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The Importance of Reporting New Host-Fungus Records for Ornamental and Regional Crops

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Abstract
Accurate and timely reports of new host-fungus records are essential for diagnostics and identification, management, and prevention of plant diseases. Important also are venues to publish these reports in a timely manner and the ability to rapidly search for the information contained in these reports. Presented herein are examples of first reports of fungal pathogens on regional crops, including ornamentals and turf grasses, which illustrate how first reports contribute to preparedness, accurate diagnostics, and knowledge of biogeography and host range. We provide a guide to sources of host-fungus records, discuss venues for publishing new records, and review the information important in a new record, including deposition of voucher specimens. We appeal to plant health professionals to increase their efforts of discovering, documenting, and reporting new records.

Introduction
Fungi are extremely diverse and common plant pathogens. One much-cited estimate suggested 1.5 million species of fungi, but with only about 5% of them characterized and described (39). Despite the economic and ecological importance of plant pathogenic fungi, much remains to be learned about their biology, particularly their host and geographical ranges. Even for common, easily found pathogens such as powdery mildews it appears that they are much more diverse, and their host relationships more complex, than commonly assumed (33). Knowledge of the biogeography of emerging plant pathogens is essential for detection, identification, and control. Often these are non-indigenous to North America (46) and not well studied in their native habitat which is often unknown. First reports provide important information for increasing our knowledge and understanding of these emerging plant pathogens.

The impact of the terrorist attacks of 9/11, the potential for use of some plant pathogens as bioweapons, and the importance of emerging plant pathogens (even aside from any use in terrorism or warfare) resulted in creation of an interconnected system of diagnostic centers, the National Plant Diagnostic Network (Appendix A), recently comprehensively described (62). These networked facilities are intended to give early warning of plant diseases and provide an excellent mechanism for the detection, identification, and reporting of emerging pathogens. Detection and tracking of invasive pathogenic fungi on staple crops or plant species of high ecological importance is a high priority and some laboratories, programs, or informational sites are devoted to single fungal pathogens. These may be at the federal level, e.g., the USDA Soybean Rust

Information Site (now USDA Public Pest Information Platform for Extension and Education, sbr.ipmpipe.org/cgi-bin/sbr/public.cgi), addressing *Phakopsora pachyrhizi*, causal agent of soybean rust; or at the state level, e.g., the Sudden Oak Death Program at Washington State University (www.puyallup.wsu.edu/ppo/sod.html), focused on *Phytophthora ramorum*, cause of sudden oak death (and diseases of numerous other plants); or, for the same pathogen, the California Oak Mortality Task Force (nature.berkeley.edu/comtf). Such web-based communication facilitates in-depth reporting of new disease incidents and their causal agents. The importance of some invasive pathogens has promoted inter-agency, including international, cooperation, e.g., *Tilletia indica*, agent of Karnal bunt, on wheat in the United States (47). Additional world-wide reporting services have been listed (2).

Like Anderson et al. (2), who reviewed secondary crops in developing countries, we make the distinction between emerging pathogens on staple crops, and those on secondary crops, but we focus here on situations in North America, especially the United States. Emerging fungal pathogens on secondary crops are often not well known taxonomically or in terms of biogeography, prior to their appearance on a given host. Nonetheless, they can have major effects locally, especially on small businesses, homeowners, or parks and recreational facilities. The cumulative impact of such "minor" novel outbreaks is substantial, as documented by recent examples. Fungal pathogens such as *P. pachyrhizi* on soybean or *T. indica* on wheat are often studied extensively for years, and their movements monitored, well prior to their detection in new areas of the United States. Such is less frequently the case for the myriad of fungal pathogens infecting secondary crops of regional importance, or those infecting plants grown as ornamentals in greenhouses and nurseries. Reporting and tracking for such pathogens is less intensive than for the high profile "invasives" mentioned above. Often the threats posed by the pathogens of secondary crops are initially communicated through the publication of "first reports." Such reports for regional or ornamental crops provide vital information for extension agents, plant disease diagnosticians, regulatory officials and other plant health professionals. We concentrate our examples below on recently published first reports originating from the United States and briefly discuss the actual usage of such reports, especially when they are incorporated into online indices and databases. We also provide suggestions for constructing first reports and for publication venues.

Recent First Reports from Ornamental Nurseries and Turfgrass

In our experience, the most frequent casualties of "minor" emerging pathogens are nursery crops and ornamentals, including turf grasses. Although these pathogens were not previously reported from a given locale, damage and loss were often considerable. For example, some 30,000 plants were rendered unsalable in Oregon, when ornamental *Leucothoë* plants were infected by the powdery mildew *Oidium ericinum*, reported for the first time in North America from this incident (55). In other cases, approximately 25% of the nursery stock of blanket flower (*Gaillardia* × *grandiflora*) was affected by *Leveillula taurica* (37) and in commercial plantings of the ornamental *Scabiosa columbaria* (dove pincushions) 20% to over 60% of plants were infected by *Erysiphe knautiae* (34).

In Virginia, losses exceeding 75% resulted from infection of container grown *Ilex glabra* (inkberry holly) by *Phytophthora cinnamomi* (48). In Florida, commercial populations of *Coreopsis leavenworthii* (Leavenworth's tickseed) were highly susceptible to *Golovinomyces cichoracearum* (61); and when *Plasmopara halstedii* was reported for the first time on perennial black-eyed Susan in that state, nearly all potted plants in a nursery were symptomatic (12). In a Louisiana nursery, disease incidence of 50% occurred on a hybrid cultivar of *Osteospermum* (African daisy) infected by *Sclerotinia sclerotiorum* (40). In Connecticut, some 10% of plants of *Begonia x hiemalis* (Hiemalis begonia) developed wilt from infection by *Fusarium foetens* in a commercial greenhouse (23).

First reports can enable preparedness. *Uromyces transversalis*, agent of Gladiolus rust, was detected in residential and commercial plantings in California and Florida. Prior reporting and good communication between agencies alerted plant protection officials to the spread of this pathogen. Prompt efforts at eradication appear to have been at least temporarily successful (7, 60). In another instance, early detection warned growers of potential problems with *Colletotrichum acutatum* on *Myrica cerifera* (wax myrtle) in Florida nurseries (45). Reporting of new records may also assist refinement of diagnoses. For example, containerized nursery plantings of *Pieris japonica* (lily-of-the-valley bush), were reported infected with *Phytophthora citricola* (42). The authors noted that *P. japonica* is also host to *Phytophthora ramorum* (cause of sudden oak death as noted above, and a federally quarantined pathogen) and that diagnosticians will need to discriminate between the two pathogens.

A new threat to turf grasses of warmer climates, rapid blight of turf, was highlighted in a web-based feature (63). The disease, caused by the fungus-like *Labyrinthula terrestris*, was first reported in Arizona (53), and the organism has subsequently been reported in the UK (24). Other recent first reports for turf include *Pyricularia grisea* on *Pennisetum clandestinum* (kikuyugrass) in the United States (68). *Pyricularia grisea* was also the subject of first reports on *Lolium perenne* (perennial ryegrass) in California (64) and in Nevada (67). The pathogen *Gaeumannomyces graminis* var. *graminis* had earlier been detected on kikuyugrass (69).

Recent First Reports of Fungal Pathogens on Food and Forage Crops of Regional Importance

In the summer of 2007, *Leveillula taurica* was detected on chickpea, a regional crop of great significance to the economy of the Palouse region of northern Idaho and eastern Washington (4). This pathogen is usually of minor impact, but under some environmental conditions can severely affect certain cultivars of chickpea (51). *L. taurica* is a powdery mildew with a broad host range, and is an emerging pathogen in this region on onion and other crops (21,32,35,36). Its cumulative impact on these miscellaneous regional crops has not been fully assessed. Chickpea was also the host in a first report in which *Sclerotinia sclerotiorum* infected the crop in both the Palouse region and in North Dakota (10). In North Dakota, *S. sclerotiorum* also affected 40% of *Echium vulgare* (viper's bugloss) plants in an oilseed planting trial (13). *Sclerotinia sclerotiorum* already impacts several crops of importance in North Dakota, such as sunflower, canola, and safflower (3,50).

Peas and lentils are also important regional crops of the Palouse region. There is now documentation that in addition to infection by *Erysiphe pisi* (formerly often called *Erysiphe polygoni*), field and/or greenhouse-grown peas (*Pisum sativum*) are infected by at least one additional *Erysiphe* species in the Palouse region. These isolates closely match *E. trifolii* on the basis of ITS sequences and several morphological characters, but often have chasmothecial (cleistothecial) appendages resembling those of *E. diffusa* (5). This situation potentially complicates field and greenhouse breeding programs for pea, and "breakdown" of resistance to powdery mildew in pea has been reported (28). This new powdery mildew from pea is indistinguishable by ITS sequence and morphology from a powdery mildew on lentil on the Palouse (5), and may be the same species as that tentatively identified on the basis of chasmothecial appendage morphology as *Microsphaera diffusa* (= *E. diffusa*) on lentil in Saskatchewan, Canada (6). Other fungal pathogens are novel to one or more of these crops, e.g., from the Palouse the first American report for *Pythium irregulare* on lentil (54). Thus, within a relatively short time, a series of new records documented several pathogens seen for the first time on cool season legumes grown in the Pacific Northwest and elsewhere.

Sometimes newly discovered pathogens are quickly documented as inducing severe losses of food crops, such as a newly reported fungus impacting Washington State tree fruits. Postharvest fruit rot of apple, caused by *Sphaeropsis pyriputrescens*, induced losses as high as 24% in storage bins (72). The same organism caused symptoms on over 40% of trees of the cultivar 'Fuji' in the field (70), and also attacked pear, in which it decayed up to 21% of the fruit (71). Online, open access, diagnostic color photographs (decay.tfrec.wsu.edu) now illustrate external and internal symptoms on apple and pear, and Sphaeropsis rot (caused by *Sphaeropsis pyriputrescens*) is now specified on the label for a fludioxonil-based fungicide (Scholar SC, Syngenta, Wilmington, DE).

Reporting of new pathogens is of heightened importance in seed crops because of the probability of seed-borne dispersal of the pathogen. *Stemphylium botryosum* was detected in spinach plants also infected with *Cladosporium variabile*, which produces similar symptoms (20). Seed-borne spread of *S. botryosum* has been subsequently posited (43), then conclusively documented, along with prospective treatments (22). A "special local need" label (Bravo Weather Stik, Syngenta) is now currently available for Washington State. Reports of fungal pathogens in multiple sources of commercial or non-commercial garlic seed cloves (16,17), notably *Fusarium proliferatum*, alerted shippers and recipients of the potential for spread of the pertinent pathogens. Following the report of the powdery mildew fungus *Erysiphe heraclei* on carrot and parsley in Washington State (38), appeared a first report of this fungus on parsley in Florida which noted the possibility that the fungus had been imported into that state on infested seed from Washington (56).

Peer-reviewed first reports greatly facilitate insertion of records into databases. In some instances, such first reports redress lack of peer-reviewed reporting. For instance, there had been no peer-reviewed report for spring black stem of alfalfa (agent = *Phoma medicaginis*) in Washington State prior to that of Akamatsu et al. (1), wherein Koch's postulates were completed and identification was supported by both morphological and molecular genetic criteria. There had been no record for *P. medicaginis* on alfalfa in Washington State in Farr et al. (27), even though an extension bulletin stated that spring black stem caused by *P. medicaginis* was common on alfalfa in Washington (44). Another bulletin (29), with reference to western Washington and Oregon, mentioned spring black stem without further specifying locale. One of the most complete compendia of crop diseases (52) had stated that distribution of *P. medicaginis* was "Not reported ... presumably widespread." Following the report of Akamatsu et al. (1), the record was soon incorporated into Farr et al. (27).

Benefits of First Reports

Issuing reports in peer-reviewed journals is the best means of ensuring that records become officially recognized and widely disseminated, and that diagnosticians have reliable, highly specific records of disease occurrence available online. Publication of such reports in peer reviewed publications, as opposed to popular grower-oriented or other publications, helps ensure the scientific accuracy and validity of such information. In addition to documenting the geographic range of a fungus, or giving warning of a new disease, reporting new host records can significantly further understanding of pathogen biology. Although *L. taurica* has been increasingly reported in the Pacific Northwest from a number of plants as noted above, the sexual stage has been less frequently observed. Discovery of the sexual stage on both a monocot (35) and a dicot (59) provided information on the potential for sexual recombination in this fungus. In another first report, the presence of the sexual stage of *Erysiphe heraclei* on carrot and parsley suggested a role for the teleomorph in seed transmission (38). An analogous first report (25) documented perithecia of *Phaeoacremonium viticola* on grapevines (*Vitis vinifera*) and ash (*Fraxinus latifolia*) in California.

Records of natural enemies (potential biological control agents) for plant pests, pathogens, or weeds are also a legitimate purview of first reports, e.g., for fungi on *Dipsacus fullonum* (common teasel) in the Pacific Northwest (14,19), or *Puccinia acroptili* on Russian knapweed in the western USA. (8). First reports also document alternative weedy hosts for fungi pathogenic on regional or ornamental crops, e.g., powdery mildews on weedy hosts (15), or *Sclerotinia minor* on the weed *Sida spinosa* (prickly sida) in peanut production (41).

New reports also contribute to taxonomic studies, including revision of species descriptions and production of keys for identification. This is especially the case when a geographic region is inadequately surveyed with respect to a group of fungi, or when a group of fungi undergoes taxonomic revision. In a recent synopsis of genera of powdery mildews in the Pacific Northwest (32), 30% of the literature cited consists of new records. Links to online first reports are also being used as supporting information for a new online identification tool for powdery mildews, the Erysiphales Database (http://erysiphales.wsu.edu/searchCriteria.aspx). In the future, such online resources, and linked supporting resources, may function as online taxonomic monographs.

Practical Utilization of Host-fungus Records

Host-fungus indices are especially helpful in the diagnosis of plant diseases (49), and are primary resources for regulatory officials (58), including officials completing pest risk assessments (57). Direct communication with plant disease diagnosticians further confirmed the utility of such indices. Farr et al. (27) is of special importance. All diagnosticians whom we consulted accessed this reference, e.g., "multiple times a week" (M. Putnam, Oregon State University Plant Clinic); "numerous times a day" (K. Snover-Clift, Northeast Plant Diagnostic Network); "I couldn't do diagnostics without it" (J. O'Mara, Kansas State University Plant Disease Diagnostic Lab). Farr et al. (27) is used in 10 to 75% of diagnoses, depending upon circumstances, in other laboratories. Individual host-fungus reports are also routinely consulted for diagnosis (J. Glass, Washington State University Puyallup Plant & Insect Diagnostic Laboratory). Although the extent to which these resources were used varied by clinic and by circumstances, our communications with colleagues performing routine diagnoses left little doubt of the importance of indices and new reports, as the foregoing examples attest.

First reports incorporated into Farr et al. (27) are especially useful, because diagnosticians, never with a surplus of time, can query this comprehensive database for "one stop shopping" and obtain a majority of summary records. However, resource constraints and other circumstances preclude inclusion of all pertinent reports into Farr et al. (27), hence awareness of other venues is important.

Construction of First Reports and Venues for Dissemination

Traditional reporting encompasses observation, diagnosis and identification, and the search for previous reports in miscellaneous databases and other sources (Appendix B). Innovative approaches have stressed the limitations of using "haphazard" host-fungus records for predictive capacity on pathogen host range. One such approach defined and tested (with plant pathogenic fungi) use of "phylogenetic signal" as an alternative (30). Computer simulation models, remote sensing systems and geographic information systems (GIS) are also playing increasing roles for management of emerging pests and diseases (9). In spite of such advances, most warnings of new threats to regional or ornamental crops still originate with on-the-ground plant health professionals (taxonomists, plant pathologists, agricultural extension agents, etc.) who notice symptomatic plants in the course of routine duties, collect specimens, identify pathogenic agents, and publish reports. The most useful reports state the accession number (s) of voucher specimens and the name or abbreviation of the culture collection or herbarium into which vouchers were deposited. Often such reports are accompanied or soon followed by communications targeted to specific interest groups, e.g., turf managers (65,66).

Persons issuing first reports for plant diseases involving fungi have a comparative advantage relative to investigators for other organisms, because host-fungus records specific to countries, regions, provinces, states, etc., have been incorporated into several comprehensive sources, most notably Farr et al. (27) online, and print records (11,31). These and other sources for records are listed in Appendix B. Although the databases of the National Plant Diagnostic Network are of high utility, they are not public and are available only to authorized personnel (62).

Farr et al. (27), the largest database of host-fungus records, is indispensible in determining whether a record is new to a host, state, or country. Additionally, this database can be used to determine current nomenclatural status, documented distribution, and host range. However, users must be aware that resource constraints and other circumstances mean that nomenclature for all taxa may not be up-to-date. Additionally, if plant-associated fungi were reported without host and/or location, the record could not be included. As with all sources of information, searches in Farr et al. (27) should be augmented by searches in the databases and journals referenced in Appendix B. With regard to diagnostic illustrations, note that *North American Fungi* (formerly *Pacific Northwest Fungi*) has a small but growing body of first reports, each amply illustrated, and Disease Notes (in *Plant Disease*) are sometimes published online with photographs ("e-Xtra"). Photographs documenting symptoms on the plant and/or diagnostic characters for the agent are frequent in New Disease Reports online (*Plant Pathology* print version carries text), and are the norm in Plant Health Briefs (in *Plant Health Progress*) and articles in *North American Fungi*. Google, Google Scholar, and other search engines can retrieve full text and figures for records from open access sources such as *North American Fungi* in addition to abbreviated records from subscription-based venues.

Specialized databases, restricted to relatively narrowly defined groups of fungi, are likely to increase in importance in the future. *The Pacific Northwest Database* (www.pnwfungi.wsu.edu) is restricted to fungi occurring in the Pacific Northwest of the United States, simplifying curatorial tasks (such as updating it with new records). The Erysiphales database (www.erysiphales.wsu.edu) is restricted to powdery mildew fungi and includes features such as capabilities for identifying powdery mildews and links to online publications about individual species. Such links enable efficient accessing of online publications, enabling readers to find such literature almost effortlessly.

Conclusion: An Appeal to Plant Health Professionals

It takes considerable time to compile a new report. Subsequent to observing the disease, pathogens must be isolated (if capable of growth on artificial media) and voucher specimens prepared, and often it is essential to perform Koch's postulates and/or provide molecular-genetic data. Additionally, the process of submission and review is also time-consuming for authors, editors, and reviewers. For these reasons, many plant health professionals submit first reports only in instances of the disease having obvious actual or potential major impact on plants of direct interest to them. Because the submission and review processes involve considerable effort, records are sometimes bundled into a single manuscript, especially if pathogens are similar, e.g., various powdery mildews (15,18,55), or if the same host-fungus record is documented in multiple locations (8).

We strongly encourage plant health professionals, especially extension pathologists, agricultural extension agents, plant disease diagnosticians, graduate students and their advisors, as well as fungal taxonomists, to publish new records. Relatively minor extensions of geographic range (e.g., from one state to neighboring states) are worthy of reporting, especially if several such new records are included in a single manuscript. With no funding agency in the US that supports surveying for fungi (with the exception of some exotic species), such reports are an essential means for increasing our understanding of the geographical and host ranges of plant pathogens. We further encourage the inclusion of ample diagnostic photographs and/or photomicrographs, and the use of online publication. The reporting venues discussed above are peer-reviewed, enabling both accuracy for the users and credit for the authors. Collectively, the production of new reports constitutes a tremendous service for plant health professionals as well as for commercial producers of plants and plant products. We encourage department chairs and other administrative officials to extend credit to those plant health professionals who publish new records in peer-reviewed venues.

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Appendix A: Diagnostic Networks

National Plant Diagnostic Network - (www.npdn.org)
This site lists diagnostic laboratories by state, as well as the five component branches of the national network:

Great Plains Diagnostic Network - (www.gpdn.org)

North Central Plant Diagnostic Network - (www.ncpdn.org)

Northeast Plant Diagnostic Network - (www.nepdn.org)

Southern Plant Diagnostic Network - (spdn.ifas.ufl.edu)

Western Plant Diagnostic Network - (www.wpdn.org/wpdn_lab_contacts.php)

Appendix B: Databases, Literature Search Engines, and Other Sources of Host-fungus Records

References consisting of author-date are given as complete citations in Literature Cited.

Agricola - (agricola.nal.usda.gov)

Australasian Plant Disease Notes - (www.publish.csiro.au/nid/208.htm)

BC Host Fungus Index (linked via www.pnwfungi.org)

Biosis Previews - URL varies by subscribing academic institution.

CABI Abstracts - URL varies by subscribing academic institution

Conners, I.L. (1967) (11)

Erysiphales Database - (www.erysiphales.wsu.edu)

Farr et al. (n.d.) SMML Fungal Databases (nt.ars-grin.gov/fungaldatabases) (27) [This is the successor to Farr et. al. 1989 (26) - a work still very useful when you need an answer quickly and your server is down!]

GenBank (NCBI) - (www.ncbi.nlm.nih.gov/Genbank) - This can also be a source of information on biogeography of plant pathogens, but only by going to the publications cited or (in the case of "in press" or "submitted") inferred from accession data. Passport data (location, date, collector, identifier) are not part of standard GenBank documentation, but must be traced, and identification of the fungus verified.

Ginns, J.H. (1986). (31)

Glawe, D. A. (n.d.) Pacific Northwest Fungi Database. Department of Plant Pathology, Washington State University, Puyallup, WA. (cru23.cahe.wsu.edu/fungi/programs/aboutDatabase.asp) (linked via www.pnwfungi.org)

Google - (www.google.com) - (The link to Google Scholar is sometimes useful.)

IMI distribution maps of plant diseases / [compiled by International Mycological Institute]. Imprint Oxon, UK : CAB International, 1992- present - online, URL variable by subscribing institution.

North American Fungi (formerly Pacific Northwest Fungi) - (www.pnwfungi.org)

Plant Pathology (New Disease Reports) - (www.bspp.org.uk/ndr) or via URL of subscribing institution.

Plant Disease (Disease Notes) - www.apsnet.org or via URL of subscribing institution

Plant Health Progress - (www.plantmanagementnetwork.org) or via URL of subscribing institution

ProMED-mail (searchable archive) - (www.promedmail.org)

Herbaria: Index Hebariorum - (sciweb.nybg.org/science2/IndexHerbariorum.asp) - Individual herbaria, varying widely in the degree to which collection data are available electronically, can be accessed via this site.