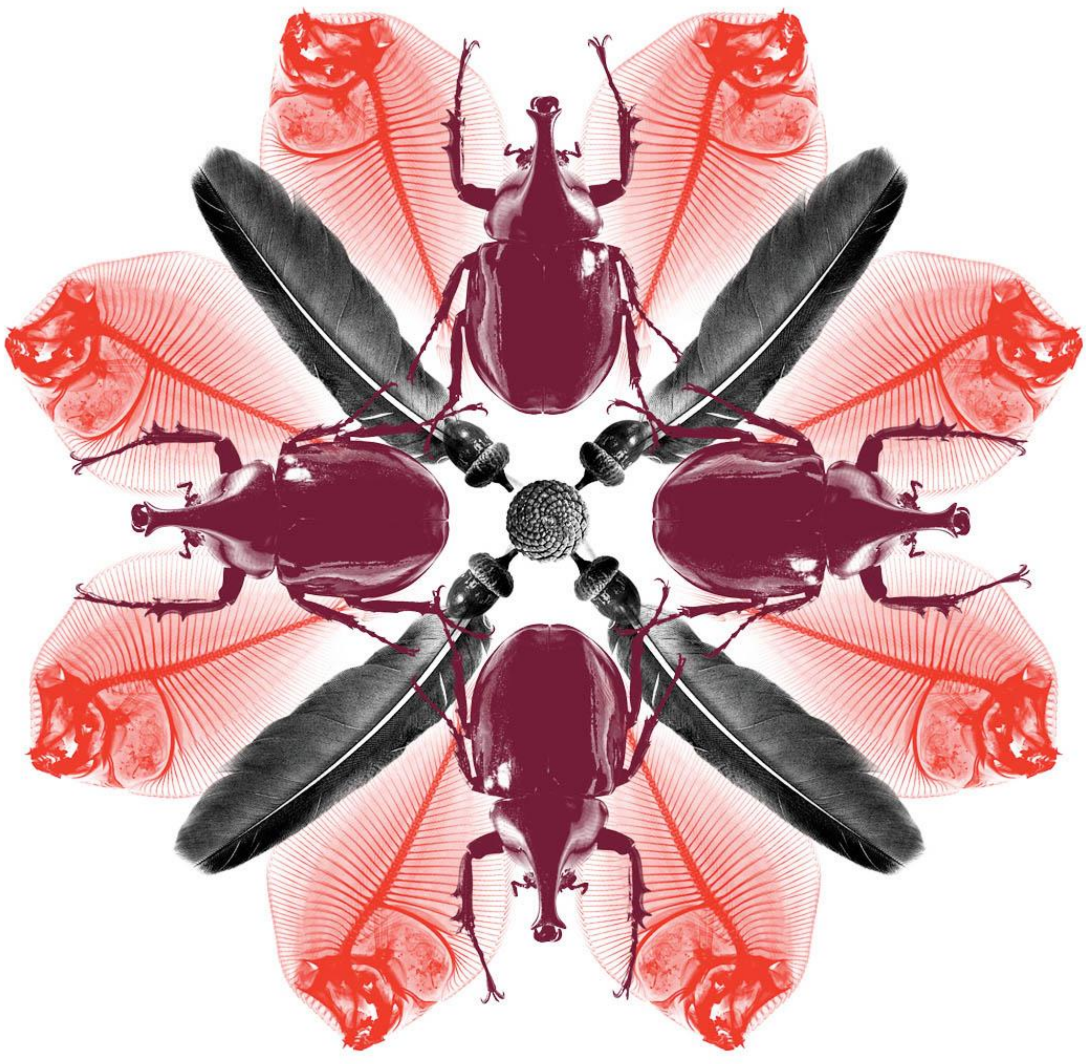
Australian Government
Department of Agriculture and Water Resources

International symposium on *Xylella fastidiosa*, 17-18 May 2017

Summary and key learnings



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Foreword

I am pleased to present the summary of Australia’s first international symposium on the bacterial plant pathogen *Xylella fastidiosa* and its insect vectors.

Xylella fastidiosa, a bacterium transmitted by common sap-sucking insects such as spittlebugs and sharpshooters, is one of the most harmful plant pathogens worldwide. The pathogen is not yet present in Australia. However, the exotic *Xylella fastidiosa* is Australia’s Number 1 National Priority Plant Pest because it has the potential to severely impact citrus, grape, olive, peach and plum, nursery stock and forestry industries, along with our native plant species.

Originating in the Americas, and now present in parts of Europe, Taiwan and Iran, *Xylella fastidiosa* is deadly, highly invasive and has significant economic and environmental impacts. It has wiped out more than a million olive trees in southern Italy and costs the Californian grape industry an estimated US$104 million a year.

To raise awareness of this threat among Australian Government agencies, industry and our regional neighbours, the Department of Agriculture and Water Resources funded and organised the International Symposium on *Xylella fastidiosa*, 17–18 May 2017, Brisbane and a related Diagnostics and Surveillance workshop, 19 May 2017, Brisbane.

Experts from Italy, France, Taiwan and the United States shared their country’s experience with the pathogen and its insect vectors and their management. Experts from Australia and New Zealand discussed potential impacts in our region and preparedness to respond quickly if *Xylella fastidiosa* is detected here.

The highly successful and well-received two-day symposium was attended by 102 international and national delegates and speakers.

This report summarises the scientific presentations covering four themes:

- *Xylella fastidiosa* and its vectors
- Diagnostics and surveillance
- Management and control
- Research and collaboration.

A key message arising from all symposium themes was the responsibility shared by all Australians, from producers to government and the general public, in guarding against the risk of *Xylella fastidiosa* and its vectors.

I trust that this symposium summary will inform our ongoing conversations and work towards improving Australian preparedness for this pest of worldwide significance.

Lyn O’Connell
Deputy Secretary
Department of Agriculture
and Water Resources

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Summary

In 2017, the Department of Agriculture and Water Resources funded and organised the first Australian international symposium on the bacterial plant pathogen *Xylella fastidiosa* and its insect vectors to raise awareness of Australia's Number 1 National Priority Plant Pest.

The aim was to inform about the science underpinning the preparedness for, and management of, this pest of worldwide significance and facilitate engagement opportunities among experts, delegates and affected industries. The International Symposium on *Xylella fastidiosa*, 17–18 May, Brisbane, covered four themes in 17 presentations:

- '*Xylella* and its vectors' provided an overview on the epidemiology, biology, and genetics of *Xylella fastidiosa* subspecies, and the complex associations of the pathogen with its hosts and vectors as modified by climate, particularly temperature and precipitation, environmental factors including irrigation, proximity of reservoir species, and phytosanitary measures.
- 'Diagnostics and surveillance' provided knowledge on current practices employed in countries and regions where the pathogen is present and the development of diagnostic capabilities to prepare for a potential incursion.
- 'Management and control' discussed the challenges of controlling and managing *Xylella fastidiosa* and its vectors from a practical and policy perspective, the impacts of *Xylella fastidiosa*-caused diseases on industry and communities, and research to address these challenges.
- 'Research and collaboration' presented an overview on the highly integrated research, development and extensions (RD&E) programs of California, the development of an RD&E program following the more recent disease outbreak in Italy, and current and potential collaborative activities across Australia and internationally.

The themes were addressed by speakers from Italy, France, Taiwan and the United States who have had extensive experience with either the ongoing management of the established pathogen and its vectors or the management of recent incursions and associated socio-economic complexities. The regional context was provided by experts from Australia and New Zealand who discussed potential impacts in the region and preparedness to respond quickly if *Xylella fastidiosa* is detected. This report summarises the speakers' presentations, provides their biographies and a delegate directory, along with the key learnings arising from the symposium and a diagnostics and surveillance workshop.

An important message arising from all symposium themes was the responsibility shared by all Australians, from producers to governments and the general public, in protecting against the risk of *Xylella fastidiosa,* its subspecies and genetic strains, and its insect vectors. Producers need to take proactive measures to identify and report any unusual pest or disease symptoms. Similarly, the general public can help keep Australia *Xylella*-free by not bringing plants or plant parts (cuttings, flowers, or leaves) through the airport or by mail.

The International Symposium on *Xylella fastidiosa,* 17-18 May, Brisbane, provided a critical forum for Australia to review its ability to keep *Xylella*-caused diseases offshore, to detect the pathogen and its insect vectors, and preparedness to respond quickly and effectively if *Xylella fastidiosa* was detected in Australia. It was supported with funding from the Stronger Biosecurity and Quarantine Initiative and the Agricultural Competitiveness White Paper.

1 Introduction

1.1 *Xylella fastidiosa*

One of the most significant emerging plant disease threats worldwide is the bacterium *Xylella fastidiosa* (Hopkins & Purcell 2002; Retchless et al. 2014). The pathogen is transmitted by common xylem sap-feeding insects. Human-mediated long-distance dispersal of infected insects or plants has been a primary driver of economically costly *Xylella fastidiosa* introductions (Almeida & Nunney 2015, IPCC 2017). In Australia and many other countries, *Xylella fastidiosa,* its subspecies (ssp.) and genetic strains, is a biosecurity concern because it:

- has the ability to expand its geographical range and invade new areas
- has a complex biology that enables it to colonise numerous host plants (including some Australian natives) and common insect vectors
- causes damage to agricultural industries totalling millions of dollars annually.

Until the late 1950s, *Xylella fastidiosa* was thought to be limited to North America (Retchless et al. 2014). Since then, *Xylella fastidiosa* has been confirmed throughout the Americas and in countries such as Taiwan and Iran. In 2016, a new *Xylella* species, *X. taiwanensis,* was identified as the cause of pear leaf scorch in Taiwan (Su et al. 2016). Over the last 10 years, *Xylella fastidiosa* was reported in Italy, France, and Spain. The bacterial pathogen is not yet present in Australia.

Xylella fastidiosa and its subspecies and genetic strains spread in the water-conducting system (the xylem) of susceptible plants. The occlusion of xylem vessels and the consequent impairment of nutrient and water uptake is the main pathogenic mechanism (Mendes et al. 2016).

A typical symptom of *Xylella*-caused diseases is leaf scorch due to prolonged water-stress. However, hundreds of asymptomatic plant species have been reported (Hopkins & Purcell 2002; Chatterjee et al. 2008). Over 350 cultivated and uncultivated herbaceous and woody plant species are known hosts of *Xylella fastidiosa*. The host range is anticipated to increase as different subspecies of *Xylella fastidiosa* invade new territory (IPCC 2017).

Xylella-caused diseases include Pierce's disease of grape, citrus variegated chlorosis of citrus species, almond leaf scorch, pear leaf scorch, and olive quick decline syndrome (Hopkins & Purcell 2002; Martelli et al. 2016). These diseases kill susceptible plants, though there is genetic diversity in tolerance to the pathogen within host plant species (Hopkins and Purcell 2002).

Managing *Xylella*-caused diseases is economically costly. For example, management activities cost the Californian grape industry an estimated US$104 million per annum and the Brazilian citrus industry US$120 million per annum (IPCC 2017).

Environment, temperature and water play a major role in the distribution of *Xylella fastidiosa* (Hopkins & Purcell 2002; Redak et al. 2004). However, the epidemiology of *Xylella fastidiosa* is complex and varies depending on the plant host, host-specific strains of the pathogen and its sap-feeding insect vectors (Almeida & Nunney 2015). Potential insect vectors are widespread and common in parts of the world currently not affected by *Xylella fastidiosa* (Redak et al. 2004). New host–pathogen combinations and invasive insects have caused 'startling increases in the problems caused by *Xylella fastidiosa'* in terms of impact and spread (Hopkins & Purcell 2002).

1.2 The symposium

In 2016, the Plant Health Committee identified *Xylella fastidiosa* as Australia's number one national priority plant pest. In response, the Department of Agriculture and Water Resources organised the International Symposium on *Xylella fastidiosa*, 17–18 May 2017, Brisbane. The aim of the symposium was to inform on the science underpinning the preparedness for, and management of, this pest of worldwide significance and facilitate engagement opportunities among experts, delegates and affected industries.

Participants included representatives from Australian Government agencies, industry and International Plant Protection Convention (IPPC) representatives of regional neighbours. The list of participants comprised 30 department representatives, 20 state and territory agencies, 15 industry representatives, six national research organisations, 11 international speakers, three national speakers and 17 international visitors. The department provided travel assistance to regional neighbours from Myanmar, Tuvalu, Tonga, Timor-Leste, French Polynesia and Sri Lanka. Appendix A documents the biographies of the international and national speakers.

The symposium:

1) Raised awareness of the pathogen and the threat to Australia and the region.

2) Enhanced scientific understanding of the pathogen for application in the Australian and regional context.

3) Improved knowledge and understanding of the pathogen, its biology, host range, epidemiology and vectors.

4) Better understanding of best practice diagnostic techniques that are currently being developed and used internationally.

5) Improved knowledge of management options, including genetic tolerance/resistance, surveillance and diagnostics procedures and processes, and novel research.

6) Enhanced linkages with key international experts.

The two-day symposium had 17 presentations covering four themes (Appendix B):

- Theme 1: *Xylella fastidiosa* and its vectors
- Theme 2: Diagnostics and surveillance
- Theme 3: Management and control
- Theme 4: Research and collaboration.

The themes were addressed by speakers from Italy, France, Taiwan and the United States who have extensive experience either in the ongoing management of the established pathogen and its vectors or the management of recent incursions and the associated socio-economic complexities. Experts from Australia and New Zealand provided the regional context in discussing potential impacts and preparedness activities in the region. Appendix C provides a list of delegates, their affiliations and contact details.

The symposium was supported by the Stronger Biosecurity and Quarantine Initiative and the Agricultural Competitiveness White Paper.

1.3 Objectives of this report

This report summarises the presentations given under each theme, provides the speakers' biographies and a delegate directory. The objective of the report is to provide key scientific information underpinning the preparedness for *Xylella fastidiosa,* its subspecies and genetic strains, and the management of the pathogen and its insect vectors.

The report also summaries key learnings that emerged in moderated conversations with participants at the symposium, and in a related diagnostics and surveillance workshop. The symposium presentations flagged the economic, environmental, and social risks associated with *Xylella fastidiosa.* Similarly, the complexity of managing a *Xylella fastidiosa* incursion or the established pathogen and its vectors became very evident.

Participants concluded that the biosecurity risk for Australia is significant and above business as usual. The key learnings identified in this report are intended to be used by Australian governments, industries, researchers and other organisations as relevant to guide short, medium and long-term goals required to build Australian preparedness for this pathogen.

A directory of participants is included to facilitate engagement opportunities among experts, delegates and affected industries. The oral presentations of speakers are available on YouTube via a link in the department's *Xylella fastidiosa* fact sheet at www.agriculture.gov.au. Presentations are subtitled.

Figure 1 Speakers at International Symposium on *Xylella fastidiosa,* 17-18 May 2017

From left to right: Peter Whittle, Robert Taylor, Marie-Agnès Jacques, Alexander Purcell, Wen-Ling Deng, Tony Arthur, Anna Maria D'Onghia, Donato Boscia, Rodrigo Krugner, Leigh Pilkington, Baldissera Giovani, Jim Farrar, and Beth Stone-Smith. Rodrigo Almeida attended via a video link (Source: Department of Agriculture and Water Resources).

2 Theme 1: *Xylella* and its vectors

To set the scene, the theme '*Xylella* and its vectors' provided an overview on the epidemiology, biology, and genetics of *Xylella fastidiosa*, its subspecies (ssp.) and genetic strains, and the complex associations of the pathogen with its hosts and vectors. Host-vector relationships are modified by climate, particularly temperature and precipitation, and various environmental factors including irrigation, proximity to species that can be a reservoir for the pathogen, and phytosanitary management measures.

2.1 Presentations

2.1.1 Ecology of *Xylella fastidiosa*

Professor Emeritus Alexander Purcell's (University of California-Berkeley, United States) presentation on the 'Ecology of *Xylella fastidiosa*' highlighted that specific *Xylella fastidiosa*-caused diseases differ in their epidemiologies and different control methods must consequently be adapted to each situation. Understanding of the multiplicities of epidemiologies is key to planning the exclusion of *Xylella fastidiosa* spp. and developing disease control programs.

All sucking insects that specialise on feeding on the xylem (the water-conducting system of plants) are potential vectors. Climate is important in the disease dynamics as temperature and precipitation influence vector activity and the growth and survival of *Xylella fastidiosa*. A high percentage, possibly 90% of plant species, can harbour *Xylella fastidiosa*. Most plants support the multiplication of *Xylella fastidiosa* without causing symptoms, and vectors can acquire *Xylella fastidiosa* from symptomless plants for at least some time interval, or in some cases, indefinitely.

Different genotypes (genetic strains) of the same subspecies of *Xylella fastidiosa* can vary in host pathology. *Xylella fastidiosa* ssp. *pauca* differentially affects coffee and citrus genotypes. The same applies to subspecies *multiplex* and oak and peach genotypes, and subspecies *fastidiosa* and grape and oleander genotypes. New *Xylella fastidiosa*-caused diseases can emerge when *Xylella fastidiosa* strains invade a new region and meet plant species that were never exposed to that strain.

The ecology of the same strain of *Xylella fastidiosa* can differ significantly for the same host plant in different regions. Introduced (exotic) insects can increase the incidence of existing strains. The accidental introduction of the glassy-wing sharpshooter (*Homalodisca vitripennis*) into southern California dramatically worsened Pierce's disease in grapes. The rate of spread and severity of *Xylella fastidiosa*-caused diseases is determined by the *Xylella fastidiosa* strain and the complex of vector species (native or introduced), host, climate, and environmental factors. Professor Purcell concluded that early detection and immediate action to control new introductions of vectors or *Xylella fastidiosa* may be the only way to prevent or eradicate *Xylella fastidiosa*-caused diseases.

2.1.2 *Xylella fastidiosa* diversity

Professor Rodrigo Almeida's (University of California-Berkeley, United States) presentation on '*Xylella fastidiosa* diversity' highlighted the challenge of defining 'a bacterial species', the gene-flow that impacts the systematics and evolution, and the role of multi-locus sequence typing (MLST) and genome sequencing in studying *Xylella fastidiosa* diversity. *Xylella fastidiosa* is primarily a species of the Americas. A distant relative is Taiwanese *Xylella,* which has been classified as a separate *Xylella* species: *X. taiwanensis*.

Phylogenetic reconstruction of genetic distances of all available *Xylella fastidiosa* sequence types using MLST has resulted in a statistically well-supported tree for the group. Currently, *Xylella fastidiosa* subspecies are *multiplex* (including recombinant types of ssp. *multiplex*), ssp. *morus*, ssp. *sandyi,* ssp. *fastidiosa*, and ssp. *pauca.* Subspecies *fastidiosa* is presumed to be native to Central America. It is a more recent introduction to North America, where it causes Pierce's disease in grapes. Subspecies *multiplex* is native to temperate North America, and causes plum leaf scald and other diseases in that region as well as in Brazil. Subspecies *morus* is a recombinant of ssp. *fastidiosa* and ssp. *multiplex.* Subspecies *pauca* is endemic in South America and has only been detected in Costa Rica and Italy. Genetic data of spp. *sandyi* are consistent with a recent introduction or new emergence event in the United States with its endemic range being unknown.

Genetic and phenotypic diversity exists at multiple levels: species, subspecies, sequence types, among and within populations, within plants, and within clonal lineages. However, there has been limited work on connecting the genotype with the phenotype causing *Xylella*-caused diseases in plants. Professor Almeida concluded that an important aim of the work on the genetics and evolution of *Xylella fastidiosa* is to eventually predict the phenotype/host plant association based on the genotype.

2.1.3 Genetics and invasion pathways in France

Dr Marie-Agnès Jacques' (French National Institute for Agricultural Research [INRA], Beaucouzé Cedex, France) presentation on '*Xylella fastidiosa,* an emerging plant pathogen in Europe' reported on the interception of contaminated coffee plants (ornamentals) from Central America in France, 2012-15, the extensive sampling that was conducted nation-wide, and subsequent research into the genetics and invasion pathways of *Xylella fastidiosa.* Over 18,000 plant samples were collected up until April 2017. A sampling hot spot has been Corsica, where 34 plant species were collected from 340 foci. Harper's (2010) qPCR was used for the detection of *Xylella fastidiosa* spp. in plant material. The method allows identification of *Xylella fastidiosa* in up to 75% of samples.

Plant species with the highest percentage of *Xylella*-infections were *Calicotome villosa* (Poiret) Link (35%), *Spartium junceum* L. (22%), *Helichrysum italicum* (Roth) G. Don (15%), *Cistus monspeliensis* L. (10%), and *Lavendula angustifolia* Mill. (9%). The known host plant species of *Olea europaea, Eucalyptus* spp., *Vitis* spp., and *Arbutus unedo* have all returned negative results up until present. Of 350 *Philaenus spumarius* (meadow spittlebug) samples collected in Corsica, 8.5% returned a positive result.

The genetic diversity of intercepted *Xylella fastidiosa* strains was investigated using multi-locus sequence typing (MLST) directly on plant extracts. The analyses revealed the presence of different genetic strains within three subspecies of *Xylella fastidiosa*: ssp. *multiplex,* ssp. *pauca,* and ssp. *sandyi*. There was no host specificity of *Xylella fastidiosa* ssp. *multiplex.* The results imply that *Xylella fastidiosa* spp. has been present in France for many years. The emergence of the pathogen is linked to several introduction events of diverse strains from different subspecies, and the generation of diversity via recombination. Current work assesses options to predict the plant host range of *Xylella fastidiosa* strains from their genome sequence (Denancé et al., in preparation).

2.1.4 Leaf scorch diseases in Taiwan

Associate Professor Wen-Ling Deng (National Chung Hsing University, Taichung, Taiwan) presented on 'Leaf scorch diseases of grape and pear in Taiwan'. In 1993, *Xylella* was demonstrated to cause pear leaf scorch in the Hengshen variety of *Pyrus pyrifolia* (Asian pear), where the disease became a key factor limiting to pear production below 800 metres altitude (Leu & Su 1993). In 2002, a *Xylella*-caused disease was found in grapes with all cultivars (table and wine grapes) being susceptible.

Phylogenetic analysis revealed that the strains present in Taiwanese grapes are evolutionarily related to those causing Pierces' disease in California but differ from the strains found in pear. The findings suggested that the strains found in Taiwan evolved independently. The strain causing pear leaf scorch was recently classified as a new *Xylella* species, *X. taiwanensis* (Su et al. 2013; Su et al. 2016).

The epidemiology of *Xylella*-caused diseases is closely related to the abundance of insect vectors, which varies with season, and the presence of weeds as alternative hosts for both vectors and *Xylella* bacteria. Vineyards that test positive for *Xylella* bacteria are either isolated or located at the periphery of grape-producing areas where they are visited by vectors living in neighbouring vegetation, which provide highly suitable habitats. The elimination of weeds to reduce the abundance of insect vectors and inoculum of the pathogen is important in disease management.

2.1.5 Irrigation and disease dynamics in California

Dr Rodrigo Krugner (United States Department of Agriculture [USDA], Parlier, California, United States) explored the 'Role of deficit irrigation on population dynamics, movement and dispersal of insect vectors and *Xylella fastidiosa*'. The glassy-winged sharpshooter is native to south-eastern states of the United States bordering the Gulf of Mexico and was accidentally introduced into southern California in the 1950s, where eco-climatic conditions were conducive for the glassy-winged sharpshooter to establish as an exotic pest-species.

The glassy-winged sharpshooter is a highly mobile vector of *Xylella fastidiosa.* Rapid population growth and range expansion of glassy-winged sharpshooters has been reported for areas of California with favourable environmental conditions. Irrigation, which is typical in the management of citrus and almond in California, influences glassy-winged sharpshooter population density, movement, feeding behaviours, and the transmission of *Xylella fastidiosa.*

Feeding preferences are largely determined by differences in xylem-fluid tension and nutrient content. Plant water-stress, which is associated with declining xylem-fluid tension, reduces the frequency and duration of glassy-winged sharpshooter feeding and probing behaviour. Thus, glassy-winged sharpshooters feed more often and longer on fully irrigated plants. While deficit irrigation in citrus has the potential to reduce the glassy-winged sharpshooter population density, bacterial transmission studies conducted in the laboratory suggest that transmission efficiency of *Xylella fastidiosa* to grapevines by the glassy-winged sharpshooter increases with increasing plant water-stress. Dr Krugner concluded that knowledge of the relationships between plant water-stress, glassy-winged sharpshooter population dynamics and feeding behaviour, and the transmission of *Xylella fastidiosa* can be a means to manage *Xylella fastidiosa*-caused disease outbreaks.

2.2 Key learnings

- *Xylella fastidiosa* ssp. is no longer limited to a few countries. Its long-term presence in Taiwan raises questions about its potential distribution in Asia, and the implications for Australia. In the recent past, human-mediated invasion has been the primary driver of economically costly *Xylella fastidiosa* introductions. The main dispersal pathway is the movement of infected, and potentially asymptomatic, plant material from areas where the pathogen occurs.
- There is the need for a 4-point model to understand the *Xylella*-caused disease dynamics and risks, and monitor and predict any changes in these. The 4 points are: genetics, vectors, hosts, and the environment. Environmental variables include the climate (particularly temperature and precipitation), landscape factors (for example alternative hosts, riparian vegetation) and management (irrigation, weed control, vector control).
- There is the need to monitor any changes in the 4-point model: in *Xylella fastidiosa* genetics and pathogenicity, new or exotic vectors, host range, and in the environment.
- *Xylella fastidiosa* is genetically highly diverse and plastic (it evolves quickly) as demonstrated by the French experience and the emergence of a new species in Taiwan, *X. taiwanensis*. Strains of *Xylella fastidiosa* differ in pathogenicity and can behave like different diseases in terms of host specificity. This means that we are not just dealing with one disease. All species, subspecies and strains, not just the one that causes Pierce's disease, need to be prevented from entering Australia.
- There is an enormous potential for the spread of *Xylella fastidiosa.* All sucking insects that specialise on xylem sap-feeding are potential vectors. Most plants (up to 90%) could be affected by *Xylella fastidiosa,* and there is the possibility for the pathogen being present in asymptomatic plants from where it can be transmitted prior to detection.
- Temperatures affect bacterium survival and vector activity and abundance. There are reports of 'cold curing' of grapevines in cooler regions of California, when specific temperature requirements are met, and the suggestion that the bacterium can die out in the absence of an effective vector. However, this is based on temperature constraints for the bacteria itself (i.e. the Pierce's disease strain). The temperature requirements for insect vectors are a different issue. Both need to be considered.
- Relationships among *Xylella fastidiosa,* vector, host plant, and crop management are complex. For example, the abundance of the glassy-winged sharpshooter is lower among water-stressed host plants compared to well-watered, irrigated hosts. On the other hand, host water-stress (laboratory study on grapevines) increased the uptake of *Xylella fastidiosa* by the vector as the bacterium's stickiness in the xylem seems to be reduced in water-stressed plants.

3 Theme 2: Diagnostics and surveillance

The theme provided an overview on current 'diagnostics and surveillance' practices employed in regions where *Xylella fastidiosa*, its subspecies (ssp.) and genetic strains, is present, and the ongoing development of diagnostic and surveillance capabilities as part of preparedness. The development of expert systems combining individual sample and spatial information and molecular biology methods and techniques were discussed.

3.1 Presentations

3.1.1 Surveillance in Italy

Dr Anna Maria D'Onghia (International Centre for Advanced Mediterranean Agronomic Studies [CIHEAM], Bari, Italy) spoke about '*Xylella fastidiosa* in the outbreak area of Italy: present situation of the infections and innovative tools for early surveillance'. The integrated pest management group of CHIEAM (a key intergovernmental research, development and extension organisation of the Mediterranean region) is closely involved in the emergency response to *Xylella fastidiosa* spp. *pauca* strain CoDiRO (the abbreviation of the Italian name of the disease, sequence type 53) detected in 2013 in Apulia, the southern region of Italy.

The strain CoDiRO causes Olive Quick Decline Syndrome (OQDS), and is otherwise only present in Costa Rica where it affects oleander and coffee. It was most likely introduced into Apulia via infected ornamental plants. A vector confirmed to transmit *Xylella fastidiosa* is the meadow froghopper, *Philamaenus spumarius,* which has a high abundance in Apulian olive groves (up to 80% of adults host *Xylella fastidiosa*).

In 2014, the Italian government and the European Commission declared a state of emergency, which resulted in the strengthening of phytosanitary measures (for example decision 2015/789, 18 May 2015). In 2016, new demarcation zones were implemented in Apulia: (i) the south of the infected zone where *Xylella fastidiosa* is established and removal of infected trees is no longer enforced, (ii) a 20 kilometre wide containment area bordering on the infected zone in the north where any infected plants are removed, followed by (iii) a 10 kilometre wide, disease-free buffer zone where any host plant within 100 metres of an infected tree must be removed regardless of health status.

In light of strong public opinion against the removal of olive trees, the Italian Plant Protection service and the European Commission launched awareness campaigns and training initiatives. Workshops were held under the lead of the FAO, IPPC, and CIHEAM to develop capacity in the European Union and the wider Mediterranean region.

In 2016 only, 158,000 hectares were surveyed in Apulia and 150,000 plant samples were tested. To improve spatial coverage and surveillance in the buffer zone, a 1000 ha geographic grid with one ha sub-units was superimposed on regional cartographical maps. All samples and field data are now geo-referenced and stored digitally via a web-application (XylApp). High-resolution aerial images (remote sensing) of the visible and near-infrared (NIR) spectral bands are used to establish tree numbers and location, and classify trees with OQDS according to mild, moderate, and severe symptoms.

Spy insects (i.e. insects colonised by *Xylella fastidiosa* that indicate the pathogen's presence before symptoms develop on plants) are captured within 10-20 metre of a geo-referenced point using sweeping nets. In addition to ELISA and PCR, on site diagnostic methods are now officially used for early detection in plant material and spy insects: DTBIA (direct tissue blot immuno-assay) and real-time LAMP (loop-mediated isothermal amplification). A web-based software (XylWeb) enables the tractability, storage, management, and analysis of multiple data layers. Dr D'Onghia concluded that the development of an expert system integrating data of different spatial resolutions over time has greatly improved surveillance and disease management. Research for enhancing the system is ongoing.

3.1.2 Assessment of olives as a host in California

Dr Rodrigo Krugner's (United States Department of Agriculture (USDA), Parlier, California, United States) work on 'Evaluation of olive as a host of *Xylella fastidiosa* and associated sharpshooter vectors' was instigated by reports on increasing occurrences of olive tree mortality associated with infection by *Xylella fastidiosa* in southern California.

Vectors of *Xylella fastidiosa* are sharpshooter species that occupy different geographical ranges depending on eco-climatic conditions. The native blue-green sharpshooter is prevalent at the north-coast of California, the central valley is dominated by the native green sharpshooter, while the exotic glassy-winged sharpshooter is a main vector in southern California.

Infections result from the vector-mediated movement of inocula into the orchard (primary spread), and the subsequent spread within the orchard (secondary spread). Surveillance for *Xylella fastidiosa* and diagnostics using PCR revealed that most of the infections in olives were in southern California, indirectly confirming the role of the glassy-winged sharpshooter as a highly mobile and efficient vector of the pathogen.

Multi-locus sequence typing analysis showed that *Xylella fastidiosa* strains in Californian olives belong to the subspecies *multiplex.* Under greenhouse conditions, only about 3% of olive plants inoculated with olive strains of *Xylella fastidiosa* (ssp. *multiplex*) tested positive for the bacterium using PCR and the pathogen was never re-isolated, i.e. Koch's postulate was not confirmed. In contrast, *Xylella fastidiosa* strains isolated from olives caused almond leaf scorch disease. Vector transmission assays confirmed that glassy-winged sharpshooters can transmit ssp. *multiplex* and ssp. *fastidiosa* to olives.

Dr Krugner concluded that symptoms seen in olive orchards in California could not be attributed to an infection with *Xylella fastidiosa* and the cause of symptoms could not be confirmed. Olives can be an asymptomatic host for *Xylella fastidiosa* in southern California and a reservoir for the pathogen. Olives are also a host for the glassy-winged sharpshooter, which uses olive trees for reproduction and overwintering.

3.1.3 Diagnostic preparedness in New Zealand

Mr Robert Taylor (Ministry of Primary Industries, New Zealand) spoke about 'Diagnostic preparedness for a *Xylella* invasion: a New Zealand perspective'. The Plant Health and Environment Laboratory (PHEL) in the Ministry for Primary Industry has a readiness program to ensure the readiness of diagnostic capability to detect and identify high impact pests. This includes *Xylella fastidiosa*.

The outbreaks in Europe highlighted the need to review the diagnostic capabilities for *Xylella fastidiosa*. Activities included (i) obtaining access to *Xylella fastidiosa*-positive controls in containment, (ii) testing and improving media to culture the bacteria, (iii) development of diagnostics tests and (iv) capabilities for high throughput detection, and (v) the genetic characterisation of subspecies and strains. Early detection and accurate identification of *Xylella fastidiosa* genotypes is fundamental to New Zealand's biosecurity. Inadequate tools and resources in the event of an incursion would constitute a worst case scenario.

PHEL has sourced positive controls through ICMP (international collection of microorganisms from plants) and the research community, which are used to evaluate and improve diagnostic tests and protocols, and has developed capabilities to culture the pathogen. The DNeasy® Blood and Tissue kit returned high quality DNA of *Xylella fastidiosa* from glassy-winged sharpshooter and spittlebug samples. LAMP technology was developed for field diagnostics, and qPCR achieved good diagnostic sensitivity and specificity in the laboratory (Harper and Ward 2010).

Evaluation of other PCR tests illustrated the potential for false negatives. It was noted that the qPCR test (Harper and Ward 2010) does not detect *X. taiwanensis* and suspect pear leaf scorch symptoms should also be tested with the conventional PCR (Minsavage et al. 1994). The qPCR was amended to simultaneously amplify both the plant internal control (*COX* gene) and the target pathogen. This doubled the number of samples that can be processed in a single qPCR run, and improved the reliability of the assay in terms of detecting false negatives. The current qPCR methods allows detection of one infected plant in a bulked sample of five plants. At present, the laboratory has a testing capacity of about 600 samples per day assuming 12 staff and access to four real-time PCR machines. Multi-locus sequence typing is used to characterise genetic strains of *Xylella fastidiosa.*

Mr Taylor concluded that PHEL has the diagnostic tools in place and considers that early detection and accurate identification of *Xylella* is likely if found on well-known horticultural crops (for example grapes and citrus) where the pathogen has been well researched. However, because of the expanding host range there are significant knowledge gaps on how *Xylella fastidiosa* interacts with other hosts (for example ornamental and native species) and early detection of potentially infected plants will be particularly challenging.

3.1.4 Spread and bio-control of the glassy-winged sharpshooter in the Pacific

Dr Leigh Pilkington (Department of Primary Industries New South Wales [DPI NSW], Gosford, NSW, Australia) explored 'Invasion pathways of the glassy-winged sharpshooter across the Pacific Ocean and activities for the spread of biological control agents'. The glassy-winged sharpshooter is native to south-eastern United States and north-eastern Mexico. After its accidental introduction into California, it demonstrated extremely high rates of population growth and rapid spread. It subsequently invaded Hawaii, French Polynesia, Easter Island and the Cook Islands. Detections of dead adult glassy-winged sharpshooters have occurred in aircraft landing in Australia from infested regions.

The glassy-winged sharpshooter is a highly mobile, polyphagous xylem-feeder, and feeds on over 100 species. Though not a serious pest in its native habitats, the establishment of the glassy-winged sharpshooter in southern California has dramatically increased the spread and severity of Pierce's disease of grapes, a *Xylella*-caused disease for which the glassy-winged sharpshooter is a highly efficient vector.

Glassy-winged sharpshooters can ingest over 100-times their body weight per day and produce high volumes of excreta ('leafhopper rain'). Female glassy-winged sharpshooters lay their eggs under the epidermis layer of leaves and the eggs hatch after 10-12 days. Wingless nymphs undergo five nymphal instars to complete metamorphosis after 40-45 days. Glassy-winged sharpshooter populations reach their peak around the summer months, and overwinter in their adult form. Mating occurs in spring and summer. To successfully complete its lifecycle, glassy-winged sharpshooters require host plants for (i) feeding, (ii) oviposition, (iii) nymph development, and (iv) overwintering.

To invade a new range, suitable hosts need to be present. Dr Anna Rathé conducted a study at the University of California in the United States on 12 Australian plant species to determine host status, *Leptospermum laevigatum* (coastal tea tree), *Acacia cowleana* (Halls Creek wattle), *Eremophila divaricate* (emu bush), *Hakea laurina* (pincushion Hakea), and *Swainsona galegifolia* (Darling pea) were classified as 'high risk' due their ability to support all three life stages: egg, nymph, and adult (Rathé et al. 2014). In coastal Australia, eco-climatic conditions are suitable for glassy-winged sharpshooters, where 142 crops plants and exotics are known to be feeding and oviposition hosts.

To control glassy-winged sharpshooters, mymarid egg parasitoids of the genus *Gonatocerus* have been released in California and French Polynesia. The biocontrol agent *G. ashmeadi* is halting the spread of the glassy-winged sharpshooter across the Pacific. Biocontrol plays a key part in the area-wide integrated pest management of glassy-winged sharpshooters in California and French Polynesia. Dr Pilkington concluded that surveillance for the glassy-winged sharpshooter in Australia and New Zealand should be informed by both its nature of being highly invasive and by its role as an important vector of *Xylella fastidiosa.*

3.2 Key learnings

- Mass-screening of thousands of plants per year is done in the outbreak areas of Europe. This highlighted the importance of reliable and readily available diagnostic tests and processes for high-throughput screening, including ELISA, PCR, qPCR, and LAMP.
- Diagnostic capabilities are needed to differentiate subspecies and genetic strains because *Xylella fastidiosa* genotypes vary in their ability to cause disease in a broad range of plant species. Capabilities include obtaining access to *Xylella fastidiosa*-positive controls in containment, controls, such as, but not limited to, the DNA of *Xylella fastidiosa* genotypes.
- Diagnostics tests are needed as disease symptoms are non-diagnostic for all host species. Symptoms are too generic and can be confused with water stress and other diseases.
- Clear guidelines are needed for sampling plants and vectors and pooling samples for diagnostics. We need to improve our knowledge of how sample pooling affects the reliability of diagnostic tests to detect the pathogen.
- Sampling and diagnostic procedures for systemic hosts and non-systemic hosts need to be better understood. In systemic hosts, the bacterium can be found throughout the host. In non-systemic hosts, the bacterium is only present at local infection sites.
- The Italians use remote sensing to detect disease symptoms and classify their severity. This information is used in response management. So while diagnostic tests are important, disease symptoms can play a role in guiding a response to an incursion.

- Work in affected countries highlighted the importance of knowing which insects are colonised by *Xylella fastidiosa,* and how efficient they are at transmission.
- Nurseries and home gardens were identified as key risk areas and sources of the pathogen (for example, coffee plants from Central America imported to Apulia as ornamentals). Surveillance protocols and procedures need to be in place to address this risk.
- Surveying is needed for glassy-winged sharpshooter given the insect's efficiency as a vector of *Xylella fastidiosa* and its invasiveness into new territory. The insect is present in the Pacific region and could be transported to Australian shores on ornamental plants on cruise boats.
- Surveying is also needed for key host plants (olives, grapes, citrus, almonds, coffee, lavender, oleander, pelargonium and myrtle-leaf milkwort) in Australia, particularly those imported from overseas hotspots, such as Costa Rica and Honduras.
- A contingency plan should be in place in the event that the pathogen is detected.
- *Xylella fastidiosa* was probably present in Europe and Taiwan more than 10 years before severe disease expression occurred. This highlights the need for effective early detection surveys.
- Short- and long-term costs and benefits of sampling schemes and strategies in an Australian context need to be better understood. This includes general versus specific surveillance needs, vectors versus hosts, asymptomatic versus symptomatic plants. For example, conducting surveillance on asymptomatic hosts at meaningful sample sizes is costly and may not be cost beneficial in the short term. However, given the value of susceptible industries (such as grape, citrus and olive) and the threat to native and amenity plants, early detection surveys are likely to be cost beneficial in the long term.

4 Theme 3: Management and control

The ‘management and control’ theme was concerned with the challenges of controlling and managing *Xylella fastidiosa*, its subspecies (ssp.) and genetic strains, and its vectors from a practical and policy perspective, the impacts that *Xylella fastidiosa*-caused diseases have on farmers and affected industries, and research to address these challenges.

4.1 Presentations

4.1.1 Measures in southern Italy and the European Union

Dr Donato Boscia (National Research Council [CNR] Institute for Sustainable Plant Protection, Bari, Italy) spoke about the ‘Re-emergence of *Xylella fastidiosa*: the ongoing epidemics in southern Italy and EU measures’. In 2013, the first reports on a new olive disease emerged in the Gallipoli area of Apulia in southern Italy. In October 2013, *Xylella fastidiosa* was identified in oleander, almond and olive trees exhibiting leaf scorch symptoms (Saponari et al. 2013). By March 2016, the majority of olive trees in the Gallipoli area were severely damaged or had died of Olive Quick Decline Syndrome (OQDS) caused by *Xylella fastidiosa*. By the end of the 2014 European summer, it was clear that eradication was no longer an option, and the eradication program was replaced by a disease containment program.

In 2015 and 2016, new demarcations for containment were implemented: the (i) southern infected zone where *Xylella fastidiosa* is established and removal of infected trees is no longer enforced, (ii) a 20 km wide containment area bordering on the infected zone in the north where any infected plants are removed, followed by (iii) a 10 km wide, disease-free buffer zone where any host plant within 100 m of an infected tree must be removed regardless of health status.

Multi-locus sequence typing analysis of *Xylella fastidiosa* samples from the area revealed the presence of a single strain of ssp. *pauca,* CoDiRO (ST53), originating from Central America. The main vector of CoDiRO is the spittlebug, *Philaenus spumarius,* for which olives are the main feeding host during summer (Cornara et al. 2017).

Pathogenicity tests (2014-16) confirmed the CoDiRO strain as the cause of OQDS in olives (Koch’s postulate was confirmed), and leaf-scorch in *Polygala myrtifolia,* a common ornamental plant, and *Nerium oleander*. Other important hosts are *Acacia saligna* (Labill.) Wendl., *Prunus avium* (L.), *Prunus dulcis* (Mill.) D.A. Webb. In contrast, grapevine and citrus are not affected by the CoDiRO strain. Some olive cultivars are tolerant to the CoDiRo strain, and genetic studies are being conducted to understand the genetics underlying this tolerance or resistance detected in some olive genotypes. The European Commission maintains and updates a database of plants found to be susceptible to *Xylella fastidiosa* in European Union territory on its website at ec.europa.eu/food/plant/plant_health_biosecurity/legislation_en.

The European Union has regulated *Xylella fastidiosa* as a harmful organism with quarantine status since 1992. Since 2013, developments in the outbreak area informed several European Union decisions to strengthen phytosanitary measures, available online at eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32015D0789. As part of these measures, demarcated areas, as described above, were implemented in Apulia, and the planting of host plants is prohibited in the infected zone. Prohibited are the export of host plant species known to be susceptible to *Xylella fastidiosa*, regardless of the strain, from the infected zone, and the trade and movement of host plants susceptible to the CoDiRO strain within the demarcated area. To import specified host plant species, importing countries are required to declare their respective *Xylella fastidiosa* status, and there is an import ban on coffee plant material from Costa Rica and Honduras. Regional measures to reduce vector populations include compulsory mechanical weed control (tillage) in spring, and the use of recommended insecticide sprays to control adult vectors.

The European Union funds multidisciplinary research into the active containment of *Xylella fastidiosa* through POnTE (www.ponteproject.eu) and XF-Actors (www.xfactorsproject.eu). A total budget of about EUR 10 million has been allocated to research into *Xylella fastidiosa*. In concluding, Dr Boscia highlighted the importance of contingency plans and awareness campaigns across European Union member states.

4.1.2 Disease management in California

Dr Jim Farrar, Director of the Statewide Integrated Pest Management Program (University of California-Davis, United States), spoke about the 'Management of *Xylella* diseases in California'. *Xylella fastidiosa*-caused diseases in California include Pierce's disease of grapes, almond leaf scorch (golden death), alfalfa dwarf, and oleander leaf scorch. Overall methods aimed at preventing *Xylella fastidiosa*-caused diseases are (i) California quarantine regulations, (ii) California permits to import plant material, (iii) citrus clonal protection program, (iv) nursery inspection program, (v) nursery approved treatment protocol, and the (vi) trapping and monitoring program.

The incidence of Pierce's disease in different regions of the state highlights the interactions between the environment, vectors and alternate hosts, and the hosts' genetics. Understanding these interactions informs disease management. Generally, there is genetic diversity in susceptibility of *Vitis vinifera* ssp. to *Xylella fastidiosa* but no complete resistance. For example, sensitive varieties include Chardonnay and Pinot Noir. Cabernet Sauvignon, Merlot, and Sauvignon Blanc can be classified 'moderately resistant', and Riesling and Ruby Cabernet are among the 'most resistant' varieties.

In all regions affected by Pierce's disease, removal of individual, infected vines and replanting is recommended to optimise economic returns. In the Napa-Sonoma wine region, green sharpshooter (*Draeculacephala minerva*) populations are managed by mowing vineyard grasses, and red-headed sharpshooter (*Carneocephala fulgida*) by removal of Bermuda grass in summer. The blue-green sharpshooter (*Graphocephala atropunctata*) uses alternate hosts in riparian corridors, which can only be altered with a permit from the California Department of Fish and Wildlife. Summer infections with *Xylella fastidiosa* may not become systemic. Cold curing (pathogen elimination or reduction associated with the exposure of *Xylella fastidiosa*-infected plant tissue to cold temperatures) has been reported in some seasons in Napa-Sonoma.

At the Central Coast, there is generally no problem with Pierce's disease due to the lack of riparian habitat for sharpshooter populations and little to no cultivation of almond and alfalfa. In the San Joaquin Valley, management includes weed control around vineyards, removal of weedy alfalfa crops upwind of grapes, and area-wide management of the glassy-winged sharpshooter (*Homalodisca vitriennis*).

In the Southern Valley, where the glassy-winged sharpshooter is the main vector, it is recommended to avoid growing sensitive grape varieties, to trap and monitor glassy-winged sharpshooter populations, and apply systemic insecticides (neonicotinoids). Almond leaf scorch develops slowly, and it takes two to three years for symptoms to develop. Green and red-headed sharpshooters are the main vectors in almonds, and population control involves appropriate management of irrigated pastures, weedy alfalfa, and field edges. The clean cultivation of orchards for six weeks is recommended.

Vectors of *Xylella fastidiosa* in alfalfa are green and red-headed sharpshooters. Alfalfa Dwarf occurs mainly in the San Joaquin Valley. Weed management (Bermuda grass, watergrass, cultivated fescues, and perennial ryegrass) is the most important strategy to manage the disease in alfalfa. Oleander leaf scorch is generally not managed, as oleander is primarily used on the median strip of highways in southern California. Dr Farrar concluded that the management of *Xylella fastidiosa*-caused diseases focuses primarily on vectors, including the exclusion of glassy-winged sharpshooters. The use of genetic tolerance or resistance will play an increasingly important role in the future.

4.1.3 Area-wide control program in California

Ms Beth Stone-Smith (United States Department of Agriculture [USDA], Sacramento, California, United States) provided insights into a successful research, development and extension program in her presentation on 'The glassy-winged sharpshooter and Pierce's disease in California: state-wide activities and the area-wide management of the vector and disease'. By 2000, the accidental introduction of the exotic glassy-winged sharpshooter had increased incidents and severity of Pierce's disease to what was called the 'California Vineyard Apocalypse' with significant implications for the economy.

The grape industry in California has an crop production value of close to US$5 billion annually with the associated economic activity contributing over US$ 57 billion per year to California's and US$114 billion per year to the US economy. The mission of the USDA Glassy-Winged Sharpshooter Area Wide Management Program (GWSS/PD program) is to minimise the state-wide impact of Pierce's disease. Related strategies aim at containing the spread of the new vector (the glassy-winged sharpshooter) to allow time to develop new solutions. The GWSS/PD program is highly cooperative and engages diverse stakeholders at various levels (federal, state, and local government, University of California, industry, and general public). Core activities include:

- Contain the spread: prevent the spread of the glassy-winged sharpshooter to new areas by regulating shipments of host plants and host material (primarily nursery material, bulk citrus and grapes).
- State-wide survey and detection: monitoring of glassy-winged sharpshooters through trapping and visual surveys (agricultural and urban areas) to verify at-risk areas and look for new infestations.
- Rapid Response: intensive surveying and application of treatments in response to glassy-winged sharpshooter detections in new areas (agricultural and urban areas).
- Public outreach: raise awareness about Pierce's disease and its vectors (meetings, brochures, website, mailings, posters, new stories, etc.).
- Research: develop solutions to Pierce's disease and its vectors. In the last 16-18 years, over 200 projects were funded, 14 symposia were held, and over 1000 reports were published (www.cdfa.ca.gov/pdcp/Research).

- Biological control: the use of natural enemies of the glassy-winged sharpshooter for its control. Seven species were released as biocontrol agents in 13 countries.
- Area-wide programs: the coordinated suppression of glassy-winged sharpshooter populations over large agricultural areas with diverse land-uses.

The area-wide management of the glassy-winged sharpshooter integrates knowledge of the vector's biology and lifecycle. There can be two to three glassy-winged sharpshooter generations per year in southern California. The glassy-winged sharpshooter overwinters as an adult with the lifespan being four to six months during winter. Adults mate and lay eggs in March-June (spring/early summer). Summer populations peak in June-September (lifespan two to three months). Adults mate and lay eggs through October (autumn). A major overwintering host for the glassy-winged sharpshooter is citrus from where the insects move into grapes in spring.

Thus, area-wide trapping (yellow sticky traps) includes citrus, grape, and any other permanent host, and the timing of treatment throughout the year needs to be coordinated among different growers and industries. Currently in citrus, foliar insecticide treatments are applied in winter (December and February) followed by an application of systemic imidacloprid post citrus bloom. Citrus growers are reimbursed for application costs. This strategy aims at preventing glassy-winged sharpshooters and Pierce's disease moving into grapes.

Grape growers treat grapes to prevent mating and egg laying and kill any nymphs. They remove potential sources of inoculum (infected vines and alternate hosts). Ms Stone-Smith concluded by summarising the challenges of the program as to (i) manage diverse agricultural systems with different requirements and (ii) a polyphagous insect pest, (iii) consider existing IPM strategies for other pests employed by growers, (iv) work with organic growers and (v) at the urban interface, (vi) be responsive to changes in weather and the associated biological effects, (vii) navigate funding and funding security, (viii) manage chemical resistance.

4.1.4 Potential economic impacts in Australia

Dr Tony Arthur (Australian Bureau of Agricultural and Resource Economics and Sciences [ABARES], Canberra, Australia) spoke about an economic modelling study on 'Potential economic impacts of *Xylella fastidiosa* on the Australian wine grape and wine industries'. *Xylella fastidiosa* subspecies *fastidiosa* causes Pierce's disease in grapes, which can be lethal to infected plants. The disease is spread by insect vectors and the movement of infected plant material.

In this study, ABARES estimated the potential economic impacts on the Australian wine grape and wine industries, should the strain establish in Australia. Scenarios were developed based on different spatial extents of impact (determined by different assumptions about the suitability of the environment for the establishment and spread of the disease, ranging from all areas suitable to areas restricted by climatic suitability and proximity to rivers (thought as a surrogate for riparian vegetation and associated vector populations) and different wine grape prices (current prices and a 25% increase based on a recovery from the current low level).

For current and future prices, the results identified three types of vineyards: those where gross margins were negative and wine grape growing would be abandoned; those where gross margins were positive, but replanting would not be profitable and therefore wine grape growing would be abandoned; and those where gross margins were high enough to make replanting with a resistant cultivar profitable.

The impacts on the wine grape industry and the vertically integrated wine making industry, which uses wine grapes as the key input, were estimated. The impacts on the wine industry were estimated as the reduction in profits (producer surplus) to non-wine grape inputs used in making wine. Based purely on a simple model for climatic suitability, almost 75% of the Australian vineyard area was classified as highly suitable for the disease. By including the proximity to rivers, where environmental conditions for insect populations are highly suitable, in addition to climate as a determinant of suitability, the Australian vineyard area potentially affected by Pierce's disease reduced to 31%.

The estimated impacts on the wine grape industry ranged from AU$0.7 billion - AU$2 billion over 50 years (present value) at current prices and AU$0.9 billion - $2.9 billion at 25% higher prices. Including impacts on the wine industry increased estimates to AU$2.8 billion - AU$7.9 billion (current prices) and AU$2.3 billion - AU$7.7 billion (25% higher prices). At higher prices, the impact on the wine industry is less, more than offsetting the increase in losses incurred by the grape industry. Dr Arthur concluded that the modelling framework is suitable to estimate the economic impact of *Xylella fastidiosa.* Model parameters and modelling results can be updated in light of ongoing research into the eco-climatic suitability for *Xylella fastidiosa* and its vectors conducted in countries affected by the pathogen.

4.2 Key learnings

- Disease dynamics differ between countries and regions, so management strategies should be designed for each agro-ecological setting. To devise effective management strategies there is the need to understand the interactions between *Xylella fastidiosa* genetics, vectors, hosts and the environment.
- Effective management strategies and plans for *Xylella fastidiosa*-caused diseases are developed for entire regions and landscapes but are implemented at the farm and field level. In southern Italy, the expert system XylWeb/XylApp supports this process by integrating spatial and temporal aspects and data.
- Both the United States and Italian experiences identified training, education, and outreach as core elements of an effective response and management strategy.
- The Californian experience showed that effective, evidence-based management strategies can be developed. While *Xylella fastidiosa*-caused diseases are significant in terms of the economic, environmental, and social impact, there is no place for panic.
- In California, multiple measures to prevent *Xylella fastidiosa*-caused diseases are integrated and include (i) California quarantine regulations, (ii) California permits to import plant material, (iii) citrus clonal protection program, (iv) nursery inspection program, (v) nursery approved treatment protocol, and the (vi) trapping and monitoring program. There are regulations for the nursery industry that recognise the biosecurity risks specific to that industry.
- The USDA Glassy-Winged Sharpshooter Area Wide Management Program (GWSS/PD program) in California involves stakeholders at various levels. The program successfully manages vectors and *Xylella fastidiosa*-related diseases at the regional and field level because it links research, development and extension.

- A key feature of the California USDA GWSS/PD program is government-funded extension and extension officers who are a highly effective interface between research providers, regulators, industry adopters, and community. There is the need for extension officers in Australia's biosecurity continuum.
- In California and the Pacific region, populations of the invasive GWSS are controlled using bio-control agents. Bio-control should be considered as part of an integrated pest management plan.

5 Theme 4: Research and collaboration

The ‘research and collaboration’ theme provided an overview on the highly integrated research, development and extensions (RD&E) programs of California, the development of an RD&E program following the more recent disease outbreak in Italy, and current and potential collaborative activities across Australia and internationally.

5.1 Presentations

5.1.1 Collaborative programs in California

Dr Jim Farrar’s (University of California-Davis, United States) presentation on ‘Collaborative programs to address Pierce’s disease in California’ provided an overview of a highly integrated approach that engages diverse stakeholders at various levels including federal (represented by the United States Department of Agriculture, USDA, and its services), state, and local government, University of California (UC), affected industries, and the general public.

Prior to the accidental introduction of the glassy-winged sharpshooter, Pierce’s disease of grapes was relatively minor with episodic outbreaks. After the introduction of the glassy-winged sharpshooter, Pierce’s disease became the economically most important disease caused by *Xylella fastidiosa* species in California, and significant federal and state funds were directed to Pierce’s disease/glassy-winged sharpshooter research. The overall disease management strategy specifies different temporal goals: (i) in the short-term, to limit the spread of glassy-winged sharpshooters until a long-term control is found; (ii) in the medium-term, to limit the spread of glassy-winged sharpshooters, manage infested areas, and identify hosts resistant to *Xylella fastidiosa*; (iii) in the long-term, to identify strong and durable Pierce’s disease resistance in hosts or other Pierce’s disease control mechanisms.

Federal funds of initially around US$22 million per year, and more recently about US$15 million per year, support trapping, monitoring, surveillance, and area-wide control programs. Until 2012, the California Department of Food and Agriculture (CDFA) contributed around US$4 million per year. In 2001, the grape industry established the Pierce’s disease/glassy-winged sharpshooter board, which is funded by self-assessment of growers (US$0.75 - US$2 per $1000 value for a total of about US$1.9 million – US$6 million per year) and managed by the CDFA. The Pierce’s disease/glassy-winged sharpshooter board continues to fund research and recently expanded the program to include other pests and diseases.

At the local level, agricultural commissioners of counties manage the nursery inspection program, the nursery approved treatment protocol, and the trapping and monitoring staff, and implement intra-state shipment regulations legislated under the federal and state quarantine acts. UC conducts research on vectors, hosts, and the epidemiology of *Xylella fastidiosa,* and runs extension programs to support grower adoption of best practices and new research. For example, the area-wide IPM program in Kern County involves collaboration of federal and state agencies, UC Cooperative Extension, citrus and table grape growers to monitor and treat for glassy-winged sharpshooters.

The glassy-winged sharpshooter is not an economically important pest in citrus, but citrus growers treat orchards to reduce populations that could migrate into vineyards, and are reimbursed for application costs. This collaboration has maintained table grape production in this region for more than 15 years despite high levels of glassy-winged sharpshooters and Pierce's disease. Dr Farrar concluded that the investment of US$104 million per year protects an US$3 billion grape industry (2014 estimate), and that over 15 years of research has improved our understanding of *Xylella fastidiosa*, the sharpshooter vectors, host response to infection, and the design of effective management options.

5.1.2 Research in the European Union

Dr Donato Boscia's (CNR Institute for Sustainable Plant Protection, Italy) presentation identified 'Research activities and research gaps in the European Union'. In 2013, when *Xylella fastidiosa* was firstly detected in olives, oleander and almonds in Apulia, southern Italy, it became quickly clear that the management and control strategies developed in the United States were not applicable within the Apulian context, and that the disease dynamics are fundamentally different to those found in the Americas, France, and Spain.

In Apulia, over one million olive trees have been affected. Knowledge on the epidemiology of *Xylella fastidiosa* in an agro-ecological region that had never experienced the pathogen needed to be developed. Understanding the complex interactions between the *Xylella fastidiosa* genetics (the specific Apulian strain of subspecies *pauca,* CoDiRO), hosts and host genetics, autochthonous vector populations, and the environment (climate, management) is a prerequisite to devising effective management strategies. In addition, any strategy aimed at minimising the impact of the pathogen in a new environment requires adequate investment into research programs and resources (monetary, infrastructure, and personnel).

The European Union currently supports two major 4-year projects on *Xylella fastidiosa* with a combined budget of about EUR10 million. These are 'Pest organisms threatening Europe' (POnTE; commenced November 2015; supported by European Union Horizon 2020 funding) and '*Xylella fastidiosa* active containment through a multidisciplinary-oriented research strategy' (XF Actors; commenced November 2016). Both involve large research consortia with ambitious work-plans covering basic and applied research on prevention, detection, surveillance and innovative control strategies for *Xylella fastidiosa* and its vectors. A multi-actor approach facilitates interactions among research groups, knowledge sharing, the establishment of new, and strengthening of existing, collaborations among European and non-European research organisations. There are 25 partners, 13 countries, and 120 researchers involved in the POnTE consortium (www.ponteproject.eu). In the XF-Actors project, 29 organisations from 14 countries in Europe, the Americas, and Asia collaborate (www.xfactorsproject.eu).

Major outcomes and products expected from POnTE are: (i) the discovery of biomolecules that can be patented, manufactured, formulated, and, applied to prevent or reduce host colonisation; (ii) chemical compounds that prevent vectors to acquire *Xylella fastidiosa*; (iii) selection of tolerant or resistant varieties of host plants; (iii) discovery of endophytic bacteria that can cross-protect against *Xylella fastidiosa*; (iv) development of early detection methods of the pathogens; (v) discovery of an optimal biological control agent for vectors; (vi) development of pest management regimes to mitigate the impact and the further spread of emerging diseases and alien pests. POnTE uses a website, social media, and a weekly newsletter to engage with stakeholders.

The overarching aims of XF-Actors are to prevent the spread of *Xylella fastidiosa,* improve early detection and disease control in Europe, and to define comprehensive and integrated management strategies for *Xylella fastidiosa*-caused diseases that mitigate economic, environment and social impacts. In this context, special attention is given to organic farming systems and the development of bio-control agents. Project outcomes are used to strengthen European Union biosecurity plans. XF-Actors has a strong stakeholder engagement component. For example, research in Apulia is carried out in cooperation with diverse industry stakeholders to test certified olive plant material under field conditions, which are provided by the world olive collection in Cordoba, Spain. Dr Boscia concluded that the amounts invested into research on *Xylella fastidiosa* by the European Union are unusual for a plant disease demonstrating the importance and urgency of combatting the threats that the pathogen continue to pose.

5.1.3 Research co-ordination: Euphresco

Dr Baldissera Giovani (European and Mediterranean Plant Protection Organisation, Paris, France) spoke on 'Research co-ordination as an answer to global plant health threats: the case of *Xylella fastidiosa*'. While collaboration is intrinsic to research, collaborations between the research community and funders and users, for example policy makers, of research are less clearly defined.

In the European Union, 85% of public investment into research and development (R&D) is administered, financed, monitored and evaluated at the national level. In 2006, the Euphresco (European Union network for phytosanitary research coordination and funding) network was initiated to overcome the fragmented nature of the research landscape to (i) develop common research agendas, (ii) facilitate transnational research funding, and (iii) share information and best practices.

Benefits of the network are not confined to the European Plant Protection Organisation region. National Plant Protection Organisations from the United States and Canada and, more recently Australia, joined the network. In 2017, the Australian Department of Agriculture and Water Resources became a Euphresco member through the Australian Chief Plant Protection Office. Information sharing is facilitated by Euphresco via a searchable, subscription, online data base of national research projects.

So far, Euphresco has funded over 70 research projects, of which several are concerned with *Xylella fastidiosa* (www.euphresco.net/projects). Funding calls are published on the website. Projects are open to non-members who participate using their own funds to contribute to the project's objectives. Participants benefit from the network by building capacity and optimising the use of resources. The shared or complementary use of research infrastructure, skills and knowledge enhances synergies and avoids overlaps.

Euphresco supports an open access and open data policy. An online portal with data and documents on regulated and emerging pests will be developed with the aim to share raw data from Euphresco projects for data re-use and cross-sectional collaboration; a prototype is currently being tested on *Xylella fastidiosa*. Dr Giovani concluded that Euphresco is much more than a website or a portal but a means to establish links and provide opportunities for more effective transnational research collaboration.

5.1.4 Australian RD&E: an industry perspective

Dr Peter Whittle's (Hort Innovation, Brisbane, Australia) presentation on '*Xylella* – towards preparedness of Australia's industries – activities, coordination, challenges' provided an generic overview of Australia's biosecurity system, the different actors within the system, and developments over the past 17 years.

The national plant biosecurity framework outlined in the Australian Emergency Plant Pest Response Plan (PLANTPLAN) provides nationally consistent guidelines for response procedures under the Emergency Plant Pest Response Deed (EPPRD). The EPPRD recognises shared responsibilities of government, industry and the wider community in preparedness, response and recovery. The framework uses industry biosecurity planning to identify high priority pests to which resources are directed. Increasingly, this process is being used to guide research and development investments in a complex system demanding rational planning.

Concerning *Xylella fastidiosa*, a series of activities in 2016 were aimed to fill gaps in knowledge and capacity, based on rising concerns about the risks posed. In 2016, *Xylella fastidiosa* was endorsed as Australia's top priority plant pest. Workshops were held under the auspices of the International Plant Protection Convention (Italy, April 2016), and by Plant Health Australia and the Department of Agriculture and Water Resources (June 2016). Key activity areas identified were: (i) diagnostics capacity and capability; (ii) communication and awareness; (iii) planning and preparedness; (iv) research, development and extension (RD&E); (v) surveillance; (vi) control and eradication.

Horticulture Innovation Australia (Hort Innovation) is a not-for-profit, grower-owned RD&E and marketing company investing more than AU$100 million annually for Australia's AU$9 billion horticulture industry. The value of Hort Innovation's biosecurity projects is over AU$23 million.

Over 33 industries participate in Hort Innovation, of which 13 industries would be potentially affected by *Xylella fastidiosa* should the pathogen arrive in Australia. The major industries are the grape, apple, pear, almond, citrus, macadamia, and the nursery industry. Hort Innovation is seeking RD&E concepts related to the pathogen and its vectors, which would be aligned with the key activity areas as mentioned above.

The Hort Innovation funding model specifies a 5-step process: (i) growers, researchers and other stakeholders submit concepts for review; (ii) an industry advisory panel prioritises concepts for investment; (iii) prioritised concepts are developed into project scopes; (iv) a request for proposal is publicly released; (v) responses are reviewed and project contracts are developed. Dr Whittle concluded that in this way, Hort Innovation is able to invest in high quality projects that address industry priorities and achieve the best industry outcomes.

5.2 Key learnings

- Successful response and management programs are characterised by an integrated and consultative approach that engages diverse stakeholders at various levels including federal and state and local governments, research organisations, affected industries, and the general public.
- Research in the European Union involves multiple organisations, is interdisciplinary, has a stakeholder engagement component, and receives substantial amounts of funding.

- The return on investment into research and integrated management practices is potentially large. In 2014, the investment of US$104 million p.a. protected an US$3 billion grape industry.
- An umbrella organisation such as Euphresco can help to improve the effectiveness of research and research delivery by overcoming the often fragmented nature of the research landscape, develop common research agendas, and share information and best practices. Since 2017, the Department of Agriculture and Water Resources has been a member of Eurphesco and can access a data base listing projects, organisations, and individuals working on *Xylella fastidiosa.*
- Diagnostics and surveillance methods continue to be developed in countries affected by *Xylella fastidiosa.* There is the need to cooperate with overseas institutions and researchers to stay up to date and implement the latest methods and technology.

Appendix A: Speakers' biographies

Professor Rodrigo Almeida

University of California-Berkeley, United States

Dr Rodrigo Almeida is a Professor at the University of California-Berkeley leading award-winning research on the ecology and evolution of insect-borne plant pathogens. He is best known for his extensive work on the fundamental biology of the plant-pathogenic bacterium *Xylella fastidiosa*, its insect vectors and the mechanisms by which it is transmitted, but also made important contributions to the understanding of grapevine leaf roll-associated viruses as well as banana bunchy top virus. Rodrigo graduated from the Universidade de São Paulo, Brazil with a BSc in agronomy in 1997 and an MSc in entomology in 1999. In 2002, he was awarded a PhD in environmental science, policy, and management from the University of California-Berkeley, where he worked under the guidance of Professor Alexander Purcell. He held an assistant professorship at the Department of Plant and Environmental Sciences at the University of Hawaii at Manoa (2003-05). He was appointed Assistant Professor (2006-11), Associate Professor (2011-16) and Professor (2016-present) at the Department of Environmental Science, Policy and Management in the University of California-Berkeley.

Dr Tony Arthur

Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES), Canberra, Australia

Dr Tony Arthur is Director and Senior Scientist of the Quantitative Sciences section in ABARES. He has an Honours degree in molecular biology from the Australian National University and a PhD in ecology from the University of Sydney. He has worked extensively on the impacts and management of vertebrate pests in Australia, New Zealand and Asia as a scientist with Landcare Research New Zealand and the Commonwealth Science and Industrial Research Organisation (CSIRO) Australia. Since joining ABARES in 2012, he has used a range of modelling and statistical analysis techniques to inform biosecurity policy and operational decisions and actions, including border inspection regimes surveillance design and analysis, and the spread and impact of plant pests and diseases.

Dr Donato Boscia

National Research Council (CNR) Institute for Sustainable Plant Protection, Bari, Italy

Dr Donato Boscia is the head of the operative unit of the Institute for Sustainable Plant Protection of the CNR in Bari, Italy. He is a plant virologist specialised in serology (development and application of polyclonal and monoclonal antibodies applied to strain identification). He has contributed extensively to the first detection of *Xylella fastidiosa* in Italy and to the subsequent development of the major research program on the bacterium currently being conducted in Apulia, in which he coordinates extensive field and laboratory activities. He has contributed to developing important scientific evidence on the novel *Xylella fastidiosa* strain spreading in Apulia. Donato has published over 60 peer reviewed papers, coordinated six Research & Development research projects, and authored two patents on a diagnostic kit. He is currently the coordinator of the Horizon 2020 Project POnTE (Pest Organisms Threatening Europe).

Associate Professor Wen-Ling Deng

National Chung Hsing University, Taichung, Taiwan

Dr Wen-Ling Deng is an Associate Professor at National Chung Hsing University of Taiwan. She has published on *Xylella*-elicited leaf scorch diseases on pear and grape in Taiwan in collaboration with Drs Su, Chiou-Chu and Shih, Hsien-Tzung. Based on the comparison of genome sequence and biochemical characteristics, she re-classified the pear strain of *Xylella* as a new species, *X. taiwanensis*. Wen-Ling received a BSc from the National Taiwan University, MSc from National Chung Hsing University, and a PhD from Cornell University, United States. Her PhD dissertation focused on the functional characterisation of *Pseudomonas syringae* Pathogenicity Island by genetics and cell biology approaches. In 2003, Wen-Ling returned to Taiwan, where she accepted a tenure-track position at her alma mater to work on plant-pathogenic bacteria. In 2016, she received the 2016 Distinguished Teaching Award for her enthusiasm and dedication to undergraduate education at the National Chung Hsing University.

Dr Anna Maria D'Onghia

International Centre for Advanced Mediterranean Agronomic Studies (CIHEAM), Bari, Italy

Dr Anna Maria D'Onghia is Head of the Division on Integrated Pest Management at CIHEAM, Mediterranean Agronomic Institute in Bari. Anna Maria has over 30 years of experience in education, training, research and international cooperation in plant protection. Her work focuses on the characterisation, epidemiology and control of major pathogens affecting fruit trees in the Mediterranean region, surveillance and monitoring methods for quarantine plant pathogens, and the certification of plant propagating materials. Concerning *Xylella fastidiosa*, her research group has contributed to the improvement of surveillance and detection methods and tools, and to the official sampling and analyses in the pathogen monitoring program. Anna Maria's extensive expertise is recognised through her invitations as keynote speaker and chair at international events where she has presented the case of *Xylella fastidiosa* in Italy.

Dr Jim Farrar

University of California-Davis, United States

Dr Jim Farrar is the director of the state-wide Integrated Pest Management Program (IPM) at University of California. The Program includes 11 IPM farm advisors and five affiliated farm advisors located throughout the state and a staff of 20 writers, editors, and IT support staff housed in the Division of Agriculture and Natural Resources. The program focuses on pragmatic IPM solutions to address important pest issues in agriculture, communities and natural areas in California. Previously, Jim was Director of the Western IPM Center for three years and Professor of plant pathology in the Department of Plant Science at California State University, Fresno, for 13 years. Jim's research primarily focused on fungal diseases of vegetable crops. He completed a masters at University of California-Davis and a doctorate at University of Wisconsin. His publications include scientific papers, extension newsletter articles, and articles in agricultural industry magazines. Jim wrote a chapter in the book 'Tomato Health Management' and several disease descriptions in the book 'Compendium of Umbelliferous Crops Diseases'. He was a senior editor for the journal Plant Disease and or for the on-line journal Plant Health Progress.

Dr Baldissera Giovani

European and Mediterranean Plant Protection Organisation, Paris, France

Dr Baldissera Giovani holds a PhD in biochemistry and molecular biophysics from Paris VI University and an MSc in Law, Economics and Management from the University of Strasbourg (France). As a research scientist, he worked in the field of plant physiology, animal and human health in Italy, France and the United States. Since 2009, he has managed research projects in agronomy and supported research scientists to get funding from national and international funders. He is coordinating the activities of over 70 national funders, National Plant Protection Organisations and research organisations in five continents. Baldissera believes that the ingredients of a successful collaboration are solid processes and structures, well-defined common priorities and timely funding. Baldissera coordinates the Euphresco (EUropean PHytosanitary RESearch COordination) network, which aims at facilitating procedures for both researchers and funders and to ease the use of research outputs for policy development.

Dr Marie-Agnès Jacques

French National Institute for Agricultural Research (Institut National de la Recherche Agronomique, INRA), Beaucouzé Cedex, France

Dr Marie-Agnès Jacques has been involved in research dealing with *Xylella fastidiosa* since the first contaminated plants were detected in France in 2012. She uses typing methods and comparative genomics to understand invasion and dispersal pathways of *Xylella fastidiosa*. Marie-Agnès received her PhD from Paris-Orsay University in 1994 on a thesis dealing with quantitative ecology and physiology of the epiphytic bacterial community. She participated in the first studies showing that epiphytic bacteria are forming biofilms on leaf surfaces with Cindy E. Morris, INRA. Marie-Agnès conducted post-doctoral research in Mark Bailey’s laboratory, Oxford, UK, where she used molecular methods to characterise bacterial strains in biofilms. Since her return to INRA, Marie-Agnès has developed projects on epidemiology and ecology of seed-borne bacterial diseases with a focus on bean-associated aerial diseases and the role of biofilms in epidemiology and seed-transmission. More recently, Marie-Agnès has researched leaf-associated commensal bacteria, their interactions with pathogenic bacteria, and their potential role in the evolution and emergence of novel pathogens.

Dr Rodrigo Krugner

United States Department of Agriculture (USDA), Parlier, California, United States

Dr Rodrigo Krugner is a Research Entomologist with the USDA, Agricultural Research Service. Rodrigo began his federal career in 2007 and has since worked on a variety of projects involving the bacterial pathogen, *Xylella fastidiosa*, and associated insect vectors. Rodrigo has conducted research on the biology, behavioural and population ecology of insect vectors and their natural enemies, focusing primarily on plant-insect-pathogen interactions. In addition, Rodrigo has served as the Lead Scientist on a project developing methods to mitigate the impact of diseases caused by *Xylella fastidiosa* conducted at the Crop Diseases, Pests and Genetics Research Unit at the San Joaquin Valley Agricultural Sciences Center in Parlier, California. Prior to joining the USDA, Rodrigo was a graduate student in the Department of Entomology at University of California-Riverside. His work focused on behavioural ecology of *Homalodisca vitripennis*, an important vector of *Xylella fastidiosa* in the southern United States. Rodrigo holds a bachelor’s degree in Agronomy from University of São Paulo, Brazil, a Master's degree in Plant Science from California State University, and a PhD in Entomology from the University of California.

Dr Leigh Pilkington

Department of Primary Industries New South Wales (DPI NSW), Gosford, NSW, Australia

Dr Leigh Pilkington is a scientist and manager of plant biosecurity research with the DPI NSW, which he joined in 2006, and where he has been involved in the development of Integrated Pest Management strategies for protected horticulture. His work involves the development and optimisation of biological control agents, reduced risk pesticides and good agricultural practices within these systems. In 1997 and following under-graduate studies at the University of Canberra, Leigh worked at DPI NSW as part of the fruit fly monitoring team. In 1998, he joined the University of Sydney and assessed the impact of Australian lucerne yellows phytoplasma disease (ALuY) in field surveys. In 1999, Leigh participated in international volunteer conservation activities in Thailand, Burma, South Africa, Greece and the United States. Leigh did his PhD studies under the joint supervision of Geoff Gurr (University of Sydney) and Murray Fletcher (DPI NSW) on 'ALuY, its epidemiology and its vector(s)' with the aim to produce a management plan for the disease (2000-03). In 2004, Leigh joined the Hoddle laboratory at the University of California, Riverside, and researched the developmental and reproductive biology of *Gonatocerus spp.*, which are associated with the biological control of *Homalodisca vitripennis*, the glassy-winged sharpshooter. The latter is the major vector of *Xylella fastidiosa* in California and has invaded many parts of the world including Tahiti and Hawaii.

Professor Emeritus Alexander Purcell

University of California-Berkeley, United States

Professor Emeritus Alexander Purcell, or Sandy as he is known by most friends and colleagues, began his graduate research at University of California-Davis in 1972 on Pierce's disease of grape. One of his guiding professors, William Hewitt, had named the disease after the first scientist who described this disease, Newton Pierce. Sandy continued research on Pierce's disease and teaching as an Assistant Professor at Berkeley. Until 1974 Pierce's disease had been considered a viral disease. Professor Purcell disproved that a *Lactobacillus* bacterium claimed in 1974 was the probable cause of Pierce's disease, and in 1978 his collaborator and a Berkeley graduate student, Mike Davis, first cultured *Xylella fastidiosa* and proved experimentally that it caused Pierce's disease and almond leaf scorch disease. Sandy's research has included studies of vector transmission and epidemiology of phytoplasma and spiroplasma pathogens and bacterial symbionts of aphids. He was also involved in work on a *Xylella fastidiosa*-caused disease first noticed in Brazilian citrus in 1987, a new disease in oleander in southern California, and *Xylella fastidiosa*-caused diseases in numerous plants in Costa Rica. Sandy's recent interest is in newly detected *Xylella fastidiosa* genotypes in Europe and he continues to do research in collaboration with his former student, Rodrigo Almeida, who succeeded him as a professor at Berkeley and is a prominent researcher on *Xylella fastidiosa*.

Ms Beth Stone-Smith

United States Department of Agriculture (USDA), Sacramento, California, United States.

Ms Beth Stone-Smith is the USDA's Program Director for the Pierce's Disease (PD) and Glassy-Winged Sharpshooter (GWSS) Program. She also has responsibilities as the California Program Manager for the European Grapevine Moth Program (successfully eradicated in 2016), as well as handling work plans and budgets for other pest surveys and activities in California. In 2001, Beth began her career with the PD/GWSS emergency program, and in 2004 assumed the position of Program Director. Beth's love of agriculture stems from an upbringing in a family owned farm supply and hardware store where interactions with hardworking farmers inspired her. She graduated college from Concordia College in Moorhead, Minnesota, with a biology degree and then went on to earn her Master of Science degree in Entomology from Kansas State University. She has worked in laboratories that focused on insect behaviour, integrated pest management, and molecular genetics.

Mr Robert Taylor

Ministry of Primary Industries (MPI), Auckland, New Zealand

Mr Robert Taylor is a senior scientist at the MPI Plant Health and Environment Laboratory in Auckland, and has over 20 years' experience as a microbiologist in plants biosecurity and diagnostics with extensive experience in quarantine and phytosanitary affairs. Rob is involved in diagnostic investigations of new diseases of plants and provision of scientific advice on biosecurity matters. He has participated as a technical expert at the WTO, and is the bacteriology discipline lead for the IPPC Technical Panel for Diagnostic Protocol. Previously to working at the MPI, Rob worked at HortResearch on research programs that focused on the molecular detection, identification and ecology of plant pathogenic bacteria that affected market access and biosecurity of New Zealand horticultural crops. Rob is involved in preparedness for *Xylella fastidiosa,* including the improvement of diagnostic capabilities, methods to culture the organism and detect *Xylella fastidiosa* in insect vectors and plant material, access to positive controls in containment, and the ability to scale up testing for high throughput detection.

Dr Peter Whittle

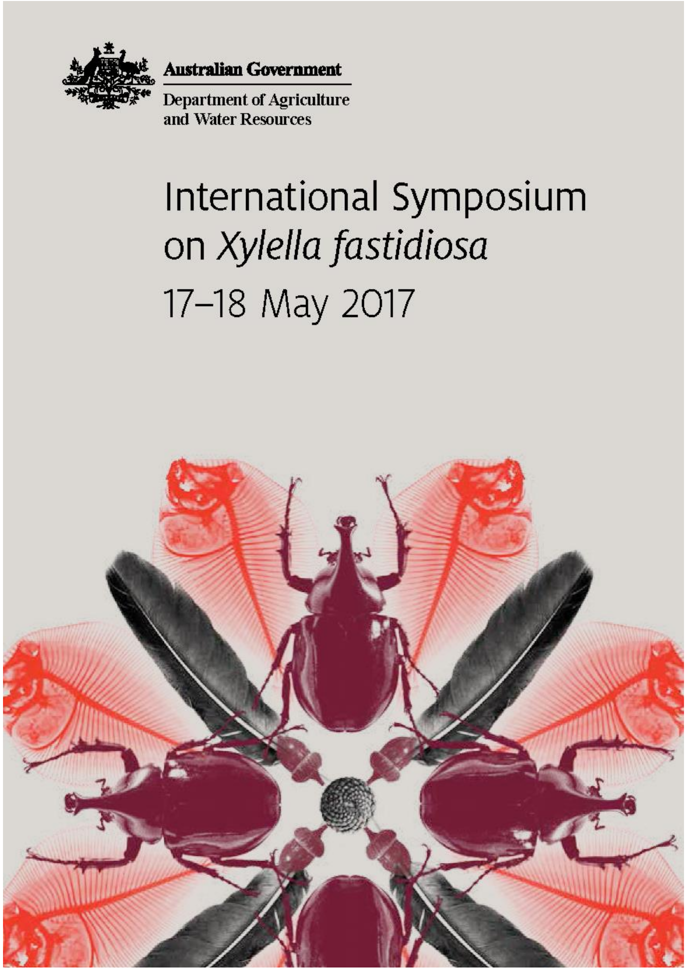
Hort Innovation, Brisbane, Australia

Dr Peter Whittle is R&D Manager for Biosecurity and Market Access at Hort Innovation, which is a not-for-profit, grower-owned RD&E and marketing company investing more than AU$100 million annually for Australia's AU$9 billion horticulture industry. Over AU$23 million are invested in biosecurity projects. Peter has over 30 years of experience in RD&E. He holds a PhD in plant pathology and breeding from the University of Adelaide, and worked on winter cereals at the South Australian Research and Development Institute, and in applied pathology research at Sugar Research Australia where he was also responsible for quarantine. He was a Principal Scientist at Biosecurity Queensland, managing projects and advising on policy. A year's study leave at Queensland University of Technology turned into a longer stay, were Peter developed the biosecurity surveillance systems for the Gorgon Project, one of the world's largest natural gas projects, advised the grains industry, and worked in a team on an aid-funded project in Southeast Asia. Peter has retained a link to the university as an Adjunct Associate Professor. After a period consulting in his firm Biosecurity Systems, he joined Hort Innovation.

Appendix B: Program

International Symposium on *Xylella fastidiosa,* 17-18 May

Brisbane Convention and Exhibition Centre, South Brisbane, QLD



Welcome to the 2017 International Symposium on the plant pest *Xylella fastidiosa* hosted by the Department of Agriculture and Water Resources

I am delighted to present the program for the 2017 International Symposium on *Xylella fastidiosa*, the vector-borne bacterium which causes diseases that can kill affected plants. The distribution and impact of *Xylella fastidiosa* is closely related to the presence of insect vectors that can carry and transmit the disease. Over 350 perennial and woody plant species are at risk, including grapevine, citrus and olives.

Xylella fastidiosa is not yet present in Australia. However, the risk that it poses to Australian plant health is reflected in it being Australia's Number 1 National Priority Plant Pest, as endorsed by Australia's Plant Health Committee in 2016.

Early detection of the pathogen is critical, but complicated due to disease symptoms which are easily confused with water stress or other pathogens. Preparedness to respond quickly and implement effective management processes are also critical to minimising the impact of this disease, should it be detected in Australia.

The two-day symposium has four sessions and 17 presentations covering:

- *Xylella* and its vectors
- diagnostics and surveillance
- management and control
- research and collaboration.

We have gathered experts from France, Italy, New Zealand, Taiwan, the United States and Australia who will share their knowledge and experience with *Xylella fastidiosa*. The panel discussions after each session will give you the opportunity to discuss the challenges in dealing with the pathogen and its vectors. I would like to thank our speakers and convenors for their generosity in sharing their time and expertise. I trust you will take advantage of the opportunities presented by this symposium, so please, contribute to the conversation and make new contacts. We look forward to your participation and working with you so Australia is better prepared for this pest of worldwide significance.

Lyn O'Connell
Deputy Secretary
Department of Agriculture
and Water Resource

Table B1 Program of day one of International Symposium on *Xylella fastidiosa*, 17 May

Time	Topic	Speaker/Moderator
9:00 AM – 9:10 AM	**Opening Addresses and Welcome**	**Lyn O'Connell** Deputy Secretary, Department of Agriculture and Water Resources, Canberra, Australia
–	**Session one: *Xylella* and its vectors, biology and the global situation**	**Marion Healy** First Assistant Secretary, Department of Agriculture and Water Resources, Canberra, Australia **Sharyn Taylor** National Manager, Broadacre Cropping, Plant Health Australia, Canberra Australia
9:10 AM – 9:40 AM	**Ecology of *Xylella fastidiosa*; the basis for its prevention and control**	**Alexander Purcell (key-note)** Professor Emeritus, University of California Berkeley, Department of Environmental Science, Policy, & Management, Berkeley, California, United States
9.40 AM – 10:00 AM	***Xylella fastidiosa*, an emerging plant pathogen in Europe that threatens agriculture**	**Marie-Agnès Jacques** Director of Research, French National Institute for Agricultural Research (INRA), Institute of Research in Horticulture and Seeds, Beaucouze Cedex, France
10:10 AM – 10:30 AM	Morning tea	–

Time	Topic	Speaker/Moderator
10:30 AM – 10:50 AM	**Leaf scorch diseases of grape and pear in Taiwan**	**Wen-Ling Deng** Associate Professor, National Chung Hsing University, Department of Plant Pathology, Taichung, Taiwan
10:50 AM – 11:10 AM	**Role of controlled deficit irrigation on population dynamics, movement, and dispersal of insect vectors and *Xylella fastidiosa***	**Rodrigo Krugner** Research Entomologist, Crop Diseases, Pests and Genetics Research Unit, USDA Agricultural Research Service, Parlier, California, United States
11:10 AM – 11:40 AM	**Panel Discussion, session one**	–
11:40 AM – 12:40 PM	Lunch	–
–	**Session two: Current science – diagnostics and surveillance for *Xylella* and its vectors**	**Gabrielle Vivian-Smith** Chief Plant Health Officer, Department of Economic Development, Jobs, Transport and Resources, Victoria, Melbourne, Australia **Kim Ritman** Australian Chief Plant Protection Officer, Department of Agriculture and Water Resources, Canberra, Australia
12:40 PM – 1:10 PM	***Xylella fastidiosa* in the outbreak area of Italy: present situation of the infection and innovative tools for early surveillance**	**Anna Maria D'Onghia (key note)** Head of Division, Integrated Pest Management of Mediterranean Fruit and Vegetable Crops, International Centre for Advanced Mediterranean Agronomic Studies (CHIEAM), Bari, Italy
1:10 PM – 1:40 PM	Via video link: ***Xylella fastidiosa* diversity**	**Rodrigo Almeida** Professor, Department of Environmental Science, Policy and Management, University of California Berkeley, Berkeley, California, United States
1:40 PM – 2:10 PM	Afternoon tea	–
2:10 PM – 2:30 PM	**Evaluation of olive as a host of *Xylella fastidiosa* and associated sharpshooter vectors**	**Rodrigo Krugner** Research Entomologist, Crop Diseases, Pests and Genetics Research Unit, USDA Agricultural Research Service, Parlier, California, United States
2:30 PM – 2:50 PM	**Diagnostic preparedness for a *Xylella* invasion: A New Zealand perspective**	**Robert Taylor** Senior Scientist, Plant Health and Environment Laboratory, Ministry of Primary Industries, Auckland, New Zealand
2:50 PM – 3:10 PM	**Invasion pathways of the glassy-winged sharpshooter (*Homalodisca vitripennis*) across the Pacific Ocean and activities for the spread of biological control agents**	**Leigh Pilkington** Research Scientist, Biosecurity and Food Safety, New South-Wales Department of Primary Industries, Gosford, New South Wales, Australia
3:10 PM – 3:40 PM	**Panel discussion, session two**	–

Time	Topic	Speaker/Moderator
From 6:30 PM	Symposium dinner hosted by the Department of Agriculture and Water Resources, The Lyrebird Restaurant, Queensland Performing Arts Centre	Welcome: **Lyn O'Connell** Deputy Secretary, Department of Agriculture and Water Resources, Canberra, Australia

Table B2 Program of day two of International Symposium on *Xylella fastidiosa*, 18 May

Time	Topic	Speaker/Moderator
9:00 AM – 9:10 AM	**Welcome and summary of previous day**	**Kim Ritman** Australian Chief Plant Protection Officer, Department of Agriculture and Water Resources, Canberra, Australia
–	**Session three: strategic management and control**	**Mike Ashton** General Manager, Department of Agriculture and Fisheries, Queensland, Australia **Tania Chapman** Chair, Citrus Australia, Mildura, Victoria, Australia
9:10 AM – 9:40 AM	**Re-emergence of *Xylella fastidiosa*: The ongoing epidemics in southern Italy and EU measures**	**Donato Boscia (keynote)** Research Manager, Italian National Research Council (CNR), Institute for Sustainable Plant Protection, Bari, Italy
9:40 AM – 10:10 AM	**Management of *Xylella* diseases in California**	**Jim Farrar (keynote)** Director, Integrated Pest Management Program, Division of Agriculture & Natural Resources, University of California, Davis, California, United States
10:10 AM – 10:40 AM	Morning tea	–
10:40 AM – 11:00 AM	**The Glassy-winged Sharpshooter and Pierce's Disease (*Xylella fastidiosa*) in California – state-wide activities and the area-wide management of the vector and disease**	**Beth Stone-Smith** Director, Glassy-Winged Sharpshooter and Pierce's Disease Program, Animal and Plant Health Inspection Service (APHIS), Plant Protection and Quarantine, USDA, Sacramento, California, United States
11:00 AM – 11:20 AM	**Potential economic impacts of *Xylella fastidiosa* on the Australian wine grape and wine industries**	**Tony Arthur** Director, Quantitative Sciences, Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES), Department of Agriculture and Water Resources, Canberra, Australia
11:20 AM – 12:00 PM	**Panel discussion, session three**	–
12:00 PM – 12:50 PM	Lunch	–

Time	Topic	Speaker/Moderator
–	**Session four: research and collaboration**	**Geoff Raven** Manager, Department of Primary Industries and Regions South Australia, Adelaide, Australia **Peter Whittle** Research & Development Manager, Hort Innovation Australia, Brisbane, Queensland, Australia
12:50 PM – 1:20 PM	**Collaborative research and extension programs to address *Xylella* diseases in California**	**Jim Farrar (keynote)** Director, Integrated Pest Management Program, Division of Agriculture & Natural Resources, University of California, Davis, California, United States
1:20 PM – 1:40 PM	**Research activities and research gaps in the EU**	**Donato Boscia** Research Manager, Italian National Research Council (CNR), Institute for Sustainable Plant Protection, Bari, Italy
1:40 PM – 2:10 PM	Afternoon tea	–
2:10 PM – 2:30 PM	**Research co-ordination as an answer to global plant health threats: the case of *Xylella fastidiosa***	**Balidissera Giovani** Coordinator of Euphresco, European and Mediterranean Plant Protection Organisation, Paris, France
2:30 PM – 2:50 PM	**Towards preparedness of Australian Industries – activities, coordination, challenges**	**Peter Whittle** Research & Development Manager, Hort Innovation Australia, Brisbane, Queensland, Australia
3:30 PM – 3:50 PM	**Lessons learnt – closing address**	**Kim Ritman** Australian Chief Plant Protection Officer, Department of Agriculture and Water Resources, Canberra, Australia

Appendix C: Symposium participants

Last Name	First Name	Organisation	Email
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Banks	Rosalie	Department of Agriculture and Fisheries QLD, AU	–
Beel	Lucy	Department of Agriculture and Water Resources, AU	–
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Bleach	Carolyn	Ministry for Primary Industries, NZ	carolyn.bleach@mpi.govt.nz
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Dall	David	Department of Agriculture and Water Resources, AU	david.dall@agriculture.gov.au
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Dann	Alison	Department of Primary Industries, Parks, Water and Environment TAS, AU	Alison.Dann@dpipwe.tas.gov.au
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Davis	Kevin	Department of Agriculture and Water Resources, AUS	kevin.davis@agriculture.gov.au
De Barro	Paul	CSIRO, AU	paul.debarro@csiro.au
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Abbreviations

Abb.	Description
ABARES	Australian Bureau of Agricultural Resource Economics and Sciences
ACPPO	Australian Chief Plant Protection Office
CDFA	California Department of Food and Agriculture
CHIEAM	Centre International de Hautes Études Agronomiques Méditerranéennes (International Centre for Advanced Mediterranean Agronomic Studies)
CoDiRO	Complesso del disseccamento rapido dell'olivo (the *Xylella fastidiosa* ssp. *pauca* strain that cause OQDS in Italy)
DAWR	Department of Agriculture and Water Resources
DNA	Desoxyribonucleic acid
DTBIA	Direct tissue blot immuno-assay
ELISA	Enzyme-linked immunosorbent assay
EPPO	European and Mediterranean Plant Protection Organisation
EU	European Union
Euphresco	European Network for Phytosanitary Research Coordination. The Australian Department of Agriculture and Water Resources is a member of Euphresco
FAO	Food and Agriculture Organisation of the United Nations
GWSS	Glassy-winged sharpshooter (*Homalodisca vitripennis*, formerly *H. coagulata*)
ICMP	International collection of microorganisms from plants
IPM	Integrated pest management
IPPC	International Plant Protection Convention
LAMP	Loop-mediated isothermal amplification
MLST	Multi-locus sequence typing
NBS	National biosecurity strategy
NIR	Near infrared
NPPO	National Plant Protection Organisation
OQDS	Olive quick decline syndrome
PCR	Polymerase chain reaction
PD	Pierce's diseases of grapes
PHA	Plant Health Australia
PHEL	Plant Health and Environment Laboratory, New Zealand
POnTE	Pest Organisms Threatening Europe; EU funded research consortium
qPCR	Quantitative [real-time] polymerase chain reaction
R&D	Research and development
RD&E	Research, development and extension
ssp.	Subspecies
ST53	Sequence type 53
UC	University of California
USDA	United States Department of Agriculture

Abb.	Description
XF-Actors	*Xylella fastidiosa* active containment through a multidisciplinary research strategy. XF-Actors is a research consortium funded by the European Union
XylApp	An application to upload geo-referenced field data to a web-based expert system developed in Italy
XylWeb	A web-based expert system to trace, store, manage, and analyse multiple data layers related to OQDS/*Xylella fastidiosa* that has been developed in Italy

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