



Programme 3: Delivering Resilient Forests

Section 1. Overview

Research Programme Title	Delivering Resilient Forests
Research Programme Short Title	
CFS programme number	3
Version	2
Date	27/3/15
Author	Dr Ian Willoughby
Programme Life (Years)	4 years
Start date	1/4/15
Completion date	31/3/19
Cost of programme (£K)	£8,312 over 4 years; £2078/yr

1.1 Summary of proposed research

The delivering resilient forests programme will undertake high quality science in order to develop practical solutions for delivering more resilient forests. It will focus on how to deliver resilience on the ground, rather than on assessing or understanding what resilience is. The programme will produce recommendations on what tree species and provenances to use to improve forest resilience and create resilient forests; on how to best propagate, establish, deploy and demonstrate those species and provenances; how to reduce impacts on critical elements of the wider forest ecosystem such as soil, water and protected species; how to manage biotic threats to forest resilience; how to improve the resilience of urban forests; and on how to overcome social factors that may be preventing the adoption of practices that would deliver improved forest resilience.

Section 2. Description of work

2.1 Background

This research programme is focussed on the issue of developing practical solutions for delivering more resilient forests. This means considering how future climate change and new pests and diseases may threaten continued sustainable forest management, and identifying how management practices may need to be adapted so that the capacity of our woodlands to withstand these future threats is improved, and that the delivery of ecosystem services can be maintained. In doing so the risks, costs and social acceptability of management practices also need to be considered. Delivering resilient forests is a key focus of the 2014 Science and Innovation Strategy for Forestry in Great Britain, and the development of practical management solutions for the forest sector underpins Outcome 1 – an evidence base of the delivery of healthy and resilient forests and ecosystems, and Outcome 2 – providing the knowledge to deliver woodland management and expansion. Delivering resilience will also underpin the UK Forestry Standard and a wide range of specific country policy objectives, as outlined in the detailed work package descriptions later in this proposal document.

2.2 Programme-level response to the research challenges

The delivering resilient forests programme will undertake high quality science in order to develop practical solutions for delivering more resilient forests. It will focus on how to deliver resilience on the ground, rather than on assessing or understanding what resilience is. The programme will produce recommendations on what tree species and provenances to use to improve forest resilience and create resilient forests¹; on how to best propagate, establish, deploy and demonstrate those species and provenances; how to reduce impacts on critical elements of the wider forest ecosystem such as soil, water and protected species; how to manage biotic threats to forest resilience; how to improve the resilience of urban forests; and on how to overcome social factors that may be preventing the adoption of practices that would deliver improved forest resilience.

As well as being fundamental to a wide range of CFS and country evidence needs, the key research challenges set by the Science and Innovation Strategy for Forestry in Great Britain Research Plan Brief for Forest Research that the programme addresses are (numbering follows the research plan brief document):-

- 2.1 What are the properties of trees we are likely to grow for increased resilience; what is the likely impact on sector productivity of a switch to alternative species?**
- 2.2 How do we design, cultivate and manage adaptive, resilient and productive woodlands?**
- 1.4 Maintaining ecosystem services and biodiversity whilst achieving resilience.**
- 4.4 Impacts of pests and diseases on the retention and creation of woodlands and forests.**

¹ Note that in this current funding proposal, work on what tree species and provenances to use to improve forest resilience and create resilient forests is limited to only the maintenance (not assessment) of 8 existing trials, and no other scientific activity or knowledge exchange in this area is scheduled to take place.

The programme also aims to address the following additional specific country research questions, identified after the Research Plan Brief was produced, which form an essential part of the wider research specification.

- 3.2 What species should we be planting to produce resilient woodlands and what are their requirements?**
- 3.1 How will the structure and species composition of our forests need to change to maximise the benefits, be resilient to climate change / pests & disease etc., and integrate more closely with other land uses?**
- 3.2 What silviculture or management systems work best with mixed species for resilience?**
- 3.4 What practical measures and habitat management techniques (including looking at the role of wood fuel and restoring Plantations on Ancient Woodland Sites to bring woodland back into management and appropriate condition) will reverse the widespread decline of woodland Priority Species? How does changing age structure influence host susceptibility?**
- 3.9 How can the challenges facing urban forests (e.g. ensuring species chosen are resilient to climate change, spread of pest and diseases, and impact of liability concerns) be better understood to ensure that urban forest benefits are realised?**

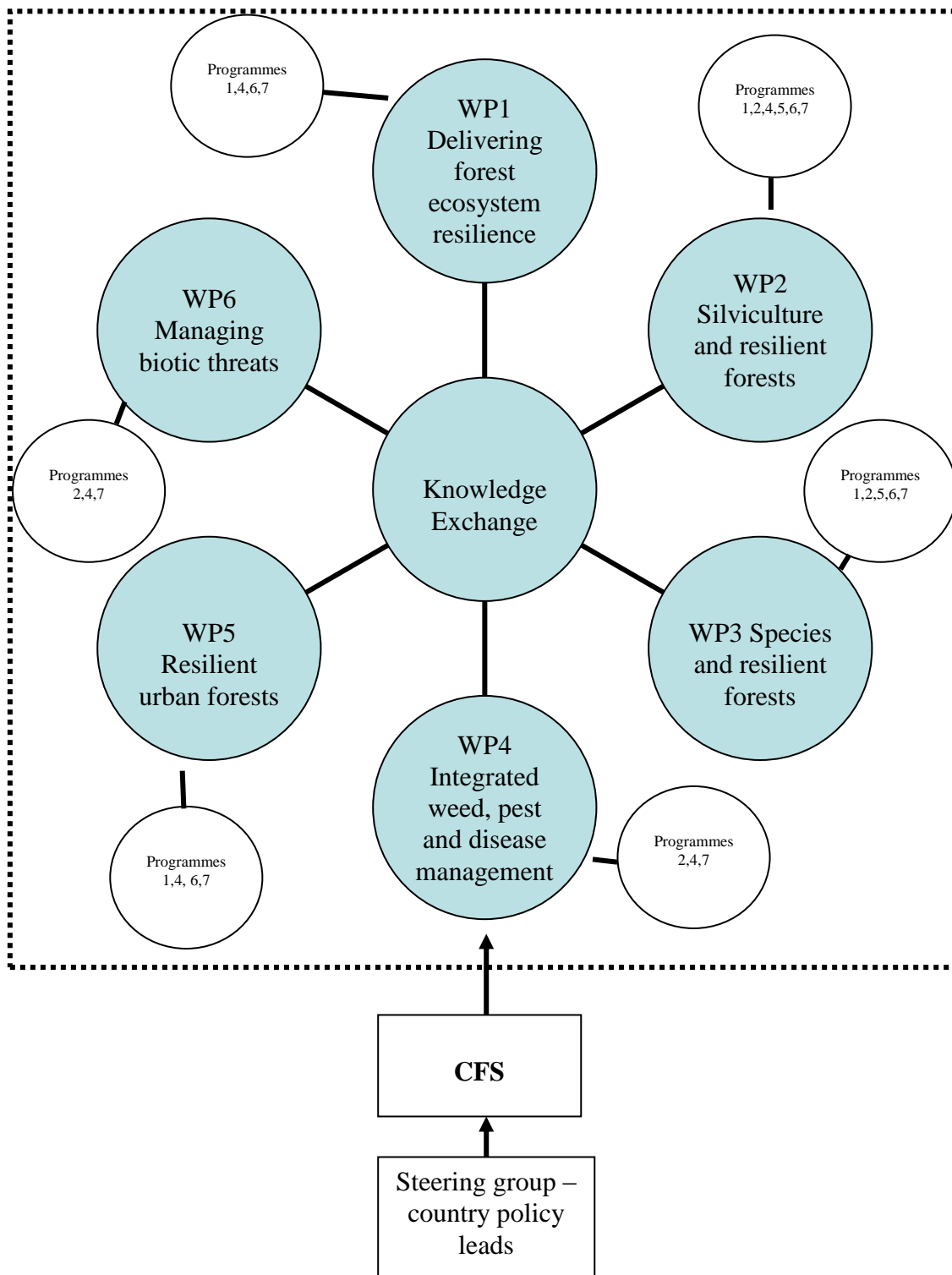
In order to address the challenges and questions listed above, the proposed programme is comprised of a series of multidisciplinary work packages which, given the size of the programme, are further divided into a number of work areas. Each work area has a named work area leader who is responsible and accountable to CFS for the delivering the scientific programme of work and the associated scheduled outputs, including knowledge exchange, to the agreed budget. Each work package has a work package leader who is responsible for ensuring integration between the work areas within their work package. The work package structure is described in Table 1, and Figure 1 illustrates the linkages between constituent work packages and with other programmes.

Please refer to the work package descriptions later in this proposal document for details of how each work package and work area will deliver against the 2014 Science and Innovation Strategy for Forestry in Great Britain, the Science and Innovation Strategy for Forestry in Great Britain Research Plan Brief for Forest Research, the additional specific country research questions, the key operational questions identified for the Great Britain national forest estate (Forest Enterprise Scotland, Forest Enterprise England, Natural Resources Wales), and any other relevant research drivers. The detailed work package and work area descriptions also indicate the impacts of the research and the key contributions it will make to the delivery of country strategies and policies.

Table 1: Delivering resilient forests programme structure

Work Package	Work Package Leader	Key Research Challenge	Work Areas	Work Area Leader
1. Planning and management to deliver forest ecosystem resilience	Peter Crow	1.4 Maintaining ecosystem services and biodiversity whilst achieving resilience.	1.1 Simulating resilient future forests in management and planning 1.2 Impacts of energy forestry on soil and water 1.3 Impacts of conventional forestry on soil and water 1.4 Resilient forests and protected species 1.5 Ecological implications of biotic threats	Duncan Ray Elena Vanguelova Nadeem Shah Alice Broome Alice Broome
2. Silviculture and resilient forests	Gary Kerr	2.2 How do we design, cultivate and manage adaptive, resilient and productive woodlands? 2.1 What are the properties of trees we are likely to grow for increased resilience?	2.1 Silvicultural systems 2.2 Plant production 2.3 Regeneration and stand tending 2.4 Long term experiments 2.5 Demonstrating adaptation 2.6 FRM regulations 2.7 Human dimensions of forest management practices 2.8 Governance structures	Gary Kerr Shelagh McCartan Ian Willoughby Victoria Stokes James Morison Stuart A'Hara Norman Dandy Bianca Ambrose-Oji
3. Species and resilient forests	Richard Jinks	2.1 What are the properties of trees we are likely to grow for increased resilience?	3.1 Emerging species 3.2 Provenance of introduced species 3.3 Resistance breeding	Richard Jinks Gary Kerr Steve Lee
4. Integrated weed, pest and disease management	Ian Willoughby	4.4 Impacts of pests and diseases on the retention and creation of woodlands and forests.	4.1 Pesticides and forest vegetation management 4.2 Fungicides and non-chemical disease management 4.3 Squirrel control 4.4 Public attitudes to pest management 4.5 Integrated <i>Hylobius abietis</i> management	Ian Willoughby Kath Tubby Robin Gill Mariella Marzano Roger Moore
5. Resilient urban forests	Kieron Doick	2.1 What are the properties of trees we are likely to grow for increased resilience?	5.1 Choosing tree species for a resilient urban forest 5.2 Urban forest creation	Kieron Doick Kieron Doick
6. Managing biotic threats	Joan Webber	4.4 Impacts of pests and diseases on the retention and creation of woodlands and forests.	6.1 Phytosanitary pest management 6.2 Advice and support for pest and disease management 6.3 Surveillance and management of DNB	Joan Webber Ana Perez-Sierra Kath Tubby

Figure 1: Delivering resilient forests programme structure



2.3 Business considerations

Delivering against country research needs

Please see earlier section titled 'Programme-level response to the research challenges' and also the work package descriptions later in this proposal document.

Impacts and constraints

Please refer to the detailed work package descriptions later in this proposal document (Section 2.4).

Innovation potential

Innovation is important in many parts of the research programme - please see the detailed work package descriptions later in this proposal document.

2.4 Work packages to address the research challenges

Work package titles and funding

WP	Name of funding/supporting organisation	2015/16 (£K)	2016/17 (£K)	2017/18 (£K)	2018/19 (£K)
1	Planning and management to deliver forest ecosystem service resilience	454	454	454	454
2	Silviculture and resilient forests	603	603	603	603
3	Species and resilient forests	101	101	90	65
4	Integrated weed, pest and disease management	355	355	355	355
5	Resilient urban forests	116	116	114	135
6	Managing biotic threats	505	505	505	505
Total Programme funding²		2134	2134	2121	2117

² Information on funding in kind from other organisations is not always clear for future years, but details, where known, are provided in the individual work package descriptions.

WP Title: WP1. Planning and management to deliver forest ecosystem service resilience

Indicative costs (£k):

Work area	2015-16	2016-17	2017-18	2018-19
1.1 Simulating resilient future forests in management and planning	87	87	87	87
1.2 Impacts of energy forestry on soil and water	98	98	98	98
1.3 Impacts of conventional forestry on soil and water	139	139	139	139
1.4 Resilient forests and protected species	120	120	120	120
1.5 Ecological implications of Biotic threats	10	10	10	10
Total for work package	454	454	454	454

Key research challenge

1.4. Maintaining ecosystem services and biodiversity whilst achieving resilience.

This work package also addresses the additional elements of the research specification listed below.

Research specification	Element met
Research Brief	Research challenge 2.2 How do we design, cultivate and manage adaptive, resilient and productive woodlands Research challenge 2.4 Which tools (and K.E.) are required to assess risk and resilience and support adaptive management?
Science and Innovation Strategy	Contributes to the achievement of SIS Outcomes: 1 – To provide an evidence base for the delivery of healthy and resilient forest and wider ecosystems to enhance benefits for society. 2 – To provide the knowledge to deliver woodland management and expansion, as a component of land-use change.
Key country research questions	
Forest Enterprise priority	Water management, priority species, and designing woodlands to maximise resilience and maintain ecosystem services are all identified as key research priorities by Forest Enterprise Scotland.
Other	FCE - Do we know enough to prevent further damage and return afforested acid-sensitive catchments to good ecological status without unnecessary impact on the forestry sector? (FCS and NRW) FCS - What degree of various ecosystem services can be provided by native woodlands and other forms of woodland? (High priority for NRW/FCE). FCE - What are the benefits of different types of woodland creation and management for water quality/availability and flood risk ecosystem service objectives, and where should new woodlands be located to maximise these benefits? Supports FC Scotland's Woods for Nature Programme 2012

Work package details

The main aim of this multidisciplinary work package is to address key elements of research challenge 1.4, by developing practical tools to help deliver forest resilience, whilst maintaining ecosystem services and biodiversity.

Research within work area 1.1 will utilise the results from the other work areas within this Package, thereby facilitating multidisciplinary collaboration. However, all of the outputs from this work package will underpin the expertise required to deliver sustainable management and the protection of the forest resource across the UK and the ecosystem services it provides as outlined in the UK Forest Standard and its associated Guidelines. It will help deliver Forestry Commission England, Forestry Commission Scotland and Welsh Government forestry policies that all include aims of minimising the environmental impacts of forestry, whilst protecting and promoting biodiversity, forest resources and other ecosystem services. The work package will be comprised of 5 work areas.

Work area 1.1 - Simulating resilient future forests in management and planning

Aim:

To simulate the impact of forest planning and forestry practice on the delivery of ecosystem services from resilient forests, under different climate projections and socio-economic futures, to assess robust adaptation options for Forest Districts (FDs) in Britain.

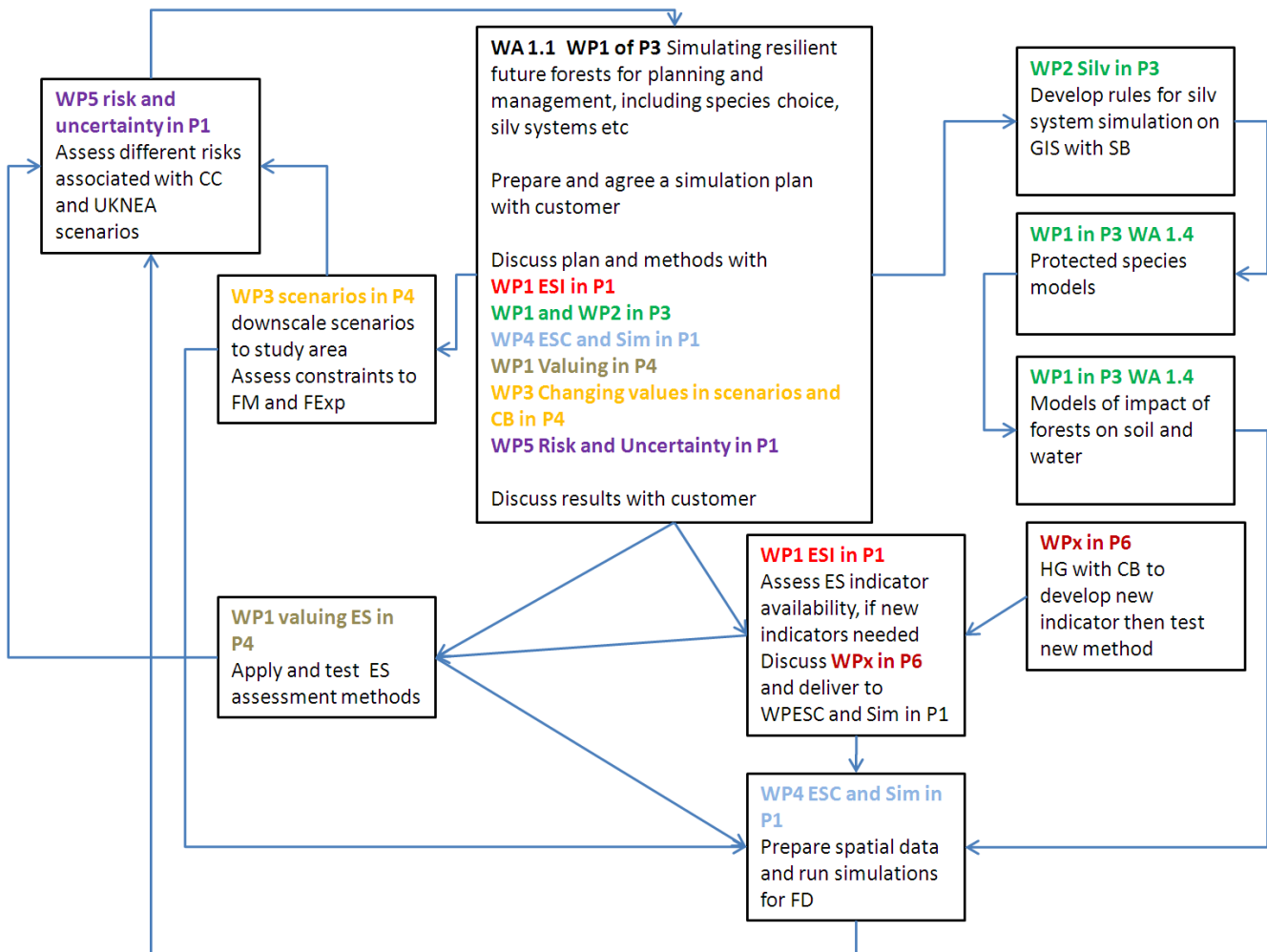
Methods:

The EU Framework Programme 7 project MOTIVE provided resources to develop a simulation framework to provide the evidence for resilient forest management adaptation strategies in Britain. The 'Motive8' simulation has been used and disseminated in the forests of North Wales, South Scotland, Central Scotland, and Lochaber. FR has provided FDs with evidence of the impacts of different adaptation management trajectories through the uncertainties of climate change and socio-economic change in the 21st century. FDs have responded enthusiastically to the work, and FC Scotland has asked for national scale evidence of ecosystem services delivery from the National Forest Estate. This work suggests that FDs are interested in accessing evidence of the effects of species choice and silvicultural systems to help in adaptation planning.

With FDM, planning and environment staff in selected forest districts, the challenges, uncertainties and perceived risks of adapting forests species and management to climate change will be discussed to develop and agree with the forest district a research question script to test in a simulation. As part of this development process, the intention is to hold a small stakeholder workshop including both private sector and public sector forest managers. With FD staff a plan will be made for the simulation and the type of outputs required (graphs, spatial GIS layers, adaptation pathway diagrams, species lists, constraints maps, reports, uncertainty estimates on ES, etc.) the time frame of the work, and agreed review meetings between FR, the FD, and the country policy advisors.

The work will link to programme 3 work package 2 silviculture and resilient forests, programme 1 work package 2 ecosystem service indicator methods, programme 4 work package 1 valuing ecosystem services, and programme 4 work package 3 UK NEA scenario downscaling. This work area 1.1 will co-ordinate the research effort in those four work packages and bring the analysis of the simulation results to work with programme 1 work package 3 risk and uncertainty to develop knowledge exchange methods (e.g. forest practice adaptation pathways) to discuss with the forest district and help plan measures to improve forest resilience (see diagram). The complete linked simulation framework across the four programmes will be the subject of one of the case studies by programme 7. Programme 7 social research will study the process of the work, advise on the techniques for stakeholder work, and report on the impact of the whole stakeholder

involved simulation process. The work will also be linked to a NERC PURE project with Edinburgh University to study methods for understanding and assessing the adaptation readiness through the private sector forest insurance industry, with Forest Research.



Impact:

An improved take up of adaptation thinking and action, based on the resilient provision and value of key ecosystem services and from the forest districts (wooded and open land) into the future.

Work area 1.2 - Managing impacts of energy forestry on soil and water

Aim:

To evaluate the impacts of energy forestry on soils and water to inform policy and guidance on possible future expansion of such activity.

Methods:

There are four linked projects within this work area involving the medium to long-term evaluation of the impacts of energy forests and their management on soils and water. These are designed to understand the risks and potential benefits of energy forestry so that future decisions on a potential expansion of short rotation forestry or the harvesting of residues can be based on an understanding of where such practices could be acceptable or where they would result in damage to soil and water resources. The work will inform work area 1.1, work package 2 and programmes 4 and 6.

1. Repeat soil measurements at the whole-tree harvesting (WTH – brash removal only) experiment at Falstone in Kielder (N England) to determine medium-long term impacts on soil condition. This involves soil sampling and analysis to compare results with earlier surveys to determine what changes can be ascribed to the harvesting of these woody residues after 35 years of second rotation Sitka spruce. In addition, an evaluation of aboveground biomass and tree growth datasets will be combined with soil and root data to calculate carbon and nutrient budgets across the whole tree harvesting treatments.

2. Evaluate the impact of stump harvesting of Corsican pine at Thetford on soil carbon and nutrient capacity, building on existing datasets. This involves chemical analysis of already collected soil samples, statistical analysis and writing up results.

3. Repeat soil measurements at selected sites from the established network of short rotation forestry (SRF) trials in Scotland and England to determine medium-long term impacts on soil condition. This involves soil sampling and analysis to compare results at the mid-rotation stage with the original baseline survey in 2009-2010, to determine the initial effects of the growth of these stands on soil condition.

4. Continuation of hydrology studies of the impact of the establishment of SRF stands at Alyth in East Scotland (ash and sycamore) and Squerryes Estate in Kent (red alder) on water resources. Recording of local climate, net rainfall and soil water content began in 2010 using a variety of techniques and is planned to continue until eventual crop harvesting to establish full rotation impacts on water yield/supply. Should a suitable SRF site become available in a flood plain, efforts will be made to try and fund this within Programme 1. A related assessment of the effectiveness of a SRF riparian buffer to control diffuse pollution is the subject of a BBSRC bid by Rothamstead Research, with FR input as a sub-contractor

Impact:

Improved knowledge of the risks and benefits presented by energy forestry to soil and water resources, which will help shape future policy on energy forestry and generate better guidance on site selection for energy forest crops and the harvesting of forestry residues. This will ensure compliance with UK and European legislation and guidelines on soil and water protection, including the EU Water Framework Directive.

Failure to continue these long term studies would prevent any updating of interim guidance on the harvesting of forest residues, and make it impossible to develop robust guidance on site selection for short rotation forestry to ensure soil and water protection, including under a future changed climate. This could undermine a future case for expansion of energy forestry or lead to inappropriate site selection and damage to soil and water resources.

Work area 1.3 - Impacts of conventional forestry on soil and water

Aim:

To evaluate the impacts of afforestation and forestry management practices on soils and water to inform policy and guidance on forest expansion, sustainable forest management and protection of soil and water services.

Methods:

There are six linked projects within this work area involving the medium to long-term evaluation of the impacts of afforestation and management practices on soils and water. These are designed to help identify if further refinement of current guidance on forest management is required to ensure the resilience of soil condition and maintenance of good water status. The research also helps in determining how the impacts of forestry on soil and water services may alter with climate change. The work will inform work area 1.1, work package 2 and programmes 1, 4 and 6.

1. Continuation of the water quality and biology studies established at Halladale in N Scotland in 1993 to demonstrate the sustainability of upland conifer afforestation in a catchment supporting an important salmon fishery. Involves monthly sampling of water chemistry at six locations plus annual surveys of fish and benthic macroinvertebrate populations. Results are important to help inform decisions about growing pressure for forest clearance and habitat restoration, with the Halladale catchment straddling the Flow Country and lying adjacent to the expanding RSPB Forsinard reserve.

2. Evaluation of the impact of tree removal for peatland restoration at Flanders Moss in mid-Scotland on nutrient (N & P) and carbon losses to water. This involves monthly sampling of water chemistry plus continuous water level recording at three sites. Monitoring started in 2008 and felling is ongoing. Results are needed to inform growing concern about the poor status of freshwater pearl mussel populations along western Britain and Ireland and threats posed by nutrient and sediment losses from commercial forestry, especially on peaty soils (has led to significant constraints being imposed on forest harvesting in Ireland). Monitoring will continue until 2 years after all felling is complete; it is expected that this work will conclude within the 4 year life of this programme.

3. Continuation of partnership funded, long-term hydrology benchmark study established in 1967 at Coalburn in N England, to evaluate the contrasting effects of different phases of the forest cycle on water quantity and quality. Shared monitoring of climate, water flow and quality. New forest road planned in 2015 prior to harvesting commencing within next five years, providing great opportunity to evaluate the effectiveness of current good forest practice measures (against a long-term baseline), as well as completing the assessment of the impact of a full harvesting cycle on extreme flows and water resources.

4. Continuation of water temperature monitoring at 12 points in the New Forest in S England to evaluate the effect of riparian shade on stream temperature and fish, including interactions with climate warming. To input to water temperature models and inform up-scaling work, including links to EA Keeping Rivers Cool project.

5. Evaluation of the impact of afforestation on soil carbon and nutrient stocks in a chronosequence study of Sitka spruce on peaty gley soils in Kielder Forest in N England. This work will input to carbon modelling and accounting in programme 1 and programme 6, including developments in the Woodland Carbon Code and supplementary guidance on forestry on peatland habitats.

6. Evaluation of the impact of felling and restocking of Sitka spruce on soil carbon and nutrient contents at Llyn Brianne Level II site in Wales (before and after soil sampling and analysis).

Possible extension of a similar assessment to N-saturated Thetford Forest site in E England. Planned felling of these sites provides an opportunity to assess the effects of felling and restocking against a very good baseline knowledge of soil condition at these research sites, reducing problems of site variation/uncertainty that often trouble such work.

Impact:

Improved understanding of the impacts of afforestation and forestry management practices on soils and water, including interactions with climate change. This knowledge will enable the FC to continue to develop and refine evidence-led policies, guidelines and practical guidance to maximise soil and water services and minimise pressures and risks. Failure to undertake this work will increase the risk of forestry operations damaging forest soils and causing deterioration in water status, with implications for complying with legal requirements and jeopardising sustainable forest management.

Work area 1.4 - Resilient forests and protected species

Aim:

To provide practical guidance on how to manage forests to ensure resilient populations of woodland protected species, hence supporting land managers in adhering to the UK Forest Standard Biodiversity Guidelines, the EU Habitats Directive, and associated GB wildlife legislation.

Methods:

Different outputs will be required to match the differing levels of legislative protection afforded to woodland species. Guidance notes are written for species with the highest level of protection and address how woodland operations can be managed to proceed whilst remaining within the law. Guidance Notes will be written /revised in light of new evidence revealed through literature review and from empirical research e.g. externally commissioned by CFS. Notes are written in collaboration with silviculturists in work packages 2 and 3, and FC forest practitioners and policy makers and Defra legal advisors, and will be subject to a wider stakeholder sign-off process which will include consultation with private sector and well as public sector forest managers. Development of habitat suitability models (HSM) for high priority species will be considered as a means to support users in the private and public sectors in applying the guidance.

For a larger number of woodland species (c.500) which are afforded a significant yet lower level of protection under domestic legislation, conservation and protection efforts targeted at the habitat rather than the species level are considered more appropriate. As an evidence base to guide such actions, knowledge has been assembled from literature review (conducted 2011-2012) on species- habitat associations and on management impacts on species. These data will be reviewed and updated by literature searches. A ground truthing and evidence gathering exercise will be undertaken using site management records and species inventory records for a sample of designated sites for which good management and species records are expected to exist, to check efficacy of management actions. Data will be added to by results from FR field trials conducted for certain protected species and guilds of species over the last 10 years (NB: use of these data will be subject to their successful analysis and publication). Any significant knowledge gaps will be highlighted which may lead to a need for further empirical research.

Development of knowledge dissemination methods most useful to the FC customer will be a key and research will develop in consultation with a FC customer group e.g. Country and District Ecologists and Country policy leads. As a first step, a structured classification of the habitat resource requirements of 200 protected species found in Scotland -Niches 4 Species (N4S) Scotland- has been linked to attributes in the spatial data sets (e.g. NWSS). This spatial N4S Scotland system is now entering the validation stage and will be used as an indicator of protected species biodiversity in Ecosystem Service (ES) spatial assessments in conjunction with other

indicators developed under Programme 1. In response to current customer requests, an attempt will be made to integrate the system with the higher-level biodiversity indicator tool being developed for England and Wales in Programme 1 to provide N4S assessments for woodlands in the whole of GB.

To further the development of conservation guidance for the broad suite of woodland protected species, a high level description of a conservation framework to utilise the N4S data in planning and intervention decisions will be presented in a Research Information Note. If, on the basis of this outline, the framework appeared to be of utility to FC customers, it could be developed to allow analysis of the synergies and trade-offs of applying different management interventions in their impact on the protected woodland species in different woodland and stand structure types in several pilot areas. Results from the pilots would inform how the information is best delivered to the user e.g. link to reporting actions for Biodiversity 2020 objectives by Districts through sub-compartment database functions, as a stand-alone system, or building on previous species conservation tools such as HaRPPS (Habitats and Rare Priority and Protected Species decision support system).

Further applications of the spatial N4S system could also be developed e.g. identifying biodiversity hot spots, and critical resource gaps in woodlands and again, user views on development will be solicited.

Impact:

Guidance will be provided on managing woodlands containing species with the highest level of protection and for multi-species conservation management when planning operations or developing forest policy. With its basis of woodland type, stand structure and management, this research to support species guidance will integrate well with other aspects of woodland resilience delivery research. Together this will help enable the forestry sector to implement the UK Forest Standard Biodiversity Guidelines, adhere to the EU Habitats Directive and associated GB wildlife legislation, and hence to better deliver forest ecosystem resilience.

Work area 1.5 - Ecological implications of biotic threats

Aim:

To understand the ecological implications of biotic threats to woodlands and to develop mitigation measures to off-set these impacts.

Methods:

A knowledge synthesis approach will be applied to study a number of key tree species that are at threat from pests and diseases and the tree species which could be used as their alternatives. This approach considers the species characteristics, dependency of biodiversity, possible scenarios and tests impact on biodiversity at different scales. Resulting knowledge disseminated at the national level would be relevant to forestry policy makers, at the regional scale for tactical/forest planning and at the site scale for operational planning.

Knowledge will be drawn from literature review with some field based ground truthing to test the likely impacts of applying different scenarios, and will rely on outputs from other work packages in programme 3 mainly work package 2 silviculture and resilient forests, work package 3 species and resilient forests and work package 6 managing biotic threats.

Guidance on the choice of the most appropriate alternative tree species for ash for maintaining ecosystem function, biodiversity, and protected species, have already been studied following this model. Oak (and alternative species to oak) and ash-elm systems will follow if bids for external funding are successful.

Impact:

As a key part of delivering resilient forests in the face of biotic threats, the research will provide the forestry sector not only with an estimate of the ecological impact of biotic threats but also options for off-setting those impacts through woodland management. The research will provide insights into how biotic threats alter the provision of ecosystem services; provide guidance on assessing ecological impacts to underpin management decisions, and on altering species mixtures and selecting suitable alternative tree species.

WP Title: WP2. Silviculture and Resilient Forests

Indicative costs (£k):

Work area	2015-16	2016-17	2017-18	2018-19
2.1 Silvicultural systems ³	160	160	160	160
2.2 Plant production	105	105	105	105
2.3 Regeneration and stand tending	60	60	60	60
2.4 Long term experiments	50	50	50	50
2.5 Demonstrating adaptation	130	130	130	130
2.6 FRM regulations	28	28	28	28
2.7 Human dimensions	35	35	35	35
2.8 Governance structures	35	35	35	35
Total for work package	603	603	603	603

Key research challenge

2.2 How do we design, cultivate and manage adaptive, resilient and productive woodlands?

This work package also addresses the additional elements of the research specification listed below.

Research specification	Element met
Research Brief	<p>In addition to 2.2 (above) work also addresses:</p> <p>2.4 Which tools (and K.E.) are required to assess risk and resilience and support adaptive management? [Such tools can only be developed for silvicultural systems that are viable and are known and understood by forest managers.]</p> <p>3.2 What are the costs and benefits of forest management options to improve resilience and expand our woodland resource? [The source data for this assessment would have to come from known and monitored sites that have used viable silvicultural systems, such as the research forests and demonstrations available in the work package.]</p> <p>4.4 Impacts of pests and diseases on the retention and creation of woodlands and forests. [Long-term experiments are essential as they contain areas of known species and genetic origin that can be used to look for resistance and resilience of existing and future pests and diseases.]</p> <p>2.1 What are the properties of trees which we are likely to grow for increased resilience; what is the likely impact on sector productivity of a switch to alternative species? [This research addresses fundamental knowledge of these 'emerging species' in terms of plant production, deployment in pure and mixed stands, use in different silvicultural systems, alignment with FRM regulations, demonstrations of good practice and important social aspects of alternative approaches to management.]</p>
Science and Innovation Strategy	<p>The following research areas listed in the strategy are central to this work package.</p> <p><u>Outcome 1</u></p> <p>Learning how to manage forests at multiple scales to ensure that they are more resilient to tree health threats, through management practices and tree breeding</p>

³ Match funding requirement of £10K per year for EU FP7 Simwood.

	<p>approaches to identify a wider variety of 'future-proofed' tree species and understand their silviculture including establishment requirements, production cycle and timber qualities.</p> <p>Evaluating approaches to woodland adaptation and increasing resilience, focusing on the composition (species, origin, diversity and stability of ecological communities) and management systems (silviculture and regeneration systems) that effectively address climate change concerns. This should include understanding of forestry from regions that currently experience climates similar to those anticipated in Britain in the future.</p> <p>Developing a greater understanding of the human impact on forest management, including forestry culture and community woodland ownership/governance, and approaches to human interactions with wildlife.</p> <p><u>Outcome 3</u> Supporting the forest industry with research to optimise timber growth, recovery and use. This will be delivered through the maintenance of a network of permanent sample plots, and by adopting a sustainable multi-benefit forest management approach, which will investigate the potential for alternative silvicultural systems, regeneration and novel tree species.</p>
Key country research questions	<p><u>England</u> How can alternative silvicultural systems, including coppicing and pollarding be used to enhance woodland resilience to climate change? What is the effect of continuous cover forestry and other establishment and management systems on timber quality? What silvicultural systems best reflect the various needs of hardwood timber markets (such as construction, joinery and biomass)?</p> <p><u>Scotland</u> How will the structure and species composition of our forests need to change to maximise the benefits, be resilient to climate change/ pests and diseases, and integrate more closely with other land uses.</p> <p><u>Wales</u> What silviculture or management systems work best with mixed species for resilience? What species should we be planting to produce resilient woodlands and what are their requirements?? What mixtures/species/scale/management systems provide ecologically resilient woodland, in order to ensure a range of products/benefits in future?</p>
Forest Enterprise priority	<p><u>FE Scotland</u> Information from FE Scotland lists 6 priority areas for research including: 1 (top priority) improving tree establishment; 3 alternative species silviculture (deployment is covered in this work package); 4 using natural regeneration; 5 broadleaved silviculture; 6 nursery techniques of alternative species.</p> <p><u>FE England</u> How will establishment regimes need to evolve to take account of a changing climate? What are the silvicultural characteristics of 'emerging species' we need to understand to ensure they can be used to adapt forests in Britain? [This work package considers deployment, demonstration and social aspects] What are the most effective methods to diversify vertical structure and species composition of a stand to adapt forests to climate change?</p> <p><u>NRW</u></p>

	<p>Species diversification</p> <p>Nursery production techniques – product types, growing regimes for unfamiliar species.</p> <p>Establishment techniques – development or modification of current practice.</p> <p>Prescriptions for mixtures of unfamiliar species.</p> <p>Climate change and planting techniques</p> <p>Shorter or non-existent plant dormancy and how this will influence plant product choice.</p> <p>The impact upon the planting window and current recommendations.</p>
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Work package details

The main aim of this work package is to provide practical guidance on how to design, cultivate and manage adaptive, resilient and productive woodlands. The multidisciplinary team includes forest scientists with experience in plant production, silviculture, genetics, climate change and the human dimensions of forest management. One output from this work package will be to scope the option of producing a guide to managing adaptation that, if it went ahead, would draw on the expertise of colleagues through the work package, and across the rest of programme 3 and more widely in FR. The work package will be comprised of 8 work areas.

Work Area 2.1 - Silvicultural Systems

Aim:

To provide the scientific basis and associated technology transfer to ensure that alternative approaches to clearfelling using a wider range of species, deployed as pure and mixed stands, become part of mainstream forestry practice in Britain.

Methods:

The main objectives of this work area are: (1) to understand how to manipulate forests to diversify vertical structure, spatial arrangement and species composition to increase resilience to climate change and biotic threats, and (2) to communicate this information to the forestry sector. The project has three main strands to its method: (a) it manages a number of formal research experiments examining a wide range of subjects including natural regeneration, underplanting, mixtures, respacing and intermediate treatments such as thinning and felling; (b) we work closely with forest managers in CCF Research forests at Glentress, Scotland; Wykeham, England and Clocaenog, Wales; formal monitoring occurs at each location, and (c) we actively engage with the private and public forestry sector through the Continuous Cover Forestry Group, the Forestry Commission Working Group on Continuous Cover, the Wessex Silvicultural Group and devote a high proportion of our time to knowledge exchange carrying out 15-20 advisory field visits per year. Recently the Continuous Cover Forestry Group has published a number of research priorities (CCFG, 2014)⁴ including: forest stand dynamics, natural regeneration, species mixtures, growth and yield, harvesting and extraction systems and the effects of CCF on timber quality. This project working jointly with other teams in FR has most of these subjects well covered and can provide guidance for forest managers and policy makers. In addition, it is well placed to provide expert input for projects on the impacts of CCF on water, soil, carbon and economics if this work is commissioned in other FR Science Groups.

In the period 2015-17 the focus of the work will be on:

⁴ CCFG (2014) *Continuous Cover Forestry: Delivering sustainable and resilient woodlands in Britain*. Conference Report. Continuous Cover Forestry Group, National Conference, Braithwaite Institute, Cumbria. 3-4 June 2014. [www.ccf.org.uk]

- Underplanting – we will complete the work we have been doing in 2014-15 and produce a draft FC Practice Guide on underplanting, which will include information for ‘emerging species’. The guide will be based on a review of underplanting experiments, the scientific literature, practical experience at sites including Glentress and an open experiment in the Clocaenog Continuous Cover Trial Area.
- The Bradford-Hutt system (Timmis, 1994)⁵ as a method of creating for creating diverse, resilient forests. A common perception is that this is an ‘old system’ that has fallen into neglect but this is wrong. The system is still actively used on approximately 80 ha of woodland on the Tavistock Estate. We will examine the current structure of the woodlands, propose methods for future management and review the method as an option for creating more resilient forests in the future.
- We will collate existing information on mixed species stands and re-assess some existing FR experiments with the aim of producing a FC Practice Guide in 17/18 or 18/19. As part of this work we will analyse data from an existing long-term mixtures experiment to gain a better understanding of the productivity gains reported for some mixture combinations reported by Mason and Connolly (2014)⁶.

Impact:

The outputs from this work area will underpin the expertise required to deliver sustainable management as outlined in the UK Forest Standard and the UKWAS. It will also help deliver Forestry Commission England policy of increasing the ecological resilience of woodlands and forests, Forestry Commission Scotland policy of encouraging the production of high quality timber and diversifying planted woodlands, and Welsh Government forestry policy of ensuring more woodlands and trees are managed sustainably (to UKWAS standards).

NB. This work area is of fundamental importance to the practical implementation of resilience and is fully integrated with the silvicultural aspects of work package 3 ‘Species and Resilient Forests’. Work area 2.1 considers the deployment of species in a range of silvicultural systems, including mixed species stands, and requires consistent funding to develop work focussed on ‘emerging species’.

Constraints on funding mean that data collection to support the development of the model MOSES-GB will have to be funded from another source.

Work Area 2.2 - Plant Production

Aims:

There are two main aims of this work area: firstly, to predict the impact of climate change on natural regeneration and assess potential risks associated with assisted migration of provenances; and, secondly, to provide technical information on processing and pre-treating seeds of alternative species associated with diversification of forests.

Methods:

1. To use a thermal time approach to predict the impact of climate change on regeneration. This involves using germination data from laboratory experiments and then developing thermal time models for tree species. This thermal time approach provides a means of :-
 - a. Assessing the influence of the so-called maternal effect on regeneration.

⁵ Timmis, T. (1994) Bradford Plan Continuous Cover Forestry: Development, History and Status Quo. *Quarterly Journal of Forestry*, 88(3):188-198.

⁶ Mason, W.L. and Connolly, T. 2014 Mixtures with spruce species can be more productive than monocultures: evidence from the Gisburn experiment in Britain. *Forestry*, 87: 209-217.

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- b. Predicting whether germination and shoot emergence remain synchronised with the seasons.
 - c. Understanding the impact of climate change, for instance, warmer, shorter and wetter winters on dormancy breakage and subsequent germination.
2. To test, develop and scale-up processes from laboratory to nursery to improve the cost effectiveness and efficiency of plant production by:
 - a. testing seed lot quality using a range of techniques including x-ray to determine the proportion of filled, empty and critically insect-infested seeds;
 - b. processing seed lots using techniques such as imbibition-drying-separation (IDS) that improve germination capacity by removing dead and empty seeds;
 - c. eradicating potential pathogens such as *Chalara fraxineus* using hot-water treatments etc.;
 - d. stratifying seeds to break dormancy promote prompt germination; and
 - e. storing seeds particularly recalcitrant seeds such as oak.

Different species present specific challenges, and therefore, technical information and technology transfer is critical for the successful nursery production of alternative species associated with the diversification of forests. Distillation and dissemination of relevant past research and experience (including, for example, FC Bulletin 83, FC Bulletin 111 and experience in propagation gained from Arboreta) is an important part of meeting customers' needs for plant production methods. We have already improved access to information on seed pre-treatment for dormancy breakage by creating a popular web-based search facility. However, recent nursery experiences have shown there are significant issues with seed quality, dormancy breakage regimes, and nursery techniques using modern methods that are limiting economic production of high quality planting stock of some alternative species.

Impact:

The outputs from this work area will underpin the expertise required to deliver sustainable management as outlined in the UK Forest Standard and the UKWAS. It will also help deliver Forestry Commission England policy of increasing the ecological resilience of woodlands and forests, Forestry Commission Scotland policy of encouraging the production of high quality timber and diversifying planted woodlands, and Welsh Government forestry policy of ensuring more woodlands and trees are managed sustainably (to UKWAS standards).

NB. This work area is of fundamental importance to the practical implementation of resilience and is fully integrated with the silvicultural aspects of work package 3 'Species and Resilient Forests'. The work area has the expertise to consider plant production of all tree species but requires consistent funding to develop work focussed on 'emerging species', and increased funding to address nursery practice. With the funding of £105K, it will be possible to establish collaborative projects with the private and public nursery sector on the propagation of cell grown and bare root stock of emerging species.

Work Area 2.3 - Regeneration and stand tending

Aims:

The main aim of this work area is to develop improved methods of regeneration that will be more resilient to abiotic and biotic threats, whilst maintaining productivity.

Methods:

This work area will focus on the creation of forests, the regeneration of woodlands and the early phase of silviculture that is crucial to the survival and growth of young trees.

There is a significant lack of knowledge about how to establish many of the emerging species that are of increasing interest for diversifying forests in Britain, which is why this issue has been identified as a key research priority for Forestry Commission England and the Welsh Government, rated as the top priority for research by forest managers working in Forestry Commission Scotland, and a top 10 priority for forest managers in Forestry Commission England and Natural Resources Wales. The research that will be undertaken in this work area is therefore critical to the successful deployment of emerging species, but progress will be constrained by the relatively low level of funding, although the recent proposal to increase funding by £30K over 14/15 levels (to £70K) for this essential silvicultural underpinning will help.

Over a four year period, research will be undertaken on:-

- Use of low cost, robust nurse species to increase early resilience (an internal review of previous nursing experiments via close liaison with work area 2.4 will be a first step).
- Enrichment of nurse species/low quality regeneration, for resilience and improved quality broadleaves.
- The use of direct seeding for low cost, high quality conversion of low productivity conifers to native species, and for riparian woodland creation.

Impact:

The outputs from this work package will underpin the expertise required to deliver sustainable management throughout the private and public forestry sector as outlined in the UK Forest Standard and the UKWAS. It will also help deliver Forestry Commission England policy of increasing the ecological resilience of woodlands and forests, Forestry Commission Scotland policy of encouraging the production of high quality timber and diversifying planted woodlands, and Welsh Government forestry policy of ensuring more woodlands and trees are managed sustainably (to UKWAS standards).

NB. This work area is of fundamental importance to the practical implementation of resilience and is fully integrated with the silvicultural aspects of work package 3 'Species and Resilient Forests', and with other elements of work package 2 including work area 2.4. Work area 2.3 considers the deployment of species in a range of silvicultural systems, including mixed species stands, and requires consistent funding to develop work focussed on 'emerging species'.

Work Area 2.4 - Long-term Experiments

Aims:

To conserve the best silviculture and genetics field experiments as a strategic resource that can be re-examined to address emerging and future questions about sustainable forest management. To promote the experiment holding and improve accessibility, enabling multidisciplinary and collaborative research groups to utilise the resource.

Methods:

A recent comprehensive review has resulted in a refined and well-documented long-term experiment holding with a broad geographical coverage of topics and species. Ongoing management of the experiment holding will ensure protection of these, allowing flexibility to rapidly address both the known and unknown research priorities of the future. This will be achieved by:

1. Mapping the experiments on the GIS layer and sub-compartment database, facilitating liaison with local managers over planning, thinning and felling, including those on private land.

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2. A regular cycle of field inspections and maintenance to monitor and conserve the resource, reviewing content to retain flexibility and coverage.
 3. Release of a new searchable experiment database providing a resource for other research groups that can be accessed to aid development of funding bids and collaborative projects.
 4. Ongoing contribution to the NoltFox network promoting and disseminating information on the experiment holding to an international research audience.
 5. A proactive advertising campaign to raise the profile of the project, identifying potential partners and enabling access to new funding streams.
 6. Funding will be sought for 'flagship' series of experiments, enabling collation and analysis of existing and new datasets on these high priority subjects.

Impact:

Many of the long-term experiments were established several decades ago and are well placed to provide answers to some of the key research questions now affecting British forestry. There are a large number of species and provenance trials containing material of known geographical and genetic origin, and situated in a range of climatic conditions around Britain. Existing data and further monitoring of growth responses and management approaches may identify candidates that could be used to adapt our forests and make them more resilient to climate change. In addition, monitoring of stands of known genetic origin could help us to identify potential individuals or provenances that are resistant to damaging pests and diseases such as Chalara, Phytophthora and Dothistroma. The resource is also well placed to provide data on how different management practices affect long-term carbon sequestration, including soil carbon.

Work Area 2.5 - Demonstrating Adaptation

Aim:

To develop forest-scale climate change adaptation demonstrations in order to provide real-world examples of where forest adaptive management and planning can help reduce the impact of changing climate conditions and improve resilience.

Methods:

Previous climate change adaptation work has demonstrated the benefits of real demonstration to explore, promote and stimulate adaptation actions, and these adaptation actions should improve resilience. In UK forestry, the work at Queen Elizabeth Forest Park (Aberfoyle) to make it one of Scotland's Climate Ready Forest Network is a good example. The main task (A) in this area is to establish further similar demonstration forests and sites, in other example areas, with contrasting climates, forest types and objectives. In particular, we want to establish one in south east England (e.g. Alice Holt Research Forest), where climate change pressures are arguably larger. Subsequent work (2016/17 onwards) may also examine Dyfi Catchment or another area in Wales, depending on progress in developing other research in these locations (e.g. within programme 3 and work area 1.1). Key to the task is working with and supporting local forest planners to explore and assess other options for the future, and using planning modelling tools developed in previous work (e.g. MOTIVE and those in work area 1.1). However, by picking contrasting forest examples, there will be new aspects to understand and develop. It will also seek to apply information from elsewhere in this work package and programme. This planning will also take information from programme 1 and 2 on abiotic and biotic threats; which will also be used to extend the work at Queen Elizabeth Forest Park, to complement continuing work funded by ClimateXChange. For example, a south east England forest will need a more in-depth assessment of future wildfire risk than Queen Elizabeth Forest Park, and could also form a case study for the wildfire risk assessed in programme 1. An important new component will be the need to bear in mind the wider resilience question, and the information emerging within the rest of this programme not simply addressing climate change. Other tasks within this work area will be (B) working with sector partners on promoting climate change adaptation (but linking with

research elsewhere on other aspects of resilience); (C) work to update and expand the Silvifuture database of novel species stands; (D) work with ICF, ConFor, MyForest and other public actors on adaptation workshops and knowledge exchange, including determining what adaptation actions are being undertaken; (E) promoting the need for contingency planning for risks, as required under UK Forest Standard, (linking to programme 1 on risk assessment); (F) supporting and advising the wider FC and Government departments on forestry climate change adaptation policy-related issues.

Impact:

The key expected impacts are:

- a) Stimulating adaptation planning across the private and public forest estate.
- b) Expansion and application of forest climate change adaptation work from the Scottish example to others across GB.
- c) Underpinning FC England adaptation action reporting for DEFRA.
- d) Promoting adaptation measures and actions in all the countries, and supporting the requirements of their Climate Change Acts for effective National Adaptation Plans, and resulting policy implementation.

Work Area 2.6 - Forest Reproductive Materials

Aims:

The work has two main aims:

- (1) To provide scientific support and advice to CFS, private and public sector forest managers, commercial suppliers and members of the public on Forest Reproductive Materials (FRM) implementation issues;
- (2) To assist the Forestry Commission FRM Officer to arrange field inspection of proposed and existing stands on the National FRM register which are located in both private and public sector forests, and to deliver training courses when required to FR staff involved in FRM inspections.

Methods:

The Forest Reproductive Material (Great Britain) Regulations 2002 regulate the marketing of FRM. These Regulations came into force on 1st January 2003 and implement EC Directive 1999/105. The Forestry Commission is the Official Body that is responsible for the FRM Regulations in England, Scotland and Wales. FRM regulations provide a system of labelling and control in the production and marketing of planting stock used for forestry purposes and the FC is the official body responsible for their implementation in GB.

This work area makes a major contribution to the implementation of these regulations and to the understanding and acceptance of their functioning in the wider forestry community. There are currently major changes to the FRM rules being debated at EU level with the objective of devising a common set of rules for forest and agricultural crops. Implementation of any resulting change would require sound scientific support. The majority of the work is responsive to need as opposed to planned in advance, as it is a support service rather than research.

Impact:

The FRM regulations are a statutory requirement which FC must implement appropriately. With planned woodland expansion it is important to ensure that the correct planting stock is used and is traceable. Implementation of the regulations without a firm scientific framework could lead to the use of inappropriate planting stock and a failure to fulfil forestry policy objectives.

Work Area 2.7 - Human Dimensions of Forest Management Practices

Aims:

To understand how the human dimensions of forest management practices deliver, or constrain, resilience.

Methods:

The core of this work area is to understand how private sector forest managers are achieving and seeking to achieve resilience in their forests. It will focus on describing and understanding the principles and practices drawn on by forest managers when making decisions. Fundamental social science will analyse established forestry behaviours, social practices, attitudes and preferences so as to improve knowledge of how resilience is being delivered, or constrained. It will utilise relevant case-studies (selected in consultation with other Work Area leaders) to identify, unpick and describe current forestry practices and link them to resilience. This research will be disseminated via a FC Research Note summarising private sector approaches to resilient forestry.

There are many management approaches to forestry, and it is important to recognise that many forest managers are already delivering, or seeking to deliver, to forest policy objectives such as resilience. Not all forest managers need to change what they are doing. Existing practices and approaches that deliver resilience are of research interest because they both provide illustrations of how resilience is possible in 'real' forestry contexts, and they can provide examples of good practice that may spread (or be spread by governmental intervention and demonstration). The 'fit' (or lack of) between forest manager's pre-set objectives and forest policy goals is a commonly identified factor in determining outcomes. This research will inform FC engagement with private sector forest owners. It will identify cases where tensions between private objectives and public policy have been negotiated successfully and silvicultural solutions found, hence providing examples for future guidance. Essentially what are these managers doing, and why? This work area will deliver demonstration events with the objective of disseminating resilience practices between private sector owners. These will complement demonstration activities under taken in work area 5.

We will focus on core contemporary areas of forest policy interest such as flood alleviation, CCF, engagement with woodfuel markets, conservation management and pest and disease management.

There are substantive links within this programme between this work area and work area 2.8 Governance Structures and work area 2.5, and links to work areas within programme 4.

Impact:

The research aims to provide evidence, including demonstration sites, showing how resilience is being achieved by private sector forest owners.

Work Area 2.8 - Governance structures

Aims:

To identify and describe different governance structures and processes (i.e. collaborative and cooperative interventions, networks) at different scale levels that support and encourage the delivery of resilient forest management.

Methods:

Work area 2.8 will extend the analysis begun in work area 2.7 "Human dimensions". Whereas work area 2.7 will identify, document and describe what private and public sector landowners do and what influences their forest management activities, work area 2.8 will investigate land

manager decision making and behaviour within the wider context of the institutional arrangements and organisations that have an important influence on initiatives and actions that support resilient silviculture and forest management. Over a four year period, research will:

- **Consolidate the current state of knowledge.** A consolidating review will establish what is already known, articulate contemporary research questions and consequently identify where new research efforts should concentrate. The review could be produced as an internal report, an FR Research Note, or other form of output depending on discussions with FC/NRW colleagues
- **Identify how and why** particular governance structures and processes are successful and where particular process vulnerabilities and risks lie. This work would lead in from the review and would include interviews with a range of stakeholders involved in different initiatives and processes related to specific silvicultural and forest management issues. We would also expect to include urban forestry collaborations and networks. We would expect to involve stakeholders in workshop-based discussions to validate our findings and co-produce the analysis so that private and public perspectives are fully represented.
- **Understand the links between policy and industry** to elaborate more fully the strategic lead, costs and barriers associated with different governance arrangements. This would be achieved through interviews with a range of FC and industry contacts.
- **Synthesise the evidence** to illustrate impacts and outcomes of different governance arrangements, and to describe the “best-bet” or “good practice” examples models and processes in the form of **practical tools that private and public forest managers can use to enhance or enable** their engagement in activities delivering forest resilience. We would expect to involve stakeholders in workshop-based discussions to co-produce this output in a form best suited to private and public sector needs.

To ensure relevance and interdisciplinary integration we would expect the specific issues and examples we investigate to be selected in discussion with other work area leaders. There is a forwards link to Programme 4 work package 2 as well as the societal limitations to governance explored in programme 3 work area 4.4 “Attitudes to pest management”.

Impact:

The outputs from this work area will produce guidance that enables forest managers (public and private) to better engage in governance processes and activities that support resilient forest management.

WP Title: WP3. Species and Resilient Forests

Indicative costs (£k):

Work area	2015-16	2016-17	2017-18	2018-19
3.1 Emerging Species ⁷	220	220	220	220
3.2 Provenance of introduced species ⁸	30	30	30	30
3.3 - Resistance breeding (living ash) ⁹	50	50	50	25
3.3 - Resistance breeding (LWEC) ¹⁰	11 ¹¹	11	0	0
Total for work package	311	311	300	275

Key research challenge

2.1 What are the properties of trees we are likely to grow for increased resilience?

This work package also addresses the additional elements of the research specification listed below.

Research specification	Element met
Research Brief	<p>1.4 Knowledge and understating of how the silvicultural characteristics of different forest tree species will be essential to understanding how they affect the ecosystem services of soils and water</p> <p>2.1-2.2 This work area is producing the science and understanding that underpins increasing knowledge of alternative forest tree species and deployment in mixed species stands. Essential to this work is the maintenance of a large number of species experiments and a new generation of experiments that were established under the REINFFORCE project. In addition, we currently have a programme of reassessing a number of experiments (from long-term experiments, see below) that are providing invaluable information on the seed origins of a wide range of alternative forest tree species.</p> <p>2.4 New information on growth and yield of emerging species needs to be passed to the ESC team to ensure that it currently holds the best information that we have. The knowledge available in the work area will be important to developing practical advice to support changes in operational practices including species selection and management.</p> <p>3.2 Knowledge of emerging species will be a key part of creating an evidence base to inform future strategies to build a resilient woodland resource.</p> <p>4.4 Information from this work area is key to recommendations for how to make woods more resilient, in terms of species, strains, and silviculture to draw upon to replant affected woods and continue the expansion for both conifer and broadleaf woodland</p>

⁷ Please note that in this current proposal only £40K of this work is funded, and unless a method of funding the balance of £180K of this work can be identified, activity in this area over the life of the programme will be strictly limited to maintenance of 8 existing species trials, and no assessments, analysis or any other form of scientific activity, advice or knowledge exchange will take place. We are exploring ways of finding additional funding.

⁸ A minimum of £30K is required for this work area but has yet to be found. Please note that in this current proposal this work is not funded, and unless a method of funding this work can be identified, no activity in this area will take place over the life of the programme.

⁹ CFS have agreed 50% funding for this work; the other 50% is from Defra.

¹⁰ A third strand of this work 'ash screening trials' is 100% Defra funded (£95K a year for three years) and is not included below.

¹¹ CFS have agreed 20% funding for this work; the other 80% is from BBSRC.

<p>Science and Innovation Strategy</p>	<p>Outcome 1. 'learning how to manage forests at multiple scales to ensure that they are more resilient to tree health threats, through management practices and tree breeding approaches to identify a wider variety of 'future-proofed' tree species and understand their silviculture including establishment requirements, production cycle and timber qualities.'</p> <p>'Evaluating approaches to woodland adaptation and increasing resilience, focusing on the composition (species, origin, diversity and stability of ecological communities) and management systems (silviculture and regeneration systems) that effectively address climate change concerns.'</p> <p>Outcome 3. 'Supporting the forest industry with research to optimise timber growth, recovery and use. This will be delivered through the maintenance of a network of permanent sample plots, and by adopting a sustainable multi-benefit forest management approach, which will investigate the potential for alternative silvicultural systems, regeneration and novel tree species.'</p>
<p>Key country research questions</p>	<p>FC England What species should we be planting to produce resilient woodlands and what are their requirements?</p> <p>FC Scotland How will the structure and species composition of our forests need to change to maximise the benefits, be resilient to climate change / pests & disease etc., and integrate more closely with other land uses</p> <p>WG/NRW What species should we be planting to produce resilient woodlands and what are their requirements??</p>
<p>Forest Enterprise priority</p>	<p>FE Scotland Alternative Species Silviculture: Review how land managers will achieve species diversification, with a particular focus on nursery and establishment practices of appropriate mixtures that will move us towards increasingly resilient forests.</p> <p>FE England What are the silvicultural characteristics of 'emerging species' we need to understand to ensure they can be used to adapt forests in Britain?</p> <p>NRW Species diversification Nursery production techniques – product types, growing regimes for unfamiliar species. Establishment techniques – development or modification of current practice. Prescriptions for mixtures of unfamiliar species.</p>

Work package details

The main aim of this work package is to provide practical guidance on the species and provenances we should be growing for increased forest resilience. The work package will be comprised of 3 work areas.

Work area 3.1 - Emerging Species

Aim:

To address critical information gaps on the silvicultural suitability of emerging species that might be grown for increased resilience based on information from current and new trials, tree collections, climate matching, and published literature.

Methods:

The challenges of climate change and the impacts of new pests and pathogens require consideration of planting a wider portfolio of species to enhance the resilience of forests and woodlands to projected climate change and to provide a pool of contingency species that can substitute when a favoured one becomes vulnerable to a new pest or disease. A changing climate may also provide an opportunity to grow species that were previously thought to be too 'tender' for UK conditions.

The FR Tree Species and Provenance web pages (<http://www.forestry.gov.uk/fr/treespecies>) summarise information on nearly 60 species based on a detailed and thorough appraisal of existing knowledge from silvicultural textbooks, historic bulletins, more recent publications and unpublished results from FR trials (see ¹² below for a list of the 25 main references used to compile these web pages). For each species, information is provided on:

- Their natural distribution.
- A summary of our current knowledge of their site and climatic preferences and other silvicultural characteristics.
- Brief information on our existing knowledge of suitable seed origins and provenances.

These pages are cross referenced to ESC3 and will be updated periodically as new information on growth performance, provenance choice, and pest and disease susceptibility becomes available.

¹² Main references used to compile FR tree species and provenance web pages

- Anon. (1996). Silviculture. ONF Technical Bulletin 31. Office national des forêts, Paris.
- Burns, R.M. and Honkala, B.H. (eds.) (1990). Silvics of North America: volume 1, Conifers. USDA Agriculture Handbook 654, USDA Forest Service, Washington DC.
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- Cannell, M.G.R., Grace, J., and Booth, A. (1989). Possible impacts of climatic warming on trees and forests in the United Kingdom: a review. *Forestry*, 62, 337-364.
- Donoso, C. (1995). Bosques templados de Chile y Argentina. Editorial Universitaria, Santiago de Chile.
- Evans, J. (1984). Silviculture of broadleaved woodland. *Forestry Commission Bulletin* 62, HMSO, London.
- Evans, J. (1986). A re-assessment of cold-hardy eucalypts in Great Britain. *Forestry* 59, 223-242.
- Fletcher, A.M. and Samuel, C.J.A. (2010). Selection of Douglas for seed sources for use in Britain. *Forestry Commission Bulletin* 129, Forestry Commission, Edinburgh.
- Hemery, G.E., Clark, J.R., Aldinger, E., Claessens, H., Malvolti, M.E., O'Connor, E., Raftoyannis, Y., Savill, P.S., and Brus, R. (2010). Growing scattered broadleaved tree species in Europe in a changing climate: a review of risks and opportunities. *Forestry*, 83, 65-81.
- Horgan, T., Keane, M., McCarthy, R., Lally, M., and Thompson, D. (2003). A guide to forest tree species selection and silviculture in Ireland. Coford, Dublin. 255 pp.
- Hubert, J. (2006). [Choosing provenance in broadleaved trees](#) (PDF-1620K), Forestry Commission Information Note 82, Forestry Commission, Edinburgh.
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- Lines, R. (1996). Experiments on lodgepole pine seed origins in Britain. *Forestry Commission Technical Paper* 10, Forestry Commission, Edinburgh.
- MacDonald, J., Wood, R.F., Edwards, M.V., and Aldhous, J.R. (eds.) (1957). Exotic forest trees in Great Britain. *Forestry Commission Bulletin* 30, HMSO, London.
- Morgan, A. (2008). The growth and use of redwoods. *Quarterly Journal of Forestry*, 102, 121-131.
- Pyatt, D.G., Ray, D., and Fletcher, J. (2001). An ecological site classification for Forestry in Great Britain. *Forestry Commission Bulletin* 124, Forestry Commission, Edinburgh.
- Rameau, J.C. *et al.* (1989,1993). Flore Forestière Française, Vols. I and II.
- Samuel, C.J.A. (1996). The influence of seed origin on the growth of Grand fir in Great Britain. *Forestry Commission Research Information Note* 280, Forestry Commission, Edinburgh.
- Savill, P. S. (1991) The silviculture of trees used in British forestry. CAB International, Wallingford. 143 p.
- Weissen, F. *et al.* (1991). Le fichier écologique des essences. Volume 2. Ministry of the Walloon region, Namur, Belgium.
- White, J. (1996). Potential and Established Plantation trees in Britain. Unpublished Forestry Commission Bulletin.
- Wilson, S. McG. (2011). Using alternative conifers for productive forestry in Scotland. Forestry Commission Scotland, Edinburgh.

However, currently available information on species performance that has been developed through the 20th century has a number of serious deficiencies, particularly for less mainstream species, and there is a great danger of drawing false conclusions from incomplete knowledge. For example:

- Information on many minor species of current interest in historic bulletins (e.g. Forestry Commission Bulletin 30) is often extremely limited, being little more than a mention of the species name with little information on actual suitability for the UK climate.
- Species and provenance choice was focussed on the existing rather than future climate. Correct choice of seed source will be an important part of adaptation to climate change given that trees planted in this decade may well experience the climate of latitudes two to three degrees further south by the time they reach maturity. Species and provenances once considered too tender for Britain may become suitable growing in the south.
- Species choice became standardised on a relatively few species, leaving a series of species whose potentials are under-researched. Some of these need further evaluation as candidates for diversification.
- Results based on limited trialling and anecdote often prejudiced the potential of particular species and has blighted their reputation ever since. A good example is how the recent re-evaluation of *Abies alba* provenance trials has provided a more rational evaluation of the species' potential.
- Species were often tested in even aged plots established on bare sites, whereas evaluation as a component of mixed-species and / or continuous cover silviculture is more appropriate for contemporary policy.

For this reason, it is proposed to carry out a limited programme of research to address critical information gaps on the silvicultural suitability of emerging species. Without this crucial underpinning understanding of silvicultural suitability, research on other aspects of emerging species such as for example timber properties, or likely resistance to pests and diseases, is potentially fatally undermined, as it may be based on assumptions about species that are not, in fact, suitable to grow in the UK now or in the future.

The existing level of knowledge about species-potential for forestry can be broadly grouped into three categories:

Category 1: introduced and native species currently widely planted and managed whose silvicultural characteristics are well understood.

Category 2: mainly introduced species that have either had limited use in the past ('minor species') or that have been tested (plot-stage testing) for forestry to varying extents but were never widely planted even though they have many suitable attributes. The living resource for this category exists in species trials and plots. A key issue for this group of species is identifying and recommending suitable provenances for the current and future climate.

Category 3: potential species ('lesser-known species') that have not been tested in plots, but are productive species in their native ranges and, based on performance in specimen collections, appear to be adapted to our climate. Specimen collections represent a vital first step in the study of introduced species by providing a pool of species from which candidates can be taken forward for testing in experimental and operational trials.

The objective of this work area is to increase our silvicultural knowledge of Category 2 and 3 species to enable suitable options to be available for developing future strategies to build a resilient woodland resource. Studies on conifer species will focus primarily on *Abies alba* (European silver fir), *Abies amabilis* (Pacific silver fir), *Cedrus atlantica* (Atlas cedar), *Cryptomeria japonica* (Japanese red cedar), *Cuprocyparis leylandii* (Leyland cypress), *Pinus peuce* (Macedonian pine), *Picea orientalis* (Oriental spruce), *Sequoia sempervirens* (Coast redwood), and *Sequoiadendron giganteum* (Wellingtonia), as well as more mainstream alternatives such as *Abies grandis* (grand fir), *Picea omorika* (Serbian spruce), *Thuja plicata* (western red cedar), and *Tsuga heterophylla* (western hemlock), while those on broadleaves species will include North American species such as *Acer macrophyllum* (big-leaf maple), *Carya* spp. (hickories) and *Liriodendron tulipifera* (tulip tree).

Information on species suitability will be sourced and compiled from several sources: published information; assessment of extant and new species trials, and species growing in tree collections and forest gardens; experts in native countries; and climate matching to target species in geographic regions with analogues of Britain's future climate. Information on survival and productivity will be integrated with available information on timber properties, potential invasiveness, and susceptibility to pests and diseases.

Existing experimental species and provenance trials are an important resource in this work area for determining survival and growth of potential species, and we will maintain and assess them to ensure that we obtain the maximum information. We will work with other partners in Europe, particularly focusing on the recent series of species trials set up in the Atlantic region under the REINFFORCE Interreg project which finished in 2013; we will endeavour to secure external funding to contribute to the continuity of these important trials.

We will also work collaboratively with the public forest estate in each country using their resources to support the establishment and maintenance of **operational species trials** designed to develop further the silvicultural requirements of species currently being considered for diversification. These trials have been set up without any CFS funding to date, and although there is no obligation to contribute in the future, the use of CFS match funding provides a very cost effective opportunity to potentially gain important new data about the suitability of emerging species that otherwise would not be collected or shared with the wider forestry sector.

Work so far on **lesser-known (Category 3) species** in collections has concentrated on cataloguing the existing resource and has been supported by non-CFS funding. We propose to assess and identify candidate lesser-known species for further evaluation in trials by assessing performance of species growing as specimens and in small plots in tree collections together with other information such as climate matching.

Climatic niche components (fundamental, realised and tolerance niches) will be determined for selected species using parameters derived from their native, naturalised, and cultivated ranges to provide not only measures of species suitability for current UK climates, but also for resilience in projected future climates.

Where necessary, field work using introduced species will be accompanied by an appropriate Environment Risk Assessment, biosecurity measures, and will follow the terms of the Nagoya Protocol.

Knowledge on the growth and survival of potential species will be integrated with information on provenance choice (work area 3.2), timber utilisation, potential invasiveness, and susceptibility to pests and diseases, and exchanged using FR's Species Web Pages and other publications.

Impact:

The knowledge produced in this work area will be vital to developing practical advice to support changes in operational practices including species selection and management. Knowledge of emerging species will be a key part of creating an evidence base to inform future strategies to build a resilient woodland resource. Without this crucial underpinning understanding of silvicultural suitability, research on other aspects of emerging species such as for example timber properties, or likely resistance to pests and diseases, is potentially fatally undermined, as it may be based on species that are not suitable to grow in the UK now or in the future.

NB. As mentioned above, the level of funding strictly limits the activity in this work area over the life of the programme to basic maintenance of 3 existing REINFFORCE and 5 existing CFS species trials only, and no assessments, analysis or any other form of scientific activity, advice or knowledge exchange will take place, which will significantly curtail actual impact.

Work area 3.2 – Provenance of introduced species**Aim:**

To contribute information on species performance and provenance to add to the knowledge bank of the properties of trees that might be grown for increased resilience.

Methods:

This work area is concerned with extant and historic provenance trials of several category 2 species that were established in the 20th century (see below). These important trials are providing vital information on both species performance and how this is affected by provenance. The priority is to reassess existing experiments and publish this information and access what is available from historic records. All these species are being more widely planted for diversification.

The plan is for the work in work area 3.1 and work area 3.2 to be integrated with the Timber Properties team led by Dr. Paul McLean but this requires funding to be made available to them in FC programme 5.

Summary of FR Provenance experiments:

Type of data available	Category 2 species
Open long-term experiments and historic data	<i>Picea engelmannii</i> <i>Picea sitchensis</i> x <i>P. glauca</i> (Hybrid spruce) <i>Abies alba</i> <i>Abies amabilis</i> <i>Abies nobilis</i> <i>Abies grandis</i>
Historic data only	<i>Abies concolour</i> <i>Cryptomeria japonica</i> <i>Pinus jeffreyi</i> <i>Pinus banksiana</i> <i>Pinus muricata</i> <i>Pinus ponderosa</i> <i>Pinus pinaster</i> <i>Pinus peuce</i> <i>Sequoia sempervirens</i>

Impact:

This work area will add to the knowledge bank being developed in work area 3.1, and will allow practical advice to be given to support changes in operational practices including species selection

and management. Knowledge of emerging species will be a key part of creating an evidence base to inform future strategies to build a resilient woodland resource.

NB. Activity on this work area is pending a decision on funding.

Work area 3.3 - Resistance breeding

Aim:

To identify tolerant genotypes in threatened species

Methods:

Field trials will be used to identify genotypes which show resistance to pathogens or insects of interest. Currently this relates to three legacy contracts to identify ash (*Fraxinus excelsior* L.) trees resistant to Chalara ash-dieback. The technique is typically to source putative tolerant trees, or carry out mass screening of random collections, and then plant out in replicated, statistically sound trials on areas of known infection and monitor comparative pest/pathogen development.

The link with programme 5 gives the opportunity of screening for tolerance using DNA-markers once techniques have been developed for the model species Sitka spruce.

Impact:

Potentially high impact as the work will provide the opportunity to consider continued planting of ash in plantations and also the natural environment. In the absence of such work, alternative less desirable or profitable species will have to be planted, and there will be no opportunity to increase the frequency of resistant genes amongst native woodlands.

WP Title: WP4. Integrated weed, pest and disease management

Indicative costs (£k):

Work area	2015-16	2016-17	2017-18	2018-19
4.1 Pesticides and forest vegetation management	150	150	150	150
4.2 Fungicides and non-chemical disease management	100	100	100	100
4.3 Squirrel control	50	50	50	50
4.4 Public attitudes to pest management	25	25	25	25
4.5 Integrated <i>Hylobius abietis</i> management and control	30	30	30	30
Total for work package	355	355	355	355

Key research challenge

4.4 Impacts of pests and diseases on the retention and creation of woodlands and forests.

This work package also addresses the additional elements of the research specification listed below.

Research specification	Element met
Research Brief	Research challenge 4.4 Impacts of pests and diseases on the retention and creation of woodlands and forests. Herbicide tolerance is also a key element of research challenge 2.1 What are the properties of trees which we are likely to grow for increased resilience; what is the likely impact on sector productivity of a switch to alternative species?
Science and Innovation Strategy	Specific evidence requirement of Science and Innovation Strategy Outcome 1 - An evidence base for the delivery of healthy and resilient forest and wider ecosystems to enhance benefits for society.
Key country research questions	Contributes to:- What species should we be planting, and what are their requirements (FCE, WG/NRW)?
Forest Enterprise priority	Identified as the number 1 research priority for FE Scotland; Top 10 research priority for FE England; Top 10 research priority for Natural Resources Wales.

Work package details

The main aim of this multidisciplinary work package is to develop practical control measures for damaging pests, diseases and weeds, including the use of pesticides. It will integrate the work of silviculturists, entomologists, pathologists, ecologists and social scientists through the production of updated guidance on how to manage all the major weed, pest and disease problems in UK forestry, in particular those that may have a chemical control options, which will take into account public attitudes to alternative control measures.

The outputs from this work package will underpin the expertise required to deliver sustainable management and the protection of the forest resource against biotic threats across the UK as outlined in the UK Forest Standard and the UK Woodland Assurance Standard, and also to fulfil national and international policy requirements to minimise pesticide use whilst maintaining pesticides as a strategic tool for managing pests, weeds and diseases in British forests. It will help deliver Forestry Commission England, Forestry Commission Scotland and Welsh Government forestry policies that all include aims of reducing the impact of invasive pest species and

diversifying forests to improve future resilience. The work package will be comprised of five work areas.

Work area 4.1 - Pesticides and forest vegetation management

Aim:

The main aim of this work area is to maintain the availability of pesticides as practical control measures for dealing with invasive pests, diseases and weeds, and to develop integrated methods of managing invasive vegetation.

Methods:

New pesticides regulations, new certification requirements, the need to reduce pesticide inputs and identify non chemical alternatives, and the evolution of new biosecurity threats that may be exacerbated by climate change all threaten the future availability of current pesticide control options. Invasive vegetation can cause potentially catastrophic losses to young trees from drought and competition, and significantly reduce long term productivity, resilience and biodiversity. Changes in the climate, new invasive weed species, pressures to reduce pesticide use and the need to reduce costs threaten the ability of managers to practice successful vegetation management.

These challenges will be addressed by providing provide specialist advice and expert support on likely implications for different policy options to the UK private and public sector forest industry, carrying out research on alternative pesticides, methods and non-chemical approaches to address the critical evidence gaps arising from the implementation of these new requirements, and to develop methods of control for existing or potential weed species where current control options are inadequate or being lost due to changes in management and herbicide availability.

Over a four year period, research will be undertaken on :-

- Alternatives to asulox (given its potential loss) for selective bracken control.
- Pesticide tolerance of emerging tree species, including those grown under alternative silvicultural systems such as under planting.
- Woody weed and selective bramble control, given the loss of the brushwood killer triclopyr.
- Ragwort control, given the loss of 2,4-D, which means there is currently no effective selective control method within grassland areas on FSC certified estates, which is a growing concern for land managers given that ragwort control can be enforced under Weeds Act.
- Buddleia control. Buddleia is an introduced species well matched to the UK climate, and in other countries with similar climates (e.g. New Zealand) it is a major invasive weed in forest situations. Although not currently a problem in UK forests, it is spreading rapidly on waste ground and railway lines, hence it is timely to develop effective control measures for forestry situations in case a control programme needs to be initiated at short notice to prevent a much more extensive problem in later years.

Results of this research and new legislative / certification requirements will be disseminated through a update to the widely respected Forestry Commission Practice Guide 15 / Field Book 8.

In addition, over the 4 year period, the following work is anticipated as likely to be directly funded by Forest Enterprise Scotland, Forest Enterprise England and NRW:-

- Alternatives to propyzamide.
- Gaultheria control.

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- Ecoplug and other chemical and non-chemical techniques for killing standing conifers, including Phytophthora infected larch.

However, as only the basic experimental set up and assessment work is funded directly by the countries, and there is no funding to disseminate any results and practical implications to the wider forestry sector, additional CFS match funding will be used to carry out more intensive assessments, analyse data, and crucially to produce scientific papers freely available under the open access model and provide practical guidance to the wider forestry sector.

Impact:

This work area will help managers deliver sustainable management and the protection of the forest resource against biotic threats across the UK as outlined in the UK Forest Standard and the UK Woodland Assurance Standard, and also to fulfil national and international policy requirements to minimise pesticide use whilst maintaining pesticides as a strategic tool for managing pest, weeds and disease in British forests. It will help deliver Forestry Commission England, Forestry Commission Scotland and Welsh Government forestry policies that all include aims of reducing the impact of invasive pest species and diversifying forests to improve future resilience.

Work area 4.2 - Fungicides and non-chemical disease management

Aim:

The aim of this work is to develop a range of practical, evidence-based management options for use in controlling significant pathogens of commercial conifer crops and native pines in Scotland, namely *Dothistroma* needle blight (DNB, caused by *Dothistroma septosporum* and *D. pini*) and Heterobasidion root and butt rot (caused by *Heterobasidion annosum*, formerly *Fomes annosus*).

Methods:

DNB has had a catastrophic impact on Corsican pine in the past 15 years, and its impact on lodgepole pine has become increasingly severe in the past 10 years. The distribution of DNB on Scots pine in England and Scotland, including the native pinewoods, is also now known to be extensive. Thus with increasing levels of DNB within all 3 of Great Britain's pine crops there is an urgent need for a suite of management options including, within work area 4.2, control using a range of fungicides and application techniques.

H. annosum is another damaging pathogen which can be responsible for chronic, persistent (rotation upon rotation) increases in mortality and decay within a number of conifer crops, especially pines and spruces. Prophylactic biological and chemical stump treatment products exist but the use of the biological product is currently restricted to pine species only. Previous experimentation indicates there is strong potential to extend its use to Sitka spruce if changes in the formulation are investigated. It is an ongoing challenge to maintain licenses for both stump treatment products (currently both held within FC, and jointly with Omex Agriculture Ltd.) as the actives, and actual products, are undergoing review within the EU and at a country level. This work area will address ongoing fungicide registration issues, and the team will provide specialist advice and expert support to ensure all fungicide-related studies within work area 4.2 are conducted in line with the regularly changing pesticide regulations and certification requirements.

For both diseases this work area aims to explore biological products, thus aiming to reduce dependency on chemicals where possible, and minimise environmental impacts. Along with work area 6.3, the aim will be to develop integrated methods to manage infection within forests.

Over a four year period, research will be undertaken on

- Aerial spraying of fungicides against DNB (a proportion of this work will have to be funded from elsewhere e.g. by Forestry Commission Scotland if it is to go ahead).
- Ground-based fungicide trials (including non-chemical products) used against DNB (growth chamber and field).
- Cost / benefit analysis of DNB control options, which will involve economists from programme 4 and form a cross programme case study.
- Re-registration issues associated with 2 products used against *Heterobasidion annosum*.
- PG Suspension formulation improvements to improve efficacy on Sitka.
- Impact of *Heterobasidion annosum* on chemically thinned larch. This research is funded by Forestry Commission Scotland, but CFS funding will be to produce a paper to disseminate the results and management implications for the wider forest industry.

Results of this research and new product registration requirements will be disseminated through a update to the widely respected Forestry Commission Practice Guide 15 / Field Book 8.

Impact:

This work area will help managers deliver the sustainable management and the protection of the forest resource against biotic threats across the UK as outlined in the UK Forest Standard and the UK Woodland Assurance Standard. It will also help deliver Forestry Commission England, Forestry Commission Scotland and Welsh Government forestry policies that all include aims of reducing the impact of invasive pest species.

Work area 4.3 - Grey Squirrel Control

Aim:

The main aim of this work is to develop effective, practical and economic options for grey squirrel control.

Methods:

Grey Squirrels are a non-native species and are responsible for causing economic damage to woodlands by bark stripping trees in Britain. Further, they have gradually displaced the native red squirrel from most of England Wales, and south Scotland through direct competition as well as transmitting fatal diseases (Squirrel Pox Virus and Adenovirus). Squirrels have no effective natural predators in Britain. Warfarin has been used to control grey squirrels but approval is being withdrawn by the European Union Plant Protection Directive for welfare reasons. Squirrels cause damage to a wide range of tree species, however the most commonly affected include beech, sycamore and oak. The recent outbreak of Chalara now threatens the suitability of ash, which has hitherto been regarded as the only valuable forest species that has a low susceptibility to squirrel damage. As a result, there is a pressing need to develop new approaches for managing Grey Squirrel populations. For squirrels, control methods need to be humane and be regarded as acceptable to the wider public. It is also important that they have little or no impact on non-target species that may be present in the area.

Current options

1. Test new trapping technologies, when these become available. One such option is to assess the suitability of CO₂ powered traps, currently available for use on possums in New Zealand.
2. Assess the effectiveness of control by attracting squirrels to bait followed by control operations using air rifles. This approach is being viewed as potentially more acceptable in woodlands open to public access.
3. Investigate the impact of pine marten expansion and re-introduction on grey squirrels. Pine Martens have apparently caused the decline of Grey Squirrels in Ireland and are

continuing to spread in mainland GB. An awareness of the impact of pine martens would help to inform and support an appropriate control strategy.

The work area will benefit from inter-disciplinary work being undertaken in work areas 4.1. (seeking approval for pesticide use) and 4.4 (public attitudes to pest management).

Impact:

This work area will help managers deliver the sustainable management and the protection of the forest resource against biotic threats across the UK as outlined in the UK Forest Standard and the UK Woodland Assurance Standard. It will also help deliver Forestry Commission England, Forestry Commission Scotland and Welsh Government forestry policies that all include aims of reducing the impact of invasive pest species.

Work area 4.4 - Attitudes to Pest Management

Aim:

The main aim of this work is to improve knowledge of stakeholder attitudes towards pest and disease management methods, and understand how these vary so as to provide evidence-based, targeted advice to managers on the most appropriate pest management approaches to adopt in particular situations to improve woodland resilience.

Methods:

Positive and negative assessments (attitudes) of forest management methods affect decision-making in a number of ways. Not only do they constitute an integral element of forest planning – formalised through stakeholder analysis and consultation processes – but presumptions about attitudes held by others also affect decisions to use specific methods. For example, widespread assumptions of public opposition to deer culling reduce manager’s willingness to take that action. Research has begun to show that support for specific management methods is often, however, contingent on the circumstances in which they used. Building upon prior research that has established broad patterns of stakeholder attitudes towards the methods used for wildlife and pest and disease management, this work area will develop more detailed and targeted knowledge regarding how the acceptability of specific management methods varies in relation to woodland type and stakeholder group. For example, which methods are acceptable in native woodlands of high conservation value? And, from which types of stakeholder does opposition to specific methods come?

These questions will be answered via a programme of desk-based (literature review) research and fieldwork. Although small-scale opposition to pest management can originate from individuals, substantive opposition tends to come from organised social groups such as non-governmental organisations, community groups, and policy-makers with contrasting objectives. Fieldwork in this work area will consist of qualitative research (primarily a substantial series of semi-structured interviews) with these groups – at various scales of operation, from local to national. We will begin research by conducting a review of the literature pertaining to attitudes towards management methods (expanding prior research focused on tree health) examining the variation between stakeholder groups and woodland settings. This will be disseminated via an FC publication (Information Note or Research Report), and a peer-review paper. Fieldwork will begin early in the four-year programme, following sampling strategy design and the consideration of the potential for using species case-studies (e.g. deer (especially muntjac), oak processionary moth, rabbits, rhododendron, capercaillie, grey squirrel) as a focus for the work, and continue throughout. The results of this fieldwork will be reported via a peer-review paper. We expect to conduct additional research in this area funded by external partners, especially in relation to grey squirrels, deer, pathogens and invertebrate pests.

Impact:

The outputs from this work area will underpin the provision of advice and will enable forest managers (public and private) to make more informed choices, based in part on an understanding of which management methods are more likely to be acceptable in their particular woodlands. This should provide a basis for the wider adoption of methods to reduce pest pressure and thus improve the resilience of British forests.

Work area 4.5 - Integrated *Hylobius abietis* management**Aim:**

The main aim of this work is to develop practical alternatives to the use of insecticides for the management of *Hylobius abietis*.

Methods:

The large pine weevil, *Hylobius abietis*, is a serious pest of small trees used to restock felled coniferous forest areas. The beetle is only a pest due to efficient mechanised large-scale patch clear fell regimes typical of modern forestry practices. These regimes produce stumps, its breeding resource, that are abundant and easily located due to large volume release of plant volatiles and this leads to very large populations and high levels of damage. The population dynamics of *Hylobius* from felling to 5 years post felling are well known and the population size/tree damage relationships established and these form the basis of a web-based decision support system known as the *Hylobius* Management Support System (HMSS). This system has been used as a tool to help forest practitioners to restock after felling but despite this many foresters still rely heavily on the use of insecticides to restock felled areas. This is due to a restricted range of options available to the user, in real terms (and within the HMSS), to reduce damage other than by using insecticides. In addition, the feedback from users suggests that some are very confident with the system but others lack confidence in the outputs and it is not clear if this is due to poor practice when adopting the system or incorrect predictions by the HMSS as damage surveys have not been undertaken to verify predicted outputs with observed damage.

This work area represents underpinning match funding to support research funded by Forest Enterprise Scotland, Forest Enterprise England, and Natural Resources Wales (currently £75K per year). UPM Tillhill, Scottish Woodlands and Maelor Nurseries all contribute resources in kind, and Swansea University undertakes complimentary research. It is hoped that all of these private sector organisations, along with the Northern Ireland Forest service, may contribute additional funding towards developing this research further.

The approach taken will be to focus on developing practical field methods to manipulate weevil movement/migration behaviour at the local clear fell and forest landscape scales as well as controlling weevil populations by innovative, non-chemical techniques. These practical approaches will also be tested in combination to evaluate synergistic/compound effects to increase control and economic effectiveness.

Over the four year period the following work is planned, subject to the level of direct funding secured from the countries and the wider forest industry:-

- Scientific papers on insecticide trials, *Hylobius* Population Dynamics and Forest Spatial Dispersal to make the results and conclusions from country funded research available to the wider forest sector.
- Investigating and quantifying the effectiveness of various operational management practices at reducing *Hylobius* damage.
- Improving HMSS models and functionality.
- Movement and Behavioural Manipulation of *Hylobius* for population/damage control.

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- Chemical studies on semiochemicals to isolate *Hylobius* attraction/aggregation pheromones and allelochemicals (released from damaged stumps, trees and billets) that could be used to modify and manipulate *Hylobius*' behaviour.
 - Manipulation of felling to concentrate populations of *Hylobius* into small areas for bio-control.
 - Developing strategies to reduce migration between emergent and breeding clearfells.
 - Developing field mass-trapping methods and strategies to reduce *Hylobius* populations/damage.
 - Advice and knowledge exchange.

Within work area 4.5, the following will be funded by the Forestry Commission (CFS):-

- Scientific paper on insecticide experiments, 2010-2014.
- Scientific paper on *Hylobius* population dynamics.
- Scientific paper on the spatial dispersal of *Hylobius* in the managed forest environment.
- FC practice note on *Hylobius* life cycle and management in forestry.
- Training, advice and guidance to the wider forest sector.
- Seed (part) funding for improving HMSS models and functionality.

Results from this research will also feed into the updated FC practice guides(s) on integrated pest, weed and disease management (see work area 4.1).

Impact:

This work area will help managers deliver the sustainable management and the protection of the forest resource against biotic threats across the UK as outlined in the UK Forest Standard and the UK Woodland Assurance Standard. It will also help deliver Forestry Commission England, Forestry Commission Scotland and Welsh Government forestry policies that all include aims of reducing the impact of invasive pest species.

WP Title: WP5. Resilient urban forests

Indicative costs (£k):

Work area	2015-16	2016-17	2017-18	2018-19
5.1 Choosing tree species for a resilient urban forest	85	85	97	115
5.2 Urban forest creation	31	31	17	20
Total for work package	116	116	114	135

Key research challenge

2.1 What are the properties of trees we are likely to grow for increased resilience?

This work package also addresses the additional elements of the research specification listed below.

Research specification	Element met
Research Brief	<ul style="list-style-type: none">RC 1.4 Maintaining ecosystem services and biodiversity whilst achieving resilienceRC 2.2 How do we design, cultivate and manage adaptive, resilient woodlands?
Science and Innovation Strategy	<ul style="list-style-type: none">SIS Evidence Requirement 1.3 Evaluating approaches to woodland adaptation and increasing resilience, focusing on compositions and management systemsSIS Evidence Requirement 2.4 Developing multidisciplinary tools to help managers identify and evaluate those new woodland sites that may offer the best potential to deliver the most ecologically efficient basket of ecosystem services
Key country research questions	<ul style="list-style-type: none">What species should we be planting to produce resilient woodlands and what are their requirements?What is the role of Urban Forestry and Green Infrastructure in creating a woodland culture?

Work package details

The main aim of this multidisciplinary work package is to provide the knowledge and practical advice for the creation and delivery of resilient urban forests.

The contribution of work package 5 to Programme 3 centres on the resilience of the 'urban forest', which may be defined as 'the ecosystem of trees and associated vegetation and animals in the urban environment'. The term urban forest therefore encapsulates street trees as well as the trees in gardens, woods and other greenspaces that make up the wider green infrastructure of a town or city. Work package 5 will be coordinated by members of the Land Regeneration and Urban Greenspace team (LRUG).

Integrating the work of urban foresters, silviculturists, mathematicians and the land regeneration sector, outputs will be produced that will consider suitability of tree species to urban environments, as well as their appropriateness and potential to deliver those ecosystem services that are highly desired in towns and cities. Multidisciplinary delivery of the work package as well as mixed authorship will ensure high impact literary outputs and web-tools for use by academic, professional and lay audiences.

Collaborations bought to the work package include those with the Universities of Reading, Surrey and Central Lancashire Reading, the Open University, AA (Arboricultural Association) and USDA's

Forest Service. Comparatively new relationships with the Universities of Birmingham and Portsmouth, the TCPA (Town and Country Planning Association), London Urban Orchards, the LTOA and MTOA (London [and Municipal] Tree Officers' Association), and the Scottish Tree Officers Group will also be progressed through this Work.

The work package comprises two discrete, though related and linked work areas.

Work area 5.1 - Choosing tree species for a resilient urban forest

Aim:

- Guide tree species choice for a resilient urban forest
- Design a tree species selection tool for guiding the delivery of resilient urban forests.
- Publish a series of evidence notes to complement the species selection tool and support the creation of resilient urban forests under a changing climate.
- Undertake quality primary research and produce publications to guide the selection of tree species suitable to urban environments according to drought tolerance.

Methods:

The main aim of this work area is to guide and scientifically inform urban foresters and associated practitioners on succession planning for a resilient and sustainable urban forest through high quality empirical and secondary research, associated literature outputs and a consolidating web-based tool. Work area 5.1 comprises three work streams.

The first work stream comprises a new and multidisciplinary task to design and deliver to proof of concept a tree species selection tool for the urban environment. The work stream will draw upon expertise from across FR on the processes of species selection and the design and construction of tools for practitioners, including from Dr Richard Jinks who has developed similar systems for mainstream forestry. The species selection tool work stream will initially focus on setting up a steering group, agree terms of reference and a development timetable. It will draw upon existing FR resources, including the Right trees for a changing climate web resource, to consolidate and develop a one-stop-shop for guiding species selection.

Work stream two will support implementation of work stream one as well as complement the new tool via the preparation of a series of evidence notes. An extensive body of literature exists that is overwhelming and time consuming for practitioners to utilise when considering alternative tree species. The Notes will consider the physico-chemical constraints to tree survival in UK urban environments, the impacts of climate change/extreme weather on urban trees, the relative importance of large and small stature trees and/or the role of different trees in urban water management and provide recommendations on those species most suited under the various conditions. Finally, work stream three investigates species tolerance to drought. Following successful trials in 2013/14, this work will lead to a deeper understanding of which tree species are most suited to droughty conditions, together with associated publications. Future work will investigate the uses of proxies, such as leaf area index, as a guide to drought tolerance and will help inform risk assessments to be carried out in Programme 1 into the susceptibility of current urban forests to extreme weather events.

Impact:

The outputs from this work will underpin the selection of tree species for urban planting according to suitability, appropriateness and potential to sustainably deliver key ecosystem services. The work area will facilitate the creation of resilient urban forests by awareness raising and enabling practitioners to make informed choices.

Work area 5.2 - Urban forest creation

Aim:

- Provide quality expertise and best practice advice to tackle the barriers to creating sustainable and resilient new urban forests.
- Undertake effective knowledge exchange and dissemination through high-profile collaborations and initiatives.
- Demonstrate the value of forestry in the wider landscape through regeneration, planning and ecosystem service delivery profiling.

Methods:

The primary focus of this work area is to deliver quality scientific knowledge in support of the practice of urban forest creation. The work will expand the range of publications and tools, and the means of accessing them in order to improve the Centre of Excellence for Land Regeneration to Greenspace and the Urban Regeneration and Greenspace Partnership. The Centre of Excellence has a longstanding record of providing quality research, public speaking, and project specific advisory that is openly used by FC staff, e.g. the Community Forests. Land regeneration and green infrastructure provision are key delivery mechanisms for many Central Government policy objectives, including improving human health and well-being, delivering sustainable land-use and protecting and enhancing biodiversity. This work should be continued in order to retain the in-house expertise and maintain FR's track record. Expansion of the Best Practice in Land Regeneration series will be achieved through web-publishing of tools for soil movement and amelioration in brownfield land regeneration. The Urban Regeneration and Greenspace Partnership is a virtual community to promote Good and Best Practice in land regeneration and urban green infrastructure creation. The Partnership is diversifying and has connected with the Green Infrastructure Partnership, led by the Town and Country Planning Association. This work area will continue to forge these relations to promote green infrastructure through collaboration and knowledge exchange.

Work area 5.2 is cross-cutting. It includes the PhD studentship on 'assessment of woodland planting on brownfield land on soil quality and provision of wider ecosystem services' (with Programme 1), and will bring together developments in Programme 1 and Programme 4 by developing a strategy to apply the i-Tree Eco model to value future ecosystem service delivery through land regeneration to woodland. Furthermore, and given that the results arising from an i-Tree Eco survey can lead to an increase in urban forest appreciation and hence management budgets, this work will seek to understand whether i-Tree Eco could prove significantly useful in securing funds for land regeneration/urban forest creation. The work will build upon embedded knowledge within the SERG and LRUG research groups on the attitudes of land managers to woodland creation. Work will focus on the perspective of three to four local authorities, likely to include Torbay, Wrexham, Glasgow or Edinburgh.

Impact:

The outputs from this work will underpin the dissemination of science and expertise required to deliver sustainable woodland and wider green-infrastructure on degraded land. Wider knowledge exchange activities will also help to raise the profile of green infrastructure and the role that it can play in delivering policy objectives for healthy communities, connecting people with nature, and socio-ecological resilience to climate change.

WP Title: WP6. Managing biotic threats

Indicative costs (£k):

Work area	2015-16	2016-17	2017-18	2018-19
6.1 Phytosanitary pest management	137	137	137	137
6.2 Advice and support for pest and disease management	273	273	273	273
6.3 Surveillance and management of Dothistroma needle blight	95	95	95	95
Total for work package	505	505	505	505

Key research challenge

4.4 Impacts of pests and diseases on the retention and creation of woodlands and forests.

This work package also addresses the additional elements of the research specification listed below.

Research specification	Element met
Research Brief	Research challenge 1.3 What are the pressures to which forests must be resilient over the next century?
Science and Innovation Strategy	Specific evidence requirement of Science and Innovation Strategy Outcome 1 - An evidence base for the delivery of healthy and resilient forest and wider ecosystems to enhance benefits for society. Evidence requires include: Horizon scanning to detect and prepare for new pests and pathogens before they arrive
Key country research questions	Contributes to:- What species should we be planting, and what are their requirements (FCE, WG/NRW)? What management techniques can be developed to reduce the risk of diseases to native species (FCE)? How does changing silvicultural practice influence host susceptibility (FCS)?
Forest Enterprise priority	Identified as the top research priority for FE Scotland; Top 10 research priority for FE England - What pests and diseases are likely to pose a threat to our forests in future and how can they be managed? Top 10 research priority for Natural Resources Wales.
Other	Plant and tree health is a major priority for all countries within the UK.

Work package details

Plant and tree health is a major priority for all countries within the UK. Trees and woodlands play a critical role in sustaining our environment and a major objective of the Forestry Commission is the delivery of healthy and resilient forests and woodlands, as described in the Forestry Commission and Defra Tree Health Management Plan.

https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/307299/pb14167-tree-health-management-plan.pdf

Trees are at risk from a wide array of damaging agents, some endemic and widely recognised, whilst others are more recently introduced with impacts that have yet to be understood. This work package will provide the practical advice for forest managers on biotic threats, based on

high quality science, which is vital to ensure healthy and resilient woodlands and forests for the future.

The work package will work with silviculturists in work package 3 to deliver updated web pages on emerging species covering susceptibility to pests and diseases, and work package 4 in delivering updated practice guides on integrated pest, weed and disease control. The work package will be comprised of three work areas.

Work area 6.1 - Phytosanitary pest management

Aim:

To identify new pests and pathogens that pose a quarantine threat to Britain's forests and trees, to evaluate scientifically the extent of the risk they pose and distil this information into practical written and verbal advice that can be used to inform policy and practitioners about the phytosanitary risks to trees in the UK (and EU).

Background and Methods:

Horizon scanning and analysis of pest risks beyond the UK forms an essential part of resilience planning for the future. The biosecurity risks posed by previously unknown as well as regulated quarantine pests¹³ are recognised globally under the WTO Sanitary and Phytosanitary (SPS) and International Plant Protection Convention (IPPC) rules. The increase in global trade, in volume, speed and variety of pathways for pest movement internationally, has greatly increased the risks to the UK and the rest of the EU. Within the EU the Standing Committee on Plant Health is responsible for developing rules for management of plant health risks. The FC Plant Health (PH) team provides the statutory input for the UK into this process.

This work area includes some monitoring and diagnosis of quarantine pests, particularly those associated with timber, verbal, written and hands-on support to the FC Plant Health and in some cases to the Defra Plant Health teams. Input is also required on tree pests for the recently instigated UK Risk Register <https://secure.fera.defra.gov.uk/phiw/riskRegister/> which now provides information on more than 700 organisms. A proactive approach is taken to assess the risks from known or previously unrecognised pests by Pest Risk Analysis (PRA) using internationally agreed standards. Interaction with FC Plant Health team and other bodies dealing with phytosanitary threats takes place at high frequency and responses may be needed within 24 hours. There is also interaction with researchers and phytosanitary practitioners internationally, especially through the European and Mediterranean Plant Protection Organization (EPPO), the International Forestry Quarantine Research Group (IFQRG) and International Union of Forest Research Organizations (IUFRO) as well as with Regional Plant Protection Organisations globally. Formal communications take the form of PRAs, written advice, production of Pest Alerts and web pages dealing with new threats and updates on previously known threats. Information and practical advice on topical findings are also given to the forestry sector via workshops, seminars, working groups, Outbreak Management Teams, and plant health training courses.

Impact:

The outputs from this work area will feed directly into the delivery of healthy and resilient forests and woodlands described in the Forestry Commission and Defra Tree Health Management Plan. It will underpin the horizon scanning to identify new pests and pathogens beyond UK borders, as well as risk analysis to define the extent of threat that could be posed to trees in the UK. The outputs will contribute to current and future choice of species and the maintenance of healthy trees.

¹³ 'Pest', under the IPPC definition includes all organisms of phytosanitary concern. Both invertebrates and pathogens are included in this generic term.

Work area 6.2 - Advice and support for pest and disease management

Aims:

The overarching aim this work area is to respond to reports of tree disorders, to investigate and diagnose the causes of the damage, and to provide advice and training about both new and old disorders and what action can be taken to manage and minimise their impact.

Background and Methods:

There are now considerable pressures to increase the resilience of our tree population and minimise the impact of pest and diseases. This work area, comprising advice and diagnosis of the causes of tree disorders affecting trees in Britain, is the basis of a coherent body of knowledge about tree pests and diseases in Britain and also transfers knowledge and provides training on how to recognise and respond to many of these disorders.

The Tree Health Diagnostic and Advisory Database is the home for reports on tree disorders accumulated over more than fifty years. The database has recently been unified and updated and the thousands of reports that it holds provide an overview of the health of trees, woodlands and forests in Britain and how this is changing over time. Reports have the potential to be analysed in relation to factors such as climate, management practice and new pest and pathogen threats. The work operates under the umbrella of the Tree Health Diagnostic and Advisory Service (THDAS) which is usually the first point of contact for reports of tree ill-health, so a disorder can be identified and advice or management options supplied. It is also often the point at which previously unknown biotic problems are first reported and the agent identified, so it also acts as an early warning system in the detection of new threats to trees and woodlands and integrates closely with the Phytosanitary Advice work area. FR scientists that undertake research in this area work also closely with FCE, FCS and NRW Plant Health staff. Reporting to the Tree Health Diagnostic and Advisory Service is mainly through the TreeAlert app or online tool (<http://www.forestry.gov.uk/treealert>), and this work also underpins two external tree health surveillance projects, namely Observatree (<http://www.observatree.org.uk/>) and OPAL (<http://www.opalexplornature.org/treesurvey>). Both encourage wider participation in understanding what pests and diseases can affect our trees and how to provide an early warning system for new threats.

Impact:

This work area will help deliver Forestry Commission England, Forestry Commission Scotland and Welsh Government forestry policies that all include aims of reducing the impact of invasive pest species. It will feed directly into developing practical help on what species to plant and improved management of healthy and resilient forests and woodlands and support the Forestry Commission and Defra Tree Health Management Plan.

Work area 6.3 - Surveillance and management of Dothistroma needle blight

Aim:

Dothistroma needle blight is a devastating disease threatening both commercial pine forests and our native pinewoods. The main aim of this work area is to understand the spread of the disease, quantify its impacts and develop potential practical silvicultural approaches that may help our pine forests to be more resilient to Dothistroma in the future.

Methods:

Dothistroma needle blight (DNB) is now so extensive, and its impact can be so severe, that it has resulted in a moratorium on planting Corsican pine on the public forest estate, and limited the use of lodgepole pine to a single provenance (Alaskan).

The distribution and impact of Dothistroma needle blight on Scots pine, is much less clear. Recent surveys within England and Scotland indicate DNB is increasing its presence on Scots pine, but anecdotal evidence suggests the impact of the pathogen on this species may be less severe. This work area encompasses a long-term experiment designed to address the critical knowledge gaps in relation to the impact of Dothistroma needle blight.

Preliminary results of stand-manipulation trials within England demonstrate that heavy thinning of Corsican pine can reduce disease intensity, at least in the short term. It is critical to maintain these long-term thinning experiments in England, as proposed within this work area. The practicality of silvicultural manipulation to manage the disease will be considered alongside the fungicide work detailed in work area 4.2 of this programme, with the aim of building an integrated approach to Dothistroma needle blight management. Future work on silvicultural manipulation will be undertaken in discussion with silviculturists in work programme 2. Initial recommendations for silvicultural manipulation to assist with Dothistroma management were produced in 2012 for the Integrated Weed, pest and disease management practice guide, the replacement for Forestry Commission Practice Guide 15 and Forestry Commission Field Book 8, but although this guidance is available internally to Forestry Commission staff it has not yet been published externally. Updated recommendations will be incorporated in the update to Forestry Commission Practice Guide 15 / Field Book 8 planned in work package 4.4.

Over a four year period, the following work will be undertaken:

- Expert guidance to Plant Health England and FC Scotland in their country-wide Dothistroma needle blight surveys.
- Evaluation of the pre-existing Plant Health (and other) survey data and its potential to link changes in disease distribution and severity to environmental factors.
- Continue long-term monitoring of impact of Dothistroma needle blight on CP plots in England.
- Continue long term studies on the effects of stand manipulation (heavy thinning) on Dothistroma needle blight infection levels and impact in Corsican pine.

Impact:

This work area will help deliver Forestry Commission England, Forestry Commission Scotland and Welsh Government forestry policies that all include aims of reducing the impact of invasive pest species. It will feed directly into developing practical recommendations on what adaptive strategies and management techniques can be used to reduce DNB impacts in already affected stands, and identify how future pine forests can be restructured to create forests with greater resilience to this disease.

Section 3. Communication Strategy

The focus within programme 3 is on developing practical solutions for delivering more resilient forests, and therefore as a general principle the intention will be that all scientific advances will be communicated in the form of both practical guidance for forest managers and policy makers, and peer reviewed papers.

Practical guidance will take the form of FC information notes and practice guides, articles in the popular press, web pages, decision tools and demonstration forests. Stakeholder involvement will be sought in the scoping / conspectus stage of significant outputs, in particular new practice guides, decision tools and demonstration forests.

Peer reviewed papers will be targeted at high impact forestry journals, with a preference for open access provision of the articles.

Provision of direct and specific advice forms an important part of the knowledge exchange activities for the delivering resilient forests programme. This advice is given to forest, land and tree managers, policy makers and the general public, through the use of email, telephone, seminars and web updates. Apps and online reporting tools are used for tree disorders, and the wider use of social media in other parts of the programme will be explored.

Over the expected 4 year life of the programme it is anticipated that over 40 scientific papers, 23 FC publications, and 20 articles in the popular / trade press will be produced.

Please see the work package descriptions later in this proposal document for further detail.

Section 4. Collaboration and networking

The programme will collaborate with a range of external partners, through science networks, formal partnerships, participation in European and other match funded projects, PhD and MSc studentships, through close links with various different elements of the private and public forestry and arboriculture industry, with national and international scientists, regulators and policy makers, and directly with the public through citizen science initiatives such as Observatree. Stakeholder involvement will be sought in the scoping / conspectus stage of significant outputs. There are numerous linkages between this programme and the other 6 proposed CFS funded FR science programmes. Within the delivering resilient forests programme, integration will be addressed by multi-disciplinary work packages, shared / work package cross work package outputs (e.g. a resilient forest simulation system, updated web pages on emerging species covering susceptibility to pests and diseases, updated practice guides on integrated pest, weed and disease control, an urban species selection tool) and, subject to stakeholder demand, a guide or manual on managing adaptation which would involve all work packages. Please see the work package descriptions later in this proposal document for further detail.

Section 5. Ethical and other considerations

5.1 Ethical considerations

Investigations on vertebrate animals are protected under *ASPA [Animals (Scientific Procedures) Act 1986 and 2010]*. Any procedures involving animals considered necessary under our experimental protocols are discussed in full with our ethics committee, a veterinary officer and a Home Office inspector before work is undertaken. Forest Research holds current Home Office site, project and investigator licenses for investigations on the bark stripping behaviour of squirrels.

5.2 Government survey control procedures

None planned.