



## CoFoRD

### Final Report

#### *Forest Genetics Research Programme - FORGEN*

DAFM Project Reference No: 10/RD/FORGEN/UCD/717

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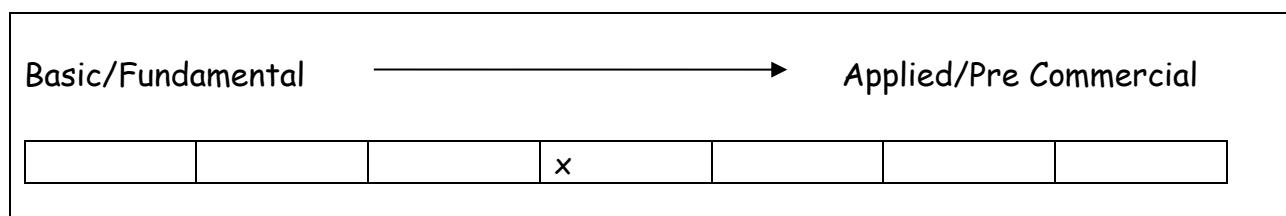
#### **Collaborating Research Institutions and Researchers:**

Teagasc: Dr Niall Farrelly

National Botanic Gardens: Dr Colin Kelleher

UCD Biology: Dr Paul McCabe

Please place one "x" below in the appropriate area on the research continuum where you feel this project fits



Please specify priority area(s) of research this project relates to from the National Prioritisation Research Exercise\* (NRPE) report;

Priority Area (s)	A Future Networks & Communications B Data Analytics Management, Security & Privacy L Manufacturing Competitiveness F Diagnostics
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Key words: (max 4) Tree improvement, forest genetics,

## **1. Rationale for Undertaking the Research**

The genetic background of the material used to establish new forests has a long-term effect on the productivity and the quality of the resulting tree crops. The planting of improved material, unlike most other silvicultural practices such as fertilisation drainage or thinning, provides a permanent change in the performance and quality of the crop. However, tree improvement programmes are not simple, short-term efforts that provide quick results. For this reason, new techniques have to be developed and tested to try and shorten the process and make it more efficient. In addition resources have to be focussed on the most important species and the traits to be improved. Protecting the current genetic resource of both native and introduced tree species is important. Not only future climatic changes, but also man's activities, can affect this valuable resource which requires protection and conservation.

The specific rationale for each of the tasks is described below.

- Task 1. Broadleaf Improvement – extensive broadleaf planting in Ireland commenced in relatively recent years, so it is not surprising that there is little scientific information on tree improvement aspects for several of the key species. The aim of this research task was to address this gap, although information of most value will emerge in the future, as the material in the trials and seed orchards develop.
- Task 2. Conifer Improvement – although there is considerably more tree improvement information available for most of the commercially important conifer species in Ireland, the amount of improved material available for use is very small. This aim of this research work was to develop methods to increase the output of improved material for use in Ireland, thus increasing yields in Irish forests.
- Task 3. Early Selection and Vigour Assessment in Sitka spruce – there is little information available about traits other than height and diameter in Sitka spruce. Height and diameter growth is influenced by other traits (e.g. phenology of growth, photosynthetic performance), but there is little information on the basis of genetic vigor in Sitka spruce. This information could be used to improve the efficiency of the selection process and in early selection in Sitka spruce. In particular, it can take 7 or 8 years to evaluate selected material based on the performance of progeny in field trials. These issues are a major bottleneck in the improvement programme for Sitka spruce and greatly increase the cost of testing.
- Task 4. Assessment of the Performance of more Southern Provenances of Sitka spruce compared with Washington and QCI Material – the main aim of this task was to determine if more southern origin material could be used in some parts of Ireland, especially in the context of climate change.
- Task 5. Breeding Tools – the supply of suitable seed that is suited to Irish conditions, including future potential threats (e.g. climate change) is important for the Irish planting programme. A high proportion of the seed of some species is imported due to the shortage of seed from Irish sources. Most of the imported seed may be less suited to Irish conditions than seed produced in Ireland. Methods need to be developed to assist in delivering more seed and to aid the decision-making process in relation to investment in tree improvement.
- Task 6. Developing a National Forest Tree Gene Conservation Strategy – it is important to describe the type of native and non-native material that is available in Ireland, especially in relation to the levels of genetic diversity. This is particularly important in relation to the potential effects of climate change and other threats (e.g. pests and diseases).
- Task 7. Dissemination – research efforts are of limited value if the results are not communicated, with view to putting recommendations into practice and as a basis for future work.

## **2. Research Approach**

The FORGEN programme is a large and integrated collaborative programme of research involving UCD, Coillte, the National Botanic Gardens, Teagasc and several experienced research consultants. It has addressed tree improvement efforts in both broadleaf and conifer species through the selection and propagation of superior individuals using breeding, propagation, and storage techniques with the aim of improving the productivity and quality of selected species. Methods have been explored to predict good seed crops, deal with the impact of climate change and develop a framework for future tree breeding efforts. The programme is also developing a strategy for a national forest tree gene conservation programme. The research approach ranges from the basic to the highly applied. The programme also includes some related operational aspects (e.g. production of improved material). The main focus of the research is to develop methods that accelerate the delivery of improved material into use in Ireland, while at the same time protecting valuable genetic resources from threats (e.g. climate change). Volume production and timber quality are the main attributes of interest, although biomass production is a secondary consideration in a few cases.

The methods for each task included, *inter alia*:

- Task 1. Broadleaf Improvement – native oak provenance trials, including 25 year, quarter rotation assessments of growth and form, thinning, production of management plans for each trials and selection of potential final crop trees and a determination of optimised seed harvesting methods. Provenance trials of oak, ash and beech included 6 year assessments. A 2 ha Spanish chestnut seed orchard was established in County Waterford with up to three copies (clones) of up to 185 parent trees. A forest tree DNA bank was established at the National Botanic Gardens, Glasnevin, using a -80deg C freezer with purified samples of DNA from a mix of species. The improvement of birch and alder continued on from work initiated by UCD and Teagasc. This included assessments of existing progeny trials maintenance of existing seed orchards and clone banks. New gene banks were established and land secured for further work.
- Task 2. Conifer Improvement – This aim of this research work was to develop methods to increase the output of improved material for use in Ireland, thus increasing yields in Irish forests. The work carried out included providing tested Sitka spruce for mass propagation and delivery clonal plants for other tasks in the programme. The potential effects of clonal deployment method on the performance of improved Sitka spruce were studied using field trials at Kilmacurragh and laboratory work, including root morphology, biomass partitioning and wood properties (Trees4Future). Selected Irish families of Scot's pine were established in a field trial at Kilmacurragh, with the aim of testing the progeny in years to come.
- Task 3. Early Selection and Vigour Assessment in Sitka spruce – The physiological and morphological basis of variation in vigour in Sitka spruce seedlings was studied. Seedlings representing nine families of genetically improved Sitka spruce (from Coillte's breeding programme), and seedlings derived from unimproved seed (as a control) were examined in a greenhouse and field trials. Identification of juvenile vigour traits and their relationship with mature attributes was elaborated in another study. The focus was on nine improved families. Assessments were made of seedlings from germination up two years' growth in the glasshouse and compared with growth trees in stands aged nine years. Measurements included different parameters of seed morphology, seedling emergence and early shoot growth.  
Screening for genotypic adaptability in the Irish Sitka spruce collection included PCR of DNA samples. A small population of spruce DNA from embryogenic and non-embryogenic lines have been deposited into the National Forest Tree DNAbank.
- Task 4. Assessment of the Performance of more Southern Provenances of Sitka spruce compared with Washington and QCI Material – the work carried out included a literature review of the topic, climatic matching of natural range and Ireland, using Cluster analysis and multi-dimensional scaling (MDS). Growth and physiological data were collected from Sitka spruce provenance trials in Ireland.

- Task 5. Breeding Tools – Methods to improve the prediction of seed crops focussed on oak seed production. Insufficient data prevented the validation of models produced. The models produced included: Harvest yield relationship with rainfall and temperature, current and prior years and effects of climatic extremes on yield. Also in this task was a study on the Effects of climate change on Irish Forest Genetic Resources. This involved collecting growth data from provenance trials and the identification of gaps in data for each species studied. A cost-benefit analysis (Prioritisation) of tree improvement effort in the breeding programme in Ireland was carried out. This study used the net present value approach to assess tree improvement investment possibilities for a large number of species of potential interest to Irish forestry, assuming that a 15% gain could be achieved and the costs of improvement were similar for all species. A study on the development and application of molecular tools to test forest trees for potential adaptability to climate change identified a suite of primers for PCR analysis. Primers were developed for oak in genes responsible for bud burst. A total of 17 different primer pairs were developed and tested. A collection of elite oaks in an orchard at the Coillte Tree Improvement station in Kilmacurra, Co. Wicklow were used as the test population.
- Task 6. Developing a National Forest Tree Gene Conservation Strategy – this study focussed on the generation of a list of all major stakeholders and a literature review was completed to establish best international practice for conservation of Forest Genetic Resources. Dynamic *in situ* conservation has been adopted as the best practice in most cases. A database of current holdings of forest genetic resources was not developed because this was already completed by another DAFM initiative and a database is already held by the Forest Service.
- Task 7. Dissemination – this task was carried out through the writing of peer reviewed research papers, articles in popular trade magazines, radio, a project website and presentations of research at national and international meetings.

#### Details of modifications

##### Task 1D Irish ash progeny trial

This sub-task was removed from the project. It was part of the contribution in-kind. This task could not be completed as originally proposed because pedigree information was not recorded for the seed collected from the trees in the seed stands.

##### Task 1E Irish wild cherry clonal trial.

This sub-task was removed from the project. It was part of the contribution in-kind and most of the work was completed before the start of FORGEN.

##### Task 1F Oak: seed stand/plantation relationships

The original work was found to be not possible, no records of where the trees were planted. However, in its place is a similar project to identify new native oak seed stands was substituted for the original work: Task 1F. New Qualified Oak Seed Stand Selection: Identification, assessment and improvement of harvesting capacity

##### WP6. Developing a National Forest Tree Gene Conservation Strategy

Milestone Number M6.3

Milestone Title Database of current holdings of forest genetic resources

Status Not Started

This was already completed by another DAFM initiative and a database is already held by the Forest Services. See the following: National Consultative Committee on Forest Genetic Resources (2012). Forest Genetic Resources in Ireland. COFORD, Dublin.

### **3. Research Achievements/Results**

## The overall programme objectives

Provenance work on broadleaves and (in context of climate change) Sitka spruce.

- Gene banks were maintained and methods were developed to increase the amount and quality of improved material emanating from the broadleaf and conifer programmes
  - This included the development of better techniques for micropropagation and cryogenic storage of Sitka spruce material
- Early selection methods were developed for Sitka spruce using morphological and physiological approaches
- A variety of breeding tools were used to support tree improvement, which included:
  - A prototype model to predict acorn crops in oak
  - Information on future potential threats (e.g. climate change) was provided, which is important in relation to decision-making concerning species/ provenances deployed in the Irish planting programme.
  - The results of a cost-benefit analysis of tree improvement in Ireland revealed that most effort should be directed towards improving a limited number of tree species.
- The potential effect of climate change on Irish forest genetic resources and prioritising species for conservation was developed, including an implementation programme were developed.

The research programme covered a wide range of tree improvement areas, including provenance selection, tree breeding, vegetative propagation and the development of a conservation strategy. Several trials were established, or maintained from previous breeding programmes, which will provide information in the future. The research also covered a wide range of tree species. Molecular markers and seed crop prediction methods were also developed, but more research is needed before these can be used operationally.

The physiological responses of Sitka spruce to water stress were investigated in a greenhouse experiment at UCD. The greenhouse experiment established in 2012 was continued through 2015 to establish the physiological and morphological basis of variation in vigour in Sitka spruce seedlings. Seedlings representing nine families of genetically improved Sitka spruce from Coillte's breeding programme and seedlings derived from unimproved seed as a control were examined. There is some evidence that those families that ceased growth earlier were dormant earlier (they showed greater tolerance of freezing temperatures). In addition to examining differences between families under optimal water availability, responses to limited water availability were assessed. In those families that grew most, limited water availability dramatically reduced leader growth. All but two of the improved families were significantly shorter in the water-limited compared to well-watered treatment. Variation in date of flushing was not related to family. It was, however, related to water availability, being delayed by 10 days in the water-limited treatment.

The relationship between traits in juvenile Sitka spruce compared with more mature Sitka spruce was examined in a PhD study at UCD. It appears that superior growth is established three months after germination and translates to the end of the second growing season. Following the harvest after 1 year of growth, it can be concluded that superior height is correlated to a higher number in needle primordial, reduced needle density, reduced branching with increased branch length, a wider stem diameter and denser roots.

The growth of juvenile Sitka spruce trees in provenance trials were established by Teagasc. There was an increase in growth that followed a north-south trend in relation to seed origin, with the greatest production being recorded for the southern Oregon provenance. Southern provenances do better on southern sites/more fertile sites as they capitalise on favourable growing conditions late in the season, thus undergoing more lamas and free growth. There is evidence from older trials that the early growth

advantage occurs only during the early years after establishment. There seems to be little opportunity to choose specific provenances for specific sites, although southerly provenances are likely to do best in the southern part of Ireland. An assessment of the potential impact of climate change on Sitka spruce performance was also carried out. Productivity increases as predicted temperatures increase and decreases with continentality. Productivity also declines as both precipitation levels and wind speeds increase.

Molecular tools to test forest trees for potential adaptability to climate change were also developed, with the main focus being on the development of markers that characterise genetic diversity associated with bud flushing. However, these markers now need to be applied to a larger population size and compared to phenotypic traits, such as the date of bud burst.

Part of the aim of FORGEN was to establish well-maintained broadleaf improvement trials. This was achieved, with several existing trials being restored and several other new trials were established for oak and common alder. A Qualified seed orchard of downy birch was also established. The testing of selected Irish families of Scots pine (*Pinus sylvestris*) continued, with the establishment of a nursery trial at the Coillte Tree Improvement Centre at Kilmacurragh.

A lot of different material is used in the planting programme in Ireland and in some cases there is relatively little information about the origin of the material, even if the seed has been harvested from a known location. Therefore, it is important to be able to characterise the reproductive material, as far as possible. To this end, alder (*Alnus glutinosa*), birch (*Betula pubescens* and *B. pendula*) and Scots pine were assessed by the NGB. Two genetic lineages in Ireland were identified for alder, one originating from the Iberian Peninsula and another from the Carpathians. The birch samples revealed an origin in the Iberian Peninsula but also showed some novel variation, which seems to be unique to Irish populations. The Scots pine work revealed three possible sites of origin of native pine.

It is also important to conserve forest genetic resources for future generations and to protect against the potential negative effects of climate change, disease and insect damage and any other potential threats. It is important to preserve as much genetic diversity as possible to increase the resilience to these potential threats. To this end, a National Forest Tree Gene Conservation Strategy was developed for Ireland. Dynamic in situ conservation has been adopted as the best practice in most cases. A network or group of sites is also considered best practice, as has been implemented already by a EUFORGEN, a pan-European conservation network.

The growth responses of elite juvenile Sitka spruce clones to two contrasting planting designs (i.e. pure plots consisting of a single clone per plot and mixed plots consisting of several intimately mixed clones per plot) were examined. The different planting designs were expected to affect the competitive environment. Fine root growth, stem growth, biomass allocation and relationships between above- and below-ground properties were assessed. The potential effect on juvenile wood characteristics of selecting clones with high vigour was also assessed.

Fine root growth and stem growth was reduced in several clones when grown in the mixed compared with the pure plots, suggesting that the competitive environment might negatively affect stand productivity in Sitka spruce. Furthermore, some clones had a greater ability to adapt to their environment, or could adjust their responses, allowing them to grow well in either mixed or pure plots. Wood properties also varied between clones, with more vigorously growing clones having less desirable wood characteristics.

The results of the PhD study demonstrated the importance of considering competitive interactions when devising clonal planting designs. Ignoring such interactions could affect tree uniformity and forest stand structural dynamics, resulting in reduced stand productivity. Additionally, the large variation in

juvenile wood characteristics demonstrated that it may be possible to improve wood quality through selective breeding.

The ForGen programme team at UCD and NBG also leveraged additional support from the EU Trees4Future programme. This allowed the team to carry out better quality research, availing of the sophisticated equipment and expertise provided through this programme.

#### **4. Impact of the Research**

The research programme addressed the vast majority of the aims and objectives of the programme. As a result of the research, there will be an increase in the availability of improved broadleaf and conifer planting stock which will lead to an increase in the productivity, quality and resilience of the forest estate. Since a key stakeholder (Coillte) was also a partner in the programme, many of the practical recommendations were put into practice quickly. A brief synopsis of the main benefits/ outputs of the programme are summarised below for each task.

Task 1 Broadleaf Improvement – extensive broadleaf planting in Ireland commenced in relatively recent years, so it is not surprising that there is little scientific information on tree improvement aspects for several key species. This research task addressed many of the research gaps. This following research work was undertaken (i) the early performance of ash, beech and oak seed in provenance and/ or progeny trials was assessed; (ii) progeny trials were established and ash seed orchards were upgraded; (iii) oak stands were assessed with view to having them upgraded to registered seed stands to supply acorns; (iv) seed orchard/ clone banks of Spanish chestnut were established; and (iv) research on birch and alder tree improvement with ultimate aim of providing seed of ‘Qualified’ FRM category (currently current ‘Source Identified’) was undertaken. Although most of the information of value will emerge in the future (e.g. as a result of establishing new trials), well after ForGen has been completed, there will be immediate benefit as a result of the upgrading of the stands and alder and birch improvement work.

Task 2. Conifer Improvement – although there is considerably more tree improvement information available for most conifer species in Ireland, the amount of improved material available for use is very small. This task focused on (i) increasing the production of full-sib Sitka spruce material in the Coillte programme; (ii) optimising somatic embryogenic potential of Sitka spruce in cell cultures and during cryogenic storage; (iii) providing information on the optimum proportion and planting matrix for the use of improved material of Sitka spruce in the planting programme; and (iv) the establishment of a Scots pine progeny trial with view to upgrading the genetic material in the future. All of these efforts will lead to an increase in the use of improved material in Ireland in the future.

Task 3. Early Selection and Vigour Assessment in Sitka spruce – there is little information available about traits other than height and diameter in Sitka spruce. Height and diameter growth is influenced by other traits (e.g. phenology of growth, photosynthetic performance), but there is little information on the basis of genetic vigor in Sitka spruce. In addition, it can take 7 or 8 years to evaluate selected material based on the performance of progeny in field trials. These issues are a major bottleneck in the improvement programme for Sitka spruce and greatly increase the cost of testing. This research task was undertaken to provide information (i) on the basis of genetic vigour in Sitka spruce and (ii) to develop method(s) that would shorten the period needed to evaluate superiority in Sitka spruce (i.e. early selection). In addition, work was carried out to test an approach for improving the selection of Sitka spruce material in the tree improvement programme. The results will provide information that will improve the efficiency of the selection process in Sitka spruce, allowing for the earlier deployment of improved lines than in the past.

Task 4. Assessment of the Performance of more Southern Provenances of Sitka spruce compared with Washington and QCI Material – the main aim of this task was to determine if more southern origin material could be used in some parts of Ireland, especially in the context of climate change. This information will inform decision-making in relation to the use of Sitka spruce provenances in Ireland.

Task 5. Breeding Tools – the supply of suitable seed that suited to Irish conditions, including future potential threats (e.g. climate change) is important for the Irish planting programme. A high proportion of the seed of some species is imported due to the shortage of seed from Irish sources, most of which may be less suitable for Irish conditions than seed produced in Ireland. In attempt to lessen the impact of some of these concerns, research was undertaken to (i) develop methods to predict seed crops for important species; (ii) assess the potential impact of climate change on forest genetic resources; (iii) develop a prioritisation strategy for tree improvement efforts based on a cost-benefit analysis; and (iv) develop molecular tools to test forest trees for potential adaptability to climate change. The result of this research revealed that further research is needed to develop better methods to predict seed crops, but some climatic indicators were useful in predicting oak acorn production. A clear strategy for tree improvement, based on the results of a cost-benefit analysis, will provide essential information on how to optimise the benefits from investment in tree improvement. Information on the potential effect of climate change on important tree species will inform decision making in relation to species/provenance selection.

Task 6. Developing a National Forest Tree Gene Conservation Strategy – it is important to describe the type of native and non-native material that is available in Ireland, especially in relation to the levels of genetic diversity. This is particularly important in relation to the potential effects of climate change and other threats (e.g. pests and diseases). This task provided key information on (i) the status of Ireland's forest genetic resources and will help in the development of a gene conservation strategy; and helped to (ii) identify the species that are most in need of conservation, along with recommended methods of conservation most appropriate for each species.

Task 7. Dissemination – research efforts are of limited value if the results are not communicated, with view to putting recommendations into practice and as a basis for future work. The objective of this task was to (i) communicate the key results to stakeholders working in forest genetic resources; (ii) publish scientific results in high impact scientific journals and (iii) inform the forestry profession and public of advances made in forest genetic resources.

#### **4(a) Summary of Research Outcomes**

##### **(i) Collaborative and Industry links developed during this research**

###### **Trees4Future**

The FORGEN programme researchers were fortunate in that they were able to access funds available in the FP7 project “Trees4Future”. Dr Philip Cubry, working with Colin Kelleher of the NBG secured funding through T4F to go to France as part of his research. Philip used the Trees4Future funding to add additional samples and to build a more comprehensive analysis for Task 1H. Trees4Future is a European Research Infrastructure project (FP7 grant agreement n° 284181). It enables researchers to access laboratory and infrastructural facilities not available in their own institution. It covers laboratory consumables and partial travel. The estimated contribution to the FORGEN project was €2500. No facility in Ireland had the capacity to rapidly process as many plant samples as that in INRA, Bordeaux. Thus, by utilising some of the time allocated to Task 1H for the Trees4Future project we were able to get far more data than anticipated. We succeeded in getting data from 18 molecular markers in 368 individuals of *Pinus sylvestris*. This adds considerable value to the FORGEN project and will make a

significant contribution to subsequent publications. FORGEN did not help really in securing the funding, the application was independent of FORGEN. However, as funding from FORGEN allowed us to setup a National Forest Tree DNA bank, the samples from this were utilised in the Trees4Future project, so we had samples ready to analyse.

PhD student, Liam Donnelly contacted a research laboratory in Sweden specialising in micro analysis of wood samples. This led to Liam spending a few days at the lab supported by T4F to carry out supervised analysis of samples as part of his research.

#### **Future Trees Trust, FTT**

The FTT supported the establishment of the Spanish chestnut seed orchard by providing advice on the design of the orchard and plant requirement. The group also provided the plants for the seed orchard.

#### **Coillte**

Coillte provided access to field trials as part of the research in FORGEN. The company also collaborated through external assistance and benefit in kind on many of the tasks in this programme through the Tree Improvement Centre at Kilmacurragh.

INRA, Avignon - Development of collaboration sharing pine data with colleagues in INRA, Avignon, France to produce combined paper for scientific journal.

CEH, Edinburgh, Scotland - Use of Scots pine samples in the National Forest Tree DNAbank. Providing samples for large scale SNP analysis.

#### **(ii) Outcomes where new products, technologies and processes were developed and/or adopted**

Generally, the advances made in FORGEN were refinements to existing methods and the research has added to our existing body of knowledge in each of the respective fields. For example in conifer improvement, improved methods in the area of micro propagation of Sitka spruce, somatic embryogenesis and cryopreservation were developed.

#### **(iii) Outcomes with economic potential**

The research may result in significant economic returns, but much of this will accrue in the future as a result of higher yields as a result of using more improved material, earlier deployment of improved lines and the application of better deployment strategies (i.e. more efficient use of scarce supply of improved material). However, it is difficult to put a value on these returns.

#### **(iv) Outcomes with national/ policy/social/environmental potential**

The information provided in relation to provenance choice, climate change and cost-benefit analysis of tree improvement will inform national policy development in relation to these topic areas.

### **4 (b) Summary of Research Outputs**

#### **(i) Peer-reviewed publications, International Journal/Book chapters.**

Cubry, P., Gallagher, E., O'Connor, E., Kelleher, C.T. (2015) Phylogeography and population genetics of Black Alder (*Alnus glutinosa* (L.) Gaertn.) in Ireland: putting it in a European context. *Tree Genetics & Genomes* (2015) 11: 99. DOI 10.1007/s11295-015-0924-4

- Donnelly L., Grant O. M., O'Reilly C. (2017). Effect of deployment-type on stem growth, biomass partitioning and crown characteristics of juvenile Sitka spruce clones. *Silva Fennica* vol. 51 no. 1 article id 1714. <https://doi.org/10.14214/sf.1714>
- Donnelly L., Grant O.M., O'Reilly C. (2017). Effect of deployment-type on stem growth, biomass partitioning and crown characteristics of juvenile Sitka spruce clones. *Silva Fennica* vol. 51 no. 1 article id 1714. 16 p. <https://doi.org/10.14214/sf.1714>
- Donnelly, L.; Jagodzinski A.M.; Grant O.M.; O'Reilly, C. (2016). Above- and below-ground biomass partitioning and fine root morphology in juvenile Sitka spruce clones in monoclonal and polyclonal mixtures. *Forest Ecology and Management*, 373 :17-25.
- Fennessy, J., Doody, P., Thompson, D. (2012) A review of tree improvement programmes in Ireland - historical developments, current situation and future perspective. *Irish Forestry* 69: (1-2) 184-203
- Glombik, P.; O'Reilly, C.; Grant, O.M. (2015) 'Early-height variation between full-sibling families of Sitka spruce growing in Ireland'. *Irish Forestry*, 72 :139-149.
- Grant, O.M., O'Reilly, C. (2016). Impact of genetic variation and long-term limited water availability on the ecophysiology of young Sitka spruce (*Picea sitchensis* (Bong.) Carr.). *Tree Physiol* (2016) 1-14. DOI: <https://doi.org/10.1093/treephys/tpw093>
- O'Reilly, C., Phillips, H. Thompson, D. (2014) Cost-benefit analysis of tree improvement in Ireland. 71 (1-2): 113-131.

**(ii) Popular non-scientific publications and abstracts including those presented at conferences**

- Charles Harper, FORGEN - Forest Genetics Research Programme Irish Timber & Forestry, No. 4, 2011.
- Charles Harper, Media Article in Forestry and Energy Review, Vol 3, Issue 2, Autumn 2013. The long term option for improved productivity and timber quality in Ireland, Autumn 2013.
- Colin Kelleher. Research into the origins of the woody plant flora of Ireland. Sherkin Comment Issue 59, p. 4. 2015
- Colin Kelleher. The rise and fall of Irish alder. Woodland – Magazine of the Native Woodland Trust, Autumn 2015, p. 10 – 13.
- Elaine O'Connor, media article, "Birch and Alder Qualified". 2013 Science Spin Issue 60 p11 <http://www.sciencespin.com/magazine/archive/2013/09/> 01/09/13
- Elaine O'Connor, Birch and Alder – the development of a tree breeding programme and a seed supply for Irish forestry. Teagasc Technology Updates 2007–2012, November 2012

**(iii) National Report**

**(iv) Workshops/seminars at which results were presented**

- Colin Kelleher, Poster presentation. EGG Conference, Belfast. Poster "Black Alder in Ireland, Putting it in a European Context". 2-4/04/2013
- Colin Kelleher. "Radio Interview [https://m.facebook.com/connemaracomunityradio](https://m.facebook.com/connemaracomunityradio/posts/538126466345718) /posts/538126466345718" "The Great Outdoors, Connemara Community Radio. 15/10/15
- Conor O'Reilly, "Forest Management Research (FORM)". Presentation to the FGRwG Committee Meeting, 21st September 2016. Note the FGRwG is the Forest Genetic Resources Working Group, established by the Forest Service under the COFOR Council 2015-2018.

- Conor O'Reilly, "Sitka Spruce Improvement", Forest Service Inspectors' Conference, Johnstown Castle, Wexford, 25th May 2015.
- Elaine O'Connor. Oral Presentation, The distribution of alder plus-trees in Ireland and early results from progeny trials in the alder breeding programme. Irish Plant Scientists Meeting, National University of Galway 2013. 17/05/13
- Elaine O'Connor Oral Presentation, Update on the Irish Birch and Alder Improvement Programme. Presentation to the COFORD Board (Council for Forestry Research and Development) AGM 2013. 12/04/13
- Elaine O'Connor, Poster presentation, Variation in response to pest and disease exposure in alder (*A. glutinosa*) progeny trials. IMPACT project final conference, Dublin 2013 07/05/13
- Liam Donnelly, Charles Harper, Poster presentation. The Irish Forestry, Woodland and BioEnergy Show 2013, Inform stakeholders - Forest Generics Research Programme. 10/05/13
- Liam Donnelly, Poster presentation. "IPSAM conference, UCC, Poster presentation ""Growth and Biomass Allocation Patterns of Eight Young Sitka Spruce Clones ". 28-29/04/2014.
- Liam Donnelly, Poster presentation. SSSE conference, UCD, "Can Advanced Selection of Elite Genotypes Lead to More Sustainable Forestry?". 11/12/14
- Niall Farrelly and Niall O'Neill, Poster presentation. The potential of more southerly provenances of Sitka spruce in Irish Forestry. Poster presentation at Forestry and Energy Show, Stradbally., Co. Laois 10/05/13.
- Niall Farrelly, Consultation process for Forest reproductive material. Teagasc submission on FRM. 23/09/15.
- Niall Farrelly, Oral Presentation. Update on the Forgen Research Presentation to the Teasgac Stakeholders Group, Tullamore, Co. offaly. 25/10/13
- Niall Farrelly, Presentation at National Forestry Seminar - Society of Irish Foresters. Silvicultural and management techniques to improve the potential of the forest resource 06/07/15
- Niall Farrelly, Presentation on are there site and environmental variables that permit the selection of provenances more suited to particular site types. FORGEN Seminar on Forest genetics a seminar for Policymakers, Glenview Hotel, Co. Wicklow 2015. 08/01/15
- Niall Farrelly, Presentation on the potential of southern provenances of Sitka spruce for volume production. FORGEN Seminar on Forest genetics a seminar for stakeholders, UCD Jan 2015 13/01/2015
- Niall Farrelly, Presentation, Irish National Forestry Conference, Enfield, Co. Meath 6th June 2014. How good silvicultural practice can increase the productivity and profitability of the forest enterprise. 06/06/14.
- Niall O'Neill, Poster presentation. The potential of more southerly provenances of Sitka spruce in irish Forestry. Poster presentation at Walsh Fellow Seminar, RDS, Dublin. 28/11/13
- Olga Grant (invited i.e. Not funded by FORGEN), Oral Presentation at the "University of Nottingham at Sutton Bonington, seminar series. Invited presentation: 'Detection, analysis, and exploitation of plant responses to environmental stress'", 06/06/12
- Olga Grant (invited i.e. Not funded by FORGEN). Oral Presentation, Sino-German training network block seminars, University of Hohenheim, Stuttgart. Invited presentation: 'Exploring and exploiting crop-environment interactions for sustainable production', 06/11/12
- Olga Grant, David Thompson, Conor O'Reilly, Genetic and environmental impacts on vigour in Sitka Spruce seedlings. Plant Environmental Physiology Group Annual Symposium
- Olga Grant, Oral Presentation. COST Action on Phenotyping, Larnaca, Cyprus, 01/10/14
- Olga Grant, Oral Presentation. IPSAM Conference, Cork. April, 2014
- Olga Grant, Oral Presentation. SBES Seminar. 01/09/14
- Olga Grant, Oral Presentation. To obtain feedback from plant ecophysologists and other scientists undertaking related research, 09-10/09/2013
- Olga Grant, Oral Presentation. To present results to date to the Irish Plant Science community, 16-17/05/2013

Olga Grant, Phillip Glombik, David Thompson, Conor O'Reilly, Determinants of variation in late season growth in genetically diverse Sitka Spruce (*Picea sitchensis*). IPSAM 2013

Philippe Cubry, Colin Kelleher, Oral presentation. IPSAM conference, Galway, Oral presentation "Assessing provenance of Irish tree species in a European context – a part of the FORGEN project". 16-17/05/2013

Phillip Glombik, Conor O'Reilly, Olga M Grant. Oral Presentation, Spreading the results won during the early selection and juvenile vigour research parts. Title: Juvenile vigour of diverse Sitka spruce full-sibling families in a changing environment. 12/05/15

Phillip Glombik, Poster presentation. A practical approach tp assess early selection traits in forestry, using image analysis and MatLab. Photo physiology phenotyping workshop, Essex, UK. 16-17 Dec 2013

Phillip Glombik, Poster presentation. Growth characteristics of improved Sitka spruce seedlings and implications for early selection and tree breeding, Solutions for a sustainable environment, Conference at UCD, Dublin, Ireland. 11/12 Dec 2014

Theresa J Reape, Dave Thompson and Paul F McCabe, Poster presentation. The Irish Forestry, Woodland and BioEnergy Show 2013. Inform stakeholders - Improved somatic embryogenesis system for Sitka spruce. 10/05/13

(v) Intellectual Property applications/licences/patents

(vi) Other

Charles Harper, All partners, Project Website. Project website. 01/01/14

Elaine O'Connor, Launch and associated media coverage generated. Launch of the Birch and Alder Qualified orchards, 10/05/13

Liam Donnelly (invited i.e. Not funded by FORGEN, Networking. COST Action (FP1106), Naples, Italy. 15-16/4/13

Liam Donnelly (invited i.e. Not funded by FORGEN, Networking. International Symposium on Wood Structure in Plant Biology and Ecology, Naples, Italy. 17-20/4/13

Niall O' Neill MSc Thesis Submitted MSc thesis 31/9/2014

Olga Grant (COST-funded), Networking. I am actively involved in two Topics within the COST action, which are providing opportunities for collaboration e.g. Phillip Glombik will apply for a short-term mission to enhance his post-graduate education. 15-18/10/2013

Olga Grant (COST-funded), Networking. This COST action relates to forests under changing climatic conditions. It offers the opportunity to collaborate with forest scientists throughout Europe. 15-19/04/2013

Olga Grant, Networking. I attended meetings relating to the EPA's developing research strategies in the areas of Water and Climate Change, summer 2013

Philippe Cubry \* Colin Kelleher (self funded). Networking at the NovellTree Workshop, Helsinki, Finland. This was an opportunity to develop contacts with other European and international researchers working in the area of forest genetics and genomics. We established contacts and are collaborating with individuals following on from this conference. Attended workshop "Genome analysis tools applied to forest tree breeding". 16-18/10/12

Phillip Glombik & Charles Harper, Networking. Dublin; CARBiFOR II: Carbon Sequestration in Irish Forest Ecosystems. 04/09/12

Phillip Glombik & Charles Harper, Networking. UCD Earth Institute Showcase Programme 06/11/12

Phillip Glombik, Networking. Attendance to plant environmental physiology group ecophysiology technique workshop, Lisbon, Portugal. 7-13 September 2014

Theresa J Reape, Paul F McCabe, Rebecca Creighton, MSc thesis. Cryopreservation of *Picea sitchensis* and *Arabidopsis* cell cultures. 01/08/14

## **5. Scientists trained by Project**

Total Number of PhD theses: 2

Please include authors, institutions and titles of theses and submission dates. If not submitted please give the anticipated submission date

Liam Donnelly, UCD. "Above- and below-ground responses to competition and wood property variation in juvenile Sitka spruce clones". Submitted April 2016.

Phillip Glombik, UCD "The determination of juvenile vigour traits which are associated with mature attributes of Sitka spruce". Submitted May 2016.

Total Number of Masters theses: 1

Please include authors, institutions and titles of theses and submission dates. If not submitted please give the anticipated submission date

Walsh Fellowship: Niall O' Neill, MSc thesis. "Impact of different sources of improved and unimproved genetic material on early growth of Sitka spruce" Submitted 1 May 2015.

## **6. Permanent Researchers**

Institution Name	Number of Permanent staff contributing to project	Total Time contribution (person years)
UCD	1	0.6
Teagasc	1	0.75
NBG	1	0.75
<b>Total</b>	<b>3</b>	<b>2.1</b>

## **7. Researchers Funded by DAFM**

Type of Researcher	Number	Total Time contribution (person years)
Post Doctorates/Contract Researchers	1	3.58
PhD students	2	7.63
Masters students	1	2
Temporary researchers		0.2
Other	1	2.26
<b>Total</b>	<b>5</b>	<b>15.67</b>

## **8. Involvement in Agri Food Graduate Development Programme**

Name of Postgraduate / contract researcher	Names and Dates of modules attended

## **9. Project Expenditure**

Total expenditure of the project: € 1,536,633.14

Total Award by DAFM: € 1,567,373.66

Other sources of funding including benefit in kind and/or cash contribution(specify): € 668,748.00

Tress4Future: Donnelly, Cubry	4,000.00
Coillte: access to facilities, infrastructure	644,748.00
FTT: Grafted Plants, advice	20,000.00

### Breakdown of Total Expenditure

Category	UCD For	UCD SBES	Teagasc	NBG	Total
Contract staff	139,362.83				137,193.91
Temporary staff			139,300.70	6,809.01	149,206.26
Post doctorates	210,045.28	77,473.96		50,119.33	339,710.91
Post graduates	168,354.91		38,000.00		206,354.91
Consumables	19,787.89	25,984.76	24,093.84	27,529.92	97,396.41
Travel and subsistence	19,929.12	876.87	32,032.64	1,343.82	54,182.45
Sub total	557,480.03	104,335.59	233,427.18	85,802.08	984,044.85
Durable equipment	5,479.06		5,180.04	29,726.07	40,385.17
Other	215,298.12		8,553.71	8,787.74	232,639.57
Overheads	167,244.01	31,300.68	62,958.45	17,160.42	279,563.55
<b>Total</b>	<b>945,501.22</b>	<b>135,636.27</b>	<b>310,119.38</b>	<b>141,476.31</b>	<b>1,536,633.14</b>

## **10. Leveraging**

Trees4Future funding was secured by two researchers.

In collaboration with the Future Trees Trust, the FTT funded the production of grafted material for the establishment of the Spanish chestnut seed orchard.

## **11. Future Strategies**

Several publications have resulted from this research work and it is expected that more will be produced over the next two years or so. Considerable progress was made in advancing knowledge in key areas of research of relevance to science and practice. The publications have helped generate interest in the research outside of Ireland. Therefore, it is envisaged that future developments will include participation in EU project(s). In addition, some of the results will be implemented in practice over the coming years, especially in light of the fact that some of the research work will continue as part of the new DAFM-supported FORM project.

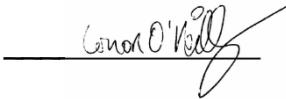
## **12. Consent to Publish Final Report on the DAFM Website and/or Through Other Dissemination channels**

I consent to this report being made available to the public, through the Department's website and other dissemination channels. \*

Yes           No   

## **13. Declaration**

I declare that the information contained in this final report is complete and true to the best of my knowledge and belief.

Signed:  Project Coordinator

Date: 10 February 2017

\*IPR sensitive information that the coordinator does not wish to make public should be highlighted in red font. All text in red font in this report will not be made publicly available by DAFM.