COFORD

Sustainable Development and Conservation of Forest Genetic Resources

2020-2030

COFORD Forest Genetic Resources Working Group

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Foreword

Forest genetic resources are integral to the success of the forest sector. Quality seed and other reproductive material suited to their environment are the building blocks for expanding the forest estate and are essential to drive the economic, environment, scientific and societal benefits that forests provide. Conservation of the forest genetic resource is essential to protect the genetic diversity of our forest resource and thus ensure that our forests are more resilient to the challenges posed by climate change.

I am therefore very pleased to introduce *Sustainable Development and Conservation of Forest Genetic Resources 2020-2030*. This publication, prepared by members of the COFORD Forest Genetic Resources Working Group, addresses key challenges faced by the sector, including climate change, and how forest genetic resources can be mobilised to increase the adaptive capacity of our forests. Other core elements include how to ensure the sustainable supply and use of seeds and other reproductive material, and steps required for the genetic conservation of our native, naturalised and exotic tree species. The report outlines the roles of those agencies and organisations involved in forest genetic resources and the need to coordinate effort.

I would like to thank the members of the Forest Genetic Resources Working Group for their hard work in putting this publication together. The Group, comprised of a broad range of experts and stakeholders, are to be congratulated in reaching a consensus on the future direction in forest genetic resources, and for bringing the many strands together into a publication that provides clear recommendations on developing a national strategy to underpin the development and conservation of forest genetic resources in Ireland.

Eugene Hendrick
COFORD Council Chairman

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The Forest Genetic Resources Working Group is a working group of the COFORD Council. The aim of the group is to develop a strategy for the development, conservation, and deployment of forest genetic resource material. The group is comprised of a range of experts and stakeholders from the forest sector, including Fergus Moore (Chair, Department of Agriculture, Food and the Marine), Brian Clifford (Department of Agriculture, Food and the Marine), Gerry Douglas (Forest Genetic Resources Trust), Seamus Dunne (Department of Agriculture, Food and the Marine), Niall Farrelly (Teagasc), John Kavanagh (None-So-Hardy), Colin Kelleher (National Botanic Gardens (Office of Public Works)), Dermot O'Leary (Coillte), Miguel Nemesio-Gorriz (Teagasc), Declan Little (Coillte), Jim McNamara (Laois Sawmills), Conor O'Reilly (University College Dublin), Jenni Roche (National Parks and Wildlife Service), Richard Schaible (Department of Agriculture, Environment, and Rural Affairs-Northern Ireland), Luke Sweetman (Department of Agriculture, Food and the Marine), Brian Tobin (University College Dublin).

Case studies included in this report were developed in collaboration with the FORM-Forest Management Research Project. Thanks are also due to the Forest Genetic Resources Trust for their input into the case study on oak.

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Executive summary

This report sets out a **strategy for the sustainable development and conservation of Forest Genetic Resources in Ireland for the period 2020-2030**. It is the successor document to *Sustaining and Developing Ireland's Forest Genetic Resources – An outline Strategy* published by COFORD in 2007. It has been developed based on the deliberations of the **Forest Genetic Resources Working Group**, first formed under the COFORD Council 2015 – 2018, and reconvened under the Council term 2019-2021. It brings together a full appraisal of current and past efforts, the potential impacts of climate change and other risks, the requirements for the development of forest genetics resources and for gene conservation.

Chapter 1 provides an update on the state of forest genetic resources in Ireland and developments since the publication of the previous 2007 strategy. It includes details on the organisations involved and their activities, an overview of the policy and regulatory framework, the current forest basic material resource and forest genetic resource conservation efforts. **Chapter 2** outlines genetic options for adapting forests to climate change and biotic risk and includes a series of actions necessary to improve the resilience of our forests. **Chapter 3** details the requirements necessary to develop the sector. It addresses a number of key issues, including, long-term research in tree improvement, research priorities, forest reproductive supply needs and knowledge transfer. **Chapter 4** outlines the requirements for gene conservation and includes an implementation plan for the conservation of native tree species. **Chapter 5** collates the arguments made into a series of recommendations. Finally **Chapter 6** includes a series of case studies in support of the recommendations. These case studies address the challenges and steps required for the development of forest reproductive material for four key species (ash (*Fraxinus excelsior*), Douglas-fir (*Pseudotsuga menziesii*), oak *(Quercus petraea* & *Quercus robur*) and Sitka spruce (*Picea sitchensis*)).

The key findings and recommendations are:

1. That this document is used as a basis of a National Strategy in Forest Genetic Resources for the period 2020-2030.	
Steps Necessary for Delivery	Key stakeholders
a. Adoption of recommendation by the COFORD Council and endorsement of the report by key stakeholders.	COFORD Council, DAFM, Coillte, FGRT, NPWS, NBG, RPOs, private-sector forest nurseries, Teagasc.

2. That the Forest Genetic Resources Working Group (FGRWG) be maintained to act as an Advisory Group to guide the development of the sector and implementation of recommendations listed in this report.	
Steps Necessary for Delivery	Key stakeholders
a. Adoption of recommendation by the COFORD Council.	COFORD Council.

3. That the Forest Genetic Resources Working Group (FGRWG) monitor the implementation of the recommendations and produce an implementation report within three years of the strategy being published.	
Steps Necessary for Delivery	Key stakeholders
a. Adoption of recommendation by the COFORD Council.	COFORD Council
b. The implementation and status of the report recommendations will be monitored annually.	FGRWG

4. That genetic options outlined in this report for adapting forests to climate change and mitigating biotic risk are considered.	
Steps Necessary for Delivery	Key stakeholders
a. Inclusion of FGR research themes in DAFM competitive research calls (see recommendation 6).	DAFM
b. Records of provenance that accompany afforestation and reforestation projects to be maintained by DAFM, and by Coillte on the public estate. Record-keeping is essential to inform FRM decisions in the future.	DAFM, Coillte
c. Tree improvement programmes should implement selection and breeding strategies aimed at increasing climate change resilience.	DAFM, Coillte, Teagasc, Forest Genetic Resources Trust
d. Policymakers, forest managers and owners should prioritise diversity, both between species and within species, to increase the adaptive capacity of Irish forests.	DAFM, forest industry & forest owners
e. For native woodland establishment or native woodland rehabilitation, provenance selection should be investigated as a means of increasing climate change resilience. Such an investigation should include further study of the adaptive potential of native trees and consideration of a desirability/needs framework to assess the risk of maladaptation	DAFM, NBG, NPWS, RPOs.

5. That steps outlined in this report for the development of a fit for purpose research capacity in forest genetic resources are implemented.	
Steps Necessary for Delivery	Key stakeholders
a. That the Sitka spruce tree improvement programme is secured, and that germplasm and the running of the programme be developed at the national level. That a National Tree Improvement Programme be considered as part of a Longer-Term Forest Research Centre of Excellence.	DAFM, Coillte, Teagasc, RPOs.
b. That organisations involved in the development of forest genetic resources build on their strengths and develop their skills and facilities.	DAFM, Coillte, NBG, Teagasc, RPOs.
c. That national and international co-operative research networks and programmes continue to be encouraged and facilitated.	DAFM, Coillte, National Botanic Gardens, Teagasc, RPOs.

6. That research into the sustainable use and conservation of forest genetic resources is strengthened.	
Steps Necessary for Delivery	Key stakeholders
a. That the sustainable use and conservation of Forest Genetic Resources are included as a research theme in the DAFM competitive research call.	DAFM.
b. That the range of species, provenances and origins recommended for use in Irish forestry are re-examined in the context of climate change to determine adaptability to future climatic conditions. Where gaps in knowledge occur, set up new provenance trials to assess the adaptive potential to respond to ongoing changes in environmental conditions.	DAFM, Coillte, Teagasc, RPOs.
c. That species listed in Table 7 (pg. 16) are prioritised for tree improvement. Species in this table have been assigned a tier 1 or tier 2 position based on their current, or probable, future importance to the national planting programme.	DAFM, Coillte, Teagasc, RPOs.
d. For native species, the genetic component of extant forest trees needs to be studied in greater details to assess adaptive potential.	DAFM, Coillte, NBG, NPWS, Teagasc, RPOs.

7. That steps outlined in this report to increase the proportion of genetically improved forest reproductive material are taken to increase the availability of genetic resources which have been developed in the categories '*Selected*', '*Qualified*' and *Tested*' in accordance with the EU Directive 1999/105/EC	
Steps Necessary for Delivery	Key stakeholders
a. The establishment of seed orchards should continue to be a priority in order to increase the availability of '*Qualified*' and '*Tested*' FRM.	DAFM, Coillte, Teagasc, private-sector forest nurseries.
b. The system of updating and registering the network of seed stands be maintained.	DAFM.
c. A seed stand activation programme should be initiated to increase the number of stands from which seed is collected. Initially at a pilot level focusing on oak (Quercus petraea & Quercus robur).	DAFM, FGRT.
d. An annual assessment of seed cropping is needed in order to provide a forecast of potential cropping ahead of time.	Coillte, private-sector forest nurseries.
e. The seed stands element of the Forest Genetic Resources Reproductive Material: Seed Stand & Seed Orchard should be maintained post-2021 and enhanced to include supports to enable effective seed collection.	DAFM.

8. That an awareness programme, overseen by the Forest Genetic Resources Working Group be prepared and implemented to inform the industry, other relevant parties and the wider public, of the importance of forest genetic resources, forest reproductive material legislation, seed collection systems, promoting the benefits of using quality material, showing the negative effects of inferior material and the overall importance of forest reproductive material.	
Steps Necessary for Delivery	Key stakeholders
a. FGRWG to develop a campaign and co-ordinate its implementation.	FGRWG & participating organisations.

9. That steps outlined in this report for the Forest Genetic Resources conservation are implemented.	
Steps Necessary for Delivery	Key stakeholders
a. Implement the strategy included in this report for *in situ* conservation of native tree species.	NBG, NPWS, DAFM.
b. Further, develop the strategy to in-corporate priority non-native and naturalised tree species.	FGRWG.
c. Maintain links with pan-European processes for FGR conservation through the EUFORGEN and the EUFGIS network.	DAFM.
d. Update the inventory of *ex situ* FGR at the national level.	DAFM.

A Sitka spruce seed orchard at Ballintemple Co. Carlow.

1 Update on the current state of forest genetic resources in Ireland

1.1 Organisations involved in Forest Genetic Resources

There are a number of organisations involved in different forest genetic resources activities. Table 1 lists these organisations and their activity as it relates to FGR.

TABLE 1 Organisations involved in forest genetic resources in Ireland.

Organisation	Activity
Department of Agriculture, Food and the Marine (DAFM)	Under the Forestry Act 2014, the Minister has overall responsibility for the development & regulation of FGR in Ireland. DAFM is responsible for implementing EU Council Directive 1999/105/EC on the marketing of forest reproductive material, and the OECD scheme for the certification of forest reproductive material moving in international trade. It is also responsible for the Plant Health Regulation (EU) 2016/2031. It maintains the National Register of Basic Material, operates the FGR seed stand & seed orchard scheme and provides development support through its Forest Sector Development Division. It also provides funding for *"public good"* research to Irish RPO's (research performing organisations) on a competitive basis.
Coillte	Coillte is the current custodian of the Irish Sitka spruce Tree Improvement Programme (ISSTIP). It operates a Forest Tree Seed Centre at Ballintemple Co. Carlow and has a well-developed network of conifer and broadleaf seed orchards, species, provenance, and progeny trials.
Forest Genetic Resources Trust (FGRT)	The origins of the FGRT began in the early 1990s via a partnership known as the British and Irish Hardwood Improvement Programme. The British component of this is now rebranded as the Future Trees Trust and the Irish component the Forest Genetic Resources Trust. Broadleaf tree improvement programmes in silver birch, sycamore, oak, ash and cherry continue to operate.
National Botanic Gardens (NBG)	The NBG carry out research in FGR conservation, population genetics and genomics. They are currently leading a programme to establish a gene conservation network for native tree species in Ireland. The NBG is also the custodian of the forest plot network at JFK Arboretum Co. Wexford, and the former tree improvement centre and associated gene banks at Kilmacurra Co. Wicklow.
The National Parks and Wildlife Service (NPWS)	The NPWS are responsible for National Parks and state-owned Nature Reserves, which contain the majority of native species *in situ* conservation areas. The NPWS is the management authority in Ireland for the Convention in the International Trade in Endangered Species of Wild Fauna and Flora (CITES) and also for EU Regulation No. 511/2014 on Access to Genetic Resources and Benefit Sharing. It is the role of NPWS to designate legally protected areas and to advise on the conservation of protected habitats and species.
None-So-Hardy (Forestry Ltd)	Private sector forest tree nursery. Commercial partner to the Teagasc birch breeding programme and has established orchards in birch and sycamore.
Teagasc	Research programmes in tree breeding & genetics, including ash breeding for tolerance to ash dieback, birch and alder improvement, the response of tree species to climate change, and genomic evaluation for the sustainable improvement of Sitka spruce.
Research Performing Organisations	Relevant RPOs include Teagasc, the National Botanic Gardens and universities such as University College Dublin, Trinity College and Dublin City University, all of whom have recently undertaken research in the FGR area.
Other relevant stakeholders	Registered foresters, private forest owners, The Society of Irish Foresters, Woodlands of Ireland.

1.2 Policy and regulatory framework

1.2.1 Policy

Forest genetic resources are recognised as being integral to the success of the forest sector within the current national policy framework, *Forests, products and people. Ireland's forest policy – a renewed vision* (DAFM, 2014), where it is recommended that: *"DAFM establish a representative National Forest Genetic Resources Advisory Group to guide all aspects of future genetic requirements and advice on the management of reproductive material and tree improvement and breeding programmes including formalising the national tree improvement programme"*. It also includes a series of recommendations:

- The genetic quality of planting stock is well adapted and fit for purpose
- Use of genetically improved planting stock to increase both the minimum and average productivity levels
- The use of genetically improved planting material e.g. improved Sitka spruce, as distinct from genetically modified material, which will deliver improved timber quality and timber wood volumes will be supported
- National forest research competence maintained and developed in the FGR programme areas
- Consolidate work in critical forest research areas such as forest genetic resources, that require continuity of effort and national coordination to provide value for money and a level of expertise to achieve the potential of the forest sector

1.2.1.1 Climate Action Plan

The Climate Action Plan (DCCAE, 2019a), highlights a wide range of actions to reduce emissions and meet internationally agreed climate targets. In the Annex of Actions (DCCAE, 2019b), the relevance of forest genetic resources to meeting climate objectives is included under Action 119. *Increase productivity and resilience of the national forest estate and tree species to improve adaptation to climate change to deliver cumulative additional sequestration potential (DCCAE, 2019b)*. Three objectives are listed under Action 119, including:

- Continue to implement tree breeding programmes for key species to increase productivity and resilience and increase species diversity in the national forest estate
- Continue to implement the Forest Genetic Resources Seed Stand and Seed Orchard scheme to increase the supply of selected and improved forest reproductive material
- Develop and implement a national tree gene conservation strategy to ensure the dynamic conservation of key tree species

1.2.1.2 Sectoral Adaptation Plan

DAFM published the Agriculture, Forest and Seafood Climate Change Sectoral Adaptation Plan under the National Adaptation Framework in 2019 (DAFM, 2019). Sectoral impacts and consequences highlighted in the plan include:

- reduced resilience and vitality of forests due to the impact of climate change.
- Increased risk of maladaptation leading to habitat and biodiversity loses.
- Reduced forest productivity, vitality and capacity to sequester carbon.
- Greater susceptibility to attack by harmful forest pests and disease.
- A change in pest and disease behaviour.
- Greater activity and impact of endemic pests and disease due to more favourable climatic conditions and the establishment of exotic pests and disease due to enhanced and favourable climate change-induced conditions.

Sectoral opportunities highlighted in the plan include the changes in plant growth habit and the opportunities that this presents in terms of increasing productivity for some species.

1.2.1.3 National biodiversity action plan

Ireland's third National Biodiversity Action Plan (2017-2021) was published in 2017 by the National Parks and Wildlife Service (DCHG, 2017). The plan sets a vision, that biodiversity and ecosystems in Ireland are conserved and restored, delivering benefits essential for all sectors of society and that Ireland contributes to efforts to halt the loss of biodiversity and the degradation of ecosystems in the EU and globally. The four high-level objectives included in the plan include:

- Mainstream biodiversity into decision-making across all sectors.
- Strengthen the knowledge base for conservation, management, and sustainable use of biodiversity.
- Increase awareness and appreciation of biodiversity and ecosystem services.
- Conserve and restore biodiversity and ecosystem services in the wider countryside.

1.2.1.4 EU & International policy

While it is outside the scope of this document to go into precise detail, at the EU and international level, there are a number of policy instruments around forest genetic resources, aswell as sustainable forest management, agriculture and biodiversity conservation that have both direct and indirect implications for the forest sector. These include the FAO Global Plan of Action on Forest Genetic Resources, the Forest Europe Process, the EU Green Deal, the EU Forest Strategy, and the EU Biodiversity Strategy. Also, it is important to note two key documents at the European level that are currently being developed. The European Forest Genetic Resources Strategy coordinated by EUFORGEN, is planned for publication in 2021. While a European Genetic Resource Strategy is also being developed, under a Horizon 2020 project, GenResBridge, also for publication in 2021.

1.2.2 Regulation

Ireland implements **EU Council Directive 1999/105/EC** on the marketing of forest reproductive material, commonly called the FRM Directive. This Directive is transposed into Irish legislation by **Statutory Instrument No. 618/2002**, the European Communities (Marketing of Forest Reproductive Material) Regulations 2002. Ireland is also a member of the Organisation for Economic Co-operation and Development (OECD) scheme for the certification of forest reproductive material moving in international trade.

The main objective of the FRM Directive is to ensure that forest reproductive material which is marketed, is from approved suitable sources and is clearly labelled and identified throughout the entire process from tree seed collection to processing, storage, forest nursery production and delivery to the final forest user. The Directive provides a set of criteria that describes the types of material which can be legally marketed throughout the EU. It provides a framework for describing the geographic origin and the phenotypic quality which the seed sources provide. Under the Directive, forest reproductive material is categorised based on its level of genetic quality and the degree of selection and testing that has been applied. It is a mechanism to provide information to growers on the genetic quality of reproductive material that they purchase for planting in their forests.

The **OECD Forest Seed and Plant Scheme** was established in 1967 for the control of forest reproductive material moving in international trade. The scheme was fully revised in 1974. The objective was to encourage the production and use of seeds, parts of plants and plants that have been collected, transported, processed and distributed in a manner that ensured their proper identification, as to source and parentage. The scheme enables participating countries to recognise equivalence in their respective FRM production systems thus facilitating trade. In 1973, when Ireland joined then EEC, the OECD scheme was partially superseded by the relevant EEC Directives on the marketing and external quality standards for forest reproductive material, produced within the EEC, but covering a limited number of species (scheduled species). For all other species, the OECD scheme still applied. The OECD scheme is now mainly applied to imports of FRM from non-EU countries and potentially will be very important in trade of FRM with the UK. The scheme covers four broad categories of FRM, '*Source Identified', 'Selected'*, untested seed orchards and tested material.

Forest seeds and plants may also be subject to the requirements of **EU Regulation 2016/2031**, the Plant Health Regulation. This regulation replaced Council Directive 2000/29/EC (commonly referred to as the Plant Health Directive) in December 2019 with an aim to modernise the plant health regime and provide more effective measures for the protection of the Union's territory and its plants and forests from destructive pests and disease.

EU Regulation No. 511/2014 on Access to Genetic Resources and Benefit Sharing obliges all users of genetic resources to exercise due diligence to find out or ensure that the genetic resources were accessed legally and that any benefits that might accrue from their use are fairly and equitably shared as per mutually agreed terms between the provider and the user. This Directive is transposed into Irish legislation by **Statutory Instrument No. 253/2019**.

CITES, the **Convention on International Trade in Endangered Species of Wild Fauna and Flora** aims to regulate and monitor the international trade in certain species of animals and plants and to ensure that trade does not threaten their survival in the wild. CITES is an international agreement between Governments, known as Parties to the Convention, which was agreed in Washington in 1973. It entered into force in 1975. Over 170 Parties (countries) have signed up to the Convention. Ireland became a CITES Party in 2002. CITES is implemented through Regulations known as the Wildlife Trade Regulations which provide the necessary legal framework for the enforcement of the Convention.

1.2.3 National Register of Approved Basic Material

The National Register of Approved Basic Material for Ireland is the source of all information on approved forest basic material. Basic Material is the plant material from which Forest Reproductive Material (FRM) is derived and consists of Seed Stands, Seed Orchards, parent material held in archives, individual Clones and Clonal Mixtures. DAFM maintains the Register and approves all material. Each entry of Basic Material in the Register is given a unique register identity encoding: species, type of Basic Material, category of FRM to be produced, region of provenance, altitude and origin (Table 2).

The six types of basic material include:

I. *Seed Source:* Trees within an area from which seed is collected;
II. *Stand:* A delineated population of trees possessing sufficient uniformity in composition;
III. *Seed Orchard:* A plantation of 'Selected' clones or families which is isolated or managed to avoid or reduce pollination from outside sources, and managed to produce frequent, abundant and easily harvested crops of seed;
IV. *Parents of Family:* Trees used to obtain progeny by controlled or open pollination of one identified parent used as a female, with the pollen of one parent (full-sibling) or a number of identified or unidentified parents (half-sibling);
V. *Clone:* Group of individuals (ramets) derived originally from a single individual (ortet) by vegetative propagation, for example by cuttings, micropropagation, grafts, layers or divisions;
VI. *Clonal Mixture:* A mixture of identified clones in defined proportions

Each type of basic material is classified according to four categories, based on genetic quality:

I. *'Source Identified'* Reproductive material derived from basic material which may be either a seed source or stand located within a single region of provenance and which meets the requirements set out in Annex II of the Council Directive
II. *'Selected'* Reproductive material derived from basic material which shall be a stand located within a single region of provenance, which has been phenotypically 'Selected' at the population level and which meets the requirements set out in Annex III of the Council Directive;

III. *'Qualified'* Reproductive material derived from basic material which shall be seed orchards, parents of families, clones or clonal mixtures, the components of which have been phenotypically 'Selected' at the individual level and which meets certain prescribed requirements set out in Annex IV of the Council Directive. Testing need not necessarily have been undertaken or completed.
IV. *'Tested'* Reproductive material derived from basic material which shall consist of stands, seed orchards, parents of families, clones or clonal mixtures. The superiority of the reproductive material must have been demonstrated by comparative testing or an estimate of the superiority of the reproductive material calculated from the genetic evaluation of the components of the basic material. The material shall meet the requirements set out in Annex V of the Council Directive

TABLE 2 Categories under which reproductive material from the different types of basic material may be marketed as per Annex VI of Council Directive 1999/105/EC

Type of basic material	Category of forest reproductive material			
	Source identified	*Selected*	*Qualified*	*Tested*
Seed source	✔	✘	✘	✘
Stand	✔	✔	✘	✔
Seed orchard	✘	✘	✔	✔
Parents of Family(ies)	✘	✘	✔	✔
Clone	✘	✘	✔	✔
Clonal mixture	✘	✘	✔	✔

1.2.4 Forest seed and plant marketing regulations

Seed and plants may only be marketed if they are derived from basic material identified with a unique reference number in a National Register of Approved Basic Material. A key principle of the Council Directive is that FRM remains clearly identifiable through the entire process from collection to delivery to the end-user. Under the Directive, there is a legal requirement for suppliers of FRM throughout the EU to be officially registered. All seed collectors, seed suppliers, nurseries, plant suppliers/brokers etc. must be registered with the Forest Service of DAFM. All seed collections must be notified in advance following which a Seed Collection Permit is issued. Seed collections are subject to audit by DAFM. Following the seed collection the seed, collector applies for a Master Certificate of Provenance for the collection. Where seed or plants are subsequently marketed the material must be accompanied by a Supplier's Document which incorporates the Master Certificate of Provenance number and the national register reference number for the basic material. Where seed is marketed the supplier, in addition to supplying specified provenance details, must also provide information on seed purity, germination percentage, weight per 1000 seeds and germinable seeds per kg.

For the DAFM grant schemes, plants may only be purchased from registered suppliers. All planting material must be covered by a Supplier's Document in the format of a Provenance Declaration Form. Only specified origins/provenances are grant-aided. The Provenance Declaration Form is divided into two parts. Part A of the Provenance Declaration Form is completed by the nursery/supplier supplying the plants. The nursery/supplier must declare that the origin/provenance complies with the Forest Service list of *Accepted Tree Species for Grant Aid and Accepted Seed Origins/Provenances*. Part B of the Provenance Declaration Form is completed by the forestry contractor or applicant applying for the grant. In all cases, the contractor/applicant must complete an original signed Part B declaring that the provenance details are correct. The number of trees planted and the applicable plot number on the certified species map must also be specified. These rules provide traceability and assurance to the end-user regarding the origin and suitability of the planting stock. Details of the provenance/origin of planted material also provide an essential forest management record for future reference.

1.2.5 Support schemes

The Forest Genetic Resources Reproductive Material measure of the DAFM Forestry Programme 2014-2020 was introduced to support the conservation and development of Ireland's forest genetic resource. The primary objective of this scheme is to: increase the resilience, productivity and quality of Irish forests; increase self-sufficiency in tree seed production; provide for *in situ* and *ex situ* conservation of forest genetic resources; provide breeding populations of broadleaf and conifer species.

The principal benefits of the scheme are increased availability of more advanced and improved FRM to the forest sector, leading to increased productivity in wood production with economic and environmental co-benefits, including improved stem straightness and branching habit leading to higher timber recovery rates; increased wood density, resulting in better wood quality and a wider range of end-product use; better resilience to Irish climatic conditions and local pests and diseases as a result of capturing genetic adaptation in landraces; decreasing the risk of pests and diseases being introduced to Ireland by reducing the need to import material from abroad; *in situ* and *ex situ* conservation of genetic biodiversity; and enabling recurrent selection and improvement through linkages to tree improvement/breeding programmes.

Five new orchards have been established under this scheme since its launch in 2015, including three orchards registered in the *'Qualified'* category (in birch, sycamore and sweet chestnut) and two *'Tested'* Sitka spruce orchards. In 2020 the first *ex situ* conservation area of ash plants potentially tolerant to Ash Dieback disease was also established under the scheme.

DAFM also operates a Native Woodland Scheme under The Forestry Programme 2014-2020. It is aimed at protecting and enhancing Ireland's native woodlands; conservation and biodiversity are prioritised, with wood production encouraged where appropriate. In 2020 DAFM launched the Woodlands Creation on Public Lands scheme, the purpose of this Scheme is to encourage Public Bodies to establish new native woodlands on suitable land. Collectively both these initiatives will increase the cover of native woodland in Ireland.

1.3 Forest basic material

Basic material is the plant material from which Forest Reproductive Material (FRM) is derived and consists of Seed Stands, Seed Orchards, parent material held in archives or genebanks, individual Clones and Clonal Mixtures.

Seed is the most commonly used reproductive material in Irish forestry apart from a small amount of cutting material of improved Sitka spruce. Seed comes from two home sources: seed stands and seed orchards, the greater proportion of which comes from seed stands. The seed stands selection and registration programme is carried out by DAFM; it is an ongoing programme that fulfils the requirements of the EU Directive 1999/105/EC (Table 3).

TABLE 3 Seed stands registered by species and category on the National Register of Approved Basic Material (DAFM, 2020).

Species	*'Source Identified'*	*'Selected'*	Total
		No. of Stands	
Noble fir	-	4	4
Sycamore	-	8	8
Italian alder	-	1	1
Common alder	10	2	12
Downy birch	5	8	13
Sweet (Spanish) chestnut	-	3	3
Lawson cypress	-	1	1
Japanese cedar	2	-	2
Monterey cypress	-	1	1
Beech	-	19	19
Ash	4	4	8
European larch	-	3	3
Japanese larch	-	7	7
Mixed Species Stands	3	-	3
Norway spruce	-	24	24
Sitka spruce	-	49	49
Lodgepole pine	-	10	10
Corsican pine	-	2	2
Monterey pine	-	8	8
Scots pine	4	14	18
Douglas-fir	-	21	21
Sessile oak	24	26	50
Pedunculate oak	20	30	50
Coast redwood	1	-	1
Yew	4	-	4
Western red cedar	-	6	6
Western hemlock	-	5	5

Progress has been made in the genetic improvement of many of the species used in Irish forestry over the last 50 years. Information from provenance trials has been used as the basis of seed source recommendations and tree breeding work has produced genetically improved planting stock for certain species. These achievements are highlighted in Cahalane et al. (2007), COFORD (2012) and described in detail in *a review of tree improvement programmes in Ireland – historical developments, current situation and future perspective* (Fennessy *et al*. 2012). Table 5 provides a summary of achievements made and lists tree species which have undergone improvement and the current status of improvement. Tree breeding programmes were established in Sitka spruce and for some broadleaves, including birch (*Betula pubescens*) and alder (*Alnus glutinosa*). Breeding programmes were also established for pines, however, the programme for lodgepole pine (*Pinus contorta*) was suspended due to reduced peatland planting and the Monterey pine (*Pinus radiata*) programme was terminated due to limited suitability of the species. The lodgepole pine programme in collaboration with the Forestry Commission in the UK resulted in an inter-provenance hybrid orchard at Ballintemple Co. Carlow, which produced a commercial seed crop for the first time in 2017.

Notable achievements in more recent years include the commercialisation of the Teagasc birch breeding programme. Downy birch is now an approved species for use in DAFM afforestation schemes since the 1st of January 2016, with material classified as *'Selected'* or *'Qualified'* eligible for use as a pure plantation species. Teagasc have also initiated a breeding for tolerance to ash dieback programme (see ash case study) under the DAFM funded FORM research programme. The Forest Genetic Resources Trust (formally the Irish arm of The Future Trees Trust) have programme in place to improve the quality and productivity of seven broadleaved species, including ash, birch, pedunculate and sessile oak, wild cherry, sweet chestnut and sycamore. Much of the FTT/FGRT work is now at a stage where it is beginning to be commercialised. *'Qualified'* orchards in sycamore and sweet chestnut have been established, with plans for two oak orchards (one sessile, one pedunculate) well advanced (see oak case study).

Sitka spruce has been the main focus for conifer tree improvement and is the only species for which *'Tested'* FRM has been developed[1]. Sitka spruce is not a regular seed producer under Irish climatic conditions, as a result, seed orchards were not considered initially to be a feasible production strategy for producing improved FRM. Instead, deployment was initially through vegetative methods, using a process of somatic embryogenesis to provide copies of full-sib crosses, and then establishing hedges of this material, from which cuttings could be then taken. The theoretical advantage of this approach is that individuals with superior traits can be reproduced. The disadvantage is that the techniques result in higher per plant costs than plants propagated from seed. Largely for this reason, the micropropagation laboratory at Newtownmountkennedy was closed in 2016. A vegetative propagation programme is still carried out in Clone Nursery, Co. Wicklow, but using a simpler serial propagation approach. Resources have instead been directed towards the establishment of seed orchards. The first *'Tested'* seed orchards were established in 2011 and expanded in 2018 and 2020. Seed was collected for the first time in 2014, with the first major collection occurring in 2019 (TABLE 4).

TABLE 4 Number of seed orchards registered on the National Register of Approved Basic Material (DAFM, 2020).

Species	*'Qualified'*	*'Tested'*
	No. of Seed Orchards	
Sycamore	2	-
Alder	3	-
Downy birch	2	-
Spanish (sweet) chestnut	1	-
Ash[2]	4	-
Hybrid larch[3]	1	-
Sitka spruce	1	2
Lodgepole pine	2	-
Scots pine	4	-
Wild cherry	1	-

[1] A "*Tested*" ash orchard was established by the Future Trees Trust in partnership with Coillte, however with the advent of ash dieback disease, and following its assessment for potentially tolerant ADB genotypes, this orchard was reconstituted in 2019.

[2] No longer in production due to Ash Dieback disease.

[3] *Larix x eurolepis*.

TABLE 5 Status of forest tree improvement programmes in Ireland.

Species	Plus trees	Provenance trials	Progeny trials	Clonal testing & development	Programme active	Highest Level of FRMon NRBM
Ash	✔	✔	-	-	✔	*NA*[4]
Common alder	✔	✔	✔	-	✔	*Qualified*
Downy birch	✔	✔	✔	-	✔	*Qualified*
Pedunculate oak	✔	✔	✔	-	✔	*Selected*
Sessile oak	✔	✔	✔	-	✔	*Selected*
Sitka spruce	✔	✔	✔	✔	✔	*Tested*
Spanish (Sweet) chestnut	✔	-	-	-	✔	*Qualified*
Sycamore	✔	-	✔	-	✔	*Qualified*
Cherry	✔	-	-	✔	✔	*Qualified*
Beech	✔	-	-	-	✘	*Selected*
Douglas-fir	-	✔	✔	-	✘	*Selected*
Japanese cedar	-	✔	-	-	✘	*Selected*
Larch	-	✔	-	-	✘	*Qualified*
Lodgepole pine	✔	✔	✔		✘	*Qualified*
Monterey pine	✔	✔	✔	✔	✘	*Selected*
Norway spruce	-	✔	✔	-	✘	*Selected*
Scots pine	✔	-	-	-	✘	*Qualified*
Silver birch	✔	✔	✔	-	✔	-
Western hemlock	-	✔	-	-	✘	*Selected*
Western red cedar	✔	-	-	✔	✘	*Selected*

1.4 Forest genetic resource conservation

A key recommendation from *Sustaining and Developing Ireland's Forest Genetic Resources – An outline Strategy* was the development of a forest genetic resources conservation strategy. This was partially achieved under the FORGEN research programme where a National Forest Tree Gene Conservation Strategy (Kelleher, 2016) for native species was developed.

Ireland also participates in the EUFGIS project (European Information System on Forest Genetic Resources), which was implemented in collaboration with EUFORGEN. EUFGIS is an online system for documenting and managing dynamic gene conservation units. To date, Ireland has seventeen units listed on EUFGIS including populations of oak, birch, mountain ash, alder, ash, aspen and Scots pine. In 2019 the GeneNet project, led by the National Botanic Gardens of Ireland in collaboration with Dublin City University and funded by DAFM, was initiated to update the network of *in situ* FGR conservation unit sites across Ireland. The project aims to further characterise these sites and to add more sites to the Irish network. New populations will be selected for the network based on criteria such as geographical spread and by using climatic zonation as a proxy for adaptive potential. An estimate of approximately eighty-four additional sites from fourteen species is to be added and characterised based on literature and GIS surveys. Sites will be assessed in the field and genetic characterisation will be carried out on the high and medium priority species (alder, ash, birch, oak and Scots pine). All of the data generated will be built into a GIS to be used by DAFM and added to the EUFGIS portal. The outputs of the project will be crucial to conserving and future-proofing Ireland's forest genetic resources. The project will provide a European context to Ireland's FGR and will enable the exploration of the adaptive potential in Irish forests.

Ireland also has an active programme of *ex situ* conservation as well as information on species and materials in germplasm collections. *Ex situ* conservation is undertaken by a number of state and semi-state agencies, including DAFM, Teagasc, the National Botanic Gardens and Coillte, the NPWS and the Forest Genetic Resources Trust. Data on *ex situ* conservation areas are maintained by the host organisations and also by DAFM at a national level.

[4] Conventional genetic improvement work suspended; efforts now concentrated on breeding for resistance to Ash Dieback disease.

Mixed woodland, Laragh Co. Wicklow.

2 Genetic options for adapting forests to climate change and biotic risk

Forests contribute to climate change mitigation by sequestering CO_2 from the atmosphere. However, forests are themselves vulnerable to the impacts of climate change, and options to increase climate resilience must be considered and implemented as part of their future management. This chapter outlines the impact of climate change on Irish forests, its consequence for key forest tree species and the opportunities that exist for increased carbon sequestration through the appropriate use of Forest Genetic Resources (FGR). The importance of FGR as a climate change adaptation measure is then discussed, and options for the development and deployment of FGR are proposed.

The decisions regarding the selection of suitable planting material to establish future forests are essential to ensuring the resilience of Irish forests to climate change and biotic attack. Strategies to assist the adaptation of forests to changing climatic conditions rely heavily on the availability of suitable forest reproductive material (FRM). While many uncertainties exist on the nature and extent of future climate projections and their application to Ireland, projections agree that an increase in seasonal temperature is certain and a decrease in summer rainfall in the eastern part of the country is likely (Nolan, 2015). Climate models also indicate that the frequency of extreme events (e.g. winter storms) are likely to increase (Noone *et al*. 2017). Table 6 outlines the potential effect of climate change on Irish forests and the potential of genetic options and forest management to address such challenges.

TABLE 6 Climate change risk factors and the potential of genetic and/or forest management options to address challenges and opportunities.

Climate change risk factors	Possible impacts and potential challenges/opportunities	Genetic	Management
Windblow	Increase damage from winter storms. Changes in the management regime or forest design may be necessary.	✘	✔
Fire	Increase fire risk owing to drier conditions. Increased protection from fire necessary, fire breaks, prescribed burning.	✘	✔
Spring & autumn temperature increases	Change in flushing patterns. Increase in the growing season. Opportunities for species or provenance change.	✔	✔
Summer drought	Increase in drought risk possible. Identify potential species and provenances more suited.	?	✔
Growing season	Increase in the growing season length, new species and mixtures opportunities, adoption of more southerly provenances.	✔	✘
Warmer winters	Insufficient chilling requirement to break dormancy, increase in outbreaks of damaging agents, increase species portfolio, monitor phenology and insect numbers.	✔	✘
Insect pest & diseases	Increase available species, species replacements, genetic diversity, resistant genotypes. Increased monitoring.	✔	✔
Lengthening of frost-free season	Opportunities for wider planting of frost-sensitive species and provenances	✔	✔

2.1 Consequences of climate change for forest tree species

Trees are long-lived species; therefore, they will need to be sufficiently adapted for future conditions. Species response to climate change will be determined by individual plasticity in the short-term and genetic adaptability in the long-term (Donnelly *et al*. 2012). The effect of rising temperatures will likely impact growth and phenology, which may result in delayed or advanced bud burst (depending on the species) or extended growing season for certain species and genotypes. Climate change will also impact the genetic composition of tree populations and the level of impact will depend on the biology of a species, and the size and distribution of populations (Kelleher *et al*. 2015). Milder autumn temperatures may provide opportunities to expand the range of suitable species and provenances in Ireland, with enhanced suitability for certain species (e.g. Monterey pine, Douglas-fir) and opportunities to select provenances more adapted to growing in warmer conditions (e.g. Sitka spruce, oak). Warmer winter and summer temperatures may present conditions for the more successful establishment of pests and pathogens (Sturrock *et al*. 2011) as well as the potential for increased growth rates. It is likely that the increase in the frequency and severity of winter storms will increase the incidence of windthrow and the risk of forests being windblown. The sequencing and frequency of extreme events could present unique challenges for certain tree species as abiotic or biotic stresses can have a cumulative effect.

It has been shown that the growth phenology of tree species is very likely to be affected by the projected increases in future temperature (Donnelly *et al*. 2006). This may result in some species not fulfilling their winter chilling requirements (necessary for dormancy release of buds) or lengthen the time needed to satisfy the chilling requirement of plants, likely resulting in delayed budburst, especially for conifers and oceanic species (Pletsers *et al*. 2015). The timing of tree budburst is highly variable, both among and within species, as evidenced by data from provenance trials, with budburst occurring later in some provenances than others (Basler and Körner, 2012). This can be attributed to differences in temperature requirements for budburst and flowering. Water availability, genetic factors and geographic variables (notably altitude and latitude), are also associated with the timing of budburst and flowering (Campbell, 1974; Deans and Harvey 1995; Badeck *et al*. 2004; Vitasse *et al*. 2009). On lowland sites in Ireland, an increase in average winter temperatures will result in later bud flushing of certain species including Sitka spruce, Norway spruce, ash, beech and sessile oak (Thompson, 1998). Differences in flushing, if linked to climate indices, may afford the potential to select origins better adapted to future conditions.

Anticipated decreases in summer precipitation, particularly in the eastern part of the country, coupled with increased evapotranspiration, may limit water availability for some tree species, and consequently, reduce their productivity. For soils where moisture availability is limited or where previous crops have been subjected to periodic drought events resulting in reduced productivity, provenance/species change may be warranted, and a range of drought-hardy species and seed origins may be considered for region-specific deployment. Genetic options worthy of consideration may include species and provenance mixtures and inter-species and inter-provenance hybrids which may vary in their water use efficiency and provide options to increase drought tolerance. It may be necessary to study the physiological responses of species to known drought episodes and the effect of drought on productivity and growth, to assess the capacity of species and seed origins to changing conditions. It may be worthwhile investigating if some species or provenances originating from drier climates show better tolerance to water stress for known drought episodes which have occurred in Ireland - the assessment of a range of species in collections such as the JFK Arboretum may provide useful data in this regard. It is likely that the range of provenances suitable for use in Ireland will need to be expanded for Sitka spruce and other tree species (e.g. Oregon and Californian provenances of Sitka spruce), especially where autumn temperatures become milder and with a reduced risk of autumn frosts. The combined effect of drought and increased temperatures are likely to create conditions more suitable for damaging agents. Rising temperature and increased global trade are likely to increase the risk of pests and disease outbreaks. There may be potential to select seed origins or genotypes that may be resistant or tolerant to specific pest and diseases. The production of such material could be scaled up through tree breeding efforts for deployment in the case of increased risk (ash case study).

Overall, forest productivity is expected to increase in Ireland as a result of climate change, especially if moisture is not limited. This will be largely due to an increase in growing season temperature, longer growing seasons, increased CO2 and increased atmospheric deposition of nitrogen. Climate change may necessitate the expansion of the range of species and provenances used heretofore to ensure that the forest genetic resources remain suitably adapted to changing conditions. It is important that the range of FRM available to the forest sector can take advantage of these opportunities to increase productivity, this may require the provision of new seed sources, seed orchards or the testing of imported material for suitability to test for adaptability for future climatic conditions.

2.2 Importance of forest genetics resources in climate change mitigation

Forests play a key role in climate change mitigation in Ireland by sequestering CO_2 from the atmosphere and storing it in the form of wood. Between 2007 and 2016 an average of 3.8 Mt of CO_2 per annum was sequestered by Irish forests. Projections of future carbon sequestration assume that forest health will be maintained and do not take into account the dynamic nature of forests and how they may be impacted by future climatic conditions. Such projections also depend on continued afforestation to offset an imbalance in age-structure of the national forest estate (Black *et al*. 2012). Genetic options can play a key role in maintaining and potentially increasing the amount of CO_2 stored in Irish forests. The selection of appropriate seed origins, suitably adapted and resilient to future conditions can help to ensure the protection of this valuable carbon resource. Also, tree improvement programmes which produce improved genetic material have the potential to increase carbon capture and storage through increased growth rates. Improved timber quality may also enhance the long-term storage of CO_2 in harvested wood products, contribute to the harvested wood pool and thus contribute to the replacement of more carbon-intensive materials. The protection of the forest timber and carbon resource, in addition to the other ecosystem services derived, is dependent on the health and vitality of the forest estate. The risk presented by damaging biotic and abiotic agents needs to be considered and how the appropriate use of FRM may alleviate these risks. The deployment of appropriate FRM will be crucial to harnessing any improved or preserved sequestration potential.

2.3 Use of forest genetics resources and climate change adaptation

The current species, provenance and origin recommendations have been developed as a result of trials carried out over many decades. However, changing environmental conditions associated with climate change are creating uncertainties about the future adaptability of forest tree species. An understanding of the adaptive potential of the range of tree species used in Irish forestry would be useful to assess if the species list and provenances currently used need to be adjusted or expanded. For long-lived species, it is perhaps more critical to understand their adaptive potential as these species will be growing into the 2100s where the climate is projected to be significantly warmer. For species with shorter rotations adjustments to the planting stock can be made at the end of the rotation period to more suitably adapted planting stock.

For many species with large geographic distributions, there may be potential to adapt *in situ* to the changing conditions or it may be necessary to select seed from more southerly locations which may be more adapted to future conditions. Species with relatively small gene pools may be most vulnerable to climate change as they are likely to have less adaptive potential to respond to changing environmental conditions. Species with high levels of genetic diversity are likely to have much larger adaptive potential.

The potential of our native and non-native trees to respond to climate change will depend on three factors: adaptive evolution, migration and phenotypic plasticity[5] (Alfaro *et al*. 2014). Species with large distributions may contain sufficient genetic diversity with distinct subpopulations containing adaptive traits for changing climatic conditions. For example, Sitka spruce has a 3,000 km north-to-south range with many distinct sub-populations, and the more southerly sources are likely to be increasingly suitable for future Irish climates. While under natural conditions adaptation of tree species may take millennia to develop, the transfer of FGR which may be better adapted to likely future conditions can ensure that the national growing stock will have the capacity to adapt to climate change (Kramer, 2010). Those species with sufficient phenotypic plasticity may have more adaptive potential, species with lower levels of phenotype plasticity are likely to be more vulnerable to the effects of climate change. Additional research will be necessary to evaluate which species are more vulnerable to the effects of climate change and to determine if certain populations contain adaptive traits more suited to future climates. Some tools have already been developed to aid decision making. The CLIMADAPT research programme developed a decision support system for forest managers and policymakers, using soil and climatic information to assess species suitability and yield for individual sites under current and future climate change scenarios. While more recently the FitForest research programme, aims to provide up to date information on provenance and seed origins adapted to future Irish climatic conditions (Teagasc, 2020).

Evidence-based research relevant to Irish conditions must be used to inform policymakers, forest owners and the forest industry about both the selection and utilisation/deployment of the most appropriate FRM. Such information should underpin a large part of national strategies for planning and preparation for climate change and are particularly significant given the long timescales involved in the growth of forests (30 to 120+ years).

2.4 Options for the development of forest reproductive material

Provenance trials are an essential source of information and should be used to provide evidence on the performance of a range of FRM under future Irish conditions with new trials established where required. There also exists an opportunity to assess records on the source and origin of FRM deployed in Irish forests by consulting the certificates of provenance that accompany afforestation and reforestation projects. For example, the growth performance of some seed origins or provenances could be assessed to indicate which material may be more suited for certain site types. This information could be used to revise provenance recommendations where necessary.

Tree breeding programmes should consider if their breeding populations are sufficiently genetically diverse. It may be necessary to introduce breeding strategies aimed at increasing diversity or traits which may increase resilience to climate change. On the other hand, adaptive measures may be more cost-effective if provenances more suited to future climates are chosen. Adaptation strategies may consider the increased suitability of more southern seed source origins under future climate change, particularly where the accumulated temperature would exceed 1,800-day degrees (Thompson et al. 2005). It is also necessary to continue to assess the performance of improved material derived from selection or breeding programmes for continued adaptation to Irish climates and to assess the levels of genetic diversity in those populations. It may be necessary to introduce additional material into Irish breeding programmes to boost diversity and/or increase the adaptive potential of species for climate change.

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[5] Phenotypic plasticity refers to the degree to which an individual genotype can modify their physiology over their lifetime in response to the environment.

Tree breeding is a long-term process, it often requires considerable time for desirable traits to manifest themselves. Genomic selection and techniques such as marker-assisted selection may reduce the time required for testing material and should be investigated for species of economic importance. Considering the time frame and the costs involved in tree breeding, for many species it may be more prudent to scientifically evaluate seed origins from international improvement programmes to determine whether these are suitably adapted for use in Ireland (O'Reilly *et al.* 2014). The use of seed orchards and strategies to increase the deployment of suitably adapted material should be prioritised. This would increase the quantity/availability of material for deployment and allow the more widespread use of improved material. The performance of seed stand material should continue to be monitored and efforts should be made to identify their seed origin where possible to ensure that this material is suitability adapted for changing climatic conditions. DNA profiling offers some potential in this regard.

2.5 Options for the deployment of forest reproductive material

While climate change is likely to present challenges to forest management there are genetic options which may assist to alleviate some of the negative consequences of climate change (e.g. maladaptation, susceptibility to temperature extremes, drought, extinction, insect pests & disease threats). The range of forest genetic material being deployed to Irish forests must have sufficient genetic diversity to alleviate abiotic and biotic challenges. This should include provenances or genotypes with resilience traits (e.g. abiotic or biotic) which should be deployed as a component of afforestation or reforestation programmes to afford the futureproofing of Irish forests. For example, future deployment of ash should be dependent on FRM which show tolerance to ash dieback disease (see ash case study). Other strategies such as the mixing of provenances (inter-provenance mixes) for sites identified as likely to have an increase in growing season length may afford an increase in yield. Other sites which are deemed to be at risk of drought, may benefit from interspecies mixtures, the addition of further species more tolerant to drought may mitigate risk (e.g. Sitka spruce-Douglas-fir mixtures on drier sites). Longer growing seasons and increased temperatures are likely to provide opportunities to diversify the species portfolio (e.g. Monterey pine, Douglas-fir, Spanish chestnut) or require the adoption of provenances more suited to warmer climates and have the potential to increase the productivity of forests, assuming that soils have adequate moisture. Existing recommendations about species' suitability may necessitate updating or renewed testing may be required for altered conditions.

Strategies such as assisted migration may be used to transfer genetic material from southern locations to northern locations, whose future climate is predicted to be warmer, to boost the genetic diversity of native populations. For example, oak provenances from northwest France or the Netherlands may be more suitably adapted to future climatic conditions in Ireland. The transfer of FRM from suitable non-autochthonous areas is already widely practised for forest plantations. However, for native woodland establishment, or native woodland restoration or rehabilitation, a more precautionary approach regarding the choice of provenance is warranted. For instance, the adaptive potential of our native trees may need to be studied in greater detail before it is recommended as a strategy. It may also require the consideration of a desirability/needs framework to assess the risk of maladaptation (e.g. Whittet *et. al.* 2019).

Clockwise from upper left: Sitka spruce seed orchard at Ballintemple Co. Carlow, Sitka spruce seed cones (post pollination), male and female alder catkins, alder indoor seed orchard at Ashtown Co. Dublin.

3 Requirements for the development of forest genetic resources

3.1 Sector co-ordination

A key recommendation of *Sustaining and Developing Ireland's Forest Genetic Resources - An outline Strategy*, was the need for coordination at the national level. This remains the case today. There are a relatively large number of organisations involved in forest genetic resources, each with their own particular focus (Table 1, pg 1). The Forest Genetic Resources Working Group of the COFORD Council was established in order to provide direction at the national level, principally through producing a renewed strategy for FGR, but also by acting as a forum for those organisations. It is essential that this forum is maintained in order to inform policy, identify and agree on ongoing priorities for research and development, national gene conservation strategies, determine seed requirements and address FRM supply issues. It is also an important platform for communicating information on FGR issues through the various organisations involved and into the wider forest sector.

3.2 Research capacity

3.2.1 A national tree improvement programme

For historic reasons, largely stemming from the breakup of the old Forest and Wildlife Service in 1989, tree improvement is highly fragmented, with different organisations carrying out work on different species. It has for the past three decades largely been split between Coillte, Teagasc and the Future Trees Trust (now the Forest Genetic Resources Trust in Ireland), with Universities contributing via project-based research. Coillte concentrated on conifer breeding, while Teagasc and the FTT/FGRT focused on broadleaf species.

However, this dynamic has changed somewhat. Coillte has limited its tree improvement activity in recent times following staff retirements and organisational restructuring. Following a strategic review of the breeding programme, Coillte's view was that it was no longer viable to independently continue the programme given its commercial remit, the long-term nature of tree breeding, and the wider industry importance of Sitka spruce. A decision was made to continue breeding work on a limited scale, and focus on deployment, i.e. vegetative propagation of elite material and the establishment of orchards based on the gains already made. Given the importance of the Sitka spruce to the national planting programme discussion on this decision followed with DAFM. It was subsequently agreed that for an interim period Coillte and DAFM would jointly support the operation of the breeding programme while the establishment of a national programme was investigated.

Project research funding has continued through DAFM research calls, such as UCD led FORGEN & FORM projects, and more recently in 2018, the Teagasc led GENESIS project. Nevertheless, project-based funding is generally limited to 2 – 4-year terms and is in itself not sufficient to sustain breeding work in the long term. Funding to support the operational requirements, including maintenance of gene banks, field trials and research infrastructure, as well as the basic breeding and testing work, is required. Without this investment, there is a real risk of losing out on future benefits to the Irish forest sector developed over the last 50 years.

This situation is not unique to the FGR sector, a reduction in research capacity was recognised generally across the wider forest research area in the 2018 COFORD Report *"Longer-Term Forest Research Proposed structures for meeting the needs and opportunities of Ireland's forest sector through longer-term research and innovation"*. As a response to this challenge, the report proposed a framework, based around a central *"Hub"*, referred to as an *"Open Innovation and Science Hub"* to lead and set direction, with associated *"Centres of Excellence (COE)"* based around thematic areas of research. Central to the proposal was that there are areas of research that are not capable of being fully addressed within the competitive research structure, (mainly due to the long cycle from seed to timber and other benefits from the mature forest) and that the *Centre of Excellence* capacity is additional to and would complement – not replace – the annual DAFM competitive research programme.

An indigenous improvement programme offers substantial advantages in terms of securing supply and maintaining the sector's ability to adapt to threats. It enables the selection of faster-growing trees with desirable traits, which has the potential to increase productivity and increase the output of sawn timber for the forestry sector in Ireland. As was discussed in Chapter 2 of this report, it is also a key climate change adaptation tool.

Given the importance of Sitka spruce to the forestry sector, securing the improvement programme must be a high priority, there is an opportunity to achieve this within a wider tree improvement *Centre of Excellence*. There is limited opportunity for a co-operatively funded programme between industry, or the establishment of green-field standalone entity, therefore government support, and the greater involvement of Teagasc in conifer breeding is likely the most achievable means of securing tree improvement in the long term.

3.2.2 Expertise

The numbers of specialised staff in FGR required to sustain the sector is small. Consequently, the loss of one or two key personnel can have a large impact. For instance, the majority of authors responsible for the 2007 strategy, *Sustaining and Developing Ireland's Forest Genetic Resources*, have since retired, while staff have in some organisations involved have been replaced, the reduction in tree breeding activities at Coillte, in particular, has resulted in a net loss of expertise at the national level. This situation is one of the consequences of not having a dedicated agency responsible for tree improvement or a long-term research funding stream. While PhD and postdoctoral researchers continue to be employed in project-based research, these are temporary posts, with expertise lost when the project terminates. If a National Tree Improvement Programme as proposed above is to succeed it will require sustained investment and the recruitment of specialised technical and field staff.

3.2.3 Collaboration

The challenges associated with climate and biotic risk are not confined to Ireland and require international co-operation if meaningful solutions are to be realised. The importance of international collaboration was demonstrated in the response to ash dieback disease, where researchers from 35 countries, including Ireland, joined forces in an EU- funded COST Action FRAXBACK. The Action produced several documents on the consequences of ADB disease and guidelines for sustainable management of ash (Enderle *et al*. 2017). Teagasc has further focused on collaborating with a number of different European research agencies and has acquired and propagated a population of ash genotypes putatively tolerant to ADB disease. Indeed, many of the species used in Irish forestry are subject to tree improvement in other countries. As previously discussed in Chapter 2, climate change will have a profound impact on our forests, for adaptive strategies outlined to succeed, it will require cooperation between countries and participation in European and international processes. In particular, fostering cooperation with our near neighbours in the UK such as Forest Research and the Future Trees Trust will be important, as well as participation in European programmes such as EUFORGEN and international organisations such as IUFRO.

3.3 Research priorities

3.3.1 Forest tree species suitability

Forest genetic resources are the basis of sustainable forest management, supporting resilience, adaptation and mitigation in the face of climate change. Furthermore, the use of genetically improved trees can result in better returns due to one or more of the following responses: higher growth rates, better timber quality and higher rates of carbon sequestration. Past research and development programmes in FGR resulted in the most suitable origins for major and minor species used in Irish forestry being identified. This information is captured in Horgan et al. (2004) and is included in the DAFM Forestry Standards Manual (2015). This list of species, including the most appropriate provenance and seed origins is relied upon by forest managers when choosing planting material. However as identified in the genetic options for climate change adaptation, there is a need now to re-examine this list in the context of climate change. Best practice would be to carry out a re-assessment of provenance trials where possible and provide an updated list of recommended seed origins that may be appropriate given climate change projections. The value of provenance trials lies in their ability to assess phenotypic responses in various environmental conditions and genomic backgrounds and thus, to enable the assessment of genotype X environment interactions. There are also gaps in the information for certain species and current recommendations on the choice of seed origin may need to be revised (e.g. Douglas-fir, Norway spruce). There is also a need to establish a range of new trials to assess the adaptability of forest tree species to future conditions. These trials should be established as soon as possible and focus on future potential important species and provenances.

3.3.2 Tree improvement

Priority species in forest reproductive material programmes were first listed in *Sustaining and Developing Ireland's Forest Genetic Resources: An outline strategy* (Cahalane *et al*. 2007). This list has been revised here based on expert opinion from the COFORD Forest Genetic Resources Working Group, taking into account a cost-benefit analysis of tree improvement carried out under the FORGEN research programme (O'Reilly *et al*. 2014). Species are assigned a tier one or tier two position, based on the current or probable future demand for FRM. An associated tree improvement action is proposed for each species (Table 7). For instance, for Sitka spruce, the proposed action includes the continuation of the improvement programme. While for ash, the implementation of a breeding programme for tolerance to ash dieback disease is recommended. For other species, the recommendation includes; testing the suitability of improved material from foreign improvement programmes (Douglas-fir); or building on past gains (e.g. Scots pine). Case studies have been developed for four of the listed, species: ash, Douglas-fir, oak and Sitka spruce. These case studies go into detail regarding potential tree improvement options and actions required to secure a supply of forest reproductive material.

There are also other species or provenances which are not listed here, but which may have some potential. For example, the *Eucalyptus* genus has hundreds of species, and although it can be utilised for biomass, the range of suitable sites is limited to coastal sites where frost risk is unlikely to cause a problem. Similarly, hybrid aspen (*Populus tremula × P. tremuloides*) is not represented owing to more limited information on the range of suitable clones available for Irish conditions and information about their adaption to Irish conditions. While other species not listed may be deemed to have more limited economic or social value their lack of inclusion is perhaps owing to more limited information on their performance or widespread adaptation to Irish conditions outside of arboreta but may have more widespread suitability for warmer climates (e.g *Cedrus libani* / *atlantica*). For other species, their exclusion is owing to considerable uncertainties as to the choice of suitable seed origins or species which have more limited economic or environmental potential. While in the main it is expected that the species listed in Table 7 can form a new forest or be component species for the establishment of new woodland, other species may be suitable for conservation objectives (e.g. *Taxus baccata*) or the objectives of agroforestry systems.

TABLE 7 Target species for tree improvement and actions proposed.

Species	Botanic name	% Forest Estate (NFI, 2017)	Tier	Priority Action
Ash	*Fraxinus excelsior*	3.8%	Tier 1	Breeding programme for tolerance to ash dieback disease
Common alder	*Alnus glutinosa*	2.7%	Tier 1	Continue genetic improvement programme
Douglas-fir	*Pseudotsuga menziesii*	1.5%	Tier 1	Evaluate suitable seed origins
Downy birch	*Betula pubescens*	3.6%	Tier 1	Continue genetic improvement programme
Larch spp[6]	*Larix species*	3.3%	Tier 1	Desk study impact of *Phytophthora ramorum*
Lodgepole pine	*Pinus contorta*	9.6%	Tier 1	Monitor performance of hybrid provenance orchard
Norway spruce	*Picea abies*	3.8%	Tier 1	Evaluate suitable seed origins
Pedunculate oak	*Quercus robur*	1.7%	Tier 1	Continue genetic improvement programme
Scots pine	*Pinus sylvestris*	1.1%	Tier 1	Evaluate past genetic gains
Sessile oak	*Quercus petraea*	1.0%	Tier 1	Continue genetic improvement programme
Silver birch	*Betula pendula*	3.4%	Tier 1	Continue genetic improvement programme
Sitka spruce	*Picea sitchensis*	50.9%	Tier 1	Continue genetic improvement programme
Spanish (sweet) chestnut	*Castanea sativa*	0.1%	Tier 1	Continue genetic improvement programme
Sycamore	*Acer pseudoplatanus*	1.5%	Tier 1	Continue genetic improvement programme
Beech	*Fagus sylvatica*	1.5%	Tier 2	Continue to assess suitable seed origins
Wild cherry	*Prunus avium*	0.0%	Tier 2	Evaluate suitable seed origins
Coast redwood	*Sequoia sempervirens*	0.0%	Tier 2	Evaluate suitable seed origins
European silver fir	*Abies alba*	0.0%	Tier 2	Evaluate suitable seed origins
Grand fir	*Abies grandis*	0.1%	Tier 2	Evaluate suitable seed origins
Italian alder	*Alnus cordata*	0.0%	Tier 2	Evaluate suitable seed origins
Japanese red cedar	*Cryptomeria japonica*	0.0%	Tier 2	Evaluate suitable seed origins
Monterey cypress	*Cupressus macrocarpa*	0.0%	Tier 2	Evaluate suitable seed origins
Monterey pine	*Pinus radiata*	0.0%	Tier 2	Evaluate suitable seed origins
Norway maple	*Acer platanoides*	0.0%	Tier 2	Evaluate suitable seed origins
Pacific silver fir	*Abies amabilis*	0.0%	Tier 2	Evaluate suitable seed origins
Red oak	*Quercus rubra*	0.0%	Tier 2	Evaluate suitable seed origins
Western hemlock	*Tsuga heterophylla*	0.1%	Tier 2	Evaluate suitable seed origins
Western red cedar	*Thuja plicata*	0.0%	Tier 2	Evaluate suitable seed origins

6 European larch, Japanese larch, Hybrid larch (*Larix decidua, Larix kaempferi, Larix x eurolepsis*)

3.4 Forest reproductive material supply needs

In order to meet the needs of the current and future forestation requirements, a secure supply of appropriate reproductive material is required. Analysing past use of FRM can give some insight into determining future requirements. Tables 8 & 9 provide a list of the main species currently used in Irish forestry, the kilos of seed and the plant number equivalent for the period 2015-2019. However, anticipating future demand is a difficult task, one that is subject to yearly variation. Forest nurseries, due to the lead-in time to produce planting material, are exposed to changes in forestation levels and other external factors. For instance, there has been a year on year steady decrease in afforestation, 2019 saw 3,550 ha afforested compared to a 10-year average of just under 6,000ha (DAFM, 2020). This been further exacerbated recently by significant delays in issuing of felling licenses which has had a consequential impact on being able to plan for future supply and demand of FRM.

However, in the medium to long term, if forest policy goals are to be realised, it is likely that there will be a continued demand for the main commercial tree species, as well as an increasing demand for native species to serve the Native Woodland Scheme, the Woodland Creation on Public Lands Scheme as well as the needs of the newly formed Coillte Nature. Therefore, an indigenous resource of high-quality reproductive material from home sources should be a priority. This can be achieved by increasing the proportion of genetically improved plant material which goes into production. This should continue to be a major objective of Irish forestry with further aspirations to increase the availability of genetic resources which have been developed in the categories *'Selected'*, *'Qualified'* and *'Tested'* in accordance with the EU Directive 1999/105/EC.

TABLE 8 Main broadleaf species sown (kgs seed with an approximation of the number of plants ('000) in forest nurseries (2015-2019)[7,8].

Species	2015		2016		2017		2018		2019	
	Kg	Plants (000)	Kg	Plants (000)	Kg	Plants (000)	Kg	Plants (000)	Kg	Plants (000)
Alder	128	3,840	117	3,510	113	3,387	92	2,754	118	3,525
Ash[9]	2	4	-	-	-	-	-	-	-	-
Beech	936	749	466	373	1,041	832	683	546	870	696
Common birch	30	1,337	49	2,192	54	2,439	52	2,343	60	2,700
Silver birch	11	338	10	300	7	204	8	227	8	225
Cherry	25	20	13	11	1	1	1	1	20	16
Pedunculate oak	6,840	684	24,635	2,464	20,663	2,066	25,302	2,530	15,406	1,541
Red oak	124	10	98	8	100	8	100	8	100	8
Sessile oak	659	53	190	15	5,363	429	4,269	342	1,400	112
Sycamore	233	326	100	141	153	214	15	21	95	133

TABLE 9 Main conifer species (kgs seed with the approximation of the number of plants ('000)) in forest nurseries (2015-2019).

Species	2015		2016		2017		2018		2019	
	Kg	Plants (000)	Kg	Plants (000)	Kg	Plants (000)	Kg	Plants (000)	Kg	Plants (000)
Douglas-fir	26	650	18	450	20	500	19	475	30	750
Larch, European	5	256	-	-	0.3	16	0.3	15	0.4	18
Larch, hybrid[11]	0.2	9	0.2	9	0.3	13	0.3	13	0.3	13
Lodgepole pine	32	2,868	17	1,530	23	2,030	22	1,983	25	2,247
Norway spruce	84	3,360	84	3,340	101	4,024	91	3,643	104	4,154
Scots pine	30	1,212	32	1,278	67	2,685	80	3,197	46	1,834
Sitka spruce	202	20,249	326	32,585	280	27,986	247	24,680	380	37,950
Western red cedar	-	-	1	38	1	37	1	44	0	28

7 Data and seed plant conversion rate supplied by Coillte and None So Hardy (Forestry) Ltd.

8 Data inclusive of subsequent sales to horticulture sector and plants for export.

9 Planting suspended from 2012 due to ash dieback disease. Small quantities of seed sown for rootstocks for breeding for tolerance to ash dieback programme.

11 Hybrid larch (*Larix x eurolepis*).

Seed stands will continue to be an important source of seed for the foreseeable future. These stands, having grown successfully in Ireland, will provide a basic level of improvement. The system of stand selection and registration is working well and should continue as at present.

The management of seed stands is central to the development of a national FGR programme. Before their selection and registration, these stands will have been generally managed for timber production or occasionally as conservation areas. A different management regime may be warranted however if seed production is to be enhanced and maximised. This may include an active thinning programme (subject to local conditions, such as windthrow), to marginal intensity in the selected stand to allow the development of larger crowns, which in turn, encourage flowering and seed production. Fencing of the large-seeded broadleaf stands may be required to reduce seed predation along with control of ground vegetation to facilitate seed collection. These operations are standard practice in other countries and should be tested in Ireland, initially at a pilot scale and depending on success, extended into routine operational practice if proved successful. However, where a stand is located within a Special Area of Conservation (SAC), these operations must be tailored to ensure that there is no significant negative impact on the qualifying interests of the SAC.

Upon registration of a stand, a management plan to enhance seed production should be drawn up in agreement with the owner. This plan would ensure that there are no conflicts between seed production and the original objectives of the owners. If too many limitations and restrictions are placed on a stand because it is registered as a seed stand, then there will be little if any incentive to register new seed stands, especially in the private sector.

It is important to acknowledge that due to the oceanic climate inherent in this country that good seed years vary greatly with the species and by location within the country. For instance, species such as oak may produce small seed crops in scattered locations every few years but produce only major crops once every 5 to 10 or more years. Indeed, the major commercial species, Sitka spruce produces a good cone crop once every 3 to 7 years, averaging closer to once every 5 to 6 years. While the storage of conifer and some broadleaved seed can overcome supply difficulties some species, particularly the large-seeded broadleaves, cannot be stored for any great length of time.

To overcome the barriers to seed production in seed stands the following steps should be taken:

- The DAFM system of selection and registration of seed stands is working well and should continue.
- Flexibility by DAFM in registering seed stands at short notice should be shown, particularly during good seed years.
- An annual assessment of seed cropping is needed in order to provide a forecast of potential cropping ahead of time. This could be carried out by forest nurseries and co-ordinated through the FGRWG.
- A seed stand activation programme should be initiated, particularly for oak. Sessile and pedunculate oak native planting material has been scarce in recent years, prompting Forest Service Circulars permitting the use of non-native material under the Native Woodland Establishment Scheme. The recently launched Woodland Creation on Public Lands Scheme, as well as the formation of Coillte Nature, will also likely increase the demand for native oak. Oak seed stands are underutilised. 56 *'Selected'* stands (30 pedunculate oak, 26 sessile oak) have been registered in Ireland. However, less than 10 are used for seed collection, for a variety of reasons, ranging from access to deer encroachment/feeding to vegetation precluding net laying, poor history of acorn production and acorn collection. Extending acorn collection to more seed stands will better enable the use of locally sourced genetic material and its conservation through fencing and management. The Forest Genetic Resources Trust (formally the Irish arm of the Future Trees Trust) have an active role in this and are currently implementing a pilot programme to bring three to four currently non-collected oak seed stands into acorn production.
- The seed stands element of the Forest Genetic Resources Reproductive Material: Seed Stand & Seed Orchard should be enhanced. The scheme supports management interventions aimed at increasing the frequency, quality and volume of commercial seed production and includes support for management planning. This scheme should be maintained post-2021 and be a feature in the next Forestry Programme. Flexibility in the timing of drawdown of funds should be introduced into the scheme. Currently, the scheme is for a fixed contract period. Given the periodicity of seed years, a lot of money may be spent on clearing undergrowth etc., to maintain a stand, but yield very little due to a run of poor seed years. If flexibility was introduced into the scheme, or another mechanism identified to support works at short notice, to gather seed in a good year, it may be more beneficial than spending money on an ongoing basis to maintain an area in the long term with little certainty of seed yields.

While seed stands will be a major source of seed, especially for broadleaves for the foreseeable future, strategies to increase the production of *'Qualified'* and *'Tested'* FRM should also be prioritised. This would increase the quantity and availability of material for deployment and allow the more widespread use of improved material. Sitka spruce has reached *'Tested'* status and additional seed orchards should be established in order to increase indigenous supply. For other species, for which a genetic improvement programme is recommended (Table 7), the most suitable improvement option is *'Qualified',* i.e. seed orchards which have been established with untested phenotypic superior individuals. Birch and oak are perhaps the exception to this where 'Tested' status may also be warranted.

While the development of seed stand and seed orchards is a priority, it is not a guarantee that all our current and future requirements can be met from home sources. The current and likely future sources of forest reproductive material for the period 2020-2030 is given below in Table 10. As discussed above there are environmental limitations to the production of seed in Ireland, (periodicity of seed years, predation etc). Furthermore, for species with an active improvement programme, it will take time for seed-producing orchards to come into production. While for many potential species and provenances recommended in the context of climate change adaptation, there are few stands in Ireland to serve as potential seed sources. As a result, the importation of FRM will continue to be important to meet forestation needs for some years.

TABLE 10 Current Sources of FRM for priority species, and likely future sources of supply 2020-2030

Species	Priority	Sources of FRM 2015-2019	Sources of FRM 2020-2030			
			Seed stands	Seed orchards	Vegetative propagation	Imports
Ash	Tier 1	NA			✔[12]	
Common alder	Tier 1	Orchards		✔		
Douglas-fir	Tier 1	Seed stands, Imports from improvement programmes in France & direct seed imports from the US	✔			✔
Downy birch	Tier 1	Seed stands, orchards		✔		
Larch spp[13]	Tier 1	Seed stands & orchards, imports from Czech Rep. & Poland	✔	✔		✔
Lodgepole pine	Tier 1	Seed stands, orchards & UK imports	✔	✔		✔
Norway spruce	Tier 1	Seed stands, imports from improvement programmes in Denmark & Sweden	✔			✔
Pedunculate oak	Tier 1	Seed stands & imports from the Netherlands	✔	✔		✔
Scots pine	Tier 1	Seed orchards & UK imports		✔		✔
Sessile oak	Tier 1	Seed stands	✔	✔		
Silver birch	Tier 1	UK imports				✔
Sitka spruce	Tier 1	Seed stands & Orchards, imports from the UK & Denmark	✔	✔	✔	✔
Spanish (Sweet) Chestnut	Tier 1	Seed stands - currently no demand.		✔		
Sycamore	Tier 1	Seed stands & UK imports	✔	✔		
Beech	Tier 2	Seed stands & UK imports	✔			✔
Cherry	Tier 2	UK imports		✔		✔
Coast redwood	Tier 2	NA				✔
European Silver fir	Tier 2	NA				✔
Grand fir	Tier 2	NA				✔
Italian alder	Tier 2	NA	✔			✔
Japanese cedar	Tier 2	NA	✔			✔
Monterey cypress	Tier 2	NA				✔
Monterey pine	Tier 2	NA		✔		✔
Norway maple	Tier 2	NA				✔
Pacific silver fir	Tier 2	NA				✔
Red oak	Tier 2	NA				
Western hemlock	Tier 2	Seed stands, Direct imports from home range in the US	✔			
Western red cedar	Tier 2	Seed stand & imports from Denmark	✔			✔

12 Early deployment of ash tolerant to ash dieback disease will likely be through vegetative means (see ash case study).

13 European larch, Japanese larch, Hybrid larch (*Larix decidua, Larix kaempferi, Larix x eurolepsis*).

3.5 Knowledge transfer

The importance of forest genetic resources needs to be made clear to policymakers, forestry practitioners and the general public. For policymakers, it is important that they understand the commitment needed to maintain our forest genetic resources in terms of funding and human capacity. Forestry owners and practitioners should understand the importance of forest reproductive material in ensuring the health and productivity of the forest. While the general public needs to be made aware to continue supporting initiatives to maintain and conserve forest genetic resources.

It is important to note that national initiatives focused on promoting the importance of FGR have increased since the last review was published by COFORD in 2007. For instance, the Forest Genetic Resources Reproductive Material measure of the Forestry Programme 2014-2020 was introduced in 2015. This scheme aims to support the conservation and development of Ireland's forest genetic resource, through the grant aid of management practices which facilitate *in situ* conservation, and also grant aids the establishment of *ex situ* conservation units such as genebanks or seed orchards.

Demonstration plots are a very useful way of illustrating the importance of FGR to forestry practitioners. The research plots in the JFK Arboretum, New Ross, Co. Wexford were setup as demonstrations of species and provenance performance (Kelly, 2013). They are an excellent resource that shows the importance of selecting the correct species and also illustrate the importance of provenance selection. However, they need investment to extract existing data, to maintain their condition and to continue establishing new trials and demonstration plots on farm forests and in established forest sites.

Potential opportunities to increase the awareness of FGR are through the Knowledge Transfer Scheme, Teagasc, forestry practitioners and also through the Society of Irish Foresters, Woodlands of Ireland, Tree Council of Ireland and the Forest Genetic Resources Trust (FGRT).

Scots pine at Rockforest Co. Clare.

4 Gene conservation

Ireland is home to a range of native, non-native and naturalised tree species that have adapted in various ways to their environments. Some of this genetic diversity has evolved naturally over generations as species have adapted at a fine-scale to local conditions. In other cases, product of deliberate efforts over many years to develop varieties that are productive in Irish conditions. Genetic diversity in tree populations enables them to adapt to conditions and optimise their growth. A greater level of genetic diversity is a buffer against biotic or abiotic change, while a lack of diversity increases the vulnerability of a population or species to changing conditions and pests.

International best practice for FGR conservation involves establishing a network of populations as conservation units to be maintained *in situ* for dynamic conservation. The EUFGIS database, an initiative by European countries under the EUFORGEN programme, maps and maintains data on these conservation units throughout Europe. To date, Ireland has seventeen units listed on EUFGIS including populations of oak, birch, mountain ash, alder, ash, aspen and Scots pine.

Ex-situ conservation of forest genetic resources plays a complementary role to *in situ* conservation by safeguarding genetic diversity away from the risks it encounters in the landscape and making it easily accessible for research and conservation. A proportion of forest genetic resources has been captured through tree improvement programmes and their associated provenance and progeny trials. Further material exists as living collections in botanic gardens and arboreta, such as the John F Kennedy Arboretum in Co. Wexford, and the former Tree Breeding Centre at Kilmacurra Co. Wicklow. The protection of forest genetic diversity in gene banks and collections will ensure that these genetic resources of various tree species are conserved should they be needed for future use or breeding programmes (see ash case study, see Sitka spruce case study). Data on *ex situ* conservation are maintained by the host organisations and by DAFM at the national level. However, with the reduction of long term research activities and in the absence of a national tree improvement programme, there is an urgent need to update the national level inventory of *ex situ* conservation areas and develop an accessible database for this resource.

A national forest tree gene conservation strategy was developed under the FORGEN research programme (Kelleher, 2016). A key objective of the Forest Genetic Resources Working Group in its terms of reference was to examine opportunities to assist in the delivery of this strategy and produce an implementation plan for its delivery. This plan is included in the section below, however, it should be noted that the conservation strategy was developed for native species only, further work will be required to incorporate important non-native and naturalised tree species.

4.1 Implementation of a gene conservation strategy for native tree species

Gene conservation strategies are a relatively new initiative, in particular for tree species as domestication is still a relatively recent undertaking for most trees. Selection of target phenotypes (such as larger fruit) from gene pools has been a common theme since the beginning of agriculture. However, the awareness of genetic resources and the methodical conservation of genetic resources has only been highlighted following the increased intensification of agriculture and an increased need for higher yields (e.g. Gepts 2006). Increased awareness of the potential of genetic resources has led to the development of conservation strategies to maintain and enhance these resources. In general, the objective of gene conservation strategies for forest trees is to maintain the adaptive or evolutionary potential of the populations being considered. In short, the aim is to safeguard future adaptability. When designing a conservation strategy there are a number of common themes in the literature relating to the selection and location of the conservation populations. Rotach (2005) provides a summary of steps to develop a conservation programme and this involves establishing objectives, setting priorities, selection of material to conserve and setting up monitoring. Objectives need to be established regarding the purpose of the conservation network. An initial consideration is whether the conservation populations should be *in situ* or *ex situ*. Following this, information is gathered to enable selection of the appropriate species and populations. Finally, a management plan should be prepared, and a monitoring programme put in place.

A consensus favouring *"dynamic"* or *"near-nature"* gene conservation for forest trees is evident from the literature (e.g. Kelleher 2018). The dynamic approach maintains a near-nature state *in situ* and facilitates evolutionary processes and generation turnover. While the dynamic approach can be undertaken with *ex situ* populations (away from the site of origin), it is a much more common method for *in situ* conservation, i.e. populations within the species range and habitat. An example of the dynamic approach is the EUFORGEN initiative in which information on forest tree populations from many European partners has been collated into a GIS database – the EUFGIS database (Lefevre *et al*. 2013). A minimum set of requirements was established for the incorporation of forest/population units into the EUFGIS system, thus creating a network of high conservation potential (Koskela *et al*. 2013). This database includes details of over 3,500 FGR conservation units in Europe, including a number of Irish populations. The EUFGIS database, through the support of EUFORGEN, allows for populations to be mapped and monitored over time. This is a key tool in conservation and monitoring of FGR in Europe and is being harnessed to develop action plans for FGR conservation in many European countries such as in the UK (Trivedi *et al*. 2019).

Related to the question of *in situ* versus *ex situ* are the concepts of assisted migration and assisted gene flow. These are human-mediated activities, assisted migration being the mass movement of a species or population from a vulnerable site to a more suitable site (*ex situ*), while assisted gene flow is the use of pre-adapted genotypes and genes to adapt *in situ* populations to future climate change. These have the potential to mitigate maladaptation to climate change (Aitken and Whitlock 2013). The potential importance of assisted migration and assisted gene flow in adaptation to the impacts of climate change is also stressed by the Inter-Governmental Panel on Climate Change report (IPCC 2014). However, the utility of assisted migration and the inherent risks need to be fully explored before it is adopted as a conservation measure.

TABLE 11 A list of native tree species to target for FGR conservation with some relevant biological information. Native status as in Webb et al. (1996).

Species Name	Common	Sex dispersal	Pollen dispersal	Seed	Clonal	Distribution
Alnus glutinosa	Black alder catkins	Monoecious - separate	Wind	Wind	No	Riparian/water
Arbutus unedo	Strawberry Tree	Monoecious	Insect	Gravity/Animal	No	Restricted
Betula pendula	Silver birch	Monoecious - separate catkins	Wind	Wind	No	Widespread
Betula pubescens	Downy birch	Monoecious - separate catkins	Wind	Wind	No	Widespread
Corylus avellana	Hazel catkins	Monoecious - separate	Wind	Gravity/Animal	No	Widespread
Fraxinus excelsior	Ash	Dioecious plants/ Dioecious flowers	Wind	Wind	No	Widespread
Ilex aquifolium	Holly	Dioecious plants	Insect	Gravity/Animal	No	Widespread
Malus sylvestris	Crab apple	Monoecious	Insect	Gravity/Animal	No	Scattered
Pinus sylvestris†	Scots pine	Monoecious - separate catkins	Wind	Gravity	No	Widespread
Populus nigra†	Black poplar catkins	Monoecious - separate	Wind	Wind	Yes	Riparian/water
Populus tremula†	Aspen	Monoecious - separate catkins	Wind	Wind	Yes	Riparian/ water
Prunus avium	Wild cherry	Monoecious	Insect	Gravity/Animal	Yes	Scattered
Prunus padus	Bird cherry	Monoecious	Insect	Gravity/Animal	No	Scattered
Quercus petraea	Sessile oak catkins	Monoecious - separate	Wind	Gravity/Animal	No	Widespread
Quercus robur	Pedunculate oak	Monoecious - separate catkins	Wind	Gravity/ Animal	No	Widespread
Salix alba*	White willow catkins	Monoecious - separate	Insect/ Wind	Wind	Yes	Riparian/ water
Salix caprea	Goat willow	Monoecious - separate catkins	Insect/ Wind	Wind	No	Scattered
Salix cinerea	Sally	Monoecious - separate catkins	Insect/ Wind	Wind	Yes	Scattered
Salix fragilis*	Crack willow	Monoecious - separate catkins	Insect/ Wind	Wind	Yes	Scattered
Salix triandra	Almond willow	Monoecious - separate catkins	Insect/ Wind	Wind	Yes	Riparian/ water
Salix viminalis	Osier catkins	Monoecious - separate	Insect/ Wind	Wind/ Water	Yes	Widespread
Sambucus nigra	Elder	Monoecious	Insect	Gravity/ Animal	No	Widespread
Sorbus aria*	Whitebeam	Monoecious	Insect	Gravity/ Animal	Apomictic	Scattered
Sorbus aucuparia	Rowan	Monoecious	Insect	Gravity/ Animal	Apomictic	Widespread
Sorbus hibernica	Irish whitebeam	Monoecious	Insect	Gravity/ Animal	Apomictic	Endemic species
Taxus baccata	Yew	Dioecious plants	Wind	Gravity/ Animal	Yes	Scattered
Ulmus glabra	Wych elm	Monoecious	Wind	Wind	No	Scattered

***Introduced, †Native status uncertain**

4.1.1 Define objectives and set targets

Objectives and targets need to be set for each species. These will vary depending on the current utility of a species. For species that are currently in improvement programmes (e.g. alder and birch) or are currently commercially used, the objectives will be more than maintaining genetic diversity. For these species, the improvement programmes will form a part of the objectives and targets, in particular, they can supplement *in situ* conservation with *ex situ* collections. For most species, the objective should be to maintain the adaptive potential of the species within Ireland. This can be done by selecting populations that represent the range of genetic diversity within the country. Ideally, this should also be done on an island-wide basis, to include both Northern Ireland and the Republic of Ireland. As Ireland is considered a single seed zone and our tree species tend to grow in a limited set of climatic zones, the level of climatic coverage will be reduced. Replication of one site per species per province (where available) should be a minimum target. Some species will have more limited distributions and will not be present in each province, e.g. *Salix phylicifolia* is restricted to a small number of sites in Sligo and Leitrim.

4.1.2 Species selection

From a forestry perspective, the commercial species should be prioritised for action. Some species have already been prioritised as commercially important and refined further in Table 11 above. Based on commercial utility, the availability of molecular data and the existence of seed stands, a conservation programme for the following species should be undertaken first; alder (*Alnus glutinosa*), ash (*Fraxinus excelsior*), birch (*Betula pendula* and *B. pubescens*), oak (*Quercus petraea* and *Q. robur*), Scots pine (*Pinus sylvestris*) and Yew (*Taxus baccata*). In the case of ash, there is also scope to screen, conserve and propagate those genotypes which prove tolerant to ash dieback—see Case study on ash in Chapter 6. Much of the work has already been undertaken for oak and this can be used as a model case to guide the other species initiatives. For example, sites have been documented and entered into the EUFGIS database for oak (Figure 1). There is also a significant amount of genetic data available for oak populations in Ireland (Kelleher *et al*., 2005, Kelleher *et al*., 2004a, Kelleher *et al*., 2004b, Lowe *et al*., 2005). If the EUFGIS database is adopted as a step in the process, then the focus needs to be placed on selecting the sites for inclusion.

FIGURE 1 Location of Sessile oak (Quercus petraea) gene conservation units listed on the EUFGIS database.

4.1.3 Selecting populations for a network

To select populations or units a set of criteria similar to that of de Vries *et al*. (2015) can be used. Selection should be based on prioritising *in situ* sites and selecting based on the size of the unit, including the number of reproducing trees (the larger the better), and a preference for sites with information from genetic studies or provenance tests. In addition, intervention in the form of thinning, removal of invasive species and collection of seed should be allowed provided it aligns with the conservation objectives of the overall site.

One option is to create units within current natural reserves or Natura 2000 sites. This will need cooperation and consultation with the National Parks and Wildlife Service (NPWS), in particular, to agree on management plans as the objectives of conservation and FGR conservation may differ.

In order to select the units, it will be necessary to undertake a GIS exercise to cross-reference multiple data sources, such as species distribution data, National Forest Inventory data, climatic and soils data. A large-scale project by Perrin *et al*. (2008) has gathered data specific to native woodland. This project provides excellent baseline data on species composition and soil for each location surveyed and it has been incorporated into spatial and non-spatial databases.

In addition to selecting populations on a climatic and geographical basis, there may be populations in Ireland that are particularly unique in a broader biogeographic context. This is seen as a national responsibility in FGR conservation (Schmeller *et al*. 2014). For example, Ireland contains populations of *Arbutus unedo* at the northern edge of the species range in the south-west of Ireland. These may be particularly useful in selecting future trees for more northerly climates and will be of interest to other European countries, such as Spain and Portugal, who both contain large populations of *Arbutus unedo*. The Tea-leaved willow (*Salix phylicifolia*) is found at the southern end of its distribution in Ireland. This species is also likely to have unique genotypes compared to populations in the core of its range.

4.1.4 Management plans

A baseline of information needs to be established for a management plan. For many populations, this information will already be available, in particular for those designated seed stands or populations already inputted into the EUFGIS database (Lefevre *et al*. 2013). The baseline information should include the following; details of the site and habitat, the target species, demographics of the population, additional information such as genetic characterisation, interventions allowed, responsible authorities, budget and human resources (see Rotach 2005 for further details). Management plans need to focus on maintaining the FGR of the targeted species, but sites can and often will contain multiple target species.

4.1.5 Monitoring

The monitoring protocol can be built into the management plan. Monitoring is undertaken to assess the status over time and to ensure that favourable conditions are maintained for FGR conservation, for example, the maintenance of natural regeneration. The frequency of monitoring will depend on the species, but a guideline of 5 to 10-year cycles of monitoring have been indicated by EUFORGEN for the pan-European network. Monitoring needs to take account of indicators or evidence of natural regeneration, changes in species composition, influx or spread of invasive species, diseases and pests.

Monitoring of the overall progress of FGR and changes in international practices need to be reviewed regularly to keep pace with best practice. For example, there has been an increased focus on the potential for genetic monitoring and indicators have been developed to track changes in genetic diversity over time (Fussi *et al*. 2016; Graudal *et al*. 2014).

4.1.6 Recommended actions

Forest Genetic Resources (FGR) are the basis on which the health of our future forests are dependent. Taking a simplistic view, the greater the genetic diversity the greater the potential for adaptation and utilisation in future. Best international practice for FGR conservation is to set up a network of forest sites *in situ* to maintain adaptive potential in natural or semi-natural populations. A set of actions for the implementation of a national FGR conservation programme are presented (Table 12). The actions are based on those proposed by Kelleher (2020). The order of these actions may not follow the order laid out in the table. This will depend on the availability of information. These actions are dependent on suitable funding and allocation of staff to undertake the work necessary.

This strategy also aligns with Target 9 of the Global Strategy for Plant Conservation, which aims to conserve the genetic diversity of crops and wild relatives (GSPC 2012). A project currently funded through the 2019 DAFM competitive research call is working on mapping and genetic characterisation of additional populations of a potential conservation network. The project entitled *GENENET – Reviewing and updating the network of gene conservation units for target native forest species in Ireland* is a collaboration between the National Botanic Gardens and Dublin City University.

TABLE 12 Table of actions for gene conservation of Forest Genetic Resources (FGR) and its implementation.

1	Set gene conservation objectives and targets
2	Select species based on objectives.
3	Biological assessment: assessment of bioclimatic envelopes and level of threat.
4	Genetic assessment: Where available utilise genetic data to categorise populations.
5	Genetic characterisation: Genetically characterise populations, where data are needed.
6	Select populations: Utilise criteria presented in this 5.1.3 to select suitable populations.
7	Assess populations: Assess the status of the populations being selected to provide a baseline for monitoring and assess threats.
8	Create management plans for conservation units.
9	Set monitoring protocols & decide the frequency of monitoring and the level of monitoring needed.

Seed orchards at Ballintemple Co. Carlow.

5 Recommendations

5.1 Strategy implementation and co-ordination

1.	**That this document is used as a basis of a National Strategy in Forest Genetic Resources for the period 2020-2030.**	
	Steps Necessary for Delivery	Key stakeholders
a.	Adoption of recommendation by the COFORD Council and endorsement of the report by key stakeholders.	COFORD Council, DAFM, Coillte, FGRT, NPWS, NBG, RPOs, private-sector forest nurseries, Teagasc.

2.	**That the Forest Genetic Resources Working Group (FGRWG) be maintained to act as an Advisory Group to guide the development of the sector and implementation of recommendations listed in this report.**	
	Steps Necessary for Delivery	Key stakeholders
b.	Adoption of recommendation by the COFORD Council.	COFORD Council.

3.	**That the Forest Genetic Resources Working Group (FGRWG) monitor the implementation of the recommendations and produce an implementation report within three years of the strategy being published.**	
	Steps Necessary for Delivery	Key stakeholders
a.	Adoption of recommendation by the COFORD Council.	COFORD Council
b.	The implementation and status of the report recommendations will be monitored annually.	FGRWG

5.2 Genetic options for climate change adaptation

4.	**That genetic options outlined in this report for adapting forests to climate change and mitigating biotic risk are considered.**	
	Steps Necessary for Delivery	Stakeholders
a.	Inclusion of FGR research themes in DAFM competitive research calls (see recommendation 6).	DAFM
b.	Records of provenance that accompany afforestation and reforestation projects to be maintained by DAFM, and by Coillte on the public estate. Record-keeping is essential to inform FRM decisions in the future.	DAFM, Coillte
c.	Tree improvement programmes should implement selection and breeding strategies aimed at increasing climate change resilience.	DAFM, Coillte, Teagasc, Forest Genetic Resources Trust
d.	Policymakers, forest managers and owners should prioritise diversity, both between species and within species, to increase the adaptive capacity of Irish forests.	DAFM, forest industry & forest owners
e.	For native woodland establishment or native woodland rehabilitation, provenance selection should be investigated as a means of increasing climate change resilience. Such an investigation should include further study of the adaptive potential of native trees and consideration of a desirability/needs framework to assess the risk of maladaptation	DAFM, NBG, NPWS, RPOs.

5.3 Forest genetic resources development requirements

5.	**That steps outlined in this report for the development of a fit for purpose research capacity in forest genetic resources are implemented.**	
	Steps Necessary for Delivery	Stakeholders
a.	That the Sitka spruce tree improvement programme is secured, and that germplasm and the running of the programme be developed at the national level. That a National Tree Improvement Programme be considered as part of a Longer-Term Forest Research Centre of Excellence.	DAFM, Coillte, Teagasc, RPOs.
b.	That organisations involved in the development of forest genetic resources build on their strengths and develop their skills and facilities.	DAFM, Coillte, NBG, Teagasc, RPOs.
c.	That national and international co-operative research networks and programmes continue to be encouraged and facilitated.	DAFM, Coillte, National Botanic Gardens, Teagasc, RPOs.

6.	**That research into the sustainable use and conservation of forest genetic resources is strenghtened.**	
	Steps Necessary for Delivery	Stakeholders
a.	That the sustainable use and conservation of Forest Genetic Resources are included as a research theme in the DAFM competitive research call.	DAFM
b.	That the range of species, provenances and origins recommended for use in Irish forestry are re-examined in the context of climate change to determine adaptability to future climatic conditions. Where gaps in knowledge occur, set up new provenance trials to assess the adaptive potential to respond to ongoing changes in environmental conditions.	DAFM, Coillte, Teagasc, RPOs.
c.	That species listed in Table 7 (pg. 16) are prioritised for tree improvement. Species in this table have been assigned a tier 1 or tier 2 position based on their current, or probable, future importance to the national planting programme.	DAFM, Coillte, Teagasc, RPOs.
d.	For native species, the genetic component of extant forest trees needs to be studied in greater details to assess adaptive potential.	DAFM, Coillte, NBG, NPWS, Teagasc, RPOs.

7.	**That steps outlined in this report to increase the proportion of genetically improved forest reproductive material are taken to increase the availability of genetic resources which have been developed in the categories *'Selected'*, *'Qualified'* and *'Tested'* in accordance with the EU Directive 1999/105/EC**	
	Steps Necessary for Delivery	Stakeholders
a.	The establishment of seed orchards should continue to be a priority in order to increase the availability of *'Qualified'* and *'Tested'* FRM.	DAFM, Coillte, Teagasc, private-sector forest nurseries.
b.	The system of updating and registering the network of seed stands be maintained.	DAFM.
c.	A seed stand activation programme should be initiated to increase the number of stands from which seed is collected. Initially at a pilot level focusing on oak (*Quercus petraea & Quercus robur*).	DAFM, FGRT.
d.	An annual assessment of seed cropping is needed in order to provide a forecast of potential cropping ahead of time.	Coillte, private-sector forest nurseries.
e.	The seed stands element of the Forest Genetic Resources Reproductive Material: Seed Stand & Seed Orchard should be maintained post-2021 and enhanced to include supports to enable effective seed collection.	DAFM.

8.	**That an awareness programme, overseen by the Forest Genetic Resources Working Group be prepared and implemented to inform the industry, other relevant parties and the wider public, of the importance of forest genetic resources, forest reproductive material legislation, seed collection systems, promoting the benefits of using quality material, showing the negative effects of inferior material and the overall importance of forest reproductive material.**	
	Steps Necessary for Delivery	Stakeholders
a.	FGRWG to develop campaign and co-ordinate its implementation.	FGRWG & participating organisations.

5.4 Gene conservation requirements

9.	**That steps outlined in this report for the Forest Genetic Resources conservation are implemented.**	
	Steps Necessary for Delivery	Stakeholders
a.	Implement the strategy included in this report for *in situ* conservation of native tree species.	NBG, NPWS, DAFM.
b.	Further, develop the strategy to in-corporate priority non-native and naturalised tree species.	FGRWG.
c.	Maintain links with pan-European processes for FGR conservation through the EUFORGEN and the EUFGIS network.	DAFM.
d.	Update the inventory of *ex situ* FGR at the national level.	DAFM.

Potentially tolerant ash ready for establishment as a genebank, Ashtown Co. Dublin.

6 Case Studies

Key findings and recommendations made in this report are supported by a series of species-specific case studies. The first case study on ash fulfils an objective of the FGRWG Terms of Reference, where the Group was tasked with developing a strategy to restore the planting of ash trees in Ireland. This strategy was published separately as a COFORD Connect Note and is reproduced here in section 6.1. The remaining three case studies, Douglas-fir, oak (sessile and pedunculate) and Sitka spruce outline the steps that need to be taken for the development and sustainable use of forest reproductive material to meet the needs of the forest sector.

6.1 Case Study 1: Ash (*Fraxinus excelsior*)

Brian Clifford[14], Gerry Douglas[15], Miguel Nemesio Gorriz[16]

The European common Ash (*Fraxinus excelsior*) is one of our most important native tree species; it comprises approximately 3.8% of the forest estate or 25,280 ha, 60% of which has been planted since 1990 (DAFM, 2017). It is the second most important component, after hawthorn, in large proportions of the hedgerow network. On the island of Ireland, it is estimated that there are over eight hundred thousand kilometres of hedgerows (689,000+ km in the Republic of Ireland (Green et al. 2019) and 113,000+ km in Northern Ireland (McCracken *et al*. 2017)). Ash is the second most frequent tree species in Irish native woodlands, being present within 90.2% of sites and comprising 18.5% of trees (Perrin *et al*. 2008). Woodlands dominated by ash have a rich shrub and herb flora as a result of their relatively open canopy and are one of the most species-rich of all Irish woodland types (Short, 2018). Ash is a key component of "Alluvial forests with *Alnus glutinosa* and *Fraxinus excelsior*", a priority habitat which is protected under the EU Habitats Directive (92/43/EEC). Ash is commonly referred to in Ireland's cultural heritage and has often been associated with sacred wooded sites. The timber is also traditionally used for the production of hurleys, while the low moisture content of the wood makes it a preferred firewood species.

The species is now under threat from Ash Dieback disease (ADB), caused by the invasive fungal pathogen *Hymenoscyphus fraxineus*. The disease is observed in most European countries, including Ireland. It results in large scale tree mortality and threatens the future of the species all over the continent. It originated in Far East Asia, spread to continental Europe in the mid-1990s, and detected in Ireland in 2012 on imported trees. The disease is now fully established and has been identified in all counties in Ireland. Figure 2 illustrates the distribution of the disease on the island of Ireland (DAFM, DAERA).

Hymenoscyphus fraxineus, also known as *Chalara*, has a complex life cycle. Infection first makes its way into a tree when the spores of the fungus are carried in the air and land on healthy leaves over the summer months. The fungus then grows into the leaves and down into the leaf petiole or rachis, and progressively into twigs, branches, and the stem, causing dieback. The infected leaves gradually wilt and blacken but may remain on the tree for some time. These infected leaves then fall to the ground over the autumn and early winter months and the fungus produces characteristic blackened rachises. These blackened rachises harbour the disease over winter. In the sexual reproductive stage of the fungus, which takes place over the summer and autumn months (June to October), very small white mushroom-like fruiting bodies develop on the blackened rachises and decaying leaf litter from the previous autumn and winter. When mature, these tiny fruiting bodies release large quantities of microscopic spores into the air, some of which will land on the leaves of ash trees to begin the cycle again, increasing the disease pressure. Where the disease is already present in a locality further local spread is likely to be caused by spores borne on the wind, each year travelling many kilometres from the source.

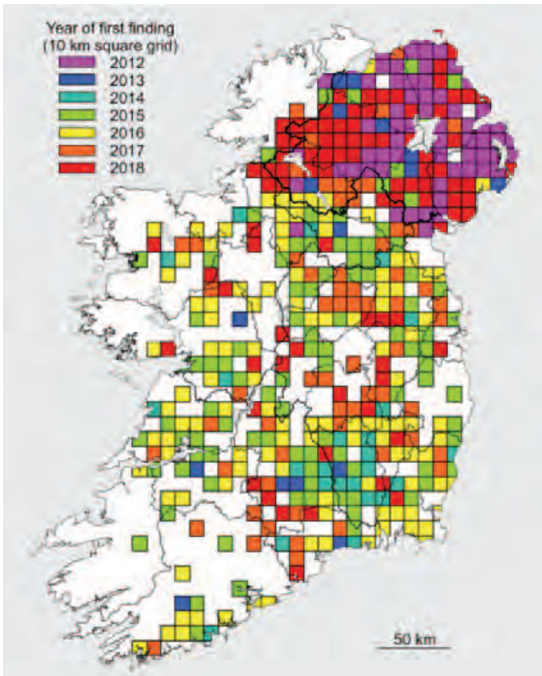

FIGURE 2 Recorded occurrence of Ash Dieback disease by year of first finding on the island of Ireland[17]

[14] Department of Agriculture, Food and the Marine.

[15] Forest Genetic Resources Trust.

[16] Teagasc.

[17] Map compiled based on data available from the Department of Agriculture, Food and the Marine, Ireland and the Department of Agriculture, Environment and Rural Affairs, Northern Ireland.

6.1.1 Impact of Ash Dieback disease in Ireland

The impact of the disease is very much in evidence and has had a substantial negative impact on young privately-owned plantation forests. In March 2013, the Department of Agriculture, Food and Marine (DAFM) introduced a Reconstitution Scheme to restore forests planted under the afforestation scheme which had suffered from or which were associated with plants affected by the disease. By the end of 2019, some €5.8 million had been paid out under the Scheme and over 1,000 hectares of infected and associated ash plantations had been cleared and replanted with alternative species. In 2018, DAFM commenced a review of its policy to ADB in recognition of the latest scientific advice, namely that eradication of ADB was no longer feasible and that the DAFM policy response should reflect this position. The review process included a stakeholder and public consultation period and detailed field consideration of damage level evaluation, together with a broader range of silvicultural and management options available to forest owners. The review was undertaken with the assistance of Teagasc and international experts. Current support schemes were reviewed to ensure the continued relevance of DAFM's response and value for money, for both the taxpayer and the individual owners and, to ensure that the forest owner is provided with a broader range of silvicultural and management options. As part of the review process, the practical management advice for forest owners and their forestry advisors is being developed to better inform them as to management options for ash plantations with the disease. It will also outline an enhanced suite of grant aid categories and other options, depending on the age of the ash plantation and degree of infection, the purpose of which is to encourage a management-based focus to deal with the disease, rather than simply clearing and replacing all infected ash forests.

The length of time that it will take for the full impact of the disease to manifest itself in our hedgerows and mature forest is also starting to become clear. The disease has caused widespread damage in continental Europe, where experiences indicate that it can kill young ash trees quite quickly, while older trees can resist for some time. However, prolonged exposure or another pest or pathogen attacking the tree in its weakened state, will eventually cause it to succumb. An analysis of surveys from across Europe was carried out by British researchers (Coker *et al.* 2019). From this they estimated that, depending on the specific conditions of a site, from year 5 to year 15 after the arrival of the pathogen, tree mortality will go up to 60%, and likely stay around those values. The long-term prognosis is therefore one of significant tree mortality. There is nevertheless a degree of hope for the future. Work has continued on the development of appropriate silvicultural strategies to minimise its impact (Skovsgaard *et al.* 2017; Short, 2018), and also on potential replacement species (Mitchell *et al.* 2016; Hill *et al.* 2019). However, it is tree improvement: selection, breeding and deployment of ash trees tolerant to the disease which offers the opportunity to restore the species to our forests and hedgerows.

6.1.2 Combating Ash Dieback disease through tree breeding

In an attempt to reduce the impact of ADB disease, researchers from 35 countries, including Ireland, joined forces in an EU- funded COST Action FRAXBACK. The Action produced several documents on the consequences of ADB disease and guidelines for sustainable management of ash (Enderle *et al.* 2017). Efforts have continued amongst the international research community, on the origin and biology of the fungus, and in understanding how the disease functions, how the tree can defend itself from it, and how tolerance[18] to the disease is passed on to the seed offspring from ash trees and onto trees which have been propagated vegetatively.

Tolerant trees in affected stands will produce a significant proportion of tolerant progeny (10-80%) that can disperse naturally in the forest environments. Therefore, by natural evolution, equilibrium with the disease may occur. However, this would likely be the case over many decades or even centuries. Scientists have focused on selection and breeding to, in effect, speed up this natural process. By carrying out a selection programme, identifying individual ash trees that can withstand the disease, and implementing breeding and deployment strategies, tolerant material may be deployed to our forests and hedgerows over a much shorter time frame.

Numerous studies have indicated that breeding for tolerance is feasible (Pliūra *et al.* 2011; Mckinney *et al.* 2011; Kjaer *et al.* 2012, Kjaer *et al.* 2017, Plumb *et al.* 2019). A number of European countries have initiated breeding programmes, including Austria, Belgium, Denmark, France, Germany, Lithuania, Poland, Sweden, Switzerland and the UK, based on the phenotypic selection of tolerant healthy trees in environments with high disease pressure. In Ireland, we have been limited by a relatively low disease pressure as a high disease pressure is needed to identify tolerant trees (although this is changing). In 2013, DAFM organised for 14,000 plants from two distinct seed lots from Ireland to be included in the UK mass screening trials. This programme involved 48 hectares of trial plantings over fourteen sites in the east of England and the mass screening of some 155,000 ash trees with fifteen different provenances. In addition, Teagasc has selected circa 1,000 genotypes on the island of Ireland and is screening this material

[18] Tolerance: the tree can be infected to a very small extent and show very mild disease symptoms without stem infections and without any significant loss of leaf canopy or tree vigour: such trees are regarded as disease tolerant, under conditions of heavy disease pressure. Approximately 1 - 3 % of a given population of the common European ash will be naturally tolerant to the disease and this tolerance is heritable and is stable in trees that are propagated vegetatively (Kjaer et al. 2017; Enderle et al. 2017; Stener 2013, 2018). Resistance: The tree is immune to the fungus meaning that it does not get infected under any circumstances. Resistance has not been found in any population of common ash.

under high disease pressure in Lithuania and resulting tolerant genotypes are expected to be brought back to Ireland in the next number of years. Teagasc has further focused on collaborating with six different European research agencies and has acquired and propagated approximately 208 ash genotypes which have been selected as putatively tolerant to ADB disease, having been observed as healthy over several years in infected locations with high tree mortality.

6.1.3 Additional challenges to ash

While outside the scope of this document, it is important to note that Agrilus planipennis, also known as Emerald Ash Borer (EAB), is an invasive insect from Far East Asia that infests ash trees causing them to collapse within 2-5 years. EAB was introduced in North America in 2002 with devastating effects. It has brought five different American ash species to a decimation point where they have been reclassified from least concern to critically endangered. EAB has also been identified in western Russia and Ukraine and is progressing westwards. EAB is absent from the EU but poses a very serious threat and is listed as a priority pest under the EU Plant Health Regulation (2016/2031). Studies have found that even though the common European ash is not as susceptible as some American ash species, it is moderately susceptible to the insect, with approximately 50% of the ash trees showing no symptoms in heavily infested areas (Straw *et al*. 2013). Several ash species are tolerant to EAB in their native range. One of these species, Fraxinus mandshurica, is very closely related to Fraxinus excelsior. Even though there are no studies on the correlation between tolerance/resistance to ADB disease and EAB, it is likely that resistance to EAB found in the gene pool of common ash (*F. excelsior*) diversity is kept as an objective of an ash breeding programme.

6.1.4 A proposed strategy to restore the planting of ash trees in Ireland

There now exists an opportunity to implement a strategy that links together initiatives that are already underway, with additional measures recommended in this document, as well as the various stakeholders in the sector, to establish a selection and deployment programme for ADB disease tolerance. It is recommended that such a strategy comprises two key elements:

- Establish a population of tolerant material, suitably adapted to Irish growing conditions; and,
- Ensure that tolerant planting material is available in sufficient quantities in the medium and long term.

Establishing a population of ash trees in Ireland with tolerance to ADB disease

Efforts to date have focused on screening material abroad. This was necessary as disease pressure was too low to carry out an effective screening programme at home. Irish ash material is being screened while growing under heavy disease pressure in different points of Europe including the 1,000 ash genotypes in Lithuania and the 14,000 plants in the UK. Additionally, Irish ash is growing in different Realising Ash Potential (RAP) trials across Europe, which were established around 15 years ago and are now ideal sources for the selection of tolerant ash genotypes (Figure 3). An effort should be put into monitoring this material and repatriate genotypes that show consistent tolerance to ADB disease.

Disease pressure has built since the disease was first detected in Ireland in 2012 (Figure 2). This offers the opportunity for the survey of indigenous stands for trees tolerant to the disease, with the aim of retaining local genetic variation. Other sources of tolerant material may include thinned stands which have been heavily infected in which some individual trees produce healthy stump sprouts among the majority which are heavily diseased. The long-term effects of ADB disease may be to diminish the total genetic diversity in Irish populations of ash. To safeguard the genetic diversity in populations and complement future breeding work, it would be desirable to collect and store seeds which are currently available from healthy seed-producing trees.

Screening programmes have been initiated in a number of European countries. It would be desirable to work together, to share knowledge and material, and with it improve cost-effectiveness, increase the genetic diversity of the tolerant ash collections and speed up the availability of tolerant material.

Movement of Forest Reproductive Material (FRM) brings with it concerns over the adaptability of imported FRM to local conditions. Fortunately, prior to the outbreak of the disease, European provenance trials (RAP) were set up to compare the performance of up to forty-seven European provenances under Irish conditions (Douglas *et al*. 2013). These trials have the potential to yield knowledge on the adaptability of European provenances to Irish conditions and may provide useful material for breeding (Figure 3).

Having acquired and propagated tolerant plant material, it is essential to conserve the collection of tolerant ash trees as living gene banks (conservation collections). These conservation collections will be a significant and valuable genetic repository, as well as a resource which will enable the scaling up of the production of tolerant plant material for deployment in the longer run. To safeguard the collections for the long term, at least three should be established in diverse locations.

Element 2: Providing tolerant planting material in sufficient quantities

Key to any tree breeding programme is to ensure that enough planting material is made available for deployment to justify the initial investment in selection and breeding. Planting material can be generated through vegetative propagation and through seed production.

Vegetative propagation

Vegetative propagation is the fastest route for producing ADB disease tolerant ash trees. It offers the advantage that the propagated trees will be genetically identical to the original trees selected with regard to tolerance to all of the forms of ADB disease attack including stem and root collar infections.

A Swedish study over a period of 10 years has proven that field resistance to dieback disease has remained stable in trees which have been selected and propagated vegetatively (Stener 2013, 2018). Large scale vegetative propagation of tolerant ash trees involves significant nursery resources, initially to propagate trees by grafting and also for the production of cuttings which must have a high capacity for rooting. Cuttings derived from saplings have juvenile physiology and a high capacity for rooting unlike cuttings derived from grafted trees. Sources of tolerant saplings would be obtainable from controlled crossings of tolerant parent trees. Grafted trees can also be a source of cuttings, however, they must first be cultivated into a state of physiological juvenility. This state ensures that cuttings will produce roots at an efficient rate of over 80%. Restoring juvenility to tolerant grafted trees involves the technology of micropropagation and/or using a process of intensive pruning, as developed and published by Teagasc (Douglas *et al*. 2017).

***FIGURE 3** Geographic location of provenances included in the Realising Ash Potential (RAP) trials. Red indicates the provenance source and blue the location of the trials in Ireland. The shaded area represents the natural distribution of the common ash (Fraxinus excelsior) (Caudullo et al. 2017).*

The system of vegetative propagation is flexible in the way that production of plants can be scaled up or down at the nursery level depending on plant demand. The second route to generating tolerant planting stocks of ash is the production of seeds which have genetic factors conferring tolerance to ADB disease. This is accomplished by facilitating the pollination of tolerant mother trees with pollen from tolerant father trees. The highest levels of tolerance can be obtained by the controlled pollination of tolerant mother trees with pollen from tolerant father trees in which extraneous pollen can be excluded/minimised. In field conditions, it involves the establishment of dedicated seed-producing orchards. Trees which will constitute the seed-producing orchards will be propagated by grafting shoots which will be collected from the gene bank trees.

A period of 12 to 20 years will be required to pass before the trees in the seed orchards reach flowering stage. Natural cross-pollination will result in the production of seed progeny that will have tolerant father and mother trees as the parents. This natural crossing of the tolerant trees is uncontrolled in the field and some level of contamination by pollen from non-tolerant local trees can be expected. However, despite such pollen contamination, it has been shown that progeny from tolerant trees have an increased level of tolerance. In addition, they have been shown to be sufficiently fit to become established as healthy trees in forests under conditions of natural regeneration (Semizer-Cuming et al. 2019). Outdoors seed orchards in areas with high disease pressure can further assist in identifying and selecting resistant trees. One caveat regarding outdoor seed orchards pertains to the fact that the plants which constitute the orchards will consist of composite trees, i.e. a tolerant shoot grafted onto a rootstock plant. The level of rootstock tolerance will be unknown in advance but likely to be low as natural tolerance is only found in 1 – 3% of the trees. If the disease pressure is extremely high within the seed orchard some trees may be susceptible to infection at the root/stem junction and may succumb. This potential threat can be mitigated by establishing seed orchards on multiple sites since disease pressure varies from site to site. The wide spacing of trees in seed orchards will mitigate the build-up of disease pressure, furthermore as rooted cuttings are produced from tolerant trees, grafted plants will be replaced by them. Efficiency in seed production is also affected by site conditions during pollination and during the period of seed development. Establishing multiple seed orchards in diverse geographic locations will improve the overall prospects for obtaining consistent quantities of seeds on an annual basis.

In 2020 a collaboration between Teagasc and Coillte, with support from DAFM, resulted in the first conservation collection being established on a Coillte property in Co. Kilkenny. The site constituted the first planting of potentially tolerant ash genotypes. The site will be monitored over the coming years in order to assess how tolerance of each genotype holds up.

6.1.5 Timeline

An outline of the timescale for producing and mobilising tolerant ash material for field planting is given below.

Short term 1-3 year

- Acquisition of shoots from tolerant trees from abroad, identify and monitor putatively tolerant trees in Ireland
- Establishment of tolerant trees in gene banks outdoors, some of which should be in areas with high disease pressure
- Bulking up of all tolerant material by grafting for field screening tests in areas with high disease pressure
- Designation of secure sites for hosting conservation collections and for confirmation screenings of all material selected as having a high tolerance to ADB disease

Medium term 2-6 years

- Micropropagation of tolerant individual trees for rejuvenation purposes
- Establishment of 'hedges' of tolerant trees using grafted plants and micropropagated plants to facilitate mass vegetative propagation on pilot / commercial scales
- Establishment of seed-producing orchards using tolerant parent trees (indoors) with controlled crossings to produce small quantities of seeds which can be bulked up vegetatively
- Evaluation of the level of disease tolerance in all material propagated vegetatively

Long term 6-20 years

- Mass propagation of multiple genotypes of tolerant trees vegetatively using tolerant trees and saplings from controlled crossings as the propagation sources
- Establishment of seed-producing orchards using tolerant parent trees (outdoors)
- Monitoring of tolerance to ADB in progeny from the seed banks
- International collaboration to assess resistance level to EAB of the gene bank

6.1.6 Conclusions & recommendations

Tolerance to ADB disease is found in natural populations and this tolerance is heritable. Therefore, breeding for tolerance is feasible. This has been supported by numerous studies (McKinney *et al*. 2011; Kjaer *et al*. 2012; Kjaer et al. 2017; Pliūra *et al*. 2017, Plumb *et al*. 2019). Tolerance to ADB disease is also stable in trees that are propagated vegetatively (Stener 2013; 2018). An approach to generating sources of tolerant ash seeds and plants has been proposed and an indicative timeline outlined. There are however significant challenges in realising such a strategy. These include providing resources for acquiring and propagating tolerant material, its ongoing field assessment for disease tolerance over several years, and the bulking up of this material by seed and vegetative means for pilot-scale field plantings and evaluation in forests. In addition, the development of robust molecular markers and physiological tests are highly desirable to accelerate the selection of tolerant genotypes in the field and among progeny produced from breeding work, and also to provide a better understanding of the interaction of the pathogen with host ash trees. The potential for tolerance breakdown by mutations in the pathogen may be possible but has not been detected in over 20 years of its presence in Europe. The genetic structure of the pathogen *Hymenoscyphus fraxineus* is stable across Europe (Gross *et al*. 2014; Burokiene *et al*. 2015). The introduction of new strains of the pathogen from Asia is the most likely route which would lead to a breakdown in the tolerance of those trees that are being selected for breeding and vegetative propagation (Mc Mullan *et al*. 2018). Of particular relevance, however, is that we in Ireland have the capacity to deliver on such a strategy. Selection, breeding, progeny testing, orchard establishment, these require a long-term vision, and structures to ensure continuity. The challenges associated with long-term research have been highlighted by a recent report of the COFORD Council (COFORD, 2018). These challenges are of relevance to the forest genetics resources community and will need to be addressed in order for a strategy such as the one outlined above to succeed.

6.2 Case Study 2: Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco)

Ignacio Sevillano[19], Brian Clifford[20], Brian Tobin[19], Niall Farrelly[21] and Conor O'Reilly[19]

Douglas-fir covers a large area of western North America. It extends from British Columbia in the north to north-western Mexico in the south, and from the Pacific Ocean coast in the west to the Rocky Mountains in the east. The coastal variety is identified as *Pseudotsuga menziesii* subsp. *menziesii*, while *Pseudotsuga menziesii* subsp. *glauca* is used to identify the interior one. This large natural range permits selection for variation in frost and winter cold tolerance, productivity and quality between origins (Figure 4).

Douglas-fir is the most abundant non-native tree species planted in Europe, about 80% of the total area covered is to be found in France, Germany and the United Kingdom (Da Ronch *et al*. 2016). Although the Irish climate is similar to that of the coastal range of the species, higher summer temperatures, including greater levels of drought are more common in its native range. Nevertheless, it appears well adapted to the moist Irish climate if planted on free-draining soils in sheltered locations. Douglas-fir has been shown to be a productive, commercially valuable species in this country with an average yield class of 15-17 m^3 ha^{-1} $year^{-1}$ (Dunbar *et al*., 2002; Thompson and Lally, 1998). There is 10,380 ha planted on the national forest estate accounting for approximately 1.5% of forested land (DAFM, 2018).

FIGURE 4 Natural distribution of Douglas-fir. The coastal variety Pseudotsuga menziesii subsp. menziesii is identified in green, while the interior variety Pseudotsuga menziesii subsp. glauca is represented in blue. (Little, 1971).

[19] University College Dublin.

[20] Department of Agriculture, Food and the Marine.

[21] Teagasc.

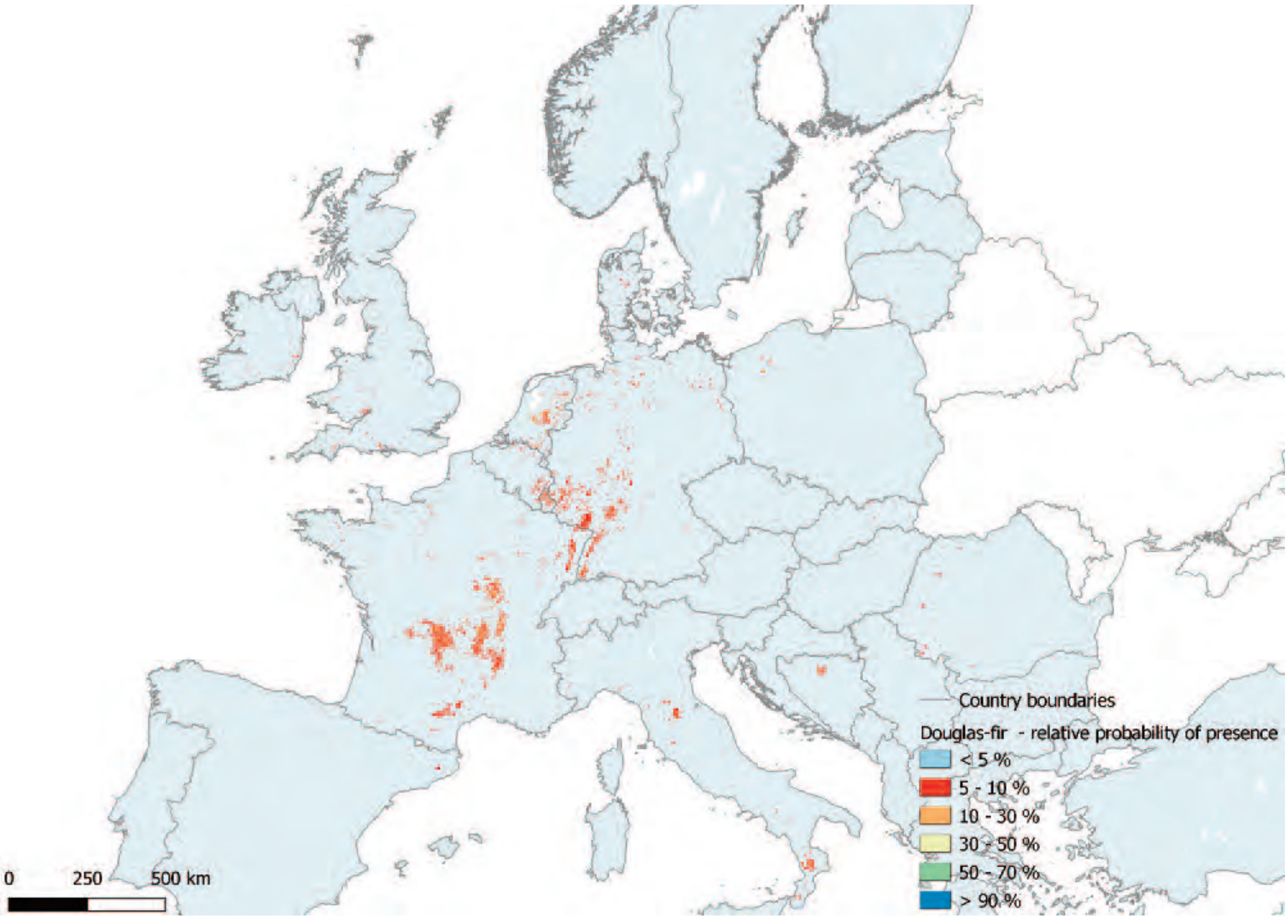

FIGURE 5 Relative probability of the presence of Douglas-fir in Europe (de Rigo et al., 2016a).

6.2.1 Silvicultural uses and site requirements

Douglas-fir has been used successfully as a nurse for Sitka spruce, particularly on nutritionally marginal old red sandstone soil (McCarthy and Horgan, 2003). Stem sinuosity (distorted growth) has been noted on sites where fast growth occurs (Horgan *et al*., 2003). A suitable site has well-drained soil of good depth and moderate fertility, on sheltered or middle-valley slopes.

6.2.2 Threats and diseases

Apart from areas where deer populations are high, Douglas-fir is not generally limited by pests or diseases. At least 86 *Pinus* species, 5 *Picea* species, European larch and Douglas-fir have been reported as hosts of the red band needle blight of *Dothistroma* needle blight disease (Watt *et al*. 2009). Douglas-fir is reported to be susceptible, although probably at a low level (also applies to Sitka and Norway spruce and European larch). Trees of all ages can become infected. The symptoms are most obvious in July and August and are first observed at the base of the crown on older needles, with infected needles developing yellow and tan spots and bands that turn red (McCracken, 2013). Swiss needle cast has caused defoliation damage, to the point of causing increment loss and mortality (Horgan *et al*., 2003). Populations from the coast range show better resistance to fungus diseases than interior sources (Bastien *et al*., 2013). This species is also the alternate host for the Cooley spruce gall adelgid. Douglas is considered moderately resistant to heart and butt rots. Douglas-fir is liable to be heavily attacked by the large pine weevil (*Hylobius abietis*) and remains susceptible for several growing seasons, which can cause substantial tree mortality on reforestation sites (Wallertz *et al*., 2014). Most pine weevil feeding occurs between early March and November, with peaks of damage occurring in spring and late summer. The woolly aphid (*Adelges cooleyi*) can severely affect the growth of young trees, causing yellowing and deformity of needles in spring and early summer (Savill, 2013). It is less susceptible to the attack of annosum root rot (*Heterobasidium annosum*) than many other conifers. Douglas-fir is a frost-tender species and can often suffer from late spring frost damage. Interior populations are more resistant to early and winter frosts but susceptible to frosts in the spring (Braun and Wolf, 2001), whereas the opposite is true for the coastal populations which are more resistant to spring frosts and more prone to winter frosts (Konnert and Alizoti, 2016). Latitude, distance to the Pacific Ocean and elevation explain most of the between-population variation in response to early and winter frosts (Bastien *et al*., 2013).

6.2.3 Provenance testing

In 1971, as part of the IUFRO experiment, 32 origins (mostly coastal) were used to establish a series of five trials around Ireland. Southern Oregon origins were the most vigorous but had the poorest stem form. Material from the Cascade Mountains provided good stem form but growth rates were lower. Southern Washington coastal origins combined good growth, late flushing, and moderate to low susceptibility to autumn frosts with good stem form. Seed from southern Washington and northern Oregon coastal origins combine good growth rates with good stem form and were determined to be the origin of choice for Ireland (Thompson and Lally, 1998).

6.2.4 Tree selection and breeding

According to a study carried out by INRA (Institut National de Recherche Agronomique -Orléans – France), high heritability values were revealed for flushing, medium for branch angle, height growth and wood density and low for forking and stem straightness (Bastien *et al*., 2013). Heritability and genetic correlations changed from one population to another, suggesting a necessity of adjustment of breeding efforts at the population level. Although provenance testing has been carried out, little tree breeding work has been completed for Douglas-fir in Ireland. There are records of a clonal seed orchard having been established in Co. Wicklow in the 1960s, however, the orchard was not successfully established due to graft incompatibility and little evidence of it exists today.

6.2.5 Sources of Forest Reproductive Material

Douglas-fir is monoecious. Although trees commonly begin to produce strobili at 12 to 15 years of age (Hermann and Lavender, 1990), in Britain, Douglas-fir has been reported to produce its first good cone crop at 30 years of age (Nixon and Worrell 1999). Douglas-fir seed crops occur at irregular intervals- one heavy and one medium crop every 7 years on the average; however, even during heavy seed years, only about 25 % of the trees produce an appreciable number of cones. There are about 87,000 seeds per kg, of which 70,000 are normally viable (Savill 2013). Seeds are usually stratified or pre-chilled for 3 or more weeks and sown in late March (Savill 2013).

Forest Basic Material:

1) *Select Seed Stands:* As of January 2020, there are 21 'Selected' seed stands, registered on the National Register of Basic Material (seed stand database).
2) *'Qualified'/'Tested' Orchards:* In the 1960s scion material were collected from a number plus tree and an attempt made at establishing an untested orchard. However, due to a high degree of grafting incompatibility, the orchard was unsuccessful and subsequently abandoned. There are currently no Douglas-fir seed orchards in Ireland.
3) *Imported sources:* Under the OECD Scheme for the Certification of Forest Reproductive Material FRM can be imported from coast range Mountains Washington and Oregon Sources from its home range.
4) *Imports from foreign improvement programmes:* While 13 European countries started breeding programmes with Douglas-fir, only a small number have continued with the breeding process beyond the first generation (Bastien *et al*., 2013). Thousands of genotypes have been selected in natural and artificial populations across Europe and they are now archived in clonal banks, representing a vast *ex situ* reservoir of genetic resources (Bastien *et al*., 2013). Improved material, originating from Darrington USA, was developed by the Danish Institute for Forestry and INRA. Darrington is located in the northwestern foothills of the Cascade Mountains. Material from the northern Cascades was deemed suitable for planting in Ireland based on the 1971 IUFRO provenance trials, as it combined 'good height growth with late bud break and early bud set to protect against late spring and early autumn frost damage' (Thompson and Lally, 1998). The improved material developed by the Danish Institute for Forestry and INRA has been categorised as *'Tested'* by the French authorities. The buds of this material flush later and it has the better form (straightened stem, reduced branching and forking) compared with unimproved material of the same origin. Although the material was selected in Denmark, the orchard was planted in France to increase the rate of flowering.

6.2.6 Conclusions & recommendations

Douglas-fir produces high-value wood suitable for a range of products. It has been identified as a high priority species for economic purposes in Ireland as well as for many parts of Europe because of its ability to maintain productivity even under drought conditions (Eilmann et al., 2013). A cost-benefit analysis determined that tree improvement for Douglas-fir would be positive and equally profitable as for Sitka spruce, (O'Reilly *et al*., 2014). The species grows well on relatively sheltered sites with free-draining soil but is prone to deer damage (Horgan *et al*., 2004). Therefore, in Ireland, the species is suitable on a relatively limited range of sites. As a result, it is difficult to justify a national tree improvement programme. It may be preferable to source seed from *'Selected'* seed stands in Ireland or improved seed of suitable origin developed abroad. Therefore, establishing trials with foreign improved material under Irish conditions should be a priority. Currently tested material is available in France (see above). The option of importing improved material directly from the US should also be explored.

6.3 Case Study 3: Pedunculate oak (*Quercus robur* L.) and sessile oak (*Quercus petraea* L.)

Ignacio Sevillano[22], Brian Clifford[23], Eugene Hendrick[24], Brian Tobin[22] and Conor O'Reilly[22]

Two oak species are native to Ireland, pedunculate oak (*Quercus robur* L.) and sessile oak (*Quercus petraea* L.). Both occur widely across most of Europe and their ranges frequently overlap, reaching northwards to southern Norway and Sweden and southwards to the northern part of the Iberian Peninsula, south Italy, the Balkan peninsula and Turkey. The range of pedunculate oak extends further northwards and eastwards than sessile oak, both oaks occur across a range of elevations from lowland to upland, though to increasingly higher elevations in southern regions. However, sessile oak is more montane than pedunculate oak (Caudullo *et al.*, 2017; Figure 6, Figure 7).

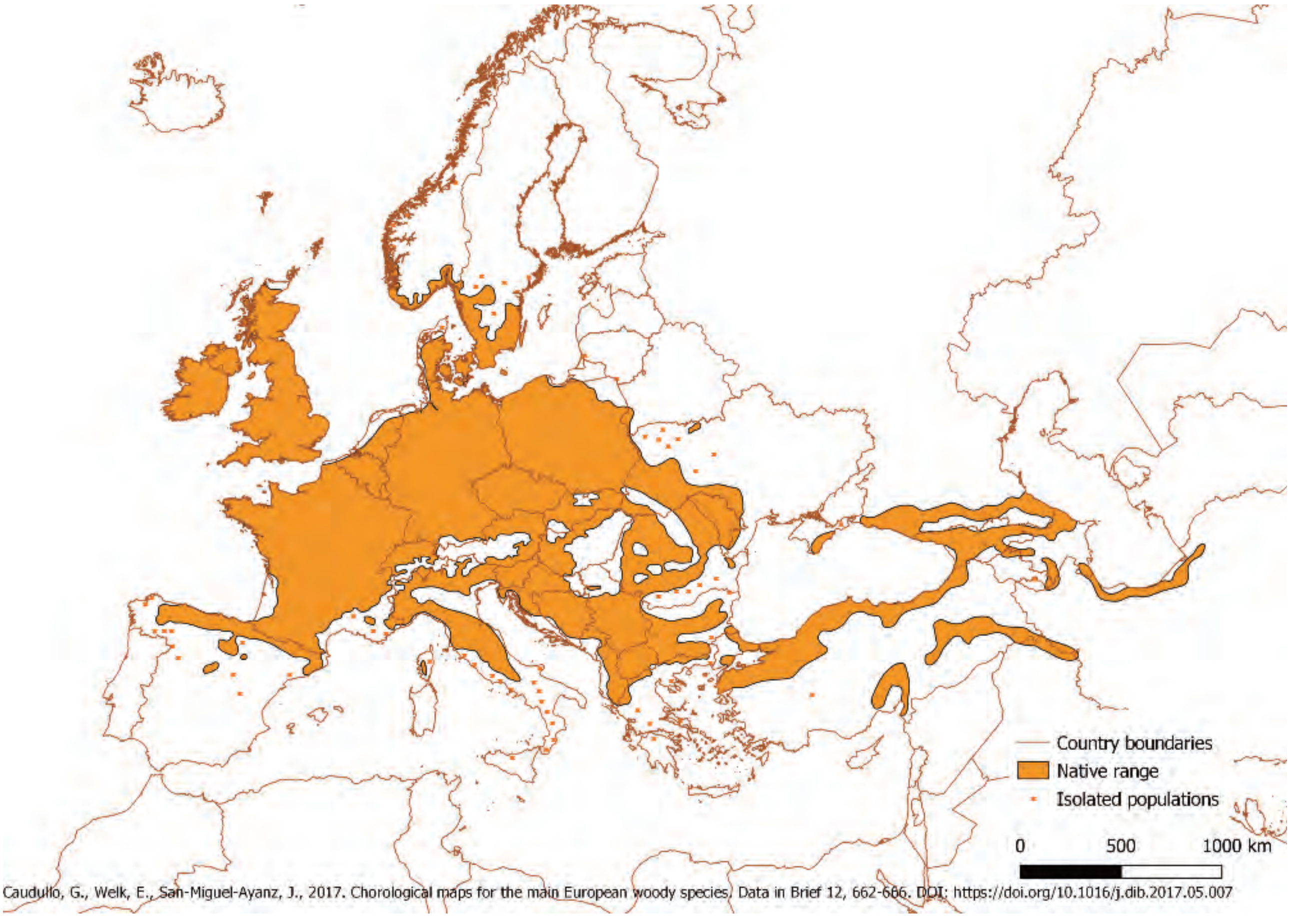

FIGURE 6 Distribution map of sessile oak (Quercus petraea) (Caudullo et al., 2017).

[22] University College Dublin.

[23] Department of Agriculture, Food and the Marine.

[24] Forest Genetic Resources Trust.

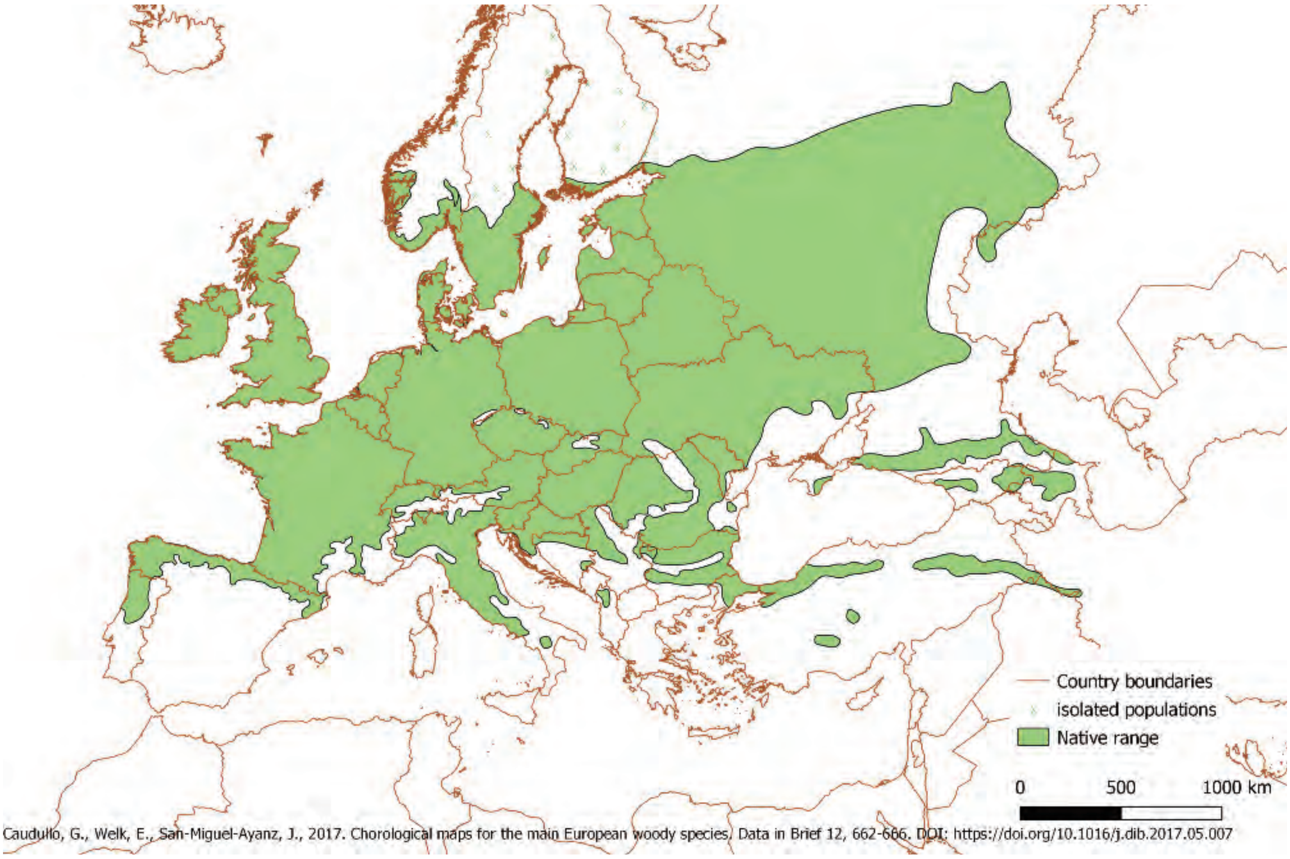

FIGURE 7 Distribution map of pedunculate oak (Quercus robur) (Caudullo et al., 2017).

Because both species co-occur at many sites as the main component of temperate deciduous mixed forests and their similarities are greater than their differences, pedunculate and sessile oak are dealt with together in this case study. Table 13 lists the main differences between both oak species. Pedunculate and sessile oak hybridize easily (Rushton, 1993) and gene exchange is quite common and extensive where they overlap, which have implications for forest tree breeding and forest management (Muir *et al*., 2000).

TABLE 13 The main differences between sessile and pedunculate oaks

Feature	Sessile oak	Pedunculate oak
Morphology		
Petiole length (Kremer et al., 2002)	Relatively longer	Relatively shorter
Number of intercalary veins (Kremer *et al*., 2002)	Relatively smaller	Relatively greater
Growth		
Early growth (Savill, 2013)	Relatively slow	Relatively fast
Shade tolerance (Savill, 2013)	More shade tolerant	Less shade tolerant
Form of tree (Savill, 2013)	Straighter, long bole, persistent main stem	Low branching, short bole, not persistent main stem
Epicormic shoots (Savill, 2013)	Less liable to produce	More liable to produce
Leaf emergence (Savill, 2013)	One week earlier	One week later
Site preferences		
Soil preferences (Savill, 2013)	Acid, freely draining	Wetter, heavier and more alkaline
Frost susceptibility (Savill, 2013)	Slightly less frost tender	More frost tender
Drought resistance (Savill, 2013)	Relatively resistant	Not resistant
Other		
Defoliation by caterpillars (Savill, 2013)	Less likely (earlier flushing)	More likely (later flushing)
Acute oak decline (Savill, 2013)	Possibly less susceptible	Possibly more susceptible
Acorns (Savill, 2013)	c. 316 kg-1	c. 273 kg-1
Oak lactones and phenolics in wood (Savill, 2013)	High lactones, low phenolics	Low lactones, high phenolics

6.3.1 Silvicultural uses and site requirements

Height growth in both oaks is rapid during the early juvenile period, but vigorous height growth is only maintained on the best sites (COFORD, 2002b). Frequent, light and intermediate thinnings is the traditional silvicultural approach, with an aim to maintaining balanced growth of potential crop trees while avoiding stress or overexposure of crowns to prevent the development of epicormic shoots (Horgan *et al*., 2004). Pure oak stands should be planted at a stocking of 3,300 stems per ha, at a recommended, 2 × 1.5 m spacing, with about 100 trees ha-1 remaining as a final crop over-rotation lengths in the region of 130 and 160 years for *Q. robur* and *Q. petraea*, respectively (Horgan *et al*., 2004; DAFM, 2015). Oak stands can be established as mixed crops with conifers, such as European larch (which may be substituted for Scots pine on poor sites) or broadleaves, such as ash, cherry, sycamore, hornbeam and lime at establishment or beech as an understorey (COFORD, 2002a). Both species can tolerate a wide range of soil conditions, but as a commercial crop it is recommended to plant on low-elevation, sheltered sites on soils of at least moderate fertility (Horgan *et al*., 2004) and drought-prone sites should be avoided (COFORD, 2002a). While pedunculate oak prefers well-aerated, deep, moist, fertile and heavy soils and can tolerate some waterlogging; sessile oak is intolerant of flooding and prefers the better drained acid brown earths (Horgan *et al*., 2004).

6.3.2 Threats and diseases

Apart from occasional damage by the grey squirrel and oak mildew, which reduces their growth, both species of oak are relatively free of pests and diseases (Horgan *et al*., 2004). Oaks may also suffer from acute oak decline, which weakens and damage trees, sometimes resulting in premature death (Savill, 2013).

The first interception of the pest Oak Processionary Moth (*Thaumetopoea processionea*) was confirmed in June 2020. Oak processionary moth is a potential risk as it causes severe defoliation of oak species and, occasionally, other broadleaved species but also it is a human and animal health hazard (Evans, 2007). The single OPM finding occurred on one imported, planted amenity tree, which was removed and destroyed. The wider intensified DAFM survey did not yield additional findings. This was the first finding of this pest on the island of Ireland. Ireland is recognised as a protected zone under EU legislation for this pest based on years of official survey data and we are the last EU Member State to be free from OPM.

6.3.3 Provenance testing

Interest in oak provenance testing was stimulated by a good acorn crop in 1984, resulting in the establishment of four native oak provenance trials in 1988 in Co. Wicklow, Co. Laois, Co. Cavan and Co. Kildare (Felton *et al*., 2006; Felton and Thompson, 2008). Early assessment of these trials showed a discontinuous geographic distribution of good and poor provenances across the country (Felton *et al*., 2006). For example, in Wicklow, the Enniskerry provenance performed well, while the close-by Delgany provenance was a poor performer (Felton *et al*., 2006). At about the same time (1988 and 1989), two IUFRO oak provenance trials including material from Ireland, the UK, France, Germany and The Netherlands were established (Lally and Thompson, 2000). Early results from these trials suggest that when native Irish material is not available Dutch and British sources, which produced good growth and stem form, are preferred (Felton and Thomson, 2008; Lally and Thompson, 2000). French and German material did not perform well in these trials and are not considered well suited under Irish conditions (Felton and Thomson, 2008; Lally and Thompson, 2000). In particular, Dutch material did very well in these trials, combining good growth rates with late flushing (Felton and Thompson, 2008).

Another series of trials, including both seed stand progeny and plus tree progeny were established in Ireland in 2005/06 (Co. Wicklow, Co. Westmeath and Co. Cork) and 2008/09 (Co. Wexford and Co. Cork) (Future Trees Trust, 2016). Data from these trials are currently being archived and analysed by the Forest Genetic Resources Trust (FGRT).

A recent study with 26 provenances (focused primarily on *Q. petraea* provenances) selected from sites throughout Europe, including Ireland, showed that provenances from places characterised by wet summers were more vulnerable to drought events and planting site (especially soil conditions) appeared to have a stronger effect on the response to climate than provenance (Bert *et al*., 2020).

6.3.4 Tree selection and breeding

The first oak plus tree selections in Ireland were carried out in 1991 under the EU-funded ÉCLAIR Programme. Some 102 plus trees were selected, with approximately equal representation of both species (with some hybrids). Most of the plus trees were conserved in clone banks established at Kilmacurra and Newtownmountkennedy Co. Wicklow (Fennessy *et al*., 2012).

More recently, oak tree improvement has been carried out by the Future Trees Trust (FTT) and the Forest Genetic Resources Trust (FGRT). The origins of the FTT and the FGRT began in the early 1990s via a partnership known as the British and Irish Hardwood

Improvement Programme. The British component was rebranded as the Future Trees Trust (FTT) and in 2019 the Irish component as the Forest Genetic Resources Trust (FGRT).

The FTT Oak Group started its activities in 1997 with the establishment of a plus tree selection programme which planned to select 246 plus trees throughout Great Britain, Ireland and north-western Europe. The selection was based on the following desirable characteristics: early vigour and rapid growth, being well-adapted to local conditions, free of pests and diseases, straight stem with good apical dominance and light branching, and vessel size of fewer than 160 microns to reduce susceptibility to shake (Future Trees Trust, 2016). These 246 plus trees were reduced to about 110 when vessel size was assessed and findings showed that French and Irish selections had smaller vessel sizes while the Dutch oaks had the largest ones and, therefore, greater predisposition to shake (Hubert and Savill, 1999).

The above-mentioned efforts resulted in the establishment of eight breeding seed orchards (BSOs) which also functioned as progeny trials, including one in Ireland, in Co. Cork (Hubert and Savill, 1999; Fennessy *et al*., 2018). Currently, five of the BSOs remain, including one at Rathluirc, Co. Cork. It was planted in 2003, comprising approximately equal numbers of both species; over 46 families, and was replicated 48 times in a randomised complete block design (Future Trees Trust, 2015). It contains a total of 2,208 individual trees in an area of 0.88 ha and is being continuously monitored to provide further information (Future Trees Trust, 2016).

From 2015, the FTT began a systematic relocation of the plus trees. Where originals were no longer extant or could not be identified with certainty, alternatives were selected, marked and recorded. Not all locations were revisited. Data records for the plus trees (including updates) are held by the FGRT. These are being consolidated, and currently (late 2020) some of the locations are being revisited with a view to collection of *Q. petraea* scion wood for seed orchard establishment. There may be a case to reconsolidate the entire oak plus tree population in a dedicated *ex situ* clone bank.

On its inception in 2019, the Forest Genetic Resources Trust (FGRT) began work on the establishment of oak seed orchards in Ireland. To that end, FGRT has worked with FTT in the establishment of a *Q. petraea* seed orchard (using some Irish, but mainly GB material) at Castlewellan Co. Down. The main thrust of FGRT work has, however, been the establishment of oak seed orchards in RoI. To that end, FGRT has worked with the forest nursery sector and has secured agreement in principle to establish four seed orchards (two with each species) in 2021-2022. Scion wood has been sourced from over fifty *Q. robur* plus trees from the original ÉCLAIR collections, and a smaller number of *Q. petraea* was collected at the end of 2019 and is now being propagated in the Netherlands. Additional *Q. petraea* material is being sought to bring the breeding population close to fifty. A further clone bank comprising Irish and British plus tree material is being established by the FGRT at the National Botanic Gardens Arboretum at JFK Park, Co. Wexford.

6.3.5 Sources of Forest Reproductive Material

Generally, the earliest age at which oak trees in forest stands bear seed is 40-50 years, but best production is usually after the age of 80 years with sessile oak being a less prolific seed producer than pedunculate oak. Seed orchards can begin production far earlier, at 5-10 years, with the level of production increasing with orchard age. First choice for material is from Irish *'Selected'* seed stands, but if Irish material is not available the material should come from *'Selected'* sources in Europe, namely Britain, northern France and the Netherlands (Table 14; DAFM, 2016). An extensive network of *'Source Identified'* and *'Selected'* seed stands have been included on the National Register of Forest Basic Material. There is 1,439 ha of Q. robur (508 ha *'Selected'*, 931 ha 'Source Identified') and 856 ha of *Q. petraea* (384 ha *'Selected'* and 472 ha *'Source Identified'*) (DAFM, 2020). It is expected that *'Qualified'* and tested material from the FTT and FGRT oak improvement programme will be available over the coming decade (Beesley and Clark, 2020; FGRT pers. comm.).

Table 14 Oak forest reproductive material considered suitable for use in the afforestation scheme[25].

	Source Identified	Selected	'Qualified'	Tested
Pedunculate oak (*Quercus robur*)				
First-choice: native Irish	✘	✔	✔	✔
Otherwise: British (English and Welsh), French (north of Paris), Belgian, Dutch, Danish, German (north of Frankfurt)	✘	✔	✔	✔
Sessile oak (*Quercus petraea*)				
First-choice: native Irish	✘	✔	✔	✔
Otherwise: British (English and Welsh), French (north of Paris), Belgian, Dutch, Danish, German (north of Frankfurt)	✘	✔	✔	✔

6.3.6 Conclusions & recommendations

Oak species (sessile and pedunculate) are among the most commonly planted broadleaves in Ireland. These are species which have undergone extensive provenance testing with a well-developed selection and breeding programme underway through the FTT and FGRT. There is a strong demand for *'Selected'* FRM for planting as pure oak in afforestation and reforestation, while improved FRM will also be in high demand when it becomes available. There is also a strong demand for *'Source Identified'* material for the native woodland establishment where there is a greater management focus on gene conservation.

Ireland does not have a climate conducive to seed production, nevertheless, the seed stand resource is underutilised. While good seed years are intermittent, acorns are generally borne to some extent every year but are collected in a small number of seed stands on an annual basis. Reliance on imported seed is high, with the preferred source being Dutch material, which comes from a long-established system of seed orchards based on *'Selected'* material (Fennessy *et. al*., 2018). Provenance testing has demonstrated that Dutch material performs well in the Irish climate. Nevertheless, there is a need to be less reliant on imported sources and to this end, the level of seed production from indigenous seed stands should be increased, the selection and breeding of oak should continue, and seed orchards established.

It is recommended that a seed orchard establishment programme and seed stand activation programme be pursued consisting of the following elements:

- Establishment of seed orchards for both oak species, based on selected plus trees from populations mainly in Ireland, but including GB material. Building resilience to future variations in climate may be achieved through incorporation of material from north-west continental Europe.
- *Ex situ* conservation of the full range of oak plus tree material in a secure location.
- Management of a selection of existing oak seed stands to increase the level of indigenous oak material being used in afforestation and reforestation.
- Consider the evaluation of provenance trials where there are a large number of seed stand seed sources to convert them to a tested seed source. This may facilitate the supply of tested seed to market relatively quickly by growing seed stand material in comparative trials.
- Further analysis and assessment of existing field trials.

[25] Under the Native Woodland Conservation Scheme FRM from *'Source Identified'* and *'Selected'* stands regarded as indigeonus are acceptable.

6.4 Case Study 4: Sitka spruce (*Picea sitchensis* (Bong.) Carr.) Ignacio Sevillano[26], Brian Tobin[26], Brian Clifford[27], Niall Farrelly[28] and Conor O'Reilly[26]

Sitka spruce (*Picea sitchensis* (Bong.) Carr.) is Ireland's most important commercial tree species, producing quality timber on relatively short rotations being adapted to the mild oceanic climate of Ireland. The species natural range extends from latitude 61ºN on Kodiak Island in the western Gulf of Alaska to latitude 39ºN in Mendocino County, in northern California, spanning a distance of about 2,900 km. The bulk of the Sitka spruce[27] growing stock is found in Alaska (63%), British Columbia (29%) and the remainder in Washington, Oregon and California (8%) (Harris,1984) (Figure 8).

It was introduced in Europe in the 1800s and is now widely planted in Ireland and the United Kingdom, it is also planted to a lesser extent in Denmark, south-western Norway, north-western France, and southern Sweden (de Rigo *et al*.; 2016b; Figure 9).

FIGURE 8 Natural distribution of Sitka spruce (Picea sitchensis) along the Pacific Northwest coast of North America (Little, 1971).

[26] University College Dublin.

[27] Department of Agriculture, Food and the Marine.

[28] Teagasc.

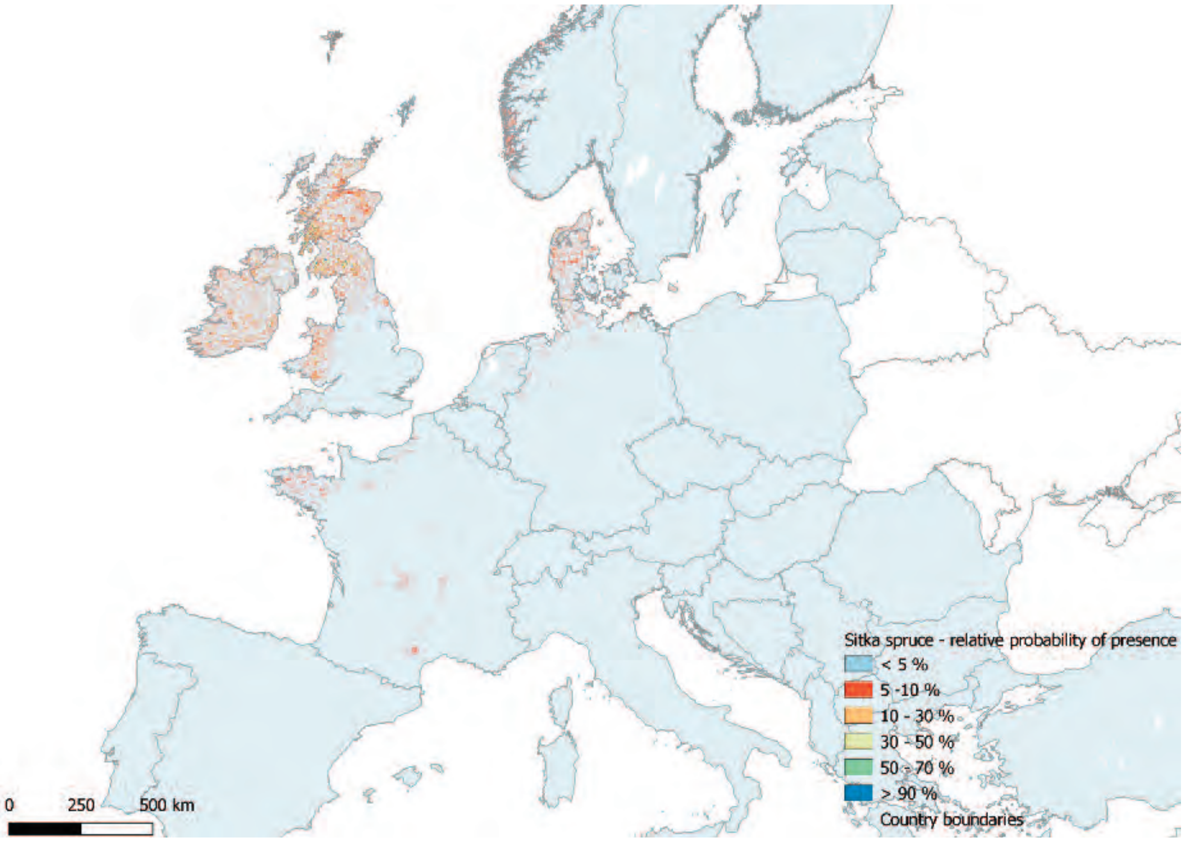

FIGURE 9 Relative probability of the presence of Sitka spruce in Europe. (de Rigo et al., 2016b).

6.4.1 History of use in Ireland

Sitka Spruce was first introduced to Ireland in 1835 as an amenity species at Curraghmore, Co. Waterford. By 1900 total forest cover was just 1.6% of the land area, probably the lowest forestry cover in Ireland's history. The lack of woodland led to a consensus that action needed to be taken to address future wood supplies. The Avondale Initiative, launched in 1903, involved the establishment of a species trial in Avondale, Co. Wicklow to assess species suitability for Ireland's new forestry programme. The first experimental planting of Sitka spruce occurred here in 1905. The early performance of Sitka spruce in this trial was impressive, so commercial planting of the species began in the 1920s. (Joyce and O'Carroll, 2002). It is now the main commercial plantation species in Ireland, producing quality timber on relatively fast rotations. It is one of the most productive coniferous species in Ireland with an average yield class of 14-17 (Farrelly *et al*., 2009; Power, 2017). There is 343,310 ha planted on the national forest estate accounting for approximately 50.9% of forested land (DAFM, 2018). In the period 2015-2019 Irish nurseries used on average 287 kg of seed per year, equating to approximately 28.7 million saleable plants (DAFM, 2020).

6.4.2 Silvicultural uses and site requirements

Sitka spruce sites are generally cultivated by either mounding or ripping. It is planted at stocking of 2,500 stems per hectare and plantations are fenced against livestock trespass. Generally, thinning commence anytime between the ages of 15 and 22 and every 4 or 5 years from then on until final felling which is generally between the ages of 35 and 45. Sitka spruce is generally planted pure but may be planted in mixtures with other conifers such as larch, lodgepole pine, Norway spruce and Douglas-fir. These mixtures are used to increase crop biodiversity, site productivity and as a tool to enhance the visual appearance of Sitka spruce woodlands in the landscape. It grows satisfactory over a wide range of site conditions, but it grows best, on moist fertile soils under conditions of high atmospheric humidity, while free-draining sites in low-rainfall areas and frost-prone sites should be avoided (Horgan *et al*., 2003). It is tolerant of exposure and is a light demanding species.

[29] Haida Gwaii.

6.4.3 Threats and diseases

Sitka spruce is susceptible to defoliation by the green spruce aphid (*Elatobium abietinum*), which can cause significant damage. In Ireland, one year´s complete defoliation might cause a reduction in leader growth of 50% (de Brit and McAree, 1978). Impacts of green spruce aphid are expected to increase under climate change scenarios, such as milder winters (Day, 2002) and drought conditions (Banfield-Zanin and Leather, 2014). Sitka spruce is particularly susceptible to damage by large pine weevil (*Hylobius abietis*) (Nordenhem and Norlander, 2014). Adult weevils feed on the root collars of seedlings and recent transplants killing the young trees (Dillon and Griffin, 2008). *Heterobasidion annosum* is the causal agent of root rot of the wood being the most commercially important disease in Ireland (Joyce and O'Carroll, 2002). Stumps are colonized by the fungus which grows through sapwood and heartwood reducing timber value and killing trees (Asiegbu *et al*., 2005). While Sitka spruce can suffer from attacks by bank vole, group dying fungus and honey fungus, none of these are limiting factors to its future planting (Horgan *et al*., 2003). Sitka spruce is susceptible to damage by late spring frosts which burn new growth and can result in poor stem form and loss of production. Therefore, it is not suited to sites where spring frosts occur regularly. Other risks to Sitka spruce include livestock trespass and fire, and windblow on unstable sites. It is less palatable to deer than most conifers, but it can be damaged if there is no other choice (Savill, 2013).

6.4.4 Provenance testing

Formal provenance testing began in the 1960s, with the establishment of a replicate of an extensive British Forestry Commission trial of 14 provenances. Results from the trial, established in the mild frost-free southwest of Ireland, showed the clear superiority of Washington provenances (Pfeifer 1984). Further trials in conjunction with the International Union of Forest Research Organisations (IUFRO) were established in 1975 where 67 provenances were tested. Results of the trials indicated that Sitka spruce originating from the southern part of its native range (Washington and Oregon) provided significant increases in productivity of up to one yield class (2 $m^3ha^{-1}year^{-1}$) over conventional Queen Charlotte Islands[29] (QCI) sources. The fears of increased susceptibility to late spring frosts among the former provenances were unfounded as there was little variation in the date of bud break between different origins (Thompson *et al*. 2005). The general conclusion from the IUFRO trials was that material from Washington was the most suitable for most of Ireland, although for sites prone to autumn frosts or above 300 m in elevation, QCI sources were recommended. Oregon seed origins for milder coastal were recommended on the southern coast. These recommendations were updated by DAFM in 2016 (Table 15) to take account of trials on the performance of improved material (see section 11.4.1).

TABLE 15 Sitka spruce Accepted Tree Species for Grant Aid and Accepted Seed Origins/Provenances (Forestry Programme 2014-2020 (DAFM 2015))

Species and origin / provenance	Category of basic material			
	Source Identified	*Selected*	*'Qualified'*	*Tested*
Irish, British, Danish (Queen Charlotte Islands (QCI) origins)	✘	✘	✔	✔
Irish, British (of Washington and Oregon origins)	✘	✔	✔	✔
Danish (of Washington and Oregon origins)	✘	✘	✔	✔
Seed imports under EU equivalence scheme from Washington, Oregon and QCI origins	✘	✔	✔	✔

6.4.5 Tree breeding

The Irish Sitka Spruce Tree Improvement Programme (ISSTIP) was set up in the early 1970s by the then Forest and Wildlife Service. Responsibility for the programme was transferred to Coillte when it was established in 1989. A programme of plus tree selection was carried out between 1973 and 1990 which identified 747 plus trees (trees that have superior phenotypic characteristics). The majority were of Washington origin, but also included a number which were of unknown origin and some QCI. Each original plus tree was assessed for height, diameter and a range of stem, and branching characteristics and shown to be superior to neighbouring trees in the same stand. In later years the wood density of the plus tree and the surrounding trees was also measured using a pilodyn (machine measuring the penetration depth of a metal pin to which is correlated with wood density).

Following selection of the plus trees, scions (branch material) and cones (if present) were collected from each plus tree. The scions were grafted onto seedling rootstock to preserve the genetic material of the original plus tree. Seeds were extracted from cones collected from the original plus tree and plants were grown to produce seedlings which were planted in progeny tests. Based on the results of the progeny tests after 6 and 15 years, 86 of the best parents were selected (vigour and stem form) from these trials to go forward for the breeding programme. After conducting tests on wood density 41 of the 86 parents were reselected and formed the basis of the current improvement programme.

A series of genetic gain trials were established by Coillte in 2005 to observe how the different sources of improved material performed in different locations (Thompson 2013). In total six trials were planted: two failed, two have been neglected since establishment and two are currently in existence notably (Callan 14/05 near Horse and Jockey in Co. Tipperary and Rathduff 03/05 near Mallow in Co. Cork).

In 2012 a series of genetic gain trials were established by Teagasc under the DAFM funded FORGEN project. Four trials were established at four locations: Athenry (Co. Galway), Ballyhaise (Co. Cavan), Oakpark (Co. Carlow) and Johnstown Castle (Co. Wexford). The trials include unimproved Washington, improved QCI, improved Washington (Danish), improved Washington (Irish vegetatively propagated) and Oregon material. The trials have been measured for survival and growth performance at 3 and 5 years and late autumn frost appears to be a problem for Danish and Oregon material on one of the sites (Ballyhaise). While there are no differences in vigour at 4 years among the seedling material, slower juvenile growth is evident in the improved Washington (Irish vegetatively propagated material). Slower initial establishment is often evident in vegetatively propagated material as a result of a less well-developed root system and a tendency towards plagiotropic growth habit in some individuals at an early age, therefore these comparisons may be under-estimating the true potential of the improved Irish material. While the FORGEN trials provide some information, they are at a young age and require a continued programme of monitoring and assessment as they mature in order to supplement existing knowledge.

6.4.6 Sources of Forest Reproductive Material

The earliest age at which Sitka spruce trees bears seeds is 30-40, but reliable seed crops occur at intervals of 3-5 years, usually from the age of 50 (Savill, 2013).

However limited availability of improved material from the Irish programme has meant that improved material has been imported from both Denmark (largely based on Washington provenance) and Britain (largely based on QCI provenance). This has been further supplemented with material from *'Selected'* Irish seed stands and the occasional imports from the US to meet demand.

Forest basic material:

- *'Selected'* seed stands: As of January 2020, there are 49 *'Selected'* seed stands amounting to just under 470 ha, registered on the National Register of Basic Material (seed stand register).
- *'Qualified'* seed orchard: There is one untested orchard of 2.5 ha established in 2011.
- *'Tested'* seed orchards: There are two orchards registered as *'Tested'* amounting to 2.92 ha. A third orchard of 1.8 ha, eligible to be registered as *'Tested'*, was established in 2020.
- *'Tested'* clonal mixtures: Coillte produces some 2.2 million vegetatively propagated plants per year.
- *Imported sources:* Seed is also imported from *'Tested'* orchards in Britain and Denmark. Occasionally there are also direct imports from the US (Table 16).

TABLE 16 Sitka spruce seed (kg) used in Irish forest nurseries 5-year average (2015-2019) (Data source: None So Hardy Forestry (Ltd) and Coillte Nurseries).

Source Country	*Source Identified*	*Selected*	*'Qualified'*	*Tested*
Denmark	-	-	-	90
Ireland	-	56	4	1[30]
UK	-	8	-	115
USA	14	-	-	-

[30] Supplemented with 2.2 million cuttings from clonal hedge orchards.

6.4.7 Conclusion & recommendations

- The continuation of the Irish Sitka Spruce Tree Improvement Programme (ISSTIP) should be a priority. Funding to support the programme, including maintenance of trials, gene banks and research facilities as well as the basic breeding and testing work is required. While improved material may be available from abroad, the national programme offers substantial advantages in terms of securing supply and maintaining the sectors ability to adapt to threats.
- Research programmes such as FORGEN, FORM and GENESIS have driven the development of breeding and propagation of Sitka spruce in recent years. Funding to support a National programme should be additional to and complement – not replace – the annual DAFM competitive research programme.
- New climatic conditions may lead to further European co-operation, particularly if existing Sitka spruce users look to more southerly origins. The continuation of the good co-operation between countries and the exchange of breeding information and technology should also be a priority.
- Seed stands are an essential part of the supply mix. The current practice is to collect seed from registered stands at clearfell. A greater focus should be placed on managing stands specifically for seed production.
- Vegetative propagated improved material (clonal material) provides a higher genetic gain when compared to forest material established from seed orchards and is the fastest way to transfer gain through improvement to the forest estate. However vegetatively propagated material is unable to meet present or forecasted demand. Therefore, the establishment of outdoor seed orchards should be prioritised for development. Circa 28 ha will meet a substantive level of demand. The DAFM seed stand and orchard scheme is available to support such establishment.
- It is recommended that the FORGEN trials are assessed between ages 9 and 11 for form, growth rate and wood properties.
- Genetic gain trials were established by the Forest Genetic Resources Working Group to assess the performance of the range of Sitka spruce sources currently used in Irish forestry. A programme of monitoring and assessment should be implemented by DAFM until such a time as the ISSTIP has been secured.

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Appendix 1 Forest Genetic Resources Working Group Terms of Reference

Forest Genetic Resources Working Group

COFORD Council 2019-2021

Terms of Reference

Objective

To outline a strategy for the development, conservation, and deployment of forest genetic resource material

Membership

Fergus Moore (Chair, DAFM), Gerry Douglas (FGRT), Niall Farrelly (Teagasc), John Kavanagh (None So Hardy (Forestry LTD), Colin Kelleher (National Botanic Gardens (OPW), Dermot O Leary (Coillte CGA), Miguel Nemesio-Gorriz (Teagasc), Declan Little (Woodlands of Ireland), Conor O'Reilly (UCD), Jim McNamara (Laois Sawmills), Jenni Roche (NPWS), Richard Schaible (Northern Ireland Forest Service), Brian Tobin (UCD), Brian Clifford, Seamus Dunne, Luke Sweetman (All DAFM).

Group Objectives

To produce a forest genetic resources strategy for Ireland, to cover *inter alia*

- A review of the recommendations listed in *Sustaining and Developing Irelands Forest Genetic Resources* (Cahalane, 2007).
- securing supply of reproductive material for key species to Irish forestry, including the need for indigenous provision, seed stands and improvement programmes, where appropriate.
- impact of climate change and the potential threat from pests and diseases, of the survival, growth, and wood quality of key species to Irish forestry.
- breeding for tolerance to ash dieback (*Hymenoscyphus fraxineus*).
- Examine opportunities to assist in the delivery of actions listed in "Developing a National Forest Tree Gene Conservation Strategy" (Kelleher, 2016).
- Advice on FGR research needs .

Appendix 2 Review of the recommendations listed in *Sustaining and Developing Ireland's Forest Genetic Resources - An outline strategy*

Sustaining and Developing Ireland's Forest Genetic Resources - An outline strategy (Cahalane *et. al*, 2007) was the first attempt at documenting the status of forest genetic resources in the country, it comprised an evaluation of historical developments, together with a review of the current national situation, and concluded by making recommendations for the future development of the sector. It was further bolstered by the publication of *Forest Genetic Resources in Ireland* in 2012, which documented the genetic resource according to criteria required for the *FAO Global Plan of Action on Forest Genetic Resources*.

TABLE 17 below lists a review of the original recommendations and documents the level of implementation according to the scale of extent as 'greater', 'moderate' or 'lesser'.

No.	Topic	Recommendation	Implementation	Comment
1	Strategy	That this report is used as a basis of a national strategy in Forest Genetic Resources.	*implemented to a greater extent*	Recommendations included were adopted, *Forests, products and people. Ireland's forest policy – a renewed vision* (DAFM, 2014).
2	National co-ordination	That a National FGR Advisory Group (chaired by the Forest Service) comprising relevant stakeholders be established to guide the development of the sector	*implemented to a moderate extent*	An ad hoc group was convened to provide the Ireland input to the FAO State of the World's Forest Genetic Resources. The Ireland submission was published by COFORD in 2012 as Forest Genetic Resources in Ireland. The Forest Genetic Resources Working Group was set up under the COFORD Council in 2015, and reconvene in 2019.
3	National co-ordination	That those organisations currently involved in forest genetic resources build on their strengths and develop their skills and facilities as part of a national programme, with defined objectives and targets under the guidance of the proposed Advisory Group.	*implemented to a moderate extent*	Organisations involved in FGR have recruited new staff DAFM, Forest Sector Development; new staff person replacing retiree. Teagasc; ; new staff person replacing retiree. National Botanic Gardens; Geneticist in place. Tree breeder not replaced at Coillte, microprogation laboratory closed, tree breeding centre at Kilmacurra closed, infrastructure relocated to Clone Nursery Co. Wicklow. FGR Advisory group – see 2

No.	Topic	Recommendation	Implementation	Comment
4	National co-ordination	That adequate long-term funding be provided and relevant agencies and business to support these developments	*implemented to a moderate extent*	Project based funding provided by Research Division, DAFM. Funding also available through the Forest Genetic Resources Reproductive Material: Seed Stand & Seed Orchard Scheme and development work by Forest Sector Development Division. FGR Advisory group – see 2
5	Research and development	That the national FGR policies are underpinned by a dedicated national R&D programme, funded by Forest Service/ COFORD and co-ordinated by the National FGR Advisory Group.	*implemented to a moderate extent*	Research Division, DAFM published the FORI report which listed research priorities in the FGR area following consultation. FGR Advisory group – see 2
6	Research and development	That national research priorities on FGR are identified, agreed, prioritised and implemented by the various institutions and coordinated by the National FGR Advisory Group.	*implemented to a moderate extent*	Research Division, DAFM published the FORI report which listed research priorities in the FGR area following consultation FGR Advisory group – see 2
7	Research and development	That resources are allocated to species depending on their importance in the national planting programme.	*implemented to a greater extent*	In 2015/16 the Forest Service DAFM carried out a consultation process on Accepted Tree Species for Grant Aid and Accepted Seed Origins/ Provenances. This resulted in an updated list of accepted seed origins/provenances. FGR Advisory group – see 2
8	Research and development	That co-operative research networks and programmes continue to be encouraged and facilitated.	*implemented to a greater extent*	Implemented across the FGR sector.

No.	Topic	Recommendation	Implementation	Comment
9	Operational plan	That an adequately resourced FGR operational programme be established under the direction of the National FGR Advisory Group to supply the reproductive material requirements of the state addressing issues such as: - Planning and management of seed production areas (seed orchard, seed stands etc.). - Seed collection infrastructure. - National seed and plant registers for monitoring FGR usage.	*Implemented to a moderate extent*	Elements of the recommendation were implemented, i.e., the launch of the FGR seed stand/orchard scheme, maintenance and update of the seed stand register, and the monitoring of FGR usage. However, as the FGR group was not formally established a co-ordinated operational plan between all parties involved was not developed.
10	Encouraging use of improved material	Forest Service-DAFM grant schemes to further promote and encourage the use of better adapted home-collected forest reproductive material and the value and benefits of utilising improved material.	*Implemented to a greater extent*	Forest Genetic Resources Reproductive Material: Seed Stand & Seed Orchard measure included under the Forestry Programme 2014-2020. Updated list of accepted seed origins / provenances.- See 7.
11	Encouraging use of improved material	That an awareness campaign be prepared and implemented by the Forest Service and COFORD to inform the industry, other relevant parties and the wider public, of the importance of forest genetic resources, forest reproductive material legislation, seed collection systems, promoting the benefits of using quality material, showing the negative effects of inferior material and the overall importance of forest reproductive material.	*implemented to a moderate extent*	Various publications have been produced, through the COFORD Connects series and through the support of organisations such as the FTT/Forest Genetic Resources Trust.

No.	Topic	Recommendation	Implementation	Comment
12	Gene conservation	That a forest genetic resources conservation strategy be developed by the National EUFORGEN Group in co-operation with the Forest Service and the National Parks and Wildlife Service, to include both native and non-native species and create links with the National Biodiversity Action Plan and other pan-European processes. The strategy would also complement the Department of Agriculture and Food's national policy on the conservation of plant genetic resources.	*implemented to a moderate extent*	Under the FORGEN project a National Forest Tree Gene Conservation Strategy has been proposed FGR Advisory group – see 1
13	Capacity building and succession planning	That infrastructure and capacity building needs in forest genetic resources be continuously reviewed by the Advisory Group to create and maintain a critical mass for the sector in the medium to long term.	*implemented to a moderate extent*	FGR Advisory group – see 1 Build strength & capacity - see 3

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