Programme 1: Assessing Resilience

Section 1. Overview

Research Programme (short title):	Assessing resilience
Research Programme (long title):	Assessing resilience and sustainability of woodlands and forests
Version:	1.4
Date:	31.05.15
Author:	Bruce Nicoll, Forest Research
Programme Life (years)	4
Start Date	1 April 2015
Completion Date	31 March 2019
Annual core funding (k)	£1.7 million p.a.

1.1 Summary of proposed research

The "Assessing Resilience" programme will:

- Assess and evaluate woodland and forest resilience[1] in the context of sustainable forestry, ecosystem service provision and the wider mosaic of land-use.
- Examine what contributes to resilience: how forest ecosystems function, and what the risks are to them.
- Explore appropriate indicators of resilience, their use in detecting ecosystem instability; and what are the vulnerabilities of the forestry socio-ecological system.
- Develop an understanding of the spatial and temporal context of forests for ecosystem service provision.
- Provide tools to assess and improve resilience across the range of functions of forests and woodlands in relation to climate change and policy and operational decisions.
- Assess resilience at scales from woodland and forest stand scale, through to landscape and catchment scale; and in terms of woodland management priorities and ecosystem service provision.
- Explore how resilience may be enhanced in native woodlands and urban forests.

[1] "Resilience" is defined here as "the capacity of our woodlands to withstand and/or adapt to changing environmental, economic and social conditions. This capacity will rely on having adequate levels of natural capital to ensure the provision of ecosystems services to meet society's demands". See Bailey and Hubert (2014) *Resilience: an agreed understanding for the SIS*.

Section 2. Description of work

2.1 Background

The research brief requires that the "Assessing resilience" programme includes assessment and evaluation of resilience in the context of forestry and the wider mosaic of land use. This should include research to assess what contributes to resilience, what are the appropriate indicators of resilience, and what are the risks and vulnerabilities of the socio-ecological system. A 'system' approach should examine risks to functioning and state of the system, considering ecosystem services such as timber production, recreation, C sequestration, C stock, water yield, habitat, biodiversity, soil stability, nutrient cycling, GHG balance, and climate change mitigation. This work will support implementation of climate change mitigation and adaptation policies, at GB, and country levels, will contribute to the maintenance and development of sustainable forestry practice as the climate changes over the next century, and will provide ongoing state of the art guidance to the forest industry on how to improve resilience.
To achieve these goals, the programme is designed to be interdisciplinary, bringing together scientists from across FR, to work together in new ways in new Work package teams with more specialised Work Areas within them (see Table 1 for WP and WA structure and responsible FR staff). These teams will also develop new collaborations between them and will inter-link with the other FR programmes. Results will be provided to forest industry practitioners and policy makers, to support their work to improve resilience, in a range of forms from the outset, with the resolution of information improving as the research programme progresses. The programme work packages structure and some of the more important linkages are shown in the diagram below:

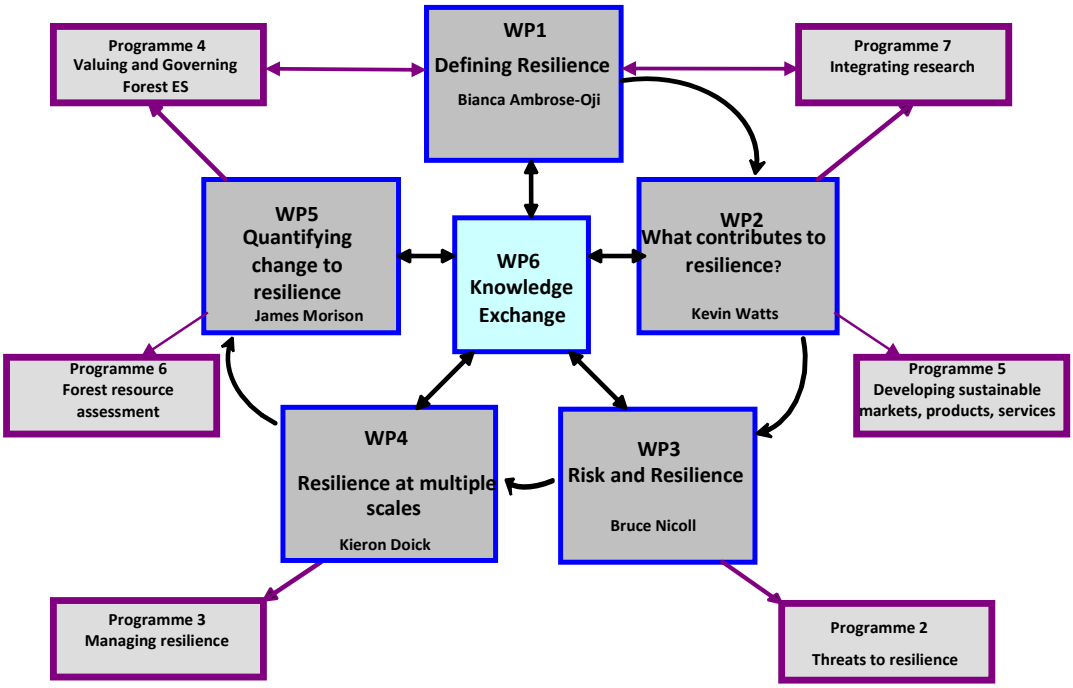


Table 1. Assessing Resilience and Sustainability of Woodlands and Forests programme structure

Work Package	Work Package Leader	Key Research Challenge	Work Areas
1. Defining Resilience	Bianca Ambrose-Oji	1.1 How to define 'resilience' of different types of woodland 1.2 Understanding influences on resilience	1.1. Exploring socio-ecological systems as a context for defining forest resilience
2. What contributes to resilience?	Kevin Watts	1.4 Maintaining ecosystem services and biodiversity whilst achieving woodland ecosystem resilience 2.4 Which tools (and K.E.) are required to assess risk and resilience and support adaptive management?	2.1 Genetic Conservation (Provenance and EUFORGEN) 2.2 Genetic Conservation (Molecular) 2.3 Influence of a diversification of forest stands on biodiversity and woodland ecosystem resilience 2.4 Assessing taxonomic and functional diversity and levels of functional redundancy in woodlands at different temporal and spatial scales 2.5 Evidence of site and landscape factors on woodland biodiversity and resilience 2.6 Spatial indicators of ecosystem services, biodiversity & resilience
3. Risks and Resilience	Bruce Nicoll	1.1 How to define 'resilience' of different types of woodland with different objectives to different types of risk at different spatial/temporal scales 1.3 What are the pressures to which forests must be resilient over the next century? 2.4 Which tools (and K.E.) are required to assess risk and resilience and support adaptive management?	3.1 Climate change forest vulnerability and risk – from concepts to practical assessments 3.2 Wind risk - ForestGALES development and application 3.3 Wildfire risk – assessment and modelling 3.4 Flood risk – Quantifying the impacts of woodland planting 3.5 Protection forestry - forest landslide and erosion risks (work area to be developed)
4. Resilience at multiple scales	Kieron Doick	1.1 How to define 'resilience' of different types of woodland with different objectives to different types of risk at different spatial/temporal scales 1.2 Understanding influences on resilience and measures to increase resilience 1.4 Maintaining ecosystem services and biodiversity whilst achieving resilience	4.1 Landscape scale forest ecosystem service simulation and Ecological Site Classification (ESC) development 4.2 Urban Forest Resilience 4.3 Afforested Peatland Restoration and Ecosystem Services
5. Quantifying changes to resilience	James Morison	1.2 Quantification of resilience, and understanding the influences on it 5.2 Quantification of ecosystem services	5.1 Integrated monitoring of ecosystem change 5.2 Quantifying forest stand C & GHG dynamics 5.3 Protecting soil C and function 5.4 Impact of forestry on acidification

2.2 Programme-level response to the challenges

The Work Packages that address each Research Challenge, with component Work Areas are mapped in Table 1. Descriptions of how RCs will be addressed are provided in Work Package and Work Area sections.

The following SIS Research Challenges (RCs) will be addressed:

RC 1.1 How to assess 'resilience' of different types of woodland with different objectives to different types of risk at different spatial/temporal scales

RC 1.2 Understanding influences on resilience and measures to increase resilience

RC 1.3 What are the pressures to which forests must be resilient over the next century?

RC 1.4 Maintaining ecosystem services and biodiversity whilst achieving resilience

RC 2.4 Which tools (and K.E.) are required to assess risk and resilience and support adaptive management?

RC 3.2 What are the costs and benefits of forest management and woodland creation decisions to improve resilience and expand our woodland resource?

RC 5.2 Quantifying the range of ecosystem services delivered by forests and woodlands. i.e. the physical science behind case studies such as 'Slowing the flow'

2.3 Business considerations

Delivering against country research needs

The following Country Research Questions to be addressed (see WP and WA sections for details) –

Assessing and evaluating woodland and forest resilience in the context of sustainable forestry
FCS1 – What empirical evidence is there to support the hypothesis that a more diverse ecosystem is more resilient than, for example, monocultures?
FCS2 - What are the specific adaptation challenges facing native woods and how do these vary regionally and what approaches can be used to meet them and whilst maintaining the maximum degree of natural character?
FCS3 – when do we risk stagnation of our native woods?
NRW1- What is the substitutability of native species (implications for character), Are native species adaptable enough? (Seed source/provenance.)

Understanding the spatial context of forests for ecosystem service provision
FCE1 - Quantifying the physical benefits of woodland creation and management on ecosystem services (such as improving water quality, soil conservation, flood prevention/alleviation and carbon storage) and comparing different woodland types with different types of existing land use - What are the benefits of different types of woodland creation and management for water quality/availability and flood risk ecosystem service.
FCE2 - 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?
FCE3 - Evidence is needed to identify whether working at landscape scale, through joining up woodlands, increasing the size of individual woodlands and creating wooded landscapes more permeable to the movement of woodland species are sufficient for adapting to the future climate; thus, what is the role of landscape scale (i.e. more widely focussed than individual sites) adaptation in forestry? What evidence is there that landscape-scale approaches to climate change adaptation are effective?
FCE4 - What is the optimum location to plant new woodlands to deliver a full range of ecosystem services?

Assessing resilience at scales from woodland and forest stand scale, through to landscape and catchment scale; and in terms of woodland management priorities and ecosystem service provision.
FCS4 - What degree of various ecosystem services can be provided by native woodlands and other forms of woodland?

Fundamental research into factors influencing resilience including forest growth, carbon and GHG balance, soil sustainability, hydrology, tree genetics, and woodland biodiversity.
FCE5 - 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?
FCE6 – How should we use the genetic resource available to us (i.e. provenance/origin) be used to enhance resilience to climate change?

Impacts and constraints

Broad-scale impacts of Programme 1 are expected to be:

Environmental impacts

Forests managed sustainably with improving resilience to changing environmental and climatic conditions, informed the latest research and state of the art tools and guidance.

Economic impacts

A forest industry adapted to a changing climate and managed to reduce environmental risks, to provide an increasing contribution to the economic development of Scotland, England and Wales.

Social impacts

Forests developed to meet the demands of society and to be resilient in terms of maintaining the provision of ecosystem services required by society and across sectors.

The main constraint is limited funding and staff time, restricting the depth of research that will be achievable in an ambitious spread of projects. This will be counteracted by maintaining, and increasing where possible, collaboration with other research groups, especially in the UK and Europe, to influence, and tap into, related projects, and to develop further collaborative funding streams.

Innovation potential

The programme will provide innovative and fundamental research into factors influencing resilience including forest growth, carbon and GHG balance, soil sustainability, hydrology, tree genetics, and woodland biodiversity. It will assess the changing abiotic risks to those functions, and it will consider alternative policy and land use management scenarios, taking into account the impacts of wind, fire, flood and drought to the system and the wider landscape context. Resilience across the main functions of forests will be assessed at scales from woodland and forest stand scale, through to landscape and catchment scale; and in terms of woodland management priorities and ecosystem service provision. Enhancing resilience in native woodlands and urban forests will be included. Opportunities for land use integration will be considered.

Innovative tools and guidance will be developed and made available to support policy development through to planning and operational decisions. They will be applicable to examining resilience of forestry and sustained ecosystem service provision in relation to management and changing climate and wider landscape context and land-use policy.

2.4 Work packages to address the research challenges

WP Title: WP1. Defining Resilience

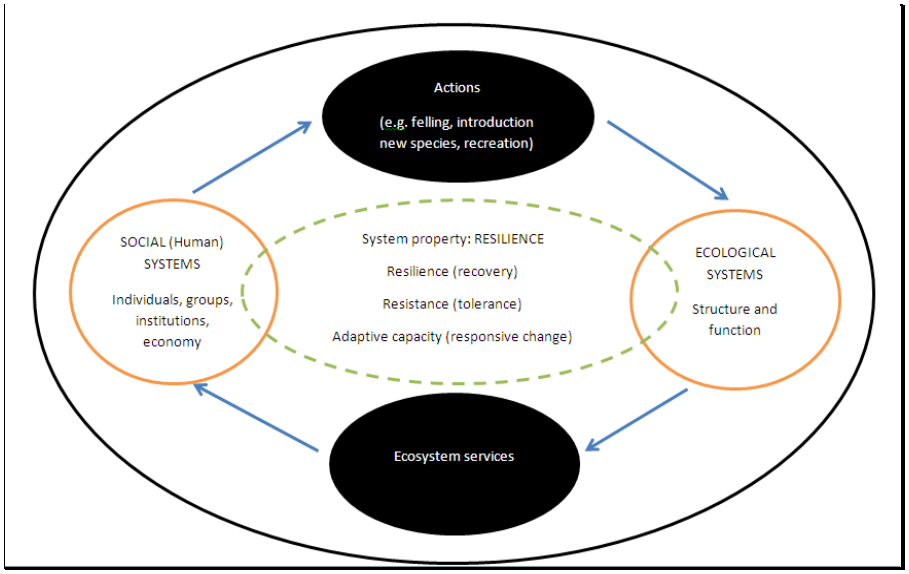
Indicative costs (£k):

2015-16	2016-17	2017-18	2018-19
35	35	35	35

Work package details:

This Work Package aims "***To define and understand the meaning of forest resilience***" and contributes to answering: *RC 1.1 How to define 'resilience' of different types of woodland ..,* and *RC 1.2 Understanding influences on resilience.* We have planned work and outputs in only one Work Area (WA) for 12 to 18 months. Subsequent to this, we will assess the scope and utility of the work and propose any further work and outputs, in the same or a different WA, in consultation with stakeholders.

The objective will be to "*evolve comprehension of socio-ecological systems and refine our understanding of resilience within forest and wooded landscapes in a way that has practical application for the British forestry sector"*. The concept of a socio-ecological system is outlined in the Figure below. Resilience is understood as an inherent property of social and ecological systems as described in *Resilience and SIS*[1]*.* The different dimensions of resilience are impacted by interactions between the two systems brought about as society reacts and acts to influence the flow of specific ecosystem services from forests and wooded landscapes. The complexities hidden within this simple model are well rehearsed within the wider academic literature and *Resilience and SIS*[1]*,* and include questions of spatial and temporal scale, stochastic disturbance and oversimplification.



Different frameworks have already been developed to explore socio-ecological systems and assess resilience, but these differ according to: disciplinary approach; how far the type, direction and level of interaction between social and ecological systems is recognised; the emphasis placed on the importance of either the social or the ecological system in determining resilience properties; and the overall purpose of the framework, i.e. whether it serves to support analysis (the Ecosystem Services Framework), or the framework is aimed at practical action and adaptive management (DFID's Sustainable Livelihoods Approach).

In the British context frameworks applicable to forestry that explore the system dynamics of resilience (i.e. the interactions between social and ecological systems driving or reacting to change) at the wider landscape scale are poorly developed, particularly those that include community or societal level resilience, urban systems, and which begin to define what resilience looks like when the human system is more fully taken into account. The research undertaken in this WP will work to overcome these limitations and produce guidance that supports analysis and adaptive management.

Work Area Title: WA 1.1 Exploring socio-ecological systems as a context for defining forest resilience

Work area details:

Objectives

Our research objectives in this work area are to evolve a framework that can:

i. Encourage structured **interdisciplinary** discussion and reasoning
ii. Establish **common** language and concepts that aide interdisciplinary reasoning and the realisation of research objectives
iii. Describe what resilience in woodland related socio-ecological system looks like, what resilience means to socio-ecological system at different management levels, and what the implications of shifting to and from such systems might be
iv. Provide tools that aide the **translation** of resilience research into more practical action focused recommendations and guidance.

Proposed methodology

1. Review and synthesise current frameworks and knowledge on socio-ecological systems and on resilience, risk and thresholds within these
2. Identify framework or elements of frameworks that can be developed into a tool appropriate to the British forestry context
3. Develop and test the framework through deliberative interdisciplinary workshops
4. Produce an agreed framework and interpretive tools

Links to other work

- Realising research objectives i., ii. and iii. will involve working with the other scientists involved in Programme 1.
- Aim iv. provides a forward link to work being undertaken in Programme 3 "Management of resilient forests", and Programme 7 "Integration of science and policy". Collaboration with programme 7 is anticipated. A degree of collaboration with Programme 3 in the production of output 2 (an interpretive tool) is desirable.

Outputs

We anticipate that production of outputs will be in collaboration with Programme 7 scientists and resource.

1. Journal paper (or similar written output) describing a UK forestry sector focused socio-ecological resilience framework and/or a review paper on resilience understanding in forestry.
2. A stakeholder "Learning Lab" style workshop to test and validate the evolved framework leading to the translation of the framework into a Research Note or similar written briefing paper for the sector.

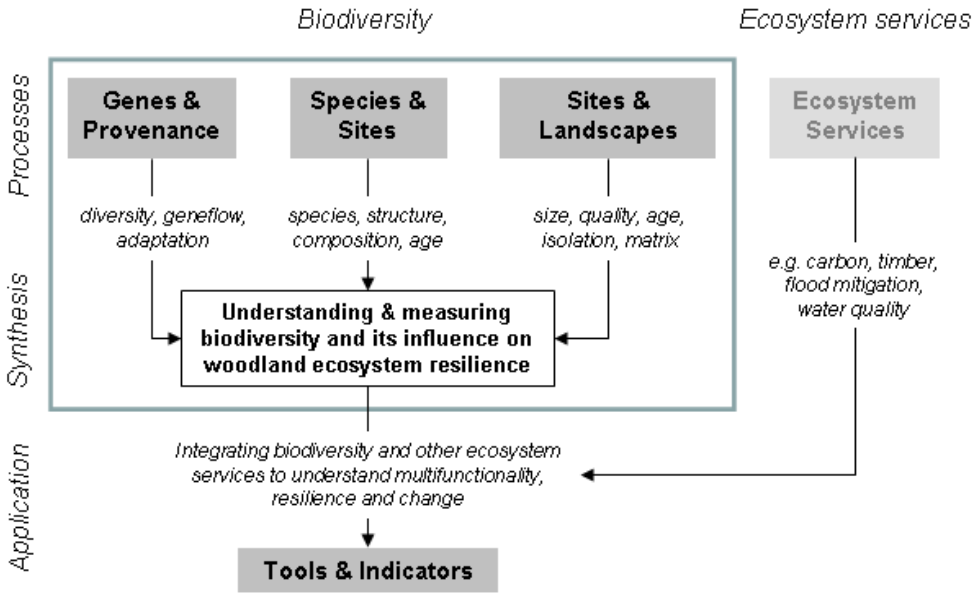
WP Title: WP2 What contributes to resilience? Understanding & measuring biodiversity and its influence on woodland ecosystem resilience

Indicative costs (£k):

2015-16	2016-17	2017-18	2018-19
449	449	449	449

Work package details:

This Work Package will tackle the research challenge of ***maintaining ecosystem services and biodiversity whilst achieving woodland ecosystem resilience*** (RC 1.4). Biodiversity is a key component of the '*natural capital*' of a woodland ecosystem, and influences both ecosystem service (ES) provision and resilience (Bailey & Hubert, 2014). We will therefore conduct *fundamental research within different woodland types* at a number of *spatial/temporal scales* (RC 1.1), as represented by the dark grey boxes in the diagram below, to understand the influence of biodiversity, and the underlying processes (in italics), on ES provision and woodland ecosystem resilience. The Genetic Conservation Provenance and Molecular Work Areas (WA 2.1 & 2.2) will focus on the processes operating at the genetic and species scale and address questions including, *are native species adaptable enough?* (NRW1) and *how should we use genetic resources to enhance resilience?* (FCE6); Work Areas 2.3 & 2.4 will focus on the Species and Sites scale, and deal with questions such as *are more diverse woodland ecosystems more resilient?* (FCS1) and *how to assess resilience of different types of woodlands*? (RC1.1) the Sites and Landscape Work Area (WA 2.5) will tackle the *spatial context* of woodland at larger spatial scales and issues within and beyond the woodland boundary and the integration of other land uses, including key questions such as *what is the evidence that landscape-scale approaches to conservation and climate adaptation are effective?* (FCE3) and *what is the optimum location to plant woodlands?* (FCE4). It is acknowledged that many processes operate across these three scales and will influence ES provision and woodland ecosystem resilience, e.g. presence of a single or a range of species as well as geneflow can be influenced by availability of appropriate habitat, isolation and the composition of the surrounding matrix. The three research areas will collectively develop our understanding of woodland biodiversity as a key component of woodland 'natural capital', and its influence on woodland ecosystem resilience. The final Work Area (WA 2.5) will focus on the *application* and *synthesis* of this information on *how ecosystem services and biodiversity can be maintained whilst achieving resilience* (RC 1.4). It will combine existing work on ecosystems services (light grey box) with additional spatial indicators on biodiversity, and ecosystem resilience. When combined they will help to *quantify the range of ecosystem services delivered by forests and woodland* (RC 5.2) and their resilience *at a number of spatial scales* and contribute to delivering RC 2.4 "*tools (and K.E.) required to assess risk and resilience and support adaptive management".*



Work Area Title: 2.1 Genetic Conservation (Provenance & EUFORGEN)

Work area details:

WA 2.1 is concerned with identifying the specific challenges facing British woods, how these vary regionally and which seed sources we should use to prepare for the future (FCS2, FCE6). We will also tackle the question of whether native tree species are adaptable enough to meet future challenges (NRW1).

Genetic diversity, a key component of species resilience, is the product of founding material, geneflow and natural selection. Neutral genetic diversity can provide insight into founding material and geneflow, whereas common garden experiments are required to study adaptive variation. The high levels of intra-specific genetic diversity and long distance geneflow in British trees suggest populations have a large capacity for reorganisation of existing genetic variation to respond to future threats and challenges. This aspect of resilience has been largely overlooked in models that predict the consequences of climate change and novel pests and diseases. Studies of both neutral (WA 2.2) and adaptive genetic diversity (WA 2.1) of our forests and of the flora and fauna they contain are required to understand the resilience of our woodlands ecosystems.

Work within this Work Area includes maintenance, assessment and analysis of results of established trials. FR has trials based on native tree species at a broad continental or a narrower British scale. These will be used to understand the scale over which local adaptation occurs and explore the phenotypic plasticity of this material when grown across a range of sites. The information will guide policy on the adaptive capacity and resilience of our native tree populations. In collaboration with Edinburgh University and CEH we have published results that demonstrate that, despite likely gene flow between remnant populations of Scots pine, differences between populations exist in terms of adaptive trait variation which are likely to be the product of natural selection. These differences often only become apparent when the trees are subjected to stress, suggesting a high capacity to adapt to future threats. Combining trait assessments with detailed meteorological records may elucidate the main drivers of adaptive differences and provide improved plant sourcing guidance based on site matching rather than geographic proximity of plant source and planting site. We will build on established collaborations to extend our understanding of adaptive variation in Scots pine, ash and rowan via common garden experiments. These will:

1. Analyse existing data and harness fast phenotyping methods to assess the adaptive potential of native tree species to climate change.
2. Examine survival of continental provenances grown in Britain to explore the feasibility of adopting the predictive provenancing approach to cope with climate change.
3. Explore whether the current seed zone policy could be improved by basing the system on biotic and climatic similarity of source and planting site conditions.

FR has had a long participation in EUFORGEN and has committed GB to another five year programme with Jason Hubert (C&FS) as the GB representative. Recent work has involved identification of gene conservation units (GCUs) and Britain has lagged behind in this initiative and currently has no GCUs. We hope to rectify this, potentially with added support from an EU grant.

Work Area Title: 2.2 Genetic Conservation (Molecular)

Work area details:

WA 2.2 will provide **fundamental research into factors influencing resilience including genetics** and contributes to addressing RC 1.4 "Maintaining ecosystem services and biodiversity whilst achieving resilience". It will harness molecular technologies to gather data relating to gene flow, genetic structure and diversity in trees and forest dwelling species and to develop methods for fast estimation of biodiversity in our woodlands and the effects of management on this. This will provide empirical evidence on whether a more diverse ecosystem is more resilient than one based on a monoculture (FCS1).

The molecular group at FR has considerable experience in using molecular methods to tackle questions relating to forest genetic resource conservation. We have applied these methods to inform on topics such as; colonisation history, geneflow in forest tree species, landscape genetics of forest dwelling species, clonal identification of tree species, sources of insect pests, genetic structure of rare forest plant species and confirmation of presence of rare and elusive forest dwelling mammals from scat and hair samples. The team make strenuous efforts to keep abreast of rapidly developing technological advances in this field and to consider where these can be applied to forestry related questions. Three of the most exciting recent advances in molecular technology include the:

- Rapidly expanding global database on the Barcode of Life
- Reduction in the cost of DNA sequencing
- Ability to sequence DNA extracts containing a mixture of species (metabarcoding).

In combination, these offer the facility to compare the effects of different management on components of biodiversity in the forest ecosystem e.g. Do mixed as opposed to monoculture forests contain a greater range of invertebrates? Does thinning modify the invertebrate composition of a woodland? Does the age of the stand affect the biodiversity? They also provide an inexpensive way to monitor changes in biodiversity and the resilience of woodland ecosystems as climate change and loss of tree species due to pest and disease begin to impact on our woodlands. Work within this Work Area intends to:

1. Keep abreast of technical developments and harness these to advance understanding of forestry related questions.
2. Continue to co-supervise (in collaboration with Kevin Watts WA 2.5) two ongoing PhD projects on landscape genetics to completion of thesis and authorship of papers that emerge from the work.
3. In collaboration with Nadia Barsoum (WA 2.3), initiate a pilot study to examine the feasibility of using novel metabarcoding methods to assess invertebrate biodiversity in our native woodlands.
4. Collaborate with CEH and Edinburgh University to extend work on neutral mitochondrial marker development in Scots pine to understand its founding history.

Work Area Title: 2.3 Influence of a diversification of forest stands on biodiversity and woodland ecosystem resilience

Work area details:

Empirical evidence is lacking on the relationships between stand structure, composition, developmental stage and resilience of woodland ecosystems. Increases in stand complexity are hypothesised to increase levels of biodiversity and the co-existence of species with similar functional roles, thereby increasing levels of functional redundancy. The assumption that high redundancy confers ecosystem resilience against the loss of valuable ecosystem services in the event of environmental change will be tested (FCS1; RC1.2). In addition, simple measures of stand structural and compositional complexity will be tested as indicators that can be applied to determine trends and quantify and predict forest ecosystem resilience.

Research will proceed through a combination of analysis of data from completed, on-going and new FR field experiments and survey work to explore 1) how the richness, diversity and functional diversity of species in multiple taxonomic groups are influenced by a 'diversification' of forest stand structure and composition, 2) how the composition of stands influences forest ecosystem resilience and the delivery of ecosystem services and 3) the practical application of simplified measures of stand complexity as a measure to increase forest ecosystem resilience and facilitate adaptive forest management (RC 2.4; RC 1.4). The concepts of functional diversity and redundancy will be explored as a means of defining, measuring and comparing forest ecosystem resilience between different stand/woodland types using a number of taxonomic groups for which there is a good understanding of functional response and effects traits (e.g. ground vegetation, carabids, spiders) (RC1.1). A functional trait-based approach has the advantage of facilitating comparisons between communities that do not share the same species composition. Close links have been formed with the forest diversification research community including the global TreeDiv network and also the NERC BESS 'Dynamics and thresholds of ecosystem services in wooded landscapes' Project. FR experiments this work area will draw from include:

1. Biodiversity in mixed and pure stands of Scots pine and oak experiment (data collection complete) - Management of Multifunctional Forests (EC MultiFor) and Forest Management Adaptation (EC ADAFOR) projects. Arthropods, ground vegetation and ectomycorrhiza have been sampled over 1-2 years in mixed and pure stands replicated within and across three 'regions' (Thetford, New Forest, Ireland). Indicators of stand complexity have additionally been developed as an adaptive forest management tool.
2. Biodiversity in Sitka spruce mixed and single age stands experiment (data collection complete). Ground vegetation and arthropods of canopy and litter layers, including insect pest species, were sampled over 1-2 years within five 'replicate' forested regions in Wales.
3. FR's Gisburn trials (planted in 1991) study of the influence on biodiversity of various combinations of commercially important tree species (i.e. Sitka spruce, sessile oak, Norway spruce, Scots pine and alder) grown as mixtures or in monocultures.
4. 'Assisted migration' provenance trials set up in 2011 in the National Forest (with the NFC) and Kent (with the Woodland Trust). Various planting ratios of local and climate-matched provenances, monocultures and mixed species plots used to study the influence of tree origin and stand composition on biodiversity (NRW1).

Work Area Title: 2.4 Assessing taxonomic and functional diversity and levels of functional redundancy in woodlands at different temporal and spatial scales

Work area details:

Research into forest ecosystem processes is problematic due to the time scales involved, but also due to the significant variation in the landscape features of different woodlands, such as levels of connectivity and woodland size. Research is needed to better understand how taxonomic and functional diversity and levels of functional redundancy vary in different woodlands (ranging in type, developmental stage, size, levels of connectivity) in order to gain a better understanding of which woodlands are most resilient and which are at greatest risk of forest ecosystem collapse (RC1.1; RC1.2). This will link to a PhD project, focussing on forest ecosystem collapse, "Dynamics of ecosystem services in forest ecosystems' funded by FC, conducted by Paul Evans and supervised by Adrian Newton at Bournemouth University. In parallel, research is also needed to help identify contributing factors to critical thresholds and tipping points. This work area will use and build upon existing datasets from a number of projects such as the WrEN project (WA 1.2.5), and:

1. Forest Biodiversity Assessment (FBA) project
In 1995, the Forestry Commission funded the FBA project to help define biodiversity through a post-harvest chronosequence in a range of common plantation types (monocultures of oak, Sitka spruce, Norway spruce, Corsican pine) located in upland and lowland regions across the UK. The FBA provided valuable baseline data for a range of target taxonomic groups (beetles, fungi, plants, birds) in these plantation types. External funding has been approved for a PhD project 'Multi-taxa functional diversity in UK plantation forests', co-supervised by N. Barsoum and A. Oxborough (Edge Hill University, Lancashire), to re-sample the FBA forest stands using comparable methods to those used 20 years previously. This project will determine long-term changes in species composition and functional diversity across the range of typical commercial plantation types. Comparisons of species composition between upland and lowland bioclimatic zones with new and past datasets will help refine models of predicted changes in species distributions for target taxonomic groups, including likely associated impacts under a changing climate. In addition, species will be grouped according to functional traits to extend our understanding of patterns of functional diversity and levels of functional redundancy between forest types, through the forest harvesting cycle, across bioclimatic zones and through time. Some additional funds will be needed to supplement this work area in order to include comparable sampling in adjacent native woodlands at comparable stages of renewal.

2. Taxonomic/ functional diversity responses and levels of functional redundancy at different stages of stand dieback in beech
This field experiment involved pitfall trapping of ground-dwelling arthropods along a gradient of beech dieback in five forest blocks in the New Forest. The field experiment and genetic analysis (metabarcoding) of arthropod samples will be complete by the start of the new programme, requiring analysis and write-up of data. This project was co-financed by the FC and EU Interreg Forest Management Adaptation (ADAFOR) Project and has been undertaken in collaboration with Bournemouth University with links to the NERC BESS 'Dynamics and thresholds of ecosystem services in wooded landscapes' Project.

Work Area Title: 2.5 Evidence of site and landscape factors on woodland biodiversity and resilience

Work area details:

There are major policy drivers across the UK, and globally, to combat habitat loss and fragmentation, conserve biodiversity and increase ecosystem resilience through a range of site (e.g. improving or expanding existing habitat patches) and landscape-level (e.g. creating new habitat to form corridors or stepping stones) actions. Although this approach is appealing and based on sound scientific principles, the empirical evidence is equivocal and there is much debate on the relative merit of, and balance between, these alternative management actions (FCE3 & FCE4).

This Work Area aims to gather the much needed empirical evidence on the spatial context of woodlands and the influence of both site and landscape-scale factors on biodiversity and how this contributes to the resilience of woodland ecosystems. It will utilise and build upon the extensive network of woodland field sites developed within the WrEN (Woodland Creation and Ecological Networks) project. This project started in 2013 as a collaborative project between Forest Research, University of Stirling and Natural England, with funding from multiple sources including Forestry Commission, University of Stirling, Natural England, National Forest, Scottish Natural Heritage and Defra to a combined value of over £500k. The project now consists of a suite of over 100 woodland field sites which were planted at different times during the past 150 years within fairly homogenous agricultural landscapes in lowland Scotland and central England. These sites have been systematically selected to consist of a range of site and landscape variables (linked to the 'bigger, better, more, joined' principles of the Lawton report) and act as a long-term, large-scale 'natural experiment'. These sites have already been assessed for a wide range of species groups (including plants, lichens, insects, mammals, bats). This allows us to understand the role of various site and landscape characteristics on biodiversity, woodland resilience and underlying ecological functions. Much work is now underway to analyse the extensive data collected to produce a number of outputs for the scientific, policy and practitioner communities.

Future work within this Work Area may expand the 'breadth' of the existing network of field sites to include other woodland types and different landscapes, and also expand the 'depth' of the species studies (a study of pollinators is currently being considered). However, the scale of expansion of the project will be linked to the availability of additional external income. We have recently secured a NERC CASE funded PhD student at Stirling University to look at birds within the existing networks of field sites. Further evidence within this Work Area will also come from collaborations with other work areas and external collaborators, including:

1. Exploration of the feasibility of assessing functional diversity and redundancy within our WrEN sites (In collaboration with Nadia Barsoum WA 2.4)
2. Theoretical work with Aberdeen and Southampton Universities to test the efficacy of various climate change adaptation strategies within real UK landscape on species persistence and range shifting potential (questions FCE3 & FCE4).
3. Provision of empirical data to test and validate various tools and indicators, in collaboration with Chloe Bellamy WA 2.6.

Work Area Title: 2.6 Spatial indicators of ecosystem services, biodiversity & resilience

Work area details:

Aims and Objectives:

1) **Synthesise information:** factors affecting woodland biodiversity and resilience, from site to landscape scale.
2) **Develop rule-based indicators:** for assessing woodland ecosystem services (including biodiversity) and resilience.
3) **Combine and apply indicators:** to provide measures of woodland multi-functionality and resilience.

Background:

To understand how we can best manage our wooded landscapes to maximise and secure the benefits they provide to people and wildlife, we need to know what benefits are being delivered where, and how resilient these areas are to potential threats and change. This Work Area will synthesise information on *how ecosystem services and biodiversity can be maintained whilst achieving resilience* (RC 1.4). It will provide spatial indicators of biodiversity, ecosystem services and resilience which, when combined, will help us to *quantify the range of ecosystem services delivered by forests and woodland* (RC 5.2) and their resilience *at a number of spatial scales* (RC 1.1).

Methods:

1) Collect and synthesis information from WA 1.2.1 – 1.2.5 (and external research) on the factors affecting woodland biodiversity and resilience.
2) Use this information to develop rule-based indicators e.g. if topographic complexity measured at the stand level, and the amount of ancient woodland within 3 km of a stand, are found to have positive associations with biodiversity, GIS will be used to measure these factors. These will be combined with other explanatory factors to provide overall spatial assessments of biodiversity and resilience potential.
3) Scope out the need for new ecosystem service indicators and identify those that we can develop with the most accuracy and confidence, given the tools and data available.
4) Combine new indicators with those previously developed by the Land Use and Ecosystem Service (LUES) Science Group (carbon, timber, recreation, flood mitigation and water quality) to *quantify the range of ecosystem services delivered by forests and woodland* and their resilience *at a number of spatial scales.*
5) Apply the indicators in case study areas validate with independent data from WA 1.2.1 – 1.2.5 (e.g. species data from the Woodland Creation and Ecological Networks project (WA 1.2.5).

WP Title: WP3 Risk and resilience

Indicative costs (£k):

2015-16	2016-17	2017-18	2018-19
260	260	260	260

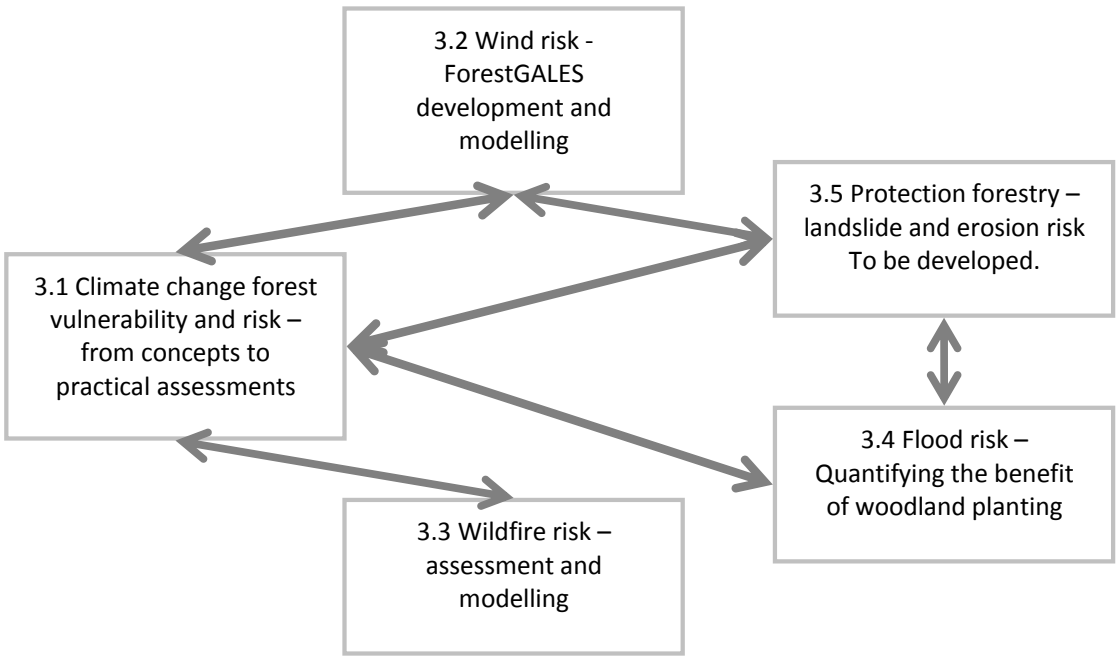
Work package details:

Work package 3 will **develop understanding of forest vulnerability and risk in relation to resilience**, to address Research Challenges 1.1, 1.2, 1.3, 2.4 and 2.5. The overall aim is 'to evaluate risks to forest resilience and develop appropriate indicators'. We will provide understanding of broad-scale vulnerability and the range of risks that have an impact on resilience, with four individual high profile forest risks examined in more detail: drought, wind, wildfire, and flood. Incorporation of other risks as work areas will be considered through the programme with initial recommendations provided by end of year 1.

A work area on forest management effects of landslide and erosion risk, and how forests can protect infrastructure, is seen as a priority for future research in this workpackage. This follows on from Scottish Government CXC funded research and a current PhD student with FR based at University of Dundee, however core funding has not yet been identified for future work. Funding options and proposals for a slope stability work area will be developed in Year 1.

The work package focuses on research and modelling of forest risk and vulnerability to abiotic factors, with the aim of providing high quality research to inform the development of practice and policy guidance. This package supports Programme 1, Programme 2, and Programme 3 work packages where vulnerability and risk are key components of assessing, understanding, and delivering resilient forests. Models and tools developed within this WP, including a new version of the established ForestGALES wind risk model that will work with CCF systems and broadleaf species, will be available for use online, and will link with GIS and for use in-house for landscape scale simulations linked into WP4 and Programme 3.

Interdisciplinary work and delivery within and across the work areas will ensure high quality scientific outputs, tools and advice applicable to policy development, forest planning and operational decision-making. The Work Package is comprised of five work areas with shared links (see figure below):



Work Area Title: 3.1 Climate change forest vulnerability and risk – from concepts to practical assessments

Work area details:

Background:
This work area aims to understand risk and vulnerability in the forestry and climate change context, and to assess different levels of risks for British forests. We will examine current and future risks – mostly abiotic – but also economic risks and risk perceptions by forest managers. Information from this WA will help to identify what adaptation measures are required to provide sustainable ecosystem services, and what measures are needed to increase resilience in the face of unpredictability or uncertainty.

Research challenges addressed:
- RC 1.1 How to define 'resilience' of different types of woodland with different objectives to different types of risk at different spatial/temporal scales
- RC 1.3 What are the pressures to which forests must be resilient over the next century?

Key objectives:
- To provide a conceptual assessment framework for climate change risks related to forests
- To assess key abiotic risks, including drought, for a range of species under climate change and attempt to combine them into integrated risk assessment
- To estimate drought risk for private forests – contribution to NERC PURE project
- To assess forest managers risk perceptions and their beliefs about climate change risks
- To provide support and coordinate forestry sector input into key UK climate change reports, in particular the CCRA2 and the LWEC Climate Change Impact Reports Cards

Methods:
- Literature review of vulnerability and risk assessment frameworks
- Expand the current drought risk assessment using UKCP09 data with new tree species. Use the historical data from the long-term experiments to improve risk estimates.
- Conduct study or focus groups with forest managers and planners
- Discussion, collaboration, and coordination with other land use experts for CCRA2

Key expected results:
- FC publications – a research note on current and future risks and vulnerabilities to British forests, and other publications on forest managers' risk perceptions
- Peer-review papers – drought risk assessment for new species, assessment of multiple forest ecosystem services under climate change, and forest managers climate change risk perceptions
- Input into the UK CCRA2 (Agriculture and Forestry chapter) and work with LWEC and partners to produce a Climate Change Impact Report Card (CCIRC) for agriculture and forestry sectors
- Conference papers – to national and international conferences, such as European Climate Change Conference (Copenhagen)
- Spatial maps providing information about different risks at various spatial scales

Work Area Title: 3.2 Wind risk - ForestGALES development and application

Work area details:

Aim: Understand the factors affecting the risk and resilience of forests to wind.

Background: Wind disturbance is the largest annual disturbance to forests both in the UK and across Europe, with more damage from wind storms than from any other biotic or abiotic agent. Wind limits planting locations, species choice, silvicultural system options, thinning options, harvesting systems and rotation lengths. Therefore as well as being a major factor in current forest management, wind restricts the available options for adaptation to climate change. Understanding wind damage to forests is therefore vital in developing resilient forests. Forest Research has built up expertise in the science of tree stability, wind damage risk analysis, assessing wind damage, and managing forests for improved resilience to wind. Much of the science around wind throw and wind risk management is embodied in ForestGALES, a PC-based wind risk model developed by FR that predicts the risk of wind damage to the average tree in an even-aged stand. ForestGALES was originally released in 2000, has since been modified to reflect developing science and knowledge, and is now widely used by the industry, and to support a range of research areas.

Objectives:

- Understand the impact of damaging winds on forests in relation to species (conifers and broadleaves), soils, terrain, wind climate and management, all in relation to climate change.
- Improve the ForestGALES wind risk model to provide estimations of wind risk to a range of forest types, from native woodland, through continuous cover to uniform stands.
- Provide guidance on wind risk from single tree to landscape scale, and support the uptake of risk management

Methods:

- Development of the model to calculate the wind risk to individual trees in uniform or uneven-structured stands. This will require a link to the mixed growth model – MOSES, in Programme 6.
- The model is currently limited to conifer species, but there is an increasing demand for it to calculate risk to broadleaf tree species, both for risk assessments to individual stands and modelling at the landscape scale. Data will be gathered from literature and from new focussed research to allow wind risk analysis of broadleaf species.
- The model currently lacks acclimation of trees to wind exposure over time and following thinning. Trees strengthen themselves in various ways to resist wind, and the model will be modified to reflect this ability based on past and new research.

Key expected outputs:

- wind risk and management advice and guidance to the industry
- a manual on managing wind risk to forests in a changing climate
- a new online and GIS enabled model that calculates wind risk from individual trees, through stand scale, to landscape scale, and works with uniform or mixed stands of either conifer or broadleaf species.

Work Area Title: 3.3 Wildfire risk – assessment and modelling

Work area details:

Aims:
To enable FR to:

- support work on the assessment of fire risk on the Public Forest Estate (PFE), (including to assist with spatial and temporal analysis of the newly available wildfire data for GB/UK)
- assess the measures being taken for reducing risk
- build contacts with the Met Office and other researchers on their fire weather severity warning systems, and climate change impacts on it
- continue to evaluate strategic tools such as WTA for their use in the UK.

Background: The risk of wildfire was added to the National Risk Register in 2013, and the likelihood of a severe wildfire was assessed as between 1 in 20 and 1 in 200 probability in the next 5 years. Recent recording of wildfires has improved, and show that wildfires in England averaged over 5k ha in 2009/10-2010/11; there was about twice that area affected in Scotland. Many of the wildfires affect woodland, either starting there or entering woodland. The CCRA identified that wildfire risk was increasing due to climate change (both directly through weather, and indirectly through effects such as tree disease increasing fuel loading). The FC has published a recent Practice Guide on *Building Wildfire Resilience into forest Management planning* (PG022) and the UKFS includes contingency planning for wildfire as a good practice requirement. A few FC districts (e.g. South England in Dorset) have started to assess risks and to plan and implement measures to reduce them. However, there is no established methodology to assess wildfire risk strategically in the UK, and how it might change with climate change regionally, and how forest resilience might be affected by risk reduction measures locally.
FR has worked recently (externally funded) on projects with FCE and fire research groups to examine whether strategic wildfire risk assessment approaches used in other countries (e.g. the Wildfire Threat Analysis, WTA) could be applicable here.

Methods: The first phase of the work will be to identify specific requirements for wildfire risk assessments and gaps for the PFE; to assess take-up of the PG022 recommendations in the private sector and to what extent contingency planning is occurring and to explore further opportunities for externally funded collaborations on wildfire risk. It links to other WA in this WP about risks, and to other WP, for example in providing information about ecosystem service losses through wildfire, and information on C & GHG impacts of wildfire.

Work Area Title: 3.4 Flood risk – Quantifying the impacts of woodland planting

Work area details:

Aims: To quantify the impacts of woodland planting and management on flood flows to help guide planting the right tree in the right place to reduce downstream flood risk (Programme 3) and underpin the valuation of forest water services and costs (Programme 4).

Objectives:

- To measure the effects of woodland planting and management, including large woody debris dams, on flood flows and flood water storage.
- To use data to help validate flood models and upscale effects to the catchment level.

Methods:

1. Monitoring the effects of woodland establishment and management on flood flows at four experimental sites or case study catchments in England, Wales, and Scotland.
2. Statistical analysis and modelling of data to determine impacts.
3. Writing reports and papers summarising the key findings

Details of the four experiment sites/catchments are:

1. Assessing the effect of semi-natural floodplain woodland, including large woody debris (LWD) dams, on flood flows at Great Triley Wood, near Abergavenny in Wales. Work will involve measuring and modelling interactions between woodland and flood water levels across a range of flood events, changes in flood response above and below large woody debris dams.
2. Measuring the effect of the establishment of new floodplain woodland on flood flows at two sites on the upper River Parrett in Somerset, SW England. Work involves monitoring river water levels above, alongside and below young woodland planted on the floodplain during a range of flood events. The development of hydraulic roughness is also being recorded. Field site also used by FC funded PhD study at Cardiff University.
3. Assessing the effect of recently planted riparian woodland along the Burnhead Burn on flood flows at Eddleston in the Scottish Borders. Monitoring changes in river water levels above and below the planted riparian woodland to determine the impact on flood response - development of 1-D catchment model. Study linked to funder partnership with Dundee University.
4. Measuring the effect of recently planted woodland, constructed LWD dams, timber minibunds and other land management measures on flood flows at Pickering in North Yorkshire. Work involves monitoring and modelling river water levels above and below the developing measures to determine their impact on flood response. Evolution and stability of LWD dams and timber minibunds will be recorded. This continues the "Slowing the Flow" partnership, for which external funding from Defra ends in April 2015.

Impact/outputs: The results will improve understanding of interactions between woodland and flood flows, and the contribution of woodland creation to managing downstream flood risk to help target planting (Programme 3) and support valuations of forest water services and costs (Programme 4). The work will inform the case for increasing fiscal incentives for woodland creation for sustainable flood management, as well as garner support from government departments, water regulators and agencies to include forestry-based measures in flood risk management planning.

WP Title: WP4 Resilience at multiple scales

Indicative costs (£k):

2015-16	2016-17	2017-18	2018-19
244	244	244	244

Work package details:

The aim of Work package 4 is **to develop understanding of resilience in the context of sustainable forestry and forest ecosystem service provision when considered at multiple scales, including within the wider landscape and cityscape**, addressing Research Challenges 1.1, 1.2 and 1.4. Fundamental research, tools, advice and linkages to other Programmes will be provided. Specifically, this Work Package will develop an understanding of the impact of urban forest composition on function, ecosystem service provision and resilience to climate change, in order assess, quantify and, where relevant, develop indicators for ecosystem service delivery and resilience at multiple scales, and deliver advice on the use of afforested peatlands and other open habitats.

The Work Package will seek to provide the evidence that is required to identify the costs and benefits of the necessary forest management and woodland creation decisions needed to improve resilience and expand our woodland resource. Multidisciplinary delivery within and across the work areas will ensure highly valued quality scientific outputs, tools and advice applicable to policy development, planning and operational decision-making. The Work Package comprises the following work areas:

- Landscape scale forest ecosystem service simulation and ESC development
- Urban forest resilience
- Afforested peatland restoration and ecosystem services

Work Area Title: 4.1 Landscape scale forest ecosystem service simulation and Ecological Site Classification (ESC) development

Work area details:

Aim: Simulate landscape scale ES delivery from Forest Districts and in the private sector through 21st century under climate change and socio-economic scenarios

Rationale and business case:

a) ESC is widely used in the private and public sectors for forest planning and forest expansion. It is now used to indicate tree species suitability for the new SRDP forestry grant scheme. However there are uncertainties with the model in relation to degrees of projected drought stress between 2050 and 2080. To continue to be useful to project species suitability with the new AR5 projections (11-member RCM) further into the future we need to research and adjust the calculation of moisture deficit.

b) ESC is central to FR's landscape scale forest ecosystem service simulations, using links to a suit of other models. The EU FP7 MOTIVE project resourced simulation development in Britain, to provide evidence for resilient forest management adaptation strategies. This was developed, used and disseminated in the forests of North Wales, South Scotland, Central Scotland, and Lochaber. Using the simulation, FR has provided FDs with evidence of the impacts of different adaptation management approaches through the uncertainties of climate and socio-economic change on ES indicators forward through the 21st century. FDs have been enthusiastic and FC Scotland has asked for national scale evidence of ES delivery from the NFE.

Objectives:

a) Develop, test and deploy 4 new ESC improvements to help projections of species suitability

b) Provide dynamically coupled simulation using existing forest models to assess changes in the provision of ES in future climates, and in relation to alternative management strategies developed in discussion with the sector; Implement valuation studies to assess the usefulness of monetised services in forest planning; Encourage the private sector to embrace climate change adaptation of forests through simulation, cost-benefit, and abiotic and biotic disturbance impact simulations

Methods:

a) ESC will be developed to better accommodate climate projections: 1) introduce available water capacity (AWC) soil storage component to better simulate water budgets for calculation of high moisture deficits, 2) 3 Very Poor Soil Nutrient Regime sub-classes, 3) dynamics between soil dryness and nutrient availability, the effects of drainage on SMR, 4) validate more tree species ESC yield predictions. AWC (from FP7 Trees4Future) will be applied. The 'very poor' soil nutrient regime class will be subdivided. A literature review validation for water stress and nutrient availability will be provided.

b) Simulation studies test forestry policy and practice into the future. The simulation dynamically links ESC, ForestYield, ASORT, BSORT, CSORT, and ForestGALES spatially to the SCDB. Forest Management trajectories determine the type of forestry to be applied in different parts of the forest. Forest growth is simulated each year, and ES indicators reported at decadal intervals. This is a small modelling package that has already been developed and is now at a wider testing phase. Currently 9 ES indicators have been deployed. New methods for ES will be developed through linkage to P1WP2 and P3WP1. Cost benefit methods and UKNEA down scaling will be undertaken in P4WP3, and the preparation and agreement of simulations for Forest Districts will be the focus of P3WP1WA1. We will scope methods for extreme weather impacts.

Work Area Title: 4.2 Urban forest resilience

Work area details:

Aim: Assess the resilience of the urban forest of major towns and cities across the UK

Objectives:

- Describe the composition and structure of urban forests across the UK
- Improve the use and uptake of tools for detailing urban forests
- Evaluate reliability and comparability of urban forest datasets
- Risk assess the resilience of urban forests to a changing climate
- Provide quality datasets to guide urban forest valuation and succession planning

Methods:

The main aim of this work is to construct key datasets for assessing the resilience of UK urban forests. Mapping and describing the forests are necessary first steps to the aim; they are the key to understanding where the urban forests are located, their species composition, age structure and condition. Empirical data collection, secondary data-mining and cross-validation with remotely sensed data will be required.

Datasets from third-party use of i-Tree Eco and Treezilla will be interrogated and adapted to create a single inventory of the UK's urban forest. This will be disseminated via the internet, in association with external partners, and form the basis of step two: evaluating urban forest composition to help assess risk against projected climate change, pests and diseases and identify specific adaptation challenges. The evaluation will consider the role of ownership - of garden trees, street trees, parks and woodlands in providing a diverse forest, and the impact of modelled changes to urban forest size, structure and composition.

To construct the urban forest inventory, we will maintain our national role in coordinating the development of I Tree Eco and Treezilla, a role that has enabled FR to become central guardians of all data arising from Eco surveys. We will continue to work with the Open University and the tree health citizen science forum to improve the role of such tools and citizen science for monitoring the urban forest. Collaborations with FR's social scientists and economists on how i-Tree surveys are impacting urban forestry decision making (P3), and what is the role of different funding mechanisms to sustain i-Tree Eco surveying across the UK (P4) will be fed into this Work Area to guide the on-going development and uptake of the tools. Analysis of the urban forest datasets will inform understanding on what adaptation measures and management changes are required to maintain and increase urban forest resilience.

Outputs from this work will underpin forestry strategies by helping clarify the role of urban forestry and green infrastructure in delivering healthy communities, people connected with nature, socio-ecological and urban resilience to climate change, and by feeding into the London and Urban Forestry and Woodlands Advisory Committees (FWAC). By delivering professionalism and scientific expertise into the development, application and utilisation of tools for assessing urban forests, this work will provide credibility to the nationwide urban forestry datasets, and the reports and recommendations that arise from them.

Work Area Title: 4.3 Afforested Peatland Restoration and Ecosystem Services

Work area details:

Aim: To improve understanding and the evidence base on how changing land use affects the balance of ecosystem services from afforested peatland and other open habitats.

Objectives:

- Quantify gains and losses of key ecosystem services when afforested peatland is restored or converted to peat edge woodland.
- Scientific input to policy and practice, including through LIFE Peatlands IP bid.

Methods:

The main aim of this work area is to obtain the knowledge and evidence needed to give sound, scientific advice to government and the industry on use of afforested peatlands and other open habitats. The outputs from this work will underpin forestry strategies by providing evidence where there are currently gaps in our knowledge and understanding, including on where woodlands should be located for optimum ecosystem service delivery within the wider landscape and how structure and composition of forests need to change in order to integrate more closely with other land uses.

This work area will capitalise on research undertaken throughout 2010-14 and complete two trials of rewetting methods for cracked peat sites to confirm the feasibility of successfully restoring such sites to open peatbog habitat. Studies of peatland restoration, drainage impact and peat subsidence will be completed and written up for publication.

We will undertake a field-based study of how key ecosystem services (wood provision, habitat provision, climate and water regulation and possibly cultural services) are affected by changing land use on afforested peatland. This long term study will provide an adequate baseline and will draw on a range of FR specialist expertise. It will complement the Flow Country Research Hub chronosequence study and will provide data useful for other FR programmes and for the Woodland Carbon Code carbon stock models. The balance of gains and losses resulting from the land use changes will be determined by cost-benefit analysis. We will participate through the Flow Country Science Group in setting up and overseeing monitoring of forest edge removal effects in the Flow Country.

External funding will be sought through consortia with universities and other external partners. Bids already underway include those with York and Aberdeen Universities and UHI for Leverhulme Trust and NERC CASE studentship funding for the study of carbon stock comparing unafforested and afforested peatland; these will be developed and submitted. We will continue to provide support to forestry policy teams in Wales, England and Scotland, helping them to develop and implement their separate policies in relation to peatlands. FR will participate in and thus influence the development of the Defra-led UK-wide LIFE Integrated Project, Peatland Restoration for Climate Adaptation. Bid development has started but the main effort will be via Working Groups in 2015-16 and 2016-17. Assuming bid success, the project starts early in 2017 and it is anticipated that FR will have substantial involvement, which will require 40% match funding through this and/or other appropriate work programme(s).

WP Title: WP5 Quantifying changes to resilience

Indicative costs (£k):

2015-16	2016-17	2017-18	2018-19
697	697	697	697

Work package details:

This WP will contribute to the **quantification of resilience, and understanding the influences on it (RC1.2).** Its prime approach is to assesses the functioning and state of particular well-studied example forest stands or catchments in order to examine forest change over time, to inform the **quantification of ecosystem services (RC5.2 & FCS)** (particularly climate control through GHG balance, soil C & nutrient protection and water quality and acidification), and **quantifying the benefits of woodland creation and management (FCE)**. It will help identify the **pressures to which forests must be resilient (RC1.3)**, and also **assess the risks (RC1.1)** to these services, informing other WPs within this programme, and it will provide understanding and expertise to underpin advice and guidance for policy and practice (**KE role, Research Area 10)**). There are 4 linked WAs:

WA5.1 *Integrated monitoring of ecosystem change* builds on 20+years of work assessing change to example conifer and broadleaf forest stands, to provide important understanding of change drivers and processes through the Level II and ECN assessment work. Most importantly, the FR work is embedded within European and UK (respectively) networks, providing much wider and more powerful information on changes in forest function and resilience. In addition, it leverages considerable expertise and resources, particularly in the interpretation and communication of results, including multidisciplinary research.

WA5.2 *Quantifying forest stand C & GHG dynamics* pushes forward our understanding of the benefits of forest management on stand C & GHG balances, by detailed study of GHG emission and sequestration rates in two contrasting managed stands – lowland oak and upland Sitka spruce. The oak site has a unique 16 year CO_2 uptake/emission and is part of the ECN (WA5.1), providing valuable data synergies. The key experiment at the spruce site is assessing the effect of clearfell on C & GHG balance. The WA builds on multi-year results, development of new methodology and substantial leveraged external funding and collaboration resources. As in WA1, the work contributes to, and benefits from, national and international research networks on quantifying C & GHG balances and land use change. It particularly informs Programme 6.

WA5.3 *Protecting soil C and function* works across a range of sites to quantify forest soil C and nutrient stocks, and assess the impacts of climate change and pollution through temporal and spatial studies, including intensive re-sampling studies. Its outputs underpin national reporting, policy and practice guidance on forest soil management and it will also use soil monitoring data to guide protocols for soil assessment in the NFI and other soil networks. It links strongly with WA1, and with WA2, and informs P2 through providing soil information to inform p & d threats and predisposition factors. Collaboration across Europe is also a key component, providing expertise, comparisons and contrasts for understanding forest soil function and resilience.

WA5.4. *Impacts of forestry on acidification* involves the long-term evaluation of forestry impacts on surface water acidification, and is designed to check that implementation of good forest practice by the forest industry prevents deterioration in water quality, and maintains ecosystem resilience. It works within important UK water acidity monitoring networks, and thus leverages substantial information, expertise and collaboration. The WA outputs will help underpin the Forests & Water Guidelines and new Practice Guide on managing forestry and acidification, providing essential KE for policy and practice. It links to, and informs, Programmes 3 & 4.

Work Area Title: 5.1 Integrated monitoring of ecosystem change

Work area details:

Aim: to use the example long-term forest monitoring sites to determine the function and condition of the forests and how they are responding to well-quantified environmental change and anthropogenic pressures, in order to understand the influences on resilience and the pressures on forests.

Objectives:

- To detect and understand environmental change (e.g. to woodland flora and fauna, tree growth, nutrient status, soil C and drainage water quality) and potential risks to forest resilience.
- To assess effects of climate variability and change, air pollution and management on forests and to attribute cause and effect from multiple acting factors
- To use this information to help the development of policy and guidance on protecting species and improving woodland habitats through management,
- To provide a harmonised set of data within UK and European networks which is used to support many aspects of research into forest function, ecosystem service provision and resilience.

Methods:

1. *The Integrated Forest Monitoring network (IFM)* facilitates periodic, highly standardised and quality controlled measurements of environmental and silvicultural variables enabling scientifically valid statements to be made on the state of selected GB forest stand types. This WA will support the 5 sites currently operating, (SS x 2, SP, and OK x2). They feature environmental contrasts that help the evaluation of forest ecosystem responses to climate change, pollution and pests and diseases. The sites form part of the European ICP forest monitoring network (Level II), integrate with the NFI, and measurements are compatible with the Biosoil network.
2. The Alice Holt Environmental Change Network (ECN) site is part of a multi-agency programme with the principal objectives of providing an evidence base and early warning system for the impacts of climate change on ecosystems across the UK. Alice Holt is one of 12 ECN terrestrial sites, and although measurements are concentrated in OK stands and chronosequences, it includes measurement in other broadleaf and conifer stands across the AH Research Forest. It contributes to European and global long-term ecosystem monitoring networks and initiatives, including ALTER-NET, LTER and ILTER. The monitoring integrates closely with the Straits C & GHG flux site, and contributes to the 'core' measurements of the Research Forest. The work regularly attracts collaboration with UK and other researchers, including multi-site analyses and publications.

This WA provides detailed information on the functioning of the forest ecosystem and its interactions at a local, national and European scale. Assessments include change over time of the function of the forest stands, and can be used to assess ecosystem service provision, such as soil protection, C sequestration, fibre production and water quality. The detailed time series enable change to be detected and response to change (a component of resilience) to be identified. This work promotes multi-disciplinary research and facilitates modelling, essential for predictive purposes in a changing environment. Several collaborations using both data and the sties themselves occur both within FR and outside, so that these monitoring sites form critical infrastructure for other work.

Work Area Title: 5.2 Quantifying forest stand C & GHG dynamics

Work area details:

Aims: to quantify the key ecosystem service of C sequestration & GHG emission control of managed forest stands, using detailed measurements of component C stocks and GHG fluxes at example sites; to develop new measurements and analyses; and to understand climatic, management and other influences on the resilience of the C & GHG function of forests.

Objectives:

- Quantify the C & GHG balances of lowland oak woodland (Straits, AH) and upland conifer plantation (Harwood Forest, Rothbury), and changes during thinning and clearfell, respectively.
- Gather information and gain expertise to inform and underpin advice on forest management and C & GHG balances, and large scale GHG inventory reporting and modelling (P 6).
- Collect data to develop process-based models of C & GHG balances (P 6), and to assess risks to function and resilience from climate change (linking to P1 WP3 on risks).
- Continue participation in the NERC-funded 'GREENHOUSE' consortium on upscaling land use and land use change GHG balances.
- Provide foci through the site infrastructure and measurements for collaborations on new techniques and methodology, within FR and with external partners, leveraging resources.
- Contribute to major international measurement and analysis networks for forest and other ecosystem C & GHG balance (FluxNet, EuroPhen, PEN, ICOS), which facilitates collaborations and KE, and provides funding opportunities and leverages expertise.

Methods:

1. Information will be primarily derived from the two intensively studies sites, where C stock components and GHG fluxes are measured, the latter using soil and stem chambers and eddy covariance methods. It will be extended as opportunities allow.
2. Focussing measurement at key sites allows fuller quantitative balances to be constructed (and contrasted) and gaps to be identified and targeted (link also to P6 modelling analysis). It also provides a test bed for methods developed in other Programmes, e.g. Rapid C Assessment Protocol (P6).
3. Continue collaborative development of novel methods for C stocks, GHG flux measurements, and related key forest functional attributes with external partners (e.g. 'phenocams', dendrometers and dendroclimatology, contributing to stress assessment; UAV for monitoring & species classification; BVOC emissions monitoring, and ground truthing for remote sensing (link to P6).

The core of the work is at the Straits and Harwood sites, where there is already major infrastructure and instrumentation investment; we expect that intensive part to continue for at least 2 years. The work will be supplemented (particularly after 2015/16) with work on assessing management impacts on C & GHG balance e.g. at Shotts/Hartwood (wind farm development & bog restoration, (also afforested peat restoration, WA 4.3)), or East Grange (SRF development). Other work may target gaps in knowledge by working at locations within the Research Forest and/or Level II network. In Year 3 we will also investigate how to tackle the questions raised about the C balance of native woodland sites, by scoping a project that could use less intensive measurements, particularly Woodland Carbon Code and Scottish Forest Alliance projects, or even the WReN sites. Where possible, these new or renewed measurements will be developed in partnership with external collaborators.

Work Area Title: 5.3 Protecting soil C and function

Work area details:

Aims: to provide research, evaluation, knowledge and advice on forest soil C stocks, their variability, uncertainties and changes in order to underpin estimation and reporting of C & GHG balance of British forests, dynamic modelling, Woodland Carbon Code, Peat Carbon Code and forest C related policy; and to understand and quantify the influences of climate change, pollution deposition and other disturbance (related to Programme 2 and 3) on forest soil C, nutrient capacity, biodiversity and function (and its contribution to assessments of resilience).

Objectives:

- The overall objective of this work area is to evaluate through measuring, modelling and mapping the impacts of forests and woodlands on soil resources under a changing climate and changing pollutant emissions. This will contribute to the quantification of the physical benefits of woodland creation.
- Carry out soil survey and research in order to quantify soil C pools, nutrient pools, soil biodiversity and establish the links with soil functions. This research will contribute to C accounting and detailed understanding of the carbon and biogeochemical cycling in soils and establish links between soil biodiversity and soil and forest ecosystem functions and resilience.
- Exploration and integration of soil plot, landscape and national spatial and temporal survey data (last two decades) within an ecosystem services approach. Current data on soil, soil C pools and deadwood C will be further developed and integrated into forest C reporting and dynamic modelling.
- Provide guidance and expertise to the forestry sector on soil C and function in forests and woodlands, and comparisons with other land-uses.
- Continued development of links and collaborations with national and international research organisations and experts to inform KE.

Methods

1. Soil carbon and nutrients - Evaluating soil C stocks, nutrient capacity and deadwood from BioSoil, Level I and Level II surveys, and on soil C and nutrient changes from chronosequence studies and long term monitoring. There is support for PhD studentships with Reading University on soil C fractionation and Dissolved Organic Carbon.
2. Climate change and pollution impacts - Temporal and spatial studies at different scales aimed at providing data for soil and forest model development and testing to underpin climate and pollution mitigation policies. Evaluation of impacts of climate and pollutant change on soil solution chemistry (using Level II sites and BioSoil spatial datasets); and impacts of N deposition on soil and forest C and biogeochemistry (Thetford and Alice Holt long term experiments) with PhD (Essex University) on microbial communities and soil C and N processes, and PhD (Central Lancashire) on earthworms in brownfield land regeneration to woodland.
3. Soil monitoring – Evaluation of soil monitoring data to guide development of protocols, soil pedotransfer functions and to underpin soil assessment in NFI and other networks. Soil C uncertainties will be tested at different scales with soil monitoring network sites in the UK and EU (COST FP1305). Level II intensive forest monitoring sites will be sampled to evaluate changes to soil C and nutrients over time.

This WA links to all the other WAs within this WP, and to Programmes 2, 3 and 6. Collaboration will continue with UK Universities and research organisations (e.g. JHI, NSRI, CEH) and European partners (e.g. ICP Soil Expert panel, EU COST).

Work Area Title: 5.4 Impact of forestry on acidification

Work area details:

Aim: To quantify the impact of forestry on the ecosystem service of provision of good quality water, particularly to assess the impact on surface water acidification in order to help underpin the Forests & Water Guidelines and the new Practice Guide on managing forestry and acidification.

Objectives:

- The long-term evaluation of forestry impacts on surface water acidification through continuation of two forest water quality and chemistry projects in the uplands,
- To evaluate the chemical response of forest streams and control moorland catchments to forest growth, pollutant emissions reduction and interactions with climate change.
- To check that implementation of good forest practice by the forest industry prevents deterioration in water quality, and hence that ecosystem resilience is being maintained.
- The work will also inform Programmes 3 and 4.

Methods:

1. Continuation of the acid waters monitoring study in upland Wales (established in 1991) to evaluate the response of ten forest streams and two moorland controls to forest growth, emission reductions and interactions with climate change. This is a joint funded project with NRW and supplements the UK Upland Waters Monitoring Network (see below) with additional forest sites, as per the recommendation of the original Department of Environment/FC Darlington report. It involves monthly water sampling and chemical analysis at each of the 12 sites.
2. Support for continuation of the UK Upland Waters Monitoring Network, including annual funding for chemical monitoring of three forested catchment sites in Scotland (total of five forest sites in network; other two in Wales). The network is led by University College London and is partnership funded by government, water regulators, research institutes and others (Defra is the largest funder). Monitoring started in 1988 and involves a wide range of biological, physical and chemical parameters. The scope for incorporating a site in NE England (Kielder or North York Moors) will be explored.

The results will be used to answer the question from the Country stakeholders "*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*?". They will be used to test and refine the established approach and measures recommended by the Forests & Water Guidelines and the new Practice Guide to address the impacts of forestry on acidification. This will ensure that the potential for forestry to act as a pressure on the water environment is appropriately managed, helping affected water bodies to recover to good status, as required by the EU Water Framework Directive. Failure to continue these long term studies would make it difficult to assess the effectiveness of forestry management on water quality, especially under a future changed climate. This could result in forestry potentially delaying or reversing freshwater chemical and biological recovery, or woodland expansion and regeneration being unnecessarily curtailed.

Section 3. Communication strategy

Communications and knowledge exchange will be a priority for the Programme from the outset, and the strategy for delivery will be developed and updated throughout in consultation with the FR Communications team and CFS and country policy leads. Case Studies conducted with Programme 7 will be used to improve the focus and relevance of communications.

Results and findings from research in combination with expert knowledge from FR scientists in the programme will be communicated from the start of the project to answer country research questions and to address research challenges. Guidance will be updated and improved based on ongoing research work and as experiments are completed. Knowledge exchange will, in part, be in collaboration with Programme 3 where workshops and meetings will be used to focus the requirements of research and translate the needs of practitioners into the most relevant and focussed outputs.

Research results will be published in peer reviewed scientific journals to maintain and improve the quality of science, aiming for high impact journals when possible. Lower impact journals may be used when they provide a more appropriate way of communicating with target groups in the forest community. Scientific papers will be published in open access journals or journals that make papers open access within 12 months of publication. Each scientific paper will be translated into a short research note or equivalent for distribution amongst relevant individuals in forest policy or practice, and for wider circulation online. Research results will also be used to further develop FR tools, models and decision support systems, including Ecological Site Classification (ESC) and the ForestGALES wind risk model. These will continue to be fully published, accessible and validated. Translation of research results into guidance for policy and practice purposes will be conducted by FR staff in collaboration with CFS, FCS, FCE, and NRW staff, and will be made available in appropriate forms, including presentations, workshops, articles, briefing notes, and web pages.

Section 4. Collaboration and networking

Staff in the programme bring with them strong links to research communities within the UK, across Europe, and the wider world.

Collaborations with universities will be maintained and a number of PhD projects are supported across the Programme either through cooperation, supervision or financial support. PhD projects contribute state of the art research, and access to the wider academic community to push research forward faster in answering research challenges and questions. Strong existing collaborations with government and other research institutes in the UK will be maintained. For example FR will continue to collaborate with Scottish Government MRPs including James Hutton Institute, through participation in the Scottish Government 'ClimateXChange' programme.

FR has in the past, and will continue to, participate in many European Commission funded projects. The Programme will benefit from European project groups formed in previous projects as well as ongoing projects and new consortia being formed. Ongoing and planned EC projects include COST actions, and Horizon 2020 (details of these projects are provided in Work package and Work area descriptions). Opportunities will be pursued to develop new consortia, partnerships and funding streams, using, where appropriate, 'core' funds from the Programme for match funding.

In addition, the programme is closely linked with all other FR Programmes and staff work across them. The integration of ecological science and social science will continue to be developed as the work progresses in the Programme, and will be kept under constant review using close links between Programme 1 WP1, Programme 4, and Programme 7. Details of inter-Programme collaborations are provided in Work package and work area descriptions.

Section 5. Ethical and other considerations

5.1 Ethical considerations

No ethical considerations currently need to be addressed. This will be kept under review.

5.2. Government survey control procedures

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

None currently planned.