Chapter IV

Phellinus noxius in Guam, Saipan, Yap, Palau, Pohnpei, and Kosrae

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Abstract: *Phellinus noxius* has a reputation of being an aggressive root rot pathogen on many forest tree species in parts of Southeast Asia and its symptoms and signs have been well documented. Previous reports from Micronesia indicated that this fungal pathogen is responsible for considerable damage in Saipan and likely present in Kosrae and Pohnpei. In this present report, an initial survey was conducted on selected islands of Micronesia (Yap, Palau, Pohnpei, Kosrae, Guam and Saipan) to determine if *P. noxius* was present and to determine its relative abundance. Preliminary observations indicate that *P*. *noxius* is infrequent on Yap and Palau, common on Saipan and Kosrae, and occasional in Pohnpei. Guam was the only island surveyed where *P. noxius* was not found during our survey; however, it has since been reported by collaborators in late 2013 on diverse hosts in native limestone forests (Robert Schlub, personal observation). Collections of the mycelial crust, fruiting bodies, and infected wood were made at every location where *P. noxius* was found on this survey trip. Fungal isolates were established in culture for species identification using DNA-based methods. The *P. noxius* isolates will also be used for genetic analyses using genetic markers to examine genetic diversity, potential origin, and potential pathway of spread for this fungus. Additional surveys are planned and disease management options for *P. noxius* are under consideration for future testing.

Figure 1. Gibson Santos (kneeling) demonstrates an advancing mycelial crust of *Phellinus noxius.* His uncle and neighbor, Joab Santos, holds flowers from the red ginger plant (*Zingiber zerumbet*). After scraping/cutting off the mycelial crust, he has used the "shampoo" of this ginger, apparently with great success, to retard the advance of this fungus on infected trees.

Introduction

As the survey of root- and butt-rot tree pathogens of trees on selected islands of Micronesia (Yap, Palau, Pohnpei, Kosrae, Guam and Saipan) progressed (refer to Chapter III for details), it became readily apparent that *Phellinus noxius* was by far the deadliest of all the butt rot pathogens encountered. This fungal pathogen spreads from tree to tree via the root systems, and it engulfs and kills the cambial tissue of the trees it infects (Brooks 2002). Because *P*. *noxius* displayed such aggressiveness, and because Norio Sahashi and Yuko Ota have expertise for *P*. *noxius* isolations and study, the focus of this survey shifted away from covering all butt-rot fungi. Instead, surveys focused primarily on *P. noxius*, which was found on trees within infested forest stands.

Several signs and symptoms of this *P. noxius* are extremely distinctive (Figures 1-5). When these signs and symptoms were present on a tree, identification of this fungal pathogen seemed readily evident. However, *P. noxius* is not always easily observed. For the obviously infected tree shown in Figure 1, both Gibson and Joab Santos knew that *P. noxius* was present on this property, yet both had walked past this particular tree many times and neither was aware that it was infected with *P*. *noxius*. We found this infection only after clearing away some understory brush at the base of this tree.

At each location where *P. noxius* was found, special attention was paid to identifying the location of the infection and measuring the infection foci (i.e., estimating the "footprint" of the disease in the forest). Additionally, as the impact of this fungus is quite dramatic and even alarming, conversations inevitably arise about what can be done to keep it from spreading. Several very novel remedies were explained by local inhabitants, and some management practices from other countries were explained by the senior author. Tentative plans were made to formally test several of these treatments to determine their relative effectiveness. The most effective control measures will likely be developed by a better understanding of the disease cycle (see below) and then implementing effective measures to interrupt this cycle at one or more critical junctures.

Figure 2. Blair Charley examines the advancing mycelial crust of *Phellinus noxius* on a buttress root of a giant *Terminalia carolinensis* (ka tree) along the Yela River, Kosrae. Note: Blair subsequently made a 30-minute trek back to the mangroves to collect mangrove mud. Then, using a machete, the mycelial crust shown here was carefully peeled/scraped away down to the cambial layer and the mangrove mud was plastered on the infected area. This is one local remedy that is used for *P*. *noxius*.

Figure 3. Conks (fruiting bodies) of *Phellinus noxius* (shown above) are rare in Micronesia. Only three were found during this trip (two in Palau and one in Saipan). However, the purplish grey color of their hymeneal layer makes them quite distinctive (Photo from Wikimedia Commons - http://google.com/Phellinus noxius).

Figure 4. An even rarer form of the *Phellinus noxius* fruiting body is the resupinate form, which is shown here on the underside of a giant *Terminalia carolinensis* (Ka Tree) log in Kosrae. The tree had fallen earlier, likely a result of infection by this fungal pathogen, total colonization of the roots/butt by its mycelia, and subsequent structural failure of the tree. This log contained approximately 5 cubic meters of wood all of which had been colonized by the fungus with characteristic zonation (see Figure 5). This resupinate fruiting body measured 3 meters in length and 60 cm in width (Photo by Carlos Cianchini).

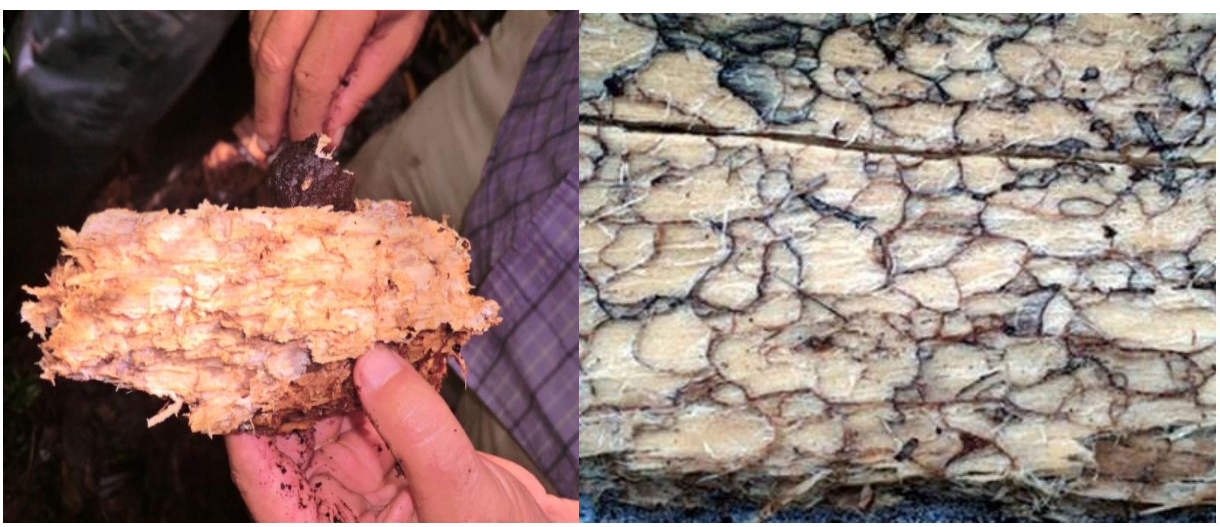

Figure 5. Wood that has been heavily colonized by *Phellinus noxius* is characteristically much less dense and weaker as a result of the rot that this fungus causes. With advanced decay, it is also likely that the fungus will form zone lines that may protect this fungus from other micro-organisms and insects. The zone lines in the left photo are about as faint as will be found for this fungus. The zone lines in the right photo are as about as distinctive as will be found.

Phellinus noxius is frequently spread when the root of an uninfected tree grows into contact with an infected root of a diseased tree. A mycelial crust forms around the roots of the newly infected tree and enzymes (e.g., peroxidases and laccases) are secreted that degrade the wood (e.g., Blanchette 1991; Bonarme and Jeffries 1990; Geiger *et al.* 1986; Poojary and Mugeraya 2012). This crust grows up the roots to the bole of the tree. The crust may be ca. 0.5 - 2.0 cm thick and may extend ca. 1 - 2 meters up the bole (Albrecht and Venette 2013). This fungus grows best at 25^{o}C to 30^{o}C under high humidity (Chang 2002). During extended rainy seasons, actively growing mycelial crusts are often black, spongy, and glisten with moisture. During the rains, the leading edge of this mycelial crust is often bright white and about 2.0 cm thick, and moisture frequently exudes from this leading edge. Although this fungal pathogen is readily observed during rainy periods, it is less apparent during drier periods and after the mycelial crust becomes inactive, because the leading edge turns from white to brown and the mycelial portion that was black turns to tan and becomes crusty.

Trees infected by *P. noxius* generally die either as a result of root rot or killing of the sapwood underlying the bole that is surrounded by the mycelial crust. This fungus lives as a facultative parasite, which means that it can both obtain nutrition from living trees and/or dead plant material. These modes for obtaining nutrition support *P*. *noxius* well, because it can infect living trees and it can also be the first fungus to colonize the woody bole and other remnants of the trees that it killed, potentially giving itself a competitive advantage over other micro-organisms and insects. After *P. noxius* colonizes the entire bole and root system of a tree, it takes an additional step that may increase its competitive advantage. A zone line is formed between areas where sections of the fungus merge together. These zone lines are typically dark brown, about 1.0 mm wide and commonly form in a manner that separates (and easily demarcates) the decayed wood into approximately 4 - 10 cubic centimeter sections (Figure 5). Presumably, these zone lines in the decayed wood provide at least some measure of protection for *P. noxius* against insects and other fungi outside the zone-line-demarcated area. In this condition, *Phellinus* can remain viable for at least 4-10 years after the host tree has been killed (Chang 1996). (Note, however, that this same author also found *P. noxius* could be killed by maintaining a site in a flooded condition for about 2 months).

In the meantime, if the root system of an as-yet-uninfected tree grows near to these areas where *P. noxius* resides, *P. noxius* can grow from behind the zone lines to infect this new root system. Obviously, this ability to survive in a semi-dormant state for long periods of time greatly increases the long-term threats that this fungus poses for a forest stand.

Another feature that increases the impact of *P*. *noxius* is its ability to attack a very wide range of hosts. In tropical and subtropical countries world-wide, with a possible exception of South America – pending confirmation of species identification, *P*. *noxius* is reported to cause butt rot on over 200 species of trees and shrubs (Albrecht and Venette 2013), but many of these species are not found in Micronesia. In Taiwan, which shares many of the same tree species with Micronesia, an extensive effort by Ann *et al.* (2002) was conducted to summarize host species records on which *P. noxius* was reported. Their list is presented in Table 1.

Table 1. List of host records of *Phellinus noxius* in Taiwan (From: Ann *et al.* 2002).

Fruit trees

1. *Annona montana* (mountain soursop)
2. *Annona squamosa* (custard apple)
3. *Annona squamosa* × *A. cherimola* (atimoya)
4. *Artocarpus heterophyllus* (jack fruit)
5. *Averrhoa carambola* (carambola)
6. *Dimocarpus longan* (longan)
7. *Diospyros kaki* (persimmon)
8. *Elaeocarpus serratus* (Ceylon olive)
9. *Eriobotrya japonica* (loquat)
10. *Ficus pumila* var. *awkeotsang* (jellyfig)
11. *Litchi chinensis* (litchi)
12. *Muntingia calabura* (Indian cherry)
13. *Pachira macrocarpa* (malabar chestnut)
14. *Persea americana* (avocado)
15. *Prunus mume* (Japanese apricot, plum)
16. *Prunus persica* (peach)
17. *Pyrus pyrifolia* (pear)
18. *Syzygium samarangense* (wax apple)
19. *Sterculia nobilis* (ping-pong)
20. *Vitis vinifera* (grape)

Ornamental trees

21. *Acacia confusa* (Taiwan acacia)
22. *Actinodaphne pedicellata* (litsea)
23. *Aleurites fordii* (tungoil tree)
24. *Alstonia scholaris* (blackboard tree)
25. *Araucaria cunninghamii* (hook pine)
26. *Araucaria heterophylla (*Norfolk Island pine)
27. *Bauhinia* × hybrid (butterfly-tree)
28. *Bauhinia purpurea* (purple bauhinia)
29. *Bauhinia variegata* (orchid-tree)
30. *Bischofia javanica* (autumn maple tree)

31. *Bombax ceiba* (silk cotton)

32. *Broussonetia kazinoki* (small paper mulberry)

33. *Broussonetia papyrifera* (paper mulberry)

34. *Calocedrus formosana* (Taiwan incense cedar)

35. *Calophyllum inophyllum* (Indian poon beauty leaf)

36. *Camellia japonica* (camellia)

37. *Cassia fistula* (yellow golden shower tree)

38. *Casuarina equisetifolia* (ironwood tree)

39. *Ceiba pentandra* (1998)

40. *Cerbera manghas* (odollam cerberus tree)

41. *Chamaecyparis formosensis* (Taiwan red cypress)

42. *Chorisia speciosa* (floss silk tree)

43. *Chrysalidocarpus lutescens* (yellow areca palm)

44. *Cinnamomum kanehirai* (stout camphor)

45. *Codiaeum variegatum* (croton)

46. C*ryptocarya concinnai* (Konishi crytocarya)

47. *Cycas taiwaniana* (Taiwan cycas)

48. *Dalbergia sissoo* (sissoo tree)

49. *Delonix regia* (flame tree)

50. *Diospyros ferrea* var. *buxifolia* (Philippine ebony persimmon)

51. *Diospyros oldhamii* (oldham persimmon)

52. *Duranta repens* (creeping sky flower)

53. *Eucalyptus camaldulensis* (murray red gum eucalyptus)

54. *Eucalyptus citriodora* (lemon gum eucalyptus)

55. *Eucalyptus grandis* (maiden eucalyptus)

56. *Ficus elastica* (rubber plant)

57. *Ficus microcarpa* (small-leafed banyan)

58. *Ficus religiosa* (botree fig)

59. *Firmiana simplex* (Chinese parasol)

60. *Fraxinus formosana* (island ash)

61. *Gardenia jasminoides* (cape jasmine)

62. *Grevillea robusta* (silver oak)

63. *Hibiscus rosa-sinensis* (hibiscus)

64. *Hibiscus schizopetalus* (fringed hibiscus)

65. *Hibiscus tiliaceus* (linden hibiscus)

66. *Hydrangea chinensis* (Chinese hydrangea)

67. *Keteleeria davidiana* var. *formosana* (Taiwan keteleeria)

68. *Kigelia pinnata* (sausage tree)

69. *Koelreuteria henryi* (flame gold rain tree)

70. *Lagerstroemia turbinata* (crape myrtle)

71. *Lagerstroemia speciosa* (queen's crape myrtle)

72. *Lantana camara* (lantana)

73. *Leucaena leucocephala* (white popinac)

74. *Liquidambar formosana* (maple)

75. *Litsea glutinosa*
76. *Litsea hypophaea*
77. *Macaranga tanarius* (macaranga)
78. *Machilus zuihoensis* (incense machilus)
79. *Maesa tenera* (Taiwan maesa)
80. *Mallotus paniculatus* (turn in the wind)
81. *Melaleuca leucadendron* (cajuput tree)
82. *Melia azedarach* (China berry)
83. *Melodinus angustifolius* (narrow leafed melodinus)
84. *Michelia compresa* (Formosan michelia)
85. *Michelia figo* (banana magnolia)
86. *Muntingia calabura* (1998)
87. *Murraya paniculata* (orange jasmine)
88. *Neolitsea parvigemma* (small bud neolitsea)
89. *Nerium oleander* (oleander)
90. *Palaquium formosanum* (Formosan nato tree)
91. *Pinus thunbergii* (black pine)
92. *Pistacia chinensis* (Chinese pistache)
93. *Podocarpus macrophyllus*
94. *Pongamia pinnata* (pongamia)
95. *Pterocarpus indicus* (rose wood)
96. *Prunus campanulata* (Taiwan cherry)
97. *Osmanthus fragrans* (sweet osmanthus)
98. *Rhododendron obtusum* (rhododendron)
99. *Roystonea regia* (royal palm)
100. *Salix babylonica* (willow)
101. *Scheffera octophylla* (scheffera)
102. *Sterculia foetida* (hazel sterculia)
103. *Swietenia mahagoni* (mahogany)
104. *Tabebuia chrysantha* (yellow golden bell tree)
105. *Taiwania cryptomerioides* (Taiwania)
106. *Terminalia catappa* (Indian almond)
107. *Terminalia boivinii* (1998)
108. *Ulmus parvifolia* (Chinese elm)
109. *Zelkova serrata* var. *serrat* (zelkova)

Special crops

110. *Camellia sinensis* (tea)
111. *Cinnamomum camphora* (camphor)
112. *Cinnamomum zeylanicum* (Ceylon cinnamon)
113. *Coffea arabica* (coffee)
114. *Cordia dichotoma* (cordia)

Herbaceous plants

115. *Artemisia capillaris* (wormwood)
116. *Artemisia princeps* (mugwort)

117. *Ipomoea pescaprae*

118. *Lactuca indica* (wild lettuce)

119. *Melicope merrilli* (melicope)

120. *Sauranja oldhami*

121. *Urena lobata* (cadillo)

Although, *P. noxius* can infect many tree species elsewhere in the humid, lowland tropics, there are only limited reports of its presence in Micronesia. Hodges and Tenorio (1984) is the most cited report of *P. noxius* in Micronesia. They reported widespread *P*. *noxius* infestations on Rota, and found that several flame trees (*Delonix regia*) in plantings near the Saipan Airport, and in row plantings along some of the principle boulevards of that country, had been infected with *P*. *noxius* and had died. Hodges and Tenorio also considered *P*. *noxius* to be the cause of a crown rot on breadfruit in Pohnpei and Kosrae, FSM and other Pacific islands, which was reported Trujillo (1971). In 2010, Cannon (unpublished observations) visited the areas where these authors had found *P*. *noxius*, and also found the fungus (both sign and symptoms) on some nearby flame trees that had become infected more recently. He then found disease caused by *P*. *noxius* in several other locations in Saipan with assistance from Sid Cabrerra (who had worked with Hodges and Tenorio, earlier). Other communications were made evident that further suggested the potential presence of *P*. *noxius* on Pohnpei (with assistance from Gibson Santos) and in Kosrae (with assistance from Erick Waguk). A subsequent email from Francis Reugorong describing something resembling the "black sock" (Figure 7) on Yap convinced the senior author that *P. noxius* surveys were merited for islands of FSM.

While these preliminary *P. noxius*-related investigations were taking place in FSM, a much more intensive search for *P. noxius* was also wrapping up in the Ryuku Islands of southern Japan. Since 1994, Japanese forest pathologists had been dedicating about 15 days of every summer to visit one of these islands and survey trees on all parts of that island to determine if any *P. noxius* was present (Sahashi *et al.* 2012). These researchers are conducting a more detailed study, in that they were also collecting mycelial crust and wood from infected trees and establishing *P*. *noxius* isolates in culture. DNA from *P*. *noxius* cultures can be used for subsequent genetic analyses to evaluate genetic variation among isolates. This Japanese team's experience with detailed research studies of *P*. *noxius* is held in high regard by the international forest pathology community, so two members of this team (Yuko Ota and Norio Sahashi) were invited to participate in the surveys for *P. noxius* in Guam, Saipan, and Pohnpei, and they enthusiastically accepted.

Methods

A tentative list of all potential sites to survey for *P. noxius* on select FSM islands and Saipan was compiled by the senior author in advance of the trip. Bob Schlub considered potential sites on Guam. On arrival in each country, additional queries were made of lead foresters and natural resource advisors, which led to the expansion of these lists of potential sites on some islands. Plans to visit the potential sites on each island were arranged, and site visits were conducted. During these field surveys, the trunks of 10,000s of living trees, 1,000s of dead trees, and 100s of stumps were examined with the purpose of detecting *P. noxius*. The symptoms and signs (shown in Figure 7) were used for making field identifications. Although these symptoms and signs are relatively easy to recognize when observed, finding them often requires the removal of brush, grass and vines from around the base of trees being inspected.

When one tree was found to be infected with *P. noxius*, all of the trees in the surrounding area were also examined carefully and data for symptoms of infection, host species, and tree diameters at breast height were collected for these infected trees. A rough map was drawn for each of the infection foci, and recorded data also included site characteristics (e.g., elevation, slope, topography), soil properties (e.g., internal drainage, soil texture), stand characteristics (e.g., mixed or pure, relative density), and GPS location.

Prior to initiating the trip, permits were obtained from the USDA-APHIS-Plant Protection and Quarantine (PPQ) that allowed the regulated shipment of collected and isolated fungi to Ned Klopfenstein (USDA Forest Service, Rocky Mountain Research Station Forest Pathology Laboratory, Moscow, ID, USA). At each infection center that was found, samples were collected of every possible source of *P. noxius* (fructifications, infected wood, and mycelial crusts; Figures 1-5). The best sample material for making isolations included the mycelial crust, the infected (brown and dead) sapwood directly below an active mycelial crust, and the region of a fruiting structure just beneath the most recently developed hymenial layer on a sporophore. A less desirable, but occasionally successful, source for isolations is from within the zone-lines of colonized wood that was recently collected. All isolations were made onto Potato Dextrose Agar (with or without benomyl), as this medium has been shown to be effective for obtaining cultures of *P. noxius* in Japan. Isolations were conducted by Drs. Yuko Ota and Norio Sahashi for samples collected on Saipan and Pohnpei, by the senior author on Yap, Palau, and Kosrae, and by Bob Schlub on

Guam. Herbarium samples were also made by completely drying the samples (fructifications, mycelial crusts, and wood sections) using an air-flow drier at 60° C for 8+ hours.

All international samples sent to Ned Klopfenstein's laboratory were shipped through the USDA-APHIS-PPQ Plant Inspection Station facility in Seattle, WA, USA. PCR and DNA-sequence analyses were used to confirm that these infections were indeed caused by *P. noxius.*

Results

The results of these surveys for *P. noxius* are summarized in Table 2 and Figure 6. All putative *P. noxius* isolations and samples sent from the collections made during this survey were successfully received by the USDA Forest Service, Rocky Mountain Research Station, Forest Pathology Laboratory, ID, USA, and subsequent DNA analyses confirmed the identity of *P*. *noxius* isolates.

Discussion

At first glance, results shown in Table 1 seem to indicate that the *P. noxius* present in FSM and Saipan is not causing extensive damage. Only 84 trees were found to have been killed in the entire region on this trip, and these trees, collectively, had only about 19 square meters of basal area and covered less than 3.0 hectares of forest area. As such, it might be tempting to conclude that *P*. *noxius* poses little threat in this region. However, many other factors must be considered:

1) This was only a preliminary survey that was conducted under strict time constraints. Basically, only one person (the senior author) conducted a 1-day survey on Palau, six people participated for 1 day on Yap, 10 people conducted a 4-day survey on Guam, which included other fungi; eight people surveyed on Saipan for 1 day; 10 people participated for 1 day on Pohnpei, and 10 people surveyed Kosrae for 1 day. Therefore, it seems highly likely that only a fraction of the actual *P. noxius* distribution and impact in FSM and Saipan was observed.

2) The first futile *P. noxius* surveys in Guam reinforce this point. We did not find *P. noxius* during this September survey, but it is one of 49 fungi reported by Guam on the Widely Prevalent Fungi of The United States website in 2009. Also, Bob Schlub (personal communication) reported *P*. *noxius* symptoms on one tree in Guam as early as 1996. Fortunately, as a direct result of *P. noxius* presentations by Forest Pathology Team members during this visit, foresters working on

Guam, who had attended that presentation, have since identified *P. noxius* on four tree species in at least six limestone forest locations.

3) *P. noxius* was found over an extensive range of sites in Micronesia, indicating that it may already be widely distributed in this region.

4) Fruiting bodies were found on multiple sites, indicating that this fungus may not have to rely on relatively slow, root-to-root spread to expand its distribution. Root-to-root spread is limited to a maximum of ca. 1.0 to 2.0 meters per year, but if sporocarps are present, and if new infections can be started from spores, then new infection centers can be started 100s of meters and even kilometers away from current infection centers.

5) The finding of a resupinate fruiting body measuring 3.0 meters by 40 cm. is especially alarming; if this can produce viable spores, neighboring trees should be receiving a heavy load of spore inoculum, and many wounds could serve as vulnerable infection courts.

6) The long-term ability of *P*. *noxius* to survive is of special concern, because it can potentially re-emerge as a disease agent decades later.

7) The immense number of tree species that are vulnerable, because of the wide host range of *P*. *noxius*, is another major concern. This wide-host range should enable this fungus to expand its distribution across natural forests, which typically contain diverse tree species, with relative ease (e.g., this appears to be what happened in the "Sister's forest" on Saipan).

8) The ability of this fungus to infect some tree species that are key to Micronesia agroforestry is also alarming. Breadfruit is a "staff of life" in Micronesia and it is especially vulnerable, while, mango and betel nut are socially/economically important trees that are also susceptible to *P*. *noxius*.

9) Breadfruit may be playing a role in the distribution of this fungus (see later discussion).

10) As a result of the surveys, there was a renewed interest in finding evidence of *P*. *noxius*. Within days of the presentations on *P*. *noxius*, forest inventory personnel (of the USDA Forest Service) and Roland Quitugua (U. of Guam) began finding infected trees in Guam's northern limestone forests. As of December 20, 2013, six sites have been located, miles from each other, on 4 tree species, and likely involving over 100 trees.

Although each of the above factors is a potential source for major concern, one more factor that might be even more concerning and that is *P. noxius* impacts appear to be just emerging in this island area of the Pacific. Prior to 1979, *P. noxius* had not been reported in this part of the Pacific, although it may have been observed. Based on the sizes of the largest infection foci, *P*. *noxius* apparently has existed on some of these Pacific islands for at least a few decades. New infections tend to become more apparent after they occupy about 0.1 hectares of land and have already begun to kill a couple of trees. In 1984, Hodges and Tenorio (1984) reported observing a few 0.1-hectare infection foci on Saipan, which suggests that this disease was just becoming established. At the same time, however, Hodges and Tenorio reported that the infection centers on Rota were already beginning to coalesce. This observation led them to postulate that *P*. *noxius* was first introduced in Rota and that it might have been introduced on wood packing materials. This postulation seems plausible. For example, a tremendous amount of relief materials was transported from the Philippines to the Rota airport, following World War II. *Phellinus noxius* could have been transported to Rota in wood materials, such as pallets. If these wood materials were manufactured in the Philippines (or another location where *P*. *noxius* occurs) and contained *Phellinus*-infected wood, this could represent a means of introducing the *P*. *noxius* to Rota. It is plausible that such infected pallets were discarded into the areas surrounding the airports, where there they could serve as an inoculum source to infect existing forests. Hodges and Tenorio (1984) were unsure how *P*. *noxius* was transported from Rota to Saipan, but they speculated that movement via spores might be one of the possibilities.

Table 2. A summary of the results of surveys for *Phellinus noxius* in Micronesia.

Island location site No	No. trees killed	Basal area of trees (sq. m)	Size of foci (ha)	Site Characteristics	Tree spp. Affected
Saipan					
Two Sisters 1	50	10.	0.2	bottom urban	10 species
Airport 2	4	0.6	0.1	flat airport	flame tree
Airport 3*	4	0.6	0.1	flat airport	flame tree
Airport 4	4	0.6	0.1	flat airport	flame tree
College 5	1	0.1	0.1	bottom gym	flame tree,
Guerrero 6*	4	0.3	0.1	flat agroforest	mango, breadfruit
Pohnpei					
Gibson's 1	1	0.2	0.1	flat, disturbed	*Ficus tinctoria*
Gibson's 2**	0	0.02	0.02	flat agroforest	breadfruit
Chickens Mtn. 3	1	0.3	0.2	flat, village	breadfruit
New Coffee 4	1	0.2	0.2	slope/agroforest	breadfruit
Yap					
Vic's Village 1	1	0.2	0.2	compacted path	mango
Forestry HQ 2*	6?	1.	0.2	slope/agroforest	mango, chestnut
Palau					
Nat. His. Mus. 1*	1	0.2	0.1	flat/arboretum	mango stump
Kosrae					
Yela Conserv. 1	2	2.	0.3	flat poor drainage	*Terminalia*
Yela Conserv. 2*	3	3.	0.4	flat poor drainage	*Terminalia*
Yesron Valley 3	1	0.4	0.1	hilly/agroforest	breadfruit

Yesron Valley 4	6	2.4	0.4	slope/agroforest	breadfruit

* A sporocarp was found at this site. The resupinate sporocarp at Yela 2 measured 3.0 m by 0.4 m.

** Near here, an infected breadfruit tree had received the red ginger "shampoo" treatment and had apparently recovered completely; Gibson's farm is in Nanmand Village, Kitty Municipality.

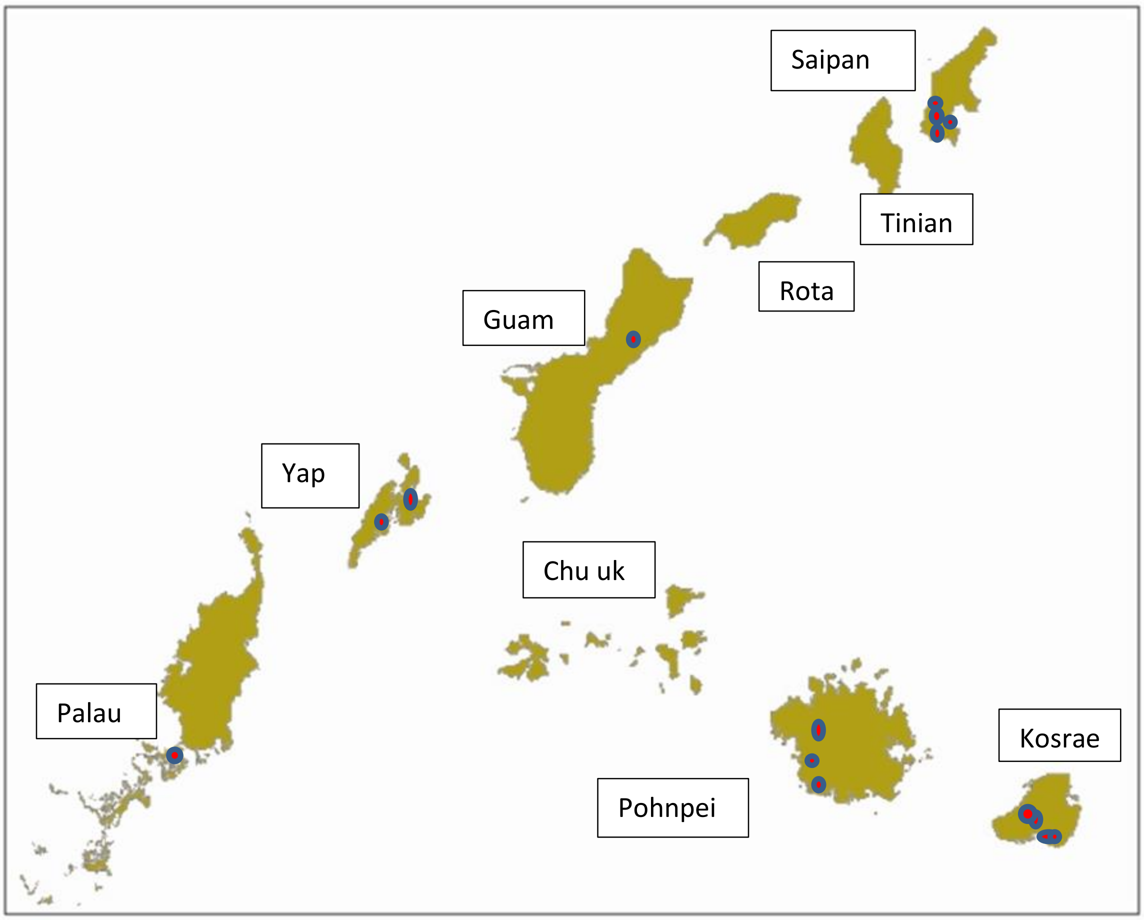

Figure 6. Locations where *Phellinus noxius* was found in Palau,Yap, Guam, Saipan, Pohnpei, and Kosrae during the September 2013, forays. On this trip, no sampling was done on Chu uk, Tinian, or Rota. Please note: geographic locations are stylized and distances between islands are not to scale.

Considerations of *P. noxius'* ability to spread via spores have resulted in a continuum of opinions. Some researchers have suggested that the spore dispersal pathway is likely not common because *P. noxius* appears to form fruiting bodies only very occasionally. Indeed, only a paucity of fruiting bodies were found during this recent foray. However, fruiting bodies were occasionally found during these surveys, which included both the bracket conks (on Yap, Palau, Pohnpei, Kosrae, and Saipan) and one extremely large example of the resupinate fruiting structure on Kosrae. The potential effectiveness of spores from these conks for initiating new infections is currently unknown. Numerous wounds that could provide infection courts of establishing new infections are created with wide-scale breakages in trees that occurs during typhoons and storms or when the bark is broken as a result of careless treatment by humans. Furthermore, the prevailing conditions in these Pacific Islands (hot and humid) represent an especially conducive environment for spore germination and colonization. If pathogen distribution via spores is possible, then *P. noxius* could spread at rates and distances that are much greater than pathogen spread that occurs only by tree-to-tree root contact.

Not all of the potential pathways of spread of *P*. *noxius* are known or even envisioned at this time, but another potential pathway of spread was discussed during this trip. Breadfruit is one of the tree species that was commonly infected by *P. noxius*. It is also the "staff of life" for most people in the Pacific Islands. Thus, a question arises: could aspects of breadfruit culture be contributing to *P*. *noxius* spread? A potential activity that may contribute to *P*. *noxius* spread is when breadfruit root suckers are collected from a tree that is already partially infected by *P. noxius* and then infected root suckers are transported to another location for breadfruit propagation and establishment. The movement of such infected breadfruit propagules could potentially promote long-distance dispersal of *P*. *noxius*.

Conclusions and Future Steps

From observations by the survey team, it appears that, so far, *P. noxius* has caused only moderate damage on Saipan and slight damage on all of the other islands examined. It is noteworthy, however, that at least small infection foci of *P*. *noxius* have been found on all of the islands that were visited during these surveys. Based on these observations, it seems reasonable that *P*. *noxius* was introduced (at least principally) subsequent to World War II. Bob Schlub and others have recently reported that *P. noxius* is a major wood rotter in Guam's northern limestone forests (unpublished observations). It seems likely that *P. noxius* was present on Guam at the time the 2002 Guam Forest Resource Inventory was taken, and it may have been responsible for some of the "conks" or "open wounds" reported on *Guamia mariannae*, *Intsia bijuga*, and *Macaranga thompsonii* (Donnegan *et al.* 2004).

In other tropical countries of Southeast Asia, where *P. noxius* has been functioning for a long time, it has established a reputation of being a very aggressive forest pathogen (e.g., Chang 1995; Mohd Farid *et al.* 2009; Ann *et al*. 1999). The forests of these countries comprise of many of the same tree species and have climatic conditions that are similar to Micronesia.

All of these circumstances should trigger alarm in the conscientious communities concerned about the future of their forests. On the other hand, large swaths of *P. noxius*-killed forests were not apparent in our surveys of FSM. Several activities are advised for each Pacific island to more precisely assess the threat posed by *P. noxius*. These activities are numbered and listed in the approximate chronological order of when they should occur; however, some of these activities could occur simultaneously.

1) Conduct additional surveys for *P. noxius* on each island. This could be achieved with the collaboration of local forestry staff, villagers, and a one-page bulletin that shows those symptoms and signs of this disease to facilitate the identification of this fungus (see Figure 7 for an example). Hopefully, many villagers will collaborate on this survey; the signs and symptoms are relatively easy to recognize once they are observed, but considerable effort is required to examine the base of every tree.

   Bob Schlub suggests that a *P*. *noxius* poster (Figure 7) should be customized, if possible, to display the typical symptoms/signs of *P*. *noxius* for each particular island, especially the tree species that are commonly infected. In addition, attempts should be conducted to sample and isolate *P*. *noxius* from trees that are potentially infected but do not show the typical symptoms. This activity would help establish the full range of symptoms and signs that are attributable to *P*. *noxius*. For example, mycelial crusts were observed on Guam that did not possess the distinctive white edge; however, a *P. noxius*-like crust was occasionally observed, but it did not originate from the soil line. Thus, detailed studies are needed to more precisely determine where *P*. *noxius* occurs and the range of its associated symptoms and signs.

2) Develop and continually update a *P. noxius* distribution map for each island; this map should have enough resolution to indicate the approximate size of infection foci.

3) Use DNA-based analysis (population genetics), coupled with local accounts, to provide insights on the history of the *P. noxius* distribution on each of the islands. This process will likely involve establishing representative isolate collections from the study areas, and the use of high-resolution genetic markers for genetic analyses. It will also involve some careful and thorough

interviewing of experienced agriculturalists, who may have been observing *P. noxius*, and its impact, for decades.

4) Use molecular genetics to better characterize aggressive isolates of *P. noxius*.

5) Conduct tests of tree species to determine their relative vulnerability to *P. noxius* (see: Mohd Farid *et al.* 2009, for an example). Such studies should be conducted for all tree species under consideration for extensive planting (e.g., coffee, breadfruit, mango, palms, citrus, etc.).

6) Complete a thorough literature survey of effective control measures for *P*. *noxius* and investigate the potential of local/traditional remedies. It is reputedly very difficult to control disease caused by *P*. *noxius*; however, disease management efforts should be much more effective when infection foci are still small vs. waiting until these foci become much larger and more noticeable.

7) Conduct local research studies to determine which disease control measures are the most effective, economical, and socially acceptable.

8) Develop and implement island-wide management plans for *P*. *noxius*.

Many of these activities occur on the islands (activities 1, 2, 8 and parts of 3 and 7), while others may require the participation of advanced forest pathology laboratories (part of activity 3 and all of 4).
The first activity is an especially critical and important step, especially considering how little we know about the distribution of this fungus, which is largely shown in Figure 6. The next step is to promote and distribute the "*Phellinus noxius* poster" or similar information on each island. Figure 7 shows an example of what such a poster might look like for an island, but perhaps better pictures of *P*. *noxius* would increase its recognition, and such posters would likely be more effective if some are written in the local language. To help spread the information, these "*Phellinus noxius* posters" could be distributed to key locations near every village (and post offices) on most islands in FSM, Guam, Palau, and the Northern Mariana Islands. Local inhabitants could be encouraged to report all of their *P. noxius* findings to the local foresters/agricultural specialists so that these specialists could record and submit GPS locations for

all locations where *P. noxius* is found. Collectively, these measures will provide much more definitive information about *P. noxius* distribution on each island.

Some of these activities are not complicated and can probably be achieved with existing staff and funding; however, additional funding is likely necessary to support some of the more complex activities. Several potential funding sources may be available, including State and Private Forestry of the USDA Forest Service. Please contact the senior author if funding for one or more of these activities is needed.

WANTED

Information Leading to the Location of This Fungus

Figure 7. Have you seen something growing on the outside of a tree base that looks anything like the fungus shown in the three pictures above? If so, please note the location of that tree and please report this to your local forester. Upper left: typical “black sock” symptoms where the fungus (*Phellinus noxius*) completely surrounds a young trees of less than 5 inches (~ 13 cm) diameter at breast height (Photo by Fred Brooks); Upper right: the typically white leading edge of a mycelial crust of this fungus as it grows up the outside of larger diameter tree (Photo Ned Klopfenstein); and Bottom: the faded out colors of both the mycelial crust and leading edge of a *Phellinus noxius* infection on a dying flame tree (*Delonix regia*) during the dry season (Photo by Ned Klopfenstein).

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