IPSN PLANT PEST MONITORING AND PREVENTION WORKSHOPS IN SOUTH AFRICAN BOTANICAL GARDENS

1ST-10TH NOVEMBER 2017

FINAL REPORT

Fig. 1. King protea *Protea cynaroides*, the national flower of South Africa, in the SANBI Kirstenbosch National Botanical Garden. The alien invasive fungal pathogen *Phytophthora cinnamomi* is causing significant mortality of endemic Proteaceae.

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Fig. 2. Delegates at the IPSN workshop at KwaZulu-Natal National Botanical Garden

Fig. 3. Delegates at the IPSN workshop at Kirstenbosch National Botanical Garden

Fig. 4. Delegates at the IPSN workshop at Pretoria National Botanical Garden

Executive summary

The increasing globalisation of trade in plants and plant material, together with the impacts of climate change, has led to an increase in the introduction and spread of new and damaging plant pests and pathogens. The International Plant Sentinel Network (IPSN) facilitates collaboration amongst institutes around the world, with a focus on linking botanic gardens and arboreta, National Plant Protection Organisations (NPPOs) and plant health scientists. The aim is to facilitate these institutes to work together to use sentinel plants to provide an early warning system of new and emerging pest and pathogen risks. The gardens in South Africa are particularly relevant to Europe as they contain many iconic European species suitable for use as sentinel plants, such as *Fagus sylvatica*, *Quercus robur*, *Platanus* x *acerifolia* and *Pinus pinea*; and *vice versa*, many South African plants, for example in the genera *Agapanthus, Aloe*, *Clivia*, *Gerbera* and *Pelargonium*, are widely grown as ornamentals in Europe. IPSN member gardens can use their collections to help gather scientific evidence regarding potential new risks and known quarantine organisms. This information can be passed to NPPOs to help inform plant health activities and thus help safeguard susceptible plant species worldwide. An important component of the IPSN is to provide training and consequently three workshops on 'Plant Pest Monitoring and Prevention' were delivered at South African National Biodiversity Institute (SANBI) National Botanical Gardens (KwaZulu-Natal, Kirstenbosch and Pretoria). Subjects covered included: the progress of the IPSN and the advantages of membership; the importance of sentinel plants; an introduction to invertebrate plant pests; alien invasive insects that may pose a future threat to plant health in South Africa; fungal pathogens including *Armillaria*, *Ganoderma* and *Phytophthora*; *Euwallacea* sp. and Fusarium Dieback; the importance of biosecurity; best practices in garden maintenance; and pruning. Practical sessions included stem-injection with potassium phosphite to mitigate the impact of *Phytophthora*; detecting and identifying causes of poor plant health; and pruning. More than 120 delegates attended the workshops including horticultural students, staff from SANBI and non-SANBI botanical gardens, municipalities, nurseries and the Department of Agriculture Forestry and Fisheries (DAFF). The workshops provided the delegates with a wealth of new knowledge, increasing their awareness of the threat from alien invasive species and the importance of biosecurity. The delegates shared experiences and best practices, developed networks, and discussed ways to disseminate the information more widely. There was excellent engagement by the participants during all three workshops.

The most important plant health concerns observed in the botanical gardens during November 2017 included the fungal pathogens: honey fungus *Armillaria* spp., bracket fungus *Ganoderma* spp. and *Phytophthora* spp. These pathogens are causing significant dieback and mortality. For example, the invasive fungus *P. cinnamomi* is killing large numbers of endemic Proteaceae at Kirstenbosch. *Phytophthora asparagi* (causal agent of spear and root rot of asparagus) was also detected at Kirstenbosch and this is the first report of this pathogen in South Africa. A major new plant health threat recently detected by Trudy Paap is the polyphagous shot hole borer *Euwallacea* sp. and Fusarium Dieback which threatens the iconic London Plane Avenue in KwaZulu-Natal. This Asian invasive ambrosia beetle has established in an area between Durban and Pietermaritzburg and occurs in wild populations of *Ricinus communis*. A pest alert for the beetle and fungus was distributed at the workshops. It could also potentially have a high impact on the avocado industry. The invasive cycad scale (*Aulacaspis yatsumatsui*) was observed at the Durban Botanic Gardens and armoured scale insects (Diaspididae) were damaging aloes and cycads at Pretoria.

EXAMPLES OF MAJOR PLANT PESTS AND DISEASES OBSERVED IN SOUTH AFRICAN BOTANICAL GARDENS

Fig. 5. *Platanus* x *acerifolia* with emergence holes of an Asian beetle *Euwallacea* sp., a vector of a fungus that kills many tree species, KwaZulu-Natal

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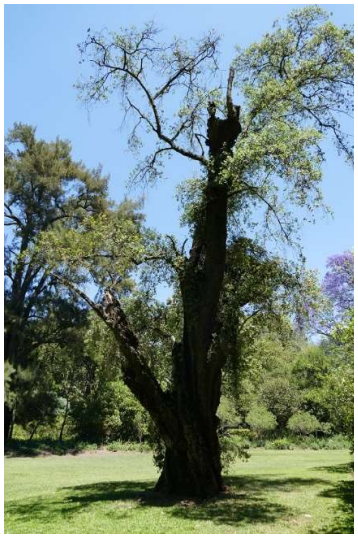

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PLANT PEST MONITORING AND PREVENTION WORKSHOPS IN SOUTH AFRICAN BOTANICAL GARDENS

Contents

1. Workshop Aims

To promote the International Plant Sentinel Network (IPSN) and help deliver its objectives by:

- Delivering three workshops at SANBI botanical gardens – KwaZulu-Natal National Botanic Garden, Kirstenbosch National Botanical Garden and the Pretoria National Botanical Garden.
- Seeking and sharing examples of best practice.
- Developing networks between botanical gardens and others working with plant health.
- Gathering intelligence on emerging plant health threats to South Africa and Europe and communicating relevant scientific evidence with Defra.

2. Introduction

The increasing globalisation of trade in plants and plant material, together with the impacts of climate change, has led to an increase in the introduction and spread of new and damaging plant pests and pathogens. Past examples of the devastating impact these organisms can have on plant populations, such as Dutch elm disease on UK elm trees and the emerald ash borer on U.S. ash populations, illustrate the significant threat these alien pests and pathogens pose to global plant health. The International Plant Sentinel Network (IPSN) (www.plantsentinel.org) facilitates collaboration amongst institutes around the world, with a focus on linking botanic gardens and arboreta, National Plant Protection Organisations (NPPOs) and plant health scientists. The aim is to facilitate these institutes to work together to provide an early warning system of new and emerging pest and pathogen risks. Member gardens help to provide scientific evidence regarding known quarantine organisms and potential new risks to NPPOs to inform plant health activities and thus help safeguard susceptible plant species worldwide.

The IPSN aims to:

- seek and share examples of best practice
- develop standardised methodologies for monitoring and surveying damaging plant pests and pathogens
- provide training materials to increase capability among member gardens
- facilitate access to diagnostic support
- develop databases to share and store information
- communicate scientific evidence with NPPOs

Plant Pest Monitoring and Prevention Workshops were held at three National Botanical Gardens in South Africa to promote and help deliver the aims of the IPSN. The workshops were run in collaboration with the South African National Biodiversity Institute (SANBI) which leads and coordinates research, and monitors and reports on the state of biodiversity in South Africa. The institute provides knowledge and information, gives planning and policy advice and develops best-practice management models in partnership with stakeholders. SANBI engages in ecosystem restoration and rehabilitation, leads the human capital development strategy of the sector and manages nine National Botanical Gardens as 'windows' to South Africa's biodiversity for enjoyment and education.

Trudy Paap (Forestry and Agricultural Biotechnology Institute – FABI) is leading a research project (FP1401) to study pests and pathogens on native and exotic congeneric plants at the SANBI gardens. Most of the pathogens recorded in this report were collected and identified by Trudy.

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3. Itinerary

An outline of the itinerary for Chris Malumphy (31st October to 11th November 2017) is presented in Table 1. Five Botanical Gardens were visited:

SANBI (www.sanbi.org/) gardens

1. KwaZulu-Natal National Botanical Garden, Pietermaritzburg (https://www.sanbi.org/gardens/kwazulu-natal)
2. Kirstenbosch National Botanical Garden, Cape Town (https://www.sanbi.org/gardens/kirstenbosch)
3. Pretoria National Botanical Garden, Pretoria (https://www.sanbi.org/gardens/pretoria)

Non-SANBI gardens

4. Durban Botanic Gardens, Durban (http://www.durbanbotanicgardens.org.za/)
5. Arderne Gardens, Cape Town (http://www.ardernegardens.org.za)

Table 1. Itinerary summary for Chris Malumphy

Date	Activities
31 Oct	Taxi from Haxby to Leeds/Bradford Airport, fly to Heathrow and Johannesburg, South Africa
1 Nov	Arrive at Johannesburg, fly to Durban. Meet Trudy Paap and drive to Pietermaritzburg. Visit KwaZulu-Natal National Botanical Garden to prepare for workshop
2 Nov	Workshop at KwaZulu-Natal National Botanical Garden, Pietermaritzburg
3 Nov	Workshop at KwaZulu-Natal National Botanical Garden; Drive to Durban
4 Nov	Visit Durban Botanic Gardens. Drive to Airport. Fly to Cape Town. Drive to Kirstenbosch and visit Kirstenbosch National Botanical Garden
5 Nov	Visit Arderne Gardens and Table Mountain National Park
6 Nov	Workshop at Kirstenbosch National Botanical Garden
7 Nov	Workshop at Kirstenbosch National Botanical Garden
8 Nov	Fly Cape Town to Johannesburg and taxi to Pretoria
9 Nov	Workshop at Pretoria National Botanical Garden. Meeting with Mike Winfield
10 Nov	Workshop at Pretoria National Botanical Garden Travel by taxi to Johannesburg Airport and fly to Heathrow
11 Nov	Arrive at Heathrow, fly to Leeds/Bradford, and taxi to Haxby

4. IPSN Plant Pest Monitoring and Prevention Workshops

Each workshop lasted two days and followed a similar format (Table 2). The programme was adapted to allow additional local speakers to give presentations and to discuss local problems. Subjects covered included the importance of sentinel plants in providing an early warning system for future plant health threats, plant pest recognition, alien invasive species that are potential threats to South Africa, biosecurity, pest monitoring and prevention, and garden and tree management.

Pdfs of the presentations and group photographs have been made available to all the delegates in a dropbox folder.

Table 2. Programme for the Plant Pest Monitoring and Prevention Workshops

Day 1	
10:00	Welcome and overview of the botanical garden
10:30	Introduction to the International Plant Sentinel Network (IPSN) – Chris Malumphy, FERA-UK
11:00	Introduction to the major groups of Plant pests – Chris Malumphy, FERA-UK
12:00	Lunch
13:00	Alien invasive species that present potential future plant health threats in South Africa – Chris Malumphy, FERA-UK
14:00	Botanic garden grounds tour. Overview of regional/garden pests and diseases – Designated garden staff
17:00	Workshop ends
Day 2	
9.00	Garden and Tree Management – best practice – Designated garden staff *Phytophthora* and other major plant pathogens – Trudy Paap Stem injection – Trudy Paap
12:00	Lunch
13:00	Questions and Answers Conclusions – Networking and Dissemination plan
14:00	Workshop ends

4.1 KwaZulu-Natal National Botanical Garden Workshop

The KZN National Botanical Garden was established in 1874 in response to the growing demand for tree seedlings in the Natal Midlands. The focus of the Garden is to collect, display and promote the conservation of plants of the eastern grasslands, particularly plants assigned to the genera *Clivia*, *Gerbera*, *Kniphofia* and *Watsonia*. The workshop was held at the garden on the 2nd and 3rd November and was attended by 47 delegates (Fig. 2), mainly from KZN National Botanical Garden, Durban Botanic Gardens and garden staff from the Durban municipality. Trudy demonstrated potassium phosphite stem injection into a *Quercus suber* to mitigate the effects of *Phytophthora cinnamomi* (Figs 12-15) and Garth Kloppenborg (KwaZulu-Natal) and Janet Gates (Durban Botanic Gardens) led demonstrations for best practice in pruning (Figs 16-17). There was excellent engagement by the participants, particularly during the practical sessions.

Fig. 12. Disinfectant, electric drill, and syringes to stem inject potassium phosphite, KwaZulu-Natal

Fig. 13. Drdrilling into a dying *Quercus suber* to insert the syringe, KwaZulu-Natal

Fig. 14. Applying the syringe containing potassium phosphite, KwaZulu-Natal

Fig. 15. Syringes are spaced at about 20 cm around the main trunk, KwaZulu-Natal

Fig. 16. Pruning demonstration at KwaZulu-Natal

Fig. 17. Garth Kloppenborg showing an example of poor pruning, KwaZulu-Natal

Plant diseases observed at the KZN National Botanical Garden and/or in Pietermaritzburg included:

- ***Phytophthora cinnamomi*** (Pythiales: Pythiaceae) was observed causing serious damage to *Quercus suber* (Fig. 7) and several other mature trees. *Phytophthora cinnamomi* is a soil-borne water mould that produces an infection causing a condition in plants called "root rot" or "dieback". First described in Sumatra, it is suspected to be native to SE Asia (possibly Papua New Guinea) and is one of the world's most invasive plant pathogens being present in over 70 countries around the world (Hardham 2005). It is widespread in South Africa and causes significant mortality of both native and exotic plants (Linde *et al.* 1997).
- ***Phytophthora parvispora*** (Pythiales: Pythiaceae) damaging *Betula nigra*. This species is closely related to *P. cinnamomic* and was only recently recognised as a distinct species (Scanu *et al*., 2014).
- ***Phytophthora multivora*** (Pythiales: Pythiaceae) causing serious damage to several mature *Cupressus sempervirens* (Fig. 8). It is widespread in South Africa and causes significant mortality of mainly exotic plants. A large mature *Liquidambar* tree located at the entrance to the garden is dying and this is suspected to be due to *P. multivora* (Figs 18-19). Abiotic factors including soil compaction are also suspected to be playing a role in the declines in the health of these trees.
- Symptoms of cypress canker, likely caused by ***Seiridium*** spp. (Xylariales: Amphisphaeriaceae), were observed on dying *Cupressus sempervirens* trees. Cypress canker pathogens including *S. cardinale* have been previously recorded in South Africa. The high pathogenicity of *S. cardinale*, wide range of Cupressaceae hosts, relative stability of its virulence, abundant production of asexual spores, its adaptation to various environments and the possibility of long-distance transport by beetle vectors or trade of infected propagation material, have allowed this fungus to spread widely and to cause pandemics in several continents (Graniti 1986).
- A third pathogen ***Botryasphaeria*** sp. (Botryosphaeriales: Botryosphaeriaceae) was also found in association with twigs and branches of dying *C. semiperivens* trees. The isolates are still to be identified to species level, however, a *Sphaeropsis* sp. (Botryosphaeriaceae) has been previously reported causing cankers of cypress in South Africa (alone and in combination with *Seiridium* spp.), and is likely enhanced by drought stress (Linde, Kemp & Wingfield 1997).
- Unidentified pathogen on *Celtis africana* (Figs 20-23). A road-side ornamental *C. africana* tree was observed to have several bleeding wounds on the lower part of the main trunk. Similar symptoms can be caused by fungal, oomycete and bacterial pathogens. Samples were taken and are awaiting diagnosis.

Fig. 18. Mature *Liquidambar* tree dying due to a suspected infestation by *Phytophthora multivora* and abiotic stresses, KwaZulu-Natal

Fig. 19. The dead trunk and main limbs of the *Liquidambar* tree in a car park could pose a health and safety risk, KwaZulu-Natal

Fig. 20. Unknown pathogen attacking *Celtis africana*, Pietermaritzburg

Fig. 21. Close-up to show the tar-like bleed on the infected *Celtis africana*, Pietermaritzburg

Fig. 22. Bark samples of the unknown pathogen were taken from the infected *Celtis africana*, Pietermaritzburg

Fig. 23. Staining could be seen beneath the bark of the *Celtis africana*, Pietermaritzburg

Plant pests observed at the KZN National Botanical Garden and/or in Pietermaritzburg include:

- Polyphagous Shot Hole Borer ***Euwallacea*** sp. (Coleoptera: Curculionidae: Scolytinae) and Fusarium Dieback are attacking the iconic avenue of London plane trees *Platanus* x *acerifolia* (Figs 5 and 24-28). These magnificent trees were planted in the gardens in 1908 and are over 40 m tall. *Euwallacea* sp. is an undescribed (un-named) invasive Asian beetle that carries its own food, a fungus ***Fusarium euwallaceae*** (Hypocreales: Nectriaceae) which causes Fusarium Dieback. The fungus interrupts the transport of water and nutrients in over 140 tree species and has been devastating in southern California and northern Mexico. Trees may experience branch dieback, canopy loss, and mortality. Once the beetle/fungal complex has killed the host tree, pregnant females fly in search of a new host. Both the fungus and beetle have recently been identified using morphological and molecular methods by Trudy in trees and woody plants in South Africa. It has been found in an area between Durban and Pietermaritzburg and occurs in wild populations of *Ricinus communis*, a common invasive weed in South Africa. The beetles have the potential to attack landscape, agricultural, riparian, and native trees. It has the potential to have a significant impact on the avocado industry in South Africa.
- ***Trioza*** sp. (Hemiptera: Triozidae) causing galls on the foliage of the native *Ficus sur* (Figs 29-30). Most *Trioza* species are highly host specific and there are two species recorded feeding on *F. sur*; *T. suavis* which occurs in the USA and Pacific region and *T. brevigenae* in India. This is potentially an undescribed species.
- African citrus psyllid ***Trioza erytreae*** Del Guercio (Hemiptera: Triozidae) causing galls on *Citrus* foliage. This insect is an important pest of citrus, being one of only two known vectors of the serious citrus disease, *Huanglongbing* or Citrus Greening Disease. The causative agent is the phloem-restricted, gram-negative bacterium *Candidatus* Liberibacter *africanum.* It is widely distributed in Africa and has recently been introduced to the Canray Islands and mainland Spain. Both the vector and bacteria are regulated in the European Union.
- The golden mealybug ***Nipaecoccus aurilanatus*** (Maskell) (Hemiptera: Pseudococcidae) (Fig. 31) was found to be abundant on *Araucaria* in KwaZulu-Natal. There were also large numbers of ladybird larvae (*Cryptoleamus* sp.) present which were feeding on the mealybugs. This species is native to New Zealand and is invasive in Australia, southern Africa

and the USA. It was first recorded from KwaZulu-Natal province more than a century ago (Fuller, 1901, 1907).

- Araucaria scale ***Uhleria araucariae*** (Maskell) (Hemiptera: Eriococcidae) was abundant on *Araucaria heterophylla*. The plant appeared to be in poor health and stressed plants are generally more susceptible to plant parasitic insects. This species was first recorded from KwaZulu-Natal province more than a century ago (Fuller, 1901, 1907).
- The Australian invasive cottony or fluted cushion scale ***Icerya purchasi*** Maskell (Hemiptera: Monophlebidae) (Fig. 32) was observed on *Citrus*. It is commonly known in South Africa as the Australian bug and was first recorded from KwaZulu-Natal province more than a century ago (Fuller, 1901, 1907). This is a major pest of crop and ornamental plants.
- 'Cuckoo spit' (Fig. 33), the protecting foam produced by froghopper (Hemiptera: Aphophoridae) nymphs was common on numerous herbaceous plants. Aphophoridae are potential vectors of plant pathogenic xylem-restricted bacteria, such as *Xylella fastidiosa* when is currently having a major impact in Europe.
- The leopard magpie moth or cycad moth ***Zerenopsis leopardina*** Felder (Lepidoptera: Geometridae) (Fig. 34) is a common minor pest of cycads. The larvae/caterpillars feed on a range of native cycads.

Fig. 24. The iconic London Plane Avenue at the KwaZulu-Natal National Botanical Garden is seriously infested by the invasive Asian Ambrosia beetle *Euwallacea* sp. and fungus *Fusarium euwallaceae*. The presence of this recently discovered beetle and fungus were first publicly announced at the IPSN workshops and an Exotic Plant Pest Alert circulated

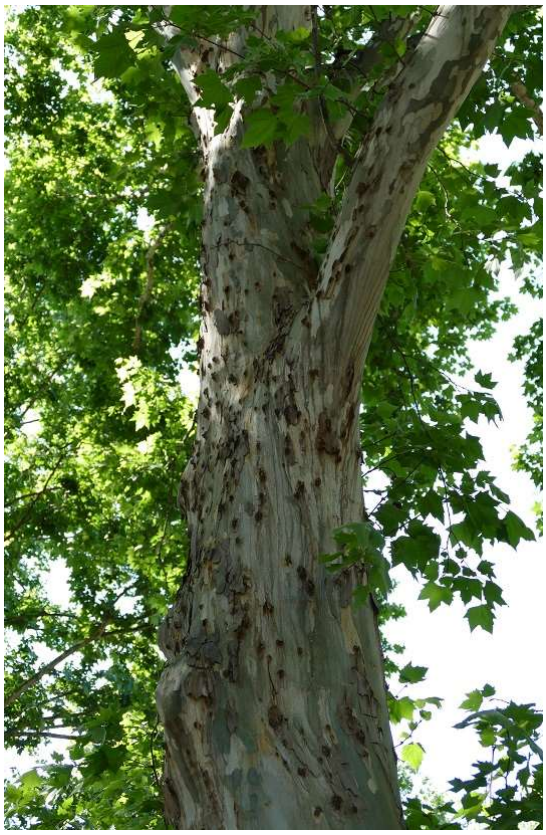

Fig. 25. *Euwallacea* sp. adult beetle emergence holes on the main trunk of *Platanus* x *acerifolia*, KwaZulu-Natal

Fig. 26. The common name 'shot-hole' borer is due to the emergence holes of *Euwallacea* sp., being clustered together like a shot gun wound, KwaZulu-Natal

Fig. 27. *Ricinus communis* stem cut open to reveal extensive mining and fungal infection © Trudy Paap

Fig. 28. Polyphagous shot hole borer adult *Euwallacea* sp. the vector of *Fusarium euwallaceae* © 2010 Jiri Hulcr

Fig. 29. *Trioza* sp. galls on the upper-surface of Ficus sur foliage, KwaZulu-Natal

Fig. 30. *Trioza* sp. nymphs on the lower-surface of *Ficus sur* foliage, KwaZulu-Natal

Fig. 31. Golden mealybug *Nipaecoccus aurilanatus* infesting *Araucaria*, KwaZulu-Natal

Fig. 32. Australian fluted scale *Icerya purchasi* on *Citrus,* Pietermatizburg

Fig. 33. 'Cuckoo spit', the protecting foam produced by frog hopper (Aphophoridae) nymphs was common on *Bulbine natalensis*, Pietermaritzburg

Fig. 34. Adult leopard magpie moth or cycad moth *Zerenopsis leopardina*, were common in Pietermaritzburg

4.3 Kirstenbosch National Botanical Garden Workshop

Kirstenbosch, with its setting against the eastern slopes of Cape Town's Table Mountain, is reputed to be the most beautiful garden in Africa and one of the great botanic gardens of the world. It was established in 1913 to promote, conserve and display the extraordinarily rich and diverse flora of southern Africa, and was the first botanic garden in the world to be devoted to a country's indigenous flora. It displays a wide variety of the unique plant life of the Cape Flora, also known as fynbos, including sugarbushes (*Protea* spp.), pincushions (*Leucospermum* spp.) and heathers (*Erica* spp.). Plants from all the diverse regions and biomes of southern Africa are also grown at Kirstenbosch, including a near-complete collection of cycads (*Encephalartos* spp.). The Botanical Society Conservatory is a custom-built glasshouse to grow and display plants from the arid regions that cannot survive outdoors. There are over 7,000 species in cultivation, including many rare and threatened species. In 2004 the Cape Floristic Region, including Kirstenbosch, was declared a UNESCO World Heritage Site. It is the first botanic garden in the world to be included within a natural World Heritage Site.

The workshop was held at the Old Mutual Conference Centre on the 6th and 7th November and attended by 32 delegates (Fig. 3) including staff from Kirstenbosch, Arderne Gardens, horticultural students, nursery owners, Department of Agriculture Forestry and Fisheries (DAFF) and from Cape Town municipality. There was a series of excellent talks by Anthony Hitchcock, Mpendulo Gabayi, Adam Harrower, Mashudu Nndanduleni, Nomama Mei (Kirstenbosch) and Joey Hulbert (FABI) and practical demonstrations of potassium phosphite stem injection into a dying *Quercus suber* by Trudy (Fig. 34) and best practice in pruning by Adam (Fig. 35).

Fig. 35. Trudy demonstrating stem injection, Kirstenbosch

Fig. 36. Adam Harrower demonstrating best practice with pruning, Kirstenbosch

Plant diseases observed at the Kirstenbosch National Botanical Garden and/or in Cape Town included:

- Honey fungus ***Armillaria*** spp. (Agaricomycetes: Physalacriaceae) are parasitic fungi that live on trees and woody shrubs. It causes "white rot" root disease and can be a highly a destructive forest pathogen. *Armillaria* is also a facultative saprophyte and can feed on dead plant material as well as living plants, thus allowing it to kill its host, unlike other parasites that must moderate their growth to avoid host death. *Armillaria* spp. (mainly *A. mellea* and *A. gallica*) are a major problem at Kirstenbosch and kill large numbers of exotic and native plants each year (Figs 37-40). Confirmed host plants at Kirstenbosch include: *Acacia burkei, Acacia sieberiana var. woodii, Albizia adianthifolia, Apodytes dimidiata, Brabejum*

stellatifolium, Cassine peragua, Celtis africana, Cinnamomum camphora, Ealaeodendron croceum, Ficus lutea, Ilex mitis, Indigofera spp., *Leucadendron argenteum, Olea capensis, Olea woodiana, Protorhus longifolia, Salix mucronate, Schotia afra, Searsia chirindensis, Trema orientalis, Trichelia dregeana, Vepris lanceolate, Virgilia oroboides, Widdringtonia nodiflora,* and many other different species of Proteaceae (Coetzee *et al.* 2003).

- Investigations of *Phytophthora* spp. present in the gardens also detected ***Phytophthora asparagi,*** the causal agent of spear and root rot of asparagus (Granke *et al*., 2012; Saude *et al*., 2008). This is the first report of this pathogen in South Africa.
- ***Phytophthora cinnamomi*** also causes major plant mortality at Kirstenbosch (Figs 43-47), mainly in the Proteaceae collections, and 6000 proteas need to be planted each year to replace the losses (Mashudu Nndanduleni *pers. comm.*). Other plants affected include a mature *Quercus suber* which was used to demonstrate phosphite stem injections.
- ***Phytophthora multivora*** is also a significant problem at Kirstenbosch although it appears to have a bigger impact on exotic plants such as *Ficus macrocarpa*, rather than the indigenous flora.
- ***Phytophthora* sp. ?*emzansi*** has been detected in association with *Podocarpus elongata*
- Bracket fungi or shelf mushrooms ***Ganoderma*** spp. (Polyporales: Ganodermataceae) are polypore mushrooms that grow on wood and cause basal rots. There are about 80 species assigned to the genus *Ganoderma*, mostly found in tropical regions. Several species are known to occur in South Africa including *australe*, *destructans, enigmaticum, gibbosum* and *resinaceum*. *Ganoderma destructans* is likely to be having the biggest impact. *Ganoderma* has killed several mature trees at Kirstenbosch, for example *Olinia ventosa* (Figs 41-42).
- ***Fomitiporia*** spp. (Hymenochaetales: Hymenochaetaceae) are another group of mushrooms that grow on wood and cause basal rots. These have also been identified at Kirstenbosch.
- ***Thielaviopsis basicola*** (junior synonym *Chalara elegans*) (Microascales: Ceratocystidaceae) is a soil-borne plant-pathogenic fungus that causes black root rot. It has been associated with the decline of some *Cinnamomum camphora* trees forming the iconic Camphor avenue (Fig. 44).

Fig. 37. *Olea capensis* tree killed by *Armillaria*, Kirstenbosch

Fig. 38. *Armillaria* fungal hyphae found under the bark at the base of the trunk, Kirstenbosch

Fig. 39. *Trachilia dregeana* (on the right) killed by *Armillaria*, Kirstenbosch

Fig. 40. *Trachilia dregeana* with *Armillaria* fungal hyphae found under the bark, Kirstenbosch

Fig. 41. *Olinia ventosa* killed by a bracket fungus *Ganoderma*, Kirstenbosch

Fig. 42. *Ganoderma* fruiting body growing on *Olinia ventosa*, Kirstenbosch

Fig. 43. The critically endangered species *Serruria aemula* var. *congesta* suspected to have been killed by *Phytophthora cinnamomi*, Kirstenbosch

Fig. 44. Mature *Cinnamomum camphora* trees forming the iconic Camphor avenue at Kirstenbosch. Some of the trees are showing decline due in part to the soil-borne fungus *Thielaviopsis basicola*

Fig. 45. *Leucadendron argenteum* killed by *Phytophthora cinnamomi*, Kirstenbosch. There is a high risk of all the neighbouring plants becoming infecting and eventually dying.

Fig. 46. *Leucadendron argenteum* exhibiting drooping foliage, a symptom caused by *Phytophthora cinnamomi*, Kirstenbosch

Fig. 47. *Leucadendron argenteum* showing staining beneath the bark, a symptom of *Phytophthora cinnamomi*, Kirstenbosch

Fig. 48. *Leucadendron argenteum* showing fungal hyphae beneath the bark, a symptom of *Armillaria*, Kirstenbosch

Plant pests observed at the Kirstenbosch National Botanical Garden and/or in Cape Town include:

- Eriophyid galls (Trombidiformes: Eriophyoidea) were very common at Kirstenbosch, for example on the foliage and stems of *Brabejum stellatifolium* (Fig. 49).
- 'Cuckoo spit' (Fig. 33), the protecting foam produced by Aphophoridae (froghoppers) nymphs was common on many plants.
- Mealybugs ***Delottococcus*** sp. (suspect *D. proteae*) (Hemiptera: Pseudoccidae) were observed on the foliage of *Leucospermum argenteum* (Fig. 50).

- An enormous infestation of soft scale insects (Hemiptera: Coccidae) and associated sooty moulds were observed on *Diospyros whyteana* (Figs 51-52). Like the flora, there is also a high biodiversity and high rate of endemism among the scale insects (Coccoidea) in South Africa.
- Gall midge (Diptera: Cecidomyiidae) damage to the foliage of *Encephalartos friderici-guilielmi* was observed (Fig. 53).
- Several species of armoured scale insect were observed infesting Aloe plants including the red scale ***Separaspis capensis*** (Hemiptera: Diaspididae) (Fig. 54).
- The foliage of several Proteaceae plants exhibited extensive marginal feeding damage (Fig. 55). Several groups of insects (Coleoptera, Hymenoptera, Lepidoptera) cause similar chewing damage.
- There was plenty of evidence of wood boring insects such as tunnelling and adult emergence holes. Large and small emergence holes frequently occurred together indicating that more than one species was feeding in the same piece of wood (Fig. 55).

Fig. 49. Eriophyid galls on foliage and stems of Brabejum stellatifolium, Kirstenbosch

Fig. 50. *Delotococcus* sp. on *Leucadendron argenteum*, Kirstenbosch

Fig. 51. Adult female coccids infesting the main branches of *Diospyros whyteana*, Kirstenbosch

Fig. 52. Sooty mould on the foliage *Diospyros whyteana* growing on the honeydew egested by scale insects, Kirstenbosch

Fig. 53. Gall midge damage to foliage of *Encephalartos* friderici-guilielmi, Kirstenbosch

Fig. 54. Aloe red scale *Separaspis capensis* on *Aloe* foliage, Kirstenbosch

Fig. 55. Proteaceae foliage showing feeding damage causing by insects with chewing mouthparts, Kirstenbosch

Fig. 56. Cerambycid beetle emergence hole (centre) together with smaller wood boring beetle emergence holes in dead log, Kirstenbosch

4.4 Pretoria National Botanical Garden Workshop

Pretoria National Botanical Garden covers an area of 76 ha and is divided by a 35m high quartzite outcrop. Its frosty south-facing section and the north-facing, warmer section present two different worlds to the botanist. A paved nature trail gives access to the fascinating natural vegetation on the ridge, which boasts a diversity of indigenous fauna and flora. Fifty hectares is devoted to developed garden, using almost exclusively South African plants. The garden includes savanna and forest biomes and grows 50% of the country's tree species.

The workshop was held in the Biodiversity Auditorium on the 9th and 10th November with 43 delegates attending, mostly from SANBI and the botanical gardens but also from DAFF. Thompson Mutshinyalo (Pretoria NBG) gave the introductory speech and Alec Naidoo (Pretoria NBG) lead a practical session in the gardens. Dr Jan Hendrik Venter (Directorate Plant Health) gave an excellent presentation entitled 'Setting Sights on Emerging Crop Pests in South Africa' which complimented the other presentations in the workshop. The practical sessions included phosphite stem injection into a dying *Combretum erythrophyllum* tree.

Major plant diseases observed at the Pretoria National Botanical Garden and/or in Pretoria included:

- ***Ganoderma*** spp. (primarily *G. destructans*) was causing basal rots on several plants. Trees that have been confirmed to be killed by *Ganoderma* at Pretoria Gardens include *Acacia*

nigrescens (Fig. 6)*, Acacia xanthophloea* (Fig. 57)*, Combretum* sp., *Dracaena* sp. and *Searsia chirindensis* (Fig. 58)

- ***Phytophthora*** sp. and abiotic stress are expected to be involved in a decline in health of *Podocarpus fulcatus* (Fig. 59-60). Samples were taken and are awaiting diagnosis.
- Suspect honey fungus ***Armillaria*** spp. was also observed and samples were taken.
- ***Phytophthora nicotianae*** or Black Shank has been isolated from roots and rhizosphere soil of dying *Encephalartos* spp. It has a broad host range comprising 255 genera from 90 families. Hosts include tobacco, onion, tomato, ornamentals, cotton, pepper, and citrus. This pathogen can cause root rot, crown rot, fruit rot, leaf infection, and stem infection.

Fig. 57. *Acacia nigrescens* killed by *Ganoderma*, Pretoria

Fig. 58. *Ganoderma* fruiting body on a *Searsia chirindensis*, Pretoria

Fig. 59. Suspect *Phytophthora* sp. on *Podocarpus henkelii*. The upper part of the tree was dying and there was epicormic growth from the base, Pretoria

Fig. 60. *Podocarpus* tree dying due to suspected infection by a *Phytophthora* sp. and abiotic stress, Pretoria

Plant pests observed at the garden and/or in Pretoria include:

- Enormous populations of an armoured scale insect ***Duplachionaspis*** sp. (Hemiptera: Diaspididae) were observed completely smothering the foliage of the endemic mountain aloe *Aloe marlothii* (Figs 11 and 61-64) and *A. arborescens*. Samples were taken and have been slide mounted. They are morphologically close to *D. exalbida* and the specimens are being studied to confirm the diagnosis.
- Enormous populations of ***Aspidiotus*** ?***capensis*** Newstead (Hemiptera: Diaspididae) (Figs 65-68) were observed completely smothering the lower-surface of the foliage of a cycad *Encephalartos senticosus* (Zamiaceae). There appears to be very little known about this insect. It is only known from South Africa and feeds on *Cycas* and *Encephalartos*.
- Woolly whitefly ***Aleurothrixus floccosus*** (Hemiptera: Aleyrodidae) is a major pest of citrus. It is native to the Neotropics and has only recently been introduced to South Africa (Giliomee & Millar, 2009).
- Aphids (Hemiptera: Aphididae) cast skins on highly distorted foliage was observed on *Podocarpus henkelii* (Fig. 69).
- Bark beetle (Coleoptera: Cucurlionidae: Scolytinae) tunnelling and adult emergence holes were observed on *Podocarpus henkelii* (Fig. 70).
- Wax scales ***Ceroplastes*** sp. (Hemiptera: Coccidae) were observed on *Podocarpus henkelii*.
- Large numbers of a wax scale *Ceroplastes* sp. were observed on an unidentified dead shrub in Pretoria (Fig. 76).
- Eriophyid mite galls were common on several plants, for example on the foliage of *Ehretia rigida* subsp. *Nervifolia* (Figs 71-72).
- Asian woolly hackberry aphid ***Shivaphis celti*** (Hemiptera: Aphididae) was observed on white stinkwood trees *Celtis africana* in Pretoria. This is an exotic Asian species that was only recorded in Pretoria in December 2016 (Visser & Millar, 2017). Small numbers of the aphid were also seen on adjacent herbaceous plants and *Rosa* sp. although these were probably incidental and are not true host plants (Fig. 73). The black-ringed ladybird ***Oenopia cinctella*** (Coleoptera: Coccinellidae) was observed feeding on the aphids (Fig. 74).
- An enormous population of the scale insect ***Lecanodiaspis*** sp. (Hemiptera: Lecanodiaspididae) was observed killing hibiscus plants in Pretoria (Fig. 75).
- African citrus psyllid ***Trioza erytreae*** was observed forming galls on the foliage of Citrus.
- Cycad aulacaspis scale (CAS) *Aulacaspis yatsumatsui* was observed causing chlorosis to the foliage of ornamental *Cycas* sp. in Pretoria.
- Cycad midge damage to cycad foliage was observed.
- Several ornamental *Aloe* plants in Pretoria exhibited extensive feeding damage consistent with mirid bugs. This is suspected to be caused by the small mirid bud ***Aloea australis*** Schuh (Hemiptera: Miridae) (Annecke & Moran, 1982; Salisbury et al., 2011).
- In addition to invertebrate plant pests, the rock hyrax ***Procavia capensis*** (Hyracoidea: Procaviidae), also called rock badger, Cape hyrax, and dassie, eats a wide variety of plants and can be a highly destructive pest. Their trails also cause soil erosion on the quartzite outcrop in the garden.

Fig. 61. *Aloe marlothii* at the Pretoria National Botanical Garden infested with *Duplachionaspis* sp., Pretoria

Fig. 62. Foliage lower surface of *Aloe marlothii* completely smothered in *Duplachionaspis* sp., turning it white, Pretoria

Fig. 63. Heavy infestation of *Duplachionaspis* sp. on *Aloe marlothii*, Pretoria

Fig. 64. Close-up of *Duplachionaspis* sp. colony on *Aloe marlothii*, Pretoria

Fig. 65. An endemic cycad *Encephalartos senticosus* being killed by a huge infestation of *Aspidiotus* ?*capensis* Pretoria

Fig. 66. *Encephalartos senticosus* foliage exhibiting chlorosis due to an infestation by *Aspidiotus* ?*capensis*, Pretoria

Fig. 67. *Encephalartos senticosus* foliage exhibiting severe chlorosis and necrosis due to *Aspidiotus* ?*capensis* infestation, Pretoria

Fig. 68 Lower surface of *Encephalartos senticosus* foliage showing a huge infestation of *Aspidiotus* ?*capensis*, Pretoria

Fig. 69. *Podocarpus henkelii* with severe leaf distortion due to an aphid infestation, Pretoria

Fig. 70. *Podocarpus henkelii* with bark beetle tunnelling and adult emergence holes, Pretoria

Fig. 71. Eriophyid mite galls on the foliage of *Ehretia rigida* subsp. *nervifolia*, Pretoria

Fig. 72. Close up of eriophyid mite galls on the foliage of *Ehretia rigida* subsp. *nervifolia*, Pretoria

Fig. 73. Asian woolly hackberry aphid *Shivaphis celti* on *Celtis africana* in Pretoria

Fig. 74. Black-ringed ladybird *Oenopia cinctella* feeding on aphids in Pretoria

Fig. 57. A large infestation of scale insects *Lecanodiaspis* sp. was causing leaf loss and dieback to an ornamental hibiscus, Pretoria

Fig. 76. Wax scales *Ceroplastes* on the bark of a dead shrub in Pretoria, Pretoria

Fig. 77. Rock hyrax or Dassie *Procavia capensis* were very common in Pretoria

Fig. 78. Grey squirrel *Sciurus carolinensis*, Arderne Botanical Garden, Cape Town

4. Arderne Gardens and Durban Botanic Gardens

4.1 Arderne Gardens

Arderne Gardens is a public park and arboretum in Claremont, Cape Town. It was established in 1845 by Ralph Henry Arderne, a timber merchant originally from Cheshire, England. In 1979, the park was named a South African Provincial Heritage Site. The large Moreton Bay fig is a Champion Tree and one of the largest trees in South Africa. The 4.5-hectare park contains over 300 trees, six of which have been distinguished as Champion Trees by the Department of Agriculture, Forestry and Fisheries.

Plant pathogens observed at the garden include:

- Suspect ***Ganoderma*** was also observed attacking *Fagus sylvatica* (Fig. 79). Samples were taken and are awaiting diagnosis (Fig. 80).
- Suspect honey fungus ***Armillaria*** spp. was observed attacking mature European beech trees *Fagus sylvatica, Lithocarpus* sp. (Fig. 81) and *Rhododendron* spp. (Fig. 82). *Armillaria* has been isolated from the samples and is being studied to determine the species.
- Suspect ***Phytophthora*** sp. was observed on *Araucaria heterophylla, Betula pendula* (Fig. 85), and *Quercus suber* (Fig. 83). Samples were taken and are awaiting diagnosis (Fig. 84).

Fig. 79. Bracket fungus growing on *Fagus sylvatica*, Arderne Botanical Garden

Fig. 80. Trudy taking a sample from the bracket fungus, Arderne Botanical Garden

Fig. 81. *Lithocarpus* sp. *with Armillaria* fungal hyphae detected beneath the bark at the base of the trunk, Arderne Botanical Garden

Fig. 82. Rhododendron killed by *Armillaria*, Arderne Botanical Garden

Fig. 83. *Quercus suber* showing dieback and epicormis growth due to a suspected infestation of *Phytophthora*, Arderne Botanical Garden

Fig. 84. Trudy (right) taking soil and root samples from *Quercus suber* with help from Chiara and Lisa, Arderne Botanical Garden

Fig. 85. Dead *Betula pendula* suspected to have been killed by a *Phytophthora*, Arderne Botanical Garden

Fig. 86. Taking samples of bark from a bleed to identify the pathogen, Arderne Botanical Garden

Plant pests observed at the garden include:

- One of the main pest problems at Arderne Gardens is caused by adult weevil (Coleoptera: Curculionidae) beetles feeding on the foliage of *Camellia* spp. (Fig. 88). These beetles are usually nocturnal and hide away during the day.
- Large infestations of pyriform scale ***Protopulvinaria pyriformis*** (Hemipetar: Coccidae) were observed on *Schefflera* and the foliage was contaminated with honeydew egested by the insects and associated black sooty moulds (Fig. 89).

- Giant scale ***Icerya seychellarum*** (Hemiptera: Monophlebidae) (Fig. 90) was observed on the palm *Archontophoenix cunninghamiana* but did not appear to have any impact.
- Araucaria scale ***Uhleria araucariae*** was abundant on several mature *Araucaria heterophylla* trees.
- Golden mealybug ***Nipaecoccus aurilanatus*** was also abundant on several of the mature *A. heterophylla* trees in association with predatory ladybird larvae *Cryptoleamus* sp. (Fig. 87).

Fig. 87. Ladybird larva *Cryptolaemus* sp. feeding on mealybugs on *Araucaria heterophylla*, Arderne Botanical Garden

Fig. 88. Leaf marginal notching, typical of adult weevil feeding, Arderne Botanical Garden

Fig. 89. *Protopulvinaria pyriformis* on the lower-surface of *Schefflera* foliage, Arderne Botanical Garden

Fig. 90. *Icerya seychellarum* on *Archontophoenix cunninghamiana*, Arderne Botanical Garden

4.1 Durban Botanic Gardens

The Durban Botanic Gardens is situated in the city of Durban, KwaZulu-Natal. It is Durban's oldest public institution and Africa's oldest surviving botanical gardens. The gardens cover an area of 15 hectares (37 acres) in a subtropical climate.

Plant pathogens observed at the garden include:

- Suspect ***Phytophthora*** sp. was observed on *Podocarpus*.
- A bracket fungus, potentially ***Ganoderma*** was also observed.

Plant pests observed at the garden and/or in Durban include:

- African citrus psyllid ***Trioza erytreae*** galls were abundant on *Citrus limon* (Fig. 92) and *Murraya koenigii* (Fig. 91) in the Durban Botanic Gardens. This species is discussed above.
- Cycad aulacaspis scale ***Aulacaspis yasumatsui*** (Figs 93-94) was observed on some cycads, mainly exotic species, and had killed some large *Cycas revoluta* in the Durban Botanic Gardens. Native cycad species appear to be less susceptible. This species is discussed above.
- ***Pulvinaria delottoi*** Gill (Hemiptera: Coccidae) (Figs 95-96) was abundant on *Mesembranthymum* in Durban. It is native to South Africa and invasive in California, USA (Gill, 1979). It has also been found on imported plants in the UK (Salisbury *et al*., 2011).
- White powdery scale ***Pseudocribrolecanium andersoni*** (Newstead) (Hemiptera: Coccidae) (Fig. 97) was abundant on *Strelitzi nicolai* plants in Durban. It is polyphagous and an occasional pest of Citrus. It is native to Africa and invasive in Asia. It has occasionally been intercepted in the UK on imported plant material.
- Palm aphid ***Cerataphis*** sp. (either *brasiliensis* (Hempel) or *lataniae* (Boisduval)) (Hemiptera: Aphididae) (Fig. 98) were abundant on coconut *Cocos nucifera* and smaller populations were present on *Strelitzia nicolai*. They are native to South East Asia but are now widespread in tropical and subtropical areas of the world. The precise distribution is unclear due to confusion between the two species.
- Mussel scales ***Lepidosaphes*** sp. (Hemiptera: Diaspididae) were abundant on *Strelitzi nicolai* plants in Durban. No species of *Lepidospahes* are recorded feeding on *Strelitzia* on ScaleNet, a web-based catalogue of the scale insects of the world (http://scalenet.info/catalogue/). There were several other species of mealybug (Pseudococcidae) and armoured scale insects (*Aspidiotus* sp., Diaspididae) on the same plants.
- In addition to invertebrate plant pests, the grey squirrel ***Sciurus carolinensis*** (Fig. 78), native to deciduous forests in the USA, has been introduced to parts of South Africa, where it has become a serious pest due to its habit of stripping tree bark.

Fig. 91. *Trioza erytreae* galls on Murraya in Durban Botanic Gardens

Fig. 92. *Trioza erytreae* galls on Citrus in Durban Botanic Gardens

Fig. 93. *Aulacaspis yasumatsui* on cycad, Durban Botanic Gardens

Fig. 94. Cycad scale *Aulacaspis yatsumatsui* kills susceptible cycad species such as *Cycas revoluta,* Durban Botanic Gardens

Fig. 95. *Pulvinaria delottoi* on *Mesembyanthemum*, Durban

Fig. 96. Teneral adult female *Pulvinaria delottoi* with ovisac, Durban

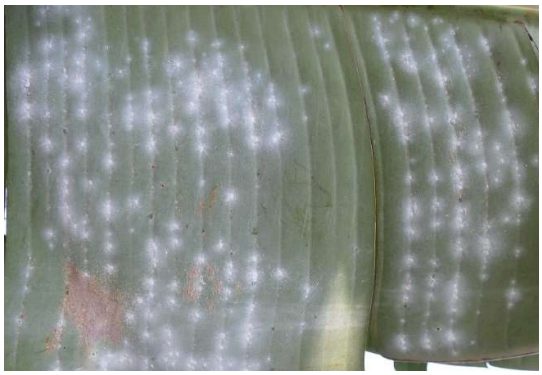

Fig. 97. White powdery scale *Pseudocribrolecanium andersoni* on *Sterlitzia nicolai* in Durban

Fig. 98. Palm aphid *Cerataphis* on *Cocos nucifera* in Durban

6. Potential future plant health threats in South Africa

One of the topics discussed at the workshop was potential future plant health threats in South Africa posed by alien invasive invertebrate species. The pests were selected by the first author, largely based on recent field experience in the Mediterranean and Caribbean. This is not an official NPPO list or a list of regulated organisms and is not based on pest risk assessments. It is also not a comprehensive review of future plant health threats in South Africa but merely examples of potential plant health risks.

There were several difficulties in compiling a list of potential plant health threats in South Africa including the size of the country, the range of climatic zones and the enormous biodiversity of plants. There are hundreds of alien invasive invertebrate species that could potentially be harmful if accidently introduced to areas of South Africa with climatic suitability and host availability. Many of the examples listed below were selected as they are invasive in the Mediterranean with a similar subtropical climate to parts of South Africa. Other species were selected as they are invasive in the Caribbean with a tropical climate, like northern areas of the country. A few of the pests are already present in parts of South Africa but have the potential to expand their distribution, and some were chosen as they have only recently become invasive and there is little published information available.

The pests are divided between those that could have an economic, environmental or social impact. However, this division is rather artificial as many of these species could have more than one type of impact depending on the locality and hosts affected. All invasive species that have a significant economic impact are also likely to have a social impact. Further information on many of the pests listed below is available from CABI Invasive species compendium (www.cabi.org/isc/), Invasive Species Specialist Group (http://www.issg.org/index.html), Invasive Species South Africa (http://www.invasives.org.za/#) and references cited therein.

6.1 Examples of invertebrate plant pests with a potential economic impact

Fruit Flies – Tephritidae

Fruit flies are among the most economically important and invasive plant pests in the world. There are many non-native species assigned to the genera *Anastrepha, Bactrocera* and *Rhagoletis* that are potential economic pests in South Africa (White & Elson-Harris, 1992). Not only can the fruit fly larvae affect crop production directly, they can affect exports and eradication is extremely difficult and expensive. One example is the oriental fruit fly *Bactrocera dorsalis* which is still widely known in Africa under its junior synonym *B. invadens*. *Bactrocera dorsalis* is native to Asia and was introduced to Kenya in about 2003. It has subsequently spread rapidly across sub-Saharan Africa. It feeds on a wide range of hosts, including mango, guava, citrus and banana. It has had a massive economic impact in Africa, for example Kenyan mango farmers lost $1.7 million in two years. Since 2015 it has been found in several provinces in South Africa and is being monitored by the NPPO (there are fruit fly traps placed in the Pretoria National Botanical Garden).

Spotted-wing drosophila – *Drosophila suzukii*

Native to Asia, introduced to N. America in 2008 and the Mediterranean in the following year, spotted-wing drosophila is a pest of a range of soft fruits including cherry, peach, raspberry, blackberries, blueberry and strawberry (EPPO, 2010).

Banana root borer / Banana weevil – *Cosmopolites sordidus*

Present in tropical areas in Asia, Africa, southern USA, Central and South America, Caribbean and the Pacific (Woodruff & Fasulo, 2015), banana root borer feeds on Manila hemp, plantain, sugar cane, yam and all varieties of banana and is a serious pest of banana throughout the world. Most damage is done by the larvae tunnelling in the corm, thus weakening the plant and causing blow-down by even slight winds. There are many other exotic species of weevil (Cucurlionidae) which are potentially harmful in South Africa.

Brown marmorated stink bug – *Halyomorpha halys*

Native to East Asia, introduced to North America (1996) and Europe (2004) (Malumphy & Eyre, 2015a), marmorated stink bug is polyphagous (100 spp.), feeding on numerous crops. It is a major plant pest and was called the 'billion-dollar bug' by the media in the USA as susceptible crops where the bug occurs are worth $40 billion. Severe damage results from the adults and nymphs feeding on pome and stone fruits, and on seeds inside legume pods. In cases of heavy infestations, fruit are severely disfigured and rendered unmarketable. Adults can also be a nuisance by aggregating in buildings in Autumn.

Avocado lace bug - *Pseudacysta perseae*

Native to Florida, USA, recently spreading through Caribbean and northern parts of South America, avocado lave bug is oligophagous on Lauraceae, including avocado (*Persea americana*), camphor (*Cinnamomum camphora*), red bay (*P. borbonia*) and swamp bay (*P. pallustris*). It can cause complete defoliation of avocado (Malumphy & Reid, 2017b).

Tobacco whitefly – *Bemisia tabaci*

Tobacco whitefly is a complex of morpho-cryptic species. It is cosmopolitan and broadly polyphagous, feeding on 800+ plant species. This is one of the world's most important agricultural pests as it vectors more than 111 plant pathogenic viruses (Malumphy, C. & Reid, S. 2017e).

Solanum Whitefly – *Aleurotrachelus trachoides*
Native to the Neotropical region it is spreading in the Caribbean and has been introduced to Africa and Asia. Polyphagous (28 families) but exhibits a preference for Solanaceae. Solanum whitefly is a potential pest of pepper and tomato (Malumphy, C. & Reid, S. 2017f).

Ficus Whitefly – *Singhiella simplex*
Native to Asia, introduced to the Mediterranean, USA, S. America and parts of the Caribbean (Avery *et al*., 2011; Kondo & Evans, 2013). It is unusual for a whitefly as the puparia (Fouth-larval instar) are common on both leaf surfaces; adults have pale banded wings. It feeds exclusively on *Ficus* but not edible fig *Ficus carica*. It is an occasional pest causing complete defoliation.

Shefflera whitefly – *Dialeurodes schefflerrae*
Native to Asia, introduced to Florida, Hawaii and Puerto Rico. Spreading in the Caribbean, shefflera whitefly feeds exclusively on *Schefflera* and is an occasional pest of ornamentals (Hodges & Dooley, 2007).

Pink hibiscus mealybug – *Maconellicoccus hirsutus*
Native to Asia, spread widely in Africa since the 1980s, in the Neotropics since the 1990s (Hoy, Hamon & Nguyen, 2014) and recently introduced to the Mediterranean. Pink hibiscus mealybug is polyphagous (78 families) feeding on many crop and ornamental plants. It is a major pest, rapidly killing susceptible plants.

Solenopsis or cotton mealybug – *Phenacoccus solenopsis*
Native to southern North America, Solenopsis mealybug has spread rapidly since the 1990s through the Afrotropical, Australasian, Nearctic, Neotropical, and Oriental regions, and recently established in the Mediterranean (Hodgson *et al*., 2008). It is polyphagous (54 families), exhibiting a preference for Asteraceae, Euphorbiaceae, Amaranthaceae, Cucurbitaceae, Malvaceae and Solanaceae. Solenopsis mealybug is one of the most economically important mealybug pests worldwide and is a major economic pest of cotton, tobacco and vegetables. It is common on vegetable crops in West Africa.

Bougainvillea mealybug – *Phenacoccus peruvianus*
Native to South America, recently introduced to Europe and the Mediterranean (Malumphy & Eyre, 2015b). It is polyphagous but shows a preference for Bougainvillea. It can cause serious damage to ornamentals and has affected an organic pepper crop grown under protection in central Europe.

Fall army worm – *Spodoptera fugiperda*
Native to tropical and subtropical regions of the Americas. Polyphagous (26 families), damages several crops including maize. In 2016 it was reported for the first time in Africa with outbreaks in Benin, Nigeria, Sao Tomé and Principe and Togo. In 2017 *S. frugiperda* spread to 17 other countries and is still spreading. Virtually indistinguishable from other *Spodoptera* spp in the field. In July 2017, a socio-economic survey has been conducted in Ghana and Zambia. The estimated national mean loss of maize in Ghana was 45% and in Zambia 40%. Based on this data, the potential impacts on maize yield and revenue in 10 other major maize-producing countries of Africa have been estimated. The estimated mean yield loss was 16,105,000 tonnes and estimated economic loss ranged from 2,482 to 6,187 million USD (Abrahams *et al*., 2017).

6.2 Examples of invertebrate plant pests with a potential environmental impact

Long horn beetles – Cerambycidae – *Anoplophora* spp.

There are many non-native species of long horn beetle that could potentially have a high environmental to trees in South Africa. Two examples are the citrus long horn beetle *Anoplophora chinensis* (Anderson, Eyre & Giltrap, 2016) and Asian long horn beetle *A. glabripennis* (Forestry Commission, 2017). Both species are native to Asia and are polyphagous. There have been many outbreaks of both species in Europe. The main pathway of introduction for *A. chinensis* has been with larvae tunnelling inside living plants (bonsai, penjing and maple rootstock from China) and *A. glabripennis* with wood packaging materials (dunnage).

Polyphagous shot hole borer and Fusarium Decline – *Ewallacea* spp. and *Fusarium euwallaceae*

There are three or more cryptic ambrosia species in the *Ewallacea* complex which are native to SE Asia. Three of these have invaded the USA: two species in California and a third species in Florida and Hawaii. In California and northern Mexico, they have killed thousands of trees, including avocado. The beetles vector fungi (*Fusarium euwallaceae*, *Graphium* sp. and *Sarocladium* sp.) (Freeman *et al*., 2013) which block the vascular tissue and kills the host. It can have up to 8 generations each year. Symptoms vary significantly with host species and may consist of discoloured bark, sugary exudate, sap-oozing, staining, gumming, piles of frass, clusters of small emergence holes, associated woodpecker damage, crown thinning, dieback and death.

Sri Lankan weevil – *Myllocerus undecimpustulatus*

Native to Sri Lanka, introduced to Florida in 2000 and spreading in the Caribbean. It is polyphagous feeding on 150+ plant species including native, ornamental, vegetable and fruit species. It exhibits a preference for Fabaceae (Thomas, 2005; Neal, 2013; Malumphy & Reid, 2017a).

Xylem-feeding auchenorrhyncha bugs (hoppers) and *Xylella fastidiosa*

Xylella fastidiosa is a xylem-limited bacterium that has had an enormous impact in Europe, killing thousands of olive trees In Italy (EPPO, 2017). All xylem-feeding auchenorrhyncha bugs (frog hoppers, spittle bugs, sharp shooters, leaf hoppers) are potential vectors although the only confirmed vector in Europe is the meadow spittle bug *Philaenus spumarius*. There are many potential vectors in South Africa and *Xylella fastidiosa* could potentially have a huge environmental, economic and social impact.

Croton scale – *Phalacrococcus howertoni*

Native to the Neotropics but precise area unknown, introduced to Florida in 2008 and spreading across the Caribbean (Hodges, G.S. & Hodgson, C.J. 2010; Malumphy & Reid, 2017d). Polyphagous (36 families) plant pest, attacks fruit trees, ornamentals and native plants.

Lac lobate scale – *Paratachardina pseudolobata*

Native to Asia, introduced to Florida (1999) and spreading across the Caribbean, also introduced to Christmas Island. Polyphagous (62 families), attacking numerous ornamental, vegetable and fruit crops and native plants. Dense populations cause dieback and in severe cases mortality Kondo & Gullan, 2007; Howard et al., 2008; Malumphy & Reid, 2017c).

Platanus lacebug – *Corythucha ciliata*
Native to North American, introduced to Italy (1964) and spread widely in Europe (Malumphy *et al*., 2007). Feeds on *Platanus* spp. causing severe chlorosis and premature loss. Suspected to be a vector of *Ceratocystis platani* and *Apiognomonia veneta*.

Asian Ficus psyllid - *Macrohomotoma gladiata*
Native to Asia, recently introduced to the Mediterranean where it is a pest of ornamental *Ficus microcarpa* (Pedata, Burckhardt & Mancini, 2012).

6.3 Examples of invertebrate plant pests with a potential social impact

Red palm weevil – *Rhynchophorus ferrugineus*
Native to parts of Asia, introduced to Europe and the Mediterranean. This beetle is the most important pest of date palm in the world and a serious pest of coconut and ornamental palms, killing susceptible palms. It has changed the landscape in the Mediterranean where thousands of mature palms have been killed. It has the potential to have a significant economic, environmental and social impact when introduced into new areas (Malumphy, Eyre & Anderson, 2016).

Ants – Formicidae
Ants are not usually direct plant pests but are often introduced with imported ornamental plants and can have a huge social and environmental impact. They can invade houses, and some can sting/bite. Invasive ants species of concern in South Africa include Crazy ant (*Anoplolepis gracilipes*), Argentine ant (*Linepithema humile*) and Fire ants (*Solenopsis* spp.).

Agapanthus gall midge – *Enigmadiplosis agapanthi*
Agapanthus gall midge is suspected to be native to South Africa and has been introduced to England where it is a serious pest of *Agapanthus* spp., popular ornamental plants. This gall midge was only described in 2016 and is currently being studied in England (Harris, Salisbury & Jones, 2016). It may be invasive if introduced into new areas of South Africa.

Bumble bee millipede – *Anadenobolus monilicornis*
Native to Neotropical region and spreading in the Caribbean region, populations of bumble bee millipede can explode after rain and be a nuisance as they crawl up the walls of hotels and apartments. When crushed they release a toxic irritant that can cause a chemical burn to skin and tourists are wary of large numbers of millipedes (Gabel *et al*., 2006).

7. Discussion and Outcomes

Plant Pest Monitoring and Prevention workshops were delivered at three SANBI National Botanical Gardens (KwaZulu-Natal, Kirstenbosch and Pretoria) during November 2017. Subjects covered included: progress of the IPSN and advantages of membership; the importance of sentinel plants; the importance of biosecurity; an introduction to invertebrate plant pests; alien invasive insects that may pose a future threat to plant health in South Africa; fungal pathogens including *Armillaria*, *Ganoderma* and *Phytophthora*; *Euwallacea* sp. and Fusarium Dieback; and best practices in garden maintenance. Practical sessions included stem-injection with potassium phosphite to mitigate the impact of *Phytophthora*; detecting and identifying causes of poor plant health; and pruning. More than 120 delegates attended the workshops including horticultural students, staff from SANBI and non-SANBI botanical gardens, municipalities, nurseries and the Department of Agriculture Forestry

and Fisheries. The workshops provided the delegates with a wealth of new knowledge, increasing their awareness of the threat from alien invasive species and the importance of biosecurity. The delegates shared experiences and best practices, developed networks, and discussed ways to disseminate the information more widely. There was excellent engagement by the participants during all three workshops.

Two non-SANBI gardens, Durban Botanic Gardens and Arderne Gardens, were also visited to look for evidence of alien invasive plant pests.

One concern highlighted during the workshops in KwaZulu-Natal and Kirstenbosch was the lack of entomological diagnostic support, or at least it was unclear who was responsible for the identification of suspected invasive or new insect pests. There was some ambiguity as to whether DAFF had the resources and expertise to deal with large numbers of such samples. One proposal was that SANBI could support FABI to employ an entomologist to help with the identification of suspected alien pests at SANBI gardens. This would complement the research carried out by the second author.

The most important plant health concerns observed in the botanical gardens included the fungal pathogens: honey fungus *Armillaria* spp., bracket fungus *Ganoderma* spp. and *Phytophthora* spp. These pathogens are causing significant dieback and mortality. For example, the invasive fungus *P. cinnamomi* is killing large numbers of endemic Proteaceae at Kirstenbosch and more than 6000 plants are needed to replace the losses each year. However, it is important to note that plant decline and mortality are often caused by a combination of abiotic (soil compaction, drought, root damage etc) and biotic (pest and pathogen) factors. Investigations of *Phytophthora* spp. present at Kirstenbosch revealed the presence of *Phytophthora asparagi,* the causal agent of spear and root rot of asparagus (Granke *et al*., 2012; Saude *et al*., 2008). This is the first report of this pathogen in South Africa. A major new plant health threat recently detected by Trudy Paap is the polyphagous shot hole borer *Euwallacea* sp. and Fusarium Dieback which threatens the iconic London Plane Avenue in KwaZulu-Natal. This Asian invasive beetle has established in an area between Durban and Pietermaritzburg and occurs in wild populations of *Ricinus communis*. An exotic plant pest alert for the beetle and fungus was distributed at the workshops. It could also potentially have a high impact on the avocado industry. The invasive cycad scale (*Aulacaspis yatsumatsui*) was observed at the Durban Botanic Gardens and several other scale insect species were observed damaging aloes, cycads and hibiscus in Pretoria. Of particular interest was *Aspidiotus* ?*capensis* causing severe damage to a Lebombo cycad *Encephalartos senticosus* which is classified as "Vulnerable" in the IUCN Red List of Threatened Species. An enormous population of *Lecanodiaspis* sp. was observed killing hibiscus plants in Pretoria. Samples of infected plant material, soil and fungi were collected for further analysis and a small number of insect plant pests were also taken to the UK for identification.

South Africa was formerly colonised by Europeans and one of their legacies is the widescale planting of European plant species, especially in urban areas. This has resulted in large numbers of mature European trees being present along streets and in parks, examples include *Fagus sylvatica*, *Quercus robur*, *Platanus* x *acerifolia* and *Pinus pinea*; and *vice versa*, many South African plants, for example in the genera *Agapanthus, Aloe*, *Clivia*, *Gerbera* and *Pelargonium*, are widely grown as ornamentals in Europe. If monitored, these plants can serve as sentinel plants to provide an early warning system of new and emerging pest and pathogen risks.

It is interesting to note that the English Oak *Quercus robur* in the UK supports an enormous number of invertebrates and the foliage in summer is almost always covered in cynipid galls, such as the spangle and silk button galls (Fig. 99). Numerus *Quercus robur* were examined in Table Mountain National Park, Cape Town, and the foliage was found to be free of pests (Fig. 100), except for occasional mildew.

It is recommended that the botanical gardens in South Africa support the IPSN and monitor their exotic plant collections (sentinel plants) for pests and diseases to provide an early warning system for future plant health threats. The workshops on 'Plant Pest Monitoring and Prevention' were well received and it is recommended that further workshops/training on biosecurity are held at all the SANBI gardens and non-SANBI gardens. It is also recommended that the surveys and research begun by the second author of potentially invasive pests and pathogens on native and exotic plants at the SANBI and non-SANBI gardens be continued. This will help identify new introductions and provide baseline data of the pests and pathogens already introduced and naturalised in South Africa.

Fig. 99. *Quercus robur* foliage in the UK covered in common spangle galls *Neuroterus quercusbaccarum* and silk button galls *N. numismalis*

Fig. 100. *Quercus robur* foliage in Cape Town without any galls or insect feeding damage

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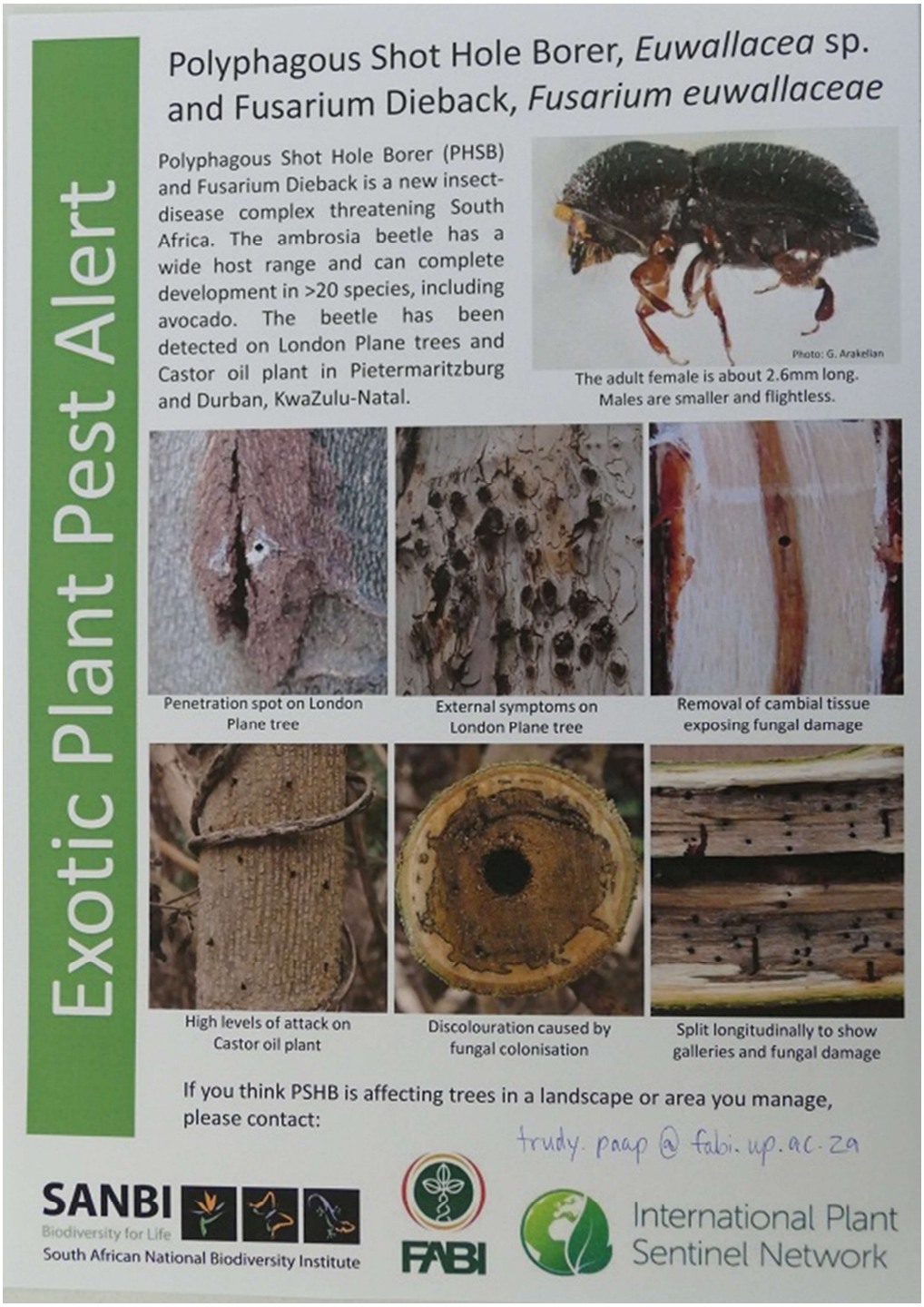
10. Appendix


Exotic Plant Pest Alert
Polyphagous Shot Hole Borer, Euwallacea sp. and Fusarium Dieback, Fusarium euwallaceae
Polyphagous Shot Hole Borer (PHSB) and Fusarium Dieback is a new insect-disease complex threatening South Africa. The ambrosia beetle has a wide host range and can complete development in >20 species, including avocado. The beetle has been detected on London Plane trees and Castor oil plant in Pietermaritzburg and Durban, KwaZulu-Natal.
Photo: G. Arakelian
The adult female is about 2.6mm long. Males are smaller and flightless.
Penetration spot on London Plane tree
External symptoms on London Plane tree
Removal of cambial tissue exposing fungal damage
High levels of attack on Castor oil plant
Discolouration caused by fungal colonisation
Split longitudinally to show galleries and fungal damage
If you think PSHB is affecting trees in a landscape or area you manage, please contact:
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