



Tree Health and Plant Biosecurity Initiative

New approaches for the early detection of tree health pests and pathogens

Early detection of tree pests and pathogens technology workshop Learning Platform 2

26th October 2015
COSLA, Edinburgh

The consortium



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Executive summary

The project “**New approaches for the early detection of tree health pests and pathogens**” runs from 2014 to 2017 and is funded through the LWEC (Living with Environmental Change) Tree Health and Plant Biosecurity Initiative. The project is focused on the development of new technologies for detecting changes in plants and arrival or presence of potential pests and pathogens. It also explores how these technologies can be developed better in partnership with practitioners involved in the use of technologies and industry representatives who may wish to take such technologies forward to commercial application. Technologies explored include:

- ‘sniffer’ technology to identify chemical changes in the air triggered by disease
- imaging techniques that can detect changes beyond the range of human vision
- new traps for detecting and capturing insects
- DNA-based detection approaches to seek established and new pests

The aims of this second Learning Platform workshop in the project were:

- to further develop collaborative networks across individuals and groups with an interest in early detection of tree pests and pathogens
- to provide an update from scientists and opportunity for other stakeholders to input on the emerging technologies
- to permit a Scotland focus to highlight particular issues (community and commercial forestry aspects, devolved policy)

The meeting was attended by 50 academics, inspectors, foresters, policy makers, commercial representatives and others. Project leader Rick Mumford (Fera) explained how the emerging technologies are testing a diagnostic **Technology Readiness Levels** (dTRLs) framework. We want to evaluate impact, find an objective method for assessing how close to use a technology sits and assess the resources required for final technology development stages. Different work packages within the project are involved at different TRLs or stages.

Jane Chard (SASA) and Anna Brown (FC Scotland) described the **context of tree health in Scotland**. Different organisations and institutions exist in different parts of UK. Responsibility sits within countries but with cross UK partnerships and a coordinated approach to enhance efficiencies. This allows for distinctive priorities to develop but is also flexible enough to accommodate for biological movement. There is a UK Plant Health risk register and a Tree Health Advisory Group. Citizen science is important and surveillance challenges remain. Detection is only part of the process in determining how we deal with outbreaks.

Bianca Ambrose-Oji (Forest Research; FR) and Jon Hollingdale (Community Woodlands Association) discussed the context of the **growing community forestry sector**. In Scotland over 200 groups are well networked. They vary from large commercially managed forest groups to small groups with social and conservation interests and include rural and urban examples. Little is known about how these groups engage with tree health. There is potential to spread knowledge and benefit from the engagement and enthusiasm of this network.

Michael Pocock (Centre for Ecology and Hydrology; CEH) discussed recent **citizen science initiatives**. Citizen science can take different forms including volunteer experts, long term monitoring with standardised protocols or mass participations. However, a) it is difficult to assess recorder coverage, because of asymmetric information, and b) there are conflicting motivations; if a group finds pests in their woodland they run the risk of chemical intervention or at worst clear felling in response.

A **panel discussion** chaired by Mariella Marzano (FR) elaborated on some of these challenges, highlighting the dilemmas of ‘unknown unknown’ as well as ‘known unknown’ harmful organisms. The use of correct tools for detection was said to be important and the difficulties of effectively

sharing detection information were highlighted. The different motivations of different groups (e.g. citizen scientists versus community groups versus commercial nurseries) were discussed.

Each of the **5 technology research groups** presented a 5 minute *Pecha kucha* style update on their technology development. Discussion sought to build on key opportunities and challenges identified in Year 1. *Pecha Kucha* is a simple presentation format based on images (here produced in powerpoint), which are advanced on automatically ensuring that presentations are focussed and dynamic.

Volatile Organic Compounds (VOCs) can provide unique chemical signatures for individual relevant pathogens. We are now at the stage where we can try to establish the chemical profiles of cultured pathogens in the lab. The next step is to try and develop handheld devices to detect pathogens using these compounds in the field. Whilst the team envisages putting devices in containers to capture these VOCs, they face practical problems in achieving this and in the possibility of false positives.

Remote sensing technologies taken from space science can be applied to detect diseases and stress in plants. We are looking at how we can detect both biotic and abiotic stresses using **hyperspectral imaging** technologies. Working in the visual spectra your eyes sees 'normal' colours e.g. red, greens and blues. However you can use technology to look in different spectral region, beyond the visual, and here you can actually start to identify particular spectral wavelengths associated with disease such as red-band needle blight. The challenges will be taking this into field and calibrating to normal environment conditions.

Spore trapping can help with surveillance and monitoring of airborne pathogens (especially fungal ones) to tell us about risk ahead of time. This is analogous with established pollen networks, which offer a risk prediction tool. We are developing two technologies - one that is targeted and one that is not. The first is a portable sampling and testing device which can test for specific pathogens. Using modelling and 3D printing we are creating cyclone samplers, that move air around a cylinder to create a change in pressure and trap spores of particular sizes. These can then be tested using a DNA technology called LAMP. The other approach is extracting DNA from air samples and then using genome sequencing to profile the whole range of species present in them. The project has access now to pollen traps and as these also trap fungal spores the project is aiming to be efficient by piggy backing onto these existing networks for disease monitoring.

Pheromone trapping can be specific and highly sensitive, whilst relatively cheap. Their specificity means we can use non-expert citizen scientists to carry out monitoring. Improved attractiveness of traps for Oak Processionary Moth was demonstrated. We are seeking pheromone attractants for species not yet in the UK, such as Citrus longhorn beetle. With the trap network, we have been working with Animal & Plant Health Agency (APHA) plant health inspectors using a multi-species lure with the Asian Longhorn Beetle trap network in Paddock Wood, Kent and are also now looking at the citizen science approach. This creates challenges since we do not want to kill rare species; and consistent negative finds may reduce motivation and are statistically difficult to interpret.

Finally, **water borne detection** of *Phytophthora* species is being developed. There are 14 species of this on the UK Plant Health Risk Register, and 142 species described in total to date, with probably many others as yet undescribed. We want to develop technology to use at ports to prevent import of these pathogens but also are looking to use in the significant UK horticultural and tree plant industry (worth £120 million/yr). Often root infections are hard to detect at import and fungicide can inhibit activity. However these infections can be detected as they release motile zoospores that can be found in water that has been in touch with those roots. A low technology sprayer can be adapted to act as a pump, with an inline filter that captures the zoospores. These trapped samples are then tested by PCR and DNA barcoding to identify all *Phytophthora* species – known and unknown – that are captured on the filter. We are now looking at practical sampling regimes for people using this, in inspection or quarantine contexts.

A **Technology Development Knowledge Café** then saw groups of participants spin through each technology discussion in a carousel of debate. Each discussion elicited questions, critique and practical advice from participants and challenged scientists to think differently.

Anna Brown (FC Scotland) gave a **keynote listener talk**, reflecting on the day’s discussions. She asked where to focus detection, pre-borders or within the environment post-border, and how to make multiple use of technologies. She commended the project on its ‘real’ interdisciplinary and attempt to engage stakeholders (beyond empty rhetoric) and on the notion of TRLs. However, she cautioned for flexibility so that technologies we develop now will be of use in the unknown future. Will they be practical to use? How will they fit with policy or industry needs and citizen science limitations? How do we allocate and share costs and responsibilities?

There followed a **visioning session** led by Rehema White (University of St. Andrews) to explore an ideal future early detection context. Small groups contemplated a vision, strategic elements and wider reflections. Plenary debate revealed a preference for *pre-border detection*; more *home grown plant* industry; greater *forestry resilience*; *industry investing* in good quality detection; better *public engagement*; *plurality* of pest/pathogen focus and technologies; changes in *trade*; *shared access to data platforms*; along with *shared responsibilities*.

Finally, Rick Mumford had **the last word**. We need scientists to contribute research findings and ideas, but other stakeholders are essential for us to understand the potential and implications of new technologies for the detection of tree pests and pathogens. Rick highlighted the unknown potential of technologies as well as the unknown pests and pathogens we face, but he also reminded us not to underestimate the time for technology deployment (average 8-15 years). Participants were all thanked for attending and wished safe travel home.

For further information, the full report and presentations, plus other project details, please see the project web site: <http://protectingtreehealth.org.uk> or contact the project lead, Rick Mumford Rick.Mumford@fera.co.uk.

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Background to project

The project “ *New approaches for the early detection of tree health pests and pathogens* ” runs from 2014 to 2017 and is funded through the LWEC (Living with Environmental Change) Tree Health and Plant Biosecurity Initiative (<http://www.bbsrc.ac.uk/funding/opportunities/2013/tree-health-and-plant-biosecurity-phase2.aspx>). The project is focused on the development of new technologies for detecting changes in plants and arrival or presence of potential pests and pathogens. It also explores how these technologies can be developed better in partnership with practitioners involved in the use of technologies and industry representatives who may wish to take such technologies forward to commercial application. Technologies explored include:

- ‘sniffer’ technology to identify chemical changes in the air triggered by disease
- imaging techniques that can detect changes beyond the range of human vision
- new traps for detecting and capturing insects
- DNA-based detection approaches to seek established and new pests

Mariella Marzano (Forest Research) welcomed everyone and introduced the aims of the workshop. The aims of this second Learning Platform workshop in the project were:

- to further develop collaborative networks across individuals and groups with an interest in early detection of tree pests and pathogens
- to provide an update from scientists and opportunity for other stakeholders to input on the emerging technologies
- to permit a Scotland focus to highlight particular issues (community and commercial forestry aspects, devolved policy)

The meeting was attended by 50 academics, inspectors, foresters, policy makers, commercial representatives and others.

Presentations

Project introduction and update

(Rick Mumford, Fera)

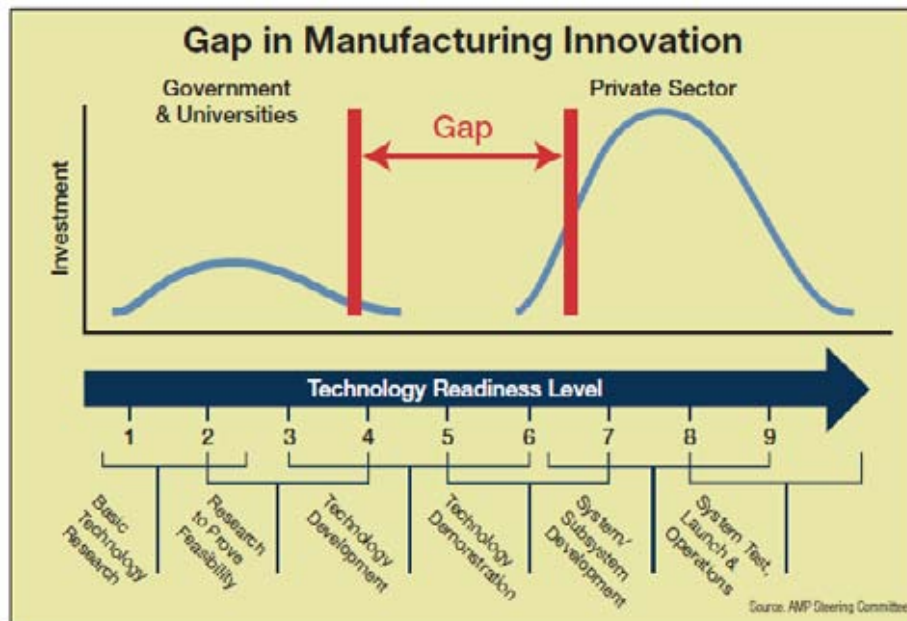
The key objectives of the Early detection technologies project are to:

1. Develop improved, cost-effective tools for the early detection, surveillance & monitoring of alien pests and pathogens of trees and other plants to improve the UK's biosecurity.
2. Exploit technical advances in fields such as genomics, bioinformatics, pest & disease detection, trapping and environmental sampling, including risk and social impact valuation to support the health and resilience of UK trees and woodlands.
3. Based on an interdisciplinary consortium bring together natural science specialists in tree research and plant biosecurity with leading-edge scientists from the physical, engineering, social & economic science research communities to develop these tools.

The project also aims to explore different ways of doing science, engaging key stakeholders from the start. The project consortium involves a number of institutions and is multi-disciplinary, including social scientists from the start. We want tools that can be used in a variety of inspection contexts including exploring whether we can put these tools into the hands of ‘new’ inspection groups such as citizen scientists. By doing so we want to add to our national capability and develop not only specific technologies but also generic tools.

Why might we need to use the Technology Readiness Levels (TRLs) framework? We want to evaluate impact, and find an objective method for assessing where a technology sits in the development pipeline. TRLs could offer an approach to assess the resources required for final technology

development stages. Different work packages within the project are involved at different TRLs or stages. We know there is usually a gap across TRLs 4 to 6 as we hand over from mainly scientists to mainly private sector for commercial development.



A NASA researcher, Stan Sadin, conceived the first TRL scale in 1974. It had 7 levels which were not formally defined until 1989. In the 1990s NASA adopted a scale with 9 levels which gained widespread acceptance across industry and remains in use today. Many industry and other organisations have tailored definitions for certain TRLs to suit their own needs e.g. The EC is now using the TRL scale (e.g. under Horizon 2020) to make decisions on the type of projects to be funded (with the proposed TRL level given in call descriptions and for use in evaluation).

The infographic features the European Union flag at the top. Below it, the title "Technology Readiness Levels" is displayed in a large, bold, blue font. Underneath the title, a list of definitions for TRL 0 through TRL 9 is provided, each starting with a red bolded TRL number and a bolded title, followed by a descriptive sentence.

- TRL 0: Idea.** Unproven concept, no testing has been performed.
- TRL 1: Basic research.** Principles postulated and observed but no experimental proof available.
- TRL 2: Technology formulation.** Concept and application have been formulated.
- TRL 3: Applied research.** First laboratory tests completed; proof of concept.
- TRL 4: Small scale prototype** built in a laboratory environment ("ugly" prototype).
- TRL 5: Large scale prototype** tested in intended environment.
- TRL 6: Prototype system** tested in intended environment close to expected performance.
- TRL 7: Demonstration system** operating in operational environment at pre-commercial scale.
- TRL 8: First of a kind commercial system.** Manufacturing issues solved.
- TRL 9: Full commercial application,** technology available for consumers.

Our proposal in this project is not only to develop technologies but also to develop an adapted TRL scale that is fit for purpose in a diagnostic/detection context (a dTRL scale). We are developing a simple, easy to use calculator to assess stages of development and are researching how these stages progress for a given technology.

Proposed TRL definitions for FPPH			
Cluster	TRL	General description	Example (LAMP technology)
Invention	1	Basic principles are observed: initial translation of basic science into potential new basic principles that can be used in new technologies.	Advances in our understanding of basic molecular biology
	2	Technology concept is formulated: potential applications of basic (technological) principles are identified but applications are speculative and there may be no proof or detailed analysis to support the assumptions.	Development of concept, e.g. for iso-thermal DNA amplification with discovery of novel DNA replication enzymes
Concept validation	3	First assessments of feasibility concept and technologies: based on preliminary study, actual research is conducted to assess technical and market feasibility of the concept.	Development of LAMP assays and Genie
	4	Laboratory validation of an integrated prototype, diagnostic method or technology platform: basic technological components are integrated to assess early feasibility by testing in a lab environment.	Testing of a model LAMP assay for plant diagnostic purposes
Application development and prototyping	5	Technology validation in a relevant environment: advanced testing and refinement of new diagnostic method or technology platform focused on a specific end-use application	Design of LAMP-based test for detecting a specific target in a specific host/matrix
Technology demonstration and Knowledge Exchange/Transfer	6	Integration of all components into a product / process / functional diagnostic test: fine-tuning and real samples testing	Bringing and testing of whole diagnostic including sampling, extraction and test.
	7	Prototype demonstration in a real environment: product / process / diagnostic test near or at planned operational system is tested by end-users	Technology transfer to: end-users (APHA, Diagnosticians) with initial testing of LAMP-based diagnostic in 'field'
Operational validation	8	Product / process / diagnostic test is commissioned: actual technology completed and qualified through test and demonstration.	Extensive 'field'* validation by PHSI and final refinement (onsite technologies), or by diagnosticians (lab-based technologies)
Deployment	9	Product / process / diagnostic test is fully operational and competitive: actual application of diagnostic is in its final form (test proven and being used routinely). A TRL-10 level might be considered for when there is wide adoption as a Standard (e.g. EPPO or IPPC Diagnostic Protocol)	Diagnostic hand over to PHSI for routine, use with appropriate support in place e.g. access to reagents, tech support etc.

*'Field' means actual use in the hands of by end-users under normal conditions (on-site, for on-site technologies; or in diagnostic laboratory for lab-based technologies), i.e. Operational use.

The context of tree health in Scotland

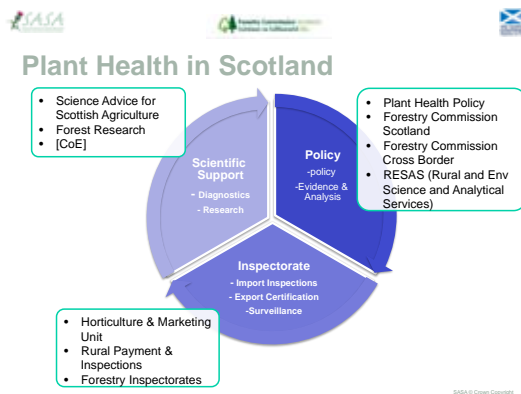
(Jane Chard, SASA and Anna Brown, Forestry Commission Scotland)

The UK Plant Health Service is made up of the following organisations:

- DEFRA leads for UK on international plant health issues; in England & Wales this includes Animal & Plant Health Agency (APHA) carrying out inspections and commissions scientific services from Fera.
- Scottish Government in Edinburgh which includes Rural Payments and Inspections Division (RPID), SASA and Forestry Commission Scotland.
- Forestry Commission (FC) which includes FC cross border, FC England and Forest Research
- Welsh Government including Natural Resources Wales (NRW)
- DARDNI in Northern Ireland

Plant health is devolved...

Responsibility sits within countries but with cross UK partnerships and a coordinated approach to enhance efficiencies. This allows for distinctive priorities to develop but is also flexible enough to accommodate for biological movement.



UK governance and actions...

There is a UK Plant Health Strategy Board, UK Plant Health Service Coordination meetings, UK Plant Health Advisory Forum and GB and NI Tree Health advisory Group. There is a Plant Health Risk Group and a Plant Health Evidence Group and obviously Outbreak Management Teams. Activities include international representation and development of the Plant Biosecurity Strategy for GB and development of the UK Plant Health Risk Register. In Scotland official activities include Risk Group meetings, developing the Scottish Plant Health Strategy, and contingency planning with specific plans for tree pests. There are official inspections with tree nurseries, wood imports and wood packaging material. There is ongoing surveillance of pests as well as research. In addition, stakeholder engagement is carried out through workshops and shows and with the Scottish Tree Health Advisory Group and the Tree health diagnostic and advisory service. Other mechanisms involve citizen scientists - Observatree, Tree Alert, OPAL.

Research and evidence...

We ensure all of our activity is underpinned by robust evidence and knowledge. We have research carried out by official services (SASA and FR) and via work programmes or EUPHRESCO projects.



Some issues

Biological

- We need a specimen culture for an identification (Koch's postulates)
- What is the scope for latency, cryptic life stages?
- Is the pest live or dead?
- How do we build taxonomy skills such as identifying unknowns, new species or subspecies
- What is the significance of a finding? – e.g. number of units, threshold required for an outbreak (also host and environmental conditions required), male or female?

General issues

- Detection is only part of the process in determining how we deal with outbreaks!
- Imports/movements of trees – we want to be able to inspect rapidly; speed is essential, as delays lead to deterioration in plant quality and this affects trade. The size of the tree matters – it's hard to inspect larger trees. Soil is a difficult substrate in which to seek pests. We also have asymptomatic plants where infections are not currently visible.
- For Surveillance, we need to inspect large numbers of samples and face the challenge of accuracy versus speed and cost. This requires choices to be made. Indigenous pests may be tackled differently from new pests. We have lists of quarantine organisms but how do we know

which organisms to add in the surveillance list? We are helped by the risk register and have over 800 species currently on this list.

Community forestry perspective

(Bianca Ambrose-Oji, Forest Research/ Jon Hollingdale, Community Woodlands Association)

For the purposes of this meeting, we have focussed on Scotland. The **Community Woodlands Association** works for all community groups across Scotland, England and Wales. Forest Research can do research for them or they commission research together.

Who/what is community forestry?

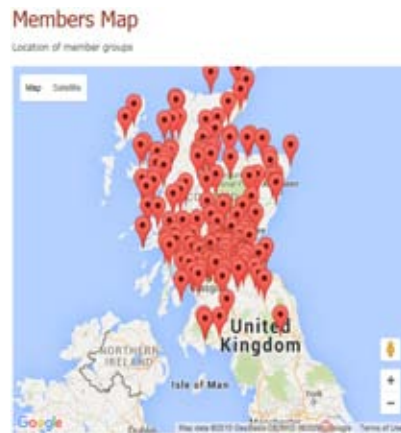
This is a growing sector especially since 2009-2010. There is no typical woodland group – they have different objectives and work in different types of woodland. Possibly in Scotland there is a closer link with land tenure reform and rural development whilst in England and Wales they may be seen as being more about conservation. We often dismiss people in community forestry as being ‘just volunteers,’ but in fact there is a growing professional body of people who are innovative and looking at enterprise development, asset ownership models and a range of social and environmental benefits that can be supplied by woodlands.

In Scotland there are approximately 200 Community Woodland Groups involved, with a range of relationships and tenures. They may own or manage woodlands and have social or environmental or both types of goals. There are unlimited levels of enthusiasm waiting to be harnessed but variation in levels of professionalism and technical knowledge. They are well networked through the Community Woodlands Association and in other ways, so there is good potential to spread ideas about technologies etc.



Community woodlands

The scales of community woodlands vary e.g. smaller woodlands in the Central Belt but could be over 1000 ha each in northern Scotland. There is no specific research on how community woodland groups are detecting or managing pests – although pine lappet moth and *Dothistroma* needle blight are acknowledged already. The motivations for community acquisition vary. Often communities end up with woodlands that are ‘market failures’ and are poorer quality, possibly more stressed and perhaps more vulnerable to pests and diseases? Some characteristics of community woodlands are known. We know that of the community woodlands that are enterprising they engage more in broadleaf than conifer, perhaps. They may engage with woodlands beyond the woodlands that they manage. They are thus also engaging with different stakeholders.



Two case studies

Urban Roots in Glasgow

Urban Roots is a community group in Glasgow that has a range of projects designed to promote social benefit in one of the most deprived areas of Scotland. They use 8.3ha of Local Authority owned mixed, mostly broadleaf woodland in their poor urban area. The community use this woodland for a range of activities and runs events focused on wellbeing. There is a high reliance on funding from various funding bodies. They have an informal agreement with the Local Authorities that own the land. Their woodland management focus is on social benefits.

North West Mull Community WC

The North West Mull WC has 700 ha community owned CLG. It is mostly mixed conifer. Community level benefits were part of the NFLS conditions; they aim to bring in financial benefits after the second rotation. They are reinvesting in woodland, forest crofts and have staff (1.5 FTE).

Community responses to pests

Each of these groups may wish to think differently about detection; objectives and responses will vary. The response to threats may be more nuanced and will be constrained by resources. They are less connected to timber processors so may be more interested in maintaining cover than in particular species goals. They will be more resistant to clear felling and sanitary felling. Deadwood may be used as firewood – so some activities will have plus consequences for some and negative for others. Pests and diseases could be a disincentive for communities to become involved in community woodlands and they can be risk averse.

Early response issues

Mostly these are social forests so they want to get more people doing activities in forests. The plus of this is the amazing resource – there are 200 groups in Scotland but more than 20,000 members UK wide plus engagement with other people. Community groups love doing surveys – they are educational and tangible and bring people together. However, they often don't know what to survey or what to do with the results. They need clear and timely information to manage for woodland resilience. There is great potential for citizen science. There is also concern about the increased use of woodlands being a biosecurity issue. We need to be sensitive about carefully balancing messages and actions. We do not want to prevent people accessing forests, but rather use the opportunity to reinforce positive behaviours such as cleaning boots and tyres.

Citizen science and early detection

(Michael Pocock, Centre for Ecology and Hydrology)

The first line of defence is about stopping entry with import controls. However, despite this, pests can enter and become established e.g. Oak Processionary Moth (OPM) and Asian Longhorn Beetle (ALB). We thus want to be able to detect nascent outbreaks early and to respond quickly. They have been called 'bipedal sensors,' because citizen scientists have such potential to get involved with detection. Colorado beetle has not become established at least partly because of the campaign of citizen science. There are other examples of floating pennywort and other invasive aquatic weeds that have been eradicated.



Citizen science can take different forms including volunteer experts, long term monitoring with standardised protocols or mass participations. We need to recognise the diversity of tools within this approach and employ a 'thoughtful enthusiasm'. There is potential for cost effective monitoring, sustainable long term monitoring and excellent coverage and resolution. However, a) it is difficult to assess recorder coverage and b) there are conflicting motivations.

Challenge 1 – Assessing coverage

There is asymmetry in information. If there is detection we need rapid observation, record submission, verification and action. Specific projects such as OPAL help with this. There is a tree health citizen science network being formed across UK to help coordinate responses.

BUT – if there is no report, does this mean:

- It was looked for or not present?
- It was seen and not reported?
- The area was not surveyed?

Examples include OPM which have been recorded within London but recording is less predictable outside of London. In the Netherlands collaboration with another project modelled probability of detecting OPM if it was present. In most places this was less than 10% but more than 0%. You can combine this information with risk maps and see how they overlap and where gaps are. This may permit targeting for particular campaigns or added input.

Challenge 2 – Conflicting motivations

Some groups may not want pest detection because of risk of chemical spraying! The project is running a trial setting up pheromone traps for Asian Longhorn beetles. You can run these traps for highly specific campaigns or for general recording. We hope this species is not found so we hope to find absence of the beetle. However, we can stimulate interest for people by setting traps to find a wider range of species. This may help maintain levels of enthusiasm for checking traps. The argument to stakeholders and funders might thus be incentives and mechanisms to find Asian Longhorn beetle pest, but to naturalists you might find native longhorn beetles. However, a positive finding means that the woodland is at risk. We thus have societal benefit but possibly local loss. Local benefits include getting long term protection of local sites /species and long term protection of

activities (despite the short term cost). Local impacts (despite benefits to society) might be that local sites suffer, activities are curtailed and financial cost incurred. Citizen science can provide costs and benefits, depending on legislation.

Panel discussion



Comment: Michael's presentation highlighted the sorts of dilemmas we've had in citizen science. One other thing to say, linking it to something Jane had said in her presentation...on the one hand we have the specificity of a pheromone trap, very specifically for ALB. On the other hand the advantage of encouraging volunteers to participate with a more general lure to trap some other beetles. The other issue about the whole detection thing is you have the 'known unknowns' but you also have the 'unknown unknowns' and some of the motivation for attracting some of these other beetles was the possibility

of some of the 'unknown unknowns'. This adds yet another dimension to what you are trying to do in early detection and also involving volunteers. It is an important element.

Q: For Bianca - is there a risk that enthusiastic people without matching technical skills might be introducing pests accidentally and how do we safeguard against that sort of thing? They might bring plants in from abroad or...is there a single way that they get information?

A: That's a really good question and I think it depends on the kind of community woodland group. So, if you look at Northwest Mull they are becoming professional foresters so their concerns align with the professional side of the sector, and maybe with the urban roots group the key managers may have good information but perhaps some of the people they are interacting with don't understand things so well. That then comes back to the messaging or communication. What messages do you want to start giving these groups and how best to tailor these messages to those groups?

Q: I've been going around forest districts to do a series of workshops on plant health. What surprised me is that we've got some really good citizen science tools like tree alert yet we don't seem to be getting it to foresters. Do you have any thoughts on how embed it in the day-to-day of professionals because they are part of citizen science after all?

A: Tree alert was originally launched as a tool for *chalara*. It was done very quickly and it had a few limitations, particularly with trying to expand to other pests and diseases. Forest Research has been in the development phase of getting tree alert up and running properly. I think they are pretty much there and the idea is to do a proper launch. I do think the uptake is getting better.

We want everyone to use this reporting tool from foresters to members of the public

Comment: Yes, I'm saying this from the grassroots because I've been encouraging everyone to use the tool but then people started emailing me back saying it wasn't fit for purpose. This can be discouraging for people. It might have been better to hold back the tool until it was better. Passing on a tool that is fit for purpose is very important.

A: The current upgrade is going on at the moment and a lot of the issues will be resolved. A press release will be going out imminently.

Comment: We need ways of getting into the field with information. The field don't read reports and don't look at newspapers so we need to find other mechanisms

Q to Rick – how do you see these early detection technologies being developed in this project linking to reporting tools such as tree alert?

A Making the distinction between the very earliest detection that something is going wrong and then having a very reliable system for verifying. Two different things but two critical parts of the process...I've always thought that we need to get people to look in order to find problems. I would rather have reports of something to investigate rather than having no reports at all. One of things we have to do is clarify the landscape as it can be quite confusing. For example when *chalara* hit there were multiple apps. So we need a platform.

Comment: Can I add to that. There always seems to be a competitive edge about who is pushing the platform out there...

Comment: How willing are people to report things? Do we do enough to publicise our successes or partial successes in what we do with management? We have to big up the threats in order to get funding to do the research and hopefully solve the problem, but do we actually convince people that the action we've taken such as cutting down a tree for ALB [Asian Longhorn Beetle] hasn't harmed the environment that much? Same with aerial spraying for OPM [Oak Processionary Moth] in Pangbourne. Do we do enough to say this hasn't change the ecology in a big way and hopefully has locally eradicated OPM there? By the same token, although we haven't stopped the spread of OPM in inner London we have probably at least slowed it down. Do we do enough to publicise our successes?

Comment: I was thinking along the same lines. We've got different perceptions by different communities within the UK. E.g. you've got the commercial sector, the environment sector and then you've got the public who may be concerned about cutting down of trees and woodlands. Do we need the message about the bigger picture; that if you don't take action here we may not have any trees left in other woods. There is an issue of shouting too loudly about the risks and then falling flat either because the spread doesn't happen so quickly or so much. It's a very complicated situation and we're not only talking about the science of it but also the politics.

Comment: Citizen science is a useful term of convenience but there are multiple audiences. Different projects will reach out to people in different ways. Perhaps rather than one platform we need to ensure that the platforms are interoperable with good relations between those setting them up so that data is shared quickly. Different platforms will appeal to different audiences. Ultimately as long as information gets to the right place as quickly as possible this, for me, is the key thing.

A I don't disagree about multiple platforms but even within one organisation there can be a struggle to even get their internal platforms to talk to each other; so consider consequences of having multiple platforms and also consider what resources are needed. It's a huge amount of resource to try and get these things to talk to each other. Movement of data from one organisation to another can be quite complicated.

Comment: In terms of single or multiple platforms, with the OPAL tree health survey, if we have one of the six most unwanted which is included in our survey we direct people straight to tree alert. You can make it work if you talk to each other and you coordinate.

Q Can we look at the motivations of people? If you are a small woodland owner you might be really worried to report something on your site. An interesting piece of research would be to compare their motivations with that of the nursery sector perhaps. The nursery sector have worked in this environment for years and faced eradication measures if pests and diseases are found. No compensation and by and large the grower will support that but they will support it on the basis that if you find it on the neighbour's nursery next year the same action will be taken and you are protecting the wider industry. The conservation groups have only just started that journey.

A With something like the nursery situation they will take the financial hit. There's a chance they might go bust, which is obviously devastating to them. If they don't go bust then they've got a chance of making it up whereas the perception of some people in terms of woodland management is that it's long-term (e.g. mature trees). Something about timescales also makes it challenging and intriguing to investigate further.

Pecha kucha style technology update

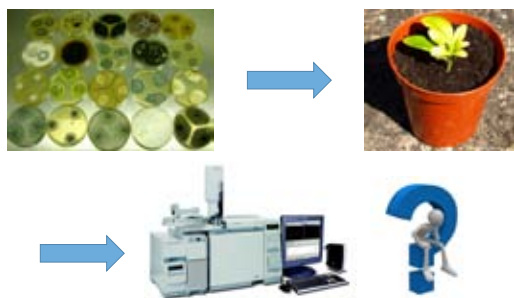
Each scientist presented a 5 minute update on their technology development seeking to build on key opportunities and challenges identified in Year 1. *Pecha Kucha* is a simple presentation format based on images (here produced in powerpoint), which are advanced on automatically ensuring that presentations are focussed and dynamic.



Work Package 2- Volatile Organic Compounds (Rainer Ebel)

If you have the structure of the chemical you are concerned with, you can train technology/instrument to detect it. You can train the technology to detect plant pathogens. An example is the tree canker of plane trees, which invaded Europe and was probably brought into Europe with American troops in WW2. In order to understand the impact of such a tree pathogen you need a trained pathologist who knows all about the lifecycle and isolated strains of relevant

pathogens to analyse the volatiles of these. You can find chemical signatures for individual relevant pathogens. We are now at the stage where we can try to establish the chemical profiles of cultivated pathogens. We will see if our chemical methods work. The next step is to try and train handheld devices to detect pathogens.



Questions

- Is this technology more for commercial imports than personal imports? A: yes.
- Is it only for pathogens or for insect pests as well? A: In principle it should be possible to detect pests
- How would you expect to get these into containers? A: You would pump the air of a container onto the cartridge. Ideally this would be a hand held device but it is not currently clear whether this would be feasible
- How many volatiles can you detect in one sample? A: We can certainly find 5-15 chemicals, which are specific for the profile of a given pathogen. The idea is to make an informed choice on which one we choose as a marker for a given pathogen. The problem is to try and eliminate false positives as we have no idea at this point which harmless organisms might produce the same volatile. We are looking into this issue but it will not be easy.

Work Package 3 - Hyper-spectral imaging (Hugh Mortimer)

We are physicists working in space science using remote sensing technologies from space science and applying them to biological diseases. We are looking at how we can detect biotic and abiotic stresses using hyperspectral imaging technologies. The images that you can expect to see are normal spectral images such as red, greens and blues. If you look in a different spectral region, in this case fluorescence, you can actually start to identify particular spectral wavelengths associated with disease. We are focusing on dothistroma needle blight (DNB), which is a challenging pathogen. We are looking at needles, which from an imaging point of view do demonstrate colour changes – red – so when looking for spectral changes. We want to look at multiple spectral wavelengths and we are

setting up a spectral database in a controlled environment where can analyse differences associated with different colours. This is a highly calibrated environment. We are working with Edinburgh University supported by Forest Research. We are combining high spectral resolution with imagery that you can see before. Using novel hyperspectral imaging we can process different wavelengths together to give information. Using colour patterns we can look at the difference between different bands and look at spectral images associated with stresses. The challenge will be taking this into field and calibrating to normal environment conditions.

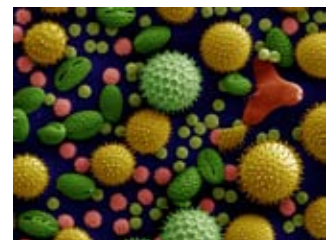


Questions

- Why is this technology not deployed on aerial photography? How are you going to deploy?
A: It is light enough to be deployed on an aerial platform. Typically hyperspectral images of the past were large and heavy. These techniques which are new are single snapshots using a single sensor with multiple wave lengths over each filter so you can use the same optics in front of these sensors to provide that high spectral resolution. We're trying to develop a hand held sensor that can be used by inspectors. You need to take many, many images to assess whether your biological sample is what you expect it to be. We're moving into an area of big data and we need to bring together different platforms and datasets
- How are you going to calibrate in the field given the other stresses there? A: We are working with experts to remove variations in different contrasts, different shading. There are crude ways of doing it at the moment using vegetation indices but we are interested in actually getting raw, physical data associated with disease itself. We can remove variations with angle, illumination to calibrate the sensor itself
- Comment: Fortunately plant diseases are quite rare compared to what normal is so I suggest that calibration is not done in the lab but in field. You could take a picture first of all and then state this zone is what is considered normal, ground truth it and then ask it to look for what is not normal. That would work well for inspectors in transit. A: This project allows us to work closely with key stakeholders such as inspectors.

Work Package 4 – Spore trapping (Neil Boonham)

This WP is about the development of surveillance and monitoring to tell us about risk ahead of time. We are looking at airborne pathogens. We are developing two technologies - one that is targeted and one that is not. Like human disease, plant disease can be transmitted in air e.g. *Chalara*. We are focussing predominately on fungal disease and looking for spores moving around in air. If we are detecting inoculum – then we are ahead of the disease. It is analogous with pollen networks, which are a risk prediction tool and we are trying to do same thing as we do with pollen. We will use trapping devices on top of buildings which trap air on daily basis. We know which species produce more risk of allergies than other and we can provide maps of allergies to highlight high risk areas and low risk areas. We can do the same thing for pathogens. We will do it in two diff ways. The first way is to target a single spore type. We can trap spores we are interested in. We are working with experts in cyclone technology at the University of Hertfordshire. The technology moves air around the cylinder to create a change in pressure. We can then look at the diameter and speed of movement of air and which pressure drop



would trap spores of the size we are interested in. From the modelling we can then use 3D printing to create different prototype cyclones. The idea is to build a device to stand in field. It will do tests every day and wirelessly send results back to lab. We also need to test samples and we will use DNA testing. We are currently building the prototype. The second device will look at mixtures. Can we profile a whole range of species present in samples of air we are trapping? This is known as genome sequencing. The technology is a lot more accessible with the drop in the price of genome sequencing. With the device we are using in a single run you can generate 30 million individual sequence reads. The trapped air in the spore trapper can generate lots of sequences from all the different spore types. We can use bioinformatics to separate the different sequences that you see into different spore types. We are making mixtures of spores of different types from different species and examining which bioinformatic tools we are going to use. This is quite challenging as it can discriminate between things that are closely related but not all. We have got access to pollen traps that also trap spores and we are aiming to be efficient by piggy backing onto the pollen trapping network.

Questions

- Many fungi are evolutionary designed to survive for a very long time in the environment. Do you see that as a potential problem for accessing DNA in this test range? A: Don't think it will be a big problem to break open the spores. We have overcome that in development but the challenge is interpreting that data e.g. can spores still cause infection if they have been around for a long time? How do we interpret findings in terms of risk of disease? Some aspects of this project are like the cart and horse. Until we've got the device we can't explore some of the science questions easily.
- How would you determine between the pathogenic and non-pathogenic bonds when there is so little difference morphologically and in some cases genetically as well? A: Techniques are based on DNA analysis. The reason we have done that is to get down to resolution to be able to achieve that. At the moment we are using conserved genes but that is not even able to discriminate between closely related species, let alone beyond the species level. The first technology can discriminate resistant genotypes. For the second technology we will be able to in fullness of time. The price of this technology continues to drop. In 5-10 years we could be looking at whole genomes of spores detected in traps.



- If you are capturing spores, that means we haven't kept them out so how important is it know we've got it? A: It might be a question about what you could do about it. This technology could form a network of spore trapping. If we use the example of *chalara* - if we had been worried about know when it was entering the country we could have had a network to say not just there are symptoms and 'it's been here for 10 years' but we could have been looking at the inoculum as it was entering the country. That potentially could have given us time to think about what to do. You can only do that if you detect early enough rather than waiting to see established symptoms.

Work Package 5 – Pheromone trapping (David Hall)

We are looking at novel approaches for improved pest trapping. We are not using passive trapping but trapping with baits and lures and we talking about insects although insects can also vector diseases. Pheromone traps can be specific and highly sensitive. They are relatively cheap to purchase and deploy. The specificity means we don't really need trained operators to sort the catch and particularly for alien tree species we are looking for the flying form before infestation has been achieved. The first objective was to improve attractiveness of traps for Oak Processionary Moth. There is a commercially available lure but

by adding another component we can double catches and reduce the amount we use in the lure. Trail pheromone are a slightly different approach. We are working on Oak Processionary Moth and Pine Processionary moth (which we don't have here) and we've started work with colleagues from another LWEC project BIPESCO looking at samples of the pheromone and trying to identify candidate compounds in the extracts that may be part of the pheromone. Citrus longhorn beetle, again not here, and we don't have an attractant for it. We've been working with the BIPESCO project trying to identify a pheromone for that. We've collected volatiles and done some analytical work and that's work in progress. With the trap network – we've been working with APHA with the Asian Longhorn Beetle trap network in Paddock wood and now looking at the citizen science approach Michael mentioned earlier. We are using a multi-species lure, the ALB pheromone which itself has a number of components and also pheromones that attract a number of wood boring pests including 'unknown unknowns'. Similar lures have been used in the USA and they attracted over 15000 beetles, 134 species over 3 years. We started the trial at the end of July - mid August. We didn't catch any beetles but volunteers are keen to repeat the experiment next year. We will start earlier. To answer questions from last year Learning Platform, one was about pheromone release rates - how long do lures last in field? They last for at least a month under extreme field conditions. Another question was how far do pheromone traps work? This is a difficult question – it depends. Some data we have suggests we are attracting anything from up to 50 metres with some coming in from longer distance. Another question was can we use pheromone traps for control? Yes it is possible. *Monocamus* traps in Spain showed we can take out 60% of *monocamus* population with half a trap per hectare. With one trap per hectare we can mop up at least 95% of the population. Future work that we want to do is complete identification of the CLB pheromone and develop the citizen science idea, starting earlier and with a wider number of participants.

Questions

- When you are using kill traps and using more generalist traps for citizen scientists to get them interested - you are potentially trapping rare species. Is this a concern especially if you are saying you can get rid of 60% of a species? A: This is something we have considered carefully and it is a dilemma. The traps we provided captured the beetles live. We recommended that people look at them every 2-3 days and once they are identified they were to release them (unless it was ALB). We asked the volunteers to photograph them and then release them. On one hand it is an attraction for enthusiasts to capture rare beetles that are difficult to find by another means but as you said you don't want to kill them.
- Is it only after a known outbreak that you put traps around or do you try and pre-empt it and put it around ports etc.? A: The idea would be to put them in ports or use a citizen science approach for wider cover. Certainly detecting any introduction would be one of the main uses
- Comment: but you can use it as a tool and give these traps to people in Southampton and Ipswich and that could be targeted citizen science.

Work Package 6 – Water borne detection (David Cooke)

Plants need water. Water is bringer of life but water can also be bringer of death in the context of plant pathogens. I'm dealing with *Phytophthora*, the plant destroyer. It is a pretty significant pathogen - there are 14 species alone on plant health risk register. We've had to be worried about it in past and should continue to be worried about it in the future. It's a big genus, 142 species described to date. There are probably many more species that we don't know exist yet. We are discovering more about them through new technologies. There is a history of *Phytophthora*. We need to be alert to future risks. We want to develop technology to use at ports, ferry terminals to prevent them coming in in the first place. The UK horticultural and tree plant industry is critical - £120 million in UK. We want to protect this industry. Detection is very hard – it is often stem based root infections, which are pretty hard to inspect in a consignment of 1000 plant. Sometimes

fungicide is used which can inhibit activity and we have a strong latent phase. Zoospores spread through water which is why it is the bringer of death. What we want to do is collect water coming of plants (that might be infected) and use that motile phase as a way of trapping and detecting it. The low technology bit is a sprayer that acts as a pump with an inline filter that captures the zoospores. Then we go to barcoding. DNA barcoding looks for minor differences in the DNA sequence. We can discriminate most of the *Phytophthora* species using this technology. The environmental DNA PCR we can use to amplify up this mix of *Phytophthoras* we've captured on our filter. We then run that through the illumina sequencing to produce vast numbers of reads. So we are looking at huge amounts of data. Does it work? We have been testing this out on some Scottish streams and we have identified 45 species and this is providing us with a baseline of what's healthy. In this project now we are looking at practical sampling regimes for people using this. In discussions with key stakeholders we are looking at ways to process those samples, how to ship the samples to keep them fresh.



Questions

- With the filters, could you fit them inline into irrigation systems? A: We could do it. In terms of plant biosecurity, that would be offshore testing so supplier nurseries. For this project we are not specifically focussed on nursery irrigation systems. We were focussed on testing plant coming in which is why portability is an issue for us
- So you can actually test plants coming into the country? A: my initial thoughts were for plant health inspectors to use this technology. Dialogue with inspectors made me realise that perhaps timescales for actually getting plants off lorries, running water through and testing these is probably not realistic. We are probably looking at material that's held in quarantine so risky batches of plants. The technology is there and one could test quite quickly.
- Is this something you could put on a phytosanitary license/plant passport – that it has been through this test? A: Well I think that could be an advantage to the industry but we are not talking about something that is handheld and two minutes later you get the results yet but it will be in the future
- What is your lower limit of detection? How many spores do you need? A: That's one of the things we've also been doing. It was rather higher than I thought. We set off with thousands of spores and working down assuming we would be detecting in the hundreds on these filters. I can't give you an exact figure but we are looking in the thousands. We are looking at testing batches of plants so its sufficient and what we're looking to improve upon is the current inspection methods
- Comment: It would be nice working through NPPOs around the world if we could insist upon an additional declaration on how an organism was tested for. This would be quite difficult to achieve. However, what is probably more achievable in the UK, there is a very few number of companies who import massive amounts of plants. I suspect a way forward is asking them as part of their QA focus when they are purchasing plants overseas to insist upon certain tests which may become industry standard before they are accepted. That's another approach that could happen.

Technology Development Knowledge café

Participants were divided up into five groups and spent 25 minutes discussing issues with each technology work package

Pheromone trapping technology

Discussion facilitated by David Hall. Notes by Michael Pocock

The discussions were very different across the different groups. Broadly people were divided as to the specific utility of the technology.

- (1) Some people said that pheromone trapping was the only technology in the project which actually had a technology readiness level that was ‘close to market’ and they could see it being useful to them.
- (2) Some people said that pheromone trapping was not especially new, and the key question was **how** and **where** it should be deployed.
- (3) Some people said that the potential for pheromone trapping to be used by citizen science was superb because it supported **both** engagement **and** monitoring. However, not all sub-groups agreed and one was sceptical of the application of citizen science for this.

Although the discussion was prompted by Asian Longhorn beetle pheromone trapping, it was not restricted to this species.

Key points

- The most important question was **where** traps should be deployed (and why)?: are they a tool for early detection at high risk sites, or are they a tool for more widespread use? How can we target pheromone trapping more intelligently (though this depends on the question that needs to be answered).
- **Who pays** for the traps and their checking? (Is it assumed that the government would pay for widespread pheromone trapping as part of the ‘greater good’? Is this realistic?
 - Currently 1 or 2 pheromone traps are used per major port for *lps*, but servicing a trap costs about £1000 per year.
 - Another estimate was the trap would cost £50 per season, with about 5 traps per port and an inspector visiting once a week for 2 months, giving an idea of potential costs.

Spatial targeting of trapping

The most important use for pheromone trapping seemed to be monitoring of specific target pests in target locations. This can provide early detection of pests. For trapping to achieve this, it really needs to be spatially targeted.

- The traps could be put **inside containers**, but the limited air flow, the fact that pests often do not emerge as adults until after transportation, and the difficulty of checking make this not so important.
- The traps could be used at **high-risk sites**, e.g. ports of entry, import destination sites or geographically vulnerable regions (e.g. the south coast for wind-blown immigrants).
- The traps could be used **at ports of entry**. (Or even at the start of the journey, i.e. pre-UK border– however would the exporter pay and use the traps without cheating?) This might be relevant where containers are opened for checking and so could act as a source of pests, however, this is probably not as important as destination sites.
- FC already use pheromone traps near major processing sites for *lps* spp.

- The traps could be used **at high risk destination sites**, e.g. using them at stone-importer yards. Currently a small number of high-risk sites are monitored (e.g. by surveying vulnerable trees around the sites for exit holes), but more sites could be monitored with cheap detection technology.
 - However, who pays for the trap? And what is to stop people cheating? How about having **non-tamper traps** or **remote-reporting traps** for these situations?
- Maybe it would be even better for neighbouring landowners to run traps. This is especially viable where the neighbouring business might suffer, e.g. plant nurseries next to stone importers. Their perception of suffering may, or may not, be correct, but they could act as diligent and honest monitors.
 - Would neighbouring landowners give permission for traps on their land? (e.g. at Paddock Wood the requirement for monitoring was statutory, but it might be harder to get access/permission for routine monitoring in some places.)

Widespread sentinel trapping network: confirming absence (and possibly early detection)

A second reason for undertaking pheromone trapping is to provide confirmation that the pest species is *not* present. One group suggested that with sufficient traps and sufficient checking we can provide a probability of the species not being present, which may be important to **support our 'protected zone' status** and potential for exporting. However, another group decided that there was no requirement for 'random trapping'.

Of course there is the risk that the trapping could reveal the pest species is present (is it better not to know??) and then the question could be asked whether pheromone traps could have actually attracted the pest to a location. Questions of liability need to be considered carefully!

Detection could be **prospective** as well as reactive. Foresters could be monitoring for a pest even when it is not present, in order to respond as soon as it does occur.

Trap design

- Foresters would like a **universal trap**, where you simply change the pheromone. However, some alternations to trap design would be needed depending on the organism and whether it is a kill or live trap.
- Even better would be traps which can run **multiple pheromones** for key pests. We would need to undertake research to see if the pheromones interfered with each other, but this is probably unlikely for unrelated species (because biologically the molecules are designed to be specific and effective despite all the other scents in the environment).
- If the trap is **not species-specific** (whether by design or not) then it cannot really be a kill trap, because of species of conservation concern that may be captured as by catch.
- The trapping can be **regionally targeted**, with different pheromones used by different people in different places. This is of interest because in some locations some species will be particularly relevant. However, in practice most species are relevant across most of the UK, so this is not really needed.

Added benefits of pheromones

- In some species, e.g. pine-tree lappet moth, pheromones are used for mating disruption and **control** as well as detection.
- Tree nurseries already use pheromone traps, but this is to monitor levels of pest species to work out **when to apply control** efficiently.

Added comments about citizen science

- It can be good for **engagement** in its own right. Pheromone trapping is one way to engage with wide audiences. Word spreads from those involved with the trapping and this all goes to raise awareness of tree health.
- Observatree volunteers could be a resource for participants interested in tree health and able to take part.

Volatile compounds technology

Discussion facilitated by Rainer Ebel. Notes by Jill Thompson

Key issues and questions

Questions

- Can this technology be used for people coming through customs?
- Can it be used to check hand luggage? [But containers are much bigger]
- Could the technology be used in forests?
 - Answer – In principle but it would be difficult because you cannot control for the environment (implication is that concentration of chemical volatiles potentially too very low). It could be used in forests in the correct conditions.
- Chestnut possible to import legally if without blight. Could this technology be used to test for blight? Can you find specific traits using this technology?
 - Answer: Still working on only two chemicals for technology development and not yet used on other things so don't know how long it would take to finish development. Once we have a reference library of chemicals it should be much easier. Need a certain volume of gas to test for successful analysis.
- How would the machine be used?
 - Answer – stick it through the door of a container. Note there are implications for the security of container contents if the is door opened and the time needed to move containers to positions where inspectors could reach the doors and open them for testing. (see also comments below)
- Most worrying are the things we do not know about so we don't know what to look for.
 - Answer: The sniffer technology could be trained easily.
- Need to have "in transit" testing so that we know if disease is in a container (for example) before it arrives so that the container can be sent back rather than landed. This would slow too much the shipping and transit times.
 - Answer: Analysis can take 45 seconds if enough chemical has accumulated.
- How easy would it be to train people at airports to use the technology?
 - Answer: Just like training drug sniffer at airports could train plant health inspectors.
- What are the costs per unit? Would the test be done on the spot in airports or would samples be sent away?
 - Answer- Testing more for containers of goods in ports. Unit costs might be high. Could extend the drug testing equipment already in use in airports rather than making new equipment. Smiths Detection are already involved in the project. The border agency is already regulated or equipment already in use.

- New Zealand are really vocal about importing plants with diseases. Why is it not so vocal in the UK?
 - Answer- Maybe because new Zealand are more threatened by diseases and still have more chance to keep out or contain threats.
- Is there anything that has spread in UK been known to have been brought in by the public rather than in containers/ bulk material?
- Are the VOC's only produced when the plants are actively growing? (Implication being if plants are not growing because then have been uprooted/cut off etc before being put in container then there may be no VOC's to test for)
 - Answer – Don't know.
- Could you use this technology to look for unknown chemicals?
 - Answer - No need to look for only chemicals that the instrument has been trained for. Could potentially look for a cocktail of different chemicals.
- Could you use this technology for CO₂ testing?
 - Answer – No
- How big is the machine?
 - Answer – small. You already as see them at UK airports.
- How long would I have to wait for my results?
 - Answer – testing in Heathrow for drugs take about 45 seconds but depends upon concentration of chemical. Higher chemical concentrations could yield faster results.
- Could the technology identify the particular country the plants came from – such as country specific volatiles by geography?
 - Answer – don't think this would be possible
- Out of 20,000 organisms – can one determine pathogen and non-pathogen strains.
 - Answer – In principle yes.
- How long should the sampler stay in a container?
 - Answer – a short time as results are fairly rapid.
- It is possible for dogs to smell *Phytophthora ramorum* – would a dog be easier and cheaper?
 - To be robust and useful you would need to know specific profile/signature of the disease and the quantity/ concentration in the atmosphere. A dog could not tell you this. It would only potentially give presence or absence. It would be good for proof in court cases to use a machine that measure versus using dogs that couldn't tell you concentration nor absolutely they had found the test chemical. Perhaps you could first use dogs then ion mobility then laboratory tests to be really sure.
- Would the sampler detect residues from earlier cargos? How long would residues last in container?
 - Answer – Volatiles are in the atmosphere so could not use to test later after contents removed, but would have to look at potential for getting false positive results. (see comments below)
- How many samples give false negatives?
 - Answer – not known yet.
- How intense would the infection have to be before the technology would be able to detect?
 - Answer – don't know still testing.
- What is the potential for using this technology detecting insects and other pests?

- Answer – it might cost a lot to test for insects but it is not impossible. You could potentially test wood packaging in containers for insects and it might be easier to test for pests and insects than diseases if you can identify chemicals in atmosphere and associated damage and then trained the machine to pick this up. You would need to develop the tests and get a high enough concentration to test for.
- What limit is there on number of chemicals that can be tested for at one time?
 - Answer – dozens at a time.
- Could equipment be used to look at many things at once?
 - Answer – yes but depends upon training the machine.
- You may have a container with many different species and only one plant of one species with a pathogen/disease. Would this be detected?
 - Answer – we may have to change policy to allow only one plant species per container to make testing easier/ more reliable.

Issues/comments

- This technology is best used for containers.
- Need proof of concept using known parameters – but these chemicals are usually in minute quantities so difficult.
- Knowing that the technology exists might affect behaviour.
- The technology platform already exists at airports.
- Might get too many false positives. E.G. In relation to the bacterial disease of potatoes, both potatoes and bacteria produce the same chemicals so might get many false positives. Difficult to distinguish effect of pathogen from non-pathogen.
- You would need a container policy e.g. if you find signature of pathogen/disease should whole container of material be destroyed? There is the issue then with false positives or potential for carry over from one shipment to another. Maybe if you find a positive sample it would be up to shipper to prove there is no disease or else the container is sent back to the originating country.
- Some commodities are 100% inspected; others on small sample basis. E.g. for Wood packaging there is random sampling but controlled timber is sampled much more. Maybe for some commodities you do remedial treatment at shipper's expense if a disease is found. This could apply only to the first and/or second offense then you could blacklist the shipper.
- Would be good to test before shipping starts and results of testing added to plant passport but this means you would have to trust the people testing before shipment sets off.
- There could be the possibility of people swapping or removing the sample from containers on arrival so no results are obtained or no diseases are recorded. There is a difficulty in keeping track of samplers – potential for using tracking device on sampler?
- Traders might inject specific chemicals to fool detector – such as drug smugglers hiding drugs in onions and coffee etc.
- People want their own variety of potatoes (implication is that people are not so interested in varieties that are more disease resistant).
- Diseases are only brought in by accident.
- Plants could be asymptomatic for disease and this technology might get around this inspection problem.
- We could not use this technology to find tree diseases by flying over forests as the concentration/signal may be too weak at height of testing above forest.

- People would use the technology if it was simple, practical and quick. It should be useful if it works!
- It would be good if the technology was portable.
- Could use this technology for import control as you would be able to avoid handling, moving and potentially damaging the produce/products (i.e. fruit and veg and plants etc).
- The requirement to test with the sniffer technology could be part of the plant passport. Commercial companies could run accreditation scheme.
- This technology could be used to support what is done at the moment – justified use to support visual inspections at ports.
- The technology could also be used to protect/safeguard inspectors by testing for substances such as methyl bromide and other gases that might be pumped into containers to kill pests or toxic/noxious chemicals sprayed on wood packaging etc. You could test the container atmosphere before inspector gets into it.
- Social Science needs to work out how to enforce messages.
- The cost and size of instrument may be an issue. Potential cost of the instrument is unknown.

Spore trapping technology

Discussion facilitated by Neil Boonham. Notes by Andrew Crowe

Questions and comments

Technology readiness

- How far off is the technology?
 - There will be a prototype this year
- There are existing air sampling networks. Supporting organisations – Defra, AHDB, Industry

What the technology can do

- The technology can extract air from containers as well as in the wider environment
- Identify if present in wider environment or confined to inspection site
- Detect what's there, help with filling in gaps in biological knowledge
- Does it work in rain/temperature/humidity constraints? A: System has met-station to activate when conditions are right
- Help setting up zones for exclusion, control zones
- The sequencing technology could be applied to multiple networks – aerial spores, waterborne spores, pollen, insect traps
- Defining the area that is at risk
- Identify when to apply treatments
- Automated device – sends data from the field. Targets 1-2 species at a time. Could be changed with new risks
- Possibility to profile more than just pathogen spores. Sell data to different organisations with different focuses.
- Allow the production of baseline data to compare against current measurements

Scope and scale

- What is the biggest need? To detect/monitor what is already here or prevent entry
- How to deal with detection without visible impacts. Also detection of new targets when symptoms are apparent?

- Potential to locate the technology with existing met stations/sample network locations

When to use the technology

- Sensitivities of new technologies. When should we take action? Need to establish baselines and time series of results
- Tools to identify when to take actions e.g. in nurseries
- Can you match biological constraints to technology e.g. diurnal rhythms, seasonality?
- How long to run for? A: dependent on container/open environment
- Technology can allow us to identify potential high risk years

Who will use the technology and where

- Citizen engagement – needs to be easy to use and cheap
- Arboretums, coastal sites, nursery locations, wind direction and land use for siting samplers
- Off-shore locations – ferries, oil rigs, wind farms for earlier detection before entering the UK
- What sort of areas are covered by a trap? A. Existing networks are based on urban locations
- Is training required to operate the technology? A. Maintenance vs specialist knowledge
- Use of other sampling devices e.g. rain traps might be simpler so might be used for citizen science.
- Scale of sampling - spatial scale block/field or regional network

Other issues

- Should work across sectors and not just plant health. Need for closer working between industry and regulators
- What about the new data being produced – how do we use, display and interpret the data?
- Should technology be used outside of UK borders e.g. buy-in from other countries
- Costs of technology – scale of costs based on number of unit manufactured and sold. 10-20k for automated systems
- Cost of the problem.
- What is lead-in time for new outbreak/organisms of interest?
- Negative for aerial spores does not mean soil/water is free of inoculum
- Reliability of data produced – number of sites in network?
- Protecting the technology from wildlife, theft, vandalisms. Could get volunteers to site samplers, make them responsible for security and maintenance
- Identifying where non-symptomatic regions are due to the lack of inoculum vs not observed symptoms but disease present. Need to quantify sensitivity – false positives and false negatives
- Still need to identify if the organisms is viable after detection
- How to deal with unknown/non-target organism detection?

Water sampling technology

Discussion facilitated by David Cooke. Notes by Rick Mumford

Key questions and comments

There was significant discussion around potential **applications** for water testing. Key ones included

- Testing for contamination in **irrigation/recirculation water** at nurseries could be a major application. This type of testing is already done at present using different technology.
- **Wider environment testing** as part of general surveillance, for example in high-risk (outbreak) areas to assess whether there are high levels present.
- Could be used as part of a **quality assurance** system for plants for export

Other niche applications identified included:

- Benefit of being able to detect **live vs dead** (captures swimming spores i.e. live pathogen)
- There was specific discussion made of testing conservation and/or intercepted illegally imported plant material, held in **quarantine at RGB Kew**. This material would constitute high value/high risk material and could make a very strong case study.
- Could also be applied in **non-tree health situations** e.g. potatoes? and possibly other pathogens e.g. bacteria?

There was also discussion about different approaches to **sampling**. Key points included:

- Potential for use of **citizen science** for sampling in wider environment
- Can link to other water sampling i.e. **environmental monitoring?**
- Could also sample from substrate e.g. bark or soil to check for contamination
- Easier to use on **plug plants**, rather than bare rooted plants. Key advantage would be speed of screening thousands of plants
- BUT there is also the physical challenge of collecting samples from nursery plants – need to develop a simple and cost effective system from collecting water from roots.

The discussions also moved onto **incentives** and mechanisms for encouraging uptake

- There is a need for **early engagement** of inspectors and other end users
- Need to understand and **clearly articulate benefits** to growers. Will need to have a commercial benefit e.g. added-value

Discussions also raise potential **barriers to uptake**, including some of the practicalities and logistics of using water testing. These included:

- Knapsack sprayer is big (postal costs) and not always available
- **Timescales for results is currently long**. Need to streamline whole test process especially sequencing and bioinformatics analysis.
- Collecting samples and shipping them has **costs and workload implications**
- Real technical issues of **sampling/testing at points of import** or at nurseries e.g. how do you collect the water samples?
- Questions also about **who will pay**. Need to ensure ongoing provision of service – best achieved as a commercial service but at what cost? And while the current project will develop the basic platform technology, who will pay for the development of the routine service?

Hyper-spectral Imaging

Discussion facilitated by Hugh Mortimer. Notes by Michelle Hamilton

Questions and comments

The main themes were:

- More interest in an airborne system rather than handheld device. An airborne device would have more impact for the applications the stakeholders had in mind
- Applications
 - Forest mapping
 - Forest management
 - Nurseries – not so much, but this focus could have reflected the stakeholders present at the discussions
- Technology low maturity but high impact
- There were few comments on policy regulation
- Stakeholders wanted more detail of how it compares with current systems and what you can see with your eye

The main take home message for this technology was that there was good interest in a potential instrument for the future but they realised that the technology is at a low TRL still. Secondly, an airborne system would have the most interest and impact.

Keynote listener - Anna Brown, Tree Health Policy, Forestry Commission Scotland

Why do we care? We have had significant loss of trees because of pests and pathogens. In Scotland, a big example for us is *Phytophthora ramorum* in larch – this picture [see presentations on the website] shows widespread mortality. The disease has to get in from somewhere so we still have to think about our pre-border and our border controls and that's where the technology side comes in. When thinking about technology it's not just what happens at our ports or is coming in on aircrafts but it's also what happens at nurseries as our next port of call. Some of the technologies we've been talking about today have seemingly been targeting one particular area or another but actually, listening to the talks this afternoon I'm wondering whether we are targeting the right places e.g. rather than at a nursery would a specific technology be better at detecting in the wider environment later on? Could you use spore sampling for containers etc? Maybe we could think more about the multiple uses of these technologies, where they can be best deployed.

What are the positives that I see for the project? Rick gave a nice summary of the project aims – it says all the right things e.g. we want a set of technologies fit for use in the real world in a range of contexts as well as early links with social scientists and industry engagement. It's actually making sure this happening in practice. It's one of the few projects where social scientists are really engaged from Day 1 and that's really good to see and it does mean that workshops like this are happening. The development of dTRL is a great idea. It will be really useful for making that risk-based decision for policy makers or how quickly we can deploy that if, for instance, there is another *chalara* incident or something like that. It will be useful to assess the likely success of tools. However, there is a question about flexibility in the system and how do you take into account changing needs? What we want today might be very different to what we need tomorrow. How can we improve flexibility in the system to ensure the technology is not 'out of date' by the time it is deployed?

As the talks have progressed some of the questions in my mind are: do the technologies address the issues of speed of detection? This is especially important at borders when you are sampling containers for example. I'm not sure substrate type has been entirely addressed. Size of tree, soil – I think it will depend on the type of technique you are using and that brings issues itself as how much kit does an inspector need to inspect a container using different technologies? I have an image of an inspector with range of tools at the belt but how will that actually work? Pretty much all we've talked about today is dealing with 'knowns'. They are always list-based pests or pathogens. They are not dealing with things that we don't know about. Even if we get that information on what we don't know, which the air sampling was talking about, what do we do with it because all we have is a

sequence. So, is DNA enough? How do we get to next stage of finding out whether it is a threat to us?

Another question is can these technologies realistically be deployed in the right location/environments e.g. an outbreak situation. How many traps would we need for pheromone trapping around the point of entry? What the range of these? Could we have enough of them? How many sniffer technologies would we need to improve on the system we've got? Can we do it at the scale that is required – if 8 million containers come in, how can we get to a reasonable amount of those? You could say we'll change legislation or we'll change plant passporting but it's very complex and difficult. I like the idea that we could introduce some sort of scheme e.g. a certification system like red tractor that is a sign of good plants

How does the technology fit within the policy or industry needs? How do we ensure we are asking the right questions? I don't think people have really entirely got to grips with this because you are looking at one small part – detection – and even that has lots of issues, different government departments and non-government departments. Different systems at each point and it has to feed into everything else like the reporting, impacts, epidemiology, managements, communications and it's got to link in and make sense within the wider framework.

There's been quite a lot of talk about citizen science but are the tools suitable for non-government specialists. Can they be used easily? Can people be trained easily to use them? Are they cheap enough to send out to people? I can give the water sampling example where people need sprayers and it might be problematic to send out ethanol chemicals. How do we engage with different sectors? Observatree is a really good example of a success story of an early warning system. It was very targeted though. We have expert volunteers who have been handpicked by the Woodland Trust. They couldn't just become volunteers. They had to pass tests and be interviewed. We need platforms for people to actually report stuff back. We've got Tree Alert but we do need a common way for all these systems to talk to each other because plant health is a GB/EU/Global issue

Also, how do we sell bad news? If you want a nursery to take up these technologies you've got to convince them to do it, that it's for their benefit. Or if you want people to clean their boots when they go into a forest, you've got to make them understand why they are doing it so that might be getting them involved in insect trapping. Something exciting and makes them think about it. But it's actually quite hard as there are costs associated with it – financial, emotional and environmental. We may like to think that most people will act for the greater good but it could be NIMBYism (not in my backyard).

Some of these technologies are now new but it is how you want to deploy it. There are newer technologies such as hyperspectral imaging and they are at very different stages of development. Some will be really good but may be used by the next or following generation! Pheromone trapping can be used now so it's how we deploy a range of tools. There is also a chicken and egg issue in that all groups are very much research focussed rather than policy or operational needs. Very little is looking at a policy structured question to push that forward and this is a problem throughout research and policy. It's a lack of communication.

How usable are the technologies? Concepts are there but not the detail but the details may make it difficult to do. How do we audit use? How do we know people are doing what they said they are doing? There's a real lack of clarity about who pays. Generally people think it will be the inspectors but resources within government are getting tighter and so we need to share responsibility differently across the industry. Not only who pays but also who uses it at the end of the day?

There was a workshop a few weeks ago on the Centre of Expertise (CoE) in Plant Health. It is a Scottish initiative. They've already got one for climate change, one for animal health and water.

- to bring together the best interdisciplinary scientific expertise (virtually) in Plant Health Scotland and wider
 - to help ensure knowledge flows between science disciplines, between science and policy and between policy teams. Policy often know what their problem is but don't always frame it in the right way to scientists.
 - to establish a platform that is dynamic with respect to the evidence and responsive to need
- This is planned to happen next year and will help our responses.

Visioning session - Rehema White, University of St Andrews

There followed a session using visioning as a way to explore the future field of early detection of tree pests and pathogens. The workshop so far had focused mainly on immediate uses of the technologies involved in the project. In an attempt to identify wider uses or alternative technologies, and to imagine what we might be aiming for, in this session workshop participants were asked to explore the following questions for a future 10-15 years ahead:

VISION

- What sort of technologies would be in use? Can you envisage an integrated system or specialised? Who uses technologies? What roles would exist to manage early detection? Who would have responsibility? Who funds it? What would the response to and consequences from early detection be? What policy framework would exist? What rights and responsibilities would different individuals and groups have?

STRATEGY

- What are the major changes that have to take place to achieve the vision above?
- How do we get there?

REFLECTION

- What can we bring from this wider visioning to inform our practice and the development of early detection technologies now?

Given the short time available, participants were asked to consider all parts but focus particularly on the Strategy aspects of this visioning exercise. Table based groups were permitted 10 minutes of discussion followed by a brief plenary report back and debate.

Plenary comments from tables:

Table 1

- Pre-border protection is ideal; we really need to have clean plants coming in and detection in the country of origin.
- We should move towards more home grown industries – hence reduce shipping across borders. By strengthening our own growing capacity we can increase confidence in the quality of what is produced.

Table 2

- The big question is what resilience means in context of forestry. If resilience is adapting to change, to what extent do we need to adapt to the changing climate and trade industries and accept that more pests and pathogens will come in? We will thus have to learn to live more with what is coming in. If we accept that more will come in, we need to be more knowledgeable about what is coming in.

- Pre border controls are important; detection can be done prior to country entrance.
- If we accept that there will be more trade, then UK protected zones become more important. Hence there is a greater requirement to be proactive to show nothing is in the UK protected zone. It would be ideal to be able to genotype pests and pathogens. Having automated systems that can work quickly will be essential in the future.
- People are willing to pay for quality rather than cheap stuff that does not work well. Industries prefer to invest and the cost of clean-up of epidemics is high.

Table 3

- Prevention of pests and pathogen outbreaks is better and cheaper than the cure.
- In the dream of the future, technology is implemented in the country of origin before export so clean plant material is imported here
- The cost would be borne more by industry and with a greater assurance of low pest and disease risk before movement
- There should be stronger border control with tri-corders.
- There is concern about unknowns – non tax on technology to improve detection.
- Better informed public and industry will produce better behaviours – public engagement needed.

Table 4

- There probably won't be one single technology but there will be better integration of technology
- We need more general use types of technology. If you are following UAV with hyperspectral technology, this will be relevant to variety of sectors. Rather than just data collection, it will be more important to understand and share access to data. This will mean the way people pay for data will be shared. This needs to be coordinated with shared access and integrated platforms. The generic use of term 'data' is not fit for purpose; there are so many types of data. We need a multi-platform and interdisciplinary approach that can cross over areas of science. Funding is also critical– getting technologies funded properly and more experts on the ground.

Table 5

- In the future maybe we will be using tiny cube satellites to look at things before they leave country of origin.
- We need to look at multiple pest and disease instead of single species
- We need an open platform for data so data can be shared and used
- Pre-border checks are essential so pests and pathogens don't leave their country of origin and plants do not have to get sent back

Summing up and general discussion points

pre-border detection:

Many tables identified pre border checks as being most important. But how do we implement these? What is the policy context? There was discussion of a need to implement further regulation but within a European context this seems very unlikely. It is difficult to get tighter or different regulation for one country. Perhaps we could have an industry supported enhancement of clean trade in which a certificate is offered for plants tested using certain technologies? More than a passport, a certification?

Where is the border? In the case of imports we know it may be point sources such as ports but in some cases we have biophysical borders such as altitude or latitude across which pests and

pathogens do not currently cross well. These may change with climate change. In some cases Europe provides our political border in terms of trade.

technology and trade:

Which technologies are useful is not fully understood but we need to keep developing a wide range of technologies to meet the need of 'unknowns'. How and where technologies are deployed and by whom will also depend on trade characteristics; whether we grow more of our own material and who imports and who pays for technology use.

data and responsibilities:

It is clear we will generate huge amounts of data and part of the problem will be determining who collects and holds data and how it is shared. In addition, we will collect different kinds of data and thus need to identify responsibilities within / industry / citizens / community / policy makers / inspectors

Farewell and final words- Rick Mumford

Sometimes we need to have **scientists** to generate the kind of discussion we have had in this workshop, but **other stakeholders** are essential for us to understand the potential and implications of new technologies for the detection of tree pests and pathogens. Hence the broad participant attendance at this workshop has fulfilled an essential need in or search for tree health.

Who knows what we can do with a technology until we have the technology? We have spent some time predicting the future and trying to develop visions, but sometimes we cannot do this effectively. For example the iPad once developed gained much wider use than people imagined would be possible.

Don't underestimate time to technology deployment. TRL 8-9 can take a long time and may be the hardest steps. On average we know it takes 8-15 years from first proof of concept publication to first use.

Participants were all thanked for attending and wished safe travel home.