The Evolution of a Process for Selecting and Prioritizing Plant Diseases for Recovery Plans

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All countries that are involved in international trade, particularly trade of agricultural, horticultural, and forest commodities, face the conflicting pressures of removing trade barriers to the extent possible, in concordance with the General Agreements on Tariffs and Trade (World Trade Organization 2015), while also protecting biodiversity and natural environments from unintentional introductions of foreign or invasive pathogens. Additional risks are associated with the illegal importation of non-native plants by private citizens for personal use or private trade that may harbor exotic pathogens or pests. Another potential source of risk is the from intentional introduction of harmful pathogens for the purpose of causing biological and/or economic damage to a country's primary production of food and natural products (Nutter and Madden 2005, 2009).

Each country develops a set of policies to balance the conflicting interests of free trade and limiting the introduction of harmful species. These policies reflect the range of priorities for each country or trading region, and the priorities, in turn, reflect a complex history of exposure to different sources of risk, economic harm, and/or damage to the environment. Reflecting the differences among countries, a wide range of different approaches can be found in the literature on risk evaluation and impact analysis for invasive pests and plant pathogens. For example, the Australian Weed Risk Assessment (WRA) system is an example of a trait-based evaluation system that helps regulatory authorities assign a risk score for invasiveness to selected candidate plants for potential importation (Hughes and Madden 2003; Pheloung et al. 1999). The WRA focuses on biological risk and leaves economic questions for consideration by other risk management agencies. Work in the European Union, in contrast, takes a broader view and attempts to balance conflicting policy goals (Baker et al. 2009; EFSA Panel 2015; MacLeod and Baker 2003). The WTO requires trading nations to follow the IPPC SPS, which requires a risk assessment protocol that has an economic component.

Here, we report on one specific element of the cost of responding to invasive plant pathogens in the United States context, associated with recovery from the arrival of exotic plant pathogens that could become invasive. We review the history of the process for prioritizing plant diseases for development of recovery plans for each, under the direction of the federally mandated National Plant Disease Recovery System (NPDRS). A team of university, government, and

industry scientists worked together over a 10-year period to ultimately develop an objective science-based approach for preparing recovery plans from introduced regulated plant pathogens, when the timing of a single introduction and resultant disease is unknown. The process evolved over time, from an ad hoc system in which recovery plans were written when a specific plant disease was deemed relevant and experts were available to write it, to a formal group prioritization-effort through discussion-based workshops. Eventually the concept of generic recovery plan templates emerged for groups of pathogens, and the resulting diseases, that have similar biological characteristics and therefore management tactics.

The NPDRS was authorized in January 2004, as part of Homeland Security Presidential Directive-9 Section 18.vb (HSPD 9), signed by President George W. Bush (Bush 2004) as part of the newly created Department of Homeland Security and the country's response to the 2001 terrorist attacks in the United States. The purpose of the NPDRS program is to ensure that the tools, infrastructure, communication networks, and capacity can mitigate the impact of high consequence plant disease outbreaks so that a reasonable level of crop production would be maintained in the United States following an outbreak (Nutter 2007).

The United States Department of Agriculture, Agriculture Research Service, Office of Pest Management Policy (USDA-ARS-OPMP) was charged with developing the protocols that needed to be implemented in the NPDRS program. To be fully prepared to address plant disease outbreaks, all aspects of disease recognition and management ideally would be put into place prior to the introduction and subsequent establishment of a plant pathogen. This includes the prevention, preparedness, response, and finally, recovery from a disease incursion. The selection of a pathogen and the resulting disease for the development of a recovery plan implies that entry of the pathogen has or could occur, that the disease has or will become established, that spread is likely, that significant economic losses have, could, or are likely to occur, and the process of recovering from the damage has been, or will be implemented. To be most effective, plant disease recovery plans should be prepared in advance of the entry of potentially high consequence pathogens, or be able to be completed quickly after discovery/detection of an introduction. However, it is recognized that meeting this goal completely is challenging, owing to the potential for many new and exotic plant pathogen entries. Further, it would take an expert significant time to prepare a detailed recovery plan and by then, it could be too late to implement an effective response, prevent pathogen establishment and spread, and thus ensure recovery.

In April 2006, with sponsorship from the USDA-ARS and the American Phytopathological Society (APS), an ad hoc committee composed of university, industry, and government scientists met in Memphis, TN for the first NPDRS meeting. During this 2-day

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workshop, participants at numerous presentations and breakout sessions discussed the concept of recovery plan, what they might include, which diseases would be addressed, and who might author a particular plan. Numerous ideas and opinions were vetted. What emerged from that workshop was a conceptual consensus of what should constitute a plant disease recovery plan (Fig. 1). Participants universally agreed that the NPDRS recovery plans should include potential threat estimation (entry pathways) and vulnerability assessment (establishment and spread potential) for each plant pathogen as an essential component. What did not become solidified from the discussions, however, was the set of criteria to use for determining and prioritizing specific diseases for which the preparation of a recovery plan was warranted. The same group of scientists has continued to meet annually to review newly written recovery plans and refine the means of prioritizing the list of new plans that need to be developed.

Prioritization Based on the Select Agent List

In 2002, the National Agricultural Biosecurity Center (NBAC) at Kansas State University, in collaboration with Purdue University and Texas A&M University, conducted an in-depth analysis of potential pathways by which agriculturally important pathogens or threat agents to both food animals and crop plants might enter the country (NABC 2004). The report listed 12 exotic plant pathogens that have the potential to infect and threaten six major food crops with the greatest economic value and levels of consumption in the United States.

The Public Health Security and Bioterrorism Preparedness and Response Act of 2002 mandated that plant pathogens be included in the Department of Homeland Security (DHS) Center of Disease Control (CDC) and USDA Select Agents and Toxins list. These were exotic plant pathogens, yet to be confirmed in the United States and whose introductions likely would result in significant economic consequences, either as a direct result of yield losses, costly containment and mitigation costs, and/or market effects (Nutter 2007). The select agent list for plant pathogens was revised several times since 2002 and presently contains only seven plant select agents (CDC and USDA 2015).

The select agents were among the highest-risk plant pathogens and therefore were chosen to create the first recovery plans. A recovery plan for two of the select agent pathogens, *Peronosclerospora philippinensis*, causal agent of Philippine downy mildew of corn, and *Candidatus Liberibacter asiaticus*, the causal agent of citrus greening disease, also known as huanglongbing of citrus, were published on the NPDRS website in fall 2006. The recovery plan for each of two additional select agent pathogens and the resulting diseases were published in early 2007, and included *Synchytrium endobioticum*, causal agent of potato wart, and Plum pox virus, causal agent of plum pox (also known as sharka of stone fruit) and similarly debilitating diseases of other *Prunus* species. *Phakopsora pachyrhizi*, which causes soybean rust, had been

on the first plant pathogen select agent list, but was subsequently removed from the revised list after its introduction and spread into the United States, making a recovery plan untenable.

Over the few next years, recovery plans were developed for more of the plant diseases caused by select agents on the list, and included southern wilt, causal agent *Ralstonia solanacearum* race 3 biovar 2; brown stripe downy mildew, causal agent *Sclerophthora rayssiae* var. *zeae*; bacterial leaf streak of rice, causal agent *Xanthomonas oryzae* pv. *oryzicola*; citrus variegated chlorosis strain, causal agent *Xylella fastidiosa*; red leaf blotch of soybean, causal agent *Phoma glycicola* (formerly *Pyrenochaeta glycines*); and plant gummosis and livestock toxicity, causal agent *Rathayibacter toxicus*, as well as several others deemed by the NPDRS meeting participants to have potential to cause high-risk diseases. Currently there are 22 plant disease recovery plans completed; at least 13 have been or are being updated and more are under development. These recovery plans are posted on the NPDRS website (<http://www.ars.usda.gov/research/docs.htm?docid=14271>) (USDA ARS 2015). The major sections and content of an NPDRS recovery plan are shown in Fig. 1.

Prioritization of Recovery Plans Other than Diseases Caused by Select Agents

Identifying select agent plant pathogens and the resulting diseases for the development of NPDRS recovery plans is logical, but after that, it becomes difficult to choose among the remaining thousands of exotic plant pathogens that potentially threaten major food, feed, fiber, and fuel crops. There are tens of thousands of different plant diseases that occur around the world, many of which do not occur in the United States. It was estimated that approximately 14% of the worlds' crop production is lost or damaged by plant diseases each year, while another 6 to 12% is made unusable as a result of postharvest diseases (Agrios 2005).

Plant pathogens are capable of dispersal over short distances, or globally by weather systems, as well as through commerce or as incidental 'hitchhikers' on travelers. The literature is replete with examples of plant pathogens that have moved around the world, including such notorious diseases as potato late blight, citrus canker, citrus greening, coffee rust, downy mildew of grapes, soybean rust, and many hundreds more (Agrios 2005; Carefoot and Sprott 1967). Given this possibility, it is almost impossible to predict what the next "pathogen *du jour*" will be.

The entry of some pathogens and their associated disease outbreaks can often be anticipated based on scientific knowledge of the pathogen's biology and epidemiology. For example, similar to the soybean rust pathogen, it is anticipated that the TKKS (Ug99) strain, or one of the derivative strains, of *Puccinia graminis* f. sp. *tritici*, the causal agent of wheat stem rust, will reach the United States from the Arabian Peninsula and Southwest Asia in the not-too-distant future. This strain overcomes the stem rust resistance genes, *Sr24* and *Sr31*, which are the primary genes conferring stem rust resistance in most of the wheat cultivars grown in the United States, making this pathogen a serious threat to the US\$13 billion wheat industry and thereby to food security in North America.

The questions of how to determine which plant diseases are worthy of the development of recovery plans and how to prioritize them has been a subject of debate from the beginning of the process. At the first NPDRS meeting in 2006, participants discussed several methods, all of which included a weighted hierarchical analysis of various selection criteria. The dilemma has been that the variety and number of suggested selection criteria renders the selection process both complicated and laborious.

As a specific example, virtually everyone agreed that the economic value and hectareage of a crop should be a "first-tier" criterion. Crops such as corn, soybean, and wheat, grown on millions of hectares and worth billions of dollars, would be obvious choices. However, using these criteria introduces the question of what economic value indicators or hectareage should be used as the threshold at which a specific crop would no longer be considered for inclusion on the list of candidates for a recovery plan. The issue becomes more complex when

Fig. 1. Key sections of a National Plant Disease Recovery System recovery plan.

one considers specialty crops that are grown on relatively small hectares, but which constitute a major percentage of a regional, national, or global market. Such crops might include grapes in the Pacific Northwest and California; apples in New England, the Great Lakes, and the Great Basin; melons in Florida, Georgia, and Texas; almonds, artichokes, and pistachios in California; peanuts in Texas, Virginia, and Georgia; pecans in the south; and many others. Additional crops of a similar nature are easy to find. What about the multibillion dollar ornamentals and greenhouse industries? Do flowers and landscape shrubs command the same level of urgency as do our major food, fiber, and animal feed crops? In spite of the complexities, the economics of the crop should and must be a major consideration for selecting disease/crop combinations for recovery plan preparation, but clear-cut thresholds for demarcating candidates are unlikely to be foolproof, and some element of deliberation will most often be needed.

In addition to selecting particular crops of economic importance, the process of specifying the diseases to focus on is even more daunting. Every crop plant has many important diseases, some known and some unknown, which are capable of causing severe economic damage under certain environmental conditions or cropping systems (Savary et al. 2006). Again, the primary focus at the NPDRS meetings was to focus first on those diseases not yet present in the United States but which might arrive by natural means or by accidental or intentional transport. The potential list is lengthy. Practicality and necessity preclude the preparation of a detailed recovery plan for each potential threat. The salient question remains: How do we choose among them?

Ranking System Approaches

In the initial stages, attempts were made to assign weighted values (from low to high) to various components of a given pathosystem. Among the criteria deemed important were: (i) the ease of entry and likely pathway(s); (ii) the potential for the pathogen to become established, reproduce, and then spread; (iii) feasibility to produce and deliver the pathogen to a new ecosystem; (iv) the potential for negative impacts on trade markets; and (v) the potential for public shock, outcry, and/or perception of risk value. Those pathosystems that scored high on most or all of the latter criteria would likely be considered primary candidates for NPDRS recovery plans.

Given the historical origin of the NPDRS program in HPSP-9, the early rounds of discussion placed a higher prominence for risk of bioterrorism than is seen in similar programs elsewhere in the world, and perhaps even as is currently perceived in the United States. For example, a combined bioterrorism index (CBTI) was suggested, where the CBTI is based on things such as the pathogen's ease of culturing, ease of introduction, spread and infection, survivability, and other factors. A complicating issue was that many, if not most, of the pathogens of concern are exotic. Consequently, little is known about their biological, ecological, and epidemiological fitness under U.S. conditions, thereby making assignment of weighted values difficult. Thus, a category of "insufficient information" was included. This made evaluating a specific pathogen's potential threat risk even more difficult and less reliable.

Over the few next years, two matrices evolved from the group discussions. One was based on the taxon of the pathogen (fungus, bacterium, virus, etc.) and the type of crop plants affected (field crops, fruits and vegetables, ornamentals, etc.). The other matrix also included the type of crop plant, but used as evaluation criteria the epidemiology and the likely pathway of entry (seedborne, airborne, vectorborne, etc.). The concept then was to identify important diseases on the various crops that would satisfy and fill in the matrix. When completed, there would be NPDRS recovery plans for some of the potential diseases and representative of a broader class of plant diseases. While these matrices were an improvement over the previous methods, the problem of the abundance of choices still remained. Which field crops or vegetables should be chosen? Which or how many fungal, bacterial, and viral pathogens on each crop should be selected? How many airborne or vectorborne pathogens would be adequate? Again, the number of potential recovery plans and how to select from among them quickly grew into an unmanageable problem.

The Generic Model Concept

Although the matrices were helpful in selecting pathogens for the development of new recovery plans, they still generated many more choices than was feasible or practical to manage. The concept of having generic recovery plans that might serve as disease templates and might easily and quickly be adapted to new pathogen threats was first introduced at the 2007 NPDRS meeting by R. D. Martyn, after a casual conversation with Dr. Kent Smith, then the lead plant pathologist in the USDA-ARS-OPMP, charged with oversight of NPDRS. The underlying concept was that plant diseases might occur in common groups based on the similarity of their biology, epidemiological parameters (Madden and van den Bosch 2002), and disease management principles (Fry 1982; National Academy of Sciences 1968; Nutter 2007) that would be likely to be implemented for their control. For example, containment, quarantine, and eradication might be appropriate management principles for some diseases (e.g., Karnal bunt of wheat) but not for others (e.g., soybean rust). The concept of "pathogen matching" gained general consensus early on, but there was no agreement on what would comprise a generic plan and which pathogens might serve as models for their development. For example, could the recovery plan for stem rust of wheat and/or stripe rust of wheat be used as a model for other rust diseases? Could they be used as a model for most airborne, foliar pathogens of cereal crops? If so, a generic plan could serve as a template to be modified quickly to produce a recovery plan for a newly introduced pathogen. Thus the techniques and protocols put in place for stem rust also might be appropriate for different rust diseases or airborne foliar pathogens on other host crops. As such, similar strategies might apply to others, or perhaps multiple diseases caused by biologically variable and/or highly distinct pathogens for which mitigation protocols might be similar.

Over the next several years, the idea that plant diseases might cluster along common epidemiological parameters and management principles and that a small number might serve as effective NPDRS recovery plan templates gained traction among the workshop participants. With support from the USDA-NPDRS, the idea moved from the concept stage to testing and then to validation.

Developing the Model

Overview. Data obtained were analyzed using an iterative process that involved alternating between statistical analyses and group deliberation (Fig. 2). The objective of going through the process was to test two interrelated hypotheses concerning the feasibility of developing generic disease recovery plans: i) generic disease types exist and these can be identified using a relatively small set of binary characters; and ii) the generic properties of disease types are apparent to non-subject-matter specialists with general plant pathology training and, therefore, classification of pathogens or diseases using the binary character set will be robust to differences in specialization and expertise among users.

An approach was designed to test these two hypotheses that allowed for expert opinion by a knowledgeable research team to be combined with objective data sets gathered from a wider group of raters with advanced training in plant pathology concepts but not necessarily experts in the particular pathogen and resulting disease. The process involved two major iterations of deliberation and analysis. The first was used to establish whether there was sufficient evidence to warrant further work, and then the second was used to provide a wider validation of the initial findings.

In 2011, a two-day workshop consisting of five of the authors of this paper developed a 75-criteria list of biological and epidemiological parameters that could be used to evaluate potential diseases. In the initial data analysis, four of the authors evaluated the original 75-criteria data set for each pathogen for which there was a completed recovery plan in 2012 (Fig. 3). The two corn downy mildews were combined into one rating and *Raffaelea lauricola* was split into two 'pathogens' since the existing recovery plans were organized this way.

The sixth member of the team analyzed the information from the four team members using multivariate statistical methods to identify key criteria, which resulted in biologically sensible clusters of the 14 rated diseases. A double-blind approach was used in this first round

of analysis so that the analyst knew neither the identity of the raters nor the 14 diseases. Subsequently, the team produced a reduced, 37-criteria data set (Fig. 4). This 37-criteria data set offered a similar capacity for classifying diseases into types or groupings as the 75-criteria list, but reduced some redundancy and ambiguity. The same four of the original team re-evaluated the same diseases using the new 37-criteria. Based upon the 37-criteria data sets, diseases were “matched” to other diseases that might warrant similar disease management strategies and tactics. Four clusters of pathogens and their resulting diseases were identified: i) actively vector-transmitted obligate pathogens; ii) passively vector-transmitted and nonobligate pathogens; iii) soil-borne pathogens; and iv) pathogens that are aurally transmitted (Fig. 5). The second phase of analysis involved validating the reduced set of criteria developed in the first phase of the study. Following discussion of the initial results by the wider NPDRS group during its annual meeting in 2013, a validation study of the reduced 37-criteria data set (Fig. 4) was carried out in 2014.

A “gold standard” data set for each of the 14 diseases was produced, in which the subject matter experts who led the team that originally developed the specific disease recovery plan used the 37-criteria for the pathogen and disease named in their authored recovery plan. These experts worked independently of each other (in two instances the “expert” was actually a pair of collaborators) so that each expert generated only the 37-criteria binary character set for a single recovery plan disease. This analysis tested whether the pathogens/diseases clustered into groups that made biological and epidemiological sense, when a different person rated each disease.

The 14 pathogens/diseases were concurrently assessed independently using the 37-criteria scale by a panel of 15 raters drawn from the wider NPDRS group. This analysis provided a test of whether the pattern of similarities among the 14 pathogens/diseases was similar among all three sets of raters: gold standard raters, original team (four members), and second phase raters (panel of 15). Similarities were compared between diseases and between raters and compared with the gold standard ratings to check for robustness.

Similarity among the different pathogens/diseases was calculated as the complement of binary distance using the Jaccard coefficient. The Jaccard coefficient measures similarity between two objects (diseases in the current case) as the proportion of the total number of characters present in at least one of the objects, which both objects have present. A range of multivariate methods was again used to examine the degree of agreement among the three groups of raters. The same four clusters of diseases emerged from the analyses regardless of whether the ratings were performed by the gold standard group, the pilot team of four, or the larger group of 15. These pathogen/disease groups were: i) actively vector-transmitted obligate pathogens; ii) passively vector-transmitted and nonobligate pathogens; iii) soilborne pathogens; and iv) pathogens that are aurally transmitted (Fig. 5). For example, obligate pathogens with a highly specific vector relationship were readily separated from the laurel wilt fungus, which

is passively vectored. Within the passively dispersed group of pathogens, the airborne species could robustly be separated from the soil-borne species. Thus, the gold standard group confirmed that the groupings made biological and epidemiological sense, while the results from the 15 raters confirmed the repeatability or reproducibility, and robustness of the 37-criteria.

This effort to devise a strategic set of criteria for preparing and implementing robust generic plant disease recovery plans with the highest of national food security interests in mind was undertaken in response to the charge by the President and Congress of the United States to the USDA to address the potential vulnerabilities within the United States agricultural and food system infrastructure. The aim of the project was to examine the potential of using a simple scoring system to identify generic types of diseases, with a view to construct a small number of generic disease recovery plan templates from which to develop new recovery plans for NPDRS. The pilot study produced sufficiently homogeneous results that led to the commissioning of a larger validation study. The results reported herein provide solid backing for the concept, and reasonably robust support for its viability when preparing and implementing recovery activities for new and exotic plant disease outbreaks.

In all phases of the work, the 14 diseases for which recovery plans were available at the time of the study were found to cluster into four distinctly recognizable groups (Fig. 5). Each is considered representative of coherent groups of disease types on the basis of a combination of biological, epidemiological, and disease management variables.

In particular, two results point to the probable success of basing future recovery plans on generic templates derived from the data variables that were defined in this study. First, as already noted, the variables appeared to allow for grouping of diseases into coherent sets

Recovery Plans Used in the National Plant Disease Recovery System Generic Rating Project	
Disease	Pathogen
Citrus variegated chlorosis (CVC)	<i>Xylella fastidiosa</i>
Brown stripe downy mildew and Philippine downy mildew of	<i>Sclerophthora rayssiae</i> var. <i>zeae</i> and <i>Peronosclerospora philippinensis</i>
Huanglongbing (HLB) of citrus or citrus greening	<i>Candidatus Liberibacter asiaticus</i> , <i>L. africanus</i> , and <i>L. americanus</i>
Late wilt of corn	<i>Harpophora maydis</i>
Laurel wilt of avocado	<i>Raffaelea lauricola</i>
Laurel wilt of redbay	<i>Raffaelea lauricola</i>
Plum pox or sharka	Plum pox virus (PPV)
Potato wart	<i>Synchytrium endobioticum</i>
Ralstonia bacterial wilt of potato and geranium	<i>Ralstonia solanacearum</i> , race 3, biovar 2
Plant gummosis and livestock poisoning	<i>Rathayibacter toxicus</i>
Red leaf blotch of soybean	<i>Phoma glycinicola</i>
Scots pine blister rust	<i>Cronartium flaccidum</i>
Stem rust of wheat (Ug99)	<i>Puccinia graminis</i> f. sp. <i>Tritici</i>
Tree and shrub diseases caused by <i>P. kernoviae</i>	<i>Phytophthora kernoviae</i>

Fig. 3. Key sections of a national plant disease recovery system recovery plan.

Fig. 2. Recovery plans used in the National Plant Disease Recovery System generic rating project.

based on epidemiological similarities. Secondly, the consistency of the clustering throughout the process, and in particular the high level of agreement between the panel of 15 raters who rated all 14 diseases, and the gold standard raters, suggested that the process of developing initial drafts of recovery plans using templates derived from these variables, would not be sensitive to the identities and discipline-specific bias of the people in the writing team.

Next Steps

During the next 12 months, several members of the group will conduct an analysis of the recovery plans that were written since the original 14 to see if the groupings are again consistent and if any new groupings emerge. The group will also create a sample template using the existing NPDRS outline and the 37-criteria ratings for diseases that are actively vector-transmitted obligate diseases. A group of experts will

National Plant Disease Recovery Plan Questionnaire

Pathogen Name:

Your Name:

Please answer Yes or No to all questions below

	Yes or No	Comments
1. Is the pathogen disseminated by wind?		
2. Is the pathogen disseminated by rain?		
3. Is the pathogen disseminated by seed or plant parts?		
4. Is the pathogen disseminated by a vector?		
5. Is the pathogen disseminated by soil?		
6. Is the disease cycle polycyclic?		
7. Is the disease cycle monocyclic?		
8. Does the pathogen survive overseasoning?		
9. Does the pathogen overseason in soil?		
10. Does the pathogen overseason in its vector?		
11. Is there trans-ovarial vector transmission (pathogen is transferred to the vector offspring)?		
12. Is pathogen reproductive potential Low?		
13. Is pathogen reproductive potential high?		
14. Is the host range broad (infects multiple plant families)?		
15. Is the host range moderate (able to infect multiple species or genera within one family)?		
16. Is the host range narrow (able to infect only a single species or genus)?		
17. Is the geospatial pattern of the host contiguous?		
18. Could the affected area be an orchard or vineyard?		
19. Could an affected area at risk be an agricultural field?		
20. Could an affected area at risk be a natural landscape?		
21. Could an affected area at risk be a forest?		
22. Could an affected area at risk be residential?		
23. Could an affected area at risk be a greenhouse production facility?		
24. Is the latency period short (less than 15 days)?		
25. Is the latency period long (more than a year)?		
26. Is testing or certification a feasible exclusion option?		
27. Is sanitation a feasible exclusion option?		
28. Is vector management a feasible eradication option?		
29. Is host destruction a feasible exclusion option?		
30. Is fumigation a feasible eradication option?		
31. Is seed or plant part treatment a feasible eradication option?		
32. Is resistant host a feasible eradication option (are there know resistant hosts)?		
33. Is avoidance a feasible eradication option (Host or pathogen free period/ restricted planting)?		
34. Is quarantine a feasible eradication option?		
35. Is there a probable trade impact of this pathogen?		
36. Is there a probable food safety impact of this pathogen?		
37. Are there efficacious chemical treatments known to exist?		

Fig. 4. National Plant Disease Recovery Plan questionnaire.

Fig. 5. The National Plant Disease Recovery System generic plan groupings.

then use this template to create the next NPDRS recovery plan on six insect-vectored, obligate phytoplasma diseases: *Candidatus* Phytoplasma australiense, *Ca. P. mali*, *Ca. P. prunorum*, *Ca. P. vitis*, *Ca. P. palmae*, and *Ca. P. pini*. The experience gained from going through this process is now intended to set the stage for the future creation of a template for each of the disease groups identified through this process.

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Neil R McRoberts

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Ray D Martyn Jr

Dr. McRoberts is an Associate Professor in the Plant Pathology Department at UC Davis. He has a B.Sc. in Crop Science and a Ph.D. in Plant Pathology from the University of Edinburgh, UK. His research, teaching, and outreach programs focus on plant disease epidemiology and decision-making. He is particularly interested in the integration of social science approaches into epidemiology and the development of quantitative methods for characterizing the impact of plant diseases on agriculture at a range of scales. His research group works on a range of diseases of perennial and field crops of importance in California, with particular interest in vectored diseases.

Ms. Thomas serves as the Chair of the Epidemiology Subcommittee for the National Plant Diagnostic Network (NPDN). She also serves as Associate Director at the Western Regional Center of the NPDN at the Department of Plant Pathology, University of California, Davis. Ms. Thomas received her B.S. degree in horticulture in 1981 and her M.S. in Botany and Plant Pathology in 1984 from Michigan State University. Her research and project management interests include biosecurity risk assessment, weather-based decision support models, and emergency response planning. She also serves as Exercise Coordinator for the Western Region NPDN.

Dr. Brown is Professor in the School of Plant Sciences, University of Arizona, Tucson, AZ. Her research interests include genomic diversity, evolution, and ecology of emerging plant DNA and RNA viruses transmitted by insect vectors, including whitefly-transmitted geminiviruses transmitted by the *Bemisia tabaci* sibling species group, with a global perspective, and recently, the *Cacao swollen shoot virus* in West Africa. Her laboratory studies the cellular, molecular, and functional genomics of effectors that govern vector transmission specificity of begomoviruses by *B. tabaci*, and recently, the functional genomics of Liberibacter-psyllid transmission and the use of RNAi to validate effectors and also for transmission abatement. She is a Fellow of The American Phytopathological Society (APS), and has served on numerous APS committees, including two terms as Senior Editor of APS Press, and as Associate Editor of Plant Disease and Phytopathology journals. She served five years as Caribbean Division Counselor, and as President of both the Caribbean and Pacific Divisions. She received the Wellman Award, which is the highest award given by the Caribbean Division for international contributions in research and service in plant pathology. She is active in the National Plant Diagnostics Network, and serves as the NPDN-Arizona Coordinator. In addition, she is or has been a member of APS, the American Association for the Advancement of Science, American Society for Microbiology, American Society for Virology, and the Entomological Society of America. She has been a longstanding member of the International Committee on Taxonomy of Viruses-Geminiviridae Study Group, and served as Chair for the past four and one half years (until

December 2014), and has served regularly on the organizing committees for the international geminivirus and whitefly workshops since their inception.

Dr. Nutter is a professor in the Department of Plant Pathology and Microbiology, Iowa State University. His research program focuses on understanding, quantifying, and forecasting the occurrence of plant disease epidemics and other plant stresses on the health and productivity of plant populations. Remote sensing, GPS, and GIS technologies are being developed and integrated to detect, monitor, and quantify the impact of new and emerging threats to crop biosecurity. Theoretical and practical approaches for quantifying the spatial and temporal dynamics of biotic plant pathogens are used to develop computer models to quantify the impacts of plant stresses on crop yield and quality. Models are also being developed to quantify the risks versus benefits of new agricultural biotechnologies. Nutter has authored or coauthored several articles concerning crop biosecurity. He has several articles concerning U.S. crop biosecurity. He has served as APS North Central Division Counselor APS North Central Division President has been a long-time member of the APS Epidemiology and Crop Loss and Risk Evaluation Committees.

Dr. Stack is Director of the Great Plains Diagnostic Network (GPDN) and Professor of Plant Pathology at Kansas State University. He is principal investigator of plant biosecurity projects regarding emerging diseases and is collaborating on international biosecurity projects in Europe, the Middle East, South America, and Australia. Stack's research interests center on pathogen detection and surveillance, pathogen ecology, and epidemiology for accidental and intentional (e.g., biological control, bioterrorism) introductions of plant pathogens into natural and agricultural plant systems; interests span from preparedness and prevention to mitigation and recovery. Of particular interest is a better understanding of the intersection of plant health, public health, and food security.

Dr. Martyn is Professor Emeritus in the Department of Botany and Plant Pathology at Purdue University. He received his Ph.D. from the University of Florida in 1977 and spent 20 years on the faculty at Texas A & M University, College Station, and almost 19 years at Purdue University, West Lafayette. His research expertise is soilborne diseases of cucurbits, especially *Fusarium* wilts and *Monosporascus* vine decline. While at Purdue he served as head of the Botany and Plant Pathology Department (1997 to 2005) and director of the Center for Crop Biosecurity and Invasive Plants (2005 to 2008). Martyn is a Fellow of the American Phytopathological Society. He has served on numerous APS committees and boards and is a past president of APS (2008), past APS Councilor of the North Central Division (2003 to 2005), past president of the APS Southern Division (1995), and past chair of the APS Foundation Board of Directors (2009 to 2015).