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Celebrating International Year of Plant Health: Botanic gardens and biosecurity

INTERNATIONAL YEAR OF PLANT HEALTH 2020
PROTECTING PLANTS, PROTECTING LIFE

BOTANIC GARDENS CONSERVATION INTERNATIONAL

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BGCI is a worldwide membership organisation established in 1987. Its mission is to mobilise botanic gardens and engage partners in securing plant diversity for the well-being of people and the planet. BGCI is an independent organisation registered in the United Kingdom as a charity (Charity Reg No 1098834) and a company limited by guarantee, No 4673175. BGCI is a tax-exempt 501(c)(3) non-profit organisation in the USA and is a registered non-profit organisation in Russia.

2011-2020 United Nations Decade on Biodiversity

IN THIS ISSUE...

EDITORIAL: PLANT HEALTH

Dear BGjournal Reader,

As 2020 is the International Year of Plant Health, it is appropriate that the theme of this issue of BGjournal is biosecurity and plant pests and diseases. This is a particularly important topic as the combination of a changing climate and greater movement of plant material across borders has exacerbated such problems in recent years. Our particular focus is on the role of botanic gardens in detecting, preventing and managing threats from new pests and diseases.

Our first article (p. 17) describes the International Plant Sentinel Network (IPSN), which is co-ordinated and managed by BGCI. The IPSN comprises more than 50 botanic gardens and arboreta who provide an early warning system for emerging pests and diseases by screening non-native plants in their collections for pests and diseases that are prevalent in their region, and alerting partners in the native ranges of those species if susceptibility is detected. In our second article (p. 21) Charles Lane and Laura Stevens explain how the IPSN is being used by the UK plant health authorities to carry out research on a range of pests included on the UK's pest risk register.

Our third article (p. 24) is an example from Belgium, where the team carried out systematic on-site sampling in the collections of participating gardens for several suspected pests and pathogens. As a result, two of the targeted organisms were recorded for the first time in Belgium: the phytoplasma '*Candidatus Phytoplasma ulmi*' and the fungus *Sirococcus tsugae*.

While this work was carried out with support from project funding, the Belgian case study also proposes a long term solution to mainstreaming plant sentinel detection through co-ordination of activities through the Belgian Association of Botanic Gardens and Arboreta.

From Belgium we cross half the world to New Zealand (p. 27), a country where biosecurity is taken so seriously that the Government's advertising campaign suggests that all 4.7 million citizens of New Zealand should be preventing the arrival and spread of pests and diseases. Here, another important role of botanic gardens is highlighted – that of raising public awareness of the risks associated with pests and pathogens, and educating people about not inadvertently introducing them to New Zealand. Auckland Botanical Garden's Biosecurity Trail is an excellent example of this.

Another approach to early detection that lends itself particularly to botanic gardens is the use of trap plants as sentinels. These are plants that are particularly attractive to pests and pathogens. This is the focus of the article by Uwe Starfinger (p. 37), who points out that botanic gardens with their wide range of collections are particularly suited to carrying out this type of work.

As well as being an important part of the solution, botanic gardens can be part of the problem. In their article on the risks of pest and disease movement via plant and seed exchanges (p.30), Iva Franić and co-authors make a series of recommendations about how botanic gardens might exchange seeds and plant material more safely to minimise these risks.

Red palm weevil found in China (IPSN)

Further examples of biosecurity measures botanic gardens can take are provided in the article by Katherine Hayden (p. 40).

Our plant hunting tale this edition is not a plant hunting tale at all. Instead, it is about finding bugs on plants - Invasive Alien Species to be precise, and in Montserrat in the West Indies (p. 8). Finally, the BGjournal interview is with Professor Nicola Spence, Chief Plant Health Officer at the Department for Environment, Food and Rural Affairs, UK who tells us all about the International Year of Plant Health (IYPH). IYPH in 2020 is a once in a lifetime opportunity to raise global awareness on how protecting plant health can help end hunger, reduce poverty, protect the environment, and boost economic development. Events are being organised around the world to celebrate IYPH and to highlight the vital role of national and regional plant health organisations in protecting plants from damaging pests and diseases. Clearly, we have an important role to play in botanic gardens, and we need to play our part in this initiative.

I hope you enjoy this edition of BGjournal and, as ever, we welcome your feedback and ideas.

Paul Smith
Secretary General BGCI

FEATURES

Olive tree affected by Xylella fastidiosa *(Jekatarinka/Shutterstock)*

NEWS FROM BGCI

Here we present a selection of the most recent news stories from BGCI. Please browse our website to keep up-to-date with the latest news and events from BGCI and the botanic garden community.
www.bgci.org

Global Botanic Garden Fund

Launched in 2019, BGCI's Global Botanic Garden Fund (GBGF) aims to support plant conservation activities, especially in smaller gardens. The Fund also administers restricted grant funding through the BGCI/ArbNet Partnership Programme and the BGCI/Minnesota Landscape Arboretum Grants.

In the first year of the fund, BGCI received 72 applications from 64 institutions located in 39 countries. As a result, 17 grants totalling $33,013 have been awarded. Of these, eight grants were provided through the unrestricted funding of the GBGF, four through the BGCI/Minnesota Landscape Arboretum Grants and five through the BGCI/ArbNet Partnership Programme.

The full list of successful applications can be seen on the BGCI website: https://www.bgci.org/news-events/2019-global-botanic-garden-fund-grant-winners-announced/

World Forum on the Global Strategy for Plant Conservation

From October 28-29, 2019, the China Wild Plant Conservation Association (CWPCA) together with the Biodiversity Committee, Chinese Academy of Sciences, BGCI, the Global Partnership for Plant Conservation (GPPC), International Union for Conservation of Nature (IUCN), and SEE Foundation organized the 2019 World Forum on the Global Strategy for Plant Conservation, in Dujiangyan City, China. More than 260 participants from all over the world attended this meeting.

The meeting was organized within the context of international stakeholder consultations on the post-2020 global biodiversity framework, to discuss and review the future of the Global Strategy for Plant Conservation (GSPC). Participants expressed strong support for the continuation of the GSPC beyond 2020 and for this to be increasingly mainstreamed into national and international biodiversity frameworks.

BGCI is working with the Global Partnership for Plant Conservation to develop new and updated targets for the GSPC, in line with the Convention of Biological Diversity's (CBD) proposed post-2020 biodiversity targets.

BGCI and ArbNet announce reciprocal accreditation

Both BGCI and ArbNet offer accreditation schemes that recognise standards for leadership, collections management, horticulture, public education, research, staff, and networking.

Each accreditation program, however, supports different target audiences. BGCI Botanic Garden Accreditation recognises botanical institutions with a focus on plant conservation and sustainability, while ArbNet Arboretum Accreditation is tailored to gardens with a strong focus on woody plants and trees.

Under this new reciprocal agreement, those applying for BGCI's Botanic Garden Accreditation who wish to be considered for ArbNet Arboretum Accreditation will be required to answer additional questions related to their focus on woody plant and tree species.

Those applying for ArbNet Arboretum Accreditation at Level III or IV who wish to be considered for BGCI's Botanic Garden Accreditation will be required to answer additional questions on their plant conservation and sustainability activities.

Gardens that have achieved BGCI accreditation since the last issue of BGjournal:

BGCI Accredited Botanic Garden
Eden Project
Institute of Botany, Czech Academy of Sciences
Botanical Garden of Vilnius University
Rotterdam Zoo and Botanical Garden
Cambridge University Botanic Garden
Jardin Botanique de Montréal
Botanical Garden of Klaipeda University
Auckland Botanic Gardens
National Tropical Botanical Garden
Giardino Botanico di Oropa

BGCI Accredited Advanced Conservation Practitioner
Conservatoire et Jardin Botaniques de la Ville de Genève
The Morton Arboretum

Bumper year for tree assessments

Over a third of tree species now have a global extinction risk assessment available on the IUCN Red List of Threatened Species. In the latest IUCN Red List update (2019.3) over 3,000 assessment for trees were published, bringing the total number of tree assessments available on the IUCN Red List to 20,116. This is 34% of global tree diversity. This means that in 2019 over 8,000 assessments for trees have been published towards the Global Tree Assessment (GTA).

Highlights in the latest update include assessments for all Eucalyptus species, of which 25% are threatened with extinction. With 826 species, Eucalyptus is the third largest tree genus in the world; these assessments therefore provide a major contribution to our global knowledge of trees.

Other highlights include the completion of assessments for all twelve monotypic tree families (of which six are considered threatened with extinction, including the well-known favourite, *Ginkgo biloba*) and all 158 Dipterocarp species endemic to Borneo. Analysis of the Bornean species shows that 60% are threatened in the wild, with 16 species assessed as Critically Endangered, 34 as Endangered and 46 as Vulnerable. The major threats to these trees are logging and conversion of land to transport corridors and agricultural space e.g. palm oil plantation.

Rubiaceae Calycophyllum *in Rio botanic garden*

Further information is available at: https://www.bgci.org/news-events/bumper-year-for-tree-assessments-on-the-iucn-red-list/

Global Tree Specialist Group honoured by IUCN

BGCI has hosted the secretariat for the Global Tree Specialist Group (GTSG) for over 10 years and at the 2019 IUCN Species Survival Commission (SSC) Leaders' Meeting, members of the Global Tree Specialist Group were recipients of several IUCN SSC awards. These awards are given to recognize the exemplary voluntary contribution of individuals and Specialist Groups towards the global work of IUCN.

The Harry Messel Award for Conservation Leadership was received by Malin Rivers, Head of Conservation Prioritisation at BGCI. Malin is also secretary of GTSG and the award recognises her key role in coordinating the Global Tree Assessment (GTA) and her innovative management of the initiative. The GTSG were the recipients of The SSC Chair's Citation of Excellence, in recognition of the '*outstanding contribution the GTSG has made in delivering the Species Strategic Plan between 2017 and 2018*'. During this period, over 2,000 assessments for trees were added to the IUCN Red List.

BGCI announces 2019 Marsh award winners

The Marsh Awards are awarded annually by the Marsh Christian Trust, in partnership with BGCI, in recognition of excellence in International Plant Conservation and Botanic Garden Education. In 2019, the winners were Ana Sandoval for International Plant Conservation and Benjamin Ong for Education in Botanic Gardens. The awards were presented at an event in London on October 8th.

Ana Sandoval receiving the Marsh Christian award for International Plant Conservation

Ana Sandoval works as a technical researcher at the seedbank of the Instituto de Investigaciones Agropecuarias (INIA) in Vicuña, Chile. While the seedbank focuses on the conservation of crop wild relatives, Ana's interests and knowledge have enabled her to utilise the facilities of the seedbank to the maximum, using it to also conserve seeds of three highly threatened Chilean endemic tree species.

Benjamin Ong guiding primary school children at the screwpine (Pandanus) clump at the fringes of Rimba Ilmu's central wetland

In Malaysia, Benjamin Ong founded and developed the Rimba Project, a platform for community engagement and volunteer development. He helped Rimba Ilmu overcome resource constraints by training student volunteers as junior nature guides, building skills in communication and teamwork, while tripling Rimba Ilmu's capacity to accommodate guided tours. He also facilitated novel approaches in garden interpretation, including two volunteer-led programmes, the creation of two new interpretive trails and Rimba Ilmu's first garden theatre performance.

New resources to support plant health

The International Plant Sentinel Network (IPSN) has released three new resources to increase awareness and aid identification of a number of priority plant pests/pathogens. These include: three wood boring beetles (Polyphagous Shot Hole Borer, Gold Spotted Oak Borer and Two Lined Chestnut Borer) on European *Quercus* species, Emerald Ash Borer and Ash Dieback on non-*Fraxinus* hosts and Rose Rosette Virus. It is hoped that these resources will help botanic garden staff and the general public to identify these damaging pests/pathogens. The resources have been developed in collaboration with UK plant health experts and each includes information on the background of the pests/pathogens in question, host species, symptom ID and who to contact if you observe symptoms.

The resources can be found at https://www.plantsentinel.org/news/1547/.

New education resources

As part of the LearnToEngage project, BGCI and partners have developed four 12-week blended learning modules and have made the resources for these modules available, open access.
Each module consists of a trainer and participant handbook and also includes online resources which are hosted on RBGE's PropaGate Learning platform. The four modules are Interpretation, Working with diverse audiences, Science communication and Evaluation and research.

The module resources can be accessed at: https://www.bgci.org/resources/bgci-tools-and-resources/learntoengage-module-resources/

LearnToEngage modules

Participants of the first South American Botanic Gardens Network Workshop (Noelia Alvarez)

First South American Botanic Gardens Network Workshop:

In December, BGCI in collaboration with the Universidad del Tolima and the Botanic Garden Alexander von Humboldt organized a meeting to bring together the South American botanic garden community and promote the creation of a new botanic garden network in the region. The event was attended by more than 40 participants from countries such as Argentina, Brazil, Chile, Colombia, Guyana, México, Paraguay, Perú, Suriname, Uruguay and Venezuela. Talks were presented by all the attendees on achievements, challenges and opportunities at their botanic gardens. The need for the creation of a South American Botanic Garden Network was agreed by participants, and an action plan to be implemented by the attendees was drafted.

BGCI's PlantSnap Initiative

BGCI has partnered with PlantSnap on the creation of possibly the most comprehensive database of plant photos and geolocational data in the world. PlantSnap is the most technologically advanced, comprehensive and accurate plant identification app ever created. It gives you a whole new way to explore the natural world in your everyday life. BGCI has partnered with PlantSnap so that our member gardens can offer the app to their visitors. Let's empower garden visitors worldwide to become citizen scientists in their own communities.

How do you get involved?

1. Let us know you're interested by sending an email to plantsnap@bgci.org.
2. Update your plant list in PlantSearch.
3. We'll send an agreement for you to sign.
4. We'll do a video call with key people from your team, helping you get a plan together to introduce PlantSnap at your garden.
5. We'll send a set of marketing materials you can easily customise including a download link connected to the initiative.
6. We'll help you launch the app at your garden.
7. Every month you'll receive demographic data of all visitors to your garden who download the app, along with all plant images (fully verified and identified) taken by your visitors.
8. You'll get ongoing marketing tips to help ensure the success of the app at your garden.

PlantSnap

Author: Chris Malumphy

BUG HUNTING TALES

RECORDING INVASIVE ALIEN PLANT PESTS IN MONTSERRAT, WEST INDIES

Soufrière Hills, Montserrat, West Indies

Montserrat

Montserrat is one of five UK Overseas Territories (UKOTs) in the Caribbean. The others are Anguilla, British Virgin Islands, Cayman Islands and the Turks and Caicos Islands. These are former British colonies that have retained their British citizenship and remain part of the United Kingdom. Montserrat forms part of a chain of islands known as the Lesser Antilles in the eastern Caribbean Sea on the boundary with the Atlantic Ocean. It is a relatively small island, 16 km long and 11 km wide, and consists of a mountainous interior surrounded by a flatter littoral region. It is nicknamed "The Emerald Isle of the Caribbean" both for its resemblance to coastal Ireland and for the Irish ancestry of many of its inhabitants. In 1995, the previously dormant Soufrière Hills volcano became active and an exclusion zone has been imposed over the southern half of the island because of the size of the existing volcanic dome and the risk of pyroclastic activity. Montserrat has many unspoiled natural landscapes, due in part to a small human population (about 5,000), low number of tourists, little development compared with most other Caribbean islands, rugged mountainous terrain, and restricted access to half the island. Consequently, it supports a diverse range of unique ecosystems and habitats that sustain many rare and threatened plant and animal species. The invertebrate fauna is particularly rich, and it is estimated that 120 invertebrate species are endemic to Montserrat. Many of these are highly vulnerable to the introduction of invasive alien species which have the potential to negatively impact biodiversity, the economy and human health on the island.

Impact of Invasive Alien Species to the Caribbean UKOTs

Invasive alien species are a major cause of biodiversity loss globally and their impacts are often most severe on island ecosystems. Island species or populations are often more vulnerable because of their previous isolation from predators, diseases or competitors. There have been some recent catastrophic declines of native plants in the Caribbean UKOTs which are directly attributable to the introduction of invasive species. For example, the introduction of pine tortoise scale (*Toumeyella parvicornis*) has resulted in the 90-95% decline of the dominant tree species, Caicos pine (*Pinus caribaea* var. *bahamensis*), in parts of the Turks and Caicos Islands. The Caicos pine is the foundation species of the pine yard habitat, a globally endangered ecosystem on which many other plants, birds, reptiles, and insects depend.

The remains of a Pinus caribaea *forest in the Turks and Caicos Islands, devastated by pine tortoise scale*

The endemic century plant (*Agave missionum*) has been almost wiped out from most areas of the British Virgin Islands following the introduction of the agave snout weevil (*Scyphophorus acupunctatus*). A UKOT team from the Royal Botanic Gardens, Kew have been working in collaboration with national government bodies and other specialists to ensure the survival of these plants and ecosystems.

It is not only biodiversity that is affected, the economy and human health can also be seriously impacted by invasive alien species. The Asian pink hibiscus mealybug (*Maconellicoccus hirsutus*), which feeds on more than 330 plant species, was introduced to the Caribbean in the 1990s and caused huge economic losses until it was managed by the introduction of a parasitic wasp and ladybird. Human health can clearly be affected by the introduction of mosquitos and the diseases they vector.

Biosecurity and Entomology workshop in Montserrat

A workshop organised by Jill Key of the GB Non-Native Species Secretariat, the Government of Montserrat and the author, with financial support from the UK Government Conflict, Stability and Security Fund was held in November 2019 to help strengthen biosecurity and protect their agriculture and natural environments. The workshop included field visits to 'backyard farms' to look for potential plant pests with staff from the Ministry of Agriculture, Lands, Housing and the Environment, and other workshop delegates. A huge range of edible plants are grown on Montserrat and in the past, the country even exported fruit and vegetables to neighbouring islands. Currently, the most productive agricultural land is no longer available as it occurs in the exclusion zone. We were fortunate to have some highly experienced extension workers, Elvis Gerald and Bernitta Serrant, show us some of their current agricultural problems. Training was provided to enable identification of the main groups of invertebrate plant pest and to diagnose plant damage. This capacity building will assist with detection of new pests. This is important as early detection and identification of invasive alien species can enable effective and appropriate measures to be taken in a timely manner to eradicate, contain and/or manage the pests.

Field work results

More than 300 observations were made of invertebrates in Montserrat between 8th-16th November 2019. More than 150 invertebrate species assigned to 4 classes, 14 orders and 43 families were recorded. Several species await identification (scale insects and whitefly need to be slide-mounted), so the number of taxa recorded will increase. Approximately 30 species, including several invasive alien pests, were recorded for the first time from Montserrat. One of the most significant pests detected was the Asian citrus psyllid (*Diaphorina citri*), which vectors the motile bacterium, *Candidatus Liberibacter* spp., causing Citrus greening or Huánglóngbìng. This is one of the most important pests of citrus worldwide. The disease was first detected in Florida in 2005 and within three years, it had spread to the majority of citrus farms, and devastated commercial citrus production. Seychelles scale (*Icerya seychellarum*) is a conspicuous pest as its body is covered with white and yellow wax. It was observed to be widespread on crops (avocado, breadfruit, citrus, guava and mango), ornamentals (palms), and more worryingly, on native plants in the Centre Hills (birch or copper wood and manceypot). Large populations cover the host plants with egested honeydew which provides a medium for the growth of black sooty moulds, thereby reducing photosynthesis and gas exchange. Another recent introduction is the croton scale (*Phalacrococcus howertoni*) which was observed causing significant damage to ornamentals (croton) and crops (mango, avocado, soursop and sugar apple). This species is spreading rapidly across the Caribbean and will kill croton plants if it is not managed.

The feeding damage of Lachnopus *weevil (shown above) to Citrus*

Some of the plant pests are host specific such as the avocado lace bug (*Pseudacysta perseae*), cassava scale (*Aonidimytilus albus*), fig whitefly (*Singhiella simplex*) and white cedar thrips (*Holopothrips tabebuia*); there are no prizes for guessing their host plants. While others are polyphagous (feeding on many different plant species), for example, a black weevil (*Lachnopus* sp.) was found causing serious damage to the foliage of many woody plants including avocado and citrus. There are at least 67 species of *Lachnopus* weevil recorded from the Caribbean, many of which are endemic to specific islands. Another example of a polyphagous pest is the coconut mealybug (*Nipaecoccus nipae*) which was common on coconut, various ornamental palms and guava. The most spectacular pest population observed consisted of about 50 giant Tetrio sphinx (*Pseudosphinx tetrio*) caterpillars (called worms in the Caribbean), each up to 15 cm long with striking black and yellow striped bodies, completely defoliating the new growth on several frangipani plants.

Although many of the pests were abundant, there were also large numbers of beneficial predatory insects including ladybird beetles (ladybugs in the Caribbean), lacewing larvae, assassin bugs, social wasps, ants and hoverfly larvae. In addition, many of the scale insects, whiteflies and psyllids were parasitized by chalcid wasps.

Some useful lessons were learnt by the delegates carrying out the field work including: be careful when turning over large leaves as there may be a Jack Spaniard wasp (*Polistes crinitus*) nest attached to the underside. The adults are very aggressive when guarding their nests, and won't hesitate to sting; be careful walking over grassy and disturbed areas as the red imported fire ant (*Solenopsis invicta*) nests are common and are also very aggressive; and high-heeled shoes are not suitable for field work (it wasn't me wearing them).

A typical 'Backyard' farm in Brades illustrating the wide variety of vegetable crops and fruit trees that are commonly grown in Montserrat

The largest and most interesting invertebrate observed was the endemic Montserrat tarantula (*Cyrtopholis femoralis*). It was found climbing a window at a hotel behind Jill Key while she ate breakfast. She calmly rescued the giant spider by encouraging it to walk onto a large seed pod and placing it safely in the hotel garden, while an audience of hotel guests watched in admiration.

My last observation on working in Montserrat is that they have some of the loudest tree frogs croaking in the evening that I have ever heard. I love the sound, but others might need ear plugs to sleep.

Seychelles scale on mango

Jack Spaniard wasp

Conclusion

The workshop was a great success with excellent participation by the delegates and a remarkable number of plant pests recorded over a brief period, largely due to local expertise. This baseline data is essential to be able to monitor any future changes in the fauna due to trade, tourism and climate change.

Invasive alien species can have a huge impact on biodiversity, economy and human health and islands are particularly vulnerable. The biodiversity and unspoiled habitats in Montserrat are globally important and need protecting. This process is ongoing and Montserrat has recently participated in a UKOT Horizon Scanning workshop to identify priority pest threats (run by the Centre for Ecology & Hydrology, part of the GBNNSS project '*Tackling invasive non-native species in the UK Overseas Territories*', funded by UK Government Conflict, Stability and Security Fund); and it has developed Pathway Action Plans to mitigate the risks.

Finally, I would like to express my gratitude to Jill Key (GBNNSS), staff from the Ministry of Agriculture, Lands, Housing and the Environment, and all the other delegates who attended the workshop. I was deeply impressed by their eagerness to participate, learn and actively 'hunt bugs' in the field.

All images credited to the author

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FEATURED GARDEN
BOTANICAL GARDEN "JEVREMOVAC", BELGRADE, SERBIA

The Japanese Garden at the Botanical Garden 'Jevremovac', Belgrade (Kate Marfleet)

The first botanical garden in Serbia was founded in Belgrade in 1874, affiliated to the Great School. It was established at the proposal of Josif Pančić, the destinguished Serbian botanist and naturalist, and by the decree of the Ministry of Education of the Principality of Serbia. Its first director was Josif Pančić, Professor of Natural Sciences, who was developing a small botanical garden in the schoolyard, even before the official garden was established, for teaching and education activities. The first location for the garden, along the banks of the Danube, was not suitable because of the possibility of flooding, which did actually happen twice. The two great floods destroyed almost the entire plant collection and Professor Pančić kept trying to find a better place for the Garden. Unfortunately, the great scientist died in 1888, without having solved the problem of the location of the Garden.

Knowing of Pančić's problems, in 1889 King Milan Obrenović donated his estate, inherited from his grandfather Master Jevrem, to the Great School, for a botanical garden, under one condition – the Garden should be named after the King's grandfather – *Jevremovac*.

Collections inside the glasshouse of the Botanical Garden (Kate Marfleet)

Soon after the transfer of the Garden to the new location, in 1892 the first greenhouse was bought in Dresden, from the firm *Monzentin*, and established in the Garden. It was one of the largest and most beautiful greenhouses in the Balkans.

In the decades to come, the Garden was developed, reaching its peak in the 1930s, under the guidance and leadership of the revered botanist and academic Nedeljko Košanin.

The Botanical Garden *Jevremovac* is today associated with the Institute of Botany. It is the teaching and scientific unit of the Faculty of Biology at the University of Belgrade, where over 1,200 students of regular and doctoral studies attend lectures dealing with algology, mycology and lichenology, microbiology, morphology and plant systematic, plant physiology as well as plant ecology and geography.

Teaching and scientific activities are realized through numerous projects and courses:

- plant and fungi taxonomic studies;
- floristic and phytogeographic studies of plant species of Serbia and the Balkans;
- ecology of plant species and communities;
- studies of microorganisms and plants as bioindicators of the environmental state;
- development of microbiological assays for the detection of genetic damage caused by environmental agents;
- identification of plant constiuents with antimutagenic/anticancerous properties;
- fundamental studies in plant physiology;

Ramonda nathalie Pančić & Petrović herbarium specimen from the Herbarium pancicianum (Snezana Vukojicic)

- plant propagation by tissue culture with special emphasis placed on the conservation of Serbian flora;
- protection of rare and endangered plants of Serbia and the Balkan Peninsula.

The Garden spreads over 5 ha, with about 2,200 native, European and exotic species of trees, shrubs and herbaceous plants. It also includes two important collections – the Library and the Herbarium.

The Library

Founded in 1853 at the Department of Natural Sciences, the Library is one of the oldest and richest botanical libraries in the region of southeastern Europe, with more than 7,000 books. In its collection, there are many precious old, rare and exclusive editions.

The glasshouse was renovated and reopened for the visitors in 2014. Thanks to the financial support of the European Union (Mira Fiskalović)

The oldest book in the library is The Natural History (*L' Histoire du Monde*) by Pline the Elder, ancient Roman author and natural philosopher from the 1st century. Our copy is an old French translation, printed in Lyon in 1562. It is a luxurious edition, with leather binding, richly gold-tooled, with gilt edges.

The Herbarium

The Herbarium was established in 1860 by Professor Pančić, and today it is one of the oldest and richest in the region, with 200,000 sheets and over 300,000 samples of Balkan, European and world flora. The most precious segment is the personal herbarium of Josif Pančić, known as *Herbarium pancicianum*, consisting of 16,000 herbarium sheets.

The work of the garden

One the most important roles of botanical gardens nowdays is to participate in the protection and conservation of endangered plant species and the wider environment, through the education of both children and the adults, and actively through diverse projects.

Ramonda nathalie Pančić & Petrović – example in ex situ *conservation in the Botanical Garden* (Snezana Vukojicic)

The garden is involved in the *ex-situ* protection of threatened plant species, covering about 20% of the total of 330 internationally significant and critically endangered plant species of Serbian vascular flora. Plants which cannot be easily grown *ex-situ*, are subjected to a special programme of tissue culture, by which hundreds of individuals are developed from a single plant and made ready to be reintroduced back into nature.

Collections inside the glasshouse of the Botanical Garden (Kate Marfleet)

The Parliament of the Republic of Serbia pronounced the Botanical Garden *Jevremovac* as a Natural Monument in 1995, due to its floristic richness and diversity. By this act the goverment undertook the responsibility for its protection and development and put the whole area of the Garden under a special regime. In 2007 the Garden was also pronounced a Monument of Culture, due to its exceptional historical and cultural heritage.

In 2017 the Garden become a member of BGCI. BGCI membership allows us not only to expand our knowledge and experience, but also to enrich our existing collections, create new ones and work on species conservation to preserve them for future generations.

In September 2019 we celebrated 130 years of work and existence of the Botanical Garden *Jevremovac* and on that occasion we hosted representatives of the botanical gardens in neighboring countries as well as representatives of BGCI.

As well as being a green oasis in the centre of the capital city of the Republic of Serbia, the Garden is a center of botanical research, a monument of both nature and culture and an extraordinary stage for diverse cultural manifestations, exhibitions, concerts, theatrical plays, ballet performances and multicultural events and spectacles.

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INTERVIEW
TALKING PLANTS

For this issue of *BGjournal*, with our focus on plant health, we spoke to **Professor Nicola Spence**, Chief Plant Health Officer at the Department for Environment, Food and Rural Affairs, UK about the International Year of Plant Health.

Can you tell us a bit about the IYPH and what it will involve?

International Year of Plant Health (IYPH) in 2020 is a once in a lifetime opportunity to raise global awareness on how protecting plant health can help end hunger, reduce poverty, protect the environment, and boost economic development. Events are being organised around the world to celebrate IYPH and to highlight the vital role of national and regional plant health organisations in protecting plants from damaging pests and diseases.

UK events are being coordinated by a small team in the Department for Environment Food and Rural Affairs (Defra) alongside partners with an interest in plant health. The UK focus of IYPH will centre around a new national Plant Health Week, taking place from 20th to 27th April 2020, and encompassing World Earth Day. It is hoped that this will become an annual event thereafter, acting as a legacy of IYPH.

A number of conferences, workshops, science outreach events and social media campaigns are planned for IYPH 2020. Defra's Plant Health Portal website will provide further information on plans for IYPH in the UK.

Is there anything our members can do to contribute/join in with IYPH?

You do not have to specialise in plant pathology to get involved with the IYPH 2020 and share its messages. The Food and Agriculture Organisation of the United Nations (FAO) and the International Plant Protection Convention (IPPC) have produced a 'getting started' guide, available on their dedicated IYPH website. The website has lots of information about events being organised around the world, and how people can get involved. Some suggestions include making a #Plant Health commitment and sharing this on social media, including messages about plant health in outreach activities for children and members of the public, or organising your own IYPH event such as a concert, festival or tree planting event. One easy way to share the message of the IYPH is to update your web page with the IYPH button and link it to the IYPH 2020 website.

Why do you think botanic gardens are important in terms of plant health?

Botanic gardens and arboreta are in a unique position to engage and enthuse their visitors about the importance of practising good biosecurity. Many of these visitors will be plant enthusiasts and keen gardeners, therefore being the ideal audience for messages about plant health. Botanic gardens are able to set standards for the responsible sourcing of planting material, and many have been making a real effort to drive up standards in biosecurity in recent years. Additionally, botanic gardens can join BGCI's International Plant Sentinel Network (IPSN), allowing their specimen collections to act as sentinels. Exotic plant species in certain gardens can be used to predict which organisms are likely to pose a threat in the sentinel's native range in the future. The IPSN aims for institutes to work together in order to provide an early warning system of new and emerging pest and pathogen risks.

Why should we be worried about plant health?

Plants make up 80 percent of the food we eat, and produce 98 percent of the oxygen we breathe. Yet, they face continuous and increasing threat from pests and diseases on a global scale. Moreover, international travel and trade has tripled in volume in the last decade and can quickly spread pests and diseases globally causing great damage to native plants and the environment.

Every year, up to 40 percent of global food crops are lost to plant pests and diseases. However, as the global population continues to rise, and as many nations become richer, it is predicted that agricultural production must rise by 60 percent by 2050 in order to feed everyone. It is therefore vitally important that we protect our plant and tree ecosystem from anything that can diminish its health, damage our landscape and impact the economy.

Barney Wilczak

What do you think the most important aspect of plant health will be for the next 5 years?

Encouraging companies and individuals to source plants and plant products responsibly will be key to ensuring high levels of biosecurity in the future. The expansion of e-commerce in recent years has made it easier for many commodities to be rapidly sold and distributed across the world, including products potentially posing a risk to plant health. These products are not always detected by national plant protection organisations as they are sent in small quantities and are not always correctly labelled. For example, seeds, which very often carry damaging viruses, can be easily bought online and it is not always clear where these seeds originate or where they will be shipped from.

By purchasing trees, plants and seeds from reputable nurseries and suppliers, and checking the product's origin, you can be satisfied that these products have been responsibly sourced and undergone the necessary checks to ensure that they are of high health status.

What are some easy things people can do to support plant health?

One of the most effective ways in which people can support good biosecurity is to avoid bringing any plants or seeds, flowers, fruit or vegetables across borders after travelling abroad, as highlighted by the recent "Don't Risk It" campaign, jointly run by the Animal and Plant Health Agency (APHA) and Defra. Pests and diseases can be present on plants, seeds, flowers, fruit and vegetables, even if they look healthy, and on soil clinging to the roots of plants or on plant products, like root vegetables.

By not bringing in any plant material, everyone can play their part, alongside the actions of government and industry, by avoiding, unwittingly, bringing back something which may be infested or diseased.

One other simple measure that people can take to support plant health is to brush mud off footwear, bikes and buggies after visiting woodlands and parks. This can prevent the spread of potentially damaging pest and diseases that can be present in mud, water and leaves in outdoor environments.

What do you think are the top threats to global plant health?

Maintaining plant health in a changing climate is likely to become a global problem and the long-term effects of climate change on our crops and natural environments are unknown. Climate change is likely to influence the occurrence, prevalence, and severity of many plant pests and diseases, affecting which crops are grown and how they are managed. A major goal will be to protect, manage and restore terrestrial and marine environments to make them more resilient to the pressures of a changing climate.

Countries may have to adapt to changing climates by diversifying the crops grown and the different species planted in the natural environment, whilst following strict biosecurity measures to help protect our landscapes from climate change, pests and diseases.

Hyperlinks

World Earth Day - https://www.earthday.org/

Defra's Plant Health Portal (IYPH page) - https://planthealthportal.defra.gov.uk/international-year-of-plant-health-2020/

FAO IYPH 'getting started' guide - http://www.fao.org/documents/card/en/c/ca5188en

IPSN - https://www.plantsentinel.org/

"Don't Risk It" - https://www.gov.uk/government/news/public-urged-not-to-bring-plant-pests-and-disease-into-the-uk

ARTICLES

Authors: Kate Marfleet and Suzanne Sharrock

THE INTERNATIONAL PLANT SENTINEL NETWORK

Agrilus planipennis *(emerald ash borer); adult, an extreme close-up of the head capsule, showing all facial details. A specimen from Maryland, USA (Public Domain - Released by the United States Geological Survey (USGS)/USGS Bee Inventory and Monitoring Lab., Beltsville, Maryland, USA/via flickr)*

Background

Plant pests and pathogens (referred to collectively as 'pests'[1]) present a significant risk to global plant health and this threat is constantly evolving and increasing due to the growing global trade of plant material and the impacts of climate change. A key issue in tackling this threat is identifying future potential plant health risks. The majority of serious invasive alien species are often not pests in their region of origin and are therefore not monitored. For example, the case of Chestnut Blight (*Cryphonectria parasitica)* which was accidentally introduced into the USA and devastated sweet chestnut forests there in the first half of the twentieth century, despite being relatively harmless in Asia where it originated (Anagnostakis, 1987). For this reason the majority of the most damaging alien pests that have or have had a dramatic impact on temperate forests would not have been predicted as pests by conventional methods for assessing plant health risks. Predicting which pests are likely to become an issue in the future is one of the greatest challenges in protecting global plant health.

Sentinel plants can provide a way to address this issue. They are individuals maintained outside of their native range and which can be monitored for attack by pests and diseases which they wouldn't normally encounter. Botanic gardens and arboreta (BG&A) are a unique resource in sentinel research for a number of reasons. They provide an incomparable source of curated plant specimens from a range of native and non-native species – often with known provenance. It is estimated that 30% of known plant species are growing in the living collections of BG&As, throughout the world (Mounce *et al*., 2017). Furthermore they employ knowledgeable, experienced and enthusiastic people,

[1] Pest: Any species, strain or biotype of plant, animal or pathogenic agent injurious to plants or plant products

Impacts of Polyphagous Shot Hole Borer

sometimes with access to diagnostic capabilities; they have strong professional international connections; and they have access to informative international databases. Monitoring these sentinel plants for damage by pests and pathogens not yet present in their native countries can provide vital information on potential future pest threats (Mansfield, 2019).

The international network

The International Plant Sentinel Network (IPSN) was established by BGCI in 2013. The main objective of the IPSN is to act as an early warning system, identifying new and emerging pest risks. It aims to do this by developing a network of interested BG&A around the world, linked to plant protection scientists and National Plant Protection Organisations (NPPOs). The network presently (January 2020) includes 56 members located in 18 countries around the world (www.plantsentinel.org). These gardens provide a first point-of-contact for information on specific plant - pest associations and are willing to carry out surveys as requested by member countries. The network acts on a reciprocal basis, with gardens, in association with their NPPO, both providing and requesting information on the impacts of pests and pathogens on specific host species growing outside their native ranges and therefore exposed to pests and pathogens they wouldn't usually encounter.

The network focuses on three main objectives:

1. **Building capacity for the early detection of new and emerging pests and diseases**, including known and unknown organisms. BGCI, through the IPSN is raising awareness of plant health issues amongst botanic gardens and arboreta (for first detection) and providing tools, such as posters and leaflets to aid early detection. Further, BGCI is working to build capability and capacity in botanic gardens and arboreta to support surveillance; encouraging monitoring for unknown threats, as well as known. The IPSN provides training to staff in botanic gardens and arboreta and develops materials to aid surveys and build knowledge.

2. **Supporting Pest Risk Analysis** (PRAs) through research coordination and evidence gathering to address knowledge gaps to support PRA activities. This includes identifying research priorities from NPPOs and RPPOs and coordinating access to trusted botanic gardens and arboreta data, as well as coordinating the activities of research partners, evaluation and data sharing. Using BGCI's unique databases, and within the limitation of data use agreements, the project can produce maps showing the location of host species in gardens and pests present. Such maps are of value in PRAs and in prioritisation of the project's activities. It also involves energising participation and identifying research funding. This includes the coordination of multi-country surveys for priority organisms and host species using relevant botanic gardens and arboreta (in specific countries/regions with particular host species) identified using BGCI's unique databases. A research survey to identify hosts of the meadow spittlebug which transmits the *Xylella* pathogen was carried out in 2017 and a report of the results has been published. Further details of our research to support PRAs in the UK, as identified by an IPSN Research and Development committee, are provided in the article by Lane and Stevens (p. 21-23) and some results of our research projects are described below.

3. **Enhancing and expanding the network**. The IPSN has been supported since 2013 by the UK's Department for the Environment, Food and Rural Affairs (Defra) as a Euphresco (European Phytosanitary Research Coordination) project. Euphresco is a network of organisations funding research projects and coordinating national research in the phytosanitary area. Phase 2 of the IPSN was accepted as a three-year Euphresco project in 2017, with BGCI providing the coordination.

Euphresco

While the IPSN is at its heart a network of BG&As, the Euphresco partners have expanded the network to include a broader range of research partners, all contributing to sentinel research. By working together, the partners provide access to an expanded pool of expertise, diagnostic services and funding. Supported by BGCI, Euphresco partners are helping to establish participation from and strong links to botanic gardens and arboreta within their own (and potentially neighbouring) countries.

A number of articles in this issue provide reports on the activities of these Euphresco partners (See Ronse *et al*. p. 24-26; Franić *et al*. p. 30-32 and Starfinger p. 37-39). See Table 1 for a full list of Euphresco partners.

Recent research activities:

As described in the article by Lane and Stevens (p. 21-23), in 2018, the IPSN UK Research and Development committee identified three priority topics for further research to support PRAs. These topics were selected on the basis of evidence gaps, suitability for research by BG&A and potential for international participation and collaboration. The research projects commenced in 2019.

The pests identified were:

Gold spotted oak borer (*Agrilus auroguttatus*), Two Lined Chestnut Borer (*Agrilus bilineatus*) and Polyphagous Shot Hole Borer (*Euwallacea whitfordiodendrus*) on European *Quercus* spp. These three wood-boring beetle pests have been shown to cause significant damage to native US oak species. All three pests have caused severe economic and environmental damage in the US, however their impact on European oak species is so far undocumented. The IPSN is therefore carrying out a survey of European oak species in US botanic gardens to gain a better understanding of the impact of these pests on European oak in order to inform the UK risk register.

Institute	Acronym	Contact	Activity
BGCI	BGCI	Katherine O'Donnell / Kate Marfleet / Suzanne Sharrock	• Coordination, capacity building, dissemination.
Core Facility Botanical Garden, Faculty for Life Sciences, University of Vienna, Austria	UNIVIE	Michael Kiehn	• Test options and identify problems for the detection and identification of potential pests and invasive organisms. • Bringing the Austrian network of botanical gardens into the project.
Agentschap Plantentuin Meise, Belgium	APM	Anne Ronse	• Surveys and identification of emerging pests and selected pest organisms in Belgian Botanic Gardens and Arboreta, including laboratory testing by using molecular methods. • Face-to-face workshops for training garden staff and providing key networking opportunities. • Elaboration of a Belgian Plant Sentinel Network, integrated into the IPSN.
Central Institute for Supervising and Testing in Agriculture, Czech Republic	UKZUZ	Vladislav Rasovsky	• Raising awareness of new phytosanitary risks. • Developing a link between botanical gardens and diagnostic labs for diagnosis of new pests, incl. a simple tool for this communication. • Surveys and monitoring of new and emerging pests in arboreta and botanical gardens in the Czech territory.
Julius Kuehn Institute, Federal Research Centre for Cultivated Plants, Germany	JKI	Uwe Starfinger	• Further elaborate the 'trap plant approach' by refining protocols for choosing plant species, for planting and for assessing damage.
Consiglio per la ricerca in agricoltura e l'analisi dell'economia agrarian, Italy	CREA	Elisabetta Gargani / Sauro Simoni	• Provide Italian botanic gardens and arboreta with information about new and emerging threats or susceptible host species. • Contribution to training material related to arthropods and nematodes.
Royal Botanic Gardens Edinburgh, Scotland	RBGE	Katherine Hayden	• Risk assessment and sentinel research projects.
Animal Plant Health Inspection Service, USA	APHIS	Heather Hartzog / Heather Moylett	• Provide expertise in risk analysis, pest data information management, and official pest reporting requirements.
University of Tuscia-DIBAF, Italy	UNITUS	Anna Maria Vettraino	• Provide Italian botanic gardens and arboreta with information about new and emerging threats or susceptible host species. • Analysis of the structure of the fungal community of *Pinus* seeds from botanical gardens and/or arboreta in Europe and abroad.
Universitat de Lleida, Spain	UdL	Xavier Pons	• Surveys in the Lleida's Botanical Garden • Develop training material related to arthropods, and arthropod pest surveys in botanical gardens in its geographical area • Develop a Spanish Plant Sentinel Network.
Plant Health Australia	PHA	Greg Fraser	• Access to the Virtual co-ordination Centre to the IPSN for collation and management of data
University of Copenhagen, Denmark	UCPH	Hans Peter Ravn	• Provide an overview of knowledge on the fate of plants introduced to our botanical gardens and arboreta and identify specific information regarding establishment • Provide a list of native tree species for monitoring overseas.
AgResearch Limited, New Zealand	B3	Mark McNeill	• Identify overseas gardens and arboreta with New Zealand native plants. • NZ sentinel plants located in "hotspots" where severe plant pathogen or pest outbreaks are occurring. • Data on pest and pathogen incidence and impact from sentinel plant locations collected, collated and analysed. • Coordinate and facilitate links with Chinese researchers and botanic gardens. • Work with Chinese collaborators to access information published in Chinese of value to NZ biosecurity and conservation authorities. • Develop a project for one or more Chinese –speaking students who could work in a reciprocal way to survey and identify plant pests and conduct research projects.
Swedish University of Agricultural Sciences, Sweden	SLU	Jonàs Oliva	• Provide expertise in monitoring tree pathogens by the use of molecular methods.
CABI (CH), Switzerland		René Eschen	• Database of pests and pathogens on selected tree species in botanical gardens, across Europe and continents. • Identify number of trees and locations (i.e. botanical gardens) that should be included in surveys to obtain a representative overview of pests on a tree species.

Table 1 provides a list of the partners included in the IPSN Euphresco project and their key activities.

Rose rosette virus (RRV) on *Rosa* spp. RRV is an emerging risk to rose cultivation. For more information, see the article by Franić *et al* in this issue (p. 30-32). The IPSN is conducting a global survey of rose collections in botanic gardens to assess the distribution of RRV outside of the known distribution area and establish whether the finding in India was an isolated case.

Ash Dieback (*Hymenoscyphus fraxineus*) and Emerald Ash Borer (*Agrilus plannipennis*) on *Chionanthus* and *Phillyrea* spp. Ash Dieback is responsible for causing severe dieback on ash species across Europe (including *Fraxinus excelsior* and *F. angustifolia*). Recently, *H. fraxineus* has been detected on the non-*Fraxinus* hosts *Phillyrea latifolia*, *P. angustifolia* and *Chionanthus virginicus* in isolated locations where *H. fraxineus* spore levels were high (Forest Research, 2019). This finding is the first non-ash host record worldwide. The Emerald Ash Borer is a wood-boring beetle native to East Asia which is currently causing significant damage to *Fraxinus* spp. in the USA and Canada. In combination, these two threats are a serious concern for European ash populations and the increased spread of these through non-*Fraxinus* hosts is extremely concerning (Hill, 2018). The IPSN is therefore conducting a survey to assess whether any further findings of Ash Dieback on *Phillyrea* and *Chionanthus* spp. and Emerald Ash Borer on *Chionanthus virginicus* have been recorded.

For each pest the main stages of the research project involved:

1. Mapping pest distribution against BG&A with host species of interest to identify target gardens
2. Developing survey resources – posters, survey materials and reporting mechanisms
3. Contacting BG&A and issuing survey resources
4. Compiling results and submitting a preliminary report of our findings to UK Risk Register scientists.

Results:

***Quercus* sp. survey:** In total, 26 BG&A in the USA were contacted – 13 from California and 40 from the East Coast. Survey forms were completed by 10 Californian gardens and 4 East Coast gardens (though the East Coast Surveys are still in progress). Of the three target pest species, only PSHB was recorded. It was found at four of the survey sites and was shown to infest: *Q. ilex*, *Q. robur* and *Q. suber*. An additional two gardens may have had either PSHB or the closely related and indistinguishable Kuroshio shot hole borer (KSHB) *Euwallacea kuroshio*.

***Rosa* sp. survey:** Survey forms and posters were sent to a large number of gardens across Europe, Australia and New Zealand. With the help of national network coordinators, there was the potential for over 700 gardens to have been contacted. So far 23 gardens have conducted surveys and none have found symptoms of RRV in their collections.

***Chionanthus* and *Phillyrea* sp. survey:** A total of 93 BG&A were contacted with the survey form and poster for these pests. To date, 12 completed survey forms have been returned and a number of gardens said they would participate but cannot provide results until later in the year.

Conclusion:

The oak pest most likely to establish in Europe is PSHB with significant infection found on *Q. robur* and *Q. suber*, both of which are of high ecological, cultural and commercial significance. For the RRV and Ash surveys, we believe more time and follow-up will result in more surveys being completed. The work conducted to date will allow us to continue to collect data and feed this into PRA's.

The plant collections of BG&A around the world are an important resource, being used to support research, conservation and education activities. In relation to plant health issues, monitoring plants growing outside their native regions provides a valuable opportunity to increase our knowledge of new pest-host relationships. While the IPSN aims to build on this and develop a global community of BG&A focused on plant health issues, it is also clear that many botanic gardens are under-resourced and lack the required expertise to carry out regular pest and disease monitoring and surveying. However, as a networking organisation, BGCI firmly believes that these challenges can be overcome through working together and sharing experiences and information. We encourage interested gardens to consider joining the IPSN and becoming part of our global effort to reduce the risk alien invasive pests pose to our native floras.


The Plant Health Checker (Kate Marfleet)

Acknowledgments

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WHAT ROLE CAN BOTANIC GARDENS AND ARBORETA PLAY IN UNDERSTANDING THE RISK THAT HARMFUL ORGANISMS POSE TO PLANT HEALTH?

Introduction

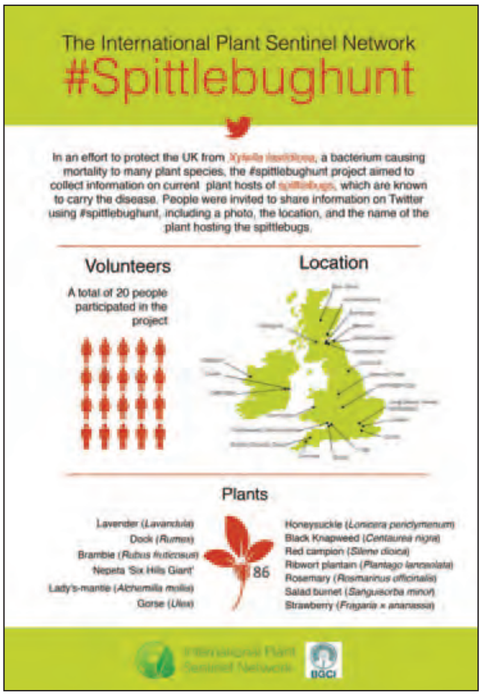
Protecting the health of plants is a difficult business; yet, through implementing good plant biosecurity and international collaboration it is possible to mitigate against these risks. However, although we now all refer to plant biosecurity what does it mean? Plant biosecurity can be defined as: '*a series of precautions that aim to prevent the introduction and spread of harmful organisms*'. This definition not only refers to introduction and spread but also 'harmful organisms'. Yet, with so many organisms living in association with plants, we need to identify which of these should be considered as harmful (also referred to as a pest – including both insects and pathogens) and able to threaten the health of a plant collection and of these, which may require regulatory plant health action?

The World Trade Organization (WTO) agreement on Sanitary and Phytosanitary Measures (SPS) provides the framework for international plant health arrangements. Phytosanitary measures must be based on scientific principles using pest risk analysis (PRA) and based on international standards. These International Standards on Phytosanitary Measures (ISPM) are produced by the International Plant Protection Convention (IPPC); many of these standards provide the basic principles of phytosanitary measures (e.g. ISPM 11: Pest risk analysis for regulated quarantine pests) or more practical advice concerning the international movement of plants, plant products or vehicles, machinery and equipment (e.g. ISPM 15: regulation of wood packaging material in international trade).

Pest risk analysis (PRA) is defined as: '*the process of evaluating biological or other scientific and economic evidence to determine whether an organism is a pest, whether it should be regulated, and the strength of any phytosanitary measures to be taken against it*' (ISPM 5; Glossary). This systematic process includes an evaluation of hosts and pathways of introduction and spread; life-cycle of the pest; it's epidemiology and sources of infestation, and determine the relative economic, environmental and social impacts of any introductions. Inevitably, there will always be areas of uncertainty in the assessment, as scientific evidence may not be available at the time of assessment. This is particularly pertinent when dealing with new or emerging plant pests or pathogens. The PRA will also include an assessment of pest risk management options - again a lack of scientific knowledge will result in levels of uncertainty.

Research and emerging threats

A key role of the International Plant Sentinel Network (IPSN) is to gather information to fill PRA evidence gaps. In the UK, research priorities that could be addressed by the IPSN are identified by an R&D committee comprised of plant health scientists, plant health policymakers and staff from botanic gardens and arboreta (BG&A). The co-design of these research projects ensures they can be delivered by BG&A staff and that they meet policy aims. Potential targets for research are drawn from the UK risk register, and other such pest risk databases (e.g. EPPO Alert) as well as information supplied by BGCI members.



The UK risk register (which now has more than a thousand entries) identifies a subset of pests that have a priority for research (approximately 40), but as a dynamic database, new pests are added on a regular basis providing further opportunities for research. Looking at these organisms, they include important plant pests and pathogens such as acute oak decline, *Sirococcus tsugae* and *Xylella fastidiosa*. The latter of these poses an interesting challenge for the IPSN. Possibly one of the most high-profile pathogens for many years and of great concern to BG&A, the diversity of symptoms does not lend itself well to BG&A-led research without diagnostic support. The general scorching dieback of a wide range of plant material could be easily confused with many other pests or pathogens, but also common cultural and environmental problems. However, the IPSN has played an important role in raising awareness about this disease to BG&A and was able to assist in gathering evidence to fill a knowledge gap concerning vector hosts in the UK.

A very successful social media-based survey #spittlebughunt collected valuable data from botanic gardens by asking participants to take pictures of the characteristic 'cuckoo spit' on any named plants in collections. Although simple, it was highly effective and provided vital information to help remove some of the uncertainty in the current PRA.

Other pests of concern, on a global scale, have included the brown marmorated stink bug (*Halyomorpha halys*), that is native to Asia, and has been accidentally introduced to other countries as a hitchhiker on containers, machinery and equipment. The bug is described as a major agricultural pest affecting a wide-range of crops, and causes further problems when they overwinter in large numbers (often in the thousands) in domestic and commercial structures. Colleagues in Australia and New Zealand, where the pest is of considerable concern, have been able to share their knowledge across the IPSN to help raise awareness against this pest. Our work on *Sirococcus* blight is another example of the IPSN's role in sharing information about new and emerging pests and diseases. *Sirococcos tsugae*, is a damaging fungal pathogen, that causes shoot blight and cankers on cedar trees (*Cedrus* spp.) and shoot blight on hemlock (*Tsuga* spp.), attacking both seedlings and saplings as well as mature trees. In the UK, it has caused major aesthetic damage to some iconic cedar trees in public and private gardens. Information about this pathogen has been shared with IPSN members to help raise awareness about this disease worldwide.

The IPSN R&D committee has identified three priorities for research working with BG&A around the world to gather valuable information to inform pest risk assessments. These are:

Rose plant showing symptoms of RRV (Ines Vasquez)

1. Determining the risk of non-Fraxinus hosts as a pathway of introduction for the Emerald Ash Borer and Ash Dieback

The Emerald Ash Borer is a wood-boring beetle native to East Asia, which is currently causing significant damage to *Fraxinus* spp. in the USA and Canada. With an estimated 100 million tree deaths being attributed to the pest which has resulted in serious economic damage as well as concern for the survival of several ash species and their associated biodiversity. The beetle was also recently recorded in a region of Moscow, Russia leading to serious concerns that it could spread to Europe. Emerald Ash Borer has also been shown to infest *Chionanthus virginicus* in Ohio, the first record of damage to a non-ash host.

Ash Dieback is responsible for causing severe dieback on ash species across Europe (including *Fraxinus excelsior* and *F. angustifolia*). It is caused by the invasive fungal pathogen *Hymenoscyphus fraxineus*, causing crown dieback, lesions and the eventual death of the tree. The disease was first detected in Poland, but originated from Asia, and has subsequently spread to most European countries. Recently, *H. fraxineus* has been detected in a UK Arboretum on the non-*Fraxinus* hosts *Phillyrea latifolia*, *P. angustifolia* and *Chionanthus virginicus* in isolated locations where *H. fraxineus* spore levels were high. This finding is the first non-ash host record worldwide.

The IPSN is therefore conducting a research project to assess whether there have been any further findings of both the Emerald Ash borer on *Chionanthus* spp. and Ash Dieback on *Phillyrea* and *Chionanthus* spp.

2. Understanding the distribution of Rose Rosette Virus to help identify introduction pathways

Rose Rosette Virus (RRV) is an emerging risk to rose cultivation (See p. 33-36). It is present throughout the US and Canada where it was described for the first time in the 1940s. In 2017, the virus was found in India, the first finding outside North America. RRV is transmitted by grafting and by the mite *Phyllocoptes fructiphilus*. The mites are transported by the wind, by insects during pollination, and by contact with clothes or gardening tools.

Quercus robur *(Pixabay)*

The symptoms include reddening of newly emerged shoots, excess lateral shoot growth and thorn production, rosetting or witches' broom, distortion of the leaves, malformations, mottling, and eventually plant death. Symptoms of the virus are variable and depend on the species or cultivar of rose affected, a diseased plant may only exhibit few of the above symptoms especially in the early stages of the disease.

3. Understanding the distribution and damage caused by three emerging pests to better understand the impact and threat to *Quercus* species:

Firstly, Goldspotted Oak Borer (GSOB), *Agrilus auroguttatus*, is a flat-headed buprestid (jewel beetle) that poses a major threat to oak trees. GSOB is native to south-eastern Arizona, but was first recorded in California in 2004. GSOB larvae feed beneath the bark damaging the xylem and phloem as well as the cambium. Trees die after several years of injury inflicted by multiple generations of the beetle, causing significant economic, ecological, cultural, and aesthetic losses. GSOB poses a severe threat to susceptible oak species throughout California and elsewhere if it spreads.

Secondly, Two Lined Chestnut Borer (TLCB), *Agrilus bilineatus*, is native to North America; adults are recognizable as dark coloured buprestids with two golden stripes running lengthwise along their back. Females lay eggs in bark cracks and crevices. Larvae burrow into the tree and form feeding galleries under the bark. These feeding galleries interrupt the transport of food and water in the phloem and eventually girdle individual branches or the entire tree. They cause similar damage to GSOB. Attacks occur in stressed or dying oak (primary hosts) and less frequently American chestnut. Live healthy trees are typically not infested. Attacks usually begin in the crown of the tree, with some branches dying in the first year. Infestations gradually worsen, and the trees usually die in the second or third year. Incidence of attack by two lined chestnut borer increases following stress such as drought or defoliation from other insect pests.

And finally, Polyphagous Shot Hole Borer (PSHB), *Euwallacea whitfordiodendrus*, is an invasive beetle that vectors three fungi in the genera: *Fusarium*, *Graphium* and *Paracremonium*. The adult female tunnels galleries into a wide variety of host trees, where it lays its eggs and inoculates the host with the fungi on which the beetle feeds. The Fusarium fungus causes a disease called Fusarium Dieback (FD), which interrupts the transport of water and nutrients in over 110 tree species, which can kill the tree. Experts believe the beetles were introduced into southern California via products and/or shipping material from Southeast Asia. The PSHB/FD complex has been found in other locations including Israel and South Africa.

Conclusions

Maintaining the health of a plant collection is a challenging task, balancing the needs to conserve the collection, whilst exchanging genetic material for conservation and allowing visitors into the collection. The movement of any plant material can be risky as it provides an opportunity for the introduction or spread of plant pests and pathogens into the collection. The same challenges are faced by national plant protection organisations trying to protect the plant health of the region whilst needing to import food, plants and plant products, and goods that may harbour pests. Phytosanitary regulations and controls are in place to mitigate against these risks and are heavily reliant on international agreement and collaboration. With scientific evidence concerning these harmful organisms being fundamental to pest risk assessment to determine an appropriate level of protection, there is a great thirst for knowledge. Research carried out in botanic gardens and arboreta is helping to fill these evidence gaps and reduce uncertainty in pest risk assessments.

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THE BELGIAN PLANT SENTINEL NETWORK

Practicing phytosanitary surveys with the PHC forms and taking samples in the botanical collections (BePSN)

Pest and disease surveys of Belgian botanic gardens and arboreta resulted in the first reports of two new tree pests in Belgium.

Introduction:

The Belgian Plant Sentinel Network project ran for two years (16 April 2017 to 15 April 2019) and was funded by the Belgian Federal Public Service for Health, Food Chain Safety and Environment. The official title was « *Belgian network and activities in the frame of the International Plant Sentinel Network (Euphresco-IPSN2): BePSN* ». The project was coordinated by A. Ronse, staff member of Meise BG (MBG, formerly called National Botanic Garden of Belgium). In 2016, she was contacted by ILVO (Flanders Research Institute for Agriculture, Fisheries and Food), partner of the National Reference Laboratory (NRL) for Plant Health, because of a call for a Belgian IPSN project. This was the starting point for the elaboration of a national project with the participation of several botanic gardens and arboreta (BG&A).

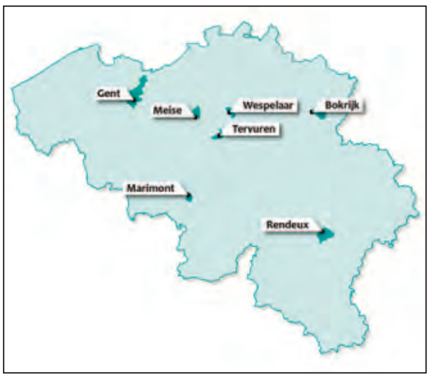


Fig. 1: Botanic gardens and arboreta participating in the BePSN project (BePSN)

Organization and objectives

The project partners were Meise BG (MBG), as coordinator, and the Belgian NRL, consisting of ILVO and CRA-W (Walloon Agricultural Research Center). In total, seven BG&A participated in the project, of which five were in Flanders and two in Wallonia (in the northern and the southern part of the country, respectively; see Fig. 1) :

- Agentschap Plantentuin Meise
- Plantentuin UGent
- Arboretum Bokrijk, Genk
- Arboretum Robert Lenoir, Rendeux
- Arboretum Wespelaar, Haacht
- Geografisch Arboretum van Tervuren
- Parc et arboretum de Mariemont, Morlanwez.

Furthermore, a Guidance Committee was established, composed of stakeholders as well as experts in the field.

The aims of the project were :

- the creation of a sustainable Belgian network of BG&A and diagnostic labs (NRL) for the survey and detection of invasive pests and emergent diseases;
- increasing the awareness and knowledge of staff from BG&A to (new) phytosanitary problems by trainings;
- to implement and validate the protocols and tools developed by the IPSN for the standardized data capture, and development / validation of tools for online data reporting.

These aims were translated into five work packages:. (1) the general coordination and management of the project, (2) capability and capacity building, (3) phytosanitary surveys in the botanical collections and taking samples, (4) the diagnostic research and analysis of the samples, and (5) outreach and dissemination.

The scope of the surveys was limited to test cases, consisting of selected pests and diseases on targeted plant species. They were specifically chosen with the aim of developing, testing and validating the activities and performance of the network. This focus on test cases was done because of the impossibility to survey all plants in the vast collections of the BG&A within the restricted time horizon of the project, and because the goal was not to generate large data sets.

Fig. 2a and 2b:Information leaflet about survey test case of the root-knot nematode Meloidogyne mali *(first page) (BePSN)*

To make this selection, we concentrated on topics and organisms:

- that were in line with the target organisms prioritized for IPSN2, yet adapted to the Belgian situation;
- with significant economic impact;
- for which limited background knowledge was available, but which may have a major impact on plant health;
- belonging to different taxonomic groups or disciplines: entomology, mycology, nematology, virology and bacteriology;
- involving tree species largely present in the outdoor collections;
- with varying degrees of specificity and novelty.

The following test cases were selected by the partners of the Belgian project :

1) Pine processionary moth *Thaumetopoea pityocampa* in conifers,
2) The fungus *Sirococcus tsugae* in cedars and hemlock (*Cedrus* spp., *Tsuga* spp.),
3) *Phytoplasma* and root-knot nematode occurrences in elm trees,
4) A general plant health survey on oaks (*Quercus* spp.).

They were discussed and approved at the International Plant Sentinel Network Workshop in Berlin on 10-13/10/2016, and were validated by the participating BG&A.

Activities and results

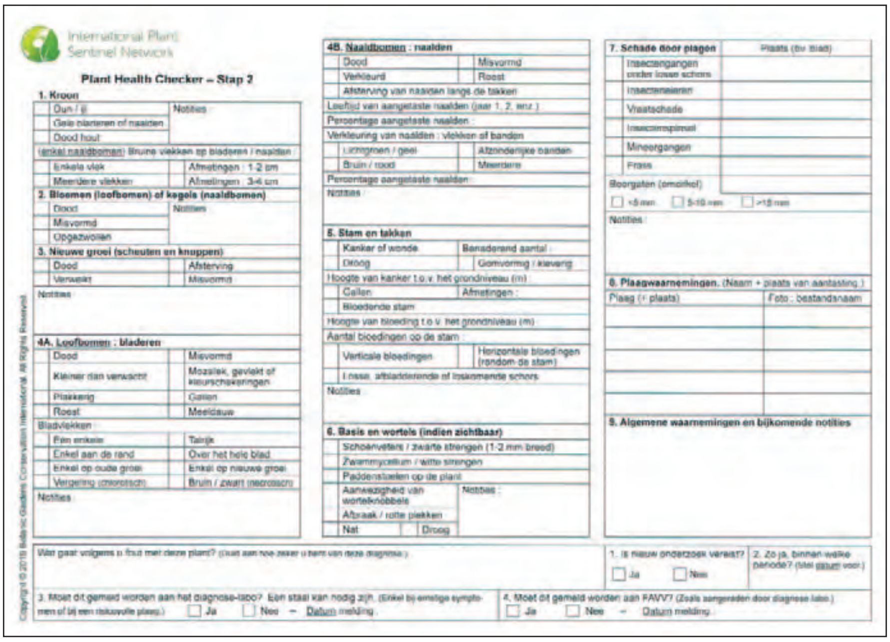
Several trainings were given for the BG&A, with presentations of the project, available tools and information sources, the survey test cases, guidelines for organising surveys and sampling, including practical demonstrations in the collections.

Information leaflets about the test cases were drafted (FR/NL) and issued to the gardens (Fig. 2A and 2B). The Plant Health Checker (PHC) form was adapted to the survey test cases, and translated into Dutch and French (Fig. 3). Moreover, a single PHC form was made for both deciduous trees and conifers, combining the former separate forms. Finally, electronic PHC forms were made in Dutch/French/English using web forms in Google Drive, in order to facilitate data recording in the field using a smartphone or tablet.

More than 100 phytosanitary surveys were made by the BG&A, focusing on the test cases. Data were recorded using the PHC, in either paper or electronic form, and photographs of symptoms were taken according to the IPSN guidelines. The symptoms were screened, and a first-line alert and diagnosis was performed by the gardens, based on the information obtained through the trainings and workshops. The diagnostic labs tested several methods for the identification of the targeted organisms, and adapted and validated them in order to develop feasible detection methods. They carried out a systematic campaign for on-site sampling in the collections of the gardens, especially for the apple root-knot nematode (*Meloidogyne mali*) and *Phytoplasma* test cases. As a result, two of the targeted organisms were recorded for the first time in Belgium within this project: the phytoplasma '*Candidatus Phytoplasma ulmi*' and the fungus *Sirococcus tsugae*. This resulted in the publication of two scientific papers: De Jonghe *et al*. (2019) and Schmitz *et al*. (2018). Moreover, the data obtained through the plant health surveys by the participating gardens were entered in a database, and were subsequently published in Zenodo, an online digital academic repository (Ronse, 2019).

The Belgian project was presented at the launch of the second phase of the international project (Euphresco-IPSN2) during the 6th Global Botanic Gardens Congress in Geneva in June 2017. Similarly, a presentation about the achievements of the project after one year was given at the final meeting of the COST action PP1401 "*Sentinel plantings for detecting alien, potentially damaging tree pests*" at Sursee (CH) in October 2018. There was regular communication with the IPSN secretariat in BGCI and participants to the transnational project by mailings, as well as by participation to the three international teleconferences organized by the BGCI secretariat in 2018 and 2019. The results and progress made in the Belgian project were presented, and opportunities for collaboration were discussed. For the outreach to the general public, information about the project was put on the MBG website, and published in MUSA, the digital newsletter of MBG. In addition, weatherproof information panels with illustrated texts about the project and the issue of biosecurity were installed in the two largest botanic gardens (Meise and Ghent).

One of the aims of BePSN was the establishment of a stable network, which could subsist in the long run and continue to operate after the end of the period. A continuation of the network would ideally be via a new project with a coordinator, but this would mean additional funding, for which the possibilities are restricted, although partial financing of the project could be realized through participation in projects for status determination of pests and diseases.



International Plant Sentinel Network

Plant Health Checker – Stap 2

1. Kroon
Dun / ijl
Gele blaarten of naalden
Dood hout
Notities
(enkel naaldbomen) Bruine vlekken op bladeren / naalden
Enkele vlek
Afmetingen : 1-2 cm
Meerdere vlekken
Afmetingen : 3-4 cm

2. Bloemen (loofbomen) of kegels (naaldbomen)
Dood
Misvormd
Opgezwollen
Notities

3. Nieuwe groei (scheuten en knoppen)
Dood
Afsterving
Verwelkt
Misvormd
Notities

4A. Loofbomen : bladeren
Dood
Misvormd
Kleiner dan verwacht
Mozaïek, gevlekt of kleurschakeringen
Plakkerig
Gallen
Roest
Meeldauw
Bladvlekken
Één enkele
Talrijk
Enkel aan de rand
Over het hele blad
Enkel op oude groei
Enkel op nieuwe groei
Vergeling (chlorotisch)
Bruin / zwart (necrotisch)
Notities

4B. Naaldbomen : naalden
Dood
Misvormd
Verkleurd
Roest
Afsterving van naalden langs de takken
Leeftijd van aangetaste naalden (jaar 1, 2, enz.)
Percentage aangetaste naalden :
Verkleuring van naalden : vlekken of banden
Lichtgroen / geel
Afzonderlijke banden
Bruin / rood
Meerdere
Percentage aangetaste naalden :
Notities :

5. Stam en takken
Kanker of wonde
Benaderend aantal :
Droog
Gomvormig / kleverig
Hoogte van kanker t.o.v. het grondniveau (m) :
Gallen
Afmetingen :
Bloedende stam
Hoogte van bloeding t.o.v. het grondniveau (m)
Aantal bloedingen op de stam :
Verticale bloedingen
Horizontale bloedingen (rondom de stam)
Losse, afbladderende of loskomende schors
Notities

6. Basis en wortels (indien zichtbaar)
Schoenveters / zwarte strengen (1-2 mm breed)
Zwammycelium / witte strengen
Paddenstoelen op de plant
Aanwezigheid van wortelknobbels
Notities :
Afbraak / rotte plekken
Nat
Droog

7. Schade door plagen
Plaats (bv. blad)
Insectengangen onder losse schors
Insecteneieren
Vraatschade
Mineergangen
Frass
Boorgaten (omcirkel)
<5 mm
5-10 mm
>10 mm
Notities :

8. Plaagwaarnemingen. (Naam + plaats van aantasting.)
Plaag (+ plaats)
Foto : bestandsnaam

9. Algemene waarnemingen en bijkomende notities

Wat gaat volgens u fout met deze plant?

1. Is nieuw onderzoek vereist?
Ja
Nee
2. Zo ja, binnen welke periode? (stel datum voor.)

3. Moet dit gemeld worden aan het diagnose-labo? Een staal kan nodig zijn. (Enkel bij ernstige symptomen of bij een risicovolle plaats.)
Ja
Nee
– Datum melding

4. Moet dit gemeld worden aan FAVV? (Zoals aangeraden door diagnose labo.)
Ja
Nee
– Datum melding

Fig. 3: Dutch version of Plant Health Checker for conifers and deciduous trees (second page) (BePSN)

Finally, it was agreed that the best way for a lasting network would be to have it coordinated by the Belgian Association of Botanic Gardens and Arboreta (VBTA; https://www.botanischetuinen.be/en). This is an active network of Belgian BG&A, which regularly organizes meetings, trainings and other activities. VBTA seems the most appropriate vehicle for the perpetuation of the plant sentinel network, acting as the focal point where all information on phytosanitary issues is brought together, and from where it is actively disseminated to the BG&A. This would require regular contacts between VBTA and the NRL, as well as the federal public services and federal agency for the safety of the food chain (FASFC) i.e. the Belgian NPPO (National Plant Protection Organisation).

Scientific output

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Conclusions

The BePSN project has been successful in bringing together a network of several Belgian botanic gardens and arboreta and the National Reference Laboratory for plant health. It raised the awareness in BG&A on phytosanitary issues, and increased the contacts with the diagnostic laboratories and with the governmental institutions competent in these matters. Plant health surveys were conducted with a standardized form, the Plant Health Checker, which was adapted and translated, and an electronic version was made and tested. This way of surveying is a novelty. In the context of this project, an active sampling campaign was done by the NRL for selected test cases, which led to first records for Belgium of two of the targeted organisms.

On the other hand, the active participation of each botanic garden or arboretum strongly depended upon their size and number of staff members, especially for making surveys. A prerequisite for surveying is also the presence of a good database of the collections, as well as detailed maps of their location. Similarly, we found that there was a high threshold for taking samples in the collections, as many gardeners were not familiar with the practice. In the course of the project, it also appeared that most gardens are in need of more clarity about the procedures to follow in case of (new) phytosanitary issues, including the compulsory notification and the possible consequences that are involved.

Through this project, it became clear that, because of their vast collections of exotic and native plant species, botanic gardens can play a major role as sentinels for new diseases and pests, and supply useful data for Pest Risk Analyses, such as the host range of pests. They can also provide reciprocal information to other countries about the occurrence of native disease and pest organisms on species that are native to those countries or continents. Moreover, they can spread information on phytosanitary issues to the general public through their contacts with a large number of visitors, who are mostly interested in plants and thus also inclined to introduce plants from abroad. For these reasons, all participants and stakeholders agreed that a continuation of this network is important and that in the future, Belgian status projects for pest and disease organism should include surveys in BG&A.

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THE GROWING ROLE OF BOTANIC GARDENS IN MITIGATING THE IMPACT OF INVASIVE ALIEN SPECIES[1]

Botanic gardens can make a tangible difference to mitigating the impact of IAS through biosecurity risk assessment, surveillance and awareness raising

Visitors to the Auckland Botanic Gardens Biosecurity Trail can scan the QR code at each check point to be directed to either a video or website for additional information on the pest or the disease and how to prevent its spread (Plant & Food Research)

Introduction

New Zealand faces immense, insidious and often irreversible economic, environmental and social impacts from Invasive Alien Species (IAS), including pests, diseases and weeds, to its valued productive and natural plant systems. Because of New Zealand's economic reliance on primary production, and its unique flora and fauna, this country is especially vulnerable to IAS. New Zealand's defence from IAS (i.e. border biosecurity) has been the top priority for its productive sector for the last 9 years (KPMG, 2019) and is a concern for many New Zealanders. Additionally, Biosecurity 2025 Strategic Direction 1 (1 of 5) "A Biosecurity Team of 4.7 Million" aims to make all New Zealanders aware of the importance of biosecurity and get them involved in pest and disease management (MPI, 2018). This article illustrates three areas where the New Zealand botanic community, and specifically botanical gardens, can make a difference to mitigate the impact of IAS.

New Zealand's relative isolation has provided it with a natural advantage to exclude the many invasive alien species that attack valued plant and animal systems. However, like many countries the biosecurity challenges New Zealand faces are intensifying with changing trade, tourism and climate, and it needs to respond accordingly. Notwithstanding the reasonable claim that New Zealand has one of the best biosecurity systems in the world there will always be an ongoing need to do better. This article provides some examples where botanic gardens can make a tangible difference to mitigating the impact of IAS.

[1] A version of this article has also been published in the Canterbury Botanical Society Journal, New Zealand

The New Zealand native/indigenous plant collection in the Royal Botanic Gardens Melbourne (Plant & Food Research)

Sentinel (expatriate) plants for biosecurity risk assessment

This concept is based on plant species being grown in foreign botanic gardens or arboreta where these plants may be exposed to pests and diseases they would not normally encounter. Better Border Biosecurity (B3) has developed a database for international gardens that contain significant planting of New Zealand native/indigenous plant species (http://b3.net.nz/expat/view.php). Information from these novel pest/plant interactions might then provide useful information on the potential damages caused if these pest and diseases were to invade New Zealand. The sentinel/expatriate approach can be particularly useful for native/indigenous plants that are predominantly grown in their native range and have limited international distribution and exposure to pests and pathogens. B3 has been an international leader in the development of the sentinel/expatriate plants concept (Fagan *et al*., 2008, Mansfield *et al*., 2019), is a founding member of The International Plant Sentinel Network (IPSN) (https://www.plantsentinel.org/) maintaining a role on the IPSN International Advisory Group. Botanic gardens in Auckland, Wellington, Christchurch and Dunedin are IPSN members.

Perhaps the best example of this sentinel/expatriate approach is a study by Groenteman et al. (2015) examining the status of the plant pathogen *Xylella fastidiosa* and New Zealand indigenous plant species in California. Important information was gained on the host status of this plant pathogen on a range of New Zealand indigenous plant species. Another, but less successful example, is a project examining the status of myrtle rust on New Zealand Myrtaceae in international gardens (Marroni *et al*., 2018). Unfortunately, very little useful information for biosecurity risk assessors was obtained from this study.

The sentinel plant concept works in the other direction as well, where New Zealand botanic gardens can inform other countries about the unique pest/plant associations found here. Such an approach was taken by B3 and Christchurch Botanic Gardens researchers to assess novel pine aphid/conifer tree interactions (Redlich *et al*., 2018).

The information gained from the sentinel plant assessments must be treated with some caution as foreign botanic gardens and arboreta will not necessarily reflect the conditions or factors represented in the disease triangle, an established plant pathology paradigm, which is used to explain plant disease interactions. The host plant and plant pathogen factors are represented in foreign gardens but suitable or comparable environment conditions for disease expression may be absent.

Plant pest surveillance in botanic gardens

In New Zealand, the Auckland Botanic Gardens carried out some of the first (and thereafter regular and ongoing) surveillance for myrtle rust starting in 2014 before this disease was found in New Zealand. Following detection in New Zealand, the main botanical gardens in Auckland, Wellington, Christchurch and Dunedin all contributed to the national surveillance programme for myrtle rust with additional data from a range of alternative sources (Campbell *et al*., 2018). There is no doubt that having more gardens involved in this programme would have been beneficial in understanding the distribution of myrtle rust as it spread throughout New Zealand (Fig. 1). Auckland Botanic Gardens also hosts one of the many Ministry of Primary Industries (MPI) High Risk Surveillance Sites where regular monitoring of plants occurs near likely points of pest entry, such as airports, seaports and container devanning sites (Stevens, 2008).

New Zealand botanic gardens have also been involved in the development of a new surveillance initiative in Australia to establish a programme of plant pest surveillance within botanic gardens and arboreta (http://www.planthealthaustralia.com.au/plant-pest-surveillance-in-botanic-gardens/). This is intended to become part of the Australia National Surveillance Framework. Australia has over 150 botanic gardens and arboreta that are spread around Australia holding a range of native flora, exotic species and relatives of crop species, and are visited by millions of people each year.

Biosecurity trail

A new walking trail developed by B3 at the Auckland Botanic Gardens provides an opportunity for local and overseas visitors to learn about New Zealand's flora as well as their potential role in protecting it. Visitors can embark on a 1.8-km walk around the garden and discover biosecurity facts at their own pace as they admire more than 10,000 native and exotic plants. Brief information about pests and diseases that threaten New Zealand's flora and primary industries, including brown marmorated stink bug, myrtle rust and kauri dieback, is displayed at each of the 12 check points along the path.

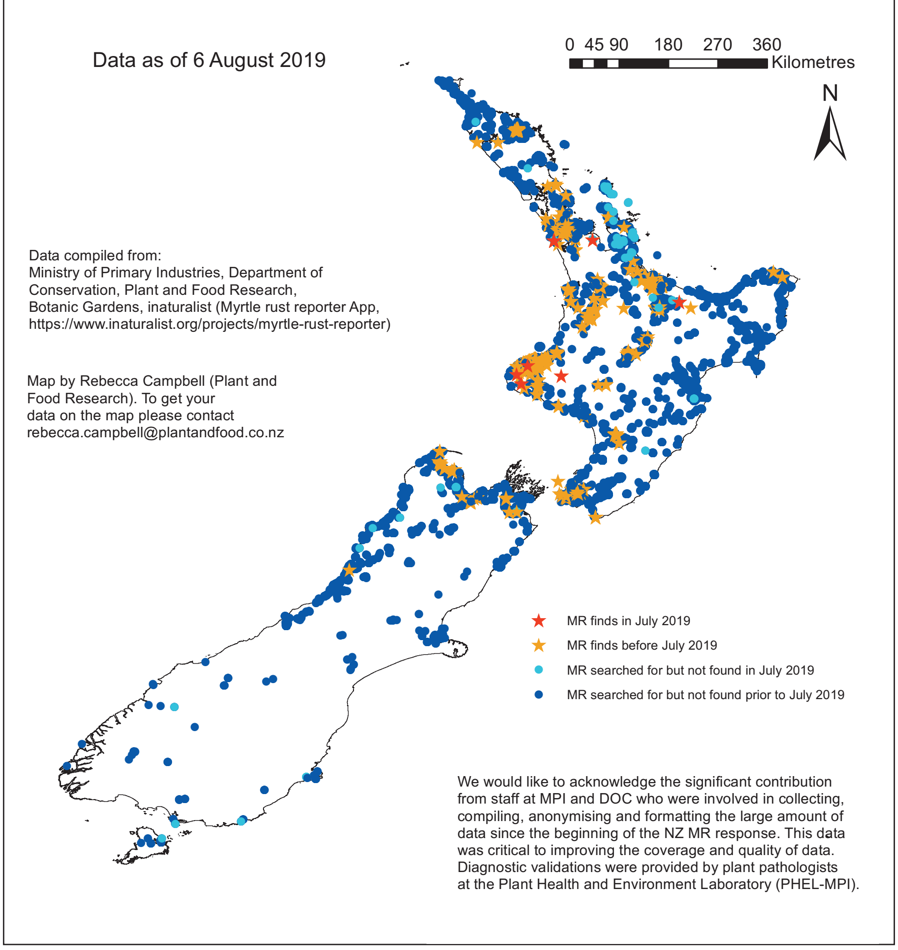

Fig 1. Myrtle rust distribution in August 2019. Four botanic gardens contributed surveillance data (Plant & Food Research)

Visitors can scan the QR code at each check point to be directed to either a video or website for additional information on the pest or the disease and how to prevent its spread.

While the trail will help raise the profile of invasive pests and diseases with overseas visitors and the general public, aligned research on the trail will be used to improve New Zealand's biosecurity system. The insights that visitors gain on the Auckland Botanic Gardens Trail can be a significant way of engaging them with this important topic.

The trail entered a 12-month trial period in April 2019, during which time it will continue to be improved on from the the experience gained by feedback from visitors. Information sheets in other major languages, in addition to English, will become available at this time.

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RISKS OF PEST AND DISEASE MOVEMENT VIA PLANT AND SEED EXCHANGES

Seeds infested with larvae and blue fungi (Iva Franić)

Seeds and dormant twigs carry a large diversity of potentially pathogenic fungi and insects – vigilance when importing or exchanging plant material is therefore highly recommended.

Live plants, including seeds, cuttings and potted plants, are moved around the world on a large scale through trade and also as part of regular exchanges among botanic gardens. This results in the movement of frequently hidden plant-associated insect pests and microbial agents of diseases, which cause important damage to trees in urban, agricultural and natural settings when they establish and attack trees in a new country.

Most countries perform risk assessment and implement phytosanitary measures and procedures to reduce the risk of accidentally importing such harmful organisms. Treatments, procedures and other conditions aimed at reducing the abundance of particularly harmful organisms on imported live plants include production at places where the pest of concern is not present, protection of the plants against pest and fungal infestation at the place of production by means of physical barriers, insecticide treatments prior to export, border inspections and import of plants during a season when pests are less likely to be associated with the plants.

Plant protection measures largely target commodities that are considered of particularly high risk and known pests. Lower risk commodities include seeds and deciduous plants without leaves. Most of the pests and agent of diseases that have become established in recent decades were not previously described, or species that were not known to be harmful prior to their introduction to a new country or continent. For most species, it was unknown whether they can attack trees in importing countries and the extent of damage they can cause. As a result, these species were not targeted by phytosanitary measures. It would be important for the development and implementation of more effective plant protection measures that more harmful organisms are detected prior to their introduction.

Detection of potentially harmful organisms in countries of origin and the damage they may cause to important tree species in importing countries can be done through surveys of organisms associated with "sentinel trees" that are planted for this purpose, or that are present in botanic gardens, arboreta or parks. Surveying of trees native to importing countries (i.e. exotic tree species where they are surveyed) provides valuable and unique opportunities to detect damaging organisms that are otherwise nearly impossible to predict. Surveying of commonly exported tree species has been shown to reveal many new host associations that may be indicative of the chance of introduction of those pests.

The large diversity of fungi obtained from seeds (Iva Franić)

In a study led by CABI and the Federal Institute for Forest, Snow and Landscape Research WSL in Switzerland, funded by the Swiss National Science Foundation and related to COST Action Global Warning, we assessed the phytophagous insects and fungi in tree seeds purchased from commercial suppliers and fungi in tree seeds collected in botanic gardens on two continents, as well as fungi and insects in dormant twigs from 32 countries to assess the diversity of such organisms and factors that may facilitate their establishment in other countries.

Fungi and insects in seeds

Seeds of eleven tree species native to Europe, Northwestern USA and China were obtained from commercial suppliers in Europe and the USA. Seeds of the same tree species were also obtained from botanic gardens in Europe and Northwestern USA. Each studied seed lot consisted of 100 seeds collected from a single tree species at a location. Seed insects were obtained from traded seeds by dissecting the seeds and fungi were grown on agar. Seed insects and fungi were both molecularly identified. Additionally, fungal communities were assessed molecularly directly from seed tissues obtained from trade and from ones collected in botanic gardens.

The number of insects in angiosperm seeds was lower than in conifer seeds probably in part because these insects leave the seeds to pupate in the soil. In the case of conifer species, many of the seeds contained specialist insects that pose a potential risk of establishment in a new country because they can survive for a long periods in the seeds and often do not need to mate to reproduce. Fungal diversity in seeds was much higher than insect diversity, especially in angiosperm seeds which contained around 50% of pathogenic fungi, in comparison with conifer species which contained around 30%. Both traded and botanic garden seed lots contained live fungi but it was found that seeds from botanic gardens have higher fungal diversity than traded seeds with the overlap in fungal communities being around 50%. It is possible that this is because traded seeds are obtained from managed forest stands and plantations, and may even be treated before being distributed, while botanic gardens have higher plant diversity and normally no treatments are used.

The combined results from the traded seeds and seeds from botanic gardens suggest that seed-associated fungal communities are more host than site specific. However, a certain degree of geographic isolation of fungal communities was found, which suggests that further exchanges of seed material could facilitate new introductions.

The results of this study suggest that seeds pose a greater risk of pest introduction than previously thought, but only a few species represent a real phytosanitary risk because these can be transferred from the seed to the seedling. More research is needed to gather data for better risk assessments.

Fungi in dormant twigs

In another study, twigs of mature, dormant trees were collected at 50 locations in 32 countries on all continents, including botanic gardens, during the month after the shortest day. We focused on dormant trees because trees or budwood are often traded in the season when deciduous species do not have leaves and foliar pathogens are less likely to be introduced. Fungi were identified using molecular tools from pooled, bark, wood and needles/leaves of evergreen species, and of bark, wood and buds of deciduous species. At each location, samples were collected from one native and up to three non-native congeneric tree species, of up to nine tree families of angiosperms and gymnosperms.

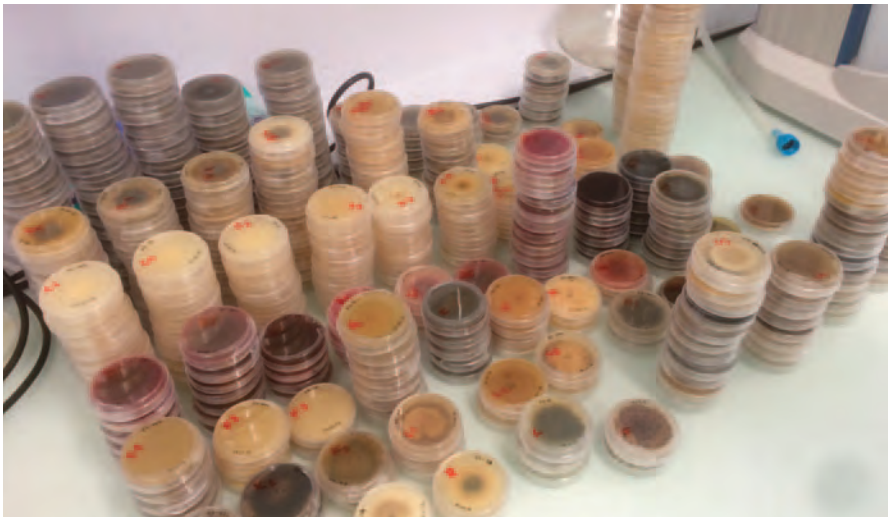
Above: Sampling for the global study in the Lushoto arboretum in Tanzania (René Eschen)
Top: Sampling for the global study in Hungary (Csaba Béla Eötvös)

A very large number of fungal taxa were identified and the fungal diversity in most tree families was highest around 45 degrees latitude. Large differences in fungal communities were found in samples from the different locations, with the fungal community in samples from geographically close origins being more similar than those from more distant locations. The fungal community was equally affected by the distance between locations and the combined climatic factors (annual precipitation and temperature, and the amplitude of the average annual temperature range), which appears to reflect differences in climate among sampling locations and dispersal limitations of the fungi. Host identity was a comparatively much less important factor in this study than it was in the two seed studies, which may indicate that many of the fungi in this study were horizontally transmitted, i.e. the trees are infected by fungi present in the environment. The results from the seed studies were not as clear with regards to the origin of the fungi and it may be that the fungal community in seeds is more affected by fungi associated with the mother tree than by spores in the air.

Recommendations

Our three studies show the diversity of organisms that may be, or are carried on plant material that is regularly exchanged among botanic gardens or traded commercially. Our results indicate that movement of plant material is likely to continue to facilitate the introduction of new pests and diseases. Although particularly seed insects are highly host-specific, some of them are able to attack related tree species if these are present at their final destination. None of the studied plant material showed external signs of insect or fungal infestation, indicating that a healthy (asymptomatic) appearance by no means guarantees that no harmful organisms are contained on or within them. The absence of visible signs of infestation highlights the need for careful surveillance of newly received material (quarantine) and good contacts with the local plant protection services. The chance of alternative hosts being present is particularly high in botanic gardens or arboreta and any seed lots and other planting material that have been received from other collections should be kept in conditions that minimize the risk of insects escaping until all insects have emerged. This may take more than one growing season, as especially conifer seed insects can stay in seeds for years, until the external conditions become suitable.

Although our studies show that fungi associated with traded plant material are very common, diverse and abundant, based on the current knowledge it is unlikely that many of them can be successfully transmitted to seedlings or mature trees and subsequently infect other trees or tree species. Some of the well-known tree pathogens, such as *Fusarium circinatum*, the causal agent of pine pitch canker, however, have this capability and future studies may reveal more cases of seed transmitted fungi.



The large diversity of fungi obtained from seeds (Iva Franić)

Sampling for the global study in the Lushoto arboretum in Tanzania (René Eschen)

The invasion potential of fungal pathogens remains very difficult to predict and vigilance when importing or exchanging plant material is recommended. Surface sterilization of seeds prior to sowing may remove fungi on the seed coat. Furthermore, growing trees in the greenhouse before planting them in the garden would allow closer surveillance to early detect pathogens. Similarly, frequent surveillance of newly planted trees may allow early detection of uncommon diseases, which greatly improves chances for eradication if that were necessary. In addition, monitoring of trees that are related to the imported species is of fundamental importance for detection of any new pests and diseases that attack new hosts in the collection.

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ROSE ROSETTE VIRUS AND ITS POTENTIAL RISK

Rosetting or witches' broom caused by RRV (Ines-Vazquez-Iglesias)

Rose rosette virus threatens one of the world's most beautiful and valuable ornamental plants

Introduction

Roses (*Rosa L.*) are one of the most valuable ornamental flowering shrubs and cut flowers grown worldwide, noted for their beauty and scent, their desirable aesthetics, landscaping and industrial properties (Dobhal *et al*., 2016). Cultivation of roses is economically important around the globe. The yearly estimated production is around 18 billion cut stems, 60-80 million potted roses and 220 million roses for landscaping (Blom and Tsujita, 2003; Pemberton *et al*., 2003; Roberts *et al*., 2003).

Roses are susceptible to infections caused by fungi, nematodes, bacteria, viruses and phytoplasmas. Rose rosette disease (RRD) is considered the most important viral disease of roses in the United States (US; Dobhal *et al*., 2016). Rose rosette virus (RRV) is the causal agent of this disease (Laney *et al*., 2011) and was first described in the 1940's in Manitoba, Canada (Conners, 1941), later in Wyoming, and California (Thomas and Scott, 1953).

Host range

Rosa is the only host identified for RRV (Laney *et al*., 2011), although the susceptibility of different plant species has been evaluated. *Rosa arkansana, R. bracteate, R. canina, R. corymbifera, R. gallica, R. glauca, R. multiflora, R. rubiginosa, R. spinossisima, R. villosa*, and *R. woodsii* are all susceptible, including multiple types: climbers, hybrid teas, floribundas, miniatures, shrub and antique roses (Martin, 2014). RRV is distributed from the eastern coast of the US to the Rocky Mountains and California (Center for Invasive Species and Ecosystem Health, 2019). It was thought to be restricted to North America until 2017, when it was reported for the first time in India (Chakraborty *et al*., 2017).

Transmission

RRV is transmitted by the eriophyid mite *Phyllocoptes fructiphilus* (Keifer, 1966; Allington *et al*., 1968.), by grafting (Amrine *et al*., 1988) and potentially by pollen (Babu *et al*., 2017a). *Phyllocoptes fructiphilus* is typically found in the angles between leaf petioles and axillary buds, feeding on the plant tissues and overwintering on plants. It is difficult to identify these mites with the naked eye because of their small size (Druciarek *et al*., 2016). Eriophyids do not have wings, but they can be transported by insects during pollination, dispersed by the wind, or by contact with clothing (Hong *et al*., 2012; Byrne *et al*., 2015). Further research has been undertaken in other mite species (e.g. *P. adalius* or *Eriophyes eremus*) to determine if they act as RRV vectors, but as yet none have been identified.

Reduced flower size caused by RRV (Ines-Vazquez-Iglesias)

Symptoms

Symptoms of RRV include reddening on newly emerging shoots, excessive lateral shoot growth, excess thorn production, leaf mosaic and mottling, witches' broom or resetting, and malformations (Laney *et al*., 2011). The virus moves throughout the plant affecting roots, and plants show reduced growth and vigour (Epstein and Hill, 1999). Other symptoms include darkening of canes, short internodal distances, blind shoots, rough leaf texture and an increased susceptibility to infections, especially by fungal diseases (Hong *et al*., 2012). Infected plants die within 3-5 years of becoming infected (Di Bello *et al*., 2017). Symptoms of RRD vary depending on the type of rose cultivars, stage of the disease and environmental factors (Epstein and Hill, 1995; Epstein and Hill, 1999).

Diagnosis

Early detection is crucial for effective control of the disease. However, diagnosis of RRD in the early stages of infection is difficult. Symptoms are often confused with pest problems, herbicide damage, nutrient deficiencies or fungal infections. Visual surveillance should be used in conjunction with molecular or serological methods, either to confirm or to assess the presence of the virus, as plants can remain asymptomatic for 30 to 146 days after transmission of the virus (Allington *et al*., 1968). Therefore, by the time the first recognisable symptoms appear, the disease could have spread to nearby plants (Hong *et al*., 2012).

Several diagnostic techniques have been developed in the last few years. Nucleic acid-based methods, including reverse transcription-polymerase chain reaction (Laney *et al.*, 2011; Dobhal *et al*., 2016; Di Bello *et al*., 2017), RT-quantitative PCR (Arif and Ochoa-Corona, 2013), recombinase-polymerase amplification (Babu *et al*., 2017a; Babu *et al*., 2017b) and loop-mediated isothermal amplification (LAMP) sequences (Salazar-Aguirre *et al*., 2016) are currently in use. Non-targeted methods, such as high throughput sequencing are also used for RRV detection (Peña-Zuñiga *et al*., 2017). Jordan *et al*., (2018) recently developed polyclonal, monoclonal and/or single-chain antibodies and associated serology-based protocols, such as enzyme-linked immunosorbent assay (ELISA).

Control

Identification and eradication of infected plants and biosecurity measures are the only current methods available to achieve control (Hong *et al*., 2012). All susceptible roses in a 100 m radius should be removed, because they serve as a source of inoculum (Department for Environment, 2016). Pruning out symptomatic parts of plants is ineffective since the virus persists in the root system (Di Bello *et al*., 2017).

Complete elimination of the mite vectors by acaricide treatment is difficult, due to their location in hidden areas of the plant (Otero-Colina *et al*., 2018). Acaricides may be useful to treat rose plants in surrounding areas where RRV-infected plants have been removed or to decrease mite populations, kill incoming mites and thereby reducing the risk of spread (Hong *et al*., 2012).

Resistant or immune rose cultivars are not yet available for RRD. The development of new resistant varieties is a long process that takes several years. Some species have shown levels of resistance to RRV infection, and others are resistant to feeding by the mite vector (Hong *et al*., 2012). Research groups in the US are making efforts to develop RRD-resistant roses: identifying genes linked to resistance, discriminating varieties susceptible and resistant to the virus and to the mite, with the aim to incorporate such traits into elite rose germplasm (Byrne *et al*., 2015; Dobhal *et al*., 2016; Roundey *et al*., 2016).

Controlling the introduction of RRV and its vector in the EU is needed to avoid a high economic, environmental and social impact.

Several pathways of introduction should be considered. Importation of infected plants is perhaps the most likely potential pathway. If infected plants were imported without the vector, the virus would be limited to that plant, except if used for propagation (Tuffen, 2016). However, this may be unlikely since plants showing RRD symptoms are generally infested by *P. fructiphilus* (Otero-Colina *et al*., 2018). Other less likely pathways are by natural spread or by the rosehip trade. Countries with RRV presence and *P. fructiphilus* are far from Europe, so vector transmission by wind is unlikely; and rosehips are generally used for domestic consumption, therefore are unlikely to act as a pathway to the wider environment (Tuffen, 2016).

RRV has not been reported infecting cut rose varieties yet, although it is highly probable that they are susceptible. The EU is a significant importer of fresh cut roses. The possibility of finding cut flowers showing symptoms in the market is small since there is a high-quality standard for commercial flower production. Nevertheless, flowers could be taken from asymptomatic parts of an infected plant. Cut flowers are mostly used indoors, which reduces the risk of mites moving outdoors to transmit the virus in gardens. However, when the cut flowers are disposed of outdoors, e.g. in compost, mites may still be able to transmit the virus to other garden plants. The possibility of RRV being introduced by cut flowers is unlikely, but not impossible.

Economic impact

The economic impact is expected to be high if RRV became established in Europe. About 35% of shrub rose sales are specifically for the landscape industry, and in the US this virus has led to a significant decline of garden roses for landscaping of cities (Laney *et al*., 2011). Recently, this market has been reducing the use of roses by about 10% per year due to RRV and associated virus complexes.

Breeders, nurseries, landscapes, and retailers of garden and pot roses would also be affected. Symptomatic rose plants would be unmarketable, and eradication measures which include destruction of roses within a range of 100 m, even if they remain asymptomatic, would be damaging (EPPO, 2018). The cost associated with replacement of rose plants in private and public landscaping is high and the rose industry would be seriously affected by the introduction of alternative ornamentals into both the garden and landscape industry. Countries such as Bulgaria and Turkey, which are the largest producers of rose oil worldwide, depend on species like *R. damascena* which is known to be an RRV host (EPPO, 2018).

Several European rose wild species are susceptible to the virus, such as *R. canina* and *R. rubiginosa* (EPPO, 2018). Roses are deliberately planted as hedges, and for game cover, slope stabilisation and erosion control. Invertebrates that rely on *Rosa* spp. would also be affected, like the gall forming wasp *Diplolepis spinosissimae*. Pollinating insects may also be affected since rose flowers are a potential food source (Tuffen, 2016).

The introduction of RRV to Europe would cause serious social impact, from affecting the mental and physical health benefits associated with gardening (Soga *et al*., 2017) to loss of employment and income in the nursery and other sectors. The availability of rose products with cultural importance like jam, rosehips, rose water, rose petals of flower or buds is likely to be reduced. More philosophically the rose is the national flower of England and other European countries, such as Bulgaria, the Czech Republic and Luxembourg.

Conclusions

Rose is a valuable flower crop worldwide and whilst it is affected by a range of pathogens, RRV is particularly devastating and could potentially be introduced and become established in Europe. Early detection and control programmes are necessary to avoid its introduction, establishment and spread. Visual assessment and the use of serological and/or molecular methods should be used for reliable diagnosis of infection in any suspicious, imported plant material, to ensure infected material is identified before the disease becomes established. Long distance (between continents) vector spread is unlikely but regulation of the movement of rose plants between countries and awareness are key to prevent the introduction of RRV.

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Rosetting or witches' broom in a dying rose stem (Ines-Vazquez-Iglesias)

Malformation caused by RRV (Ines-Vazquez-Iglesias)

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ARTICLE

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TRAP PLANTS AS PLANT SENTINELS

Growing trap plants according to common protocols – *Gazania* and other spp. in the Julius Kühn Institut, Braunschweig (EUPHRESCO Project IPSN I)

What are trap plants

It is a well-known practice in horticultural and agricultural systems to grow other plant species in addition to the desired crop. These "secondary plants" (Parolin *et al*., 2012) or "companion plants" can have various positive effects on the health and production of the main crop, e.g. by enhancing nutrient supply, by repelling or excluding pests and diseases or by attracting beneficial organisms. However, attracting pests can also be a useful function, either by retaining the trapped pest and avoiding damage on the desired plants or by indicating the presence of given pest species that are otherwise not visible (Parolin *et al*., 2012).

In this article, the term 'trap plants' is used to describe plants that trap pests and pathogens.

History

The use of trap plants to reduce insect damage dates back centuries and is still used today in traditional farming systems and in organic farming (Hokkanen, 1991). Traditional examples include the use of parsnip to trap and destroy parsnip webworms (*Depressaria radiella*) in carrot farming (Curtis, 1860) or reducing the impact of the parasitic broom rape (*Orobanche ramosa*) on tomatoes by trapping it on cowpea (*Vigna sinensis*) and other plants (Qasem, 2019). In modern agriculture there are still a few crops in which this type of trap cropping is successfully applied (Hokkanen, 1991). In sugar beet for example, trap plants can reduce the damage by cyst nematodes (Hemayati *et al*., 2017).

Use of trap plants

For the trap plants to be effective it is important that they really act as a sink for the pest population and do not develop into a source for new infestations. This works for the rice striped stem borer *Chilo suppressalis* attracted by vetiver grass (*Vetiveria zizanioides)* because the latter is a dead-end trap plant where larvae are unable to complete their life cycle (Lu *et al*., 2019). In other cases additional techniques may be needed like vacuuming, sticky traps etc. (Holden *et al*., 2012). A specific example is the use of trap plants treated with an insecticide to attract and kill insects, for example in cucumber and squash production (Pair, 1997).

Growing trap plants according to common protocols – seedlings of *Rudbeckia hirta* (EUPHRESCO Project IPSN I)

Growing trap plants according to common protocols – Nolana napiformis in the Julius Kühn Institut, Braunschweig (EUPHRESCO Project IPSN I)

Trap plants may provide an important tool in protecting plants from pests that are currently spreading in Europe. A study in the U.S. found that the brown marmorated stink bug (*Halyomorpha halys*) is attracted by sunflower (*Helianthus annuus*). There could be potential benefits of using sunflower as a trap plant in the production of bell peppers, but more research is needed before this can be applied (Soergel *et al*., 2015). In the case of the emerald ash borer (*Agrilus planipennis*), girdled ash trees were effective in trapping larvae and may therefore offer an element in strategies against the insect (McCullough *et al*., 2015).

The use of trap plants is applied preferentially for pests and pathogens that are small or hard to detect. For example, airborne inoculum of pathogens can be detected by physical traps, but trap plants are far more efficient in detecting them (Mahaffee & Stoll, 2016). Modern examples include the use of tomato plants for the indication of whitefly infestations in poinsettia (*Euphorbia pulcherrima*) crops (Parolin *et al*., 2012). Trap plants can also be used to monitor herbicide drift. In a 1996 study by Felsot *et al*., seedlings of pea, bean and corn (referred to as sentinel plants in this experiment) were used to detect such drift into nearby non-target areas.

Potential use for early detection of (new) pests and pathogens

In relation to the sentinel plant concept, the term trap plants can be used for plants that are specifically planted for attracting new pests (as opposed to those sentinel plants that already exist in botanic gardens or arboreta). As such, trap plants are ex-patria sentinel plantings in the sense of Eschen *et al*. (2019a). The idea to plant plants for this purpose was developed in the EU funded PRATIQUE project (https://secure.fera.defra.gov.uk/pratique/workPackages.cfm#WP1). Roques *et al*. (2015) planted European tree species in Chinese gardens and monitored the insect damage on these sentinel trees, while Vettraino *et al*. (2015) studied pathogens on them. Many pest species were found associated with the plants that were not previously known to attack them. The obvious disadvantage of using trees as trap plants is their long lifespan and slow development, so for woody species, the use of existing plantings instead of deliberately planting trap plants is often preferred. Trap plants may also help in commodity risk analyses, which investigates the possibility that a traded plant from a given region can pose a phytosanitary risk. Kenis *et al*. (2018) planted sentinel plants of species that are exported from China in two different Chinese regions and found a high percentage of pest-host combinations not previously known from the literature.

Conclusion: When is the planting of trap plants advisable?

While research is continuing on a wide range of methods to detect new invasive pest species, the use of sentinel plants for enhancing biosecurity is now a widely accepted concept (Eschen *et al*. 2019b; Mansfield *et al*. 2019; Morales-Rodriguez *et al*. 2019).

The use of trap plants can offer the same possibility as sentinel plants already established, i.e. to monitor the occurrence of known pests in an area and to discover new pest-host relations. Trap plants may however, have several advantages:

- They may be applied more flexibly over a given area, as the use of trap plants does not depend on already established plants.
- New trap plantings may be initiated from seeds rather than larger plants, which can help overcome legal restraints of cross-border transport of plants for planting (Vettraino *et al*., 2019).
- The number of specimens of a given species growing in botanic gardens and their genetic diversity is often limited so that the deliberate planting of trap plants may be advantageous (Roques *et al*., 2015). In some cases, a broader genetic diversity may be better to attract different strains of a pathogen or specifically attractive clones or types of a trap plant can be used.
- The propagation of trap plants may follow detailed protocols so as to ensure that the plants have comparable attractiveness for the studied pest or pathogen.

These features together offer the possibility of conducting new vigorous tests as they make the results comparable over larger geographic areas.

Growing trap plants according to common protocols – Gazania and other spp. in the Botanic Garden of Potsdam (EUPHRESCO Project IPSN I)

[1]FFH = Fauna-Flora-Habitat

Growing trap plants according to common protocols – Schizanthus pinnatus damaged by unidentified pathogen in the Julius Kühn Institut, Braunschweig (EUPHRESCO Project IPSN I)

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BIOSECURITY BEYOND QUARANTINE: THEMES FROM THE 2020 PLANT HEALTH ISSUE OF SIBBALDIA

Biosecurity notice at the entrance to the Royal Botanic Garden, Edinburgh (Ines-Vazquez-Iglesias)

The mission of botanic gardens and arboreta (BGA) – to conserve plants by growing them outside their native habitats – presents a challenge for biosecurity. Harnessing what we know about novel species interactions can help guide best practice. These themes were explored in a recent special issue of *Sibbaldia*, the journal of conservation horticulture published by RBGE. Articles in this issue outline the peculiar space BGA occupy between 'natural' plant communities and highly managed systems (Antonovics and Hayden), the challenges that the climate emergency and introduced and emerging pests[1] pose to BGA (Frediani; Saddler; Sharp *et al*.), the risks that pathogens pose to conservation horticulture (Frankel *et al*.; Green *et al*.; Summerell and Liew) and the approaches BGA are taking to learn from (Marfleet and Sharrock) and mitigate them (Hayden; Ives; Marfleet and Sharrock; Summerell and Liew).

In this article I summarise the themes that emerged from this issue specifically concerning biosecurity. These themes and example strategies are outlined in Table 1; see the articles for explanation in greater detail.

While diseases are an important part of plant community dynamics, *emerging* diseases caused by invasive non-native pests (INNP) present a grave threat to collections and to species at risk.

[1] Defined broadly to mean any disease-causing organism

Goal	Mitigation	Example techniques
Preventing arrival of new pests with collections	• Sourcing & importing procedures • Inspection procedures • Quarantine procedures	• Sourcing by seed if possible and only from healthy plants, cleaning away soil or growing media before importing • Accept only healthy propagules; inspect at least on intake and end of quarantine period • Seclusion period for all plant material on intake. Longer length and higher security for high risk and international origin
Reducing opportunities for growth and transmission of established pests, whether invasive or endemic	• Biosecurity procedures in propagation • Biosecurity procedures in living collection • Monitoring signs and symptoms of disease • Monitoring pests independent of disease • Cultural practice • Curating for diversity • Visitor procedures	• Limited access, foot and hand sanitation on entry and exit, elevating plants, organising workflows to reduce contamination • Cleaning tools and shoes, avoiding unnecessary soil disturbance or spread, separating unfinished compost from collection • Regular condition checks, IPSN plant checker, surveys in propagation areas. Staff training, culture to protect collection as well as individual accessions • Insect traps, bioassays or DNA-based monitoring for cryptic pests like *Phytophthora* spp. • Removing and safely disposing diseased material, maintaining drainage, pruning canopies to maintain airflow and keep above soil level • Where possible avoid large groupings of a single species • Sanitising visitor footwear; education and outreach
Reducing risk of transmission from living collections to the environment	• Procedures to reduce pest prevalence in collections • Procedures for inspection before dispatch • Hygiene during translocation	• All of the above • Rigorous visual inspection; DNA-based screens or bioassays for cryptic pathogens • Sanitising vehicles, equipment, shoes, tools before leaving home and between sites; minimising soil movement; beginning work in areas least likely to be contaminated before moving to higher risk sites

Table 1. Biosecurity goals, mitigation measures to achieve those, and some example techniques employed by BGA. Table compiled from articles in the 2020 Sibbaldia *Plant Health Issue. For greater detail see especially Frankel* et al*.; Frediani; Hayden; and Summerell & Liew.*

Symptoms of Ash Dieback

Limited access in plant propagation areas and sanitation for footwear are biosecurity measures help prevent new pests from establishing and reduce transmission rates and population sizes of pests that have already arrived.

Emerging diseases in collections threaten specimens directly and through destruction as a part of eradication efforts, while additional mortality can put extreme pressure on populations already under stress, as are many of the species targeted for conservation (Frankel *et al*.; Summerell and Liew). BGA may harbour more pathogens than they realise: *Phytophthora* incidence and diversity in soils in BGA is remarkably high (Green *et al*.), and can spill over to new hosts in collections and through translocations (Frankel *et al*.; Hayden; Summerell and Liew).

With this view, biosecurity in BGA can be seen to follow two organising principles: 1. Pests are most dangerous to plants when they establish outside of their co-evolved systems (e.g. in naive hosts in a new geographic area) and 2. The larger the pest population, the larger the chance of transmission and disease emergence in new hosts and new localities (Table 1).

From the first point follows a need to reduce the risks of importing new pests with new collections. This is primarily addressed with procedures for sourcing and for inspection and quarantine of incoming plant material, beyond what is required by national and international statutes. Sourcing procedures can help to reduce the risk that material carries pests, whether from the wild, from other collections, or from commercial sources. The risk of latent pathogens is never zero, so some kind of quarantine period for all incoming plants, with the type determined by relative risk of plant material type and its origin.

From the second point follows a call to reduce pest populations and opportunities for transmission in propagation nurseries and living collections. A successful pest must transmit itself to at least one host for each one it infects; less than that and it will die out. Thus biosecurity in BGA is not just to prevent pests from arriving: good biosecurity practices reduce the opportunities for transmission of pests that have already arrived, whether native or new arrivals. In turn, this both reduces direct threats to the collection from these pests, and reduces the chance of a new epidemic originating from the collection.

Amentotaxus argotaenia in collection at RBGE

Large-scale production systems create an opportunity for pathogen populations to grow large and diverse enough to beat the odds against adapting to new environments, and to overcome resistance in normally non-susceptible hosts. The relatively small size and high plant diversity of most BGA is helpful, because while intensive production favours large pest populations and fosters adaptation, host diversity can help prevent pest epidemics, reducing the number of susceptible hosts and by increasing the complexity of the environment to which pests must adapt. These factors all help to reduce risk that new pathogens establish in BGA. However, this reduction is offset by the frequency and distance of trade among them, which increases risk, and the increased opportunity for new host relationships (Antonovics and Hayden). Biosecurity within collections is thus called for to reduce i) the likelihood that a newly introduced pest becomes established; ii) the likelihood that a more aggressive or damaging pest will arise out of an established population through adaptation and/or hybridisation; and iii) the likelihood that endemic pests will reach epidemic numbers.

From both points follows a call to reduce the risk of transmission from living collections to the environment. This is especially important when plants from *ex situ* collections are used to re-establish or augment wild populations. These risks are necessarily reduced when the opportunities for contamination and transmission within the collection and propagation facilities are lowered, as above, but as significant escapes from conservation nurseries into the environment have shown (Frankel *et al*.), translocating plants to sensitive environments requires extra care (Hayden; Summerell and Liew).

Conclusion

Biosecurity in BGA is of increasing importance, and goes beyond keeping new pests out of our collections. Actions to reduce the opportunities for adaptation and emergence of pests –primarily by reducing their numbers – are a key part of conservation horticulture, and are necessary to protect threatened species within and outside collections.

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Only a single tree remained in the source population, so to help augment it rooted cuttings of A. argotaenia *were sent from RBGE to Kadoorie Farm & Botanic Garden in Hong Kong. Cuttings were transplanted into inorganic media prior to shipment to reduce the risk of accidentally transporting pathogens in soil.*

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Water runoff from the cuttings was tested for cryptic pathogens using pears as a bioassay. Once a 'clean' result was returned from bioassays, phytosanitary inspections were performed by the national plant protection organisation and the plants were shipped.

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