SECURING TREE HEALTH IN A CHANGING ENVIRONMENT

UPDATED BACKGROUND PAPER

This Background Paper was written to inform a Research Workshop on *Securing Tree Health in a Changing Environment* held on 6 May 2011. Subsequent to the workshop, this background paper has been updated to reflect identified evidence needs. A longer note of the workshop is provided separately, available also on the LWEC website (www.lwec.org.uk)

1. Introduction

Trees represent an important component of our rural and urban landscapes, contributing significantly in terms of the ecosystem services they provide to society, as well as through direct economic value. Preserving the health and vitality of our trees, woodlands and forests is therefore important, especially in the context of a changing environment. The Forestry Commission (FC) will shortly launch a new GB Tree Health Strategy entitled 'Protecting Britain's Forest and Woodland Trees against Pests and Diseases' and this will be available on the FC website thereafter.

Over the last few decades the UK has experienced increasing threats to Plant Biosecurity (agricultural, horticultural, forestry and environmental plants[1]) as increased global trade acts as a pathway for the arrival of new organisms, with impacts potentially exacerbated by climate change and EU enlargement (new pathways of introduction into the EU). This has been highlighted by the increasing number of plant disease and pathogen outbreaks, most notably in relation to trees. Such examples include: *Phytophthora ramorum* and *P. kernoviae* affecting trees, heathland plants and heritage gardens; oak processionary moth (*Thaumetopoea processionea*), with its associated threat to human health; and horse chestnut bacterial canker (*Pseudomonas syringae* pv. *aesculi*). In the wider European arena, the introduction and spread of pine wood nematode and red palm weevil are examples of recent high profile biosecurity failures.

At the same time, other pests, such as the horse chestnut leafminer (*Cameraria ohridella*), have emerged unexpectedly to become damaging, as have some pathogens that have been present in the UK for some time, such as red band needle blight of pine (*Dothistroma septosporum*). Similarly, some tree species are suffering declines for which the causal agents and associated contributory factors are not yet fully determined (e.g. acute oak decline).

As well as dealing with such newly introduced pests and pathogens, there are also a range of other pest and pathogen threats on the horizon. Examples include: Chinese and Asian longhorn beetles (*Anoplophora chinensis* and *A. glabripennis*) which have been intercepted by the UK and have caused serious and on-going outbreaks in other European countries; the emerald ash borer (*Agrilus plannipennis*) and birch borer (*Agrillus anxious*); the spruce bark beetle (*Ips typographus*); the pine-tree lappet moth (*Dendrolimus pini*), which is found throughout Europe and has been found recently in the UK; *Phytophthora lateralis* on Lawson cypress (first findings in the UK in 2010, under eradication); ash die back (*Chalara fraxinea*); chestnut blight (*Cryphonectria parasitica*), which has spread significantly into northern Europe; pine pitch canker (*Gibberella circinata*) recently arrived in Europe; and brown-spot needle blight of pine (*Mycosphaerella dearnessii*).

A recent workshop 'Tree health and Plant Biosecurity' Workshop held on 16 February 2011 explored a range of issues to help inform an action plan that would be centred on four main themes: practical actions; import controls; public engagement; and research. The report from this workshop is available as a separate paper.

[1] Plants include trees

2. Aims, expected outcomes and outputs of research workshop

The aim of this second workshop, principally with expert scientists and woodland managers, is to:

Identify evidence and innovation needs, gaps and priorities, and scientific opportunities, to protect tree health

The outputs from the meeting will be a prioritised list of evidence and innovation needs. This will build on work from the workshop on Tree Health and Plant Biosecurity, held on 16 February 2011. The key output will be identification and prioritisation of evidence and research gaps (both generically, for the immediate and longer-term, and specifically for specific tree pest and pathogen species or groups, where appropriate). The highest priorities would then be included in the Action Plan for "*Tree Health and Plant Biosecurity*".

The desired outcome is: better co-ordination of UK research activities and funding supporting tree health; better capacity and preparedness for dealing with tree pests and pathogens.

3. Scope

The scope of the workshop is focused on tree health and related Biosecurity in Great Britain. This includes trees in woodlands, forests and in the wider environment, including amenity and urban trees. Woody shrubs associated with trees and green spaces, are relevant as either a pathway of introduction/ spread of serious pest and pathogen threats, or where they act as sources of infection or infestation of trees.

4. Generic and Specific Research Areas

The workshop will consider several generic areas that could be used for mapping both strategic and pest-specific research needs and priorities. These generic areas are as follows (see Annex 1 for additional detail on state of the knowledge and currently suggested evidence and innovation gaps):

- Pest and disease biology, epidemiology, host interactions, modelling and risk
- Detection and identification of pests and diseases
- Prevention and control (including novel solutions)
- Awareness and behaviours

There is, however, overlap between these areas to greater or lesser degrees and there are also clear opportunities (and desirability) for integrating inter-disciplinary research approaches to address tree health problems.

There are a range of quarantine[2] pests and pathogens, as well as serious endemic pests and pathogens, which are considered threats to tree health. Annex 2 lists the possible top 20 pest and pathogen threats to trees, with accompanying information about: presence/absence; R&D gaps; pest-prioritisation criteria, such as predicted impacts and potential for research to provide

[2] Quarantine pest or pathogen definition: a pest or pathogen of economic importance to the area endangered and not yet present, or present but not widely distributed and being officially controlled (ISPM 5)

solutions; and overall suggested prioritisation of pests. These have been compiled from the EPPO list, and many have had pest risk analyses undertaken for them. This list is a subset of a longer one drawn up in revising the Tree Health Strategy, and represents the FC Plant Health Service's view of the potentially most damaging threats.

5. Current and future funding sources for research related to tree health

Currently, research related to tree health in Great Britain is primarily funded by the FC. Pest and pathogen research funded by the FC is mainly within a programme called 'Advice and scientific support for tree health' which has three work packages as follows:-

(i) Pest/pathogen-specific research to provide management solutions. Priorities are currently *Phytophthora* species, Red Band Needle Blight, Oak declines, Pinewood nematodes, Pine-tree Lappet Moth, Oak Processionary Moth and *Hylobius*.

(ii) The Forest Research (FR) tree health extension service (which includes disease and pest diagnostic and advisory services).

(iii) Knowledge transfer and advice including new pest and pathogen risks, plant health regulations, climate change, control measures and management strategies.

Relevant FC-funded research is also undertaken on pests and pathogens in other programmes (changing environment covered in the Climate Change Adaptation Programme) and in the Integrated Forest Monitoring Programme.

Pest-specific research is also funded in England and Wales by Defra with the Welsh Assembly Government (i.e. research on *Phytophthora ramorum* and *P. kernoviae)* as well as more strategic horizon scanning or foresight projects, e.g. A New Agenda for Biosecurity (Waage *et al.,* 2004). The Scottish Government also funds research on some tree-health-related issues. There are also some limited funds from some Research Council, e.g. in RELU (Rural Economy and Land Use) or LWEC-sponsored projects, e.g. RELU Dutch elm disease and sudden oak death project.

National funds are also increasingly deployed in collaborative transnational projects via the EUPHRESCO (European Phytosanitary Research Coordination) ERA-Net which is a Plant Health research funders' network e.g. the recent ANOPLORISK Project on the detection and risk management of EU-listed *Anoplophora* longhorn beetles. Both Defra and FC (via Forest Research (FR)) are partners in EUPHRESCO.

The EU Seventh Framework Programme (FP7) has also funded research related to tree health, including some recent pest-specific projects on *P. ramorum* (RAPRA) and pine wood nematode (PHRAME and REPHRAME), and a recent call for research on red palm weevil (*Rhynchophorus ferrugineus*) and a palm borer moth (*Paysandisia archon*).

EUPHRESCO advises the Commission's Directorate General for Research on Plant Health research priorities for FP7. This has resulted in FP7 calls and projects in more strategic research areas such as: developing risk analysis techniques (PRATIQUE); developing DNA-barcoding approaches for identifying statutory and associated pests and pathogens (QBOL); and developing detection tools for inspection services (QDETECT). All these projects are relevant to trees as well as plants and plant products moved in trade. FP7 has also funded a recent project specifically on 'Increasing Sustainability of European Forests: Modelling for Security Against Invasive Pests and Pathogens under Climate Change' (ISEFOR). There have also been a range of past and on-going relevant COST actions, e.g. PERMIT on 'Pathway Evaluation and Pest Risk

Management in Transport' (COST Action FP080) and on 'Established and Emerging Phytophthora: Increasing Threats to Woodland and Forest Ecosystem in Europe'. There are also a number of EU projects like BACCARA and IMPACT which are looking at risks to European forests resulting from climate change which include consideration of pest and pathogen interactions.

Annex 1: State of Knowledge and Suggested Evidence and Innovation Gaps

Broadly speaking, there are several main generic areas which may help frame evidence and innovation needs, both generally and for specific pests in the area of tree health, though there is likely to be overlap between areas to greater or lesser degrees:

i) Pest and disease biology, epidemiology, host interactions, modelling and risk
ii) Detection and identification of pests and diseases
iii) Prevention and control (including novel solutions)
iv) Awareness and behaviours

A) General background

- The Defra-funded study entitled "*A New Agenda for Biosecurity*" (Waage *et al.,* 2004) looked generally at biosecurity issues across a range of areas and invasive species groups. It aimed to: generate a broad understanding of biological threats; develop a modelling approach to predict potential impacts in the absence of government action; predict how environmental and societal change will affect predictions of impact; develop an approach for evaluating the benefits and costs of government action, including prevention or eradication options. It concluded: threats from non-native species generally were likely to increase as a result of increased global trade and would most likely be exacerbated by climate change and societal factors; different pests will require different strategies depending on their probability of introduction, rates of spread and potential impacts; development of technologies that support both prevention and eradication are particularly desirable (e.g. tools for rapid detection and monitoring, especially in-field devices and remote sensing, connected to real time geographical information systems for management of control campaigns; new technologies for control; improved methods for increased traceability); public awareness and understanding of the concept of non-native species is poor.
- For quarantine pests and pathogens, key evidence and research gaps are typically captured in Pest Risks Analyses (PRAs). Biological information (e.g. epidemiology, aetiology) is important for underpinning PRAs and a range of other activities including: developing surveillance and monitoring approaches; developing management strategies and control methods.

  The general state of knowledge and suggested evidence and innovation gaps for each generic area are given below, but is not intended to be fully comprehensive.

B) Specific information on 'State of Knowledge', suggested 'Evidence & Innovation Gaps' and 'Scientific Opportunities' for generic areas

1. Pest and disease biology, epidemiology, host interactions, modelling, and risk

- There have been significant new advances in the development of pest risk analysis techniques in recent years, including risk communication. This is exemplified by: recent EU-funded projects such as PRATIQUE (Pest Risk Analysis Techniques for Plant Health, led by

the UK), ISEFOR (Increasing Sustainability of European Forests: Modelling for Security Against Invasive Pests and Pathogens under Climate Change) and DAISIE (Delivering Invasive Alien Species Inventories for Europe, which has produced a database); further development of an EPPO (European and Mediterranean Plant Protection Organisation) Phytosanitary Pest Risk Analysis (PRA) Scheme with its application to all invasive non-native species; establishment of an EFSA (European Food Safety Authority) Plant Health Panel which reviews PRAs, develops PRA guidelines, including those for assessing environmental impacts, and funds research, e.g. the EFSA-funded project Prima Phacie. It is noteworthy that the current review of the EU Plant Regime will put more emphasis on contingency planning.

- Modelling approaches underpin a range of activities ranging from the assessment of climatic suitability for invasive non-native species, to enhancing methods for surveillance, monitoring and sampling to inform intervention strategies. Modelling approaches are perhaps more advanced for use with invertebrate pests than pathogens, especially GIS-based risk mapping approaches. A current project (Project PH0406) is developing a model epidemiological framework for plant pathogens of statutory concern and these are being applied to the on-going *P. ramorum and P. kernoviae* disease management campaigns (including mapping risk and hazard areas, modelling outcomes of different management approaches, and informing surveillance and sampling plans). A more specific piece of modelling for *P. ramorum* investigated the risks of spread via the hardy ornamental nursery trade network (Defra Project SD0413). Defra's Science Advisory Council (SAC-MOD: Modelling, Prediction and Uncertainty) recently reviewed Defra's use of models and made recommendations, including the promotion and enhancement of long-term relationships between Defra agencies (who often have greatest disease-specific and policy-related knowledge) and leading academic modelling groups (who often have greater technical expertise in model development).
- Research on the biology of specific pests and pathogens varies according to the individual organism. Generally, there is more information available for endemic pests compared with those that are not yet present, or newly emerged; clearly there is only very limited data for pests that emerge which were previously unknown to science. In some cases (e.g. acute oak decline), the causal agent/s are not yet fully determined. Generally, however, there can be significant amounts of information on quarantine pests and pathogens from their countries of origin or where already introduced.

Evidence and innovation needs might include:

- Research on organism biology, including pest/pathogen and tree interactions to improve understanding of disease aetiology and epidemiology, to better inform risk assessment and management. This includes provision of data for use in modelling that informs transmission rates, dispersal kernels (relating probability of spread to distance), infectious periods (how long does an infected/infested host remain infectious, e.g. is it killed or does it recover), cryptic infectious periods (how long is the host infectious before symptoms are expressed) and host distributions (vegetation maps). Also, drawing of data and knowledge on pest and pathogen ecology from their areas of origin. How do introduced pests/pathogens spread in new environments, free from natural enemies; how do such pests/pathogens evolve as spread occurs; can surveillance of invasions past the time official control is ended improve understanding of invasion processes, spread and resilience of native tree populations; can genomic analysis of introduced pests/pathogens and their hosts provide benefits?

- Host-pathogen interactions, especially those that may inform management strategies or breeding programmes, as well as wider soil and microbial interactions that may mitigate pest or disease problems. Improved understanding of the extent and spatial structure of genetic diversity in host tree populations, specifically for variation in susceptibility, resistance and resilience to pests and diseases, including progeny trials to establish heritability of pest or disease response traits for improved understanding of the evolutionary responses of tree populations to selection pressures imposed by pests and diseases. Approaches should take advantage of emerging genomic resources for tree species and of the current state of the art in plant community genomics. Data is also lacking on: effects of climate change and unusual weather events on pests and pathogens of concern to tree health and the influence of stress factors on host-pathogen and host-pest interactions.
- Improved approaches for host testing, for determining both host range and potential impacts (e.g. in conjunction with other countries). Evaluation of the usefulness and reliability of host range testing and its prioritisation against other research needs.
- Further evaluation and development of generic model frameworks for practical application. The following issues are relevant in relation to model development and practical use:
    - *Data collection* (how to optimise data collection from surveys and experiments to produce better spatio-temporal maps that can predict spread and impact; how best to produce data that informs transmission rates, incubation and infectious periods);
    - *Sampling strategies* (different sampling strategies are required depending on whether presence/absence is being determined, or the actual density of a pest/pathogen);
    - *Parameter estimation* (can spatial and temporal signatures be extracted from incidence maps showing the spread of pests or pathogens, e.g. through optimised data collection; how can parameters be estimated using statistical methods applied to incomplete data or biased data);
    - *Model innovations* (adapting generic models for different host-pest/pathogen systems and evaluating them against specific exemplars; determining and communicating uncertainty to better estimate risk; approaches for providing models to stakeholders in formats that they can use to test ‘what-if’ scenarios and model utility; approaches for dealing with missing or incomplete vegetation data when trying to predict spread and the effectiveness of control options).
    - *Tractability:* it is important to be realistic about what experimentation can realistically achieve, e.g. can spore dispersal distances be determined. What can be done practically in the time and resource available and how useful is it?
- Development, testing and application of methods for assessing socio-economic and environmental impacts in a manner that supports more rapid decision making, especially in emergencies where hosts are removed by statutory action before pest/disease impacts can be assessed. Improved inclusion of social and economic data within models; linking pest and pathogen models to GIS, economic and ecosystem services models.
- Integrating land-use and vegetation data from a wide variety of local and national sources linked to increased use of remote sensing techniques for vegetation mapping; improved knowledge of host distributions; a national tree database could be considered that brought together Forestry Commission and Botanical Society of the British Isles (BSBI) data on species distributions, as well as county wildlife trust maps and the very detailed tree distribution data from city councils.

- Assessment of risks from species hybrids (that could be generated if species which have diverged through allopatric speciation are brought into close contact through plant trade), as well as the risk from genetic change of indigenous pests (mutation, evolution, adaptation).

2. Detection and identification of pests and diseases

- Detection and identification methods have undergone rapid development also in recent in years, especially molecular (e.g. DNA and immunological) approaches.
- Detection approaches are increasingly moving into the field for on-site or point-of-entry use (e.g. Lateral Flow Devices (LFD); SmartCyclers (DNA-based field technology); traps using pheromones or other attractants); use of sentinel plants or plots. Other approaches are less well advanced and require more development. However, some are moving towards practical application, especially acoustics, remote sensing and other imaging technologies, and detection of volatiles (see the EU-funded QDETECT project, and EUPHRESCO transnational project (ANOPLORISK) on *Anoplophora* detection and risk management.
- Defra and FC have also recently commissioned several smaller projects, e.g. the use of remote sensing to detect *P. ramorum* hosts, and looking at the feasibility of using high-through-put molecular methods for samples from environmental monitoring networks.
- Additionally, there has been significant recent work surrounding surveillance, monitoring and sampling approaches, e.g. the EU PRATIQUE Project, the EU QDETECT project, the Defra and Scottish Government funded epidemiological modelling Project PH0406, the Defra-funded 'Tools for Plant Health Inspectors' Project PH0439, and the EFSA-funded PERSEUS project (review and analysis of pest surveillance approaches across EU member states).
- Taxonomic projects support detection efforts by underpinning pest and disease identification (Defra-funded Plant Health Taxonomic Fellowships since 2003/4; EU-funded QBOL project on DNA-barcoding).
- For most established or emerging pests and pathogens, identification methods are fairly well established, with some exceptions, e.g. 'declines' or 'syndromes' where the causal agents are not fully determined.

Evidence and innovation needs might include

Surveillance and monitoring strategies and tools that better support early detection and identification and improved prospects and likelihood of achieving successful intervention (eradication, containment or control), including: design; diagnostic (detection and identification) methods; data management; analysis and interpretation. More specifically:

- Developing and deploying statistical and modelling tools and Standard Operating Procedures (SOPs for decision making and implementation) to inform surveillance planning, especially to underpin: improved targeting and prioritisation of surveillance, monitoring and sampling, including detection of latent infection/infestation; decisions on the selection and use of detection and diagnostic tools and their impact on desired outcomes for both surveillance and eradication.
- Improved analysis and understanding of trade networks and the trade landscape (pathways of introduction and spread), including the whole production and supply chain to identify critical control points to reduce risks of introduction and spread.
- Development and use of in-field tools which best ensure early detection of pests (including 'unknowns'), including for example: remote sensing, aerial imagery, thermal imaging; lure and trapping techniques (pheromones or other attractants) for specific pests; acoustic methods; etc. This might also include novel approaches that facilitate environmental monitoring, e.g. non-specific trapping or baiting approaches, or better use of existing environmental

monitoring networks linked to modern diagnostic approaches, or better use of sentinel plants. Remote sensing might be applied both to the identification of where hosts occur as well as for the early detection of pest or disease damage.

- Routine surveys to audit nurseries to look for any new or evolving pathogens or pests, particularly those that pose the most risk in this environment such as phytophthoras, not just surveys for organisms on quarantine lists. Methods for monitoring pathogen change and evolution, including species hybrids.
- Development of new technologies for gathering, managing, analysing and using data in support of surveillance and monitoring activities, e.g. linking detection/diagnosis to real-time GPS systems and economic models to better manage control campaigns (targeting control and resources).
- Analyses and lessons-learned reviews from past or current campaigns and Biosecurity successes and failures in the UK, Europe or more widely, with respect to early detection and surveillance and monitoring (see also current EFSA-funded Project: PERSEUS). Improved horizon scanning approaches.
- Improved understanding of public/stakeholder awareness of non-native pest issues and strategies for engaging them more in the detection and reporting of incursions and outbreaks (see also section on 'Awareness and Behaviours' below). Evaluation of the role of citizen science. Determining best approaches for increasing public and stakeholder understanding of what 'unhealthy' looks like (recognition of pest and disease problems); how to increase awareness of plant health issues in such groups so that they can better act as 'eyes and ears'; how best to encourage reporting of new problems and incentivise this. Improved networks for environmental surveillance and surveys (improved training in symptom recognition), possibly through citizen science approach.
- Taxonomic research to better underpin diagnostic methods, pest risk analysis and legislation.
- Modern metagenomic approaches such as Next Generation Sequencing (NGS) which could be a powerful tool for rapidly identifying both known and unknown causal agents from samples, particularly if they are not easily cultured in a laboratory (e.g. declines/syndromes in specific tree species), as well as wider microbial populations that may be beneficial.

3. Prevention and Control (including novel solutions)

- Eradication and containment methods (quarantine pests and pathogens) and more general control and management methods (for serious endemic pest) are areas where there are still significant gaps in the tools available.
- FC-funded work has generally focused on the use of biological control agents for the management of serious endemic pests such as conifer root and butt rot (controlled by a fungal biocontrol) and the large pine weevil (controlled by nematodes), as well as for introduced pests such as the great spruce bark beetle which is now very effectively controlled by a highly specific predator insect. Similarly, most recent Defra-funded Plant Health research (mostly in relation to protected crops) has focussed on the development of eradication and containment approaches which do not rely on pesticides, e.g. IPM-based approaches, and investigation of more novel (strategic) approaches such as the use of fusion proteins or temporal synergists. Other novel approaches are of course also researched as part of wider crop protection programmes.
- Other recent projects cover the use of slow-sand filtration for *Phytophthora ramorum/kernoviae* in nurseries, the use of heat treatment to decontaminate plants,

rhododendron clearance approaches in managing *P. ramorum/kernoviae*, and waste management projects dealing with quarantine-contaminated plant material.

- More generally, PRATIQUE has reviewed various past campaigns to learn lessons. It has also developed protocols for selecting the most appropriate management option following an incursion and for conducting cost:benefit analyses of new and ongoing campaigns. It has also explored surveying of arboreta in third countries for early risk identification of pest and pathogens damaging 'British' trees in such arboreta.
- Modelling work has also begun to more specifically underpin intervention strategies to guide decisions on the best management actions for eradication and containment to give the most effective outcomes, e.g. in the case of the current Defra *P. ramorum* and *P. kernoviae* Disease Management Programme (see Project PH0406 and Project SD0413)

Evidence and innovation needs might include

- Analysis and lessons learnt from past biosecurity failures and successes, e.g. with respect to intervention strategies (eradication and containment actions). This could include evaluating legislative and biosecurity approaches in other countries, as well as management approaches for specific pests and pathogens used in countries where they occur.
- Models and decision-support systems that inform policy decisions on action against outbreaks of invasive non-native pests and pathogens of trees (whether to start eradication action; the best approaches for action; division of resources between action and monitoring/surveillance; the point at which eradication efforts should be stopped). Research that better underpins approaches for rapid emergency response (action and associated monitoring, surveillance and sampling).
- Improved and refined pest risk analysis methods and approaches, including impact assessments, which underpin regulation and risk management, and methods for communicating risk and uncertainty.
- Development of novel control and management methods, e.g. novel biosecurity and disinfection/disinfestation approaches for imported propagating material (post-entry quarantine or biosecurity measures); novel, environmentally-friendly control methods, potentially also addressing issues related to plant resistance and pesticide resistance (novel pesticides; novel non-pesticide approaches); biological control approaches for specific endemic pests and pathogens (particularly looking for natural enemies to introduced pests and pathogens in their centres of origin, e.g. mycoviruses for fungal pathogens); lure/kill and sterilisation/mating competition approaches for insect pests and improved disinfectant treatments for treatment; determining best integrated pest management approaches. Evaluating the efficacy of treatments and controls in order to inform future management strategies.
- Behavioural change, e.g. determining best approaches to increase stakeholder responsibility and cooperation, including best management practices etc. (see also section on 'Awareness and Behaviours' below). Research comparing legislative and non-legislative approaches (public and stakeholder engagement and behaviours) to reduce risks of entry by non-native pests and pathogens.
- Approaches for future proofing against future threats, potentially including: working with trading partners; plant breeding; planting strategies; microbial interactions that contribute to healthy trees). Strategic research into how to increase resilience of trees to pest and pathogens and climate change by taking advantage of genetic diversity, high gene-flow

capabilities and latent potential for adaptive change; testing strategies through modelling. This may also include the identification of resistance/recovery genes to enhance plant selection and/or breeding programmes. What landscape-level planting schemes and tree species might be used in the future in a changing environment (variations in spatial structure, density, genetic diversity, etc.)?

- Surveys of areas that may harbour high-risk pathogens e.g. phytophthoras in the Pacific Rim. This might also include studying networks of arboreta in third countries which have 'British' trees: this may determine which pests and pathogens present in such third countries could affect tree species grown in the UK (as trialled in PRATIQUE) and which may therefore be of future concern.

4. Awareness and behaviours (understanding and influencing behaviours)

- There has been only limited social science research in the area of Plant Health and this is an important area for prioritisation and expansion; public and stakeholder awareness and behaviours are key factors limiting our ability to prevent or quickly detect new introductions.
- An Imperial College study looked at options for responsibility and cost sharing for quarantine plant health.
- Two RELU projects have involved social science studies: Memory and Prediction of Tree Disease Control has investigated new non-native tree pests and diseases with respect to 'public awareness, knowledge, perception and who pays'; Assessing the Potential Rural Impact of Plant Disease .
- A Defra-funded project Wildlife Management and Invasive Non-Native Species Report of Research Findings among the General Public, Anglers and the Horticultural Retail Trade investigated attitudes and awareness of some specific stakeholder groups in the context on specific invasive Non-Native Species.
- Other areas have used citizen science approaches and these might have value if applied to the tree and wider plant biosecurity area.

Evidence and innovation needs might include

- Stakeholder analysis and mapping, including land ownership: who are the stakeholders; what are their motivations?
- Improved valuation studies to better describe the benefits from trees and the potential impacts from pests and pathogens.
- Understanding public awareness and determining best approaches for increasing it and improving their engagement on tree health and biosecurity issues. How to best communicate risk. How best to educate the next generation.
- Understanding and influencing public and stakeholder motivations and behaviours, drawing on, and analysing, experience and knowledge from other areas. For example, how can we incentivise nurserymen/landowners/merchants to take biosecurity more seriously and to look for, and report, pest problems? How could we influence plant sourcing/buying behaviours (both for the industry and for the public)? Can citizen science be utilised? Research into the role of governance (e.g. compared to other countries, and including certification and assurance schemes, regulation, etc.), economic instruments (e.g. market creation, grant schemes, cost and responsibility sharing), incentives and social motivation (e.g. community involvement) in improving Biosecurity. What landscape-level governance structures would

best promote tree health? Research could also be considered that investigates the potential for payments for ecosystem services to capture the full value of forests and woodlands. How can the value of trees and woodlands be appropriated by landowners to better encourage engagement.

- Stakeholder engagement: developing new approaches and adopting best practice, including learning from other areas (public health; animal health) and other countries.
- Introduction of certification schemes into nurseries, e.g. ‘freedom from pests’, that the public could recognise and ask for.

Annex 2 – Forestry Commission's current table of top pests and pathogens that threaten tree health in Great Britain, especially: those already present and causing impacts; those not yet present but for which there may be a high impact if introduced. The overall priorities (right hand column) have been amended in response to discussion at the workshop on 6th May 2011 (changes in blue; original in squared brackets).

Common Name	Name of organism	Type	EU* status	UK* Status	R&D Needs (and current research)	Prioritisation Criteria			Overall priority for R&D 1= Higher 5= Lower
						** Impact or Potential Impact (forestry) 1. Host range – narrow/wide 2. Killing disease/pest? 3. Commercial species? 4. Probability of introduction, global trade, etc	** Impact or Potential Impact (urban or environmental) 1. Environmental impact 2. Climatic interaction, exacerbation by climate change 3. Experience elsewhere 4. Alternative species – future spp choice 5. Societal factors – use in urban greenspace	1. Potential for R&D providing solutions 2. Potential of technolog--ies for prevention and eradication	
8-toothed Euro spruce bark beetle	*Ips typographus*	Beetle	Present	Absent Incurs-ions	•Resilience of forests • Interaction with Sitka Spruce	Tree mortality causes significant loss of timber in Europe, mainly Norway spruce.	Impact on landscape could be large-scale	Med/high	1/2
Acute Oak decline	*Brenneria spp* plus one newly detected and as yet unnamed bacterium	Bacteria	Present (*Brenneria)*	Present	• Causal agents. •Epidemiology/dispersal. • Mitigation. • Host resistance.	Dieback and/or rapid death of infected oak trees, currently limited distribution.	Dieback and/or rapid death of infected oak trees.	Med	1
Ash dieback	*Chalara fraxinea*	Fungus	Present	Absent	• Pathways/analysis • Improved surveys • Epidemiology	Dieback, mortality	Wilting, branch dieback; death of the ash crowns. Significant impact on environment emerging in some European countries	Low/med	3/4

Bleeding Canker of Horse Chestnut (non-native tree)	*Pseudomonas syringae* pv *aesculi*	Bacteria	Present	Present	• Pathway analysis • Dispersal mechanisms and persistence • Host resistance • Virulence factors	Not a timber species?	Dieback and death of horse chestnut; c.50% of GB trees symptomatic. Safety issues for trees in urban environment	Med (resistance/ manage-ment)	2 (urban / environ. trees) 5 (forestry) [5]
Brown spot needle blight	*Mycosphaerella dearnessii*	Fungus	Present	Absent	• PRA specific to GB • Diagnostics/detection • Climatic modelling			Unknown	3/4
Chestnut blight	*Cryphonectria parasitica*	Fungus	Present (wide-spread)	Absent	• Improved PRA specific to GB • Improved surveys • Diagnostic/detection • Host testing	Dieback and mortality of Sweet chestnut		Med/high	2/3
Citrus Longhorn beetles	*Anoplophora chinensis* and *Anoplophora glabripennis*	Beetle	Present (UOC*)	Absent Incurs-ions	• Detection methods. • Establishment risks • Intervention strategies. • (ANOPLORISK project) • Interaction with climate	Extensive damage to urban/forest tree genera (particularly broadleaves) if beetle establishes here.		Med	2
Emerald ash borer and birch borer	*Agrilus plannipennis* and *A. anxious*	Beetle	Absent	Absent	• Detection methods. • Improved surveys.	Extensive damage to ash.		Unknown	3
Oak Processionary moth	*Thaumetopoea processionea*	Moth	Present	Present (UOC*)	• Detection methods. • Control methods • Interaction with climate	Major oak defoliator; some mortality in peak activity periods	Potential public health issues.	Low/med	2
Lawson cypress root rot	*Phytophthora lateralis*	Fungus-like	Present (*UOC)	Present (*UOC)	• Host testing • Pathway analysis	Very minor timber species	Widespread as an ornamental (parks, gardens)	Low/med	3

Pine-tree lappet moth	*Dendrolimus pini*	Moth	Present	Present (*UOC?)	• Host preferences • Development under GB conditions • Climate interaction	Potentially very damaging, but impact uncertain.		Med	4
Pine pitch canker	*Gibberella circinata*	Fungus	Present (*UOC) PT, ES ...	Absent	• Host testing • Interaction with climate • PRA specific to GB	Very damaging in Southern Europe		Low/med	3/4
Pine wood nematode	*Bursaphelenchus xylophilus*	Nema-tode	Present (UOC*) PT, ES	Absent Incursions	• Predicting impacts. • Vector. • (EU REPHRAME project).	Major tree damage and death caused in Portugal		Low/med/ high	3/4
Ramorum/ Kernoviae dieback, leaf blight, bleeding canker	*Phytophthora ramorum & P. kernoviae*	Fungus-like	Present (UOC*) (*Pk* UK,IE)	Present (UOC*)	• Detection (remote sensing) • Understanding/ Influencing behaviours. • Larch epidemiology. • (Defra-funded programme)	A range of susceptible trees; Major commercial timber species (larch) killed	Heritage gardens and heathland affected.	Med	**1** [1/2]
Red Band Needle Blight	*Dothistroma septosporum* and *Dothistroma pini*	Fungus	Present (UOC*)	Present (UOC*)	• Disease management • Monitoring and detection • Epidemiology • Influencing behaviours	Some mortality and major loss of timber yield in pine. Current FC moratorium on planting Corsican pine. Most commercial pine spp susceptible; moratorium on planting CP & LP		Med	**1** [1/2]
Spruce budworm	*Choristoneura*	Moth	Absent	Absent	• PRA for GB • Interaction with climate	Severe defoliation and death of spruce		Med	?

Also considered*: Dendroctonus micans, Hylobius,* other *Ips* species * UOC: Under Official Control

** Impact: risk/probability of entry (if not already present), establishment and spread; expected economic, social or environmental damage