Programme 5: Tree Breeding & Timber Quality

Section 1. Overview

Research programme Title	P5: Tree breeding and developing sustainable markets, forest products and services
Research programme Short Title	Tree Breeding & Timber Quality
CFS Programme number	CFS5
Version	27
Date	24/02/2015
Author	Steve Lee
Programme Life (years)	4
Start Date	01/04/2015
Completion Date	31/03/2019
Cost of programme (£k)	£2,656 (4 years); £664/yr.

1.1 Summary of proposed research

This Programme will investigate research associated with 'Tree Breeding' for tradition solid wood traits, and 'Wood Quality'. 'Resistance Breeding' is not included here. This means the 3 existing contracts designed to find Chalara-tolerant ash trees is covered under Programme 3 (Delivering Resilient Forests) and more exploratory work into the tolerance of a new pest or disease across a species will be covered under Programme 2 (Understanding Threats to Resilience).

Tree Breeding: The species investigated in Programme 5 will be many and include secondary conifer and broadleaf species as well as any legacy breeding associated with programmes to be continued. Species-specific breeding plans will suggest the most suitable seed source, and the future approach to be employed in a programme to improve the genetic quality of planting stock. New field trials of alternative species are anticipated. The most cost-efficient bio-technology tools will be considered where appropriate as a means to increased selection accuracy and speed up genetic gains reaching the field. Existing work with tissue culture of Sitka spruce will be reviewed prior to possible extension to other, new species. The DNA-marker work in Sitka spruce will also be reviewed within the period of this proposal.

Wood Quality: The Programme also considers the wood quality of the various new species to be considered as selected by the 3 countries (England, Scotland & Wales). This includes research into assessing the quality of all the various species against each of the potential end-uses, so determining the most suitable end-use for each species. The Programme will develop new tools to assess timber quality non-destructively, indirectly and at an earlier age than final or mid-rotation according to data collected from the field, lab and sawmill.

Section 2. Description of work

2.1 Background

From the 'Research Brief' of 12th Sept 2014, the initial Research Challenges (RC) of this Programme were:
RC5.1: Supporting Development of new and innovative sustainable markets for forestry products and service;
RC5.2: How can we improve our understanding on non-timber products and services delivered by forests and woodlands?
RC 5.3: How can we ensure supply-chain investment, diversification and efficient management?
After additional consultation with the three countries by Corporate Forestry Services (CFS, FC), 5 key questions were derived and agreed with all the countries. The guidance from CFS was that these 5 questions should now form the basis of Work Package structure within Programme 5 rather than the earlier RCs. CFS considered RC5.1 was amply included within the new country questions; RC 5.3 was more applicable once RC5.1 had been addressed; and RC5.2 was not seen to be immediately relevant to the Programme.
The 5 key country questions were:

1. *What tree species (hardwood and softwood) are most likely to provide the timber properties required for future markets, including engineered timber to bio-refining?*
2. *What are the timber properties and characteristics (durability, strength, stiffness, kwh/m3, etc.) of the species prioritised by the countries?*
3. *Are there significant differences in the carbon sequestration performance of these species?*
4. *What is the effect of silvicultural systems on the timber quality and characteristics of chosen species?*
5. *What tree breeding techniques/technologies can be used to improve the timber properties of these species*?

Question 4: will be covered by Programme 3; work regarding carbon sequestration will be in close association with Programme 6.

2.2 Programme-level response to the Research Challenges

As explained above, under guidance from CFS, the shift of emphasis was from the original Research Challenges to the 5 key questions agreed with the countries.
The main aim of Programme 5 is to provide forest managers, saw millers and policy makers with more complete information regarding the possibilities and potential of planting alternative species (otherwise known as emerging or secondary species). In a bid to make forests more resilient to an increasing number of attacking pests and diseases (both natural and introduced), and also better able to cope with the impact of predicted changes in climate change, managers are seeking to plant a more diverse range of specie. It is natural that those managers demand to know more about these alternative species in terms of growth performances, the most suitable source of planting stock from across the distribution range, the possibilities of selection and breeding, and the best end-uses for the timber. Saw millers in particular want to know how these new species will vary from what they are familiar with (Sitka spruce, Scots pine, Douglas Fir) so they can seek out new processing techniques and markets if necessary.
Stakeholders will demand information regarding suitability of planting stock and timber quality as soon as possible. To that end, models will be developed to make predict ions regarding (i) genetic gain from different approaches of selection and breeding (including the use of new DNA-technology and tissue culture techniques where applicable), (ii) the quality of timber from the new species and (iii) the ability to measure those timber characteristics as accurately, as quickly and as early in the life of the tree as possible. Programme 5 aims to meet all these

requirements.

Species-specific breeding plans will firstly entail a literature review to determine if the species and provenance has been bred by others elsewhere in the world. Next there will be cost: benefit assessments of whether a breeding programme can be justified assuming certain predictions of areas to be planted, potential growth rates, and price-size curves. The biology of the species and availability of existing plantation in Britain or similar climatic zones will then be considered to see how the programme may progress. This will include the possibility of using DNA-marker techniques and tissue culture to bulk-up rare planting stock if thought to be of sufficient value. There is currently nothing more than a watching brief on the science associated with Genetic Modification.
Timber quality work will characterise the wood of the various chosen species at the level of both 'small clears' and larger sample sizes (in conjunction with Napier University) such that ultimate strength classes (C16, C24 etc.) can be determined along with potential for other uses such as biomass, bio-refining. This will be done by sourcing existing plantations across as wide a selection of site-types and latitudinal spread as possible.
In conjunction with Programme 3, the variation in wood quality according to different silvicultural systems (from clear fell to continuous cover) will also be studied. Carbon sequestration studies and models of not just the trees but the whole ecosystem will be carried out in conjunction with Programme 6.
Innovative new timber assessments techniques will continue to be developed often in conjunction with other research institutions e.g. X-ray densitometry to indirectly measure wood density and LiDar for possible remote sensing of wood properties.

2.3 Business Considerations

Delivering against country research needs

The questions received from all three countries have a common thread and that is a desire to plant a greater range of species (conifer and broadleaves) than presently is the case, but with expert information regarding what are the best provenances to be planted, how can the quality of planting stock be improved further (including importing from other breeding programmes), what can the timber be used for, the benefits or compromises of planting an alternative species relative to the optimum (often Sitka spruce), and how can the quality of the end-product timber be predicted using site data and models associated with timber quality.

Impacts and constraints

Main impacts will be:

1. Advice regarding the most appropriate current source of planting stock (e.g. wild collected in native range; existing seed orchards elsewhere in world);
2. How planting stock can be improved further through breeding and selection using traditional and bio-technological tools,
3. Improved knowledge of the timber characteristics and properties of the species being planted,
4. Recommendations as to the most suitable end-uses of the species being investigated;
5. Development of tools and models to help predict timber suitability according to measured characteristics taken indirectly and at an early stage in the rotation.

Innovation potential

Innovation will take placed in the following areas:
1. DNA-marker association with actual (phenotypic) fields performance;
2. Development of tissue culture techniques;
3. New methods of measuring timber qualities and characteristics;
4. New timber quality prediction models.

2.4 Work Packages to address the research challenges

Work Package titles

WP1	Breeding Techniques to improve timber properties
WP2	Breeding plans for alternative species
WP3	Legacy Breeding
WP4	Diversifying the timber supply
WP5	Measuring and modelling timber properties

WP Title: WP1. Breeding Techniques to improve timber properties

Indicative costs (£k):

2015-16	2016-17	2017-18	2018-19
160	160	120	120

Work package details:

Sub-divided into 3 Work Areas:

DNA-marker association studies

Good progress is being made in collaboration with Roslin Institute and colleagues across Europe to find associations between DNA-markers and phenotypic performance in the field. Three very large Sitka spruce clonal trials (4,500 clones x 4 replications = 18,000 trees per site; 54,000 trees including all 3 sites) were established 10 -years ago. The same clones are planted and replicated, on all three sites in north Scotland, Wales, and north Devon. These trees have been studied as part of DNA-marker studies in x2 EU contracts (NovelTree and ProCoGen) and in past collaborative work with Genome Canada. Early results from NovelTree show good potential for the science as a correlation of around 0.6 is found between DNA-markers and predictions of 6-year height for just one family at one site. It is important to develop this work to the other three families, to other traits (such as wood quality) and to investigate stability of markers across sites. The trials need to be maintained in good condition.

Tissue Culture of model and alterative species

Tissue Culture (TC) is seen as a means of bulking-up rare genotypes of high value. This could include genotypes which combine characteristics rarely found in nature e.g. high growth rate and high wood stiffness. In times of scarce seed supply, TC could also be used to bulk-up more regular stock provided commercially viable techniques have been developed. The intention during the earlier part of this 4-year period is to investigate the feasibility and economics of TC techniques (somatic embryogenesis) and cryo-preservation storage associated with Sitka spruce genotypes. These skills may then be transferred to other conifer or broadleaf species depending or the science may be passed onto third parties. It is intended that a limited number of some clonal field trials will accompany this work towards the end of the period.

EU ProCoGen contract

EU ProCoGen is a practical application of DNA-marker work The contract has a further 12-months to run and is 66% funded by EU; 33%from CFS. The intention is to expand the earlier work performed under NovelTree into more families, and looking at their association with wood density as well as growth rate.

WP Title: WP2. Breeding Plans for alternative species

Indicative costs (£k):

2015-16	2016-17	2017-18	2018-19
144	144	175	200

Work package details:

Sub-divided into 2 Work Areas:

New breeding plans

On receipt of the agreed species list from the three countries the intention is to prioritise their importance prior to a literature review of breeding the species elsewhere in the world. Great effort will be made into determining if selected and improved stock from a suitable provenance is already available which could then be bought into the UK. Otherwise, plans will be made for a new breeding programme the intensity and cost of which reflects the likely financial value of the species as determined by a cost:benefit analysis. It is hoped to address x2 species a year in this way, keeping close contact with the countries; feeding back directly and also to the '*Genetics and Timber Quality Steering Group'.*

Selection of seed stands & plus trees, grafting for seed orchards and archives, and collection of seed for genetic evaluation in field trials will be the next steps. Field trials are expensive (around £10k/hectare) and need to be replicated across at least x3 representative sites to determine GxE interaction. It is hoped to lead up to field trials for x2 species towards the end of this 4-year period.

Work with Future Trees Trust

Future Trees Trust (FFT) is a broadleaf breeding co-operative with a loose membership, of which Forest Research are key players. Following publication of *'A future with Broadleaved Trees'* FFT is keen to expand their species portfolio beyond Silver Birch, Oak, Sycamore, Ash, Cherry, Sweet Chestnut and Walnut. Other species may include Aspen, Wild Service Tree, and Downy Birch. FR currently contributes a considerable amount of time and resources to FFT as it progresses its various breeding programmes. Membership of FFT avoids duplication of effort across the species and better use of resources, access to students and privately owned land for field trials.

WP Title: WP3. Legacy breeding

Indicative costs (£k):

2015-16	2016-17	2017-18	2018-19
120	120	80	80

Work package details:

Sub-divided into 2 Work Areas:

Clone-bank and database management

For 60 years Forest Research has been breeding a number of conifer species: Sitka spruce, Douglas fir, Corsican Pine, Scots Pine, Lodgepole Pine, Hybrid Larch. Selected genotypes of each of these species have been grafted and planted in clonal archives whilst data pertaining to these trees is maintained in databases. Key experiments are still assessed, and a larger suite of experiments still require routine maintenance (fence mending; occasional TSU visits to inspect their condition). Whilst some of these species are not in favour at the moment mainly due to problems with pest or diseases, this may change in the future. These are trees we know something about - where they were selected, perhaps genetic value of their quality or growth rate through filed-trials measurements.

Meanwhile, the Intellectual Property (IP) associated with Sitka spruce is now shared with the Sitka spruce Breeding Co-operative. Further, more than one private company has recently shown interest in the IP of Douglas fir. Hybrid Larch trials may become important as we start the search for *P.ramorum* tolerant genotypes. There are also dozens of grafted copies of plus trees from many other species (mainly conifer, but some h/wood) selected in the late 1950s and 60s in our field clone banks. Some of these may have a value in the future. It becomes important that over-mature grafts are replaced, clone banks maintained and databases kept up to date. Contact will be maintained with the private sector to see if public/private initiatives are possible by sharing species-specific IP. If FR does hold material of interests, it should be made available to the private sector for exploitation under controlled conditions of mutual benefit – an improvement in the quality of planting stock and a reduction on the public purse to maintaining the clone banks.

EU Trees4Future contract

Trees4Future is an EU contract with 12-months left before completion. 66% funded by EU; 33%from CFS. It involves 13 countries across Europe exchanging data, breeding material and knowledge obtained through historic breeding programmes. FR is very active in the area of developing models to predict best provenances for DF, Ash and Beech to be planted anywhere in Europe based on data from IUFRO and old EU-sponsored field-trials in conjunction with FR experts in Ecological Site Classification (ESC). We are also leading social forestry research connected to tree breeding, and participating in the development of a tree-breeding specific, yet powerful statistical package for data analysis and breeding value determination. We are also sharing meta-data regarding most of our field-trails (content, site-specific data). This is a tight network of key tree-breeders sharing knowledge and information across Europe. This contract is already an extension of a previous contract (TreeBreedEx) and we are hopeful it will lead to another.

WP Title: WP4. Diversifying the timber supply

Indicative costs (£k):

2015-16	2016-17	2017-18	2018-19
198	190	135	135

Work package details:

The main aim of this work package is to address the changes in raw material supply to the forest product industries that will occur due to a change in planting and management strategies.

Additionally we aim to investigate the ecosystem service of carbon sequestration provided by a range of tree species to inform the public and practitioners alike.

This work package is comprised of three work areas:

- **Assessing the wood properties of conifers and broadleaves that are likely to be part of the future forest resource.**
- **Assessing the impact of different management regimes on wood properties. This will include continuous cover management, stocking density and mixtures.**
- **Understand the carbon sequestration of a range of tree species and describe the impact of forest diversification on the C-balance.**

The plan is for work to be integrated with (i) the Silviculture team led by Dr. Gary Kerr in Programme 3; and (ii) the Mensuration, Modelling & Forecasting team (Robert Mathews) in Programme 6, whereby the outputs here can be used to compliment yield forecasts, the though the specific tasks proposed here focus around work "Timber Properties" do on stem from and wood density.

Work Area: Assessing the wood properties of conifers and broadleaves that are likely to be part of the future forest resource.

Aims: To determine the commercial potential of trees that might be grown for increased resilience or diversity based on measurements of the key physical and mechanical properties relating to a range of forest products' end uses.

Background: For a range of reasons, highlighted in the national forest strategies, current plantings consider a wider range of tree species. The choice of species planted in a commercial capacity must satisfy end user requirements, and we wish to determine the potential impact of changing the business as usual strategy from even-aged plantations of Sitka spruce.

Methods: When it comes to choosing which species of conifers and broadleaves to study, we would recommend studying species in the areas that wish to grow them, as we know from past and current research that the environmental variation can play a significant role. We would also recommend focusing on trees that will grow well. We would like to point out that we cannot test trees if they do not currently exist, though we do plan to increase our capacity for testing young trees, which we seek to establish as a viable method of screening future forests.

We need to measure timber grade defining properties of stiffness, strength, and density of these species when grown in GB, we already know that many species have different properties when grown here as opposed to their native environments. We can derive other information, such as calorific values and biomass potential, from the measurements that will be performed.

This requires already having example stands of merchantable volume. Assessments of tree from (straightness, taper, branches) are made in the stands. Logs and discs samples are then collected form a subsample of trees in order to make laboratory measurements to obtain the key properties.

Ultimately properties are compared to Sitka spruce, as a benchmark, growing on the same site.

Expected impact and contribution to country strategies: The knowledge produced in this Work Area will be important to developing practical advice to support changes in operational practices including species selection and management.

Finally we would note that the testing of structural sized timber or detailed work on chemical composition requires work to be contracted externally, so this must be specifically requested if desired and specific funding provided for that purpose.

Work Area: Assessing the impact of different management regimes on wood properties.

Aims: To determine the commercial potential of trees grown under different management regimes (e.g. CCF) based on measurements of the key physical and mechanical properties relating to a range of forest products' end uses.

Background: In the future, for amenity reasons, but also potentially for different end uses requiring small diameter stems, it is probable that management techniques may change from the standard, plant and harvest (or plant, thin and harvest) at 2m spacing. The choice of management must produce timber that can satisfy end user requirements, and we wish to determine the impact of changing the business as usual strategy from even-aged plantations of Sitka spruce.

Methods: The objective of this WA is to increase our knowledge about the timber grade defining properties of stiffness, strength and density of material when grown under a range of management techniques.

This requires already having example stands of merchantable volume, although we have plans to be able to measure smaller stems. Assessments of tree from (straightness, taper, branches) are made in the stands. Logs and discs samples are then collected form a subsample of trees in order to make laboratory measurements to obtain the key properties.

Forest Research do not have the ability to measure structurally sized timbers or chemical properties in house, but work in a network whereby these can be measured if the cost can be met.

Ultimately properties are compared to an even aged stand of Sitka spruce, as a benchmark, growing on the same site. Where possible, such material will be sourced as a control.

Expected impact and contribution to country strategies: The knowledge produced in this Work Area will help inform growers about the impacts of various management options that diverge from standard practice.

Work Area: Understand the carbon sequestration of a range of tree species

Aims: To evaluate any changes in Carbon sequestration performances of a range of commercially viable species.

Background:
Forests play an important role in carbon sequestration, the question of whether changing their structure and composition will impact on their potential to sequestrate carbon has been raised.

Methods: Carbon sequestration is a key role provided by the national forests. The degree to which different species, or different trees within a species (for example at different locations) affects the carbon balance will be investigated based on tree form and wood density.

This work area will make use of measurements of tree form and wood density gathered in different Work Areas, and of the DSS to provide a clear statement of any effect of planting different tree species on forest C sequestration.

This WA will need to liaise with "Forest Mensuration, Modelling & Forecasting" within Programme 6.

Expected impact and contribution to country strategies: In addition to understanding commercial implications of varying what is planted where, forest managers need to consider the impact on the wider environment

WP Title: WP5. Measuring and modelling timber properties

Indicative costs (£k):

2015-16	2016-17	2017-18	2018-19
140	140	140	135

Work package details:

The key aims of this workpackage are to develop measurement techniques that will allow us to more effectively assess and monitor the national forest resource. Plus we wish to gain further insight into how trees are shaped, in a physical and structural sense, by their environment.

We are focusing on tree and wood properties that are essential for productive, yet resilient forests (in terms of climate change), in line with current and future end uses/markets. We aim to add value to all values of the forest wood chain promoting economic growth.

Within this work package there are three work areas:

Work Area: Developing efficient methods of measuring and monitoring timber properties

Aims: Delivering cost effective means of assessing tree and wood properties relevant to merchantability.

Background: We need to measure tree, wood and timber properties in order to meet all of our other objectives. This can be done through existing methods, but we must acknowledge that with technological developments, these may no longer be the most accurate or efficient methods of achieving our goals. It is important therefore to keep an eye on developing methods, or even pioneer methods, to measure properties that are vital for commercial exploitation. We currently do not monitor crop quality as much as modern technology might allow.

Methods: We know from our current research that wood stiffness is a limiting factor when assigning a timber grade to GB softwoods, therefore a more efficient temporal measurement of wood stiffness is highly desirable in order to help us understand what drives it in relation to tree growth. Similarly, the ability to accurately assess stiffness of young sapling trees will provide advances in measurement potential and could accelerate a breeding programme.

Knots are key component in determining timber value, yet currently we do not have a clear link between tree branches and knot form and volume. We can use emerging technology and techniques to gain a better understanding of this.

Other properties of interest are dimensional stability and distortion. We can investigate methods of measuring these that have been published in international scientific journals, to expand our own repertoire.

Expected impact and contribution to country strategies: The knowledge produced in this Work Area will be important to enhance what can be produced within the resources of this programme, both currently and looking forward. We also similarly hope to make better crop quality monitoring possible.

Work Area: Modelling important tree and wood properties

Aims: To provide forest scientists, forest managers and forest industry practitioners with an understanding of tree and wood properties that can impact upon business.

Background: The measurement of important wood and tree properties is not valuable unless we have the means of disseminating it in a way which is beneficial for both forest scientists and forestry practitioners. This requires models to be constructed that can help in decision making processes.

Methods: Trees are highly variable based on a combination of genetic and environmental influences. This affects the way that we use them. This WA seeks to disseminate what we know about how tree and timber properties vary with genetic origin, tree growth and environment in a way that informs economic decision making.

In order to describe the trends in what we measure we need to produce and validate mathematical models and place them into our existing suite.

A timber properties decision support system (DSS) that is compatible with ESC has been produced and we propose to maintain and update it with new models (e.g. water content of wood) as they become available.

Expected impact and contribution to country strategies: The knowledge produced in this Work Area will help inform growers about the impacts of various management options prior to making decisions. It will also help practitioners make best use of, and add value to, the timber supply chain.

Work Area: Tree biomechanics and environment

Aims: To evaluate how growing environment affects the physical and mechanical properties of trees.

Background: Trees are shaped by their growing environment. By better understanding and describing the effect that the environment has on tree form, wood physical and mechanical properties we can make better recommendations for management, plus inform the public about the nature of trees.

Methods: Here we want to investigate how exposure affects stem form and mechanical properties.

We want to investigate how drought affects word formation and conductivity.

Expected impact and contribution to country strategies: We can help forest managers understand the impact of the environment on their eventual crop and we can provide some foresight into the likely effect of changing or extreme climate on the current and future timber properties.

Section 3. Communications Strategy

WP 1:
This is high-quality science and outputs will take the form of

i. Internal reports to EU (against contracts) and FC
ii. Publication in high-quality scientific journals.

WP2 & 3:
The nature of the work in these WPs lends itself more to FC Practice or Information Notes with the objective of keeping the industry informed on progress. Articles in trade magazines and lower-value journals such as Quarterly Journal of Forestry and Scottish Forestry are also anticipated.

WPs 4 & 5:
Results will be published in a mixture of:

i. Applied research information notes
ii. High quality scientific journals with respect to the relevant impact.
iii. Annual research seminars open to relevant practitioners.

In addition, there is an existing '*Genetics and Timber Quality Steering Group'* which will be seen as a key means of dissemination and source of Stakeholder feedback and there shall be regular contact with other members of the Strategic Integrated Research in Timber (SIRT) group which represents most stakeholders in the UK timber industry. The new Sitka spruce Breeding Co-operative and contact with ConFor are seen as further avenues of sector engagement. There will also be collaboration with Programme 7 to include breeding, genetic improvement, and timber quality assessment of one or more alternative species as a 'case study' over the 4-year period.

Section 4. Collaboration and networking

Collaborations are intended as follows:

WP1:

i. DNA-marker association studies with Roslin Institute and colleagues across Europe within the EU contract ProCoGen;

ii. Tissue-culture links with INRA (Orleans); JD Irving's and Canadian Forest Research (New Brunswick and Nova Scotia) and private industry via the Sitka Spruce Breeding Co-operative.

WP2:

i. Links with other tree breeding institutes across Europe and the USA through EU contracts, workshops and conferences

WP3:

i. Links via existing EU contract 'Trees4Future' that shares metadata and techniques between tree breeders across Europe.

ii. Links with industry seeking to enter into partnership with future breeding plans.

WPs 4 & 5:

i. Links with the UK timber industry and SIRT

ii. Forest Enterprise (Scotland) and Forestry Commission;

iii. Universities of Glasgow, Aberdeen, Surrey, Napier, Oregon State, Laval (Quebec) and hopefully University College Dublin.

iv. Links with INRA (France).

Section 5. Ethical and other considerations

5.1 Ethical considerations

There are no ethical conflicts associated with this Programme 3.

5.2 Government survey control procedures

Ministerial approval must be sought before statistical surveys of businesses or local authorities can proceed so please describe briefly any relevant planned surveys.

The only surveys planned will involve analysis of existing databases relating to areas of land, site type and growth rates of species to be studied.