Forest Pathology in Yap, Palau, Pohnpei, Kosrae, Guam and Saipan, Sept. 2013

By: Phil Cannon

Overview: In September of 2013, an opportunity was seized by the Regional Forest Pathologist to do some work on the following islands in Micronesia and the Marianas: Yap, Palau, Guam, Saipan, Pohnpei, and Kosrae. The principle justification for doing the work at this time was that satellite images showed large areas of dead mangroves on Yap (Liu, pers. com*). Many parties wanted to know the cause of this extensive dieback. However, it is a long and expensive trip to Yap, so it was decided to couple the investigation of this mangrove problem with several other ongoing forest pathology activities in this region. The author spent 100 hours preparing for this trip, 310 hours working and/or traveling during the 23 days of the trip; and 280 hours subsequently researching and writing this current set of reports. Another 100 professionals participated in some aspects of this project: about 50 persons for about 1-2 hours apiece; about 30 persons for about 6-8 hours apiece, about 15 persons for 10-16 hours apiece and about 15 persons for between 40 and 200 hours apiece. In sum: this was not a small undertaking.

Figure 1. Heading out to study diseased and healthy mangrove forests at Yinof Mn, Yap; the kayaks were used as floating sampling platforms (photo by Margie Falanruw).

*personal communication: Zhangfeng Liu, GIS consultant with the U.S. Forest Service, Vallejo, California. There are 11 chapters in this report. The first provides a list of the principle contacts and highlights of the work done on each of the six islands worked on during this trip. So, f**or the reader that has little time,** please, at least see Chapter I. **For the reader who has a deep curiosity about one or more of the themes explored during this trip** please read the corresponding chapter where that theme is developed in depth. Gratitude is expressed to all of the co-authors of these chapters. At some point in the future, after some additional analytical work can get done, chapters III, IV, and V may be developed into publications.

Chapter I

Highlights, Personnel Contacted and Forest Pathology Activities Undertaken During the September, 2013 Trip to Yap, Palau, Pohnpei, Kosrae, Guam, and Saipan

By: Phil Cannon

YAP

Highlights: The author worked with Margie Falanruw, Francis Ruegorong, Andrew Yinfel, and others to determine causes of the extensive mangrove dieback (Chapter II). The group also found the super-pathogen *Phellinus noxius* (Chapter IV). The author was introduced to the difficulties that forest trees have when they are planted on acidic, poorly-drained, upland soils (Chapter VI). Forest fungal pathogens were collected, isolated, and mailed to the USDA Forest Service – Rocky Mountain Research Station (RMRS) for identification by DNA analyses (Chapter III). Three *ad hoc* debriefing/training sessions were held to discuss the mangrove dieback situation, discuss *Phellinus noxius*, and demonstrate techniques for making fungal isolations. Future forest pathology activities for Yap were discussed (Chapter X).

Personnel Contacted	Institute	Hours worked together
Margie Falanruw	US Forest Service	20
Francis Ruegorong	Yap Forestry	12
Pius Liyagel	Yap Forestry	12
Andrew Yinfel	Yap Forestry	8
Valentino Orohaitil	Yap Forestry	5
Francis Liyeg	Yap Forestry	1
Frank Haregaichig	(Director Yap Resources & Devl.)	1
Tamdad Sulog	Chief, Yap Agric. and Forestry	2
Ryan Talken	Yap Forestry (ex Peace Corps)	1
John Buchun	Yap Forestry	1
Joseph Ochay	Yap Forestry (nursery)	1
Julius Buchun	Yap Forestry (intern)	5
Eric Defan	Yap Forestry (intern)	5
Linda Buthung	Yap Forestry	5

Day-by-Day Forest Pathology Activities on the Island of Yap

Day #3 - Met 12 Yapese foresters; then, with 7 of these foresters, we surveyed several coastal and upland sites in NE Yap for pathogens attacking forest trees and some agroforestry crops. We collected fruiting structures of pathogens, made observations on two root-rot infection centers and determined that these are being caused by *Phellinus noxius*. We then held a 1-hour impromptu training session on *P. noxius* and made plans with Yap foresters for future activities with this pathogen.

Day #4 - Made arrangements with FedEx to ship fungal specimen to the Ned Klopfenstein lab of the USDA Forest Service – Rock Mountain Research Station. Visited the Yinuf Mn mangrove area with six members of Yap Forestry. This is the largest area in Yap where there has been mangrove dieback. At each of 8 plot sites (four paired plots) we took samples of mangrove muck, and measured seawater pH, seawater temperature, seawater salinity, seawater depth and seawater turbidity. Half of these plots are in areas where mangroves are healthy; the other half were nearby but in areas where mangroves were dying. We made additional observations on features of the massive mangrove dieback site and speculated on the factors which may have contributed to this extensive problem. In the evening, Francis Ruegorong, Pius Liyagel and the senior author made fungal isolations onto selective media using an *ad hoc* lab set up in a hotel room.

Day #5 - Shipped fungal isolates to the Ned Klopfenstein Forest Pathology Laboratory in the USDA Forest Service – RMRS (Moscow, Idaho) via Fed-Ex; lunched with the entire Yap forestry department and provided a debriefing on the tentative hypotheses as to why mangroves are dying in Yap (especially to the Director Frank Haregaichig, who has hosted the lunch, and Francis Ruegorong). We then returned to the mangroves with Margie and Andrew and traveled up a long channel to see a large section of mangrove that had not died back.

Day #6 - Traveled with Pius and several other foresters to see volcanic (acid) soils derived from breccia and Agroforestry on MAAP and then to see plantation efforts with *Acacia auriculiformis, Sweitenia macrophylla* and other tree species. Comparisons were made between these plantations and plantations elsewhere in the world where these species are being grown commercially. We also looked at more mangroves on the south Island (near the Seawall).

PALAU

Highlights: The aggressive pathogen *Phellinus noxius* (Chapter III) was found first thing in the morning in the arboretum at the Balau Natural History Museum; we continued observations on mangrove dieback (Chapter I) became familiar with many more tree problems that occur when seedlings are planted on poorly drained, acidic soils (Chapter V); discussed the possible role of forest pathogens in counteracting some of the high CO_2 sequestration rates of mangrove forests (Chapter VI); and collected and isolated fungi responsible for butt rots in Palau (Chapter II).

Personnel Contacted	Institute	Hours worked together
Rich MacKenzie	US Forest Service (IPEF)	20
Omekrael Sadang	Bureau of Ag. Technician	12
Pua Micheals	Palau Forest Dept. (State Forester)	2
Ann Kitalong	Belau Natural History Museum	3
Larry Mamus	Palau Forest Dept.	6
Rayban Wasisang	Palau Forestry Dept.	6
Hilda Etpison	Quarantine at the Airport	2

Day by Day Forest Pathology Activities on the Island of Palau

Day #8 - Found *Phellinus noxius* early in the arboretum at the Belau Natural History Museum; met with Ann Kitalong and then Pua Micheals to get an orientation to forestry in Palau; spent the remainder of the day traveling with Palau Forestry staff (Larry Mamus and Rayban Wasisang) seeing reforestation efforts on Babeldaob and visiting places where trees are having dieback problems and/or poor growth such as the plantation area around the Lake Ngardok reservoir. We also visited more mangrove stands and collected more butt-rot pathogens for isolation.

Day #9 - Went to Babeldaob by boat with Rich MacKenzie to visit an area near the village of Airai (in Airai State). Here, mangroves surrounding a channel had been reported as dying by Dr. Pat Colin of the Coral Reef Research Foundation. Dr. Colin had noticed these dead trees during a routine aerial survey he conducted of the entire Babeldaob Island. We determined that 99% of this death is by deliberate girdling of trees along the sides of this channel. This was done, almost certainly, to improve small-boat access of this channel. We collected sporocarps (conks) of pathogenic butt-rot for subsequent identification. Then we went to a second mangrove area where measurements are being made by Rich and Omekrael Sadang in a permanent mangrove sampling plot to document the changes in the depth of mangrove muck and thereby monitor below-ground carbon accumulation as well as changes in the overall depth from the water surface to the forest floor. A large number of fungal conks were seen in this section of mangroves, especially on the big *Xylocarpus* and *Calophyllum* trees. Representative sporocarps of these fungi were collected and isolations from these were made by night in the hotel.

Day #10 - We returned to the plantation area near Lake Ngardok to collect six soil samples from areas where trees planted 9 years earlier were now barely alive. Subsequently, we traveled to a second permanent mangrove sampling plot that was established with the help of Rich MacKenzie. This plot was known to have been lightly affected by Typhoon Bopha 6 months earlier. We made some measurements of the amount of damage that this typhoon had caused to the trees and discussed the effect that butt-rot fungi were having on increasing the vulnerability of mangrove trees to storm damage and also their countervailing influence on the amount of carbon being accumulated in these permanent sample plots (Chapter VII). At night, in an *ad hoc* hotel-room lab, fungal isolates were prepared by Rich and the senior author for mailing to the USDA Forest Service – Rocky Mountain Research Station for molecular genetics analyses.

GUAM

Highlights: The senior author was on Guam four times during this trip. During the first two visits, preparations were made for the visit by the International "Dream Team" of Forest Butt Rot Pathologists (Chapter III). The International *Casuarina* Provenance test (Chapter V) was also reviewed during the first visit and marked for thinning. Interviews were also held with Drs. Bob Gavenda and Mohamud Golabi on properties and management of the acid soils of Yap, Palau, and Guam (Chapter VI) and with Dr. George Wall to discuss other plant diseases that were found on Yap (Chapter XI). Three opportunities were taken to debrief local forestry experts on the impact of butt-rotting fungi on Guam, the largest of these audiences was at the *Phellinus noxius* lecture delivered by Dr. Yuko Ota (22 persons in attendance) (Chapter IV). An opportunity was taken to catch up on recent developments at the Cetti Bay reforestation project with Bob Wescomb. Future forest pathology activities were discussed with over a dozen individuals (Chapter X).

Personnel Contacted	Institute	Hours worked together
Robert (Bob) Schlub	U. of Guam	80 (includes time on Saipan)
Roger Brown	U. of Guam	30
Sheeka Tereyama	U. of Guam	10
Joe Afaisen	U. of Guam	12
Ruddy Estoy	Guam Forest Dept.	6

Justin Santos	Guam Forest Dept.	2
Belmina Soliva	Guam Forest Dept.	1
Roland Quitugua	U. of Guam	3
Bob Gavenda	NRCS Guam	2
Bart Lawrence	NRCS Guam	2
Mohammad Golabi	U. of Guam	2
Chancy Thomas Iyekar	U. of Guam	1
George Wall	U. of Guam	1
Ashley Lehman	USDA Forest Service - FIA	8
Robert Wescom	US Navy, Guam (ex Cetti Bay)	2
Gary Denton	Guam Marine Lab	1
12 Students	U. of Guam	12

International "Dream Team" of Forest Butt Rot Pathologists

Name	Institute	Hours worked together
Yuko Ota	Forest Res. Inst. Japan	70 (includes time on Guam, Saipan, and Pohnpei)
Norio Sahashi	Forest Res. Inst. Japan	70 (includes time on Guam, Saipan, and Pohnpei)
Mee-Sook Kim	Kookmin U, Korea	70 (includes time on Guam, Saipan, and Pohnpei)
Ned Klopfenstein	USDA Forest Service - RMRS	75 (includes time on Guam, Saipan, and Pohnpei)

Day by Day Forest Pathology Activities on the Island of Guam

Day #2 - Reviewed the *Casuarina* provenance test at Yigo and marked it for thinning; reviewed six potential sites in NE Guam for their appropriateness for collecting fungal specimen for DNA analysis.

Day#7 - Reviewed eight potential sites in south western Guam for the possibility of collecting fungal material for DNA analyses and identification.

Day #11 - Interviewed Dr. Bob Gavenda about acid, Al^{+++} saturated soils in Guam, Yap and Palau; met with Dr. George Wall to discuss Yapese diseases on Taro, Betel nut and Betel Piper; met with Dr. Mohammad Golabi to hand off soil samples for analysis; met with Gary Denton at the Marine Laboratory to see if it would be possible to get aluminum saturation assessed from soil samples collected in Yap and Palau; made final arrangements for the visit by the Butt Rot experts from Japan, Korea and the US.

Day #12 - Gave lecture on butt rot pathogens of forest trees to Bob Schlub's plant pathology class (12 students); met with Ruddy Estoy and Justin Santos at Guam Forestry; met Bel Soliva who is working on reducing damage to trees via programs in the Guam school system, picked up all of the visiting Butt Rot specialists at the Guam Airport and helped with their initial orientation to Guam and to the personnel and plant pathology laboratories at the University of Guam.

Days #13-14 - Set up an early Saturday lecture on *Phellinus noxius*. The lecture was provided by Dr. Yuko Ota. There were 22 persons in attendance including the U. of Guam Department of Agriculture (professors and students), the Forest Inventory Analysis team of the USDA Forest Service and the Guam Forestry Department. Subsequently, most of this group traveled to the North side of Guam to make a collection of butt rot fungi. The next day collections were made on the south side of Guam. Fungi were isolated on selective media and samples were mailed to both the USDA Forest Service – Rocky Mountain Research Station and to Japan for molecular genetic analyses.

SAIPAN

Highlights: Worked almost exclusively on *Phellinus noxius* on this island as this is the place in Federated States of Micronesia (FSM) where this fungus has caused the most damage (Chapter IV); took two opportunities to debrief Saipan professionals and leaders on the nature of this fungus; discussed future steps in ways of understanding and dealing with this pathogen (Chapter X).

Personnel Contacted	Institute	Hours worked together
Vic Guerrero	Saipan Forestry	10
Manny Tenorio	Saipan Forestry - Director	8
Sid Cabrera	Private Consultant	2
Arnold Route	Marianas College Professor	6
Arnold Palacios	Saipan Forestry - Chief	1
2 Students	Marianas College	4

Day by Day Forest Pathology Activities on the Island of Saipan

Days #15-17 - Found and documented six sites with *Phellinus noxius* in Saipan; collected fungal samples at all sites; isolated samples onto selective media (Chapters III and IV); debriefed with professor Arnold

Route and students in the plant protection lab and in the field. Also debriefed with the Chief of Forestry for Saipan, Arnold Palacios.

POHNPEI

Highlights: Worked almost exclusively on *Phellinus noxius* on this island because the NRCS team was so eager and well-prepared to work on this disease (Chapter IV). We debriefed Pohnpeian audiences on this disease during three occasions and picked up some local suggestions on managing this disease. A little extra State and Private grant work was performed with Simon Liphai.

Personnel Contacted	Institute	Hours worked together
Arlene Rosenkrans	NRCS	5
Gibson Santos	NRCS	10
Rodasio Samuel	NRCS	10
Simon Liphai	Pohnpei Forestry Dept.	4
Andrew Joseph	Pohnpei Forestry Dept.	1
John Wichep	FSM Quarantine Chief	2
Konrad Engleberger	Coordinator Plant Protection FSM	8
Doria Rossen	US Ambassador to FSM	2

Day by Day Forest Pathology Activities on the Island of Pohnpei

Day # 18-19 - Met and debriefed on what is known about *Phellinus noxius* with the NRCS team and US Ambassador to FSM, Doria Rossen. Reviewed sites with *P. noxius* in Pohnpei and collected samples and information about the sites; talked with Gibson's uncle (Joab) about some control measures he has employed with apparently very successful results; isolated fungal samples; presented *P. noxius* in a formal lecture to the authorities charged with managing Pohnpei's forests (20 in attendance) and discussed future steps for dealing with this fungus.

Day # 20 AM - Mailed fungal samples to the USDA Forest Service – RMRS and Japan for DNA analyses; discussed S&PF grant administration with Simon Liphai; said good-bye to those specialists from Japan, Korea and the US that had participated in this butt-rot foray for eight days straight.

KOSRAE

Highlights: Traveled to the Yela Conservation area with Blair Charley, Katie Friday, and others (Yela is the first Forest Legacy Project in Micronesia). The objective was to determine if there were any forest pathology problems present. We found *Phellinus noxius* both on a few enormous *Terminalia carolinensis* at Yela and on breadfruit trees on the other side of the Kosrae Island (Chapter III). Good discussions on this pathogen ensued in the field and back in the forestry headquarters. This included planning next steps for dealing with this pathogen (Chapters IV and X). We also studied two mangrove areas with problems: one area, on the exposed coast, was losing a large number of trees from wave action/higher seas (Chapter II); the other had a high proportion of its trees infected by butt rot fungi (Chapter III). We also saw new forest protection problems in Kosrae (a white fly and a new termite species) (Chapter XI).

Personnel Contacted	Institute	Hours worked together
Blair Charley	Kosrae Forestry	8
Maxson Nithan	Kosrae Forestry	12
Katie Friday	US Forest Service	22
Erick Waguk	Kosrae Forestry (State Forester)	1
Robert Jackson	Director Kosrae Forestry	1
William William	Yela Conservation Area	4
Rickson Johnathan	Outreach Yela Conservation	4
Leonard Sigrah	Kosrae Forestry (Forest Health)	6
Carlos Cianchini	Education	6

Day by Day Forest Pathology Activities on the Island of Kosrae

Day # 20 - Arrived in Kosrae late in the afternoon. On the way to the hotel saw several forest problems near the roadside with Blair Charley and Maxson Nithan.

Day # 21 - Traveled by boat to the Yela Conservation area with the purpose of seeing if there are forest pathology problems that merit attention in this area; found and documented two *Phellinus noxius* infection foci in this area; we discussed this disease *in situ* with most of the Kosraen Forestry staff. We also collected samples of the fungus and infected wood and fructifications and also tried our hand at employing a folk remedy for controlling *P. noxius* (the application of mangrove mud to the leading edge of the *P. noxius* crust). Subsequently, we traveled to Yesron Valley, near Utwe and climbed up through some agroforestry lands to find two more *P. noxius* infection foci on breadfruit trees; we interviewed Maxson's uncle who has been observing this fungus on Kosrae for over 40 years (Note: Katie Friday subsequently interviewed Erick Waguk who revealed that the fungus has also been in nearby Kuplu Wan valley for at least 40 years. Erick also indicated that he thinks the disease is spreading very slowly).

Towards treating this fungus, Erick has tried three things: 1) removing the mycelial crust and applying seawater to the cleared bark; 2) clearing out the understory brush around the base of affected trees in an attempt to dry out this mycelial crust; and 3) piling up leaves of banana, *Pandanus*, and coconut at the base of affected trees and then burning these to singe the fungus.

Day # 22 - Started writing the trip report, made fungal isolates onto selective media and, with assistance from Katie Friday, did a survey where trees, which had been growing on a reef ridge left by the 1905 Tsunami, were now being undercut by wave action at high tide.

Day # 23 - Got quarantine clearance for sending isolates and mailed them to the USDA Forest Service - RMRS; debriefed with Robert Jackson (Director of Kosrae Forestry) and Erick Waguk. Developed future *Phellinus noxius* plans with Leonard Sigrah. Traveled back to California.

Chapter II

The Causes of Mangrove Death on Yap, Palau, Pohnpei, and Kosrae

By: Phil G. Cannon, Margie Falanruw, Francis Ruegorong, Rich MacKenzie, Katie Friday, Amy L. Ross-Davis, Sara M. Ashiglar, Ned B. Klopfenstein; with Zhangfeng Liu, Mohammad Golabi, and Chancy Thomas Iyekar.

Abstract: The area of a massive mangrove dieback in Yinuf Mn Island, Yap, was selected as the first location to study mangrove dieback problems. Seawater and soil samples were collected from plots where the mangrove trees were dead/dying and these samples were analyzed for eight different seawater and soil floor properties. Seawater and soil properties from dead/dying/missing mangrove samples were then compared with these same eight properties for seawater and soil samples collected in nearby plots where mangrove trees appeared healthy. For these eight properties, no apparent differences were found that might help explain why mangroves had died or stayed healthy. Consequently, other possible explanations for mangrove dieback were sought, based on current stand conditions and a consideration of extenuating circumstances in the recent history of this site. At this Yinuf Mn island site, a plausible explanation for the massive mangrove dieback was that Typhoon Sudal, which had struck 9 years earlier (in April, 2004) with both strong winds and a powerful storm surge, had pushed over about 100 acres (40.5 ha) of trees on the seaward edge of this mangrove stand. These trees may also have been heavily butt rotted or impacted by an oil spill, factors which could have rendered trees more prone to toppling during Typhoon Sudal. In a separate incident, Typhoon Bopha (December, 2012), caused minor but still measurable damage to a mature mangrove stand in Babeldaob, Palau. Other potential contributors to mangrove-stand dieback in this region include girdling of trees along channels to improve boat navigation through mangroves (in Airai, Palau), the undercutting of coastlines by wave action and rising seas (in Yap, Saipan, and Kosrae), and, of course, some harvesting of mangrove trees for poles and timber (in Pohnpei and Palau). Extensive butt rot was observed in many older mangrove stands, especially in stands with high proportions of *Sonneratia alba* and *Xylocarpus granatum*.

Introduction

Death of trees in the mangroves has been reported for many islands in Micronesia. In some cases, tree mortality has been attributed to excessive harvesting or improper selection of the mangrove trees for harvesting, based on their position in a stand; however, no clear explanation has been provided for other cases. After reviewing recent satellite images of Yap in 2012, Zhangfeng (Leo) Liu found that approximately 10% of Yap's very extensive mangroves had died since the previous images had been released in 2006. In some locations on Yap, nearly 50% of the mangroves had been killed. One area where dieback was exceptionally high was near the Yinuf Mn Island, as shown in Figure 1. Initially, scientists in the Regional Office of the US Forest Service postulated that a few causal factors that may have contributed to mangrove mortality included the following: 1) influence of sea level rise; 2) effect of erosion occurring in the watersheds above these mangroves, which filled the coastline with sediments in a manner that may have suffocated the mangrove roots; or 3) unfavorable changes in the salinity, temperature, and/or pH of the mangrove. Differences in water salinity between and within mangrove stands has been documented previously by Ewel *et al.* (1998).

In early conversations with Margie Falanruw (USFS, Yap), four other factors that may also have contributed to mangrove death were also discussed and considered: 1) the construction of a second airstrip running parallel to the new airstrip upslope from the Yinuf Mn (this new airstrip had damaged taro patches just upslope from this mangrove); 2) the building of the main road that apparently had resulted in an earlier conversion of the mangrove on the island-side of the road into a marsh; 3) an oil spill that had occurred after a ship hit the reef in the main harbor (mangroves in the area of Yinuf and Luech had been coated in oil, but did not die at least within a year following the spill); and 4) impacts of Typhoon Sudal which had inflicted extensive damage to the mangrove in 2004.

Methods

During this visit, three approaches were used to investigate the death of mangroves in Yap and elsewhere in the Federated States of Micronesia (FSM): 1) A measurements approach at Yinuf Mn Island, Yap; 2) A "common-sense" approach at Yinuf Mn Island, Yap; and 3) a "common-sense" approach at other mangrove stands in FSM. The methodologies and information gained by these approaches are presented separately in the Methods, Results, and Discussion sections of this report.

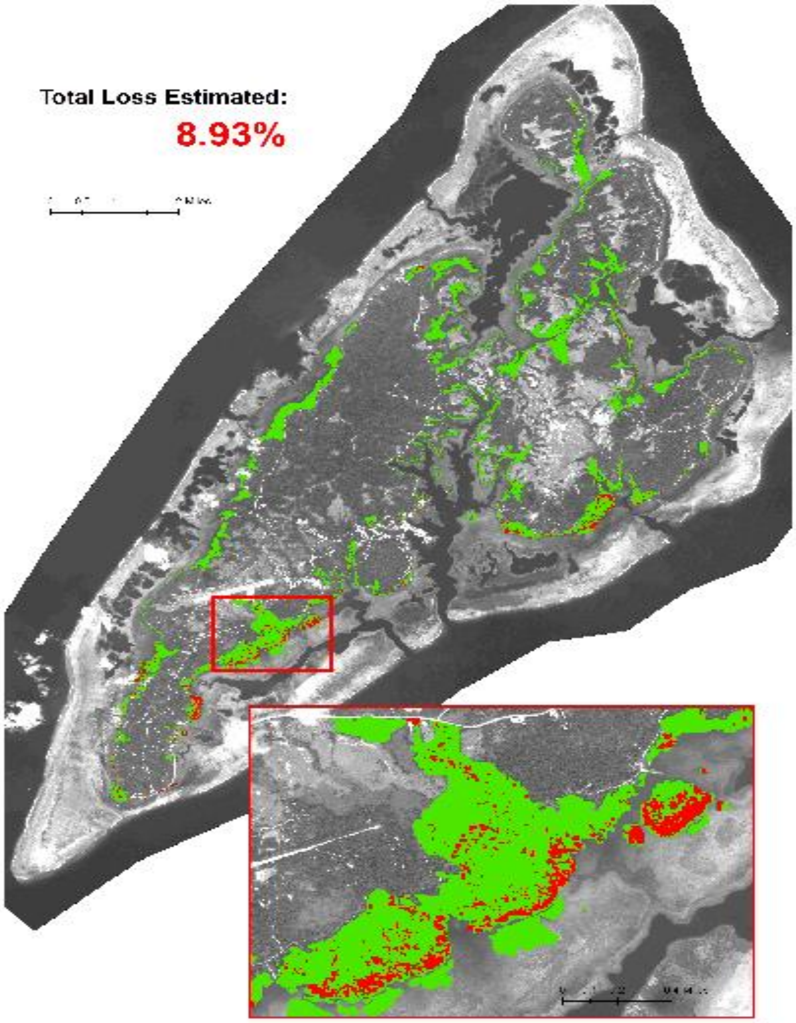

Figure 1. The mangrove forests of the biggest islands of Yap are shown in green in this transformed satellite image taken in 2012. The red areas depict mangrove areas where trees had largely disappeared since a similar image was taken in 2006 (image analyses by Zhangfeng Liu, USFS contractor). The greatest damage is shown along the southeastern coast of Yap and especially on the island of Yinuf Mn, shown in the northeastern (upper right) corner of the inset image. This report includes a concentrated, on-site effort to determine why the mangroves in the island of Yinuf Mn disappeared from satellite view between 2006 and 2012.

I) A measurements approach at Yinuf Mn Island, Yap

Towards determining potential changes in the sea floor or seawater properties in the vicinity of the mangroves that might be influencing mangrove health in the Yinuf Mn area of Yap, the following pieces of equipment were purchased (or borrowed or made) and used on site: salinity meter, pH meter, turbidity meter, thermometer, and yardstick (0.91-m, depth-measuring device).

Figure 2. Because this study required plots that represented both high and low tree survival, we used a "mobile laboratory platform", comprised of two double kayaks carrying the equipment set, to move ~1 mile (1.6 km) during the course of this examination.

Figure 3. A green yardstick (0.91-m, depth-measuring device) was used to measure the depth of seawater to the mangrove muck.

Figure 4. The use of a turbidity meter is straightforward, although calibration of this instrument is more involved. Water samples are collected in a cuvette (a 3-cm-long glass vial with a plastic, screw-on top, shown at the right in the photo above) and then inserted in the meter. (Photo by M. Falanruw).

Figure 5. Seawater salinity, pH, and temperature were all measured with this device. In all cases, the probe of the sensor was positioned at 1 inch (2.54 cm) below the water line.

Figure 6. Relics of fallen mangrove trees provided testament to the fierce wind and storm surge-generated forces that pounded this area during Typhoon Sudal (April, 2004). Margie Falenruw reported that the leaves of many of these trees turned tan as soon as Typhoon Sudal passed through. It was readily apparent that the exposed root systems had become progressively more damaged by sunscald and a brown cubical rot.

Figure 7. This *Rhizophora* sp. mangrove tree survived Typhoon Sudal (April, 2004), but it is still suffering from damage. Its crown is leaning towards land, suggesting that it was pushed by the typhoon (wind and/or storm surge), and the neighboring trees are missing entirely. Since then, many exposed stilt roots have become badly cankered (sunscalded) because they are exposed to direct sunshine. The wood beneath these cankers had become colonized by wood-rotting pathogens (largely *Ganoderma* and *Phellinus* species). Over the next few years, this wood rot will likely weaken these roots to the point where they fail structurally, and the tree will fall over completely.

Figure 8. Soil samples were also collected from a mangrove area that appeared to be in good health. At each setting, one sample was collected for analysis of soil physical and chemical properties, and another sample was collected for a potential soil metagenomics study.

Figure 9. The collection of a mangrove floor sample sometimes includes both mangrove muck (dark material) and reef rubble (white material).The sample was drained in a small sieve for 2 minutes prior to being stored in a preservation solution to prevent degradation of microbial DNA and/or RNA.

Figure 10. Two cm^3 (ml) of seafloor (the mix of mangrove muck and reef rubble shown in Figure 9) was added to a screw-topped centrifuge tube containing 2.0 ml of the preservation solution. These tubes were then sealed with Parafilm® and stored in refrigerators, freezers, and/or ice boxes, as practical, for the trip from Yap to the Rocky Mountain Research Station Laboratory, where they can be analyzed.

Figure 11. Margi Falanruw, Natural Resource Technology Transfer Specialist, with the USDA Forest Service, Institute of Pacific Islands Forestry, recorded plot notes.

In the mangrove sites, this equipment was used to carefully sample and measure seawater pH, salinity, turbidity, temperature, and depth. These measurements and samples were collected at four locations where mangrove trees were dead/dying/missing and for four nearby locations (paired plots) where mangrove trees appeared to be healthy. Similarly, soil samples were collected from the sea-floor surface at each of these sites and subsequently transported to the Golabi Soils Laboratory at the University of Guam for analysis of the mechanical and chemical properties. In this laboratory, soil mechanical properties were analyzed for percent sand, silt, and clay. In addition, soil chemical properties were analyzed for pH, percent organic matter content, and percent P, Ca, and K. A tactile analysis was also performed on site with these soil samples to obtain a very rough estimate of their mechanical properties and organic matter content. To examine any significant differences that might provide a plausible explanation as to why some mangrove trees had died, results were contrasted for all of these parameters between mangrove plots that appeared healthy and plots that contained dead/dying/missing trees.

For potential soil-metagenomics analyses, a tea-cup-sized (~175 ml) scoop was made of the surface soil right at each plot center, and this sample was then placed in a strainer and allowed to drain for 1 minute. Then, a 2.35-cm^3 (ml) soil sub-sample was collected from this strainer and placed in a screw-capped test tube which contained a solution to prevent degradation of microbial RNA (LifeGuard Soil Preservation Solution™, MoBio, Carlsbad, CA) and shaken so that the soil sample was well mixed. This would stymie any future biological reactions as long as the sample was kept below freezing. To ensure that the samples were kept as cool as possible, the samples were kept in a refrigerator in Yap. Subsequently, samples were transported on a short flight to Guam, where they were stored in a freezer. Samples were sent on dry ice to the Forest Pathology Lab of the Rocky Mountain Forest Research Station, where they will be stored at -80°C until they can be processed. Dependent on funding, amplicon sequencing of DNA is planned to profile the bacteria and manglicolous fungi (fungi found in mangroves) present in the samples via the Illumina MiSeq system using 2 x 300 bp-end processing. Sequences will be associated with specific sediment samples via DNA barcodes, and will be grouped into discrete taxa based on percent similarity. Soil samples can also be used for metatranscriptomics, in which mRNA is sequenced to determine which microbial genes were being expressed at that particular seafloor at the time of sample collection.

II) A “common-sense” approach at Yinuf Mn Island, Yap

Of course, it is especially important to consider whether other factors might also be influencing mangrove dieback in these stands. No special equipment was required for these assessments, which only required strong communication with well-informed professionals (especially Margie Falanruw and Francis Ruegorong) and other local inhabitants who were familiar with the mangroves, an open mind, and a basic understanding of ocean dynamics and tree physiology within mangroves.

III) 3) A “common-sense” approach at other mangrove stands in the Federated State of Micronesia (FSM).

Similar “common sense” assessments occurred in 11 other “dying” mangrove stands during this trip. Three more mangrove plots were examined in Yap (with Margie and Pius); five more in Palau (with Rich, Ome, Larry, and Rayban); one more in Pohnpei (with Kevin Eckert); and two more in Kosrae (with Maxson and Katie). Nine of these 11 mangrove stands were selected because local foresters suspected they had health problems. The other two stands were inadvertent finds.

Results

I) A measurements approach at Yinuf Mn Island, Yap

The results from the measurements of seawater properties and the tactile assessments of soil properties in healthy and dead/dying mangrove plots at Yinuf Mn Island, Yap are shown in Table 1.

The seawater measurements showed only very slight differences between healthy stands and stands with dead/dying mangrove trees. The average water depth was slightly more than 1 inch (2.54 cm) deeper where the mangroves have died; the seawater temperature was 1^{o}C warmer in plots where the mangroves have died compared to apparently healthy mangrove plots; and the water turbidity of the dead/dying mangrove plots was 2.98 Nephelometric Turbidity Units (NTU) vs. 3.8 NTU in healthy-appearing plots (excluding plot 10, which was in very shallow water). The salinity was exactly the same (2.27 %) in the dead/dying/missing and apparently healthy mangrove plots.

The soil samples that were collected from the surface soils in the healthy and dead/dying mangrove plots were transported to Guam, where they were received by the Mohammad Golabi Soils Laboratory. These samples were analyzed by Chancy Thomas Iyekar, and the results are shown in Table 2. As shown in Table 2, no consistent differences in the measured soil properties of the ocean floor were observed between the healthy and dead/dying/missing mangrove plots.

Table 1. Properties of seawater and soil in healthy and dead/dying mangrove stands near Yinuf Min Island, Yap. The amount of organic matter is proportional to the number of + signs (+ almost none, +++++ approximately 25%).

Plot #	Mangrove health status	Water depth (inches)	Water Temp. °C	Salinity %	Turbidity (NTU)	Soil texture	Amount organic matter	Time of day**
4	healthy/young *Rhizophora* sp.	3 (7.6 cm)	32.4	2.20	2.00	sandy	+++	
5	missing/seagrass	4 (10.2 cm)	32. 8	2.27	1.96	sandy	+	12:30
6	healthy/young *Rhizophora* sp.	2 (5 cm)	33.0	2.28	3.13	sandy	+	12:45
7	missing/dead trees	2 (5 cm)	34.0	2.27	3.16	sandy	+++	
8	missing/dead trees	2 (5 cm)	33.7	2.21	4.10	sandy	+++	
9	missing/dead trees	2 (5 cm)	35.2	2.19	2.63	____	+++++	13:15
10	healthy/young *Rhizophora* sp.	0 (0 cm)	33.5	2.21	10.54***	sandy	+++++	
11	healthy/young *Rhizophora* sp.	2.5 (6.4cm)	32.4	2.28	6.35	sandy	+	14:25

** Low tide occurred at about 13:30 this day.
*** water depth was too shallow

Table 2. Properties of soils from Yinuf Mn where samples were collected from healthy appearing mangrove stands (H) and from mangrove stands which are currently dead/dying/missing trees (M).

Sample ID	pH	Salinity (EC) µS/cm	% O.M.	Available P (ppm)	Available K (ppm)	Available Ca (ppm)	Available Mg (ppm)
S-1H	7.14	36	21.90	2.84	2806	11288	7195
S-2M	7.55	25	14.50	2.18	1506	9127	5626
S-3	7.65	72	18.60	6.37	3005	7911	7069
S-4H	7.73	21	9.70	6.76	1563	7572	3453
S-5M	8.18	15	1.60	5.99	532	6448	832
S-6H	8.20	13	1.40	7.80	375	6380	1109
S-7M	7.68	63	20.20	3.99	2625	8444	7435
S-8M	7.82	53	13.00	5.99	1603	7761	4896
S-9M	7.34	62	20.90	4.45	2891	8250	7932
S-10H	7.60	71	18.80	6.18	3958	10850	7665
S-11H	8.03	16	3.00	6.56	6883	6548	1415

The tactile assessments indicated that the mangrove "soil" of all plots was largely composed of a coarse, sandy textured matrix or rubble (actually this is a mixture of degraded and ground-up reef and coralline algae). These results indicate soils from both healthy and dead/dying (or missing) mangroves were associated with variable organic matter content (soil organic matter varied from 3% to 21.9%).

II) A "common-sense approach at Yinuf Mn Island, Yap

Upon inquiry, Dr. Margie Falanruw (USFS, Yap) suggested that four incidents may have played a role in the massive demise of mangroves at Yinuf Mn Island. The first was that sea level rise had been reported in this part of the Pacific. Margie had since discounted this as sea level has remained constant for a number of years, now. The second was the construction of two airfields in areas south and west of this mangrove. She had considered it possible that massive amounts of sediment could have washed down the watershed and ended up in this mangrove area. The first airport had been constructed by the Japanese during World War II, the second about 20 years ago. The sediment from this construction may have had some adverse impacts on mangrove trees at Yinuf Mn, but the damage at Yinuf Mn is extensive and much of it seems to have occurred at one time between 2000 and 2012 (between the times when Yinuf Mn was photographed remotely with full vegetation in 2002 and the time when remote photography showed the massive mangrove loss in 2012). Thus, construction of the airports seems to have occurred too long ago to be a major contributor to the extensive mangrove death that is currently evident. A third potential incident involved the collision of a ship with the reef near the entrance to Yap's main harbor. Some possible repercussions were anticipated, but a post-spill monitoring program did not find any dieback or death in mangrove trees up to 1 year after the spill. Because this incident took place 2 decades ago, it also seems to have occurred too long ago to have been the primary cause of this present problem with mangrove health.

A fourth potential incident is an apparent correlation between the path of Typhoon Sudal and the location of the massive mangrove dieback at Yinuf Mn. Typhoon Sudal was traveling west and southwestward on April 11th, 2004 when it struck the east coast of Yap with a wind force estimated at 115 mph (185 km per hour). Additional evidence also indicates that much of the mangrove damage at Yinuf Mn was due to Typhoon Sudal:

1) At least two-thirds of the tree trunks were laying with their tops pointing in a westerly direction; in other words, in the direction that the typhoon winds and storm surge might have pushed them;

2) Most of the fallen tree trunks were in a similar state of decomposition, suggesting that they had fallen over at about the same time (same year);

3) The amount of decomposition that had occurred on the outside portions of the dead and tipped trees appeared to have been accumulating for about a decade; and

4) Most of the trees that had tipped over were about 8 to 20 inches (20 to 51 cm) in diameter; in other words, the fallen trees were much larger and older than trees in the current stands, which consisted of rather small, 4- to 6-inch (10- to 15-cm) diameter *Rhizophora* mangroves that were found in the nearby plots of healthy mangroves.

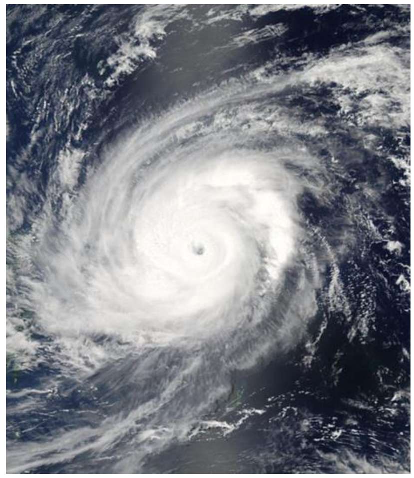

Figure 13. Eye of Typhoon Sudal as it passed 12 miles (19 km) to the south of Yap on April 11, 2004, moving at about 20 mph (32 km per hour). The winds from this storm were estimated at 115 mph (185 km per hour) and the storm surge is estimated to have been at between 8 - 12 feet (2.4 – 3.7 m) in height when it hit the coast (from: Wikipedia.org/wiki/Typhoon _Sudal).

Figure 14. Photo was taken in the same mangrove area in Yap as Figures 1-12, but about 0.5 mile (0.8 km) from the devastated area and much closer to the land. This section of the mangrove was buffered from both the powerful wind and the storm surge that was experienced by the outermost mangroves, because more mangrove trees were present between this section of mangrove forest and the open sea. In this section, the mangrove trees here are fairly large, with many in the 10- to 14-inch (25.4 – 35.6 cm) diameter range, and many of them were quite rotten. The range in rot varied widely by tree species. Multiple conks were present on over 50 % of the trees of some species; whereas, conks were present on less than 10% of the trees of other mangrove species. The conk in the hand is a member of the *Phellinus* genus. The exact species identification of this conk (and eighty other conks collected during this trip) is currently being conducted using DNA-sequence and morphology-based techniques by forest research laboratories in the USA and Japan (see Chapter III of this report for more details on the fungal identification process).

3) A “common-sense” approach at other mangrove stands in the Federated State of Micronesia (FSM).

The locations, causes of death, and approximate percentage of dead trees found in all 12 of these mangrove areas are summarized in Table 3.

Table 3. Summary of apparent contributors to mangrove death found during the September 2013 foray to the Federal States of Micronesia.

Island and # of stand	Location on the island	Principle causes of death	Approximate % dead trees
Yap			
1	Yinuf Mn Island, southeast of the college, YAP	Typhoon Sudal and over-mature stand	100% in about 10 acres (4 ha) 10% in remaining 90 acres (36 ha)
2	Yinuf Mn Rock island	Typhoon Sudal and mature stand	80% in 0.5 acre (0.2 ha) 1% in remaining 2 acres (0.8 ha)
3	Channel west of Yinuf Mn Island	Basidiomycete conks in overmature stand	2% in 300 acres (121 ha)
4	Shoreline mangroves near S. seawall	Undercutting of coast by waves at high tide	15% in 400m of coast
Palau			
5	Southeastern shore Babeldaob	Girdling of trees along 500m of channel	99% within 5m of channel 2% at > 5m from channel
6	Carbon Sequestration plot, southeastern Babeldaob	Basidiomycete conks in overmature stand	4% of all trees infected 50% of all large *Xylocarpus*
7	Growth plot in northeastern Babeldaob	fungal conks & minor typhoon breakage	6% dead & with substantial stem breakage
8	Overmature coastline stand near capitol	fungal conks and wave undercutting	5% of trees dying recently; trees fall from waves; rotten limbs fall off quickly
9	Mature stand in mid-Babeldaob near bridge	Clearcutting of about 10 acres (4 ha)	100% of trees were cut in this stand; neighboring stands OK
Pohnpei			
10	Nan Medal mangrove		

		Heavy selective cutting	about 50% of all mangrove basal area
Kosrae 11	Yela River Conservation Area (Forest Legacy)	Basidiomycete conks	2% in the mangrove section of this conservation area
12	Coastline near Kosrae Village Resort	Severe wave under-cutting at high tide*	70% in mature section 1% in regenerating section

*Berm position on Kosrae was being adversely influenced by nearby road construction.

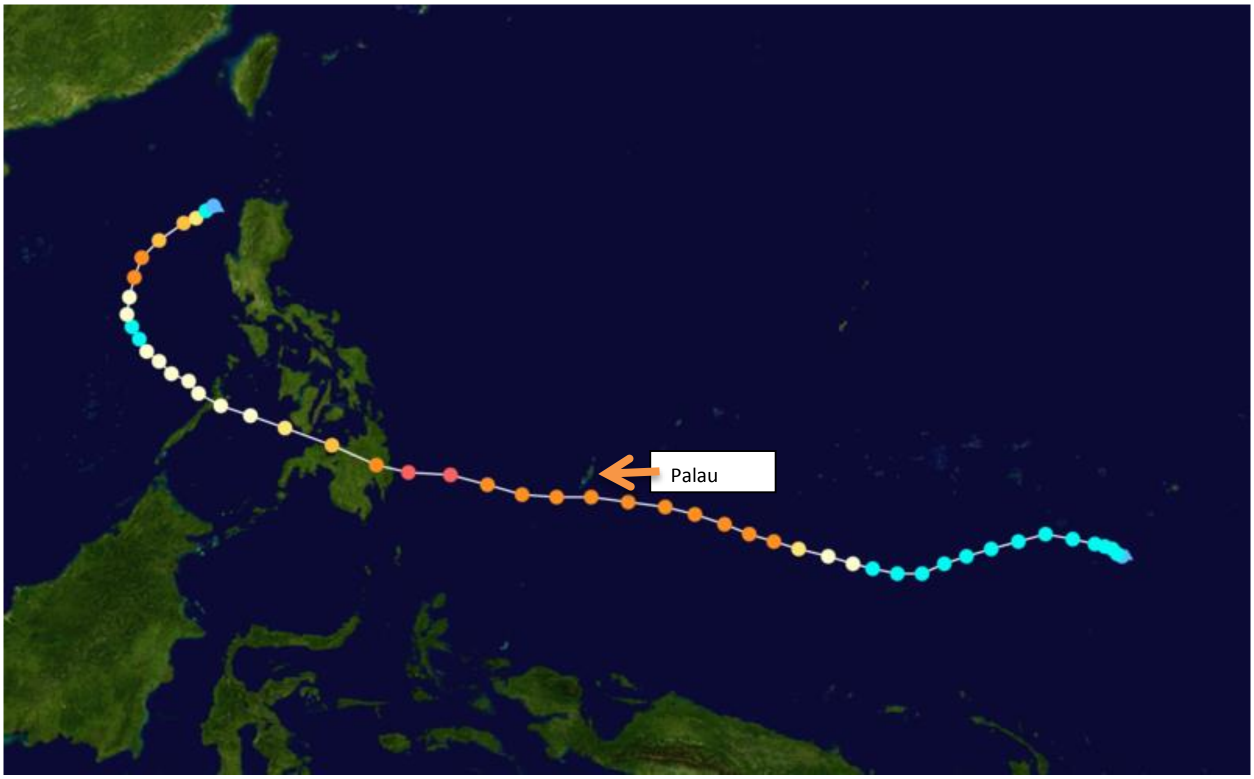

Figure 15. Track of Typhoon Bopha as it passed by Palau, 51 km to the south, on Dec 3, 2012 (from http://en.wikipedia.org/wiki/Typhoon_Bopha).

Discussion

A measurements approach on Yinuf Mn Island, Yap

Although slight differences were apparent in three of the four seawater properties between healthy and dieback mangrove plots (Table 1), it is likely that two of these differences in seawater properties might be reflecting the absence or presence of mangrove overstory, rather than a contributing cause of the absence or presence of the mangrove. The sunlight was very intense on the day these measurements were recorded, and it seems reasonable to assume that the temperature of seawater shaded by a mangrove canopy would be cooler than seawater in open sunlight. Furthermore, the 1°C temperature difference for water in the shade versus water in the open is exactly the same as that found by Ewel *et al.* (1998). In addition, deeper seawater would undoubtedly require more calories to heat up than shallower seawater. And, again, the 1°C difference in temperatures due to depth (comparing samples in shady plots) and the 1.7°C difference due to depth (comparing samples in sunny plots) seem to approximate differences that would be expected. The relationship between seawater depth and soil turbidity was not clear from the measurements that were recorded. Such inconsistencies are perhaps attributable to slight disturbances of the seafloor that occurred in locations where seawater depth was quite shallow, such as, < 1 inch (2.54 cm). Thus, these studies did not provide strong basis to suggest that water temperature, turbidity, or salinity had exerted any influence on mangrove health. These preliminary measurement did, however, provide some reason to further investigate whether seawater depth has an influence on regeneration success of mangroves. A potential role of seawater depth is discussed later in this chapter.

The chemical and physical analyses of the seafloor samples also showed no significant variation between the healthy mangrove plots and the plots with missing/dead/dying mangrove trees (Table 2). Thus, the dieback of the mangroves at Yinuf Mn, Yap could not be directly attributed to variation in measured properties of the seawater or ocean floor. Nevertheless, three additional points must be considered. First, sampling was not exhaustive in terms of the numbers of samples that were collected. Second, the organic muck was relatively deep in some apparently healthy mangrove stands, but the organic muck appeared very shallow or nonexistent in other healthy mangrove stands. Thus, a deep muck layer does not seem to be essential for supporting healthy mangroves. Finally, it was also observed that the muck layer was thin and sometimes nonexistent in dead/dying mangrove stands that were surveyed. This last point could have important repercussions in terms of carbon sequestration. It was observed on multiple occasions during this trip, and has been well documented by Donato *et al.* (2011), that the presence of mangrove forest is strongly related with the ability to collect and maintain what is known as mangrove muck. Indeed, during this foray to the Yinuf Mn area where the mangroves had disappeared, both Margie Falanruw and Francis Ruegoroug observed that considerable mangrove muck had been lost since a previous trip to this same area 3 years earlier. This carbon loss situation is discussed in more detail in Chapter VII of this report.

II) A "common-sense" approach at Yinuf Mn Island, Yap

After examining the evidence, it was concluded that much of the mangrove dieback problem at Yinuf Mn Island in Yap was likely attributable to Typhoon Sudal. It is difficult to reconstruct everything that happened during and after this typhoon, but perhaps some conjecture will provide potential insight. Yinuf Mn Island that is conspicuously void of trees, many trunks remain from the big trees that that were pushed over. It appears this area formerly contained a relatively mature mangrove stand. Almost certainly, the wind was not the only significant lateral force that impacted these trees. The storm surge, storm tide, and breaking waves that came through this area were also quite forceful, as currently evidenced by plastic chairs and other debris that were deposited 8 feet (2.4 m) high in the crowns of the smaller, more flexible, mangroves that had survived. (Note: some this debris was probably deposited by backwash, which is discussed later).

There are no eyewitness accounts as to what exactly happened when Typhoon Sudal made landfall in the Yinuf Mn Island area, and any witnesses would likely not survive such forces. However, some information is available. According to the Wikipedia account of Typhoon Sudal (Wikipedia.org), winds hit Yap at 105 mph (169 km per hour) over 10-minute periods, with occasional gusts of up to 140 mph (225 km per hour). Over more sustained periods, the winds were 45 mph (72 km per hour).
As the eye wall of this typhoon passed over the southern tip of Yap, 6-9 inches (15-23 cm) of rain fell, accompanied by a storm surge of 8-12 feet (2.4-3.7 m) and a pounding surf of 22 feet (6.7 m) (NOAA 2010).

The reason that a storm surge occurs is based on simple physics. The strong winds of the typhoon push on the surface of the ocean. The water cannot move as fast as the wind because of friction from the relatively stationary ocean so it becomes heaped up into a section of ocean that is now several feet (>2 m) higher than the ocean level would normally be in the absence of the storm. As such, this mass, or surge of water may be several feet (>2 m) higher than the normal ocean level and moving at a velocity of 10 to 15 mph (16-24 km per hour) (www.wunderground.com). The exact force with which these storm surges exert when they strike land can vary considerably but are generally proportional to the strength of those winds generated by the typhoon and the directness with which they hit the island. The National Oceanic and Atmospheric Administration (NOAA) provides an interesting summary on the factors that influence the force of a storm surge when it makes landfall: "The size of a storm surge for a particular location depends on a number of factors. Storm surge is very sensitive to the shape of the coast, and to changes in storm track, intensity, forward speed, and size. Tidal height at the time of maximum storm surge is an important factor, too. (The combined effect of the storm surge and the astronomical tide is called the storm tide.) The slope of the sea floor also influences the level of surge in a particular area. Areas with a shallow slope of the sea floor off the coast will allow a greater surge. Areas with a steeper slope will not see as much surge, but will generally have large breaking waves that can destroy lower elevation buildings near the coast and open bays" (http:www.noah watch.gov).

From these indications and the fact that Yap is surrounded by a reef on most sides, one could conjecture that some very large breaking waves accompanied this storm surge and that these breaking waves would have been most powerful where the storm surge blasted into the reef at a perpendicular angle. In the case of Typhoon Sudal, these breaking waves would have been directed almost precisely at the Yinuf Mn island location on the reef. Another key factor is that coastal configuration can also influence the power of the surge received at a given point on the coast. This was graphically demonstrated in Tacloban, Philippines when the storm surge from Typhoon Haiyan (=Typhoon Yolanda) was forced into a bay whereupon the shoreline acted as a funnel to create an exceptionally powerful force. Perhaps something similar occurred when the storm surge from Typhoon Sudal approached Yinuf Mn. Regardless of the combined forces that toppled these big trees, it appears that some of these fallen trees continued to maintain at least partial anchorage of their root systems in the sea floor and green leaves on part of their crowns subsequent to this event. This condition would also have given the appearance that these stands were alive and healthy for several years after the typhoon, especially when viewed from satellite imagery. The effect of a storm surge in a mangrove area differs from that of most forests established in coastal areas. Mangroves necessarily have a very shallow root system, whereas trees in other coastal forests typically possess deeper root systems. Because of the shallow root system, mangroves are more prone to being pushed over instead of broken off. This is consistent with the type of damage observed at Yinuf Mn, except for those trees that had advanced butt-rot.

Finally, although all of the aforementioned, typhoon forces (high winds, high tide, storm surge, and high waves) come from a seaward direction, the forces arising from a powerful backwash must also be considered. Backwash occurs after a storm surge has passed, when all of that surge-displaced water returns back to sea level. In some places, the land topography can channel these returning waters in a manner that creates tremendous force. A powerful backwash could have contributed additional damage to standing trees, and almost certainly cause some reorienting of the fallen trees.

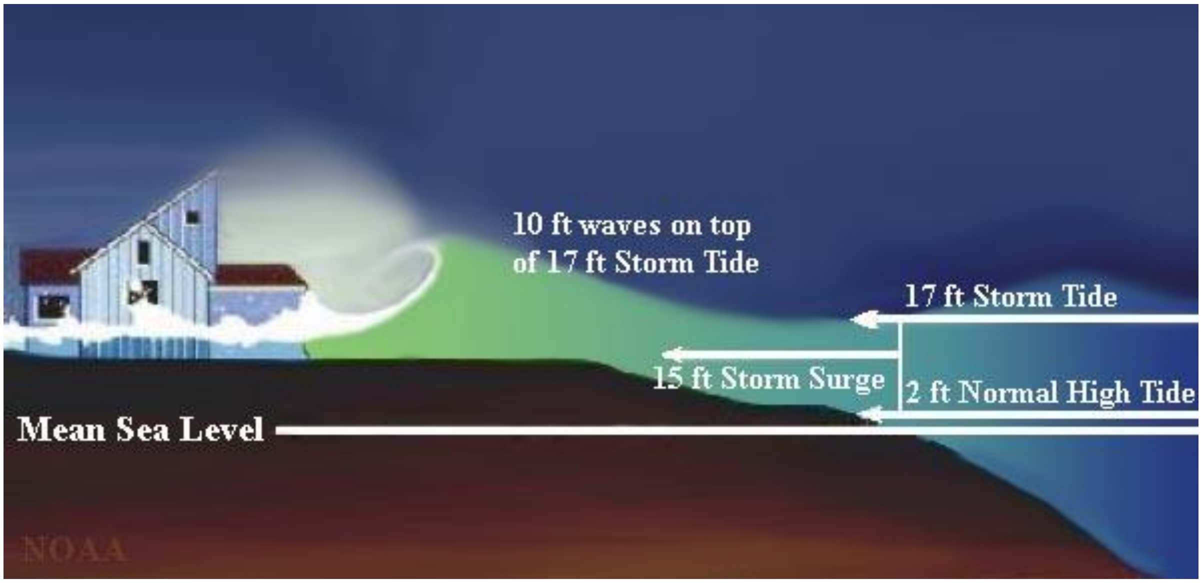

Figure 16. A conceptual illustration of the forces provided by a storm surge (from Wikipedia).When Sudal Typhoon hit the coastline of southeastern Yap, the forces from each source were a little different than those shown above. During Typhoon Sudal in Yap, the storm surge was estimated at about 10 feet (3 m) and it is undetermined if the tide, which varies by about 3 - 6 feet (0.9 -1.8 m) from high to low tide, was up or down when Typhoon Sudal hit. The height of the waves that came on top of the storm tide is also unknown. These waves can be heavily impacted by the rate of change in depth of the seafloor just before the storm surge makes landfall. Since the seafloor depth rises abruptly as the reef on southeastern Yap is approached, it is expected that these waves may have been substantial at Yinuf Mn.

Future prospects at Yinuf Mn Island-

While we were in the midst of the mangrove dieback on Yinuf Mn Island, the most prominent question that we considered was what is the future fate of mangroves in this area? Fortunately, we were musing over this question at low tide, and what we observed was encouraging. We could see a small, but significant number of naturally established *Rhizophora* seedlings that had begun to fill in portions of the large gaps that occurred sometime after Typhoon Sudal. Furthermore, we noted that 30 out of 34 (88%) regenerating *Rhizophora* seedlings were growing on land that was definitely above the low-tide water mark. Although ~70% of the dieback area appeared slightly underwater at low tide, it seemed very likely that the new mangrove seedlings would continue to grow and trap muck in their aerial roots, and this, in turn, would raise the seafloor to allow the establishment of even more *Rhizophora* sp. In this manner, it seems that the entire area could again become colonized by mangroves. It remains uncertain how long the process will take, but it seemed evident that the mangrove was regenerating to fill in this massive mangrove gap within the Yinuf Mn Island area of Yap.

Of course, chances remain that this same area will get impacted again by a future typhoon. Discussion about which part of a mangrove might be most impacted by future typhoons is presented later in this chapter.

III) A "common-sense" approach to understanding mangrove dieback throughout the Federated States of Micronesia.

From the summary provided in Table 1, six factors are apparent that potentially play significant roles in limiting or reducing the size of mangrove stands in Micronesia: 1) a sea water depth that is too high at low tide, e.g., > 1 inch (2.54 cm) of depth; 2) typhoons; 3) conk-forming basidiomycetes; 4) harvesting for wood products; 5) girdling to open boat transportation channels; and 6) high-tide wave action. In some cases, potential interactions between two or more of these factors were apparent, and sometimes other anthropogenic activities also appeared to be acerbating these problems.

Considerations of potential effects of future typhoons on a mangrove trees are especially interesting. The winds from typhoons would likely have their greatest impacts on large mangrove trees because of the large area of their crowns. If these older trees also had butt rot, they would be even more vulnerable. In contrast, the trunks and the aerial roots of the trees would likely be more vulnerable to the forces from the storm surge itself. Mangrove trees that are more distant from the exposed (seaward) edge of the mangrove stands are likely less vulnerable to breakage or pushover by high winds and storm surge.

The amount of damage can vary with each typhoon. For instance, the influence of Typhoon Bopha (2012) on Palau (Table 3, Stand 7) produced only a small fraction of the damage that Typhoon Sudal (2004) wrought on the Yinuf Mn island of Yap (Table 3, Stand 1). This difference in damage is largely because the center of Typhoon Sudal was much closer and remained longer (including time when the tide was at its peak) when it passed by Yap than the center of Typhoon Bopha when it passed by Palau. Therefore, wind speeds and the accompanying storm surge from Typhoon Bopha on Palau would have been lower than those from Typhoon Sudal on Yap.

Of course, a typhoon center could also pass even closer to an island than Typhoon Sudal did on Yap. If this were to happen, even heavier levels of damage than occurred at Yinuf Mn could also be expected. For example when this report was being written, radio announcements indicated that Typhoon Haiyan (= Typhoon Yolanda) was pounding down on the Philippine, accompanied by the wind gusts of 170 mph (270 km per hour) and the storm surge was registered at 20 feet (6 m) and moving at 25 mph (40 km per hour) (Samenow 2013). In addition, the analyses of Typhoon Haiyan showed that certain topographic features of the coastline, such as the inlet at Tacloban, acted as a funnel and caused the storm surge to be even higher. Although Typhoon Haiyan was one of the most powerful typhoons on record, many other typhoons have been powerful and very damaging (e.g., Typhoon Bopha as it passed directly over Mindanao, Philippines). From this perspective, it seems that living in Yap, Palau, Guam, or Saipan (either as a person or as a mangrove forest on the windward side of the typhoon's path) can seem like a risky proposition, especially about twice a year during typhoon seasons. People, of course, can vacate to higher ground when NOAA issues a typhoon warning. Trees, and especially mangroves, are not so lucky.

It might be noted that the loss of overmature mangrove stands by typhoons is not necessarily a negative consequence. Indeed, as long as the intervals between typhoons are not too short, typhoons provide mangroves with an opportunity to regenerate in a manner that replaces older, senescing stands with younger, more vigorous stands. According to Margie Falanruw, some meteorologists predicted a few years ago that climate change would greatly increase the number of typhoons coming to Micronesia. Subsequently, the interim period between typhoons appeared to follow the historical norm; however, several huge typhoons have pounded Micronesia and the Philippines between late September and late October of 2013, when these island nations endured some of their worst typhoons ever.

Not all of the typhoon damage occurs during the time of the typhoon. For example, stem or limb breakage can produce large wounds on the affected tree, which exposes decay susceptible-heartwood to spores of decay fungi, such as species of the genera *Phellinus* and *Ganoderma*. In the decades following a typhoon, it might be expected that a mangrove of a certain age that had suffered wind damage would be have substantially more wood decay than a similarly aged mangrove that had not suffered wind damage.

Although so far this report is largely focused the near-term effects of typhoons on coastal mangroves, typhoons have also had another very important effect on island formation for many Pacific islands, because typhoon can influence the formation and location of islands berms. For example, Kosrae, an island that currently gets few powerful typhoons, experienced two very powerful typhoons in 1891 and 1905. These typhoons were, in fact, so strong that they moved a substantial amount of reef rubble around and formed a 5-foot (1.5 m) high, 30-foot (9.1 m) wide berm that runs parallel to the Kosrae coast for miles (>3.2 km). Since 1905, these berms have separated low lying sections of Kosrae from the ocean (Chaoxiong 2001). Today, many Kosraeans live in this flat area between this temporary berm and the main road surrounding the island at the base of the hills.

If this berm line is ever breached at high tide, thousands of acres would be inundated with seawater. No breaching occurred during this visit, but it was evident that such breaching does happen occasionally. Areas prone to inundation in this manner cannot be farmed except with plants that are very salt-tolerant (e.g., coconut). Most houses in this area have been built on stilt risers of about 2-3 feet (0.6-0.9 m), which is high enough to keep the floorboards above this water. In areas where the flat area between the island road and the berm is under water much of the day, mangroves predominate. Mangroves and slightly less manglicolous species (e.g., palms, *Thespesia populnea,* and *Barringtonia* spp.) tend to grow on the margins of the berms and the top of the berms, respectively.

Apparently, these flat areas between the berm and the road are most susceptible to inundation when a "King tide" (unusually high tide) occurs. Of course, if a typhoon hit as it did in Yap, a wall of water up to 8 feet (2.4 m) high might come over the berm during the storm surge. (Note: a tsunami might also produce a major problem of similar ilk). Fortunately for the people of Kosrae and Pohnpei, typhoons tend to originate in these island areas and reach dangerous force levels only by the time they reach Guam, Yap, Palau, Saipan, or other areas to the west (and there are is no recent history of tsunamis in Pohnpei or Kosrae).

The damage to mangroves that are located right on the coastline (Table 3, stands 4 and 8) or on these temporary berms (Table 3, stand 11) was only partially surveyed during this visit. Although there was local concern that sea-level rise might increase wave undercutting on berms, several inhabitants had observed no evidence that the sea level had been rising. Regardless of whether a rising sea level is occurring, it was quite evident that strips along some coastlines, where a large number of mangrove and other tree species (e.g., palms, *Thespesia populnea,* and *Barringtonia* spp.) occur, are being undercut by waves at high tide.

Although the majority of this report has focused on the impact of typhoon damage, or damage from waves at high tide, this survey also noted several other agents were contributing to death and health declines of mangroves. In the case of the girdling at Babeldaob, Palau (Table 3, stand 5) and the harvesting in Kosrae (Table 3, stands 10 and 11), the reasons for tree mortality were obvious (i.e., opening the channel and harvesting for wood products, respectively) and local communities should determine if these kinds of tree losses are acceptable. However, because so many mangrove species are vulnerable to colonization by *Phellinus* and other conk-forming fungal species after even minor damage to their bark, tree harvesters should be educated on methods to limit damage on the residual trees. Conveniently, some very insightful harvesting plans have been developed for some large mangrove areas, which show how sections of the mangrove can be harvested while still having expectations for speedy stand recoveries (Macintosh and Ashton 2003). Such plans should be shared among villages that plan to continue harvesting mangroves. Approximately half of the 12 mangrove stands visited during this trip had forest disease problems (biotic and/or abiotic), which may represent additional concern. However, these twelve mangrove areas that were surveyed during this visit, represent less than 2% of all mangroves in Micronesia and most of the remaining mangrove stands that were only casually observed appeared to be in good health

Conclusions

Six different factors appeared to be the major contributors to damage on surveyed mangroves in Micronesia. In mangroves surveyed on this trip, Typhoon Sudal seemed to be the major factor for the largest single dieback, which included several hundred acres of mangroves on the eastern coast of Yap. Older mangrove trees near the eastern seaside edge of Yap were apparently impacted the most by Typhoon Sudal. Butt-rotting fungi (largely in the genus *Phellinus*) also appeared to render infected mangroves more vulnerable to wind and storm surge damage.

In a number of locations in the Micronesian shoreline, mangroves and other tree species are being undercut by wave action at high tide; this causes the toppling of many thousands of trees, and, in some cases, increases the vulnerability of land inside the coastal ridgelines to inundation by seawater. Harvesting for wood products and girdling to increase channel width were two other causes of mangrove demise.

In spite of all of the setbacks to mangroves documented in this report (both from natural and anthropogenic causes), the mangroves of Micronesia are generally vibrant with life, and they even seem to be expanding in many parts of these island nations.

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Chapter III

Characterizing forest root- and butt-rot fungi in Yap, Palau, Pohnpei, Kosrae, Guam and Saipan.

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Figure 1. Ned Klopfenstein and Rodasio Samuel admiring the mucilaginous mycelial crust of the aggressive *Phellinus noxius* fungus attacking a breadfruit tree (*Artocarpus altilis*) on Pohnpei.

Abstract: *Ganoderma* and *Phellinus* are two common fungal genera causing butt-rot on trees growing on USA-affiliated islands of the western Pacific. Although these fungi can be quite prevalent, especially in some older mangrove stands, it appears that the majority of infections caused by these fungi leads to severe rotting of the heartwood but do not kill the living tissues of the sapwood, cambium and phloem. Thus, the usual consequence of infection by butt-rot fungi in this part of the world is a loss of structural strength in the bole, but not mortality to the tree. Three notable exceptions were found to this general

observation. One is where typhoon winds or storm surges hit mangroves, in which case, butt-rot-afflicted trees are exceptionally prone to breakage and toppling. A second exception is when typhoon-strength winds break or otherwise wound previously healthy trees, subsequently enabling butt-rot fungi to colonize heartwood and spread via root contact to neighboring trees. The third exception is when *Phellinus noxius,* the cause of brown root rot, is the pathogen affecting a stand. This aggressive pathogen can kill trees outright. Although a number of different butt-rot fungi occur in these islands, not much was known about their classification prior to this trip. In this foray, efforts were made to collect the full range of sporophores (conks, fructifications) that were found in association with butt-rotted trees, and isolations were made of these collected fungi onto the appropriate culture media. When the butt rotter appeared to be *P. noxius*, efforts were focused to collect samples for isolation. Molecular genetics techniques were then used at the Rocky Mountain Research Station (USDA Forest Service) for preliminary identifications of fungi that had been collected and isolated.

Introduction

From September 1-23, 2013, the authors collectively surveyed butt-rot fungi in natural forests, agroforestry settings and urban forests in the western Pacific islands of Palau, Yap, Guam, Saipan, Pohnpei and Kosrae. The participation of Drs. Yuko Ota and Norio Sahashi (Appendix I) on Guam, Saipan and Pohnpei was especially useful during this survey, because they have been working on a similar, but much more intensive, survey focusing on *Phellinus noxius* on of all of the Ryukyu islands of Japan over the past 14 years (Sahashi *et al.* 2012). In this present survey, local forestry staff on all islands (Chapter I) were key in helping find the butt-rot fungi. For years, they have noted butt-rot problem areas and they were also able to obtain local permission to visit, survey, and sample most of these areas. They also assisted with the collection of the samples during this trip, including the identification of the host species and the characterization of the infection foci.

On the sites where fungal samples were collected, the following stand parameters were evaluated: date of survey, collector, elevation, GPS points, host species, and other information relating to site characteristics, impact of the disease and extent of the problem (Table 1). Fruiting bodies (conks) were collected where possible (note: *P. noxious* rarely forms these sporocarps, but many other butt-rot fungi found on this trip produced them in abundance). Samples of infected wood were also collected. In the evenings, impromptu phytopathology laboratories were set up and used to make fungal isolations onto slants and/or plates with Potato Dextrose Agar (PDA) or a more selective media (which included benomyl) in accordance with methods detailed by Sahashi *et al.* (2012). Isolations were made from both fruiting bodies and infected wood, as appropriate. In addition, some sections of fruiting bodies and/or infected wood were also dehydrated in an air drier at 60° C for 8 hours.

Figure 2. Rudy Estoy helps the sporophore (conk, fructification) collection exercise in Guam.

Collected samples in both culture form (plates and slants) and herbarium form (dried conks and wood) were then sent in accompaniment with APHIS permits to the USDA Forest Service - Rocky Mountain Research Station (RMRS), Forest Pathology Laboratory in Moscow, Idaho.

Once a clean culture isolate was obtained, the next step towards getting its identification was to extract the DNA from the culture, followed by the use of the polymerase chain reaction (PCR) technique to make thousands to millions of copies of selected regions of that isolate's DNA, such as ITS (internal transcribed spacer) and other DNA regions. These amplified DNA regions were sequenced for each isolate and the resulting sequence information was "blasted" against the GenBank database (http://blast.ncbi.nlm.nih.gov/Blast.cgi) to compare the closest database match, based on DNA sequence similarity, which helps to determine the isolate's most probable identity. Using this approach, the genus- or species- level identities of most of these fungal samples can be determined. However, a match with GenBank sequences is not sufficiently close for some of the fungal isolates; this may provide an opportunity to describe a new fungal species or add new DNA sequences for an identified species to the GenBank database.

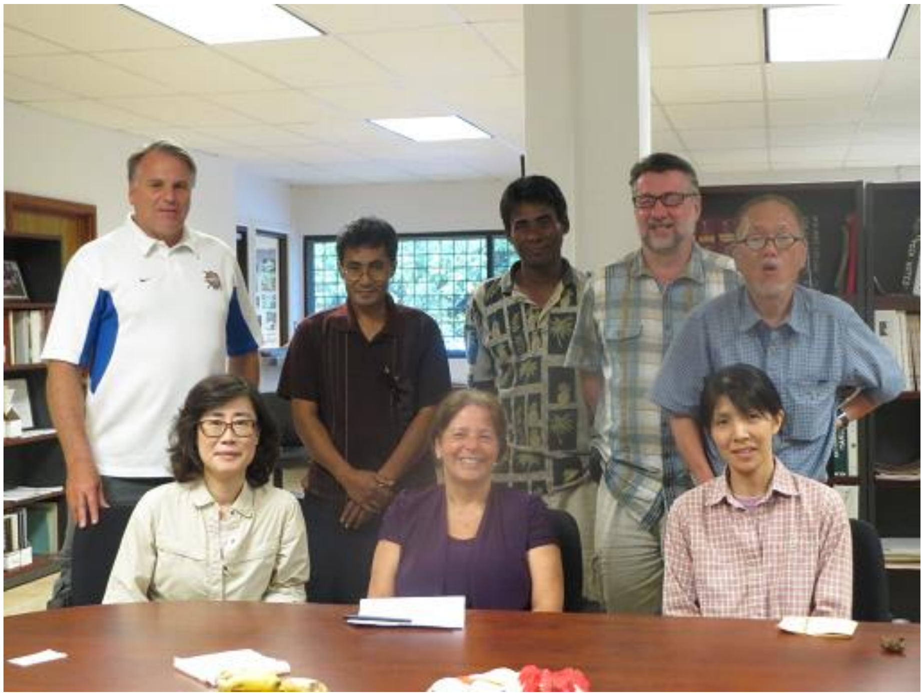

Figure 3. Part of the *Phellinus noxius* survey team (dubbed the “dream team” by the senior author). Front row left to right: Mee-Sook Kim, USA Ambassador Dorothea-Maria “Doria” Rosen, Yuko Ota; Back row: Phil Cannon, Gibson Santos, Rodasio Samuel, Ned Klopfenstein, and Norio Sahashi (photo by Arlene Rosenkrans). Not shown are Robert “Bob” Schlub, Roger Brown and Roland Quitugua (Guam); Vic Guerrero, Manny Tenorio and Arnold Route (Saipan); Francis Ruegorong (Yap); Ann Kitalong (Palau); Blair Charley, Erick Waguk, Maxson Nithan and Leonel Sigrah (Kosrae); and Konrad Engleberger (Pohnpei).

Figure 4. Yuko Ota (left) and Norio Sahashi (right) using their well-honed techniques to isolate *Phellinus noxius* and other wood-rot fungi onto culture media for subsequent mailing to the USA and Japan, where DNA-based molecular techniques are used to help identify the fungal species.

Initial Results

From the surveys conducted on each of the islands it appears that many butt-rot infections on the USA-affiliated islands of the western Pacific are either being caused by *Phellinus* and/or *Ganoderma* spp. Table 1 contains the list of many of the fungal specimens and isolations that were made during this survey of these six islands (a total of 246 samples were collected).

Table 1. List of fungal collections made during the in September 2013 foray of forest butt-rotting pathogens in Yap, Palau, Pohnpei, Kosrae, Guam, and Saipan. This list includes the sample (or isolate) reference number, the preliminary fungus identification, the island where collected, the name of the collector, the name of the host tree or substrate and a very brief summary of the collector's notes.

RMRS Isolate No.	Fungal Species Identified	Place of Origin	Collector	Host Tree	Collector's Notes
Palau 1F		Palau	Phil Cannon	mangrove	near Capitol
Palau 2F		Palau	Phil Cannon	*Casuarina*	Burger Hut
Palau 3F	*Coriolopsis sanguinaria*	Palau	Phil Cannon	*Rhizophora*	girdled Airai
Palau 4F	*Ganoderma orbiforme*	Palau	Phil Cannon	*Rhizophora*	girdled Airai
Palau 5F	*Fusarium* sp.	Palau	Phil Cannon		girdled Airai
Palau 6F	*Ganoderma gibbosum*	Palau	Phil Cannon	Stump	Nat. Hist. Mus.
Palau 7F.1	*Trichoderma* sp.	Palau	Phil Cannon	mangrove	girdled Airai
Palau 7F.2		Palau	Phil Cannon		
Palau 8F.1	*P. noxius*-like culture	Palau	Phil Cannon	stump	Nat. Hist. Mus.
Palau 8F.2		Palau	Phil Cannon		
Palau 8W		Palau	Phil Cannon	stump	Nat. Hist. Mus.
Palau 9P	*Trichoderma* sp.	Palau	Phil Cannon	mangrove	girdled airai
Palau 10P	*Pestalotiopsis* sp.	Palau	Phil Cannon	mangrove	girdled airai

Palau 11P	*Fulvifomes sp.*	Palau	Phil Cannon	mangrove	Airai Village
Palau 12P	looks like *Fulvifomes*	Palau	Phil Cannon	*Rhizophora*	Airai Village
Palau 13P		Palau	Phil Cannon		Nat. Hist. Mus.
Palau 14P	*Psilocybe* sp.	Palau	Phil Cannon		Nat. Hist. Mus.
Palau 15P	*Ganoderma boninense*	Palau	Phil Cannon		Airai girdle
Palau 16P	*Ganoderma sp.*	Palau	Phil Cannon		Airai girdle
Palau 17P	*Coriolopsis sanguinaria*	Palau	Phil Cannon		Airai tree
Palau 18P	*Coriolopsis sanguinaria*	Palau	Phil Cannon		girdled Airai
Palau 19P	*Trichoderma* sp.	Palau	Phil Cannon		*P. noxius*-like
Palau 20P	*P. noxius*-like culture	Palau	Phil Cannon		Nat. Hist. Mus.
Palau 21P	*P. noxius*-like culture	Palau	Phil Cannon		Nat. Hist. Mus.
Palau 22P	*P. noxius*-like culture	Palau	Phil Cannon		Nat. Hist. Mus.
Palau 23P	*Fomitiporia bannaensis*	Palau	Phil Cannon	*Casuarina*	baseball Park
Palau 24P.1	*Fomitiporia bannaensis*	Palau	Phil Cannon	*Casuarina*	baseball Park
Palau 24P.2	*Chaunopycnis* sp.	Palau	Phil Cannon		
Palau 25P	*Pestalotiopsis* sp.	Palau	Phil Cannon	mangrove	Odamelach
Palau 26P.2		Palau	Phil Cannon	mangrove	Odamelach
Palau 27P	*P. noxius*-like culture	Palau	Phil Cannon	stump	Nat. Hist. Mus.
Palau 28P	*Phellinus noxius*	Palau	Phil Cannon	stump	Nat. Hist. Mus.
Palau 29P	*P. noxius*-like culture	Palau	Phil Cannon	stump	Nat. Hist. Mus.
Palau 30P	*P. noxius*-like culture	Palau	Phil Cannon	stump	Nat. Hist. Mus.
Palau 31P	*P. noxius*-like culture	Palau	Phil Cannon	stump	Nat. Hist. Mus
Palau 32P	*P. noxius*-like culture	Palau	Phil Cannon	stump	Nat. Hist. Mus
Palau 33P	*Phellinus noxius*	Palau	Phil Cannon	stump	Nat. Hist. Mus
S916-03W.1	*Phellinus noxius*	Saipan	Yuko Ota	*Delonix regia*	decline

S916-03W.2	*Phellinus noxius*	Saipan	Yuko Ota	*Delonix regia*	decline
S916-05W.1	*Phellinus noxius*	Saipan	Yuko Ota	*Delonix regia*	almost dead
S916-05W.2	*Phellinus noxius*	Saipan	Yuko Ota	*Delonix regia*	almost dead
S916-04W.1	*P. noxius*-like culture	Saipan	Yuko Ota	*Delonix regia*	green tree
S916-04W.2	*P. noxius*-like culture	Saipan	Yuko Ota	*Delonix regia*	green tree
S916-06W.1	*Phellinus noxius*	Saipan	Yuko Ota	*Delonix regia*	gym, dead
S916-06W.2	*Phellinus noxius*	Saipan	Yuko Ota	*Delonix regia*	gym, dead
S916-01W	*Fulvifomes sp.*	Saipan	Yuko Ota	*Casuarina*	>40yrs
S916-02W	*Ganoderma gibbosum*	Saipan	Yuko Ota	*Casuarina*	host healthy
S916-02		Saipan	Yuko Ota	*Casuarina*	host healthy
S916-07W.1	*Phellinus noxius*	Saipan	Yuko Ota	*Mangifera*	dead Kagman
S916-07W.2	*Phellinus noxius*	Saipan	Yuko Ota	*Mangifera*	dead Kagman
S916-07C	*P. noxius*-like culture	Saipan	Yuko Ota	*Mangifera*	dead Kagman
S917-06W.1		Saipan	Yuko Ota	*Delonix regia*	dead
S917-06W.2	*Phanerochaete sordida*	Saipan	Yuko Ota	*Delonix regia*	dead
S917-06W.3	*Scedosporium* sp.	Saipan	Yuko Ota	*Delonix regia*	dead
S917-06W.4	*Scedosporium* sp.	Saipan	Yuko Ota	*Delonix regia*	dead
S917-07W.1	*Phellinus noxius*	Saipan	Yuko Ota	*Delonix regia*	living
S917-07W.2	*Phellinus noxius*	Saipan	Yuko Ota	*Delonix regia*	living
S917-02		Saipan	Phil Cannon	*Thespesia*	beach Road
S917-03C		Saipan	Phil Cannon	*Thespesia*	beach Road
S917-01C.1	*Trichoderma* sp.	Saipan	Phil Cannon	*Casuarina*	beach Road
S917-01C.2	*Trichoderma* sp.	Saipan	Phil Cannon	*Casuarina*	beach Road
S917-01C.3	*Fulvifomes sp.*	Saipan	Phil Cannon	*Casuarina*	beach Road
S917-04		Saipan	Phil Cannon	*Casuarina*	beach Road
S917-08C		Saipan	Phil Cannon	*Delonix regia*	dead
Yap 1	*Cerrena sp.*	Yap	Phil Cannon	*Areca catechu*	betel nut

Yap 2	*Psilocybe* sp.	Yap	Phil Cannon	Cocos	leaf spot
Yap 3A	*Phellinus noxius*	Yap	Phil Cannon	chestnut	Andrew conk
Yap 3F	*Phellinus noxius*	Yap	Phil Cannon	chestnut	Andrew conk
Yap 4.1	*Lenzites/Trametes sp.?*	Yap	Phil Cannon	Betel Pep	Chool Village
Yap 4.2	*Fusarium sp.*				
Yap 5A	*Phellinus noxius*	Yap	Phil Cannon	*Mangifera*	near For. Hdqr.
Yap 5B	*Phellinus noxius*	Yap	Phil Cannon	*Mangifera*	near For. Hdqr.
Yap 5C.1		Yap	Phil Cannon	*Mangifera*	near For. Hdqr.
Yap 5D		Yap	Phil Cannon	*Mangifera*	near For. Hdqr.
Yap 5E		Yap	Phil Cannon	*Mangifera*	near For. Hdqr.
Yap 5F2	*Phellinus noxius*				near For. Hdqr.
P919-08W.1	*Rigidoporus vinctus*	Pohnpei	Yuko Ota	*Artocarpus*	healthy
P919-08W.2		Pohnpei	Yuko Ota	*A. altilis*	healthy
P919-08W.3	*Wrightoporia tropicalis*	Pohnpei	Yuko Ota	*A. altilis*	Healthy
P919-08W.4	*Phellinus noxius*	Pohnpei	Yuko Ota	*A. altilis*	healthy
P919-08W.7	*P. noxius*-like culture	Pohnpei	Yuko Ota	*A. altilis*	healthy
P919-02W.1	*Phellinus noxius*	Pohnpei	Yuko Ota	*Ficus tinct.*	Gibson's farm
P919-02W.2		Pohnpei	Yuko Ota	*Ficus tinct.*	Gibson's farm
P919-02W.4		Pohnpei	Yuko Ota	*Ficus tinct.*	Gibson's farm
P919-02W.5		Pohnpei	Yuko Ota	*Ficus tinct.*	Gibson's farm
P919-02W.7	*Phellinus noxius*	Pohnpei	Yuko Ota	*Ficus tinct.*	Gibson's farm
P919-02W.10	*Abundisporus roseoalbus*	Pohnpei	Yuko Ota	*Ficus tinct.*	Gibson's farm
P919-02W.11		Pohnpei	Yuko Ota	*Ficus tinct.*	Gibson's farm
P919-02W.12		Pohnpei	Yuko Ota	*Ficus tinct.*	Gibson's farm
P919-07W.1	*Wrightoporia tropicalis*	Pohnpei	Yuko Ota	*A. altilis*	Yellow Kitti
P919-07W.2	*Phellinus noxius*	Pohnpei	Yuko Ota	*A. altilis*	Yellow Kitti

P919-07W.4	*Fusarium* sp.	Pohnpei	Yuko Ota	*A. altilis*	Yellow Kitti
P919-07W.5	*Phellinus noxius*	Pohnpei	Yuko Ota	*A. altilis*	Yellow Kitti
P919-07W.9	*Ceriporia lacerata*	Pohnpei	Yuko Ota	*A. altilis*	Yellow Kitti
P919-07W.10		Pohnpei	Yuko Ota	*A. altilis*	Yellow Kitti
P919-07W.12		Pohnpei	Yuko Ota	*A. altilis*	Yellow Kitti
P919-07W.13		Pohnpei	Yuko Ota	*A. altilis*	Yellow Kitti
P919-07W.15	*Tinctoporellus?*	Pohnpei	Yuko Ota	*A. altilis*	Yellow Kitti
P919-01W		Pohnpei	Yuko Ota	*Cananga* sp.	stem canker
P919-06W1A	*Wrightoporia tropicalis*	Pohnpei	Yuko Ota	stump	*P. noxius* kill
P919-06W1B	*Phlebia sp.?*	Pohnpei	Yuko Ota	stump	*P. noxius* kill
P919-03C		Pohnpei	Yuko Ota	*Ficus tinct.*	not *P. noxius*
P919-4C	*Earliella scabrosa*	Pohnpei	Yuko Ota		Gibson's farm
P919-03C.1	*Abundisporus roseoalbus*	Pohnpei	Yuko Ota	*Ficus tinct.*	not *P. noxius*
Entomopath	*Conidiocarpus?*	Pohnpei	Engleberger	chili pepper	on insect
Kosrae 1.1	*Fusarium* sp.	Kosrae	Phil Cannon	*A.* altilis	Max uncle up
Kosrae 1.2	*Rigidoporus vinctus*	Kosrae	Phil Cannon	*A. altilis*	Max uncle up
Kosrae 2	*Bacillus* sp.	Kosrae	Phil Cannon	*A. altilis*	Max uncle up
Kosrae 3.1		Kosrae	Phil Cannon	*Terminalia*	Yela River
Kosrae 2.2		Kosrae	Phil Cannon	*Terminalia*	Yela infected
Kosrae 4	*Phellinus noxius*	Kosrae	Phil Cannon	*Sonneratia*	Conk Walk
Kosrae 5	*Ganoderma sp.*	Kosrae	Phil Cannon	*Terminalia*	last landing
Kosrae 6	*Phellinus noxius*	Kosrae	Phil Cannon	*A. altilis*	Max uncle low
G914-01	*G. australe* complex	Guam	Klopfenstein	*Casuarina*	YIGO Exp.
G914-4	*G. australe* complex	Guam	Klopfenstein	*Casuarina*	Watson farm
G914-05	*Ganoderma sp.*	Guam	Klopfenstein	*Casuarina*	Watson farm
G914-08	*G. australe* complex	Guam	Klopfenstein	*Casuarina*	Watson farm
G914-22		Guam	Klopfenstein	*Casuarina*	Ritidian
G914-12		Guam	Klopfenstein	*Casuarina*	3/4dead

G914-13		Guam	Klopfenstein	*Casuarina*	3/4 dead
G914-10		Guam	Klopfenstein	*Neisosperma*	? disease
G915-01C/W	*Phellinus*	Guam	Klopfenstein	*Thespesia*	#1 sample
G915-04	*Perenniporia tephropora*	Guam	Klopfenstein	*Casuarina*	fire killed
Roger	Xylariaceae?	Guam	Roger Brown	Stump	recent cut
UOG1	*Trichoderma* sp.	Guam	A. Lehman	*Guamia sp.*	Sample 1
UOG2		Guam	A. Lehman	*Guamia sp.*	Sample 1
UOG3	*Phellinus noxius*	Guam	A. Lehman	*Macaranga*	Sample 2
UOG4		Guam	A. Lehman	*Macaranga*	Sample 2
UOG5		Guam	A. Lehman	*Macaranga*	Sample 2
UOG6	*Phellinus noxius*	Guam	A. Lehman	*Guamia sp.*	Sample 4
UOG7	*Phellinus noxius*	Guam	A. Lehman	*Guamia sp.*	Sample 4
UOG8	*Phellinus noxius*	Guam	A. Lehman	*Guamia sp.*	Sample 4
UOG9		Guam	A. Lehman	*Macaranga*	Sample 5
UOG10		Guam	A. Lehman	*Macaranga*	Sample 5
UOG11	*Phellinus noxius*	Guam	A. Lehman	*Macaranga*	sp 4 FHA
UOG12	*Phellinus noxius*	Guam	A. Lehman	*Macaranga*	sp 4 FHA
UOG13	*Trichoderma* sp.	Guam	A. Lehman	*Intsia bijuga*	sp 4 FHA
UOG14		Guam	A. Lehman	*Guamia sp.*	sp 3 FHA
UOG15	*Phellinus noxius*	Guam	A. Lehman	*Guamia sp.*	sp 3 FHA
UOG16		Guam	A. Lehman	*Guamia sp.*	sp3 FHA
UOG17	*Phellinus noxius*	Guam	A. Lehman	*Ochrosia sp.*	dead stand
UOG18	*Phellinus noxius*	Guam	A. Lehman	*Ochrosia sp.*	dead stand
UOG19	*Phellinus noxius*	Guam	A. Lehman	*Ochrosia sp.*	dead stand
UOG20	*Phellinus noxius*	Guam	A. Lehman	*Ochrosia sp.*	dead stand
UOG21	*Trichoderma* sp.	Guam	A. Lehman	*Ochrosia sp.*	sp 3 FHA
UOG22	*Lasiodiplodia theobromae*	Guam	A. Lehman	*Guamia sp.*	dead stand

Discussion and Next Steps

The total of 246 samples collected during this entire trip may seem like a fairly large collection; however, a collection several thousand times larger would easily have been possible if there had been no focus on which conks were collected and if there had been ample time. The variation/diversity in forest trees, forest environments and hence all of the associated microflora, including these butt-rot fungi, is extremely rich in this part of the world. Towards keeping this collection at a reasonable level, and to make this collection survey as useful as possible for forest health purposes, two criteria were used to decide which samples to collect. First, to be considered for collection, the fungus had to have associations with butt rot and, second, surveys were focused on the potentially invasive *P. noxius*. In addition, a portion of this survey on Guam was devoted to examinations of ironwood (*Casuarina equisetifolia*), which was recently summarized by Schlub (2013). During this survey, we made a collection of almost every putative *P. noxius* infection that we found and made a collection of ca. one of every 500 fructifications of all other conk-forming basidiomycetes that we came across. As a consequence of these selection criteria, this particular fungal sample collection was heavily biased towards *P. noxius.*

On each island, efforts were devoted toward isolating these fungi onto culture media. For conducting fungal isolations, suitable plant pathology laboratories were available at the universities on Guam and Saipan, and the NRCS building in Pohnpei also had ample working space. On Yap, Palau and Kosrae, make-shift isolation facilities were set up in the senior author's hotel room. For the majority of the samples collected, between 2 and 18 isolations were attempted. Many of these isolations produced clean cultures, but some cultures contained contaminate fungi (e.g., *Trichoderma* spp.) that required that re-isolation of the target fungus. As a consequence, identification work for some of these samples continues to be conducted at the Forest Pathology laboratories at the USDA Forest Service – RMRS and at the Forestry and Forest Products Research Institute, Tsukuba Japan.

The surveys of *P*. *noxius* are an important follow up to previous reports on the Northern Marianna Islands by Hodges and Tenorio (1984). The reason for focusing on *P. noxius* collections for this survey is two-fold. One, because of the high pathogenicity of this fungus, we wanted to be absolutely certain we were identifying it correctly. The second reason is our interest in the genetic diversity among *P*. *noxius* isolates from diverse regions. To better understand these genetic relationships we plan to design molecular markers (e.g., microsatellites or Restriction-site Associated DNA Sequences, RADSeq) and evaluate genetic relationships among *P. noxius* isolates. Currently, translation elongation factor (*tef*) 1-alpha gene sequences are also being evaluated for potential use in phylogenetic studies. Specific genetic data can be useful both for determining gene flow, where an isolate may have come from and genetic diversity, which, in some cases, may help to identify especially aggressive strains of this fungus. *Phellinus noxius* is discussed in more detail within the next chapter (Chapter IV).

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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).

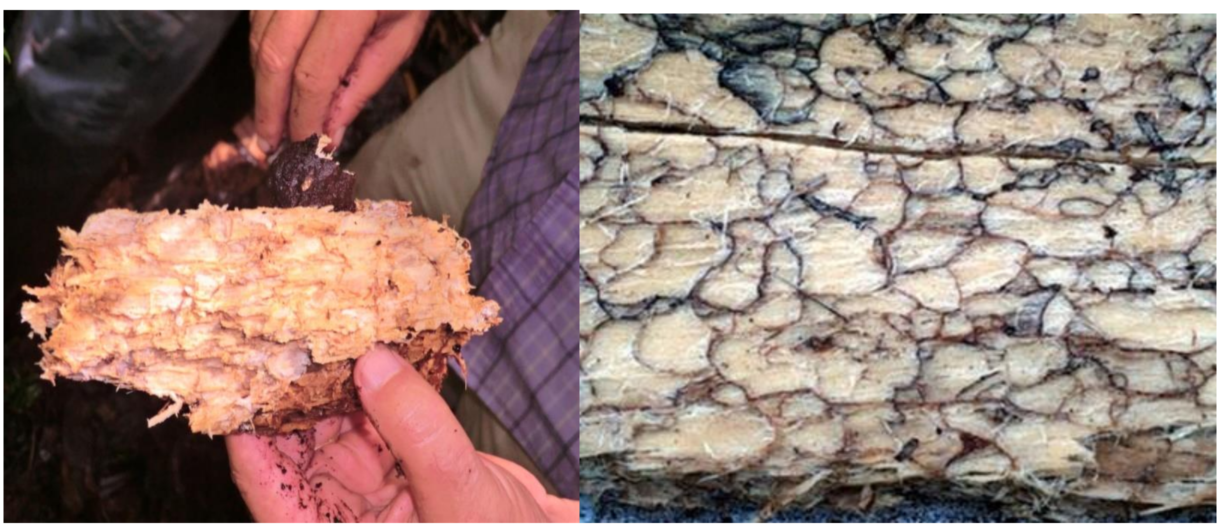

Figure 5. Wood that has been heavily colonized by *Phellinus noxius* is characteristically much less dense and weaker as a result of the rot that this fungus causes. With advanced decay, it is also likely that the fungus will form zone lines that may protect this fungus from other micro-organisms and 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°C to 30°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^{o} 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.

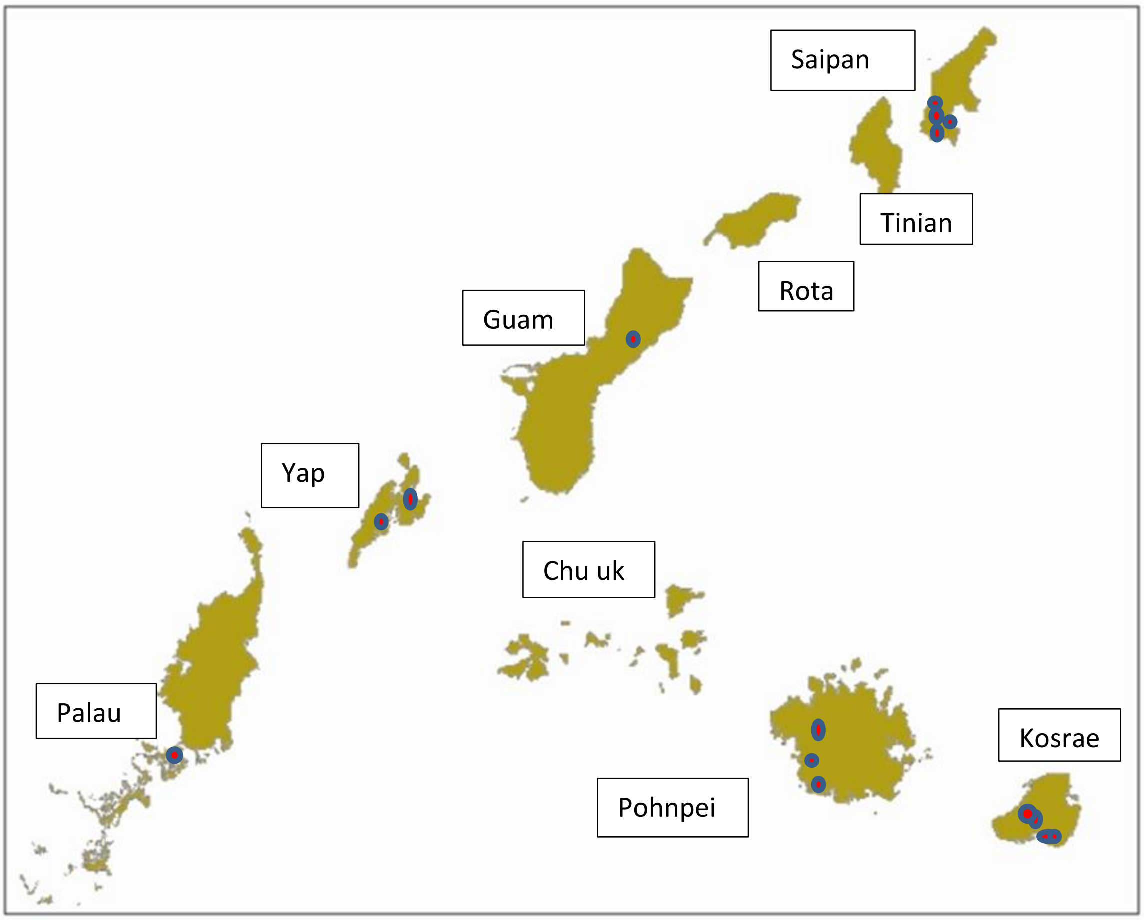

Figure 6. Locations where *Phellinus noxius* was found in Palau,Yap, Guam, Saipan, Pohnpei, and Kosrae during the September 2013, forays. On this trip, no sampling was done on Chu uk, Tinian, or Rota. <u>Please note</u>: geographic locations are stylized and distances between islands are not to scale.

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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Chapter V

A 1-Year Evaluation of an International Provenance Trial of *Casuarina equisetifolia* in Guam

By: Phil Cannon, Robert L. Schlub, Roger Brown, and Joe Afaisen

Abstract: An international provenance test was initiated to determine if a source of seed for this species that was tougher or faster growing than Guamanian sources of this species. At the end of one year, 17 of the 18 foreign seed sources of *Casuarina equisetifolia* had grown faster than the two Guamanian sources of *C. equisetifolia* in this test. It was also found that seedlings of the same seed source grew measurably better when planted in blocks with deeper soils and in these blocks were also less prone to bending from the wind of a mid-strength typhoon.

Introduction

There may be several million *Casuarina equisetifolia* trees growing in Guam and historically they have grown well. However, since 2008 it has been noticed that a large number of these *Casuarina* trees have been dying back. Since this time, Dr. Robert Schlub, at the University of Guam, has led a concerted effort to determine the causes of this *Casuarina* dieback and also to look for solutions to this problem (Schlub *et al*. 2013). Several factors have been identified as possible causal agents in different locations where the dieback has been assessed (Schlub *et al*. 2013); among the most common is the fact that *Casuarina* trees are affected by butt rots. The senior author believes these butt rots are much more common in trees that have had some breakage in their main bole. This breakage could be a horizontal snapping of the stem or the extensive popping of the bark and sapwood along the grain when these trees are twisted by strong winds around their vertical axis. It appears that once access is gained, the fungal species colonizing the now- exposed heartwood are capable of growing quickly throughout the bole of these trees and then spreading to the root systems of neighboring trees (Cannon, unpublished).

Dr. Schlub believes the high frequency of Ganoderma on Guam may also be linked to the presence of two bacteria *Ralstonia solanacearum* and *Klebsiella variicola*. Possible points of infection for these bacteria also include wounds to roots, stems and branches caused by storms (and also poor tree care, and termites). Tree topping, a practice sometimes used to limit Casuarina trees planted in windbreaks to a compact size, may also provide some infection opportunities for these bacteria.

One of the circumstances of Guam's geographic location is that it is occasionally hit (or nearly hit) by typhoons. In 2002, the Super Typhoon Pongsona made a direct hit on Guam. Maximum wind speeds of between 100 and 160 miles per hour were recorded on most parts of the island during this typhoon (NOAA, 2003). A good deal of the Casuarina breakage and butt rot ingress into Casuarina trees seems to date from this event. This has been the largest typhoon in the past decade, but there have also been smaller typhoons since then, the most recent being Typhoon Nari (Oct. 13th, 2013) which did not make a direct hit on Guam but nevertheless produced wind speeds of up to 45 mph (72 km per hour).

Although Casuarina is one of the toughest trees available for planting in the tropics, it is apparent that if it were a little tougher or if it could grow with a form that was less vulnerable to wind damage, then it might be able to come through future storms a little less scathed and a little less vulnerable to butt rot and *Ralstonia*. Some of the features that might make a tree tougher when there is an onslaught of wind include a higher wood density, an absence of ramicorn (or acute-angled) branching, small, short, limbs (not a wolf tree) and good tree health.

In the early 1990's a seed collection of *Casuarina equisetifolia* was made from 67 major locations (21 countries) around the world where this species was growing either in natural forests or plantations. Complete details of this collection are available in Pinyopusererk *et al.* (2004).These seeds were used to establish international provenance trials in several countries. By 1994, 60 seed sources had been planted in 20 countries in fairly standard provenance/progeny test layouts. Though seeds from Guam were included in the collection, the trial itself was never conducted on Guam. Results from 14 of these sites have since been analyzed and, very generally, there were enormous growth differences among all *Casuarina* sources at the different sites and between the different provenances of *Casuarina* at the individual test sites (Pinyopusarerk *et al*, 2004).

In 2011, Dr. Zelalem Mersha and Dr. Schlub purchased some of the seeds from this collection, for evaluation on Guam. And, in 2012 it was decided to initiate this International Casuarina Provenance Test to see if Guam's toughest plantation tree could be made more resilient or, in other words, to determine if there was a source of *Casuarina* that could grow faster or have a form that made it less vulnerable to wind damage.

Methods

At the University of Guam, seedlings from 18 of these international *Casuarina equisetifolia* sources were grown in sufficient number to be included in a provenance test. Casuarina wildlings were also collected from two sites in Guam for inclusion in this test. A summary of all sources included in this test is shown in Table 1. The location of the test was at the Bernard Watson Farm in Yigo, Guam. The soils at this site are classified as belonging to the Yigo series (USDA, 1988) and, over the extent of the test site, are shallow with 1 to 4 inches (2.5 to 10 cm) of topsoil overlying limestone rock. Site preparation consisted of plowing the field and running an 8 inch- (20 cm-) wide auger down to a depth of 1 foot (30.5 cm) at each planting site. The spacing between rows of trees was 12 feet (3.7 m) and the spacing between trees within rows was 8 feet (2.4 m).

In general, most *Casuarina* trees in this test grew very fast. By the end of year one, it was obvious that the test would soon need to be thinned in order to maintain tree health and allow continued measurements for this test. It was decided to measure and analyze the 1-year growth.
All measurements prescribed by the International Casuarina Provenance test organizers (Pinyopusarerk *et al*, 2004) were made at the time of the 1-year assessment, but only the 1-year height measurements were analyzed and are reported on in detail in this report. Statistical Analyses were done in accordance with Steele and Torrie (1980).

The test was planted in August, 2012 in a complete randomized block design. There were three blocks with each seed source being represented by a four-tree row plot in each block.

Table 1. Sources of *Casuarina equisetifolia* seed for the International Provenance Test in Guam.

U. G. #	CSIRO Seed lot	Provenance	Country	Area grouping	Natural or introduced
2	18348	Kuantan Penang	Malaysia	SE Asia	Natural
3	18375	Desaru Johor	Malaysia	SE Asia	Natural
4	20586	Horno Island	Papua N G	Pacific	Natural
5	18153	Ela Beach	Papua N G	Pacific	Natural
6	18402	Kolombangara	Solomon Is	Pacific	Natural
7	18297	Ban Kam Phuam	Thailand	Asia	Introduction
8	18299	Hadsamira Songhla	Thailand	Asia	Introduction
10	19821	Melville Island	Australia	Australia	Natural
11	18378	Prince of Wales Is	Australia	Australia	Natural
14	18015	Chandipur Balasore	India	Asia	Introduction
15	18119	Rameswaram Island	India	Asia	Introduction
18	18141	Robinson Island	Kenya	Africa	Introduction
19	18144	Baobab	Kenya	Africa	Introduction
20	18312	Efate	Vanuatu	SE Asia	Natural
21	18267	Yanging	China	Asia	Introduction
22	18268	Daodung SF	China	Asia	Introduction
23	18586	Beihai Guangxi	China	Asia	Introduction
24	18152	Ninh Tuan	Vietnam	Asia	Introduction
25		North, Ritidian	Guam	Pacific	Natural
26		South, Inarajan	Guam	Pacific	Natural

Results

Table 2. One-Year Height Growth Results of the International *Casuarina equisetifolia* Provenance Trial in Guam. Differences between means for height were significant at the 0.001 level of significance. LSD =2.36 feet.

Rank In test	Guam ID #	CSIRO #	Source	Region	Type of stand	Height at 1 year (feet)
1	6	18402	Solomon Is	Pacific	Natural	16.27
2	4	20586	Papua N G	Pacific	Natural	15.48
3	2	18348	Malaysia	SE Asia	Natural	14.33
6	22	18268	China	Asia	Introduction	13.06
4	3	18375	Malaysia	SE Asia	Natural	12.99
7	14	18015	India	Asia	Introduction	13.86
5	5	18153	Papua N G	Pacific	Natural	12.73
8	23	18586	China	Asia	Introduction	12.56
9	20	18312	Vanuatu	SE Asia	Natural	12.53
10	18	18141	Kenya	Africa	Introduction	12.47
11	21	18267	China	Asia	Introduction	12.37
12	24	18152	Vietnam	Asia	Introduction	11.88
13	19	18144	Kenya	Africa	Introduction	11.42
14	7	18297	Thailand	Asia	Introduction	10.59
15	10	19821	Australia	Australia	Natural	10.3
16	15	18119	India	Asia	Introduction	10.14
17	8	18299	Thailand	Asia	Introduction	9.68
18	25	North	Guam	Pacific	Natural	9.35
19	26	South	Guam	Pacific	Natural	9.28
20	11	18378	Australia	Australia	Natural	8.76

Figure 1. Bernard Watson, farm manager on the left, stands in front of a row of *Casuarina* from Chandipur, India, which was among the faster growing provenances (#6 out of 20) at this location. Phil Cannon stands by a row of *Casuarina* from Melville Island, Australia which is growing much more slowly (#19 out of 20). Trees were planted 1 year before this photo was taken (photo by Ned Klopfenstein).

Discussion

Growth of many of the *Casuarina equisetifolia* sources was outstanding during the first year in Guam. No doubt this is partly due to an exceptional abundance of rainfall that fell throughout this first year. Also, clearly, there were some very obvious differences in the performance of the different provenances. The very fastest growing provenances were nearly twice as tall as the slowest growing provenances or, in other words, approximately six times as big in terms of their average tree biomass (based on the observation that the volume of young trees increases seven-fold for each doubling of DBH (in turn derived from the general metric volume formula Volume = $0.0004d^2h$ and the senior author's observation that, in young trees of fast growing species, there is almost a doubling of height (in meters) with a doubling of diameter (in cm)).

Patterns in terms of where the fastest growing provenances had come from and where the slower growing provenances had come from were not especially clear. However, as a very general rule, some of the slowest growing provenances came from the very driest sources and some of the faster growing provenances came from areas with high annual rainfall. It is important to note that test results for these provenance rankings in this Guam *Casuarina* provenance test are also somewhat different from the rankings of these same *Casuarina* seed sources in 14 other *Casuarina* provenance tests conducted in other parts of the world (Pinyopusarerk *et al*, 2004).

Reasons for these differences are conjectural at this point. One factor that may be having a large influence on the way this particular provenance test is developing is that the soils at Yigo are exceptionally shallow (1-5 inches or 2.5-12.7 cm of red clay soil over white limestone); whereas, the soils were reported as very deep in all other *Casuarina* tests (Pinyopusarerk *et al.*, 2004). The importance of soil depth to *Casuarina* is readily apparent, even in this trial. When it was laid out, the person doing most of the planting (Joe Afaisen) noticed that the soil in Block 1 was shallower than the soil in Block 2 and much shallower than the soil in Block 3. Indeed, it is possible to see bits of the white, ground-up reef at the surface of Block 1 even today. This has had an effect on tree growth. At 1-year, average heights of given provenances in blocks 2 and 1 were only 90% and 75%, respectively, of the heights of these same provenances in Block 3. This suggests that selection of sites with deeper soils and/or a deeper ripping and plowing of the sites prior to planting could enable these same *Casuarina* provenances to grow even faster.

One other factor of note is that the first growing season for this Guam *Casuarina* provenance test was an especially wet one for Yigo, Guam. This wet weather may have favored an especially optimal performance by *Casuarina* sources coming from wetter native environments than they might have demonstrated during a drier, more typical, year.

Epilogue

This *Casuarina* test at Yigo currently offers at least one additional reason to recommend deeper soils or at least deeper site preparation when planting *Casuarina*. On Oct. 13th, 2013, Typhoon Nari approached Guam. This was after these first-year measurements had been made, and after the first thinning had been performed. Although Nari did not make a direct hit on Yigo, it did produce sustained winds of 45 mph (72 km per hour). Very significantly, those *Casuarina* seedlings in Block 3, where the soils were deepest, had only 7.5 % of their seedlings bent (and 0% were wind-thrown); whereas, seedlings growing in the shallower Block 2 had 27.5% of their seedlings bent (and 5% wind throw), and seedlings growing in the shallowest soils of Block 1 had 57.5% of their seedlings bent and 15% had been windthrown.

Overall, the seedlings from Guam had the highest propensity to be bent as a result of this wind (59.5% of these seedlings were bent), whereas the seedlings from Australia had the lowest propensity to be bent (9% bent). Other provenances had wind damage falling between these extremes: 17% Papua New Guinea; 22% China and Sri Lanka; 25.5% for seedlings from Kenya, Thailand, and India; and 34% for seedlings from Viet Nam and Malaysia. From this test it appears that there may be some differences in wind firmness between the different sources of *Casuarina* used in this trial. However, this experiment was limited in size (number of blocks), so not too much weight should be put on just the results shown here. Also, the very high level of blow-down in the Guam sources of *Casuarina* may be partially attributed to the way the seedlings for this particular provenance were obtained. In this case, these seedlings were wildlings and were dug up from natural seedlings that occurred in the sandbanks at Ritidian and Inarajan, respectively. It may be that heavy root pruning took place when these seedlings were collected and they were unable to form the same stabilizing distribution of roots as seedlings produced a nursery. It may also be true that these dug-up seedlings had root systems that shortchanged the trees a bit in terms of their ability to provide water and nutrients and this may also have hampered their growth rates. It is recommended that a portion of this provenance test be repeated, this time growing the Guamanian *Casuarina* sources from seed.

Figure 2. Effect of a Typhoon Nari on *Casuarina* in Block I of the Provenance trial in Yigo, Guam. On the left, trees bent from this wind. On the right, the exposed root wad of a wind-toppled *Casuarina*.

There was another lesson learned from Typhoon Nari's impact on this provenance trial. None of the stems of these young, 1-year-old seedlings in this trial was broken along a horizontal axis and no bark cambial tissue popped open as a result of excessive torque around a vertical axis, so no courts of infection ever developed with this level of wind and there probably will be no butt rotting in these *Casuarina* trees or *Ralstonia* infections that will be traceable to this storm.

Shortly after the typhoon, all but one of the wind-bent *Casuarina* trees in this test was propped up and these have continued growing in an upright manner (Roger Brown, personal communication).

The net lesson from this experience is that storm winds such as this one produced by Typhoon Nari (sustained 45 mph or 72 km per hour wind speeds with some gusts) must also be recognized as potential damaging agents for young *Casuarina* trees. Although it is not possible to control the wind velocity or its direction, other means of diminishing the impact of wind on young trees probably should be considered. A few of these include deep ripping of subsoil, choosing line planting orientations that will not be at right angles to typhoon winds, and increasing numbers of rows in line plantings.

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Chapter VI

Forestry Possibilities for Acid Soils in Upland Portions of Yap and Palau

By: Phil Cannon, Puis Liegel, Larry Mamus, Mohammad Golabi, and Bob Gavenda

Overview

Considerable prior work has been implemented to better understand the chemical and physical properties of the upland soils in Yap and Palau and to determine how to grow agricultural crops in these soils (Smith and Bubik, 1988, NRCS, 2008). Some work has also gone on to figure out how to grow trees on these soils as well. However, although there are some impressive forest plantations on both Yap and Palau, the dismal condition of many forest plantations which have been attempted on the extremely acid and poorly drained soils of these countries indicates that more needs to be learned about coping with these soils when using them for forestry.

Elsewhere in the tropics, a considerable amount of effort has also been applied to learn how to grow trees on acid soils. In this present exercise the plantation forestry situation for the uplands of Yap and Palau is described as the author saw it during a short visit during 2013 and a few ideas for overcoming the continuing shortfalls are borrowed from forest plantation experiences elsewhere in the tropics.

Figure 1. Suffering *Acacia mangium* trees, growing at only a fraction of their genetic potential, are shown in the center of this field of feisty ferns (red arrows). The soils in this area are, shallow, acidic and have high aluminum saturation (photo by Bob Gavenda).

During a visit during 2013 it was apparent that much of the upland portions (above 20 masl) of Yap (and especially MAAP) and Palau (and especially the island of Babeldaob) have a vegetation comprised of only of a sparse grass and a short-statured fern. A rough estimate of vegetation maps indicates that this non-productive landscape condition prevails in about 40% of both of these countries.
This dearth of large-statured forest vegetation in the uplands is rather ironic as both countries have ample rainfall throughout most of the year and both have temperatures conducive for tree growth all year round.

Figure 2. Top photo shows an overview like the landscape where reforestation is being attempted near Lake Ngardok on Babeldaob, Palau (photo is actually in Airai State). Lower photo shows a typical soil profile in this area; the A horizon has been burned away by fires, or oxidized away by micro-organisms or simply eroded away to expose bauxite gravel (high in Aluminum) laying on the present soil surface. The underlying horizon is also strongly acidic (photos from USDA-NRCS).

A big part of the problem is that the soils on these landscapes are very acidic, a product of excessive cation leaching caused by all the rain that falls on these islands and the tropical very warm climate. In much of this area the problem is exacerbated by frequent fires which kills live vegetation, consumes much organic matter on the soil surface and makes the A horizon (which would be more favorable for plant growth because of its higher organic matter, higher pH, better moisture release properties) much more vulnerable to surface erosion. Beneath this A horizon is a B horizon that has the following troublesome properties:

Low pH;

High phosphorus fixing capacity

High aluminum saturation (>60%) and hence a tendency for aluminum toxicity;

Low availability of essential base nutrients;

Poor moisture release properties;

Little available nitrogen or phosphorus;

And, possibly, low available levels of boron and other micronutrients.

Towards getting a somewhat more precise handle on the soil properties in the area of the Lake Ngardok plantations, we took six soil samples which we dubbed as follows:

Native A came from the A horizon of a soil profile located under one of the few remaining trees from the native forest; it was a composite sample of 5 sub-samples from the one-inch depth in this horizon.

Native B came from the B horizon of that same profile.

Sweet Soil A came from the A horizon of one of the tree planting spots that had been "fertilized" (see ahead) by Karen Bennett and her Yap collaborators, this was in a barren area that had only ferns and grass prior to planting;

Sweet Soil B came from the B horizon of that same profile;

Auriculiformis Top Soil came from the top 5 cm of an area that had been planted with *Acacia auriculiformis* approximately 8 years earlier;

and Auriculiformis Sub Soil came from the B horizon of that same profile.

These samples (accompanied with all of the appropriate phytosanitary papers) were transported and delivered to the Mohammad Golabi Soils Lab at the University of Guam where they were subsequently analyzed by Clancy Thomas Iyekar for pH, salinity, organic matter, P, K, Ca and Mg. The results are shown in Table 1.

From these results, a few very tentative patterns seem to emerge. In its A horizon, a soil in this area found below remnant trees from the native forest is likely to have a far more favorable pH, a higher percentage of organic matter, and higher levels of available phosphorus and calcium than A horizons where this native overstory had been removed but which had been amended with the Karen Bennett fertilizer recommendation. They also had tremendously more favorable levels for all of these properties than are found in the A horizon of the unfertilized *Acacia auriculiformis* plantation. It does seem apparent that the Karen Bennett fertilizer recommendation nudged the organic matter content of the A horizon upwards a little and increased the available phosphorus very significantly, but still not to a point where it could pass the deficiency threshold for this element (Note: the minimal available phosphorus level (Bray II) for unrestricted growth of hardwood trees is 4.0 to 5.0 ppm (Cannon, 1984). The B horizon underneath the native trees also had more favorable properties (higher pH and slightly more organic matter) than the B horizons where the Karen Bennett fertilization had taken place, and where there had been no fertilization, but at this depth there was little difference in the availabilities of P, K, Ca and Mg.

Table 1. Results of chemical analyses from a composite sample of the A horizon of three soil profiles near the Lake Ngardok *Acacia auriculiformis* plantations on Babeldaob, Palau. The Native soil is from a small patch of remaining native forest; the Sweet Soil comes from an area that was deforested years ago but since fertilized in accordance with recommendations by Karen Bennett; the Auriculiformis profile comes from ground between *Acacia auriculiformis* trees which had been planted 8 years earlier.

Sample ID	pH	Salinity (EC) µS/cm	O.M. %	Available P (ppm)	Available K (ppm)	Available Ca (ppm)	Available Mg (ppm)
Native A	6.06	636	7.10	3.69	43	5935	90
Native B	5.56	234	3.50	1.20	31	939	39
Sweet Soil A	4.26	673	5.30	1.44	78	155	82
Sweet Soil B	4.38	47	1.50	2.05	27	93	74
Auriculiformis A	4.37	58	4.80	0.10	63	281	132
Auriculiformis B	4.46	46	1.40	1.68	20	214	93

Discussion

From this analysis (Table 1) it can be seen that native forests in this area have soil properties that are marginal for tree growth and where these native forests had been previously cleared

(Auriculiformis) the remaining soils had become remarkably less fertile. The attempt to take some measures to improve the chemical content of the impoverished condition (Sweet soil) did improve soil chemistry perceptibly, but still nowhere nearly enough to enable trees to grow well.
The question is: at reasonable costs, could soil chemical properties be made even more favorable than was possible using the Bennett recommended fertilization (Sweet Soil in Table 1)? Both Bekker and Yapa (1994) and NRCS (2008) describe ways of cheaply and effectively incorporating lime and “manufactured sand” (comprised of ground up, dead, coral reef) into these soils to neutralize their acidity and discuss ways of improving soils in disturbed upland sites and then conducting grass species trial in combinations with fertilizers and mulch to find winning combinations.

The question is: what else can be done to improve tree growth a whole lot more on these problematic upland sites? One school of thought indicates that finding a tree species already adapted to these adverse soil conditions would help. A second suggests that use of well-prepared seedlings is important. Yet another suggests that there may still be other soil amendments such as fertilizers and mulches that might lead to substantial growth improvements. A fourth suggests that finding microbial symbionts especially adapted to acid soil conditions could be helpful. All four of these possibilities will be explored next.

Tree Species changes-

From the senior author’s personal experience with low elevation, high rainfall, highly acidic sites, I would like to suggest that species trial work in other parts of the world (with similar climatic conditions to Yap) be examined and that possibly some of the species that proved the best growth in these trials might be tried in future experiments on acid soils in Yap and Palau. In Central America, for example, it was found that *Vochysia ferruginea* (family Vochysiaceae) could grow very fast and with excellent form in soils with very similar conditions as those found in Yap. This, in part, was due to ability of *Vochysia* to absorb aluminum from the soil and compartmentalize this into its luxuriant leaves (which assay out at nearly 90% aluminum); this effectively neutralizes the aluminum saturation of the soil (and the acidity problem) and makes any phosphorus in that soil much more available for absorption by that same tree. Other species that have done astonishingly well under these conditions include *Vochysia guatemalensis, Hyeronima alchorneoides, Dipteryx panamensis, Calophyllum brasilense* (Butterfield and Espinoza, 1995) and *Araucaria hunsteinii* (Russo and Briscoe 2002). Other species worth trying include *Jacaranda copaia* which has been widely planted in Ecuador’s Amazon region (personal observations), and *Goethalsia meiantha, Stryphnodendron microstachyum, Eucalyptus deglupta, Terminalia ivorensis*, *T. amazonia* and *Schizolobium parahybum.* There are also two pines that could also be tried, *Pinus caribaea* and *P. tecunumanii* according to Carpenter et al (2004). Indeed, these authors found that these pines were imminently more successful at establishing and growing on badly degraded sites than any other species and that subsequently these sites could then be easily planted to (or colonized by) native species. A similar experience of using pines to set up a "foster ecosystem" was found in Puerto Rico (Parrotta, 1993). The fact that several of these pine species are reproductively sterile below 15 degrees of latitude essentially ensures that they will not become a weed problem. There is also a suite of acid-tolerant leguminous tree species that could be tried including *Acacia mangium* (and some of its hybrids), *Samanea (Albizia) saman, Calliandra calothyrsus, Inga edulis, Albizia falcataria, Pterocarpus indicus* (Winrock, 1996). Of course, it would also be important to include *Acacia auriculiformis, Sweitenia macrophylla* and *Tectona grandis* in any new species trials, as well, since these represent the three most widely planted tree species in previous tree planting efforts (Note: the potential of any of these species to become weed species in Yap or Palau should definitely be considered). It was unclear whether the *Acacia mangium x auriculiformis* hybrid has been tried in Yap or Palau, but this, of course would be another good candidate. Suggestions as to where to obtain seed for any of the aforementioned species are available, on request, to the senior author.

Use Seedlings that Are Better Prepared for Out-planting

In mid-2013 Diane Haase and J.B. Friday made a trip to Palau to study current forest nursery practices on that island and offer suggestions. Unfortunately, during current this trip it was raining about 6 inches per hour when we were at the nursery so we did not look at the nursery carefully during this visit. However, on a subsequent visit, Katie Friday was able to verify that the nursery recommendations that had been made by this duo had largely been followed. It should be pointed out that during this first trip JB Friday had also noticed that seedlings were not establishing well in these acid upland soils, and that, indeed, that was a primary motivation for studying tree growth performance on this present trip.

Improving Soil Fertility

One area for research that is strongly recommended for the uplands of Yap and Palau is an advanced set of fertilizer trials. Three things strongly point to a need for these experiments: 1) none of the tree species planted on these acid upland sites has grown at even 10% of their genetic potential for growth rates with the climates that are offered in Yap and Palau, and 2) the fertilizer trials that have been tried, to date, do show at least some response to some of the fertilizers that have been applied (NRCS, no date), but 3) even with the fertilizers that were applied (the kind and their dosage) trees have still not grown anywhere close to their genetic capacity; clearly other prescriptions are called for. The crushed “mechanical sand” (NRCS 2008) undoubtedly has a little soluble phosphorus and calcium in it and this is probably producing the small (but statistically significant) blip in growth rates and plant health that has been observed where this treatment has been included earlier (NRCS, no date). In this same study, additions of organic matter also supposedly contributed to improved growth (actually just the low vegetation then currently growing on the site was cut and left in place so the growth benefit may also have been a result of reduced competition). None-the-less, the growth improvements of any of these treatments were just a fraction of the response that could be hoped for if a more soluble form of P and Ca were available and today, several years after the initial results of this experiment were recorded, the effects of these fertilizers are scarcely visible at all.

It is therefore suggested that a small amount of Super Triple P or acidulated rock phosphate be added into the planting site as well. The P in these two fertilizers will be available to the seedlings almost immediately and will enable the young trees to grow and subsequently accumulate the Ca and P from the manufactured sand. Of course, it is important to apply enough P to first satiate the soils ability to fix P; only the amount applied in excess of this fixation capacity will be available to the young seedlings. It should be noted that a review of the study design of this first experiment (NRCS, no date), and Karen Bennett’s notes provided by Bob Gavenda) shows that all organic matter and fertilizers were broadcast -applied over a 10 foot by 30 foot plot. Thus large proportions of these P and K fertilizers (maybe 95%) were never available to the developing seedlings because they were too far away from the seedling’s root systems and much of the nitrogen would have volatilized (gone up in the sky) within a day or two after the first rains following application. Much, much better results could be anticipated by placing these fertilizers in a position where there will be accessible to the roots (but not so close that they burn them) and under the soil surface so the nitrogen isn’t volatilized. For more ideas on how to lay out this fertilizer placement experiment, refer to Cannon, (1984b).

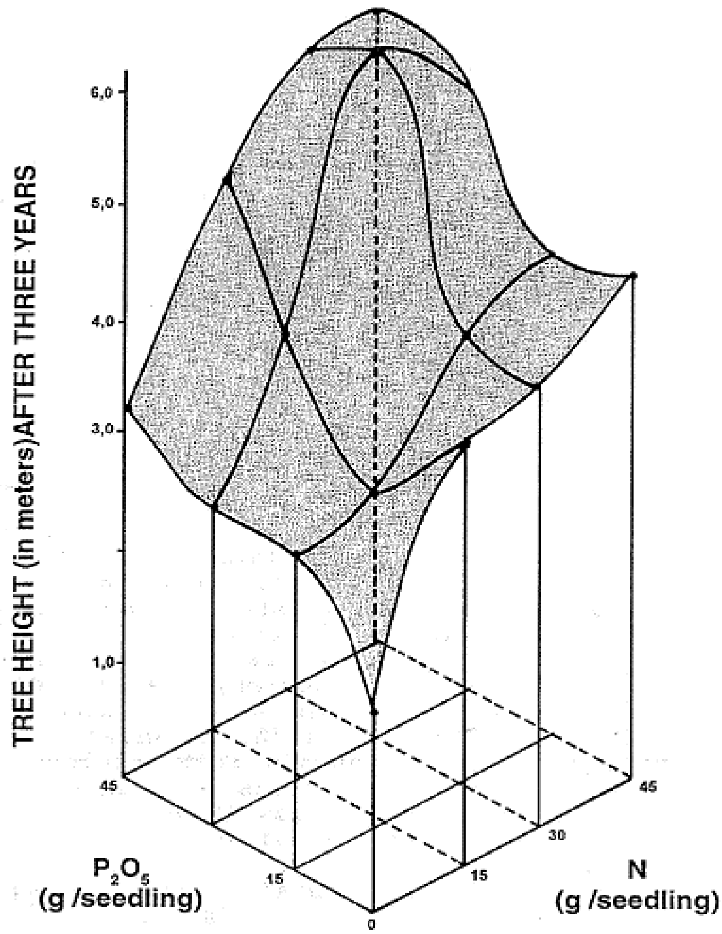

Figure 3. Response of *Acacia mangium* to different dosages of P_2O_5 and N in Bukidnon, Mindanao, Philippines. Results three years after planting (from Manubag *et al*, 1995).

Young trees on these soils could certainly use a little more available nitrogen. Even the nitrogen fixing species which have been tried have shown that the tiny amounts of N that can be fixed by symbiotic nitrogen-fixing bacteria present on these young seedlings is falling far short of the tree species ability to assimilate this element. This has been demonstrated very graphically by Manubag *et al.* 2002 (See Figure 3). Their results showed that by just applying 20 gm of P_2O_5 and 30 gm of N per seedling at the time of planting that there was a 4 x improvement in height growth. This corresponded to approximately a 49x improvement (yes a 4,900% improvement) in volume growth rates over control seedlings which had received no fertilizer.

The role of applying mulches and other nutrients can also be discussed. The bottom line is that there is some obvious merit to figuring out a substantially better fertilization recipe at planting time prior to establishing any new species trials as the current fertilization procedures are not permitting any of the tree species to exhibit much more than a fraction of their growth potential.

New Microbial Symbionts

One line of research that has led to big improvements in growth of some tropical crops when planted on acid soils has been in the arena of microbial symbionts. The three main types of symbionts that can be explored include the rhizobial bacteria (which associate with the leguminous species and are helpful for fixing nitrogen that is subsequently available for plant growth), the various genera of fungi that form ectomycorrhizae or endomycorrhizae (important to note: all tree species have at least one form of mycorrhizal fungi; a few have both) and the actinomycetes (which also have a capacity to fix nitrogen, and, importantly are symbiotic on the *Casuarina* species). The senior author has experience in experimentation with all three forms of symbionts but each line is a little complex in its own way. At this time, therefore, the recommendation is made to start with the first three lines of research (trying new species, improving seedling quality and improving soil fertility) and then perhaps tweaking the microbial symbionts.

Final Observations

It should be pointed out that in some reforestation trials, on soils that are not the badly disturbed it has been possible to get good to even excellent growth of *Swietenia macrophylla* and *Acacia auriculiformis* as demonstrated by Puis Liyagel in Yap and by Larry Mamus on Palau. However, on the most degraded soils in the uplands of these two countries the growth of planted trees has been very, very slow indeed. Small chlorotic leaves and very low leaf retention are other symptoms that these trees are way off-site.

During this visit it was possible to dedicate only about 20 hours to the subject of improving forest plantation growth on the fairly extensive acid soils of Yap and Palau. And, whereas there was excellent input from several foresters (Puis Ligeyel, Larry Mamus and J.B. Friday) and soil scientists (Bob Gavenda and Mohammad Golabi) that reinforced the concept that additional tree improvement activities in the areas of species selection and soil fertility could be useful, the senior author has no illusions that this chapter, in its current condition, is anywhere near a complete recipe for improving future forest plantations in these vast acidic, poorly-drained soils of these two islands nations. The recommendations made here are really just a few steps that seem to be obvious and straight-forward. And still lacking from this present list are suggestions on how to improve internal drainage of some of these soils and the most cost effective ways to increase soil organic matter.

The senior author would like to let it be known that he will be delighted to help design experimental studies which could be used to examine any of the suggested research areas presented in this chapter and would also be delighted if there was an opportunity to help install, measure, analyze or write up any of this research.

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Chapter VII

The Countervailing Impact of Typhoons, Coastal Wave Erosion, Butt Rots, Timber Harvest and Saltwater on CO_2 Sequestration in Some Micronesian Mangroves

By: Phil Cannon, Rich MacKenzie, Katie Friday, and Omekrael Sadang

Introduction

In the 1980s, there was a mounting realization that global climate change was really happening and that it would eventually lead to several adverse environmental impacts (Brown et al. 1996). In the 1990's quite a number of forestry projects were initiated first to determine how much carbon could be sequestered by planted trees and then to financially support the establishment of tree plantations (Moura Costa, 2001). One of the choice places for investors to initiate such CO_2 sequestering plantations was in the humid (1500-3000 mm of rainfall per year) lowland tropics because it was realized that, on a per hectare basis, such areas had the potential to capture carbon at rates that were 5 to 10 times faster than plantations in at higher latitudes or in areas of lower rainfall.

A naturally evolved nuance to the plantation scheme of capturing CO_2 was the realization that conserving already forested areas that were in jeopardy of being clear-cut might offset CO_2 emissions as much or even more than the establishment of plantations. Following this observation there was a push to evaluate natural forests around the planet to determine how much CO_2 was being sequestered by each of the different forest types. There were a few surprises, for example the grasslands of the more Nordic latitudes and high-altitude areas in the tropics have sequestered some amazingly high levels of CO_2 largely because the slow mineralization (decomposition) rates of soil organic matter under the cold conditions that persist much of the time in these regions. Never-the-less, the number one tropical forest ecosystem for holding sequestered CO_2 was determined to be the mangrove (Donato *et al,* 2011a). Reasons for mangroves being tops at sequestering include the following:

1) Temperatures are ideal for plant growth year round (air and soil temperatures in the 80s ^{o}F, or ~27-32 ^{o}C) most of the year);
2) They are wetlands and have hydric sediments that are constantly saturated in water and thus anaerobic. With so little oxygen the carbon in branches and roots below the waterline cannot be decomposed.

3) There is ample water available to the root system (indeed mangroves need to be inundated at least once a day (albeit with brackish water or seawater) in order to be called a mangrove;
4) There are almost no pathogens on the foliage and insect pests are rare (Gara and Cannon, 1995).
5) There are almost no pathogens or insects that attack the below-ground root systems of mangroves (probably because these organisms cannot tolerate the salinity that prevails in the rhizosphere).
6) Furthermore, there is only very retarded decomposition of litter falling to the floor of a mangrove forest, again the salinity and prevalence of saturated soils (low oxygen availability) are the two main factors which retard litter decomposition so there is a tendency for the floor of a mangrove forest to develop substantial depths of mangrove muck.
7) The root systems of the mangroves (which are highly varied but which generally consist of some form of raised roots with ventricles to help aerate the root system below ground) also help to trap the muck on the site;
8) And sea organisms (and especially crabs) are extremely effective at depositing fallen leaves at depths within the sea floor.

Over the past two years Richard MacKenzie has developed some very ambitious monitoring projects to determine just how much CO_2 is being sequestered in mangroves. His focus is on measuring just how fast this organic muck is being gained (accretion) or being lost (subsidence) (MacKenzie, pers. comm.) This ability of mangroves to accumulate and/or store massive amounts of belowground C is an important mechanism that allows the forest floor to rise at similar rates as sea level rise (SLR). The inability to keep up with SLR would be detrimental to mangroves, resulting in their permanent flooding, death of mangrove trees, and also make them unable to continue sequestering CO_2 from the atmosphere.

A fairly casual on-site review of the methodology that Rich MacKenzie is using to study above ground carbon sequestration and also to monitor the accumulations (or depletions) of mangrove muck in the mangroves of Micronesia was enough to convince the senior author that in general the methodology and sampling procedures being applied were rational and imaginative and would probably lead to precise, informative results.

Never-the-less, during this casual review, the author brought up a few items for consideration by Rich that may influence the interpretation of the data that he is collecting. Namely what would be the impact of an increase or decrease in salt content of the seawater entering mangroves, what would be the impact of typhoons, what is the impact of coastal wave erosion and what is the impact of butt rots. The case for each of these factors possibly influencing CO_2 sequestration in the mangroves of Micronesia will be discussed in continuation.

The influence of saltwater-

Mangroves exist (by definition) in areas where there is brackish water covering the root system of trees at least once a day. In order to extract water and nutrients under these circumstances, trees classified as mangroves have all evolved a number of very clever anatomical features and physiological mechanisms (Lighthouse Foundation, no date). One drawback is that all of these mechanisms end up costing the mangrove some ATP energy and limit the amount of water that a tree can absorb, translocate, use in photosynthesis and ultimately transpire. For example, the mangrove root system basically has to pump some oxygen down into the lower reaches of its root system to operate effectively. This costs energy and means that mangrove species cannot use water as easily as trees growing in upland soils where the soil water salinities are much lower and when those soils are at field capacity (water being held at 0.1 to 0.3 bars of tension in the soil matrix). This basically means that there are some limitations on the rates that water and nutrients can be supplied to a mangrove and this, in turn, hinders growth potential. In general it could be expected that these limitations would be more extreme where soil water was most saline or where the soil surface was underwater for the longest period of time. Rich MacKenzie has very clearly perceived this situation and the positioning of his mangrove growth plots along transects that run from near land (where there is generally less water and less salinity) to near the sea (where there is more water/higher salinity) would appear to be spot on for capturing this variability in CO_2 sequestering capacity due to variations in salinity.

The influence of typhoons-

There is a huge amount of variability in the strength of the wind hitting mangroves when this wind is produced by typhoons. Similarly there can be a huge variation in the power of the storm surge that might accompany a typhoon and the backwash that might follow those surges when the water is returning to sea level. Some of these forces are fairly predictable (and NOAA does good job of estimating these), but some require enormous amounts of very involved calculations and generally fall outside the service that can be provided by NOAA.

In terms of what can be predicted, it does seem that there will continue to be a couple of dozen typhoons somewhere near Micronesia every year for the foreseeable future and that these typhoons will continue to originate mainly in eastern Micronesia (Kosrae and Pohnpei) and tend to reach peak strength in Western Micronesia and the Marianas (Palau, Yap, Guam and Saipan). However, there is an enormous amount of variability in terms of the exact number of typhoons, the amount of strength these typhoons might have and the exact path they will take in their meander across the Pacific. Likewise, there is a huge amount of variability concerning when these typhoons will peak in strength, in terms of whether the full force of a typhoon will make a direct hit on a Micronesian Island, and whether there will be accompanying storm surge.

Throughout the typhoon season NOAA does an excellent job of monitoring most factors that will determine how a typhoon develops (largely using sea temperatures and pressure systems aloft). But even NOAA has a very difficult time predicting the exact track of typhoons and, as a consequence, their ability to predict the amount of damage a given typhoon will cause is limited for any exact location. The forces of destruction generated by a typhoon consist of strong winds (and here objects on the windward sided of islands/forest stands/ buildings etc. are generally subjected to the greatest wind forces), storm surges (generally below 3 meters of elevation and again on the windward and seaward side of the typhoon) and funneling effects which basically result in enhanced amplitude of the storm surge as a result of pushing the storm surge upward as the seafloor goes from deep to shallow when approaching a coastline or from forcing the storm surge to bunch together as the storm surge pushes into a bay. Objects that are positioned with their widest surfaces at perfect right angles to the to the advancing wind or storm surge (note: and these directions are a little different than the direction of the direction of the advancing eye of the typhoon) will be subject to the greatest force…..and objects that receive these forces at an angle that is less than a right angle, or that are buffered from these forces (e.g., by more seaward stands of mangroves) will receive proportionately less force. Bigger objects will receive more force than smaller objects. Furthermore, objects that are flexible can dissipate forces better than objects of the same size that are not flexible and objects that have toughness (e.g., healthy trees) have better resistance than trees that have less toughness (e.g., trees with butt rot).

Because of their location, between sea and shore, mangroves are exceptionally vulnerable to the forces of typhoons. Many of the effects of a typhoon in a mangrove can be almost immediate; there is a certainly a lot of damage to a forest right when the wind and the storm surge hit. Many trees are killed immediately, and others will be pushed over and become less well anchored. If completely unanchored, some of these trees can be washed away. Obviously, a fair amount of carbon can be lost when these things happen and that amount of carbon could be fairly accurately measured by simply measuring the change in the above and below ground tree volume at the affected site, but there are, potentially, some other carbon losses that also take place in the event of a typhoon.

Some of the organic muck that had accumulated in the mangrove could be washed away at the time of the surge. And more of the organic muck could be washed away after the mangroves and their entrapping root systems had disappeared. Indeed, Francis Ruegorong and Margie Falanruw both expressed amazement at the amount of muck that had disappeared from the site at Yinuf Mn (where the mangrove had been destroyed 8 years earlier) over just the last three years. They said that three years earlier, when they had tried to explore this same site, they were sinking in up to their knees and hips in the residual mangrove muck. However, at the time of this present visit perhaps 90 % of the affected area had coral rubble rather than organic muck as a sea floor. In other words the mangrove muck had been largely washed away.

The carbon sequestration situation post typhoon damage is expected to be a very dynamic situation. At the time of this visit to Yinuf Mn Island (8 years after Typhoon Sudal) the area was still losing a few thousand large malingering mangrove trees and so both the carbon that they held in their boles and the muck that was held by their root systems was continuing to be lost as well.

On the other hand, it was also obvious that in some parts of this decimated area a few hundred new *Rhizophora* mangrove seedlings had been able to get established and in some cases small groves of these new mangroves were also forming. It would appear to be only a matter of time (perhaps 20-30 years) before this typhoon-affected area will again be covered with dense, large mangroves. And these, perhaps, might even be healthier (less butt rot, anyway) than trees in the preceding stand that had occupied this site.

Thus, from this perspective, it is almost as if a reset button has been pushed for carbon sequestration. In this respect, mangroves affected by a powerful typhoon have many similarities to upland forests affected by stand- replacing wildfires.

Influence of Butt Rots

In Micronesia, a butt rot caused by *Phellinus* spp. is the only fungus that was found with much regularity in the mangroves. This fungus preferentially colonizes the inner heartwood of species of mangroves and causes a brown cubicle heart rot. This means that the fungus is consuming both lignin and cellulose. As a consequence, trees with butt rot caused by this fungus loose a great deal of strength in the central portion of their bowls. Two other observations were made. Some species of mangroves appear to be much more vulnerable to degradation by this *Phellinus* and older (larger) trees of any given species are invariably more vulnerable to this fungus than younger ones of the same tree species.
The simplest way of knowing that a tree has been colonized by a *Phellinus* butt rot species is by noticing if there are conks. Very roughly, a volume inside the tree of about 0.2 cubic meters can be assumed to have been decayed for each conk that is present (note: this relationship could be refined by doing some simple studies). Thus a tree with five conks on it could be assumed to have about 1.0 cubic meters of decayed heartwood. Of course, using conks as the sole basis for estimating the decayed volume in trees is likely to give an underestimate of the amount of decay in a tree; some trees could be infected by a fungus but at volumes insufficient to support a conk and in other cases trees may be infected but their conks (which usually adhere pretty well) may have fallen off.

The impact of Typhoons and Butt Rots in Combination-

In terms of the influence that butt rots have on carbon sequestration, there is, of course some carbon that is lost as a result of the decay (roughly 0.25 tons of carbon for every cubic meter decayed) but by far the greatest loss in terms of carbon is that butt rots weaken the structure of trees and cause them to lose their structural integrity. An extreme case is where Typhoon Sudal hit the Yinuf Mn Island and basically leveled about 100 hectares of mature forest. Examination of the boles of all of these trees indicated that these trees were older and that there was already a lot of brown cubical rot when the typhoon hit which would have made them much less able to resist the force of the wind and the sea surge. In this extreme case, therefore, the effect of a typhoon could be considered like a reset button, simply causing most of the mangrove’s carbon to disappear from the site.

The chances of a mangrove getting a fairly direct hit by a typhoon are fairly rare. However, the possibility of a typhoon coming somewhat close to any given mangrove, especially on Yap and Palau, is much more likely. Such was the case of Typhoon Bopha which passed to the south of Palau by about 180 km. This generated enough wind on Palau to enough to knock out a few tops of trees that were already affected by butt rot, and to cause large limbs with heart rot to fail, but no completely blown over trees were seen. In a “passing blow” case like this, the impact of a typhoon is more like a setback in the accumulation of carbon rather than a complete reset. Also, as mentioned before, the strong winds generated from typhoons can also cause significant stem and limb breakage and this can greatly increase the numbers of courts of infection for the butt-rotting fungi.

Impact of Coastal Erosion of Mangroves-

Some mangrove species and some other salt tolerant species such as *Barringtonia spp., Tebebuia* spp. and coconut palms have historically occupied the strand of shoreline immediately adjacent to the reef where the temporary geological features called reef berms have been set up. These reef berms formed during an earlier powerful typhoon that left a ridge of reef rubble in a neat row some 100 to 200 meters outside the usual coastline and 100 to 200 meters inside the reefs edge. In this visit to FSM several of these strand forests were in the process of being undercut by wave action during high tide. In some places over 50% of the trees in the strand had fallen recently or were in the process of falling. Losing trees in this way obviously reduces that amount of carbon that is being stored in these strand forests. Strand trees that have butt rot were even more likely to be affected by losses of carbon as large limbs tended to break off much more easily when they had been hallowed out by heart-rot.

Conclusions

There are no final conclusions for this section because there was not enough time to make a full study of all of the mangrove forests in all of Micronesia or to figure out all of the area in these mangroves that was being affected by typhoons, butt rots and coastal strand erosion. Never-the-less, it should be apparent that where they are occurring these phenomena are having a major impact on the amount of carbon being held in these mangroves and that any attempt to calculate the amount of carbon being sequestered by these forests should be taking these phenomena into account as well as monitoring the growth rates of the trees and the mangrove muck accumulation rates.

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Chapter VIII

Micronesia Needs Help With Hazard Trees

By: Phil Cannon, Kevin Eckert, Robert L. Schlub, Pete Angwin, Anand Persad, and Bal Rao

Introduction

Trees can be very beautiful and they can provide a huge number of services that enrich the lives of humans and indeed most life on planet earth. Never-the-less, during this trip a fairly large number of hazard tree accidents were brought to the attention of the senior author. Crushing of private property (cars, houses) and damage to utility systems (telecommunications/electrical power lines) were the most common incidents reported. This present piece will introduce the rationale for developing some hazard tree guidelines for some of the islands of the Pacific so that these unfortunate hazard tree accidents can be reduced in both their incidence and impact.

Tree Growth on the Pacific Islands-

When it comes to tree growth on the islands, there are three things that have a bearing on the incidence of hazard trees: 1) because of ideal growing climate (plenty of rainfall and warm temperatures) trees grow very fast and become huge, quickly; 2) many tropical tree species have low density and do not have an high levels of extractives in their heartwood; these features make these trees vulnerable to limb and bole breakage and internal decay, respectively; and 3) there has not been much training on techniques for avoiding the creation of hazard trees.

A Super-brief History of Dealing with Hazard Trees-

The senior author has not pursued this particular topic to any great depth; rather, he has just made a few observations and discussed this hazard tree situation briefly with the co-authors listed above. Certainly much additional information could be gathered as a result of additional assessments. One of the things that is commonly observed in much of Micronesia is that many urban trees are hacked off somewhere between 20 to 30 feet in height. This is done, apparently, in acknowledgement that if trees get much bigger in height they will become especially dangerous to live near or operate beneath. Although the logic behind these top prunings makes some sense, not all trees get pruned and, in many cases, the way these topping cuts are done leaves trees especially exposed to infection by heart rot fungi.

Recognizing the need for better tree care, a few tree courses have been offered to foresters and landscapers in the Pacific region. They courses include the following:

Kevin Eckert, with support from State and Private Forestry, organized and taught the first two-week International Society of Arborists Course for 25 foresters from across the Pacific.

Kevin Eckert, with support from State and Private Forestry, organized and taught a second two-week International Society of Arborists Course for 25 foresters in Micronesia.

Bob Schlub, with support and participation from Davey Tree Company, organized a tree care workshop for arborists in Guam.

Kevin Eckert, again with support from State and Private Forestry USDA Forest Service, organized a third two-week International Society of Arborists Course for 25 foresters in Micronesia.

In all of the courses taught by Kevin Eckert or organized by Bob Schlub, maintenance of tree form to avoid development of hazard trees is a part of the curriculum.

Also, Pohnpei has just completed a huge project to remove hazard trees from the entire length of their trans- island telecommunication lines (See Figure 1). Never-the-less, in spite of efforts to date, the truth is that there are still a lot of hazard trees in Micronesia that probably should be dealt with and there may be additional opportunities for spreading the word on how to recognize and deal with hazard trees.

Figure 1. In Pohnpei, tired of repeatedly having to go out and having to fix the main trans-island power line when it had been knocked down by falling trees during storms, the government finally ordered a wide swath of trees to be felled to avoid a recurrence of this problem (Photo Ned Klopfenstein).

One of the features that was missing when providing arborist training in the Pacific was a good, customized reference on how to recognize hazard trees and how to deal with them. In 2011, a workshop was organized on how to take care of trees, and especially *Casuarina equisetifolia* in Guam. A set of papers had been compiled by Schlub *et al*. (2011) in preparation for this workshop. Twelve pages in this compilation (pp 44-53) do a good job of outlining, in general, of explaining how to do a hazard tree analysis and there are also some sections on how to mitigate certain hazard tree problems, but many of the problems that are mentioned in this text, and means of mitigating them, were developed with a North American reference point and with North American trees being used as examples.

The reasons for not just adapting hazard tree guidelines developed for North America is that there are some substantial differences in the way trees grow in the Pacific Islands. In the wet tropics trees grow exceptionally fast, may produce very brash wood and are especially vulnerable to decay because many tropical tree species produce little or no latewood (which gives trees added strength) have very little heartwood (which makes them decay resistant). There are also some extraordinary forces that trees may have to contend with in the Pacific, the most obvious, of course are the extremely powerful winds associated with typhoons. There are also some root rots (such as *Phellinus noxius*) which can destroy the structure of a tree in very short order and make it quickly prone to becoming a hazard tree.

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Chapter IX

Advances in Cultivating an Awareness of a Need to Protect Trees from Physical Harm

By: Phil Cannon, Robert L. Schlub, Sheeka Tareyama, and Belmina Soliva

Overview: This appendix is extremely brief. On a 2010 trip to Guam it had been noticed that many trees were being damaged because some of the local populace was taking a very casual attitude towards these trees perhaps because they were unaware of how trees function. Specifically, a lot of boles of trees were being banged up by weed eaters, vehicles, machetes, wildfires and campfires. Also, a less common but still obvious problem was that root systems were not being given sufficient consideration; sometimes excessive soil fill was being piled around the base of the trees or there was excavation or soil compaction in the rooting zone.

Since this last visit, several activities have taken place or are being initiated towards correcting these problems. Bob Schlub, in collaboration with Anand Persad and Bal Rao of Davey Tree Company organized a Tree Care Workshop for Guam. They began by compiling a book on "Plant health care for ironwood, *Casuarina equisetifolia*" (Schlub *et al*. 2011) and then presented this during a workshop held in Guam. This is an excellent reference on the general nature of good tree care, but is does not completely satisfy the needs for information on how to take care of trees in Guam. For one thing, it does not explore a strategy on how to get the mainstream Guam population motivated to the point where it is anxious to protect the trees of Guam from physical abuse and wildfire.

New Developments

Fortunately, two new developments are now taking place on Guam by two very dynamic young women that hopefully will help turn the table on this problem:

Belmina Soliva, of the Guam Forestry Department, has just started a program that is focusing on educating school-age kids on the importance of avoiding wildfires. Any degree of success that she has in this pursuit will be important. Guam, at present has an extremely casual attitude towards fire and, indeed, in some locations, such as parts of southern Guam, setting fires, which later become wildfires, is almost a tradition. In some cases, the setting of these fires is excused by hunters as something that is necessary to promote the regeneration of grasses needed for foraging by wild-game species. In some cases, the kids setting these wildfires are just trying to raise a little hell.

Sheeka Tareyama, at the University of Guam, has just started a similar program working with young people to educate them on the problems that physical damage to cambial tissue can cause in the health of trees. She is a part of Bob Schlub's plant pathology team and so has access to all of the information about the pathogens that get courts of entry into a tree when the protective features of a tree (bark, callus tissue etc.) are abused unwittingly by a public that is careless with its trees.

It was very nice to be able to introduce these two young women to each other during this visit. Hopefully they can work together to reach many young Guamanian kids and hopefully they can also tap into (and perhaps simplify, as appropriate) a number of lessons that Kevin Eckert has developed over the years, as well.

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Chapter X

Next Logical Steps in Forest Pathology Activities for Guam, Saipan, Yap, Palau, Pohnpei, and Kosrae

By: Phil G. Cannon, Francis Ruegorong, Puis Liegel, Victor Guerrero, Robert L. Schlub, Leonard Sigrah, Maxon Nithan, Blair Charley, Sara M. Ashiglar, Ned B. Klopfenstein, Mee-Sook Kim, Bob Gavenda, Katie Friday, Erick Waguk, Yuko Ota, Norio Sahashi, Gibson Santos, Rodasio Samuel.

As a result of the forest pathology trip that occurred during September of 2013, advances were made on several important fronts, and future activities were also identified as critical for addressing threats to forest health in Micronesia. The purpose of this chapter is to list and briefly describe each of these activities.

Activities to be performed by the local forestry staff

The first forest pathology activity that should occur on each of the islands of Micronesia, except for Guam, is to develop better information on the distribution and damage caused by *Phellinus noxius*. Several foresters on each of the islands indicated their willingness to participate in the development of this information, and suggested activities that address how this development could proceed are as follows:

1) Adapt the "*Phellinus noxius* poster" (Chapter IV; Fig. 7) to improve its effectiveness on each particular island. For instance, if one is working in Yap, one could produce this poster in Yapese.
2) Assign a local forester (or team of foresters) to be responsible for distributing, generating, and recording *P. noxius* information for every village on the island.
3) Distribute locally adapted "*Phellinus noxius* posters" to all of the villages on each island, and provide contact information for the responsible local forester or other professional, who should be contacted if anyone knows of a tree that is potentially infected with *P*. *noxius*.
4) Encourage the local forester/professional to visit each of the reported locations to confirm the presence (or absence) of *P. noxius*.
5) Ensure that the geographic coordinates of *P. noxius* infection centers are determined using GPS and that this information is recorded.
6) The *P. noxius*-affected trees within each infection center should be mapped. For example, gridded paper could be used, the distance between grid lines could represent 2 m or another appropriate distance.

7) Record the species and diameter of each tree that has been affected, and further note whether the tree is still alive, dead, or already fallen.

Activities planned by Phil Cannon, Regional Forest Pathologist

1) Compile a list of all the tree species known to be susceptible or resistant to *P. noxius* (started)
2) Contribute to the development of a locally adapted "*P. noxius* poster" for each island or island nation, as needed (initial example provided in Chapter IV; Fig. 7)
3) Devise a test for determining whether a tree species is susceptible or resistant to *P. noxius* (completed)
4) Develop and continuously update maps that denote all known infection foci of *P. noxius* in Micronesia (started)
5) Compile a compendium of all known treatments that have been used to control *P. noxius*, and conduct preliminary evaluations to help determine which of these treatments merit further testing in Micronesia (started)
6) Deliver a presentation on *P. noxius* to the Pacific Island Commission (recent opportunity was missed)

Activities to be performed by the Regional Pathologist and local forestry staffs

1) Record and map the known locations of *P. noxius*
2) Test potential control measures for efficacy
3) Hold *P. noxius* workshops on each island
4) Help arrange and participate in an international butt-rot workshop
5) Seek supplemental funding if any of the activities listed above cost more than the available funding.

Other forest (and plant) health activities

1) Establish a liaison to coordinate among the groups (e.g., USA and Japan) conducting molecular genetic studies on *P. noxius* (collected from Micronesia and other regions) and other butt-rot fungi. Molecular genetic approaches can be applied to identify species, evaluate genetic diversity, and determine potential pathways of spread, etc. Two specific molecular genetics activities seem likely to occur in the near future:

a. The USDA Forest Service-Rocky Mountain Research Station will conduct the DNA extractions for ~ 50 *P*. *noxius* isolates that were collected in Yap, Palau, Guam, Saipan, Pohnpei, and Kosrae. PCR and DNA sequencing (e.g., ITS1-5.8S-ITS2, LSU, rpb2 or *tef-1α*) will help confirm identification of fungal species, and phylogenetic analyses will examine evolutionary relationships among the isolates.

b. Mee-Sook Kim (Kookmin University) and Jane Stewart (Colorado State University) plan to develop genetic markers for examining genetic diversity, gene flow, and other population genetic parameters for the *P. noxius* isolates. The potential for genomic sequencing will also be considered, although multiple efforts focused on Asian isolates are reportedly already underway.

2) Arrange for an international workshop on butt rot fungi and their management. Hopefully, part of this workshop can be conducted in Malaysia or Indonesia, where there is a history of managing *P. noxius*.

3) Complete the metagenomic study based on mangrove soils. The soil samples that were collected from the surface soils in the healthy and unhealthy mangrove tree plots for the purposes of doing soil metagenomic analyses arrived in Moscow, Idaho and are currently in a freezer. Metagenomic analyses can proceed if supporting funding is obtained. The basic steps in the analysis are as follows: DNA will be isolated from replicate sediment cores from healthy and declining mangroves, and DNA will be analyzed via amplicon sequencing targeting bacteria and manglicolous fungi via the Illumina MiSeq system (using 2 x 300-bp, paired-end processing). Sequences will be associated with specific sediment samples via barcodes and will be grouped into discrete taxa based on comparison to reference databases. Community composition and diversity will be related to environmental metrics and ultimately mangrove health.

4) Continue surveys of Myrtaceae to monitor for the potential occurrence of the myrtle rust caused by *Puccinia psidii*.

5) Locate appropriate contacts for information that will lead to better control of some additional plant health problems, including the stinky corm problem in taro, anthracnose disease of betel

(*Piper betel*), the white fly problem on Kosrae, and the emerging termite (*Neotermes rainbowii*) problem on Kosrae. Each of these is described in Chapter XI.

Chapter XI

Other Plant Protection Opportunities in Micronesia

By: Phil Cannon, Andrew Yinfel, Roland Quitugua, Francis Ruegorong, George Wall, Robert L. Schlub, Maxson Nithan, Blair Charley, and Aubrey Moore

Because there is a limited amount of plant protection services available on some of the islands the author leant an ear when plant health problems were mentioned and tried to collect some relevant information whenever someone wanted to discuss these problems. Four plant protection problems were shared.

1) The stinky corm problem of taro on Yap
2) The betel piper leaf spot on Yap
3) The rampant white fly infestation in Kosrae
4) The new termite problem of coconut palms on Kosrae

Each of these will be discussed in turn.

The stinky corm problem of Taro on Yap.

Andrew dug up some corms of taro in the field directly behind the Forestry Department Headquarters in Yap. The overall appearance of the aerial parts of these plants was that they were a bit chlorotic but otherwise were more or less normal. However, when the corm of these taro plants were cut in half, an evil stench emanated and the cut area quickly filled with a stinky clear liquid.

Some research has been done on taro disease by George Wall out of the University of Guam. One of the most likely possibilities is that the nematode *Radopholus similis* is involved. This nematode and the disease it causes have been well documented by Murukesan *et al.* (2005) who studied this disease fairly exhaustively in Yap. They had the following to say about the disease.

"The rot caused by the nematodes is wet with a loose mass of brown dead tissues and a deep brown necrotic center housing nematodes inside. Usually, the infected tissues spread a disgusting odor typical of this disease. The dead tissues progress into shallow to deep cavities that advance towards the edible, central portion of the corm giving a perforated appearance on the outside of the otherwise smooth corm. The disease becomes more severe as the age of the plant increases. Nematode-infected plants seldom show any above-ground symptoms. The market quality of the corm is greatly reduced by the nematode damage. The widespread occurrence of the disease and the type of damage *R. similis* causes to the corms pose a serious threat to giant swamp taro production, food security and the continuation of traditional customs on those islands where *R. similis* occurs".

These authors go on to hypothesize that planting nematode-free cormlets could prevent the spread of the disease. Considering the enormous importance of taro in the diet in Yap it is recommended that the identification of the causal agent of this disease be carefully verified.

Betel Piper leaf spot.

Francis Ruegorong showed the senior author the leaf spot that is affecting much of the betel piper in the northern coast of Maap (Yap's main northern island). As far as the senior author could determine, these symptoms are identical to those caused by the fungus *Colletotrichum capsici*. Samples were collected on this trip and have been submitted for confirmation. A cursory review of the literature indicates that Bordeaux mixture and ziram and carbendazim can all be used as prophylactic fungicides to protect the betel piper vine. Additionally experiments showed that a wider spacing between betel piper vines lowered the number of infections on leaves because it lowered the humidity between betel plants.

The betel in Yap is not currently planted at especially tight spacings, however, at least in the areas reviewed during this visit it was usually planted in the forest understory. Perhaps by reducing the overstory above the Yapese betel piper plantings their leaves will have less humid ambient air and, as a result, then get less of this Colletotrichum leaf spot build up. The importance of climate in fostering conditions conducive for this disease was confirmed in studies by Goswami *et al*. 2002. These same authors found that there was a phenomenal amount of variation in the susceptibility of different varieties of betel piper to this disease, so changing betel planting stock for a more resistant variety provides another possibility for fixing this problem.

The rampant white fly infestation in Kosrae.

In these days, as soon as one descends from the plane into Kosrae one is immediately impressed with the huge number of white flies that are flitting about seemingly everywhere. This is something that is relatively new on Kosrae (it was definitely not evident three years ago when the senior author was last on Kosrae) and there are still many areas away from the airport where the white fly is still not common. It appears that this white fly, recently identified as *Aleurotrachelus trachoides* can do some damage to at least some plant species. The most heavily affected appears to be the mikania, an invasive vine. At one location (across the street from the gas station near the Nautilus Hotel) an entire mountainside of this vine has been heavily defoliated. Aubrey Moore at the University of Guam, is working with forestry staff in Kosrae to learn much more about this White Fly infestation in this country. (Note: since writing this report there has been news from Aubrey Moore, Gillian Watson and others that a biological control of this white fly has been found and will probably adequately control this white fly outbreak in Kosrae in future years. This information is being carefully developed and/or followed by Jackson Jack, Aubrey Moore, Gillian Watson, Sheri Smith and Katie Friday).

The new termite problem of coconut palms on Kosrae.

At one spot, about half way between the airport and Utwe, Blair Charley and Maxson Nithan stopped the car so we could look at about 7 coconut palm trees which had become thoroughly infested with a new termite problem caused by *Neotermes rainbowii*. The impact of this termite on these few trees is incredible and one tree which we partially broke open produced as heavy a termite swarm as I have ever seen. Again, Aubrey Moore is studying this situation. He considers this a potentially very dangerous problem for Micronesia especially as coconuts, on these islands, are often considered the "tree of life". Several publications are out on this insect (Lever, 1969; Pestnet).

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