# Programme 2: Understanding Biotic Threats

## Section 1: Overview

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| Research Programme Title | Understanding biotic threats to resilience |
| Research Programme Short Title | Understanding biotic threats |
| CFS programme number | 2 |
| Version | 1 |
| Date | 26th February 2015 |
| Author | Sarah Green |
| Programme Life (Years) | 4 |
| Start date | April 2015 |
| Completion date | March 2019 |
| Cost of programme (£K) | £4504K (over 4 yrs) £1126K pa |

### 1.1 Summary of proposed research

This programme aims to increase our understanding of forest resilience to pests and pathogens and to mitigate risk of future outbreaks by; i) investigating how environmental factors influence pest and pathogen behaviour, ii) examining the evidence for natural resistance in UK tree populations, iii) identifying key future threats and promoting preparedness for them, and iv) investigating methods for improved surveillance and detection. Pest and pathogen infection cycles, populations, biotic interactions and mechanisms of dispersal will be examined in relation to environmental factors such as climate, soil type, host variability and forest stand structure. Healthy host trees in outbreak locations will be investigated to determine the potential for generating resistant populations to assist recovery of damaged ecosystems. Climate and landscape modelling in relation to pest and disease outbreaks will identify factors that make particular ecosystems more susceptible to infestation, including the role of human activity in spread. Future pest and disease threats will be identified from both national and global perspectives, involving surveys, literature review, data collation, climate modelling and an analysis of potential pathways of introduction of exotic organisms from source regions into the UK. Surveillance and detection methods will be explored for a range of pests and pathogens with a view to improving the speed and efficacy of control strategies, and to understand better population expansion of currently invasive species. This programme will provide the evidence base for managing resilient forests better able to cope with the biotic challenges of the 21st Century, ensuring the continued delivery of a range of quality services and benefits for industry and society. It will also inform national biosecurity policy aimed at reducing risks from future pest and pathogen outbreaks.

## Section 2: Description of work

### 2.1 Background

The UK's forest and woodland ecosystems are suffering from increasing impacts of pests and pathogens, primarily through the inadvertent introduction of exotic species, but also due to changes in the behaviour of native species. Climate change is also likely to further increase biotic damage to forests by expediting pest and pathogen life cycles and population pressure, and by causing stress in trees ill-adapted to a rapidly changing environment. Management practices resulting in high host density, limited genetic diversity, a lack of natural regeneration and planting outside the native range may be exacerbating these problems. Improving management to lessen the impacts of biotic threats is currently compromised due to a lack of basic biological understanding of the systems involved, including how environmental variables affect pest and pathogen life cycles and host responses, their potential spread, and whether natural resistance within tree populations can be exploited to build healthier forests and woodlands. Globally and nationally, a considerable diversity of pests and pathogens pose a threat to UK woodland ecosystems, and strategies for generalist surveillance and detection of these threats need to be developed. In this programme, scientists from a range of disciplines including pathology, entomology, tree breeding and genetics, climate and ecological modelling, and social science will collaborate to provide the evidence base for delivering forests with greater resilience to biotic threats. This work will complement a number of FCS/FCE, EU and Defra-funded research projects addressing threats to tree health.

### 2.2 Programme-level response to the research challenges

Understanding the impacts of pests and diseases on the retention and creation of woodlands, and promoting resilience in UK forest ecosystems to current and future biotic threats, taking into account climate change, are key issues underlying the Science and Innovation Strategy. In this programme, an interdisciplinary team will address the threats to UK forest ecosystems from pests and pathogens by providing the evidence base to deliver healthier and more resilient ecosystems.

One way to enhance resilience is by understanding the environmental influences on pest and pathogen behaviour, identifying influences that can be manipulated to reduce damage impacts, and incorporating these mitigating factors in forest design and management. Work package 1 will examine these influences, the long term aim being to produce a suite of recommendations for forest management including risk analyses for diseases. Epidemiology of key pests and pathogens will be studied under different ecological systems to understand population pressure, biotic interactions, infection cycles and damage impacts in relation to environmental variables such as climate, soil type, host variation and forest stand structure. At a broader scale, modelling will also elucidate landscape factors that make particular ecosystems more susceptible to infestation, including the potential role of human activity in spread.

Resilience can also be achieved in the longer term by exploiting natural resistance in tree populations. Work package 2 aims at achieving a greater understanding of natural resistance in larch, juniper, pine and Sitka spruce, involving a new collaboration between pathologists, tree breeders and geneticists. Healthy host trees in outbreak locations will be investigated, material collected and progeny/clonal trials established and challenged with the appropriate pathogen to determine whether they are indeed naturally resistant and whether this resistance is heritable. If so, there is potential for generating resistant tree populations to assist recovery of damaged ecosystems. To further understand host resilience, pathogen population studies, including genotyping and comparative genomics, will investigate population origins and pathways of spread, and estimate likely time frames for existence in the UK. In addition to elucidating the question of native vs exotic for two key pathogens, this work will help to unravel which part of

the disease triangle (host, environment, pathogen) has changed to increase the scale and intensity of damage in the last few decades.

Building resilience in forests to future biotic threats relies on understanding the nature of those threats and being prepared for them. Work package 3 will address this by using climate and environmental change spatial data to model a broad range of pest and disease outbreaks, identify how past climate trends can be linked to pest and disease impacts and whether certain parts of the country are more at risk than others under climate change scenarios. The broader threats posed to UK forests by invasive bark beetles and Phytophthoras will also be assessed. This work will inform forest managers and policy makers as to how forest resilience might change in the future. Work package 3 also aims to identify pests and pathogens not currently on the risk register but which can threaten UK ecosystems. This desk-based study will utilize the 'Trees 4 Future' database to identify global regions that climatically match the UK, and through a network of global contacts and literature search tools, identify the 'risky' genera known locally to exist there. Social scientists will identify pathways linking these regions to the UK.

Effective surveillance and detection methods are integral to rapid eradication or control and in understanding population spread of invasive species. In work package 4, improved surveillance methods for key pests and pathogens will be developed based on a greater understanding of their epidemiology. This work will include the use of novel tools such as mating disruption traps for invasive insects and remote sensing for tree health monitoring. Metabarcoding will also be explored as a tool for generalist surveillance and detection through a network of monitoring traps located at ports and other high risk sites for introductions.

## 2.3 Business Considerations

**Delivering against country research needs**

Improving resilience in forests and woodlands to pests and pathogens, including the influences of climate change, are core country requirements. This programme will examine, through detailed epidemiological studies, ecosystem effects on pest and pathogen behaviour to identify factors that can be manipulated or mitigated to reduce damage impacts. Using broader modelling approaches it will determine the extent to which climate and other environmental factors have influenced past pest/disease outbreaks and identify those parts of the UK most at risk from pest and disease under future climate change. Achieving long term resilience to existing pests and pathogens will rely on building natural resistance into our forests. This programme will explore the potential for selecting and breeding for natural resistance in several economically and ecologically important tree species. Understanding the interactions between exotic and native organisms will be addressed in several of the pest and pathogen research strands, for example *H. fraxineus,* OPM, PtLM and bark beetle surveys. Sitka spruce remains a major production species and will be studied in relation to risks from *Elatobium*, native and invasive bark beetles and drought stress. Grey squirrels cause significant damage in England and Wales, and the factors leading to bark stripping as well as survey methods for wider damage assessments will be studied across two work packages. The programme will deliver enhanced understanding of future threats including those pests and pathogens not currently on the risk register but which also threaten UK ecosystems, identifying pathways linking these regions to the UK and facilitating the development of diagnostic tools. To enable more rapid outbreak control, improved surveillance methods for key pests will also be developed based on a greater understanding of pest epidemiology and the potential for novel detection tools such as metabarcoding and remote sensing will be explored.

**Impacts and constraints**

This programme will deliver greater interdisciplinarity to the study of biotic threats, with highly focused biological research linking up with broader modelling and social science approaches to better understand pest and pathogen impacts at different scales. This programme will bridge the gap between fundamental science and the practical needs of stakeholders by producing evidence-based technical advice on how to manage forests with less vulnerability to outbreaks, in concert with high quality peer-reviewed publications building on the international science base and aimed at an academic audience. The research will inform national plant pathogen surveillance and biosecurity policy, providing the evidence for stricter measures against exotic organisms entering the UK and an updating of the Plant Health Risk Register. Constraints to achieving these impacts may result from a lack of effective stakeholder engagement. A knowledge exchange plan involving links with programme 7 will be developed to address this. Climate projections are subject to change, and new emerging pests and diseases may divert resources away from the main programme objectives. The short time scale in producing this proposal means that individual research approaches and priorities may shift during the first phase of the programme.

**Innovation potential**

The research in this programme will lead to a more fundamental understanding of the nature of biotic threats. Data generated will inform management and mitigation strategies, in some cases underpinning the development of resistant species breeding programmes, new control options (for example the *P. ramorum* Phosphonate work or novel insect control work area) and surveillance and detection tools with marketable value, such as metabarcoding. However, such innovations are a long term process and some (such as resistance breeding and control options) are likely to be continued to completion within Programme 3 'Delivering Resilience'.

## 2.4 Work packages to address the research challenges

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| WP1 | Environmental effects on pest and disease impacts |
| WP2 | Understanding natural resistance |
| WP3 | Future threats |
| WP4 | Surveillance and detection |

**WP Title: WP1. Environmental effects on pest and disease impacts**

Indicative costs (£k):

| 2015-16 | 2016-17 | 2017-18 | 2018-19 |
|---|---|---|---|
| 520 | 512 | 569 | 567 |

Work package details:

Work package 1 will examine the environmental influences on pest and pathogen behaviour, identifying those influences that can be manipulated to enhance forest resilience and improve pest/disease risk analyses. The following research questions will be addressed within five work areas;

- Which environmental variables promote or reduce pest/disease damage?
- What are the key epidemiological factors, including human factors, influencing pest/pathogen persistence and spread?
- Which are the least and most heavily impacted ecosystems?
- Do other biotic/abiotic agents interact to increase/reduce pest/disease damage?
- How can management mitigate impacts?

This WP links most closely with WP3 (Future threats) in terms of climate and ecological modelling of risk factors and also WP4 (Surveillance and detection). Dothistroma work will also involve close collaboration with Programme 3.

**Work area 1**

**Pathogen epidemiology in relation to distribution and impact**

Research will involve three pathogens with serious impacts across the UK; *Phytophthora ramorum*, *Phytophthora austrocedri* and *Dothistroma septosporum*. It is anticipated that improved disease risk analyses for all three pathogens will be derived from the data generated here.

For *P. ramorum*, studies will focus on what inoculum levels in the field are likely to result in foliar and bark infections of intact tissue by zoospores, focussing on comparisons between Japanese and European larch. Also, how changes in host tissues, particularly moisture content in relation to soil moisture availability and climate fluctuations, may alter the susceptibility of larch to EU1 and

EU2 lineages of *P. ramorum.* The potential of phosphonate as a management tool for *P. ramorum* will also be investigated.

*P. austrocedri* work will define the optimum conditions (temp, moisture, pH) for growth, sporangial production and zoospore release, and oospore survival and identify key mechanisms of spread, including human mediated spread in soil resulting from management and recreational practices. This work involves collaboration (mainly isolate exchange to enable comparative studies) with Argentinian researchers studying the pathogen in Patagonia. UK-wide modelling of the known distribution of *P. austrocedri* in relation to climate and landscape features will be done partly in collaboration with CEH (externally funded) and a risk analysis for *P. austrocedri* in Britain developed. A NERC-CASE PhD studentship entitled 'Evolutionary epidemiology of *P. austrocedri'* (2014-2018) will undertake aspects of this work.

Previous studies of *D. septosporum* in England indicate that the fungus may undergo two infection cycles per year under suitable weather conditions, with low levels of infection occurring all year round. Infection cycles of *D. septosporum* will be investigated in relation to climate and inoculum load, including the validation of a quantitative real-time PCR assay to measure inoculum loads in air and water. Additionally, a large dataset on *D. septosporum* occurrence in Britain since 2006 will be used to investigate links between pathogen occurrence and intensity, and climate, soil type and sulphur deposition data. This will illustrate the interplay between weather, inoculum load and infection levels and help to predict future risk of increased disease intensity under climate change.

**Work area 2**

**Spruce pests under changing climate and management**

Insect pest populations (*Elatobium,* bark beetles and saw flies) and populations of their natural enemies will be analysed in even-aged and mixed-age (group selection and shelterwood CCF) Sitka spruce stands to determine which types of forest suffer higher or lower pest populations and damage. Another research focus will be to investigate how populations of endemic bark-beetles (Scolytidae) and defoliating insects (i.e. *Elatobium*) of Sitka spruce will respond to the projected changes in climate. Experimental plots have been established on elevational gradients at forest sites in Wales and assessments of insect populations made using standardised trapping techniques. Information from both these projects and results from previous experiments on temperature tolerances in *Elatobium* will be collated to enable a new modelling analysis of how *Elatobium* responds to climate change.

**Work area 3**

**Understanding the causal interactions in oak declines**

Studies will continue investigating factors which may interact to cause symptoms of oak decline, linking in with the Defra-funded TH0108 project involving collaboration with RRes and the University of Bangor, particularly in regard to generating data to help improve models of Acute oak decline (AOD) distribution and disease risk prediction. Survey work will address knowledge gaps in the broader distribution of AOD and eight study sites will continue to be monitored intensively to identify changes in disease impacts over time and fungal and bacterial species present in bark lesions. Work will continue on the micro biota and insect species found on AOD affected trees with the overall aim of re-creating symptoms of AOD *in planta,* including i) elucidating the statistical associations between tissue condition and microbial taxa and ii) confirming pathogenic status of bacteria isolated from AOD lesions. Chronic oak decline (COD)

work will focus on analyses of root health and dendrochronology will be used to study historical patterns of growth in both AOD and COD-affected trees to look at environmental drivers of decline and tree health history. The life cycle and role of *Agrilus biguttatus* in AOD will also be investigated to determine whether adults can transmit bacteria. Another key objective (also investigated through dendrochronology) will be to determine whether trees affected by AOD are predisposed to *A. biguttatus* by primary stress factors (for example drought), or a longer term decline (e.g. COD) and to identify the point at which trees become susceptible to colonisation by *A. biguttatus.* An externally funded PhD studentship forms a key part of the *A. biguttatus* work.

**Work area 4**

**Biology and ecology of introduced pests**

Research will involve three important invasive pests; Asian longhorn beetle (ALB), oak processionary moth (OPM) and pine tree lappet moth (PtLM). The overall aim of this work will be to understand the history and development of outbreaks at different sites, and the possible role of natural enemies in suppressing insect numbers, so that risk-based management strategies can be devised.

Data on host preference, life cycle and spread of Asian Longhorn Beetle will be analysed and written up as a case study of how this invasive pest performs in southern England.

The population ecology of OPM and its parasitoids will be studied to identify the conditions under which severe infestations are most likely to develop. In 2015/16 this work is funded by FCE through a PhD student based at the University of Southampton and post-doc based at Hull University. A key objective is to develop a DNA library for the parasitoid and predator species attacking OPM. This will facilitate a molecular study in 2017/18 of how interactions with other insect species affect the distribution and abundance of OPM, whether parasitism and predation of OPM are increasing as the moth becomes established, and whether current spraying regimes are having a negative impact on parasites and predators.

A PhD studentship with the University of the Highlands and Islands (2014–2017) will look at factors controlling the abundance of PtLM and other insect pests of pine forestry in north-east Scotland. This includes identifying parasites and predators and determining the role of forest structure in regulating numbers of insect pests that damage pine. This project will also aid in assessing the long term threat from PtLM in the UK and provide evidence to underpin future management strategies.

**Work area 5**

**Understanding causes of bark stripping in grey squirrels**

This work area currently comprises a PhD studentship (until Oct. 2016) aimed at determining whether calcium deficiency in squirrels is a primary motive for bark stripping. Future research will focus on investigating why some tree species are damaged more than others, including climate aspects, for example to understand why damage might increase after hard winters.

**WP Title: WP2. Understanding natural resistance**

Indicative costs (£k):

| 2015-16 | 2016-17 | 2017-18 | 2018-19 |
|---|---|---|---|
| 265 | 265 | 290 | 300 |

Work package details:

WP2 aims to achieve a greater understanding of natural resistance in a number of key host species. The overall hypothesis is that individuals with greater heritable resistance can be identified. The long-term goals of this WP are to generate resistant tree populations to assist the recovery of damaged plantation forest and natural woodland ecosystems and promote management methods that exploit natural resistance. The following research questions will be addressed in six proposed work areas;

- Is there evidence for natural resistance in host populations?
- Is it feasible to select for quantitative resistance in a host breeding programme?
- How can pest/pathogen population studies help us understand host resilience?

This WP will formally establish a collaboration between pathology and tree breeding/genetics, and will link in with both WP1 (understanding infection/population cycles in relation to host damage) and WP3 (genetic analyses of *P. ramorum* populations in terms of future risks posed by the dominant genotypes). Work on drought susceptibility in Sitka spruce will link with Programme 1 Risk and Resilience 'climate change vulnerability and risk' and proposed health assessments of alternative species and provenance trials will also link in with Programme 1 'Understanding the influence of tree species origin and the composition and structure of forest stands on forest biodiversity and resilience'. Tree breeding work will link with both Programme 3 'resistance breeding in ash to *H. fraxineus*' and Programme 5 'species breeding plans'.

**Work area 1**

**Resistance in larch to *Phytophthora ramorum***

Cones and scion material for grafting will be collected from healthy individuals within larch stands infected with *P. ramorum* and the progeny grown on in a nursery for field assessments of heritable resistance. A proposed PhD studentship will use the resources in Glentrool forest (where infected larch stands are being held over for research purposes) to study natural infection processes and physiological host responses in larch trees showing different levels of disease, including European (EL) and Japanese larch (JL). JL and EL will also be challenged in non-wound experiments to determine bark susceptibility to EU1 and EU2 lineages and sporulation using levels of inoculum that reflect those found in the field. If an Oxford led LWEC proposal is successful, this experimental approach will be extended to studies exploring how larch tissue responds to infection by *P. ramorum*, what the processes are, and what the genetic basis of this host-pathogen recognition process is. This could form the basis of selection criteria required for breeding for resistance against *P. ramorum* in larch, and would make use of available and new data on genome sequencing for *P. ramorum* and *P. lateralis* being provided through collaboration with Genome Canada.

**Work area 2**

**Understanding resilience in pine to *Dothistroma septosporum* and PtLM**

Population genetics of *D. septosporum* will be examined to i) investigate population origins and pathways of spread, ii) estimate likely time frames for population existence in the UK and iii) determine whether pine species and provenances differ in their susceptibility to different pathogen genotypes. One hypothesis being tested is that *D. septosporum* has been present in Britain for much longer than previously thought and that resilience in UK pines is related to the length of exposure to different pathogen populations. This work will involve phylogenetic analyses of microsatellite and genomic resequencing data from isolates representing six genetically distinct *D. septosporum* populations in the UK together with a broad range of isolates from across Europe and potentially worldwide, utilising international collaborations established through the DIAROD COST action and an on-going collaboration with the University of Edinburgh. Estimates will be provided for the length of time to which Scots pine has been exposed to different pathogen populations. A PhD studentship is already exploring the susceptibility of provenances of Scots pine to *D. septosporum* in pot and field based infection trials. To develop this work further, pathogenicity of the six UK *D. septosporum* populations will be tested on pine provenances to assess the risk of increased future damage through population spread. This work will unravel which part of the disease triangle (host, environment, pathogen) has changed to create the scale and intensity of *D. septosporum* in Britain, allowing a greater understanding of future risks to Scots pine.

The work aligns well with FR involvement in the LWEC PROTREE project 'promoting resilience of UK tree species to novel pests and pathogens: ecological and evolutionary solutions' in which Scots pine is used as a model species in which to develop a holistic understanding of resilience of our trees to future biotic and abiotic threats, including an analysis of the genetic and environmental components of pine resistance to PtLM. This element of the project will determine how PtLM larval food utilization, growth and fitness is affected by variability in host provenance by comparing chemical and morphological resistance traits among i) natural Caledonian pine woods, ii) commercially planted woodlands and iii) putative alternative host species. Pine shoot food material will be assayed by JHI for needle toughness characteristics, phenolics and their glycosides, monoterpenes, sesquiterpenes and alkaloids and the analyses will also monitor natural phenological changes and any induced chemical changes in needles.

**Work area 3**

**Understanding resilience in juniper to *Phytophthora austrocedri***

To test the hypothesis that there is natural resistance in native juniper to *P. austrocedri,* cuttings will be collected from healthy juniper individuals within outbreak sites in the different seed zones and a clonal nursery established for pathogenicity testing with *P. austrocedri*. Juniper from three different provenances already growing in the nursery will be included in the inoculation trials. DNA will be extracted from healthy and symptomatic juniper at different sites and analysed using already available microsatellites to look for 'resistant' genotype markers. NERC and FCS funded projects will explore the population genetics of *P. austrocedri* through genome sequencing and microsatellite analyses, involving collaboration with the University of Edinburgh and Edinburgh Genomics. This work will test the hypothesis that *P. austrocedri* is a recent introduction into Britain and is genetically distinct from the pathogen in Argentina (thus originates from an unknown location). It will also aim to elucidate 'source' populations and routes of spread within Britain.

**Work area 4**

**Drought tolerance in Sitka spruce**

This work will involve visual assessments of drought cracking and other drought damage indicators in existing Sitka spruce clonal trials and Sitka spruce x white spruce hybrid trials, the hypothesis being that genetic variation in drought tolerance exists within the species, and within hybrids. If this hypothesis is true, a feasibility study will determine the potential for incorporating genotypes of apparently greater drought tolerance for planting on drier sites.

**Work area 5**

**Tolerance in horse chestnut to bleeding canker and *Cameraria ohridella***

This work will build on two projects: (1) a six year study which has led to an advanced understanding of the epidemiology of infection and spread of the bacterial bleeding canker pathogen *Pseudomonas syringae* pv. *aesculi*, the genetics of the host-pathogen interaction, and the evolutionary processes by which *Pseudomonas syringae* pathovars have evolved to infect woody hosts, and (2) a long term monitoring project set up in England in 2002 to quantify the long-term impact of the leaf miner *Cameraria ohridella* on red and white horse-chestnuts and to investigate the interaction between the leaf miner and bleeding canker symptoms. The objectives of this proposed work area are i) to continue the long term monitoring project in order to gain field data on potential resistance to *Cameraria* and bleeding canker and ii) propagate from white horse chestnuts with apparent tolerance to bleeding canker and leaf miner with a view to developing a breeding programme to replace lost urban shade trees. External funding will be sought in collaboration with Keele University to investigate further the genetic nature of the bacterial/host interaction.

**Work area 6**

**Health assessments of novel species and provenance trials**

There is a national resource of novel species and provenance trials planted out across Britain to assess their future suitability as alternative species in forest and woodland ecosystems. The widespread planting of non-natives is potentially a high-risk approach, not only in terms of new biotic introductions, but also because non-natives may have little resistance to Britain's existing pests and pathogens and suffer greater attacks, thus raising pest and pathogen population pressure and risk of further epidemics. It is proposed here that a PhD studentship is funded to test the hypothesis that novel species/provenances in already established trials are more susceptible to endemic pests and disease than native species/provenances. This work will link in with general assessments of survival, growth, phenology and associated biodiversity conducted within Programme 1.

**WP Title: WP3. Future threats**

Indicative costs (£k):

| 2015-16 | 2016-17 | 2017-18 | 2018-19 |
|---|---|---|---|
| 210 | 215 | 190 | 195 |

Work package details:

Building resilience in forests to future biotic threats relies on understanding the nature of those threats and being prepared for them. The overall aim of WP3 is to identify key future threats and promote preparedness for them. An element of this preparedness will stem from a better understanding of past outbreaks in addition to future predictive analyses of spatial distribution. The following research questions will be addressed in four work areas;

- Which environmental variables promote pest/disease damage?
- Which are the least and most heavily impacted ecosystems?
- How can we be better prepared to rapidly assess risks from new pests and pathogens as they arise (or undergo population expansion) in the UK?
- What are the pest/pathogen 'source' regions that climatically match the UK and which 'risky' genera are known locally to exist there?
- What pathways link these regions to the UK?

This WP links with WP1 work areas aiming at improved pest/disease forecasting based on climate interactions. It also links with WP4, surveillance and detection, and Programme 3 (Impacts of pests and diseases).

**Work area 1**

**Climate modelling to understand pest and disease impacts at national and regional levels**

As pests and pathogens are sensitive to climate conditions, this work area will build upon past and present climate modelling for the UK (i.e. last 50 years and future scenarios) and knowledge of pest sensitivity to environmental conditions (for example temperature, moisture, nutrient deposition) to investigate the relationship between specific climate conditions and known distribution for a broad range of pests and pathogens. Environmental change network data (i.e. on phenology and nutrient deposition) will be included in the analyses. This will involve collaboration between climate and species modellers, environmental scientists and tree health project leaders. The work will determine the extent to which climate has influenced past outbreaks, what and when future outbreaks we can expect, and whether some parts of the UK are more at risk than others. Estimates of future changes in spatial distribution of these threats under climate change will be generated. This work will link in with the European Cost Action PROFOUND (Climate Change and Forest Disturbance).

**Work area 2**

**Risks to UK forests from invasive bark beetles**

Species composition and richness of bark beetle communities will be determined in a range of UK forest types (pine and oak currently, spruce in future). A baseline data set will be compiled against which future changes (due to the impact of climate or invasive species) can be measured. This work will identify vacant niches which may be exploited by invasive species and determine the vulnerability of key UK forest types to the establishment of such species based on the abundance and diversity of the native bark beetle community. The influence of forest management practices upon bark beetle community structure will also be investigated, identifying how management might help protect against the establishment of invasive species. To date, three invasive species new to Britain have been found; risks will be assessed for these and any additional exotic scolytine species identified in the study. Fungal associates transported by the scolytines will be characterised in collaboration with Imperial College London, and any potential vectors of pathogens identified.

**Work area 3**

**Risks to UK forests from Phytophthoras**

Data on *Phytophthora* occurrence in the UK will be collated from THDAS and survey records to yield detailed maps of the distribution of existing *Phytophthora* species. Sequencing will also be done of *Phytophthora* isolates in the culture collection that have not yet been identified to species level. The analysis will provide baseline data on the presence of Phytophthoras in Britain (extending back over the past 20 years). This would also complement a recently initiated metabarcoding project (FCS and FCE funded) aimed at detecting *Phytophthora* species in the wider environment (mainly focused on Scotland and involving a sequencing collaboration with JHI). Linking in with work area 1, distribution mapping will be correlated with data on host prevalence, soil type, and climatic factors which, taken in combination with basic data on max, min and optimum temperature for growth for each species, could generate likely species vulnerability zones. Host testing and epidemiological evaluation will also be done for some of the most recently found Phytophthoras (eg *P. siskiyouensis*, *P. gallica*), to provide more information on the level of threat that they could pose to trees in the UK.

Micro-satellite analyses of populations of *P. ramorum* and *P. lateralis* will be completed, with interpretation of what dominant genotypes have emerged overtime and how this may alter the level of risk associated with these pathogens.

**Work area 4**

**Identifying key future pest and pathogen threats**

The 'Trees 4 Future' database will be used to identify regions around the globe that climate-match the UK, taking baseline, 2050 and 2080 scenarios. This will be used as the basis for identifying risky pest and pathogen genera that are known to exist in these regions locally (through IUFRO contacts, local specialist networks and literature/internet searches). Known data on biological traits will be collated and key threats identified in this desk-based study. Through collaboration with social scientists, trade pathways linking these regions to the UK will be identified. This work area will link in with an LWEC phase 3 proposal (if funded) for which one

objective is to identify global *Phytophthora* threats based on their likely adaption to UK ecosystems.

**WP Title: WP4. Surveillance and detection**

Indicative costs (£k):

| 2015-16 | 2016-17 | 2017-18 | 2018-19 |
|---|---|---|---|
| 314 | 320 | 345 | 385 |

Work package details:

Effective surveillance and detection methods are integral to rapid eradication or control and in understanding population spread of invasive species. This WP aims to investigate methods for improved surveillance and detection of pests and pathogens based on a greater understanding of their epidemiology. The following research questions will be addressed;

- In what ways do gaps in our understanding of pest/pathogen epidemiology present barriers to the development of effective detection methods?
- How can accurate monitoring assist risk forecasting?
- Can metabarcoding approaches be effectively employed at a national level for the generalist early detection of pests/pathogens?
- What other novel surveillance/detection methods should we be exploring?

This WP links most closely with WP3 (Future threats), WP1 (Environmental effects on pest and disease impacts), and Programme 3 (Impacts of pests and diseases).

**Work area 1**

**Surveillance and monitoring for invasive insect pests**

Research will involve OPM, bark beetles and PtLM.

For OPM, longer term monitoring using pheromone traps will relate trap catches to climate variables and number of larval nests. This work underpins the development of risk-based control strategies in London and provides the tools for monitoring spread. Further studies will evaluate the role of the host plant in determining trap catches, especially whether tree species influences adult behaviour and the chances of adults being caught.

Monitoring for invasive bark beetles will be expanded to include sampling across the UK in forests adjacent to the 10 busiest ports and other key importers of timber. This will be done in collaboration with the plant health teams of FC England and Scotland, and Natural Resources Wales. The work will also link in with European-wide pest monitoring networks. Forest sites will include both conifer and broadleaf habitat to maximise the chances of detecting historic introductions of exotic scolytines. Traps will collect other wood and bark boring beetles (and hence other invasives). Collecting will be done with a view to preserving DNA so that metabarcoding can be explored in a collaborative approach.

Monitoring of PtLM is ongoing to establish the extent of the current infestation and its potential rate of range expansion as well as population changes and ensuring containment/control effectiveness. Managing this insect is important to enable early warning of new outbreaks and population foci, to prevent spread, and provide advice for the forest industry. Surveys will also inform future strategies for containment and deployment of various control methods (biological/chemical/ physical) to limit or eradicate breeding populations.

**Work area 2**

**Surveillance and detection of invasive pathogens**

This work area will involve monitoring of invasive *Phytophthora* spp. and the ash dieback pathogen *Hymeoscyphus fraxineus.* Other pathogens (for example *Ceratocystis platani*) will be included as the research need arises.

*Phytophthora* monitoring will focus on *P. ramorum*, *P. lateralis*, *P. pseudosyringae* and *P. austrocedri* analysing samples from Plant Health surveys and other sources including citizen-science/industry initiatives (for example LTOA *C. platani* survey and the Arboricultural Association *P. lateralis* survey) to understand pathogen distribution. For *P. ramorum* a focus will be to track changes in the distribution of the EU1 and EU2 lineages as well as continuing surveillance for the presence of NA1 and NA2 lineages. This will be done using the recently developed molecular tool applied directly to samples collected during FC surveillance. For *P. lateralis* a focus will be on understanding the distribution of the two lineages (Pacific North West and UK) present in Britain and occurrence of aerial infections. *P. austrocedri* surveying will focus on the west and north of Scotland to determine the ubiquity of the pathogen on juniper and confirm genotype (British vs Argentinian). Collaborative genome sequencing of *P. ramorum* and *P. lateralis* isolates (the Genome Canada 'Taiga' project) and the FCS funded *P. austrocedri* sequencing project will yield data to help understand the evolutionary relationships among the different lineages.

For *H. fraxineus* (Chalara), *P. lateralis*, and *C. platani*, the effectiveness of using a citizen science approach for detection is already part of the externally funded OPAL and Life Plus Observatories projects (linked to Programme 3), so this area of work will not be pursued in this programme.

However, work on *H. fraxineus* will aim to understand more fully the timeline of disease development within Britain in order to gain a more accurate overview of the rate of spread of the pathogen to date and thus inform future estimates of likely disease spread. Robust and adaptable spore trapping methodologies applicable to *H. fraxineus* and other forest pathogens will be established in order to quantify the inoculum of the pathogen present (and hence the disease risk) in different parts of the country. This will involve testing of capture efficiency of spore traps by deployment in areas of high inoculum production and in parallel with fixed Hurst spore traps of known efficiency. A field study of ash stands across the current boundary of disease distribution (in cooperation with FCS and other stakeholders) will be conducted including periodic ash litter sampling and establishment of temporary spore traps. Laboratory analysis of DNA will determine presence / density of pathogen inoculum. Laboratory analysis of DNA from an historic time series of spore samples collected at fixed points will be compared with inoculum density predicted by current disease models (in collaboration with SRUC and Ouch). Data will be used to improve the accuracy of current disease development models.

**Work area 3**

**Improving survey methods for grey squirrel damage**

Existing methods for assessing squirrel damage rely on being able to see and identify bark damage on the main stem from the ground. However, squirrels also inflict damage in the canopy which is invisible from the ground. Recent results from air surveys for *Phytophthora* have indicated that squirrel damage can be identified from the air and potentially confused with other forms of ill-health in trees. This work area will explore options for airborne surveillance and the use of digital analysis software to identify and quantify squirrel damage. Options for combining surveys for insect and pathogen outbreaks will be explored.

**Work area 4**

**Feasibility of metabarcoding as a generalist survey tool**

An FCS-funded metabarcoding project aimed at analysing the diversity of Phytophthoras in Scottish soils in an Illumina sequencing collaboration with JHI is enabling the technology to be developed 'in house'. This WP will assess the feasibility of extending the use of metabarcoding for broader generalist surveillance of pests and pathogens, for example linking in with work area 1 (surveillance for invasive bark beetles) and utilizing DNA extracted from national fungal spore trapping networks (i.e. operated by SRUC and others). The work will link in with JHI's existing LWEC-funded work optimising Illumina metabarcoding methods for detection of Phytophthoras in water samples, and an LWEC THI Early Detection project in which Fera are exploring metabarcoding to detect and identify airborne fungal pathogens caught in spore traps.

**Work area 5**

**Novel methods for detection and control of insect pests**

The LWEC-funded BIPESCO (Biological Pest Control) project aims to develop novel and environmentally friendly pest control products and strategies to improve the management of native and invasive pest species. This work will take place in collaboration with Swansea University and leading industry pest control companies. The main objectives are to develop effective biological control of the large pine weevil, *Hylobius abietis,* ALB, and pine processionary moth (PPM) using entomopathogenic fungi as biocontrol agents both alone and in combination with a range of plant-derived attractant and repellent botanicals to enhance the efficacy of current monitoring traps. Similarly, the EU LIFE+ PISA project is focused on developing innovative eco-friendly traps (physical barrier, pheromone and mating disruption traps) for the monitoring and control of pine Lepidoptera, including PtLM and PPM. These moths are currently found in pine woods in north, central and southern Europe and periodically outbreak to cause significant economic and environment damage.

**Work area 6**

**Remote sensing for tree health surveillance**

Experiments will be conducted in a quarantine regulated growth chamber to monitor reflectance and temperature of larch saplings artificially inoculated with *P. ramorum* relative to non-inoculated saplings. Weekly reflectance measurements will be taken with a field spectrometer covering the visual (400-700nm), the near infrared (700-3500nm) and short wave infrared (3500-7000nm). Samples will be taken to Edinburgh University for foliar analysis. This work will allow us to establish a relationship between level of stress and alterations in the reflected spectral signature. The different band ratios derived from the spectrometer will be empirically related to concentrations of pigments (chlorophyll, Ca+b and carotenoids, Cx+c). Pigment concentration will be taken as a proxy to determine plant reactions across the different stages of plant infection. Temperature measurements will be undertaken with an FLIR camera covering the thermal infrared part of the spectrum (8000-12000nm). The information will be used in a modification of the Energy Balance Model that measures rate of exchange between atmosphere and foliage through stomata ($H_2O$ and $CO_2$). Temperature differences between control and inoculated canopies will help quantify the level of stress associated with different disease stages. The information gathered in this experiment will be used to train airborne sensors in the early detection of *P. ramorum* on larch.

## Section 3. Communication Strategy

### Communication and collaboration

More than twenty peer reviewed journal papers are anticipated during the first two years of this programme, as well as six PhD theses (and additional associated papers) during the four year timespan, in addition to presentations at a range of international scientific conferences. This will underpin the science quality, advertise the work to national and international science and policy audiences (including NERC/BBSRC, Defra, IUFRO, EFI, EPPO), and build on the global understanding of biotic threats to woody species, facilitating international collaborations. Planned FC publications, internal reports, webpage updates and spatial datasets focused on providing practical information and pest/pathogen distribution data will be disseminated through internal communications mechanisms such as the FC website, email-distributed news bulletins and other digital media. Target audiences will be FC staff, (including Plant Health) and other stakeholders who will use the information to assist pest and disease management and containment strategies. Work in this programme will also lead to the development of improved detection tools, i.e. for Phytophthoras and bark beetles, for which information will be disseminated via conference presentations and scientific papers, to be used by Plant Health-related bodies. Several staff members within the programme are involved in external projects, for example LWEC THI, Defra Tree Health Programmes and EU-funded initiatives including COST actions, thus resulting in knowledge transfer to other research organisations such as universities, CEH, JHI, SASA, FERA, RRes etc.

A key part of all work packages within this programme are the knowledge exchange activities ongoing throughout the year, such as forest health days, outbreak management team meetings, seminars, workshops and training courses aimed at FC policy teams, tree health officers and forest management staff as well as external audiences including (among others) Defra Plant Health, the Aboricultural Association, Scottish Natural Heritage, Natural England, The Woodland Trust, Cumbria Tree Health Group, Natural Resources Wales, private woodland owners and the National Association of Tree Officers. These audiences will be given the latest information on distribution, symptom awareness and biology of pests and pathogens, informing management decisions on felling, planting, conservation and containment efforts, and what constitutes risky and safe practices.

It is also proposed that work package leaders identify a key stakeholder for each work area (for example in WP2 this might be Dumfries and Borders FD (WA1), Inverness, Ross and Skye FD (WA2) and Scottish Natural Heritage (WA3)) and an outline strategy developed for continued engagement between stakeholders and researchers throughout the course of the programme. This would involve key stakeholder staff keen to liaise with FR in terms of project direction, thus helping to build trust and confidence in the research outputs.

A key research challenge will also be identified for Programme 7 (Integrating Research for Policy and Practice), work package 2 involving case studies for tree health to inform responses by forest managers to outbreaks of pests and diseases. The aim of this interdisciplinary work is to enhance dialogue and collaboration between researchers and other stakeholders as a means to enhance the impact of the research.

## Section 4. Collaboration and networking

This programme will deliver greater interdisciplinarity to the study of biotic threats, involving collaboration among scientists from pathology, entomology, tree breeding/genetics, climate and ecological modelling, and environmental and social science. For example, new, formally established intra-FR collaborations will take forward research into understanding human mediated spread of *Phytophthora* (work package 1), natural resistance in tree species (work package 2), and future threats (work package 3). Within each of the four work packages, scientists will operate, where possible, within interdisciplinary work areas applying similar research approaches to facilitate scientific discussion and sharing of resources. Many of the scientists have work strands in different work packages providing effective linking across the programme. A shared drive will be set up for the programme to enable exchange of information and documents. Staff within the programme also have input and linkages to other programmes; mainly Programme 3 (for example Advisory and *D. septosporum*), but also Programmes 1 (climate change impacts), 5 (tree breeding) and 7 (stakeholder engagement). A research update seminar will be held annually for staff within the programme to exchange results and other information. Elsewhere within the FC, the programme will tie in with numerous projects funded by the countries and will continue strong connections with Plant Health and associated staff resources, as well as other Plant Health related bodies (FERA, APHA, SASA). Within the programme there are six on-going PhD studentships involving collaboration with a range of universities across Britain, as well as Defra- and LWEC- contracts involving various consortia (TH0108, PROTREE, BIPESCO, CHALARA), the EU-funded PISA project and new funding initiatives (LWEC Phase 3) being developed in collaboration with institutes such as CEH, JHI, RRes, Fera, University of Bangor and the University of Oxford.

## 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 considered necessary under our experimental protocols are discussed in full with our ethics committee, a veterinary officer and a Home Office (HO) inspector before work is undertaken. Forest Research holds current HO site, project and investigator licenses for investigations on the bark stripping behaviour of squirrels. All work on quarantine regulated organisms will be done within government licensed quarantine regulated facilities. There are no other ethical issues to consider within this programme.

### 5.2 Government survey control procedures

n/a