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A new approach to stopping the spread of invasive insects and pathogens: early detection and rapid response via a global network of sentinel plantings†

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Abstract

The Sanitary and Phytosanitary Agreement of the World Trade Organisation specifies that countries cannot regulate against unknown pests, yet many alien invasive forest pests are unknown to science prior to discovery in a new land. Many of these pests are introduced via nursery stock, but lack of pest information makes this pathway difficult to mitigate. Botanic gardens and arboreta worldwide offer a unique opportunity to help detect potential invasive threats to forest health before they spread. Monitoring pests in gardens with international collections could inform prevention activities as well as help promote early detection and rapid response to new pest incursions. While recognising the inherent value of single country-pair studies currently ongoing, and the scientific integrity expected of resulting peer-reviewed publications, we believe opportunities for synergy across these efforts and for more immediate response to new host-pest associations should be explored. The strengths and weaknesses of various current approaches to sentinel plant monitoring are described, as well as a strategy for developing a worldwide network of gardens sharing information on pests that would extend the lessons learned and direct timely information to National Plant Protection Organisations to enhance protection of natural resources.

Keywords: pathway; prevention; invasive pests; sentinel plant network.

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Introduction

Botanic gardens all over the world offer a unique resource to help detect potential invasive threats to forest health. Like the European traveller to the Amazon with no resistance to malaria, expatriate plants established in botanic gardens and arboreta everywhere are standing sentinels for potentially invasive pests. With a combination of rigorous scouting and open sharing of information, botanic garden pest managers can provide advance warning for potential pests for every country represented in their collections.

Nursery stock is well-recognised as a major pathway for the introduction of invasive insects and pathogens to native ecosystems. For many agricultural products, the pests abroad are fairly well-known. However, when it comes to forest pests, plant health regulators in

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every country are stymied by lack of knowledge about what pests they should be watching for. Furthermore, the growth in volume of international plant trade has greatly diluted the protection that can be achieved by inspection at ports of entry. In 2002, a United States National Research Council study recommended expatriate plant monitoring as one of 12 ways to improve the prediction of invasions of non-indigenous plants and plant pests (Mack et al., 2002).

The scientific community recognises that international communication and collaboration offer the best hopes for preventing new pest incursions. Several pest databases on the worldwide web catalogue known pests, such as the University of Georgia's "Bugwood Network" (n.d.), The European Commission's "Delivering Alien Invasive Species In Europe" (DAISIE, n.d.), and North American Forestry Commission's "Exotic Forest Pest information system" (EXFOR, n.d.). However, pest information is often not available to such websites until the scientists publish their investigations, which can result in a delay of one to two years. In addition, many of the worst forest diseases, such as sudden oak death (*Phytophthora ramorum* Werres, De Cock, & Man in t'Veld), Dutch elm disease (*Ophiostoma ulm*i (Buisman) Nanff.) and dogwood anthracnose (*Discula destructiva*, Redlin) were unknown to science prior to their introduction into a new land. In fact, scientists estimate that fewer than 7% of the world's fungi are currently known to science (Crous & Groenewald, 2005). How can pests and their potential impact be identified before they arrive? A network of participating botanic gardens and arboreta, committed to sharing information about pests observed on non-native host plants, would allow nurserymen and plant health care professionals to sharpen scouting efforts and develop mitigation programmes to stem the tide of alien insect pests and diseases. In return, gardens would receive diagnostic support that could help preserve their valuable germplasm collections.

Gardens with diverse international plant collections are invited to participate in a Sentinel Plant Network. Staff at participating gardens will monitor their collections and report any unusual pest (insect, disease, and weed) problems. Diagnostic support and a clear reporting system will ensure taxonomic accuracy and prompt, effective use of the information to inform prevention, and promote a rapid response. If an unusual pest is detected on an introduced plant, experts overseas can help to stop or slow further movement of the pest from its source. If the problem is a local pest found for the first time on an exotic host plant, counterparts overseas will be grateful for an early warning that such a pest exists. If hosts are moving in trade, the relevant National Plant Protection Organisations (NPPOs) will take steps to ensure that such exchanges are from clean stock only.

Efforts in Progress

1. The New Zealand expatriate plant five-year pilot programme co-ordinated by Biosecurity New Zealand (part of the Ministry of Agriculture and Forestry) is a good model for demonstrating that systematic observation of native plants overseas is effective in enhancing natural resource protection (Fagan, 2008). Various collections databases were analysed to identify botanic gardens world-wide with strong collections of plants of New Zealand origin. Climate matching was used to target gardens most similar to New Zealand; gardens were ranked and the 14 top gardens were visited with a "blitz" approach by New Zealand experts in virology, ecology, entomology, nematodes and plant pathology. Using a standard survey protocol designed for non-experts, 91 attacks were observed, 32 pest taxa were identified, and 10 new host/pest associations were discovered. Mealy bugs, scale insects, nematodes and fungal pathogens were the most commonly collected pests. For example, the exotic foxglove aphid, *Aulacorthum solani* (Kaltenbach) was discovered in a German botanic garden. This pest is of concern because it has ten other known New Zealand host associations and is capable of vectoring more than 40 plant viruses, Unfortunately, there were difficulties in diagnosing plant pathogens, so many of these risks remain un-assessed. A thorough analysis of the potential of this programme, including cost/benefit comparisons of various approaches and recommendations has been reported by Fagan et al. (2008). To date, however, the programme has not been fully implemented.

2. The European Union (EU) established collaborative plantations of European trees in two locations in China in 2008. Dedicated plantations have the advantage of statistically rigorous design and frequent monitoring. Substantial mortality occurred in the first year after planting, and the pests collected are currently being identified (Alain Roques, Unité de Recherches de Zoologie Forestière, Institut National de la Recherché Agronomique (INRA), personal commmunication).

3. The Centre for Agriculture and Biosciences International (CABI) is collaborating with entomologists to monitor existing European trees in arboreta in Russia (Marc Kenis, Forestry and Ornamental Pest Research, CABI Europe-Switzerland, personal commmunication).

4. In the wake of the discovery of the Asian longhorned beetle, the United States Department of Agriculture (USDA) - Animal Plant Health Inspection Service (APHIS) collaborated with scientists in China to establish plantings of potential hosts. In addition,

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the USDA Forest Service recently collaborated with Chinese scientists to assess the possibility of monitoring existing plantings of North American trees in Chinese botanical gardens, plantations and nurseries. Most of the trees of interest in the botanical gardens are large, and collecting pests from the canopy has proven to be problematic. Use of "knockdown" insecticides is being considered.

The four different approaches described above all have strengths and weaknesses. Fagan et al. (2008) compared the advantages and disadvantages of several scenarios for New Zealand, and recommended a "do-it-yourself" approach, involving a team of New Zealand scientists visiting gardens regularly. This approach has the advantages of direct control of the survey method and its intensity, and diagnostic quality control. Disadvantages of this approach include the expense of international travel, and possible unfamiliarity of New Zealand experts with local pests. Furthermore, a "blitz" approach can only capture pests present at a single point in time, while pests may flit in and out seasonally. In addition, it is often difficult to transport samples from one country to another, and this limited their ability to identify all the pests that were found – particularly fungi.

The EU project staff encountered difficulties in exporting seedlings, with the first shipment languishing in customs so long that many plants had to be replaced. Since pests of seedlings and saplings are sometimes different than those of mature trees, it might be best to try to merge the new plantation approach with one that looks at well-established hosts.

The CABI project is currently focused on a single country of origin, and is expected to provide valuable information on that source. However, the ability of countries to carry on such projects with every trading partner is limited. Benefits would multiply if countries conducting such country-pair studies could find a way to share the data globally.

One untapped resource is the existing international network of botanical gardens and arboreta. Many gardens with international collections already have staff who monitor their collections daily and examine any ailing plants. In many cases, if problems cannot be diagnosed locally, pest experts are consulted. However, the information on these host/pest associations is not being systematically collected and shared. In addition, plant failure is often attributed to poor adaptation to local climate without benefit of a professional diagnosis. Enhancing the ability of garden staff to identify problems and providing them with professional diagnostic support would enhance the probability of new pests being detected and reported.

We envision a "Sentinel Plant Network" where each participating botanic garden has appropriately trained specialists and diagnostic support, and a clear reporting system for new pest finds. This would greatly increase the scope of monitoring activities and the speed with which detections can be reported. Botanic gardens and arboreta could also provide outreach to amateur gardening enthusiasts, who would then be recruited to monitor and report pests in much the same way that Master Gardeners trained by State Cooperative Extension Services provide this information for residential landscapes in the United States of America (USA). The Extension Services that manage the Master Gardener programmes provide laboratories that screen pest finds and report new incursions to APHIS. Thus, in addition to informing prevention efforts in the same manner as country-pair studies, this approach would also enhance opportunities for early detection and rapid response nationwide for the host country.

The United States Department of Agriculture - Animal Plant Health Inspection Service recently funded two collaborative projects to foster the development of this "Sentinel Plant Network". The American Public Gardens Association (APGA) received funding to develop a training and outreach campaign for botanic gardens. The APGA will work with the USDA National Institute for Food and Agriculture (NIFA) to develop training modules to teach garden staff how to identify and report plant pests. This will help gardens to protect their collections, and to get better diagnostic support and control recommendations. The grant will also help gardens enhance their outreach programs, enlisting plant lovers everywhere in the effort to detect new pests as soon as they arrive.

Botanic Gardens Conservation International (BGCI) also received funding from APHIS. Botanic Gardens Conservation International currently maintains online databases of resources at member gardens (BGCI, 2009). They will increase the scope and content of two existing global botanic garden databases in order to support key components of the Sentinel Plant Network. They will enhance data representation in China and eastern European countries, where botanic garden representation in the databases is lower than in other regions. They will add information on where expertise in horticulture, taxonomy, mycology and entomology can be found in the world's botanic gardens. Finally, they will add information on which plant species demonstrate weediness in their new climate or location. These two programmes will help APHIS, growers, agencies, and researchers predict when and where future outbreaks may be likely in order to prevent them.

Gardens Willing

In the United States of America, staff at every one of the ten major botanic gardens and arboreta we have contacted have indicated a desire to participate. The

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APGA will work with Extension Service personnel to develop training materials for garden staff and for garden outreach programmes. Of the 600 garden members in BGCI, 455 have signed an "international agenda" directed primarily toward preserving biodiversity. Helping to prevent new pest introductions would clearly promote this goal. Public gardens are frequently supported by volunteer organisations of "Friends", many of whom are also private plant collectors.

This "Sentinel Plant Network" of participating botanical gardens also has limitations. First of all, the small number of representatives for different plant taxa present in any one garden will reduce the likelihood of pest infestation and pest detection. Furthermore, gardens are often located in urban environments which may have fewer forest pests than rural environments. Management practices in botanic gardens aim to reduce pests, again reducing detection likelihood. And lastly, diagnostic expertise is unavailable in many locations to support definitive identifications. International collaboration is recommended to overcome this last obstacle, as support for systematic in general is a serious need everywhere.

Diagnostic Infrastructure in the USA

After September 11, 2001 the United States Congress mandated the formation of a broad spectrum national response system. For agricultural threats, this effort was led by the Cooperative States Research, Extension and Education Service, recently renamed NIFA, which provides funding for the land-grant university system. Each land-grant university already had a diagnostic laboratory, but these are now linked to form a National Plant Diagnostic Network (NPDN). Recent events such as the 2004 diaspora of *Phytophthora ramorum*-infected plants from a California nursery, and more recent incursions of chrysanthemum white rust (*Puccinia horiana*, Henn) and *Ralstonia solanacearum* race 3 biovar 2 (Smith) Yabuuchi have exercised this system, and it has begun to function as designed. National Plant Diagnostic Network laboratory staff report unusual finds to colleagues at regional "hub" laboratories, who then feed information to the APHIS, which has legal authority to deal with new pest arrivals into the USA.

Because these university laboratories have a long history of providing diagnostic services and management advice, they are willing to help identify pests in their State, and direct clientele to experts who can provide management strategies. If the pest is both new and exotic, a standard reporting protocol is activated, engaging plant health regulators to deal with new pests that may have arrived with the plant in the USA. Counterparts overseas may be able help mitigate the problem where possible and appropriate but only if they are aware that there is a problem. If the problem is endemic to the region of the garden and not known in the country of origin for the host plant, counterparts overseas would be grateful for information that such a pest exists, so they can ensure that plants moving in trade are pest-free.

A more holistic approach is needed for global information sharing

As seen above, each approach to identifying new pest/host associations has its strengths and weaknesses. Taken together they can provide richer information about the full suite of potential pests. The international community of scientists needs to consider how to maximise the benefits that can be accrued from these efforts. Everyone agrees that information about what pests exist and what plants they will attack is sadly lacking. Can we collect information from ongoing and new studies into some central repository, or use a data portal system, to make information more useful for informing prevention activities world-wide?

Two kinds of pest information are needed:

> One need is a user-friendly source of diagnostic information searchable by host, so that both garden personnel and the interested public can try to answer the question: "What's eating/killing my plant?" A list of pests in categories that link to photographs and on to biology and control information would be most useful. A button to allow input of postal code or address information to locate the nearest appropriate diagnostic laboratory would help ensure follow up on questionable samples. Individual countries would have to provide the diagnostic infrastructure to serve this need, but the investment might pay off in avoided damages.
>
> The second type of data needed is pest (both native and exotic) occurrence data that can be sorted by host and location. These data are needed by regulators who want to answer the question "What are the risks associated with Plant X imports from Country A, B or C?

Despite the fact that pest data-sharing is a country responsibility identified in International Standard for Phytosanitary Measure number 8, the current reality is a stark contrast to the vision above. Information on pest occurrence is currently published sporadically in a dispersed fashion on a host of pest-oriented websites, which mostly require some expertise to navigate. Several regional plant protection organisations issue phytosanitary alerts when new pests are discovered or when pest status changes substantially, but this information is not currently compiled in the most useful way. Most websites fail both groups of users because the data cannot be sorted by host plant. Native pests are generally included only if regulated by other countries. If the International Plant Protection

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Convention Secretariat or the United Nations Food and Agriculture Organization were to undertake the development and maintenance of a more complete and usefully organised pest list, NPPOs could control pest listings, ensuring data quality.

Various other global approaches are already underway. The Global invasive Species Information Network (GISIN), for example, is a distributed data system which uses a single web portal to "mine" data from a number of sites maintained by vetted academic sources who agree to use a common minimum set of data fields. At present, however, forest insect pest and disease records are sparse in GISIN as well as all other global invasive species databases, which tend to greater depth in invasive vertebrates and plants.

Collections information:

Most gardens retain information on the sources of plants in their collection equivalent at least to what would be found on a herbarium specimen label. Many botanic gardens and arboreta are working to place their collection catalogues on the worldwide web. This means collection information will be very accessible to collaborators overseas. For example, the Chicago Botanic Garden, in collaboration with American Public Gardens Association (APGA), the University of Kansas, and 15 public gardens nationwide, is developing *PlantCollections*, a distributed database system for web-based querying that will allow information from multiple institutions currently in a variety of incompatible database formats to be accessed and integrated into comprehensive inventories. The results can then be analysed to identify gaps and redundancies within the combined holdings, a first step in coordinating a continent-wide approach to plant germplasm preservation. This 3-year project will strengthen relationships among the participating institutions and foster the sharing of information with the public.

As discussed above, BGCI currently maintains online databases of resources at member gardens. The international *PlantSearch* database (BGCI, 2009) currently contains 575,000 records of taxa found in botanic garden collections around the world. These resources will be useful for identifying key gardens in prioritising our recruitment efforts.

Conclusions and Call for Action:

Several notable efforts are underway to use the "Sentinel Plant" concept to predict and prevent new invasive forest pests. The science and regulatory communities should provide the systematic expertise to support quality diagnosis of pests, and a system, be it a central repository or data portal that can be sorted by host plant, to more effectively inform prevention activities. Perhaps using "distance diagnosis" countries can help each other to meet critical systematic needs.

Many botanic gardens and arboreta are willing to participate in a Sentinel Plant Network. Training materials for garden staff and outreach programs will be developed over the next year in the USA. The global community of pest professionals should capitalise on the outreach opportunity gardens offer, through partnerships to enhance monitoring and early detection of pests. Such collaborations can build an audience that understands the risk invasive pests pose to native plants, animals, and economies around the world and in their own backyard.

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