or species complexes, resulting in 32 published research papers (Whittet pers comms). Due to their high mutation rates, they are mostly used in studying gene flow, parentage analysis and processes associated with random genetic drift. Therefore, published articles cover research topics such as measuring the impact of population fragmentation, forest management, recolonisation after disturbance, clonal structure, hybridisation processes, species reproductive biology, and more general population genetic questions.

With the advent of genomic methods, SSR markers are being replaced by use of single nucleotide polymorphisms (SNP), providing more robust estimates of demographic statistics. Identification and assessment of SNP markers for researching UK FGR has used a variety of sequencing platforms and approaches, including genotyping by sequencing, exome capture, and genotyping arrays. There are now readily available SNP chips for *Picea sitchensis* (Sitka spruce) and *Pinus sylvestris* (Scots pine). These resources can be used in genomic breeding, adaptive response, association genetics and more general population genetics use.

5.3. Patterns and trends in the geographical distribution of genetic diversity

Most UK tree populations recolonised from glacial refugia located in southern Europe, for example Iberian refugia for selected *Quercus spp.* and *Fraxinus excelsior* (ash) (Petit et al. 2002; Heuertz et al. 2004) or southeast Europe for *Fagus sylvatica* (beech) and *Populus nigra* (black poplar) (Magri et al. 2006; Cottrell et al. 2005). Although many tree species are at, or close to, their western range margins in the UK, studies of selectively neutral genetic variation have tended to show relatively little differentiation between marginal and core (continental) populations and no loss of genetic diversity at the edge of the species distribution range (e.g. Wachowiak et al. 2011; 2013). Anthropogenic translocation of genetic material has also influenced genetic structure (e.g. Palmé and Vendramin, 2002; Sjölund et al., 2017).

Whittet et al. (2019) reviewed studies of provenance variation in native tree species to assess the benefits and risks of adopting predictive approaches to provenance choice in England. Most studies reviewed found most phenotypic trait variation occurs within populations so that differentiation among populations is low but is nevertheless significant in some cases (although the use of SNPs might clarify such patterns in future). Most of the trait variation in multi-site provenance trials is explained by differences among sites (which is partly a sampling effect) and genotype x environment interactions are common but not ubiquitous, usually of very small effect. The review concluded that a sufficient working knowledge base had been established for *Fraxinus excelsior* (ash), *Pinus sylvestris* (Scots pine), *Betula pendula* (Silver birch), *Sorbus aucuparia* (rowan), and to a lesser extent *Quercus petraea* (Sessile oak) to understand overall patterns of adaptive variation but for other species, insufficient data were available.

Clinal latitudinal variation in traits associated with annual growth (e.g. phenology and height) are common (Deans and Harvey, 1995; Worrell et al. 2000; Lee et al. 2015; Wilkinson et al. 2017; Rosique Esplugas et al. 2022). For traits associated with water use efficiency and humidity (e.g. leaf morphology, disease tolerance), longitudinal clines are more common given the major differences in precipitation regimes between the west and east of the country (Donnelly et al. 2016; Perry et al. 2016a; 2016b; Rosique Esplugas, 2018).

The ability to detect the scale and pattern of adaptive variation depends heavily on geographic sampling and population history of provenances, location and nature of trial sites, sample size and experiment design. Most experiments have weaknesses in one or more of these aspects although newer designs which are based on random sampling of a similar number of parents within a comprehensive sample of autochthonous populations (e.g. in *Fraxinus excelsior* (ash), *Pinus sylvestris* (Scots pine) and *Sorbus aucuparia* (rowan)) are suitable for adaptive characterisation.

Little work has yet been conducted which explicitly aims to characterise temporal trends in genetic diversity, although land race formation has been inferred in some conifers (e.g. *Abies grandis* (Grand fir), (Bennuah, 1992)) and monitoring of genetic diversity of highly improved *Picea sitchensis* (Sitka spruce) is currently under investigation at Edinburgh University and Forest Research. The current newLEAF project, is attempting to evaluate the rate of adaptive change that has occurred over generations following translocation of several exotic conifer species to UK.

5.4. Sources of information on genetic diversity

The UK FGR website provides a map-based metadata platform for UK FGR which operates from a web browser. Two map browsers are currently available on the website - one entitled ‘Research trials’ and the one entitled ‘Conservation units’. ‘Research trials’ contains summary details of provenance trials, progeny trials, clonal seed orchards, clone banks and the geographic location of plus trees from broadleaved tree improvement programmes organised by the Future Trees Trust (FTT), and a selection of resources from other organisations. ‘Conservation units’ includes the location and summary details of seed collections made for native trees by the UK National Tree Seed Project (UKNTSP) organised by Royal Botanic Gardens, Kew and the location of dynamic in situ GCUs displayed in the European Information System on Forest Genetic Resources (EUFGIS). All locations are currently presented using “fuzzy” mapping in accordance with General Data

Protection Regulations (GDPR). The website offers the facility to contact a named researcher or the system administrator for further details of each resource.

Reviews of provenance experiments have been prepared for native species by Worrell (1992) and Whittet et al. (2019), for the main commercial species by Lines (1987) and for broadleaves by Hubert and Cundall (2006). Forest Research hold a Silviculture Experiment Database (including genetics) and a Tree Improvement Branch Database which host data relating to experiments and improvement programmes and open Forest Research experiment sites are mapped on a GIS platform ForesterWeb. The Silviculture Experiment Database contains records of over 10,000 open and closed experiments and sample plots covering all aspects of applied forest research, each of which is backed up by physical experiment files which contain experiment plans and layouts. Both databases were set up for internal use and contain high levels of technical information and terminology is only meaningful to Forest Research employees. Metadata have historically been contributed to multinational efforts to compile data on FGR. For example, the NOLTFOX database (Northern European Database of Long-term Forest Experiments) contains metadata pertaining to 237 UK trials under the category of 'genetic diversity and tree breeding', and details of 720 trials in eight species were contributed to the 'TreeBreedEx' project (Pâques, 2013). Data from Forest Research trials are regularly requested from researchers and practitioners and are shared under memoranda of understanding pertaining to fair use and acknowledgement. However, there is no current facility for open sharing of data. Opening up these databases, even at the level of metadata, for wider use would be a significant undertaking requiring major investment in digital infrastructure and personnel.

The Royal Botanic Gardens, Kew have prepared 'genetic risk assessments' for many tree species which bring together information on distribution, taxonomy, life history, demography and genetic diversity to make recommendations and identify knowledge gaps in genetic conservation (Gargiulo, 2019). The Royal Botanic Garden Edinburgh have assembled a database of abstracts and metadata from genetics studies in the British flora which includes native trees and shrubs, known as the Genetic Flora of the British Isles (Ruhsam et al. 2021). Digital sequence information is stored in standard repositories such as GenBank and EMBL (European Molecular Biology Laboratory).

5.5. Needs, challenges and opportunities

- Most native tree species are poorly characterised genetically, which hampers our ability to set genetic conservation targets, develop seed production strategies and devise evidence-based systems or advice for seed sourcing.

- There is growing interest in planting additional non-native species – that previously have not been widely used in UK forestry. However, gaps in knowledge about appropriate provenance choice for many of these species require attention as part of any domestication process. Similarly, the genetic background and diversity of introduced populations requires resolution as part of any efforts to enhance the UK resource.

- A strategic approach to characterisation of all species is needed to help set priorities, and coordinate research and development of supporting infrastructure. Such studies could provide better understanding of how genetic diversity is distributed and how natural selection is acting on this. This should involve non-molecular and molecular approaches to ultimately allow prediction of adaptive responses of trees across the UK. Protocols for sampling, and data ownership, use and sharing would support this work.

- Data and results from early (1920s-1950s) provenance experiments are difficult to access. A review could assess the feasibility and value of making such data available but should bear in mind the statistical weaknesses of early experiments.

- Research is needed to better understand whether and how species can adapt to climate change, particularly, extreme events. This requires development of methods and infrastructure for ‘fast-phenotyping’ stress responses in trees to assist our understanding of how populations differ.

- Trials are needed to explore the impacts of assisted migration. These could include testing the opportunities and risks of moving genetic material from further south in the UK and also include testing movement of UK native species from populations further south in the Atlantic region of Europe (i.e. in France, NW Spain and Portugal).

- An interactive genetic atlas of the UK’s woody flora, based on existing resources (e.g. Gargiulo., 2019; Ruhsam et al. 2021) with links to digital sequence information could be generated to visually demonstrate data availability, patterns of variation and knowledge gaps. Such an approach could include genetic monographs of woody species, based on similar resources.

Chapter 6. In situ conservation of forest genetic resources

6.1. The state of in situ conservation of forest genetic resources

The UK played a leading role in the early development of the concept of in situ conservation of FGR (Hubert and Cottrell, 2014; Lefèvre et al. 2013), and has embedded into practice general principles for genetic conservation. These include encouragement of generational turnover, development of a diverse age structure, maintenance of large population sizes and connectivity as priorities in management of native woodlands via the UKFS (Forestry Commission, 2023a).

An estimated 290,000 hectares (~9%) of woodlands in the UK are in statutorily designated areas under varying level of protection. This includes Sites of Special Scientific Interest (SSSI), National Nature Reserves (NNRs), Local Nature Reserves (LNRs), Special Protected Areas (SPAs) and Special Areas of Conservation (SAC) (Fouracre and Ward, 2020).

The statutory nature conservation bodies in England, Scotland and Wales (Natural England, NatureScot and Natural Resources Wales) hold ‘Ancient Woodland Inventories’ which assign an antiquity status to woodlands, or plantations on ancient woodland sites, based firstly on their representation on historical maps. In England and Wales, these are sites for which evidence of ecological continuity based on the earliest maps is available from 1600 AD and for Scotland, 1750 AD. Since broad-scale planting was uncommon before these dates, tree populations on these sites are considered to have self-sown and are described as forming “ancient semi-natural woodland” and so these sites are considered to represent the national autochthonous forest genetic resource. Ancient semi-natural woodlands form approximately 2.5% of the land area of Great Britain (Reid et al. 2021).

The National Forest Inventory report on woodland ecological condition assigned favourability scores to British woodlands against 15 indicators (Ditchburn et al. 2020). An aggregated score calculated from these indices and assessed against benchmark ancient semi-natural woodlands in good condition found that 7% of native woodland in Great Britain was in favourable condition. Indicators of most relevance to genetic conservation relate to natural regeneration, grazing intensity, and age structure (Ditchburn et al. 2020).

The UK declared its first GCU in 2019, for *Pinus sylvestris* (Scots pine) at Beinn Eighe National Nature Reserve, on the site of one of Scotland’s largest remnants of the ‘Caledonian’ pinewoods. A further fifteen GCUs for six species on eleven sites have since followed on land owned by the Woodland Trust, an environmental NGO. Additionally, one GCU for *Malus sylvestris* (Wild apple) was registered on private land in 2023 (Table 6.1;

Figure 6.1). Research commissioned by Nature Scot and delivered by UK Centre for Ecology and Hydrology has identified further potential sites for new GCUs moving forward (Cavers et al. 2022).

Table 6.1. Number and total area of designated Gene Conservation Units (GCUs) in the United Kingdom registered in EUFGIS in 2024. *Total designated area is the summed area of GCUs where species is listed as a target species. It does not represent the area occupied by a given species within GCUs. Some GCUs have multiple target species.

Species	Number of GCUs	Total designated area (ha)*	GCU identities
Pinus sylvestris	2	269	1,2
Quercus petraea	5	133	3, 4, 5, 8, 10
Betula pendula	4	125	3, 7, 8, 10
Sorbus aucuparia	2	28	3, 11
Fraxinus excelsior	3	28	6, 9, 12
Quercus robur	1	13	5
Malus sylvestris	1	87	13

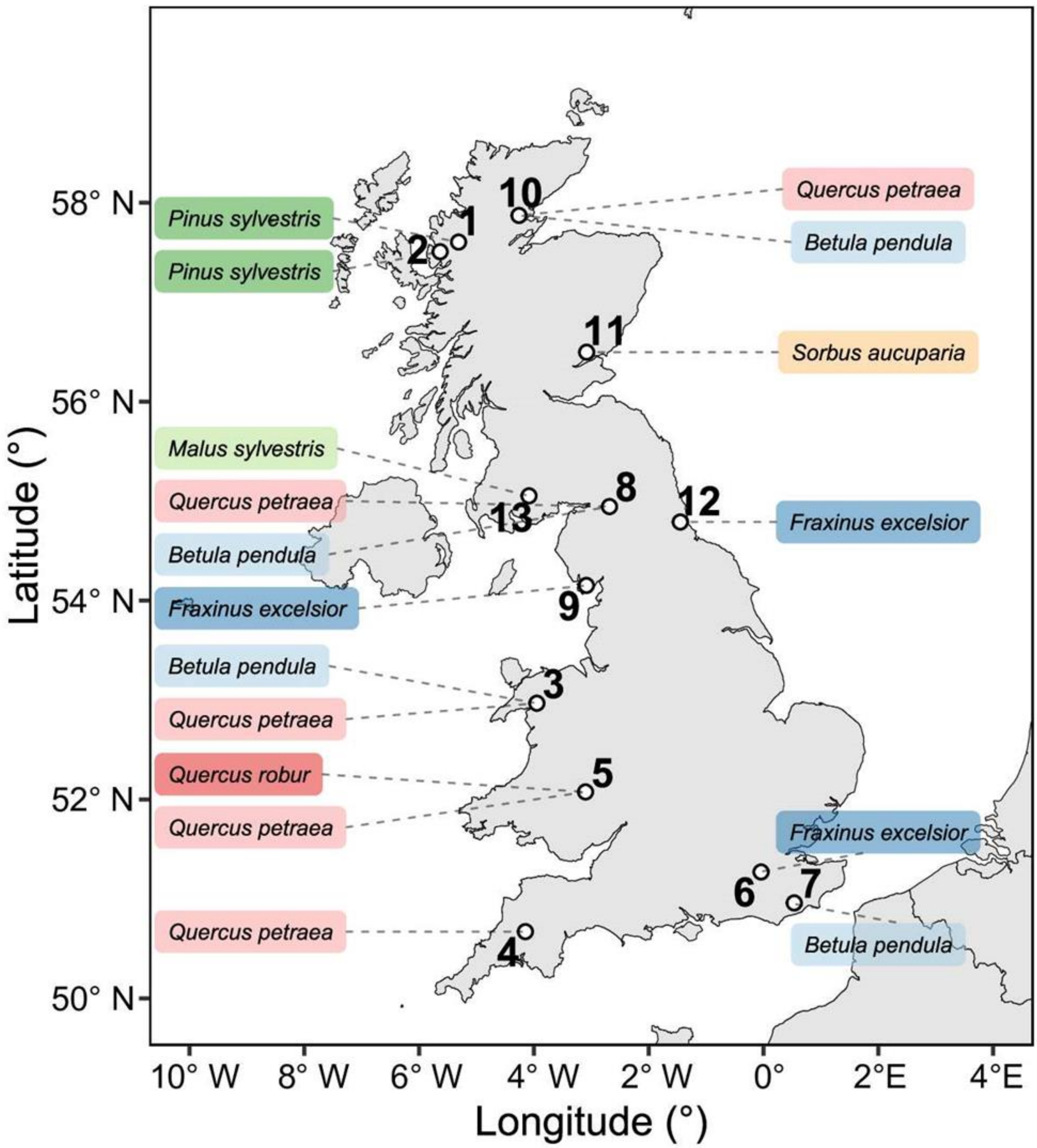


Figure 6.1. Locations of UK Gene Conservation Unit sites, some of which contain populations of multiple target species (as of March 2024).

6.2. Approaches to, and organisation of, in situ conservation of forest genetic resources

In situ conservation of FGR is supported and encouraged through the UKFS which provides guidance on general principles for genetic conservation in management of woodlands.

In addition, landowners may designate sites as dynamic GCUs and register these via the EUFGIS. Forest Research provides the UK national focal point to EUFGIS and has the role of managing and entering data pertaining to GCUs into the EUFGIS database.

The UK follows pan-European minimum requirements for dynamic GCUs (Koskela et al. 2013; Lefèvre et al. 2013; Hubert and Cottrell, 2014). To be included into the EUFGIS information system, a GCU must meet one of the following minimum requirements in terms of population size:

1. If the purpose of the unit is to maintain genetic diversity of widely occurring and stand-forming conifers or broadleaf species, the unit must consist of 500 or more reproducing trees.

2. If the unit was established to conserve adaptive or other traits in marginal or scattered tree populations (both scattered conifers and broadleaf species), the unit must harbour a minimum of 50 reproducing trees or, in the case of dioecious tree species with sexual dimorphism, 50 seed bearing trees.

3. If the unit is aiming to conserve remaining populations of rare or endangered tree species, it must harbour a minimum of 15 unrelated reproducing trees.

Silvicultural interventions are allowable in a GCU to ensure the continued existence of the target tree populations and create favourable conditions for growth and natural regeneration of the target species.

To date, identification of appropriate sites for GCUs has been led by the UK Centre for Ecology & Hydrology. Initial steps in identifying these sites were made by examining records of sites under existing protection from statutory designation and consultation with and later ground-truthing by landholders/managers to verify that populations met the European forest genetic resources programme (EUFORGEN) standards for registration as GCUs.

As all GCUs are relatively new, a formal and centralised effort to monitor them has not yet been developed and there are no dedicated personnel to undertake this role. In addition, the vast majority have been identified on the basis of proxy variables (predominantly climatic, following EUFORGEN guidance) and have not been explicitly characterised for genetic variation.

6.5. Needs, challenges and opportunities

- Herbivore grazing pressure provides a challenge to natural regeneration in many UK woodlands (Forest Research, 2020b). However, approaches such as disturbance-based management', 'close-to-nature' silviculture (Brang et al. 2014) and 'evolution-oriented management' (Lefevre et al. 2014) are becoming more prominent and provide opportunities to boost adaptive capacity. Practitioner awareness could be further raised by naming genetic conservation as an objective within adaptive management in national guidance and standards such as the UKFS and UK Woodland Assurance Standard (UKWAS).

- Awareness and recognition of in situ genetic conservation of biodiversity is low, although the concept is gaining traction as an effective and useful tool in reporting to global assessments such as the Aichi targets (Hollingsworth et al. 2020; Minter et al. 2021; O'Brien et al. 2022).

- Better understanding of the scale and pattern of genetic diversity among tree populations is needed to assist in our understanding of gaps and targets for genetic conservation. GCUs that are characterised in situ are ideal candidates for characterising in common-garden experiments to understand genetic diversity due to their qualifying criteria.

- Rapid progress could be made to increase the number of species that have designated GCUs, and the number of sites per species represented, using the EUFORGEN protocols. This would require access to reliable inventory data, which could potentially be provided by the National Forest Inventory team at Forest Research.

- National standards for monitoring GCUs and reporting back to the EUFGIS national focal point need to be established. The Forest Genetic Monitoring manual produced under the LIFEGENMON project (Bajc et al. 2020) provides a possible template for monitoring, although basic non-molecular monitoring is likely to be sufficient for most purposes. The Horizon 2020 project "FORGENIUS" supported trawls of satellite imagery of GCUs. This approach could assist in future monitoring of GCUs.

- Tree populations in GCUs which meet Case 1 for effective population size (large) could be considered for registration on the National FRM Register of Basic Material. Management- which could provide an incentive to landowners to designate sites as GCUs.

- Public awareness could be raised by designing and placing branded interpretation panels at GCU sites.

Chapter 7. Ex situ conservation of forest genetic resources

7.1. Approaches to ex situ conservation of forest genetic resources

Ex situ conservation of FGR falls under two main categories:

1. Ex situ conservation of germplasm (seed banking).
2. Living collections of known genotypes (clone banking/clonal archiving), the majority of which are selections made in breeding programmes.

These activities are conducted separately and are not coordinated centrally and there is no accepted definition of an ex-situ conservation unit applied nationally.

Other resources, such as research arboreta (e.g. Mason et al. 2018), provenance trials (chapter 5) and seed orchards (chapter 8) can serve as ex situ conservation units as a secondary objective but are not treated as such in this national report.

7.2. Seed banks

Between 2013 and 2020, the Royal Botanic Gardens, Kew coordinated the UK National Tree Seed Project (UKNTSP), in order to "establish an ex situ gene conservation program for the United Kingdom forest genetic resource" (Trivedi and Kallow, 2017). The aim of UKNTSP was to "establish multi-provenance seed collections representing the majority of adaptive genetic diversity present in the UK." A list of 70 woody taxa were considered for the UKNTSP. Sampling followed the seed zones established for native trees and shrubs set by Herbert et al. (1999) and the project aimed to make at least one low-altitude (<300 m) and one high-altitude (>300 m) collection for each of the 24 seed zones in which a taxon was present. Where possible, 30 georeferenced and permanently tagged mothers were sampled per population with a target minimum of 15 maternal trees per population and seedlots were collected, processed and stored as half-sibling maternal families. Several thousand seed were targeted for each collection and seed were collected from all parts of tree crowns in order to capture variation in paternal contribution. Seed were collected by more than 30 agencies (Trivedi and Kallow, 2017). All seed are stored in the Millenium Seed Bank, with duplicates at the Scottish Agricultural Science Agency.

Of the 971 collecting targets identified by the UKNTSP, 702 had been fully met by 2020, comprising 76 species of which 50 were 'fully sampled' from every seed zone in which they occur. Royal Botanic Gardens, Kew continues to maintain an active tree seed collecting programme, prioritising outstanding UKNTSP targets, disease-tolerant *Fraxinus excelsior* (ash) and populations or species in high demand for research or conservation use.

Many of the locations from which seed were collected, and metadata associated with the collections are displayed on a map browser of the UK FGR website (Chapter 5). An initiative is currently underway to create a publicly accessible database detailing the individual collections to maternal tree level.

The UKNTSP also engaged in research to identify and overcome constraints in seed banking which led to the preparation of genetic risk assessments for many native woody species (Gargiulo, 2019) and is delivering research on thresholds for allelic capture (Gargiulo et al. 2019), seed storage, stratification, and germination (Trivedi and Kallow, 2017; Davies et al. 2020). Seed and/or metadata has been supplied for uses including efforts to generate associations between genotype and environmental conditions, germination responses to climate change, the identification of potential new GCUs and Registered Seed Stands and the establishment of new seed orchards.

Table 7.2. Summary of accessions and numbers of seed collected as part of the UK National Tree Seed Project. Number of seed is a total count adjusted by results of x-ray testing. Number of accessions is equivalent to number of populations in most cases. Data extracted March 2022.

Species	Accessions	Adjusted seed count
Acer campestre	30	100072
Alnus glutinosa	54	885066
Betula nana	5	48643
Betula pendula	39	1222938
Betula pubescens	57	2692186
Buxus sempervirens	2	5046
Carpinus betulus	6	39816
Cornus sanguinea	22	47772
Corylus avellana	37	33146
Crataegus laevigata	10	11678
Crataegus monogyna	63	322052
Cytisus scoparius	1	10263
Euonymus europaeus	29	53397

Species	**Accessions**	**Adjusted seed count**
Fagus sylvatica	5	11973
Frangula alnus	15	38989
Fraxinus excelsior	87	2358068
Ilex aquifolium	64	398976
Juniperus communis	52	68254
Ligustrum vulgare	13	76369
Malus sylvestris	52	125031
Pinus sylvestris	11	221666
Populus nigra	4	18056
Populus tremula	4	245287
Prunus avium	39	32437
Prunus padus	31	85239
Prunus spinosa	56	131127
Rhamnus cathartica	15	106929
Salix arbuscula	1	1240
Salix aurita	20	1190454
Salix caprea	18	1866284
Salix cinerea	5	513940
Salix myrsinifolia	1	7797
Salix pentandra	1	37719
Salix phylicifolia	1	17270
Salix repens	8	97296

Species	Accessions	Adjusted seed count
Sambucus nigra	49	1035888
Sorbus aria sensu lato	63	64804
Sorbus aucuparia	65	693335
Sorbus torminalis	22	13554
Taxus baccata	25	148436
Tilia cordata	18	4564
Tilia platyphyllos	8	42942
Ulmus glabra	51	295622
Viburnum lantana	15	51691
Viburnum opulus	25	82841

7.3. Clone banks

Forest Research are responsible for 16 standing clone banks for 24 species and pot-based clone banking in principal conifer species. Clone banks and specialist collections are also held by other organisations including FTT and Conifer Breeding Cooperative (CBC).

Various organisations also hold specialist collections of taxa such as *Populus tremula* (aspen), *Populus nigra* (black poplar) (and hybrids), *Ulmus* (elm) and *Tilia* (lime). Information from such collections has not been compiled.

Forest Research have used clone banks since the 1950s to secure grafted copies of selections made in tree improvement programmes. Clone banks serve as a reference collection, a source of scion material (for example to regraft for seed orchards) and for controlled pollination work. Clone banks were set up for the most important conifer species between the 1950s and 1970s. Clone banks have also been set up by broadleaved tree improvement programmes under the control of the FTT, some of which are held in collaboration with Forest Research. Summaries of open clone banks are provided in Tables 7.3.1. and 7.3.2.

Table 7.3.1. Planted clone banks managed by Forest Research. Many clone banks are multi-species and the number of ramets per clone is variable among locations and species. Area is based on an average spacing of 2 m x 4 m, which is likely to be an underestimate. Pot-based clone banks are not included in this list. Data extracted 2022.

Species	Clone banks	Number of accessions	Area (ha)
Picea sitchensis	4	1821	6.31
Larix decidua	6	584	1.78
Pinus sylvestris	3	384	1.57
Larix kaempferi	5	346	1.26
Pinus nigra	4	355	0.52
Pseudotsuga menziesii	2	158	0.41
Abies grandis	1	34	0.11
Picea engelmannii	2	43	0.11
Picea omorika	2	39	0.09
Thuja plicata	1	49	0.07
Picea abies	2	9	0.05
Larix x *eurolepis*	1	9	0.04
Abies procera	1	11	0.04
Hybrid pines	1	24	0.04
Abies amabilis	1	3	0.01
Picea glauca	2	31	0.01
Hybrid red cedar	1	7	0.01
Hybrid spruces	1	12	0.01
Fraxinus excelsior	2	355	0.85

Species	**Clone banks**	**Number of accessions**	**Area (ha)**
Quercus robur	1	50	0.12
Quercus petraea	1	18	0.04
Betula pendula	1	332	0.79
Acer pseudoplatanus	1	48	0.11
Aesculus hippocastanum	1	39	0.03

Conifer clone banks were generally established on sites conducive for flowering to optimise opportunities for controlled-pollination work. Clone banks arrange multiple grafted copies of a clone (often six) in a row, numbered sequentially by clonal identity throughout to enable ready access to clones of interest. Most clones were archived in more than one location although no two clone banks had identical composition and clones were mixed between two to four locations (Sykes, 2007). Since work at clone banks (e.g. in pollination programmes) was intensive, it was common to locate them at or near to research stations and to include temporary office space and other facilities.

More recently pot-based clone banking on research station nursery sites has been used. This means ramets can be held close at hand, managed to retain a small stature, protected in polyhouses and treated with flowering induction methods. Intensive management of the pot-based clones is rare, and the plants are not used for seed production. Certain clone banks have been established more recently than the 1970s and have tended to adopt closer spacing and lower replication of grafted ramets.

The CBC (Chapter 9) now holds the responsibility to secure Forest Research clone banks for *Picea sitchensis* (Sitka spruce) and has been engaged in a rolling programme of regrafting high-ranking clones from old and at-risk clone banks.

Broadleaved clone banks for several species have been set up in recent years by FTT (Table 7.3.2) and Forest Research and a new archive of putatively tolerant *Fraxinus excelsior* (ash) trees selected from trials and in situ locations was established in 2018.

Figure 7.2. (Upper) Part of the national *Picea sitchensis* (Sitka spruce) tree bank at Ledmore, Perthshire. Lower: a larch clone bank at Altonside, Moray. By the 1980s, ramets in many clone banks had grown to inaccessible heights for pollination work and major programmes of top-pruning, mowing and re-labelling were introduced (Sykes, 2007). In the early 2000s, clone banking policy was rationalised to reduce the costs and effort involved in their management. At this stage, the management objective of standing clone banks became a reserve source of scion material, rather than a location for controlled pollination and the criteria and thresholds for clone banking were adjusted.

Table 7.3.2. Planted clone banks managed by Future Trees Trust

Site	Species present	Accessions	Area (ha)
Backhouse Wood	*Quercus petraea; Quercus robur*	130	0.3
Bradbourne	*Acer pseudoplatanus; Castanea sativa; Fraxinus excelsior; Prunus avium; Quercus petraea; Quercus robur*	388	
JFK Arboretum	*Quercus petraea; Quercus robur*	95	0.1
Kinsealy	*Acer pseudoplatanus*	86	0.1
Shenmore	*Castanea sativa*	109	0.4
Sotterley Hedge	*Quercus petraea; Quercus robur*	27	0.2
Southern England	*Fraxinus excelsior*	974	1.5

7.4. Needs, challenges and opportunities

- Better characterisation of FGR is needed to improve our ability to identify gaps and thresholds for efficient ex situ conservation. For example, better understanding of population genetic structure would enable identification of thresholds for allelic capture in seed banking and will demonstrate how those thresholds vary among species with different life history characteristics (e.g. Hoban and Strand, 2015; Gargiulo et al. 2019).

- Species with recalcitrant and intermediate seed (e.g. *Quercus* spp.) provide a challenge for long-term seed banking. Alternative means are needed to safeguard germplasm for those species (e.g. cryopreserved in culture) or significant in situ conservation should be explored.

- UKNTSP collections provide significant opportunities for research for example to understand natural patterns and trends in seed traits, which can inform commercial seed collection and processing, as well as tree improvement.

- Clone banks provide essential research and deployment infrastructure but are costly to establish and maintain and rarely of intrinsic research value due to their non-randomised layout, management, atypical spacing, tendency to be planted on benign sites and use of grafting to produce ramets which affects growth and form. However, evaluating certain traits on ramets in clone banks could be a rapid way of phenotyping for new traits, provided selection efficiency can be tested by performing evaluations on a large enough sample of families in existing trials.

These may include timber properties (Zhou et al. 2019), certain reproductive and phenological characteristics (Choi et al. 2004; Mutke et al. 2005) and inoculation of removed tissues *in vitro* with pathogens (e.g. Graham et al. 2018). Some of these approaches are now underway in the UK and have particular value where original progeny trials have closed.

- In long-established breeding programmes, there are opportunities to rationalise the clone banking effort, by discarding selections that have poor breeding values and reducing the number of ramets conserved for clones with mediocre breeding values for known traits, but these clones could have other desirable characteristics for the future (Sykes, 2007).

- For future breeding programmes of new species, in which modest levels of genetic gain are desired quickly based on a limited number of selections, the clone banking function could be absorbed into ‘qualified’ (untested) seed orchards. Provided record-keeping is accurate, such clonal seed orchards could be set up for later genetic thinning and replication of reselected parents in place of those which had been removed.

Chapter 8. The state of use of forest genetic resources

8.1. The state of use of forest genetic resources in the United Kingdom

FGR are used in the UK for afforestation schemes and restocking forest plantations. Afforestation is usually known as “woodland creation” in the UK and includes establishment of woodland by planting nursery raised stock, natural regeneration and natural colonisation. Direct seeding is used in some contexts in the UK but is much less common than planting (Willoughby et al. 2004). Trees are also planted outside woodlands in a range of settings. All these activities are supported by public incentive schemes and cover a range of objectives for sustainable forest management, including production of timber, habitat creation and restoration, recreation, amenity and landscape purposes.

The UK does not have national or sub-national tree seed programmes. Trade in forest tree seed takes place in both private and public sectors and is controlled by The Forest Reproductive Material (Great Britain) Regulations 2002 and the Forest Reproductive Material Regulations (Northern Ireland) 2002. Historically the public sector has supplied seed from improved conifer seed orchards under their control, including sales to the private sector. Private enterprises have also established their own seed orchards for important species, some of which are now registered and harvested operationally with seed used internally or traded.

The state bodies with the responsibility for managing the national forest estate in England and Scotland, Forestry England and Forestry and Land Scotland, have their own forest nurseries producing tree seedlings for use on the national forest estate. Forestry England grew approximately 7.5 million trees in 2024. FLS production was 6.4m in 2024. Their Newton Nursery is under redevelopment and will in future have capacity to produce up to 16 million trees per annum.

Major private sector forest nurseries are connected via professional bodies such as the Confor Nursery Producers’ Group and the Horticultural Trades Association Tree and Hedging Group and are represented internationally on the European Forest Nursery Association. The Confor Nursery Producers’ Group, whose membership includes 11 private nurseries, accounts for the vast majority of annual tree production for forestry use in Great Britain.

8.2. Certification of Forest Reproductive Material

The Forest Reproductive Material (Great Britain) Regulations 2022 provide a system of control for seed, cuttings and planting stock used for forestry purposes in Great Britain. In Northern Ireland it is the Forest Reproductive Material Regulations (Northern Ireland) 2022. The Regulations ensure that planting stock is traceable throughout the collection and production process to a registered source of Basic Material. In addition, the category of registered basic material provides information on the stock's genetic status. The UK is also a member of the Organisation for Economic Co-operation and Development (OECD) Forest Seed and Plant Scheme. This provides the assurances that FRM which is certified for marketing in the UK is equivalent to the same standards as acceptable for marketing in international trade and ensures our capacity to trade FRM with countries that participate in the scheme.

The scope of the FRM Regulations applies to the marketing of FRM from 46 statutory tree species and the genus Populus for forestry purposes. The term ‘forestry purposes’ is taken to cover the wide range of functions that are eligible for (but not restricted to) publicly funded woodland creation schemes. There is also a voluntary scheme for other, non-statutory, trees and shrubs that follows the same rules as the FRM Regulations. In situations where suppliers do not choose to market material for these reasons it must be clearly labelled as ‘not for forestry purposes’.

Only approved parent trees or, basic material, may be used to produce and market FRM and it is only the FRM which is derived from these sources which may be placed on the market. Different levels of approval are granted according to both the level of selection (the type) and the genetic quality of the basic material (the category).

Information describing all the approved sources for FRM is held in a National Register of Approved Basic Material. The register is publicly available through Gov.uk and provides the location and owner details for each unique identity along with the:

- Species
- Type of Basic Material
- Category of FRM to be produced
- Region of provenance
- Native seed zone
- Altitude and origin of material (where this is known)

Any person who intends to market FRM must be registered as a supplier and the details for all registered suppliers are included on another public register on Gov.uk. Once registered, a supplier may collect FRM for marketing as seed and/or grow on seed into plants to be marketed for planting. All suppliers must make a notification prior to collecting seed in order that collections may be inspected to ensure that they are made from approved basic material. Suppliers must label collections of FRM in a way that can be traceable throughout any processing up to the point that material is ready for marketing.

A Master Certificate must be issued to a supplier of FRM before it can be marketed. The Master Certificate is a document setting out the relevant information about the FRM and identifies it to a particular collection which has been made from a unit of approval in the National Register. The certificate number is the reference that must be used when marketing all subsequent sales of seed or plants which are derived from that seed.

Where FRM is imported for use it must meet certain conditions to be treated as equivalent to material from Great Britain. Where the FRM is sourced through an internationally recognised scheme it may only be marketed within GB when it has been issued with a Master Certificate to show that it has been supplied from an approved country of origin.

When FRM is marketed it is typically divided up into separate lots either as seed or as plants derived from that seed. FRM suppliers are required to label the FRM and to provide accompanying documentation about the quality and numbers of FRM along with the original Master Certificate number to identify the collection. This is referred to as the supplier's document and must accompany all sales of FRM as evidence of traceability. Suppliers must retain all records relating to the collection and production of FRM for at least 5 years after it sold.

Suppliers are regularly inspected to examine their records and to check that they have labelling systems in place to ensure traceability of FRM. Within the Regulations there are sanctions which may be used to correct non-compliance, although these are only expected to be used as a last resort. Suppliers have a right of appeal if they wish to contest decisions around compliance with the Regulations.

The Forestry Commission is the organisation with the legal responsibility for enacting the FRM Regulations in Great Britain. The Department of Agriculture, Environment and Rural Affairs (DAERA) is responsible for enacting the FRM Regulations in Northern Ireland.

8.3. Guidelines and incentive mechanisms for using forest genetic resources

The UKFS (Forestry Commission, 2023a) is the UK government's reference standard for sustainable forest management and provides guidance on use of genetic resources including that:

"*Linking and expanding native woods, using natural regeneration or by planting with well-adapted stock, will increase gene flow and increase the capacity of tree populations to adapt. For all new woodlands it is vital that material is drawn from a broad genetic base. When planting native species and native woodlands, it is generally best to use well-adapted local or regional origins from similar elevations. Consideration can also be given to planting a proportion of native species from non-local provenances with conditions that are well matched to the predicted future climate at the planting site*".

The UKW Woodland Assurance Standard (UKWAS, 2018) is an independent standard based on the requirements of international forest certification schemes Forest Stewardship Council (FSC) and Programme for the Endorsement of Forest Certification (PEFC). UKWAS states that, as a requirement, natural regeneration or planting local "source-identified" seed sources should be used as a first choice in and around statutorily protected sites that are to be maintained as local seed sources. Guidance within UKWAS under the heading "woodland creation" includes "*use of a diversity of species, clones and provenances"* among a list of criteria for achieving diverse woodland. On the topic of "tree species selection", UKWAS states as guidance that:

"*Results of research into site suitability of different species' origins and provenances and their resilience to climate change should be used to assist species choice. Because of the uncertain effects of climate change, selecting a range of genotypes may be prudent.*"

Further and more detailed guidance about sources of FRM varies among the countries of the UK and by the purpose of tree planting. Where timber production is a primary objective, use of FRM from domestic improvement programmes or select seed stands is generally encouraged. Where the primary objectives are for restoration or new planting of native species, local provenance is typically favoured, and local provenance is determined using a map of fixed seed zones (Herbert et al. 1999) which divides Great Britain into four 'regions of provenance' subdivided into a total of 24 'seed zones' with are further divided into two altitude bands at 300 m above sea level (Figure 8.3). For indigenous origin *Pinus sylvestris* (Scots pine) in the Scottish Highlands, a separate set of zones were delimited based on genetic characterisation using monoterpenes (Forrest, 1980). Northern Ireland and the Republic of Ireland are considered one seed management unit with no subdivision (Beatty et al. 2015).

Provided that material certified for forestry purposes is used for those species covered by FRM Regulations, there are no fixed rules about choices of seed origin, although different grant schemes across the countries may have different requirements. In general, a more conservative approach to provenance is favoured in heterogeneous upland environments and a more relaxed approach in the more homogenous lowland environments (Whittet et al. 2016a).

However, the need to adapt to the changing climate through the planting of a proportion of non-local provenance material is increasingly being recognised and this is reflected in the UKFS, and other guidance.

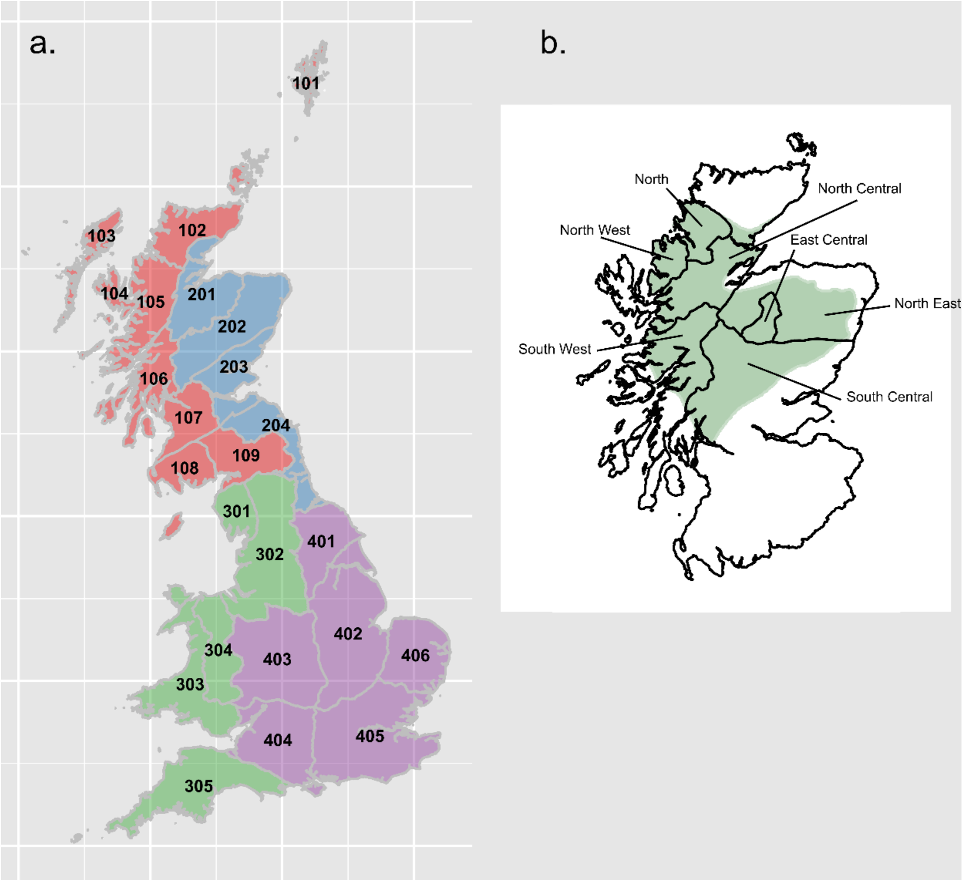


Figure 8.3. a) Seed zones for native trees and shrubs and their inclusion within four 'Regions of Provenance', coded numerically and with colour (Herbert et al. 1999). b) Biochemical zones (Forrest, 1980) for *Pinus sylvestris* in the native range (shaded in green). Figure reproduced from Whittet (2016).

8.4. Sources of basic material

Types of basic material and categories of reproductive material follow internationally recognised standards as shown in Table 8.4.1.

There are 230 source-identified stands on the national register of basic material for GB, covering 30 species and a total area of 16294.56 ha (table 8.4.2). There are 191 selected seed stands, covering 25 species and a total area of 1781.94 ha. Source-identified sources need not be registered on the national register of basic material.

There are 34 qualified seed orchards on GB's national register of basic material, covering ten species and a total area of 5 56.6 ha. There are 21 tested seed orchards on the national register of basic material, covering three species and a total area of 103.91 ha. Seed orchards for several species, in both 'qualified' and 'tested' categories are under development but not yet registered, especially in the private sector.

Table 8.4.1 Types of basic material and the categories of reproductive material available from them (FRM regulations, 2019).

Type of Basic Material	Category of reproductive material			
	Source-identified	Selected	Qualified	Tested
Seed Source	●			
Stand	●	■		■
Seed Orchard			●	■
Parents of Families			●	●
Clone			●	■
Clonal Mixture			●	●

Increasing refinement of source ↓

Increasing genetic quality →

■ in both old and new Regulations

● introduced in new Regulations

Table 8.4.2. Source-identified and select seed stands on the Great Britain's National Register of Basic Material. Data extracted April 2024. Areas rounded to nearest full number.

Species	Source identified		Selected		Total	
	count	total area (ha)	count	total area (ha)	count	total area (ha)
Pinus sylvestris	76	13,947.96	22	542.57	98	14,489.53
Quercus petraea	51	1,421.94	20	321.92	71	1,743.86
Quercus robur	24	222.65	32	155.37	56	378.02
Picea sitchensis	3	166.63	6	91.69	9	258.32
Corylus avellana	9	215.55	0	0	9	214.55
Pseudotsuga menziesii	2	3.74	17	173.76	19	177.50
Larix decidua	1	4.94	14	145.06	15	150.00
Pinus contorta	6	39.07	0	0	6	39.07

Species	Source identified		Selected		Total	
	count	total area (ha)	count	total area (ha)	count	total area (ha)
Fagus sylvatica	4	8.98	23	137.22	27	146.20
Fraxinus excelsior	9	67.65	2	3.64	11	71.29
Pinus nigra	4	45.03	3	22.16	7	67.19
Larix kaempferi	1	1.32	8	36.38	9	37.70
Crataegus monogyna	3	36.89	0	0	3	36.89
Picea abies	0	0	5	27.26	5	27.26
Castanea sativa	2	15.46	5	24.53	7	39.99
Betula pubescens	6	25.91	1	3.78	7	29.69
Betula pendula	3	15.43	6	14.04	9	29.47
Acer pseudoplatanus	3	11.53	5	10.73	8	22.26
Abies procera	0	0	3	14.01	3	14.01
Tilia cordata	1	8.38	3	20.65	4	29.03
Sequoia sempervirens	1	1.68	3	10.68	4	12.36
Thuja plicata	2	3.46	4	3.84	6	7.30
Abies grandis	0	0	3	6.90	3	6.90
Taxus baccata	0	0	1	7.01	1	7.01
Tsuga heterophylla	1	0.79	2	4.66	3	5.45
Quercus rubra	1	3.52	1	0.88	2	4.40
Larix x eurolepis	1	2.23	1	1.10	2	3.33
Picea omorika	0	0	1	2.11	1	2.11

Species	Source identified		Selected		Total	
	count	total area (ha)	count	total area (ha)	count	total area (ha)
Abies alba	1	1.68	0	0	1	1.68
Alnus glutinosa	4	5.48	0	0	4	5.48
Alnus rubra	1	0.40	0	0	1	0.40
Sorbus aucuparia	2	4.25	0	0	2	4.25
Prunus padus	1	0.06	0	0	1	0.06
Populus tremula	4	13.92	0	0	4	13.92
Salix lapponum	3	0.04	0	0	3	0.04
Total	230	16,295	191	1781.94	421	18076.50

Table 8.4.3. Seed orchards registered on the Great Britain's National Register of Basic Material. Data extracted April 2024

Species	Qualified		Tested		Total	
	count	total area (ha)	count	total area (ha)	count	total area (ha)
Picea sitchensis	1	2.40	13	64.77	14	67.17
Larix kaempferi	5	15.91	0	0	5	15.91
Pinus nigra	0	0	3	17.92	3	17.92
Pinus sylvestris	0	0	5	21.22	5	21.22
Larix decidua	4	10.62	0	0	4	10.62
Fraxinus excelsior	6	6.47	0	0	6	6.47
Prunus avium	6	4.28	0	0	6	4.28
Pseudotsuga menziesii	3	8.55	0	0	3	8.55

Species	Qualified		Tested		Total	
	count	total area (ha)	count	total area (ha)	count	total area (ha)
Pinus contorta	1	2.37	0	0	1	2.37
Acer pseudoplatanus	3	2.83	0	0	3	2.83
Betula pendula	3	1.14	0	0	3	1.14
Thuja plicata	2	2.031	0	0	2	2.03
Total	34	56.6	21	103.91	55	160.51

8.5. Production of forest reproductive material

Currently, around 152 million seedlings are grown by forest nurseries annually to supply new planting and restocking programmes (Forestry Commission, 2023b). Records of sales are only published for *Picea sitchensis* (Sitka spruce) and *Pinus sylvestris* (Scots pine) through an annual nursery survey by the Forestry Commission. From 2008/2009 onwards, the proportion of *Picea sitchensis* (Sitka spruce) plants of improved origin has been close to 100%. For *Pinus sylvestris* (Scots pine), the average proportion of improved seed has varied around a mean of 60% during the same period (Forest Research, 2021).

The most important broadleaved tree and shrub species for new planting are those which are common and widespread throughout the country such as *Betula pubescens* (downy birch), *Alnus glutinosa* (alder), *Crataegus monogyna* (hawthorn), *Betula pendula* (silver birch), *Sorbus aucuparia* (rowan) and *Quercus petraea* (sessile oak) (Forestry Commission, 2023b).

Parts of plants (usually cuttings) have been marketed for forestry purposes for macropropagation (vegetative propagation), for three species between 2019 and 2021 (Table 8.5).

Table 8.5. Summary of 'parts of plants' (usually cuttings) certified FRM from 2019-2021. Data source: Forestry Commission.

Species	**2019**	**2020**	**2021**
Populus tremula	121,214	140,789	159,184
Populus nigra	300	9,275	24,400
Picea sitchensis	15,517,935	13,717,967	477,5125

8.6. Needs, challenges and opportunities

- The origin of seed used in tree planting is not consistently collected or routinely analysed meaning it is challenging to understand how genetic diversity is deployed in the landscape.

- Stakeholder engagement suggests that the number and locations of registered sources of basic material may be insufficient to provide future security and diversity of requirements for a number of species meaning ongoing effort is needed to identify/plant further sources. Further analysis of master certificate data (with the permission of suppliers) would enable evaluation of how basic material is accessed by seed collectors.

- The FRM category 'source-identified' is often favoured for planting in schemes where conservation is an important management objective because material hasn't been selected according to any specific criteria. However, identifying genuinely wild-type basic material can be complicated by historic planting of unknown origin stock and crop-to-wild gene flow (e.g. Ruhsam et al. 2018). There is a need for wider registration and use of 'indigenous' SI stands which are of known local origin and inspected to help overcome this.

- Activities to improve levels of awareness and understanding in FRM terminology and genetic concepts (e.g. origin vs provenance) are needed to improve liaison between plant suppliers and purchasers and instil a better understanding of the resources involved in producing quality seed of the appropriate type.

- Better genetic characterisation of native species to understand the scale and pattern of adaptive differentiation would help inform the number of seed zones required for FRM to avoid maladaptation and facilitate climate adaptation and this number may vary by species. For example, it is speculated that the number of seed zones in eastern England is unnecessarily high for widespread species and could be reduced (Whittet et al. 2016b).

Chapter 9. The state of genetic improvement and breeding programmes

9.1. Organisation of improvement and breeding programmes

UK government first supported tree improvement through the establishment of the Forestry Commission Genetics Section in 1948. The Section aimed to develop strains of trees showing increased vigour, improved stem form, better adaptation to adverse conditions, increased resistance to pests and diseases and improved timber quality (Samuel et al. 1998).

This work is now undertaken by Forest Research, the research agency of the Forestry Commission, which is responsible for the largest share of provenance tests, progeny tests and clone banks in the UK. Members of the Forest Genetics group at Forest Research are currently working research projects relating to forest genetics and tree improvement in *Picea sitchensis* (Sitka spruce), *Pinus sylvestris* (Scots pine), *Pseudotsuga menziesii* (Douglas fir)*, Fraxinus excelsior* (common ash)*, Betula pendula* (silver birch) and *Larix* spp.

In 2013, a public-private partnership named the ‘Sitka Spruce Breeding Co-operative’ was established with objectives to: ensure an adequate supply of improved vegetatively propagated full-sibling *Picea sitchensis* (Sitka spruce) for growers; to support Forest Research in securing genetic material in clone banks; and to take forward a Sitka spruce breeding programme. The partnership has agreed a license to allow use of Forest Research’s intellectual property, know-how and technical skills thus allowing private operators to carry out pollination programmes in their own seed orchards to produce full-sibling seed for the creation of stock hedges for cuttings. The ‘Sitka Spruce Breeding Co-operative’ was renamed the ‘Conifer Breeding Cooperative (CBC)’ in 2017 to reflect a wider interest in the improvement of conifers and employed its first member of staff in 2021. Full members of the CBC pay an annual subscription and perform work-in-kind to share costs of activities. In return they have full access to the intellectual property and can obtain full-sib seed at reduced cost. The work of the CBC is divided across four subgroups in research and strategy; operations; communications and finance.

Broadleaved tree breeding is organised by a non-governmental organisation called Future Trees Trust (FTT). FTT was formerly known as the British and Irish Hardwoods Improvement Programme (BIHIP), which was formed in 1991 as a voluntary collaboration of Great Britain and Ireland’s tree scientists and practitioners working in partnership to advance tree improvement programmes of important broadleaved species. Recent funding has allowed FTT to employ full-time members of staff and fund PhD and scholarship positions. FTT uses traditional selective breeding to improve traits for eight of our most commercially important broadleaved species: (*Betula pendula* (silver birch), *Betula pubescens* (downy birch), *Quercus robur* (pedunculate oak), *Quercus petraea* (sessile oak), *Acer pseudoplatanus* (sycamore), *Prunus avium* (wild cherry), *Castanea sativa* (sweet chestnut) and *Fraxinus excelsior* (ash).

The National Tree Improvement Strategy (NTIS) was launched in 2017 to act as a forum to discuss and co-ordinate tree improvement activities. NTIS aims to promote UK trees through selection and breeding of a wide range of tree species capable of thriving in UK conditions. The NTIS steering group meets twice a year and has unrestricted and open membership drawn from across the forestry sector including nurseries, to forest managers of natural, semi-natural and plantation forests and woodlands, saw millers, ecologists and sectors of academia.

9.2. Approaches used for tree improvement

The first 50 years of tree improvement mostly involved traditional improvement approaches of selecting parents in situ based on phenotypic characteristics and reselecting (backward selection) superior parents based on the performance of their progeny in field trials for inclusion in breeding and production populations.

To build up base populations of conifers for selection and testing, candidate plus tree selection programmes took place in domestic plantations, which recorded observations and measurements of performance, tree architecture, health and physiological traits, and wood quality (Fletcher and Faulkner, 1972). This allowed the field progeny testing programme to focus on fewer traits. The selection intensity in the early phases of tree improvement was extremely high (approximately 1 in 5000 trees) but was later relaxed as information about the level of genetic control for traits became available.

Assessment schedules for conifer progeny tests tended to involve evaluation of height and survival at ages 1, 3, 4 and 6. Beyond 6 years, growth tended to be evaluated through diameter at breast height (DBH) and stem straightness (and sometimes branching characteristics) was routinely evaluated on ordinal scales. In the mid-1980s, the use of the Pilodyn tool became standard practice to obtain an indirect measure of wood density.

Picea sitchensis (Sitka spruce) is the only species to have advanced beyond first generation testing. The provisional general breeding population of 240 parents was reselected following first generation progeny trials and divided into four breeding sublines of equal size and equivalent mean breeding values for full-sibling trials. A circular mating design was followed in each subline to prepare full-sibling seed from each subline for new trials. Trials from the first of these four sublines are now approaching rotation age and there are opportunities to select a second breeding generation based on harvest-age measurements.

Controlled pollination (Figure 9.2.1) was regularly used to generate ‘polymix’ crosses for half-sibling tests and for full-sibling tests in *Picea sitchen*sis (Sitka spruce) and is now used for deployment of family mixtures (Chapter 8). Controlled pollination has also been developed for *Larix* (larch) and *Pinus sylvestris* (Scots pine).

Figure 9.2.1. Controlled pollination of *Picea sitchensis* (Sitka spruce)

First generation testing of five conifers has been completed (Table 9.2.1). The genetic merit ('breeding value') of selected parents was estimated for multiple traits which allows users to specify the balance of potential genetic gain for particular traits in production populations (e.g. seed orchards).

Table 9.2.1. Summary of selection and testing of conifers by Forest Research. **area is inferred based on number of plants in the design planted at 2 x 2 m spacing in a contiguous rectangle without guard rows. ** Original selections and reselections under the Hybrid larch programme were a mixture of Japanese and European larches for use as parents. Selections is the number of phenotypic selections (plus trees). Tests is the number of progeny tested. Test series is number of progeny test series. Total entries is the total number of entries in tests (eg families, lots). Breeding Population size is the number of members of reselected breeding populations. Years planted is the years in which tests were planted.*

Species	Selections	Tests	Test series	Total area of tests (ha)*	Test entries	Breeding population size	Years planted	Current status
Sitka spruce	3398	357	105	293.87	4862	360	1967-2005	Open
Lodgepole pine	3980	157	50	88.33	1774	NA	1964-1989	Closed c. 1990

Species	Selections	Tests	Test series	Total area of tests (ha)*	Test entries	Breeding population size	Years planted	Current status
Scots pine	1522	139	44	86.86	1642	226	1957-1987	Reopening 2022
Hybrid larch	29 (855**)	46	22	18.31	713	150**	1959-1994	Dormant
Douglas fir	596	40	14	28.05	651	NA	1959-1995	Reopening 2022
Corsican pine	1015	37	14	29.22	1044	120	1966-1989	Closed c. 1990

From the early 21st Century, the majority of tree breeding effort has shifted from traditional recurrent selection schemes to high-tech approaches, which are concentrated on *Picea sitchensis* (Sitka spruce), with the ambition to develop clonal forestry (CF) using somatic embryogenesis and supported by molecular approaches such as marker assisted selection and (most recently) genomic selection. At present, none of these approaches are operational in tree improvement programmes.

Trials to explore marker-assisted selection (MAS) in *Picea sitchensis* (Sitka spruce) were established in 2005 in which four clonal replicates of 1500 siblings from each of three full-sibling families were planted out in three locations to identify quantitative trait loci (QTL) associated with beneficial trait variation. This type of MAS since has fallen out of favour globally as virtually all economically important traits are highly polygenic and finding the genetic basis of complex traits in tree populations is typically unrealistic (Grattapaglia, 2023). Nonetheless, the trial design has proven useful in exploring the potential for genomic selection to be used in an improvement programme (Fuentes-Utrila et al. 2017; Ilska et al. 2023), which is a more realistic technology than MAS in well-characterised breeding populations that are under active improvement. The ‘Sitka spruced’ project was launched in 2017 to develop a training set for genomic prediction of timber quality traits that are difficult to measure and late to express. A sample of families within 20-year-old full-sibling tests were genotyped at high marker density and destructively sampled for intensive mechanical testing. Work is ongoing to determine the requirements for design of a training set, but early results suggest that genomic prediction may become competitive with pedigree-based selection with larger training sets. Genomic selection, once established and linked to an active improvement programme, could lead to faster breeding cycles.

Two types of micro-propagation technologies have been used by the UK’s tree improvement and breeding programmes. Firstly, the use of somatic embryogenesis (SE) techniques for use with *Picea sitchensis* (Sitka spruce) was first investigated by Forest Research and is now approaching commercialisation by Maelor Forest Nurseries. SE is also under development for *Larix* (larch) species by Forest Research with the objective of helping to breed and propagate plants that are resistant to *Phytophthora ramorum* disease. Secondly, shoot proliferation methods have been employed mainly by Forest Research with *Fraxinus excelsior* (ash), with a view to maintain and propagate breeding material that might be resistant to ash die-back disease. The uptake of these methods and the plants produced by them by the UK forestry sector has been quite limited so far, possibly due to uncertainties about the cost implications.

9.3. Uses and traits prioritised in tree improvement and breeding

The main end use targeted by conifer tree breeding in the UK is timber for construction markets. Therefore, most tree improvement programmes have concentrated on improving volume and tree architecture traits (e.g. stem form) in native and non-native conifers. Wood density became an important, and practicably measurable trait in the 1980s (as described in 9.2). However, the key mechanical property limiting the entry of *Picea sitchensis* (Sitka spruce) into higher strength grades for construction timber is modulus of elasticity (stiffness). In the last twenty years, use of acoustic tools, which provide an indirect assessment of stiffness to evaluate both standing trees and crosscut logs has become typical in Sitka spruce and is also being used in Douglas fir and Scots pine. A campaign of selecting candidates for superior stiffness from an IUFRO provenance trial began in 2019 (Lopez et al. 2020). Candidate plus trees were selected dynamically on a plot-by-plot basis and then felled and processed so that acoustic velocity could be measured on standard log lengths. The top trees were grafted and are held in clone banks for later infusion into the breeding population. Wood discs from the candidate trees were taken for intensive mechanical testing (Lopez et al. 2020).

Methods to evaluate tree responses to environmental stress such as drought, waterlogging, pest and disease susceptibility are also under development, mostly at pilot stage across a range of species. This includes early-stage phenotyping in manipulative glasshouse conditions, evaluation of long-term growth responses using core samples and the use of imagery or ‘point-clouds’ generated from aerial or terrestrial laser scanners. Development of these approaches is taking place in genetic trials but these are not yet at the stage of being actively incorporated into breeding programmes.

A new campaign of selecting plus trees in *Picea abies* (Norway spruce) and *Pseudotsuga menziesii* (Douglas fir) organised by the CBC began in 2021 using various phenotypic selection methods (White et al. 2007). Phenotypic scores including DBH, stem straightness and branching quality are recorded by measuring a representative, random sample of fifty trees per sub compartment during stand reconnaissance. Candidates surpassing the baseline threshold from the baseline survey are revisited for more detailed evaluation, including classification of neighbouring trees and the threshold values are used to guide more expansive ‘mother tree’ selection efforts in the remainder of the stand. All new selections are being genotyped, leading to the creation of new low-marker density genotyping arrays for pedigree correction and traceability of genetic material.

Base populations for eight broadleaved species have been established by FTT to improve growth and timber quality of productive broadleaved species. The approach of FTT has been to select superior parent trees (referred to as plus tree selection) and establish clonal seed orchards containing, depending on species, 50 to 200 clones for later genetic thinning based on the outcome of progeny trials. These orchards supply improved seed to the forestry sector (Table 9.2.2). A series of *Fraxinus excelsior* (ash) progeny trials was undertaken in the early 1990s, planted as breeding seedling orchards, and genetically thinned to provide tested seed. Limited progeny trials were established for *Acer pseudoplatanus* (sycamore), in 2016, and an extensive series of progeny trials testing both *Quercus petraea* (sessile oak) and *Quercus robur* (pedunculate oak) across eight sites in 2003. Two of these trials have been thinned to provide tested seed orchards, one for each species. More recently, comprehensive progeny trials for *Acer pseudoplatanus* (sycamore) and *Betula pendula* (silver birch) have been established testing 120 and 110 parents respectively.

Table 9.2.2. Summary of broadleaved tree improvement programmes organised by the Future Trees Trust.

Species	Selections	Traits Favoured	QU Clonal Seed Orchards	Progeny Trials Established	Progeny Trials Completed	TE Seed Orchards
Acer pseudoplatanus	217	form, vigour	Yes	Yes		
Betula pendula	192	form, crown quality	Yes	Yes		
Betula pubescens	28	form, crown quality	Initiated			
Castanea sativa	206	form, vigour	Yes			
Fraxinus excelsior	493	form, vigour, disease resilience	Yes	Yes	Yes	Yes
Prunus avium	191	form, vigour, health	Yes			

Quercus petraea	144	form, vigour	Yes	Yes	Yes	Yes
Quercus robur	164	form, vigour	Yes	Yes	Yes	Yes

The beginnings of a programme to breed *Fraxinus excelsior* (ash) trees with resilience to ash dieback caused by *Hymenoscyphus fraxineus* and attack by the *Agrilus planipennis* (Emerald Ash borer) are underway. The initial step, in 2013, was to purchase *Fraxinus excelsior* (ash) seedlings derived from a mixture of sources and plant these out in mass screening trials in the south-east of England where the highest levels of background inoculum were expected. In parallel, the Living Ash Project screened the 40,000 individual trees in tree improvement programmes prior to the arrival of ash dieback, and utilised citizen science to locate trees with tolerance in the wider population. Approximately 1000 tolerant trees were selected from these two programmes and planted in the National Archive of Tolerant Material in 2019. In 2023, a final round of selections was made from these resources, and will replace poorer selections in the National Archive, and a second replicate archive site is to be planted in Scotland. A series of progeny trials, based on seed collected from FTT's breeding seedling orchard have also been established to estimate heritability, breeders values and genetic correlations among traits, sites and sampling instances.

9.4. International transfer of germplasm for research and development purposes

Historically, when all tree improvement efforts and research nursery production programmes were under the control of the Forestry Commission and many genetic trials were established each year, records of import, export and allocation of seed for research and development purposes were held in ledgers. The now much reduced scale of establishing genetic trials, the broader range of stakeholders involved and the absence of requirement to document exchange in seed through the FRM system for purposes other than forestry mean that there are no central records of international transfer of germplasm specifically for research and development purposes.

9.5. Needs, challenges and opportunities

- A challenge and an opportunity is the range of organisations involved in tree breeding and improvement, which includes both public and private organisations. Furthermore, effort is currently applied across a range of species. There is a need to further enhance co-ordination across these organisations and to establish a more strategic approach to future breeding programmes.

- Skills shortage is also a challenge and both scientific and technical skills (such as grafting and controlled pollination) need to be retained and further developed.

- Scientific advances provide significant opportunities. Further exploration of the role of molecular tools such as genomic selection of traits, as well as the use of molecular markers for pedigree reconstruction and for traceability purposes is important. Digital infrastructure employing up-to-date statistical methods should be developed to increase the efficiency and precision of tree breeding. New phenotyping approaches, including remote sensing, and ecophysiological tools can be used to develop new approaches for measuring traits, especially those associated with responses to environmental stress.

- There is a need to demonstrate gains available through the use of genetically improved trees by updating growth and yield models that are currently based on unimproved material.

- A key challenge is to protect existing research infrastructures such as clone banks and experiments and establish new ones.

Chapter 10. Institutional framework for the conservation, use and development of forest genetic resources

10.1. National coordination and strategies for forest genetic resources.

Until around 2010, the Forestry Commission, largely through Forest Research, have been responsible for most aspects of FGR management in Great Britain. Recent years have seen new actors engaged in these activities and various elements of work are carried out across organisations, however co-ordination of these activities and advice to government policy has been patchy.

The UK Forest Genetic Resources Strategy (Trivedi et al. 2019) set out a high-level ambition to engender cooperation to advance availability of information on FGR in the UK. The document gained endorsement from a wide range of stakeholders, including governmental agencies. Similarly, the National Tree Improvement Strategy (NTIS, 2017) sets out objectives to promote UK tree selection and breeding and provides an umbrella to co-ordinate such activities across the public and private sectors.

Figure 10.1. Front covers of the National Tree Improvement Strategy (2017) and the UK Forest Genetic Resources Strategy (2019).

Other elements of coordination include the Forestry Commission's FRM secretariat which communicates regularly with national stakeholders through mailing lists and newsletters. Forest nurseries and seed suppliers are connected in professional bodies such as the

Confor Nursery Producer's Group and the Horticultural Trades Associations Tree and Hedging Group.

The UK is a member of EUFORGEN and is represented on the steering committee by the Forestry Commission.

10.2. Main institutions and stakeholders involved in forest genetic resources

The Department for Environment, Food and Rural Affairs (Defra) is the government department responsible for environmental protection, food production and standards, agriculture, fisheries and rural communities in the United Kingdom of Great Britain and Northern Ireland. Forestry and nature conservation are devolved issues in the UK, with separate agencies serving each of England, Northern Ireland, Scotland, and Wales (Table 10.2.1). A summary of the roles and responsibilities of different organisations, or groups of organisations is provided in Table 10.2.2.

Table 10.2.1. Subnational public bodies associated with forests and nature conservation

Country	Forestry authority	Management of national forests	Nature conservation body	Forest research agency
England	Forestry Commission	Forestry England	Natural England	Forest Research
Scotland	Scottish Forestry	Forestry and Land Scotland	NatureScot	Forest Research
Wales	Welsh Government (policy and funding) Natural Resources Wales (forest regulator)	Natural Resources Wales	Natural Resources Wales	Forest Research
Northern Ireland	Department for Agriculture, Food and Rural Affairs (DAERA)	DAERA	DAERA	Agri-Food and Biosciences Institute

Table 10.2.2. Main players and stakeholders in UK Forest genetic resources

Topic	Main players and stakeholders
In situ conservation of FGR	EUFORGEN, Subnational nature conservation and forestry bodies, Environmental NGOs (e.g. Woodland Trust), UK Centre for Ecology and Hydrology, Forest Research
Ex situ conservation of FGR	Royal Botanic Gardens Kew, Forest Research, Royal Botanic Garden Edinburgh, Future Trees Trust, Conifer Breeding Cooperative
Controlling use of FGR	Forestry Commission (GB), DAERA (Northern Ireland)
Advising on use of FGR	Subnational forestry bodies, Forest Research
Producing FGR	Private nurseries, Forestry England, Forestry and Land Scotland
Using FGR and managing forests	Private forestry companies and landowners, NGOs and community groups, Subnational forestry bodies
Tree improvement	Forest Research, Conifer Breeding Co-operative, Future Trees Trust
Commissioning research in FGR	Defra, Subnational forestry bodies, Research councils, European Union, Professional Bodies, NGOs
Research in FGR	Forest Research, UK Centre for Ecology and Hydrology, RBG Kew, Universities, other research Institutes (Section 10.4)
Education in FGR	Forest Research, Professional Bodies, Colleges and Universities

10.3. Legislation and policy relevant to forest genetic resources

A summary of legislation in UK forestry is provided in Appendix 1 of the UK Forestry Standard 4th Edition (Forestry Commission, 2017).

10.4. Research and development in forest genetic resources

Forest Research is Great Britain's principal organisation for forestry and tree related research and is responsible for the largest number of genetic trials, datasets, and clonal archives of any organisation in the UK. as of June 2024, the forest genetics science group at Forest Research has six permanent members of staff and their work is supported by field technicians stationed throughout Great Britain. Research in Northern Ireland is led by the Agri-Food and Biosciences Institute.

Other research institutes involved in specialist research associated with FGR include UK Centre for Ecology and Hydrology, Royal Botanic Gardens, Kew and Royal Botanic Garden Edinburgh. The UK Centre for Ecology and Hydrology are involved in research and conservation of FGR in temperate and tropical regions, have specialist expertise in genomics and are regularly engaged in EU projects on FGR. Royal Botanic Gardens Kew manage the Millennium Seed Bank and have specialist expertise in ex-situ conservation, genomics and bioinformatics. The Genetics and Conservation group at Royal Botanic Garden Edinburgh are engaged in conservation of FGR internationally and domestically. Other research institutes with involvement in FGR are James Hutton Institute, John Innes Centre, FERA Science Ltd and NIAB-EMR.

Many universities are involved in research and development in FGR, especially through co-supervision of students with industrial and research institute partners. The Universities of Oxford, Edinburgh, Bangor and Birmingham all have notable research presence in FGR.

Although UK forestry is largely controlled by the private sector, there is no formal system for reinvestment into research and development from the private sector. Exceptions to this include the establishment of the Conifer Breeding Co-operative (Chapter 9) and internal investments in R&D within the sector such as Maelor Forest Nurseries engagement in research into somatic embryogenesis. Many private companies have responded to publicly-funded innovation funds, such as the 'Tree Production Innovation Fund' administered by Forestry Commission and the Scottish Government's 'CivTech' programme call sponsored by Forestry and Land Scotland to encourage innovation in seed resources.

Several independent consultants who combine woodland management with research are influential in forest genetics research in the UK. Their contribution is valuable due to their expertise in forest systems and ability to engage end-users efficiently.

10.5. Education and training in forest genetic resources

The UK has a skills shortage in forestry in general and there is a significant gap between the number of vacancies and the number of educated candidates (Institute of Chartered Foresters, 2021). Training in forestry is principally achieved through technical college courses and continuing professional development.

There is no known specialised university or college module on forest genetics in the UK but many degree level and MSc-level courses include teaching on relevant areas like population genetics, forest ecology and conservation biology.

Forestry professionals trained to degree level are often recruited to the sector from other subjects (e.g. geography, environmental sciences) and may engage peripherally with FGR continuing professional development and on-the-job training although awareness of the importance of FGR in the sector is regarded as low (Trivedi et al. 2019).

Most of the personnel engaged in FGR (in the strict sense) in the UK are researchers. Researchers in FGR generally become engaged at postgraduate or postdoctoral level, entering the field from other subjects in ecology, evolution, environment, conservation, and plant sciences. Skills in methods such as genomics, bioinformatics and quantitative genetics can be transferred with relative ease from other domains but the lack of researchers with deep expertise in forest systems is a cause for concern.

10.6. Needs, challenges and opportunities

- There has been a lack of overall coordination of FGR-related activities although the number of agencies involved is growing. Activities have recently begun to explore better UK-wide oversight and co-ordination.

- Technical language around FGR and FRM can be inaccessible and so there is a need to develop activities to build awareness and understanding across both policymakers and practitioners.

- There are thought to be skills gaps in both technical skills (e.g. grafting, controlled pollination) and low overall scientific capacity in forest genetics. Assessing training opportunities in topics of relevance to FGR (e.g. 'omics' sciences, bioinformatics, and quantitative genetics) from other plant and animal genetic resource domains and insertion of FGR subjects into further and higher education would be helpful.

- Reduced investment from the mid-1990s in critical research infrastructure such as genetic trials, breeding programmes, and the development of skilled technical personnel led to a decline in national capacity (Whittet et al. 2022).

- There may be opportunities to explore further investment from the private sector in research and development.

- UK research and development strengths in areas like genomics and bioinformatics provide opportunities to transfer skills to the FGR domain.

Chapter 11. International and regional cooperation on forest genetic resources

11.1. UK involvement and contribution to international and regional projects on forest genetic resources

The UK has been a member of EUFORGEN since 2000 and was influential in early developments of the programme. Through EUFGIS, membership of EUFORGEN provides the UK with standards and support for in situ genetic conservation and facilitates exchange with partners across Europe.

Selected major European research projects on FGR that the UK organisations have been involved with since 2013 are summarised in table 11.1.

Subregional collaboration based on proximity or environmental and biotic similarities are mutually beneficial. The REINFFORCE project was a collaboration between countries along the Atlantic seaboard of Europe (Portugal, Spain, France, Ireland and the UK) which resulted in a network of species-provenance trials being established along a latitudinal gradient of 21°, which will become increasingly useful as the climate changes (Correia et al. 2018; Reynolds et al. 2020).

Great Britain has the most advanced breeding programme for *Picea sitchensis* (Sitka spruce) in the world (Chapter 8) and exchanges technical expertise with other countries in Europe, namely Ireland and Denmark and, to a lesser extent, Norway, France, Sweden and Iceland (Lee et al. 2013).

Forestry in upland Scotland shares characteristics with Nordic forestry and Scotland has participated in Nordic collaborations on FGR as an honorary Nordic country along with Ireland and the Baltic states (Eysteinsson, 2003).

Table 11.1. Major European research projects on FGR that UK organisations have contributed to since 2013 (as of March 2022).

Project	Duration	Coordinating partner	UK partner(s)	Official Description
EVOLTREE	2011-present	European Forest Institute (EFI)	Centre for Ecology and Hydrology	The EVOLTREE Network forms a *European Research Group*, a cooperation instrument devoid of any legal personality, which started in January 2011.The mission of the Network is to link four major disciplines (Ecology, Genetics, Genomics and Evolution) to address global issues that European forests are currently

Project	Duration	Coordinating partner	UK partner(s)	Official Description
				facing as environmental change and erosion of biodiversity.
REINFFORCE : REsource INFrastructure for monitoring and adapting European Atlantic FORests under Changing climatE	2009-2013	Institut Européen De La Forêt Cultivée (IEFC)/Forest Research	Forest Research	The purpose of this project is to pool the capacity of 12 institutes to face a transnational issue, namely adaptation to climate change impacts on Atlantic forests. The project will set up tools for monitoring climate change and its impact on the Atlantic coast and test the efficiency of adaptive measures.
ProCoGen– "Promoting a functional and comparative understanding of the conifer genome-implementing applied aspects for more productive and adaptive forests"	2012-2016	Universidad de Alcala	Forest Research; University of Edinburgh	The main goal of this project is to develop an integrative and multidisciplinary genomic research in conifers, using high-throughput platforms for sequencing, genotyping and functional analysis, to unravel genome organization and identification of genes and gene networks controlling important ecological and economic traits, such as those related to the control and the reduction of climatic change impact in relation to growth, drought and cold stress.
Trees4Future	2011-2016	Institut National de la Recerche Agronomique (INRA)	Forest Research	Trees4Future is an Integrative European Research Infrastructure project that aims to integrate, develop and improve major forest genetics and forestry research infrastructures. It will provide the wider European forestry research community with easy and comprehensive access to currently scattered sources of information (including genetic databanks, forest modelling tools and wood technology labs) and expertise.
MaP-FGR	2012-2016	Consiglio per la ricerca in agricoltura e l'analisi dell'economia agraria (CREA)	Centre for Ecology and Hydrology	MaP-FGR aims to bring together experts in FGR to collect knowledge on Marginal and Peripheral (MaP) populations throughout Europe

Project	Duration	Coordinating partner	UK partner(s)	Official Description
GenTree	2016-2020	Institut National de la Recerche Agronomique (INRA)	Centre for Ecology and Hydrology	The goal of GenTree is to provide the European forestry sector with better knowledge, methods and tools for optimising the management and sustainable use of FGR in Europe.
B4EST: Adaptive BREEDING for Better FORESTs	2018-2022	Institut National de la Recerche Agronomique (INRA)	Forest Research; Centre for Ecology and Hydrology	B4EST is an EU-funded H2020 project which focuses on adaptive breeding for productive, sustainable and resilient forests under climate change.
GenResBridge	2019-2021	European Forest Institute (EFI)	University of Birmingham; Botanic Gardens Conservation International. *Contribution was on Plant Genetic Resources*	The project will accelerate collaborative efforts and widen capacities in plant, forest and animal GenRes domains by sharing perspectives, exchanging best practices, harmonizing standards, trainings and sharing resources under the auspices of the three pan-European GenRes networks: ECPGR, EUFORGEN and ERFP.
FORGENIUS: Improving access to FORest GENetic Resources Information and Services for End-Users. Coordinated by INRA.	2020-2024	Institut National de la Recerche Agronomique (INRA)	Centre for Ecology and Hydrology; Forest Research	FORGENIUS project— an H2020 project, funded by the EU — will give an insight into the diversity of European forests and their resilience to climate change. The project uses state-of-the-art technology and knowledge in plant and evolutionary biology, ecology, remote-sensing, genomics, genetics, modelling, and forestry.

Organisations in the UK participate in conservation and development of FGR for species that are not used domestically. Examples include the development of FGR in African dryland species as part of the SUNRISE project led by UK Centre for Ecology and Hydrology.

Royal Botanic Gardens, Kew's Millennium Seed Bank Partnership (MSBP) has been working with international partners to support the collection and ex situ conservation of FGR over many years. Since 2014, for example, the MSBP's Global Tree Seed Bank Programme has worked with partners in more than 35 countries to collect, bank and conserve up to 5000 species, prioritising rare, endangered and useful trees and shrubs. Seed collecting is supported by training and capacity building and an active research programme including the taxonomy and ex situ conservation of palms and protocols for banking recalcitrant (desiccation sensitive) seeds.

The UK is also engaged in conservation of global FGR via the International Conifer Conservation Programme (ICCP) at the Royal Botanic Garden Edinburgh. The ICCP is engaged in in situ and ex situ conservation and has established a network of 200 sites, the majority of which are in Great Britain and Ireland. These hold 14,000 individual trees representing 155 conifer taxa, 95 of which are threatened in situ (Gardner et al. 2019), although the majority of these are not currently used in a UK forest context. The programme includes a major collection of vegetative material from iconic yew trees (*Taxus baccata*) throughout Great Britain and Ireland, supplemented with seedling collections from seventeen countries across its native range, grown as a boundary hedge for the botanic garden (Gardner et al. 2019).

11.2. Benefits and application of results from international and regional cooperation on forest genetic resources.

The UK has participated in many multi-national provenance trials organised by IUFRO. Results from these trials have been influential in selection and development of planting stock in UK forestry, for example in *Picea sitchensis* (Sitka spruce) (Samuel et al. 2007); *Pseudotsuga menziesii* (Douglas fir) (Fletcher and Samuel, 2010); *Quercus petraea* (sessile oak) (Hubert, 2005); *Quercus rubra* (northern red oak) (Kerr et al. 2022); *Abies grandis* (grand fir) (Bennuah, 1992); *Abies procera* (noble fir) (Kerr and McMinn, 2018) and *Picea abies* (Norway spruce) (Lines, 1987). Provenance trials for many other exotic species were established in Great Britain between the 1920s and 1970s. International exchange was routine at this time and visits were regularly made to Pacific Northwest of North America, from where many of the species used in UK forestry originate (e.g. Lines, 1987).

Data from UK trials within larger international networks are not only of use domestically but are regularly contributed to efforts to characterise genetic resources and predict adaptive trajectories of species at a continental scale (e.g. Saenz-Romero et al. 2017; Robson et al. 2018). Metadata from UK organisations have been supplied to multinational FGR databases under the NOLTFOX and TreeBreedEx projects.

Development of genomic resources has benefitted from international collaborations in which resources, genetic materials and expertise are pooled. For example, PiSy50k is a new SNP array for *Pinus sylvestris* (Scots pine) developed through international collaboration (especially between Scotland and Finland) under various EU-funded projects (Kastally et al. 2021).

UK researchers regularly benefit from training in FGR through European research projects and networks.

11.3. Needs, challenges and opportunities

- Continued, and deepened, membership and engagement with EUFORGEN is essential to maintain involvement and make contributions to Pan-European initiatives in FGR and to benefit domestically from new innovations in EUFGIS delivered through the FORGENIUS project (see chapter 6).

- Opportunities to develop or rejuvenate sub-regional collaborations could be explored further. Sub-regional collaborations of particular interest are those with Ireland, those along the Atlantic seaboard of Europe, and involvement in Nordic collaborations (e.g. SNS – Nordic Forest Research).

- Conifers from the Pacific Northwest of North America are essential to UK forestry and exchange was historically routine. These relationships provide opportunities to help the UK horizon scan and prepare for potential future threats to North American conifers used in the UK.

- Nominating a national focal point for future assessments of the State of the World's FGR will ensure that liaison between the UK and the Intergovernmental Technical Working Group on FGR is established formally.

Chapter 12. Actions for the future

12.1. Availability of information on forest genetic resources

Genetic characterisation of most tree species is minimal, which hampers our ability to set bespoke genetic conservation targets, develop seed production strategies and devise evidence-based systems or advice for seed sourcing and tree planting. Establishment of common methodologies to improve characterisation of FGR using molecular markers and by evaluating well-designed common-garden experiments (species, provenance, progeny trials etc.) would help link conservation, management, development, and use of FGR.

Such studies could provide better understanding of how genetic diversity is distributed, how natural selection is acting on this to allow adaptation to change and how genetic diversity can be deployed.

A strategic approach to improving characterisation would help prioritisation and coordination of such work and development of supporting infrastructure.

12.2. Conservation of forest genetic resources

Maintenance of genetic diversity and adaptive potential in forests will continue to be encouraged by UKFS and wider guidance.

Recent momentum in establishing GCUs can be built upon to identify and designate further units. The demonstrative and educational value of GCU designation should be maximized with outreach efforts.

Better linkages between conservation and use of FGR could be made and the potential for in situ GCUs to act as sources of true-to-type seed can be explored, where it is contingent with other management and conservation objectives. This would encourage designation of sites and incentivise their management.

The potential to carry out research in clone banks of well-tested species (in conjunction with existing field trials) could be explored to rapidly phenotype members of breeding populations for new traits of interest.

Ex situ germplasm collections will continue to be used as a research resource and should be continually updated and refined as more evidence becomes available.

12.3. Use, development, and management of forest genetic resources

The FRM system provides a functional system of audit and compliance with FRM regulations but does not provide an advisory function.

A significant number of seed stands and seed orchards are registered on the FRM system but ongoing effort is needed to identify/plant further sources. There is a need for wider registration and use of indigenous SI stands of known origin.

Maintaining genetic diversity of tree populations will be crucial so that this diversity can be exploited to support the future adaptation of woodlands and treescapes to the rapidly changing climate, as well as other stresses.

Scientific advances in molecular tools, digital infrastructure and phenotyping provide opportunities for tree improvement but it is necessary for improvement programmes to be active and operating at scale for these opportunities to be fully exploited.

Explicit consideration of evolutionary processes in adaptive forest management (e.g. Lefevre et al. 2014) could be instilled through training in the profession. Many concepts are already present in modern silviculture but are not yet formalized in current forestry practice in the UK with genetic terminology which means that efforts are difficult to record.

12.4. Policies, institutions, and capacity building

Work is underway to establish a group to facilitate information exchange and deliver technical advice and co-ordination of activities covering all aspects of future species selection and supply to support delivery of resilient woodlands and forests across the UK. The group will facilitate information exchange and deliver technical advice and co-ordination for activities including identification of priority species for planting across the UK, species trials, tree seed supply and tree improvement. It includes understanding the genetic diversity of UK forests, current approaches to *in situ* and *ex situ* gene conservation and use of Forest Genetic Resources (FGR), with the secretariat also providing the function of a national focal point on FGR.

Communicating the importance of FGR is a priority and opportunities should be taken to incorporate teaching on FGR into relevant college or university courses and develop continuous professional development events in the profession. A challenge is the shortage of personnel who are capable of delivering such training alongside existing responsibilities.

Strengthening existing international partnerships, identifying new ones, and rejuvenating past ones will provide valuable learning opportunities.

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Appendix . Technical Questionnaire

This appendix contains responses to technical questions in the FAO Forest Genetic Resources questionnaire for the second report on the State of the World's Forest Genetic Resources. A formal submission would be achieved by means of an online survey.

Responses are provided in two parts, Part A contains ten questions and forms a draft UK response to the Global Plan of Action for the Conservation, Sustainable Use and Development of Forest Genetic Resources. Part B contains fifteen questions and describes the State of Conservation, Use and Development of UK Forest Genetic Resources, summarising more detailed information provided in the complementary report.

Part A: Responses of countries to the Global Plan of Action for the Conservation, Sustainable Use and Development of Forest Genetic Resources

Table A.1. Summary responses to questions 1-10 in Part A.

1	Does your country have an operational national (or sub-national) FGR inventory (-ies)?	No
2	Does your country have an up-to-date national (or sub-national) FGR information system(s)?	Initiated
3	Does your country have an operational national (or sub-national) in situ conservation system(s) for FGR?	Yes
4	Does your country have an operational national (or sub-national) ex situ conservation system(s) for FGR?	No
5	Does your country have an operational national (or sub-national) tree seed programme(s)?	No
6	Do public entities, private companies and/or other stakeholders operate a tree breeding programme (or programmes) in your country?	Yes
7	Does your country have an extension programme (or programmes) that organizes extension activities on FGR use on a regular basis?	No
8	Does your country have a national (or sub-national) coordination mechanism(s) on FGR?	Initiated
9	Does your country have a national strategy (or sub-national strategies) for FGR conservation and use?	Yes
10	If your country has a national strategy for FGR, is it aligned with a regional or subregional FGR conservation strategy (-ies)	Yes

Table A.2. Expanded responses to questions 1-10 in part A.

<table>
<tr><td>1</td><td>Does your country have an operational national (or sub-national) FGR inventory (-ies)?</td><td>No</td></tr>
<tr><td></td><td colspan="2"> FAO glossary definitions: National (or sub-national) FGR inventory (-ies) refers to a mechanism that gathers data and information, often from several data-providers within a country, on areas and facilities managed for the conservation of FGR and the production of forest reproductive material, as well as related research and development (R&D) efforts, for example. A national (or sub-national) FGR inventory is operational when the collection of data and information is repeated frequently, and when the data and information are processed, stored and made available to support policymaking, management of FGR and R&D efforts. </td></tr>
<tr><td></td><td colspan="2"> The United Kingdom does not have centrally designated national nor subnational FGR mechanism(s) for data and information gathering on multiple aspects of FGR conservation, management and use. Component parts of a potential mechanism exist and are described in our response to the questions in this technical appendix. </td></tr>
<tr><td>2</td><td>Does your country have an up-to-date national (or sub-national) FGR information system(s)?</td><td>Initiated</td></tr>
<tr><td></td><td colspan="2"> FAO glossary definitions: National (or sub-national) FGR information system refers to a database (or databases) and other electronic documentation systems (off-line or on-line) that is used by a national FGR inventory to gather, store and/or make available the data and information on FGR. A national FGR information system is up-to-date when the data and information are updated periodically (e.g. annually) or whenever new data and information have become available. </td></tr>
<tr><td></td><td colspan="2"> The UK Forest Genetic Resources Group, which is a cross-institutional partnership offer a map-based metadata platform for UK FGR which operates from a web browser. The UK Forest Genetic Resources Group is a partnership between Future Trees Trust, Forest Research, UK Centre for Ecology & Hydrology, Woodland Trust and Royal Botanic Gardens, Kew Two map browsers are currently available on the UKFGR website. One shows ‘research trials’ and the other shows ‘conservation units’. Research trials contains summary details of: Provenance trials
Progeny trials
Clonal seed orchards
Clonal archives (clone bank)
Plus trees (geographic locations of founders) The seed orchards, clone banks and plus trees shown are those operated or established under the auspices of the Future Trees Trust, which is a third-sector organisation dedicated to broadleaved tree improvement. The data held do not yet include any details on conifer species used in commercial forestry which represent by far the largest resource of genetic trials, seed production units and ex situ collections. These details are held by multiple agencies in different formats. Conservation units contains summary details of: Genetic conservation units (in situ)
Seed collection locations (from the UK National Tree Seed Project) All locations are currently presented using “fuzzy” mapping in accordance with GDPR. The website offers the facility to contact a named researcher or the system administrator for further details. The service is hosted by the Future Trees Trust. </td></tr>
<tr><td>3</td><td>Does your country have an operational national (or sub-national) in situ conservation system(s) for FGR?</td><td>Yes</td></tr>
</table>

	FAO glossary definitions: National (or sub-national) in situ conservation programme (or system) for FGR refers to a longterm in situ conservation programme of FGR that is undertaken and coordinated by a designated national (or sub-national) agency working in collaboration with various stakeholders. Typically, the main aim of such conservation programme is to establish and maintain a network of in situ conservation units for FGR in a country (or state).	
	The Forestry Commission represents the UK as a member of EUFORGEN and uses EUFGIS to store and manage information on genetic conservation units. The national coordinator for EUFORGEN is employed by the Forestry Commission. The national focal point for EUFGIS is employed by Forest Research (the research agency of the Forestry Commission) and acts as a deputy and scientific advisor to the national coordinator for EUFORGEN. Genetic conservation units have only recently been designated in the United Kingdom (one in 2019; sixteen in 2021). Responsibilities for information management are held by the domestic EUFGIS national focal point. A system to coordination monitoring and management of GCUs has not yet been established in the UK but will be put in place as the concept of GCUs matures.	
4	Does your country have an operational national (or sub-national) ex situ conservation system(s) for FGR?	No
	FAO glossary definitions: National (or sub-national) ex situ conservation programme (or system) for FGR refers to an ex situ conservation programme of FGR that is undertaken and coordinated by a designated national (or sub-national) agency working in collaboration with various stakeholders. An ex situ conservation programme is often based on a combination of ex situ conservation stands, field collections (e.g. clonal archives and stool beds) and storage facilities for seed, pollen or other tissue.	
	The United Kingdom does not have a coordinated system for ex situ conservation of FGR. Two main categories of ex situ conservation of FGR have been recognised in the United Kingdom. These are: 1. Ex situ germplasm collections for long-term genetic conservation (seed banking). Royal Botanic Gardens, Kew holds a comprehensive collection of seed for UK native tree species under the UK National Tree Seed Project which was established for conservation purposes. A current project is scoping the means to make metadata pertaining to these collections available to stakeholders. A duplicate of this collection is held by Royal Botanic Garden Edinburgh. 2. Ex situ collections of FGR for improvement and deployment purposes. Clone banks/archives are held for species of economic importance by agencies engaged in tree breeding such as Forest Research, Future Trees Trust and the Conifer Breeding Cooperative. Storage of tissues, pollen and seed for these species also takes place under tree improvement programmes but is not centrally organised.	
5	Does your country have an operational national (or sub-national) tree seed programme(s)?	No
	FAO glossary definitions: National (or sub-national) tree seed programme refers to a mechanism (or mechanisms) that oversees and/or coordinates the selection, procurement, documentation, storage and testing of forest reproductive material at national or sub-national levels. Such mechanism typically brings together an official body responsible for approving basic material and maintaining a national or sub-national register of this material, as well as other stakeholders (public and private) involved in the selection, procurement, storage and testing of forest productive material.	

	The United Kingdom does not have a centrally coordinated national (or sub-national) tree seed programme(s), although component parts exist. The Forestry Commission, through its Forest Reproductive Material (FRM) secretariat is the official body responsible for approving basic material, maintaining a national register of approved basic materials, a register of approved FRM suppliers and issuing master certificates. Both public and private sector entities are involved in selection, procurement, storage and testing of FRM. Guidance relating to the use of FRM is issued by public forestry bodies at sub-national level and supported by evidence generated by researchers and practitioners.	
6	Do public entities, private companies and/or other stakeholders operate a tree breeding programme (or programmes) in your country?	Yes
	FAO glossary definitions: Tree breeding programme refers to systematic efforts based on the application of genetic principles and practices to develop improved trees. Tree breeding programmes may be public, private or private– public partnerships, and they may operate at sub-national, national, regional or global scales.	
	Tree breeding programmes have operated in the United Kingdom since the 1940's. The Forestry Commission (via its research agency Forest Research) made the most progress in the 20th Century on several economically important conifers. Public-private partnership working has developed in the last decade with the formation of the Conifer Breeding Co-operative. Broadleaved tree improvement is conducted under the auspices of the Future Trees Trust, a third-sector organisation. The Future Trees Trust works in partnership with a range of public and private entities. The National Tree Improvement Strategy was launched in 2017 to act as an umbrella body for domestic tree improvement efforts.	
7	Does your country have an extension programme (or programmes) that organizes extension activities on FGR use on a regular basis?	No
	FAO glossary definitions: Extension programmes or activities refers to training and communication efforts targeted to users of FGR (farmers, local communities, forest owners, etc.) with an aim to help them enhance their use of FGR to derive economic and other benefits. Extension activities may include short-term training courses and workshops, field trips, exhibitions, media campaigns and dissemination of information through leaflets, posters and guidelines, or even development of online tools	
	The United Kingdom does not have a centrally coordinated, regular programme of training and communication in the use of FGR. Guidance related to legislation pertaining to forest reproductive materials is issued periodically in the form of newsletters by the Forestry Commission. Guidance and decision support tools pertaining to species and provenance choice are managed by Forest Research.	

	Other extension activities take place periodically but are either broader in scope than (i.e. activities organised by professional bodies) or associated with specific projects.	
8	Does your country have a national (or sub-national) coordination mechanism(s) on FGR?	Initiated
	FAO glossary definitions: National (or subnational) coordination mechanism on FGR refers to a range of approaches that are used to coordinate the work on FGR at national or subnational levels. Various stakeholders (e.g. farmers, forest owners, the private sector, non-governmental organizations, research organizations and relevant ministries) are typically represented in such a national coordination mechanism. Examples of national coordination mechanisms include national (or subnational) FGR programmes and national (or subnational) committees or working groups on FGR.	
	Multiple groups have been convened which have the remit of coordinating work on FGR. The UK Forest Genetic Resources Strategy is overseen by a steering group led by Future Trees Trust, Forest Research, UK Centre for Ecology & Hydrology, Woodland Trust and Royal Botanic Gardens, Kew. The strategy is formally endorsed by Government and a range of stakeholders. The National Tree Improvement Strategy (NTIS) aims to promote UK trees through selection and breeding of a wide range of tree species capable of thriving in UK conditions. The NTIS steering group meets twice a year and has unrestricted and open membership drawn from across the forestry sector: from nurseries, to forest management of natural, semi-natural and plantation forests and woodlands, through to saw millers, ecologist and sectors of academia. Forest nurseries and seed suppliers are connected in professional bodies such as the Confor Nursery Producer's Group and the Horticultural Trades Associations Tree and Hedging Group The UK's national coordinator for EUFORGEN and national focal point for EUFGIS work together to disseminate European cooperation on FGR to national policy leads via a mailing list. An advisory group was convened in 2022 to support compilation of a UK FGR report (this report), in line with FAO reporting guidelines. There is a high level of overlap between membership of these groups but no hierarchy.	
9	Does your country have a national strategy (or sub-national strategies) for FGR conservation and use?	Yes
	FAO glossary definitions: National (or subnational) strategy(-ies) for FGR conservation and use presents the country's (or its states') vision and goals for the conservation and use of FGR, and describes how it intends to achieve these goals. A national (or subnational) strategy for FGR conservation and use typically reflects both binding (e.g. the Convention on Biological Diversity) and non-binding (e.g. the Global Plan of Action for the Conservation, Sustainable Use and Development of Forest Genetic Resources) international commitments made by the country	
	As above: UK Forest Genetic Resources Strategy, National Tree Improvement strategy.	
10	If your country has a national strategy for FGR, is it aligned with a regional or subregional FGR conservation strategy (-ies)	Yes
	FAO glossary definitions: **Regional or subregional FGR conservation strategy** refers to a vision and goals for the conservation of FGR that a group of countries may have agreed in the context of regional or subregional networks or other collaboration platforms on FGR. **Regional or subregional network** on FGR refers to a regional or subregional network, programme or working group that promote international collaboration on forest genetic resources.	
	The UK Forest Genetic Resources Strategy is aligned to EUFORGEN, who contributed to the development of the strategy.	

Part B. State of Conservation, Use and Development of Forest Genetic Resources.

Table B.1. Key to questionnaire responses

Column title	Chapter in complementary report	Meaning of question	Form of answer	Included in Summary table B.2.
Species	4. The state of diversity between species	Species according to scoping criteria	Text (binomial name)	Yes
Native species	4. The state of diversity between species	Is taxon considered native?	Yes = 1, No = 0	Yes
National distribution available	5. The state of diversity within species	National distribution assumed for all taxa	Yes = 1, No = 0	No
Molecular characterisation (studies)	5. The state of diversity within species	Have there been any molecular studies	Yes = 1, No = 0	Yes
Non-molecular characterisation (common gardens)	5. The state of diversity within species	Have there been any common garden experiments comparing genetic entries?	Yes = 1, No = 0	Yes
In situ programme	6. The state of in situ conservation	Does taxon currently have any GCUs registered in EUFGIS?	Yes = 1, No = 0	Yes
In situ units (number)	6. The state of in situ conservation	Number GCUs are registered in EUFGUS	Numeric	No
In situ units (area ha)	6. The state of in situ conservation	Summed area of GCUs in EUFGIS	Numeric (hectares)	No
Ex situ programme (UKNTSP)	7. The state of *ex situ* conservation	Was taxon included in UK National Tree Seed Project?	Yes = 1, No = 0	Yes
Ex situ programme (living)	7. The state of *ex situ* conservation	Are living accessions of taxon held in clone banks?	Yes = 1, No = 0	Yes
Ex situ units (number)	7. The state of *ex situ* conservation	Number of clone banks with living accessions	Numeric	No
Ex situ accessions	7. The state of *ex situ* conservation	The sum of number of populations sampled for UKNTSP and the number of clones in clone banks	Numeric	No
Ex situ units (area ha)	7. The state of *ex situ* conservation	Summed area of clone banks	Numeric (hectares)	No

Column title	Chapter in complementary report	Meaning of question	Form of answer	Included in Summary table B.2.
Seed stands	8. The state of use	Are there registered seed stands in the National Register of Approved Basic Material?	Yes = 1, No = 0	Yes
Seed stands (number)	8. The state of use	Number of seed stands	Numeric	No
Seed stands (area ha)	8. The state of use	Summed area of seed stands	Numeric (hectares)	No
Seed orchards	8. The state of use	Are there registered seed orchards in the National Register of Approved Basic Material?	Yes = 1, No = 0	Yes
Seed orchards (number)	8. The state of use	Number of seed orchards	Numeric	No
Seed orchards (area ha)	8. The state of use	Summed area of seed orchards	Numeric (hectares)	No
Macropropagated plants produced (thousands)	8. The state of use	Number plants produced by macropropagation	Numeric	No
Micropropagated plants produced	8. The state of use	Number plants produced by micropropagation	Numeric (0 response for all taxa)	No
Tree breeding programme	9. The state of breeding and improvement programmes	Has a tree breeding programme taken place?	Yes = 1, No = 0	Yes
Tree breeding programme (generation)	9. The state of breeding and improvement programmes	How many generations of tree breeding have taken place?	0.5 = initiated, 1 = first cycle complete, 1.5 = programme of single pair matings	No

Table B.2. UK responses to questions 11-26

Species scoping was based on a list of species which are either i. considered native to Great Britain, ii. controlled or iii. certified voluntarily under Forest Reproductive Material regulations (Forestry Commission, 2019). Taxa for which the sum of positive responses to the summary questions in Table B.3 was zero have been excluded from the list.

Species	Native species	Molecular characterisation (studies)	Non-molecular characterisation (common gardens)	*In situ* programme	*In situ* units (number)	*In situ* units (area ha)	*Ex situ* programme (UKNTSP)	*Ex situ* programme (living)	*Ex situ* accessions (number)	*Ex situ* units (area ha)	Seed stands	Seed stands (number)	Seed stands (area ha)	Seed orchards	Seed orchards (number)	Seed orchards (area ha)	Macropropagated plants produced (thousands)	Tree breeding programme	Tree breeding programme (generations)
Abies alba	0	0	1	0	0	0	0	0	0	0	1	1	1.68	0	0	0	0	0	0
Abies alba	0	0	1	0	0	0	0	0	0	0	1	1	1.68	0	0	0	0	0	0

Species	Native species	Molecular characterisation	Non-molecular characterisation	*In situ* programme	*In situ* units (number)	*In situ* units (area ha)	*Ex situ* programme (UKNTSP)	*Ex situ* programme (living)	*Ex situ* accessions (number)	*Ex situ* units (area ha)	Seed stands	Seed stands (number)	Seed stands (area ha)	Seed orchards	Seed orchards (number)	Seed orchards (area ha)	Macropropagated plants produced (thousands)	Tree breeding programme	Tree breeding programme (generations)
Abies amabilis	0	0	1	0	0	0	0	1	3	0.01	0	0	0	0	0	0	0	0	0
Abies grandis	0	0	1	0	0	0	0	1	34	0.11	1	4	8	0	0	0	0	0	0
Abies procera	0	0	1	0	0	0	0	1	11	0.04	1	5	21.04	0	0	0	0	0	0
Acer campestre	1	0	0	0	0	0	1	0	30	0	1	1	9.4	0	0	0	0	0	0
Acer platanoides	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acer pseudoplatanus	0	0	1	0	0	0	0	1	48	0.1152	1	8	21.07	1	2	0.758	0	1	0.5
Alnus glutinosa	1	1	1	0	0	0	1	0	54	0	1	2	0.45	0	0	0	0	0	0
Betula nana	1	1	0	0	0	0	1	0	5	0	0	0	0	0	0	0	0	0	0
Betula pendula	1	1	1	1	4	124.5	1	1	371	0.7968	1	9	21.46	1	2	0.3512	0	1	0.5
Betula pubescens	1	1	1	0	0	0	1	0	57	0	1	4	24.59	0	0	0	0	0	0
Buxus sempervirens	1	0	0	0	0	0	1	0	2	0	0	0	0	0	0	0	0	0	0
Carpinus betulus	1	0	0	0	0	0	1	0	6	0	0	0	0	0	0	0	0	0	0
Castanea sativa	0	1	1	0	0	0	0	1	0	0	1	6	30.35	0	0	0	0	1	0.5
Cornus sanguinea	1	0	0	0	0	0	1	0	22	0	0	0	0	0	0	0	0	0	0
Corylus avellana	1	1	0	0	0	0	1	0	37	0	1	8	195.44	0	0	0	0	0	0
Crataegus laevigata	1	0	0	0	0	0	1	0	10	0	0	0	0	0	0	0	0	0	0
Crataegus monogyna	1	1	1	0	0	0	1	0	63	0	1	3	36.9	0	0	0	0	0	0
Cryptomeria japonica	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cytisus scoparius	1	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0
Euonymus europaeus	1	0	0	0	0	0	1	0	29	0	0	0	0	0	0	0	0	0	0
Fagus sylvatica	1	1	1	0	0	0	1	0	5	0	1	25	116.95	0	0	0	0	0	0
Frangula alnus	1	0	0	0	0	0	1	0	15	0	0	0	0	0	0	0	0	0	0
Fraxinus excelsior	1	1	1	1	3	27.53	1	2	442	0.852	1	14	80.32	1	7	7.207	0	1	1
Ilex aquifolium	1	1	0	0	0	0	1	0	64	0	0	0	0	0	0	0	0	0	0
Juniperus communis	1	1	1	0	0	0	1	0	52	0	0	0	0	0	0	0	0	0	0
Larix decidua	0	0	1	0	0	0	0	6	584	1.78	1	15	146.2	1	5	14.25	0	1	1
Larix kaempferi	0	0	1	0	0	0	0	5	346	1.26	1	13	58.74	1	6	18.75	0	1	1
Larix x eurolepis	0	0	1	0	0	0	0	1	9	0.04	1	2	3.33	0	0	0	0	1	1
Ligustrum vulgare	1	0	0	0	0	0	1	0	13	0	0	0	0	0	0	0	0	0	0
Malus sylvestris	1	1	0	1	1	874	1	0	52	0	0	0	0	0	0	0	0	0	0
Nothofagus obliqua	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Species	Native species	Molecular characterisation	Non-molecular characterisation	*In situ* programme	*In situ* units (number)	*In situ* units (area ha)	*Ex situ* programme (UKNTSP)	*Ex situ* programme (living)	*Ex situ* accessions (number)	*Ex situ* units (area ha)	Seed stands	Seed stands (number)	Seed stands (area ha)	Seed orchards	Seed orchards (number)	Seed orchards (area ha)	Macropropagated plants produced (thousands)	Tree breeding programme	Tree breeding programme (generations)
Picea abies	0	0	1	0	0	0	0	2	9	0.05	1	6	34.4	0	0	0	0	1	0.5
Picea engelmannii	0	0	0	0	0	0	0	2	43	0.11	0	0	0	0	0	0	0	0	0
Picea glauca	0	0	0	0	0	0	0	2	31	0.01	0	0	0	0	0	0	0	0	0
Picea omorika	0	0	0	0	0	0	0	2	39	0.09	1	2	2	0	0	0	0	0	0
Picea sitchensis	0	1	1	0	0	0	0	4	1821	6.31	1	9	265.84	1	14	55.815	11337	1	1.5
Pinus contorta	0	0	1	0	0	0	0	1	0	0	1	7	126.81	1	1	2.1	0	1	0.5
Pinus nigra	0	0	1	0	0	0	0	4	355	0.52	1	7	69.34	1	3	17.3	0	1	1
Pinus pinaster	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pinus radiata	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pinus sylvestris	1	1	1	1	2	269.32	1	3	395	1.57	1	93	11337.23	1	4	14.3	0	1	1
Populus nigra var. betulifolia	1	1	0	0	0	0	1	0	4	0	0	0	0	0	0	0	11	0	0
Populus spp.	0	1	0	0	0	0	0	0	0	0	1	3	0.027	0	0	0	0	0	0
Populus tremula	1	1	1	0	0	0	1	1	4	0	0	0	0	0	0	0	140	0	0
Prunus avium	1	1	1	0	0	0	1	1	39	0	0	0	0	1	6	4.68	0	1	1
Prunus padus	1	0	0	0	0	0	1	0	31	0	1	1	0.06	0	0	0	0	0	0
Prunus spinosa	1	1	0	0	0	0	1	0	56	0	0	0	0	0	0	0	0	0	0
Pseudotsuga menziesii	0	0	1	0	0	0	0	2	158	0.41	1	21	186.05	1	2	2.68	0	1	0.5
Quercus petraea	1	1	1	1	5	132.18	0	1	18	0.0432	1	67	1674.66	0	0	0	0	1	0.5
Quercus robur	1	1	1	1	1	12.8	1	1	50	0.12	1	50	299.17	0	0	0	0	1	0.5
Quercus rubra	0	0	1	0	0	0	0	0	0	0	1	2	3.92	0	0	0	0	0	0
Rhamnus cathartica	1	0	0	0	0	0	1	0	15	0	0	0	0	0	0	0	0	0	0
Ruscus aculeatus	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Salix arbuscula	1	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0
Salix aurita	1	0	0	0	0	0	1	0	20	0	0	0	0	0	0	0	0	0	0
Salix caprea	1	0	0	0	0	0	1	0	18	0	0	0	0	0	0	0	0	0	0
Salix cinerea	1	0	0	0	0	0	1	0	5	0	0	0	0	0	0	0	0	0	0
Salix lapponum	1	0	0	0	0	0	0	0	0	0	1	2	0.017	0	0	0	0	0	0
Salix myrsinifolia	1	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0
Salix pentandra	1	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0
Salix phylicifolia	1	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0
Salix repens	1	0	0	0	0	0	1	0	8	0	0	0	0	0	0	0	0	0	0
Sambucus nigra	1	0	0	0	0	0	1	0	49	0	0	0	0	0	0	0	0	0	0

Species	Native species	Molecular characterisation	Non-molecular characterisation (common gardens)	*In situ* programme	*In situ* units (number)	*In situ* units (area ha)	*Ex situ* programme (UKNTSP)	*Ex situ* programme (living)	*Ex situ* accessions (number)	*Ex situ* units (area ha)	Seed stands	Seed stands (number)	Seed stands (area ha)	Seed orchards	Seed orchards (number)	Seed orchards (area ha)	Macropropagated plants produced (thousands)	Tree breeding programme	Tree breeding programme (generations)
Sequoia sempervirens	0	0	1	0	0	0	0	0	0	0	1	4	12.36	0	0	0	0	0	0
Sequoiadendron giganteum	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sorbus aria s.l.	1	0	0	0	0	0	1	0	63	0	0	0	0	0	0	0	0	0	0
Sorbus aucuparia	1	1	1	1	2	27.7	1	0	65	0	1	1	0.2	0	0	0	0	0	0
Sorbus torminalis	1	0	1	0	0	0	1	0	22	0	0	0	0	0	0	0	0	0	0
Taxus baccata	1	1	0	0	0	0	1	0	25	0	1	1	6.7	0	0	0	0	0	0
Thuja plicata	0	0	1	0	0	0	0	1	49	0.07	1	6	8.09	1	1	0.2	0	0	0
Tilia cordata	1	1	0	0	0	0	1	0	18	0	1	3	20.5	0	0	0	0	0	0
Tilia platyphyllos	1	1	0	0	0	0	1	0	8	0	0	0	0	0	0	0	0	0	0
Tsuga heterophylla	0	0	1	0	0	0	0	1	0	0	1	2	5.41	0	0	0	0	0	0
Ulmus glabra	1	0	0	0	0	0	1	0	51	0	0	0	0	0	0	0	0	0	0
Viburnum lantana	1	0	0	0	0	0	1	0	15	0	0	0	0	0	0	0	0	0	0

Table B.3. Summary table for species with four or more positive responses to binary questions in the questionnaire

Species	Native/Non-native	Molecular studies	Common garden experiments	Gene conservation units	*Ex situ* (germplasm)	*Ex situ* (living)	Seed stands	Seed orchards	Breeding programme	Sum
Fraxinus excelsior	Native	1	1	1	1	1	1	1	1	8
Pinus sylvestris	Native	1	1	1	1	1	1	1	1	8
Betula pendula	Native	1	1	1	1	1	1	1	1	8
Quercus robur	Native	1	1	1	1	1	1	0	1	7
Prunus avium	Native	1	1	0	1	1	0	1	1	6
Quercus petraea	Native	1	1	1	0	1	1	0	1	6
Sorbus aucuparia	Native	1	1	1	1	0	1	0	0	5
Fagus sylvatica	Native	1	1	0	1	0	1	0	0	4
Betula pubescens	Native	1	1	0	1	0	1	0	0	4
Crataegus monogyna	Native	1	1	0	1	0	1	0	0	4
Alnus glutinosa	Native	1	1	0	1	0	1	0	0	4
Populus tremula	Native	1	1	0	1	1	0	0	0	4
Picea sitchensis	Non-native	1	1	NA	NA	1	1	1	1	6
Larix kaempferi	Non-native	0	1	NA	NA	1	1	1	1	5
Larix decidua	Non-native	0	1	NA	NA	1	1	1	1	5
Pinus nigra	Non-native	0	1	NA	NA	1	1	1	1	5
Pseudotsuga menziesii	Non-native	0	1	NA	NA	1	1	1	1	5
Acer pseudoplatanus	Non-native	0	1	NA	NA	1	1	1	1	5

Pinus contorta	Non-native	0	1	NA	NA	1	1	1	1	5
Castanea sativa	Non-native	1	1	NA	NA	1	1	0	1	5
Thuja plicata	Non-native	0	1	NA	NA	1	1	1	0	4
Larix x eurolepis	Non-native	0	1	NA	NA	1	1	0	1	4