Okinawa Trip Report and Study Plan
December 30, 2002

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Introduction

In the early 1970's pine wilt disease was introduced to Okinawa from mainland Japan, and it is now a well-established pest of Ryukyu pine throughout Okinawa. On March 18 1982, Colonel Ernest D. Strait, Tyndall Air Force Base asked R. Max Peterson, Chief, U.S.D.A. Forest Service (USFS) for technical assistance. As a result, John W. Dale and Jerry W. Riffle spent a week studying the disease at Kadena Munitions area, which has a large stand of Ryukyu pine. Their trip report with recommendations (April 1982) is on file with U.S. Department of Defense (DoD) agencies in Okinawa and with USFS State and Private Forestry, Forest Health Protection, NE Area.

At the invitation of the U.S. Marine Corps I visited Okinawa in December 2002 to evaluate the current status and management of pine wilt disease. DoD installations on Okinawa have been treating Ryukyu pine for pine wilt disease as specified by the Okinawa Prefectural Government (OPG) but the incidence and severity of the disease has not abated. I discussed the problem with representatives from the branches of U.S. Forces Japan, OPG Department of Agriculture in Naha, OPG Fruit Fly and Melon Fly Eradication Office, OPG Experiment Station in Nago, University of the Ryukyus, and Keio University.

The primary purpose of this report is to discuss management alternatives for pine wilt disease on Okinawa. A brief review of pine wilt disease biology is given here. Those wishing more detail are referred to the 1982 trip report and to a publication by Dr. Yoichi Kishi titled "The Pine Wood Nematode and the Japanese Pine Sawyer" (1995). This book is the most recent, detailed and comprehensive text on pine wilt disease in Japan. Dr. Kishi is currently a professor at Tokyo University of Agriculture and Technology.

Biology of pine wilt disease

Japanese pine sawyer beetles vector the pine wood nematode. On Okinawa in April and May, the newly-emerged sawyer beetles have a dispersal flight that is usually completed within 7 days. Flight distance may exceed 3 km for males, and may exceed 2 km for females (Enda 1985). Following the dispersal period, sawyers feed on pine twigs for maturation. Duration of maturation feeding is 20-30 days. Females are attracted to weakened, dying, and freshly cut pines for oviposition. Females use mandibles to excavate conical depressions, and insert ovipositors through the scars to deposit eggs into the phloem. Eggs hatch in 7 days, and larvae enter the sapwood in August. Larvae overwinter in the 4^{th} instar, and pupate in March or April.

Nematodes, attracted by volatile pine compounds during maturation feeding of the sawyer, move out of sawyer spiracles and enter feeding scars on the twigs, then invade the tree. If the tree is susceptible, nematode populations build rapidly and the tree begins to fade in late summer. Nematodes cluster around sawyer pupae and invade sawyer spiracles when sawyers emerge from pupal cells in April or May as adults.

Tree death occurs when nematode infestations cause a water deficit due to tracheid cavitations. This occurs in the summer when trees are experiencing water stress from normal weather conditions.

There are some differences between pine wilt disease biology on Okinawa vs mainland Japan:

a. On the mainland, Japanese black pine and Japanese red pine are the most susceptible species. On Okinawa, Ryukyu is the most common pine species and is the species most susceptible to pine wilt disease.

b. Adult emergence of the Japanese pine sawyer is earlier on Okinawa than on the mainland, and as a result the subsequent life stages also occur earlier in the year.

Management Alternatives

In the following section I have attempted to objectively discuss several alternatives for management of pine wilt disease on Okinawa. I have not factored in political considerations or the expense of any particular approach. It is up to the reader to insert politics and expenses.

Cut-and-burn

In 1974, OPG conducted a survey to identify infected pines in the Kadena Munitions storage area. Based upon this survey, OPG recommended a program of cutting and burning infected trees, and spraying foliage and branches of healthy pines with an insecticide during the emergence / maturation stage of the sawyer. Since that time, DoD installations on Okinawa have conducted cut-and-burn operations. Cut-and-burn operations off-base on OPG and private lands have also been conducted.

The cut-and-burn approach is an attempt to eradicate pine wilt disease. In 2002, OPG developed a modified eradication strategy that involves the creation of four buffer zones on Okinawa. Each buffer is projected to be 2 km wide, extending across a section of Okinawa from beach to beach. The first buffer is to be established on a narrow segment of land north of Kadena Munitions. Within each buffer, all Ryukyu pine are to be cut except occasional high-value pines, which will receive systemic insecticides. In phase one, cut-and-burn is to be applied aggressively to pines south of buffer #1. There is a five year plan to establish the buffer zones.

Pine wilt disease is established throughout Okinawa, having been present for about 30 years. Pine wilt disease is found in isolated Ryukyu pines in the southern, highly developed part of Okinawa and in the northern jungles. Some of the infected trees are in locations with very difficult access. Professor Norikazu Kameyama, University of the Ryukyus, said that in the northern, more remote part of Okinawa, natural forest succession is from pine to deciduous trees, and that succession would be considered an acceptable part of the overall OPG eradication program.

Experience in North America has shown that the best chance for eradication of an exotic organism is within the first or second year of its discovery e.g. Asian gypsy moth. After an exotic organism has had many years to become established, eradication is usually no longer feasible e.g. European gypsy moth. The addition of buffer zones, in my opinion, does not significantly change the efficacy of a cut-and-burn approach. Sawyer beetles can fly more than 2 km, and wood infected with sawyers and nematodes could be unknowingly transported across the buffer zone. Insects also commonly "hitchhike" by resting on, under, or in vehicles. And perhaps most important, some of the infected Ryukyu pines outside of the buffer zones will be missed in surveys.

<u>Insecticide applications</u>

Insecticides have previously been sprayed on Ryukyu pines in an attempt to kill adult sawyers during maturation feeding. Objections to spray projects are common for several reasons:

◊ Most insecticides are not specific to the target organism.

◊ Aerial applications result in spray drift; ground applications expose the applicator to higher levels of exposure.

◊ Applications must cover large areas during a short period of time.

◊ Insecticide projects in forestry have the best chance of succeeding during the first year or two of discovering an exotic organism. After that, the chance of eradication drops precipitously.

◊ No matter how benign the compound may be, it's still an introduction of a toxic compound into the environment.

◊ Depending upon the compound, repeated applications may result in genetic resistance in the target organism.

◊ More than one application may be necessary if weather reduces or removes the insecticide from pine foliage and branches.

◊ Timing of the application has to be accurately determined in order to be effective.

◊ Pine wilt disease has a nematode and a vector. Presence of a vector complicates any eradication program. In pine wilt disease, killing sawyers does not kill nematodes residing in pines, some of which may appear to be healthy at the time of inspection.

Biocontrol

Hideki Irei, OPG Forest Experiment Station, Nago, has identified four native insects that prey upon adult and immature stages of the sawyer. Three of the four are Elaterids, commonly called click beetles. Presumably, other native insects also attack sawyers. It would be unusual but fortuitous if native insects controlled pine wilt disease. I suspect that the 30 years that have elapsed since the introduction of this disease have provided ample opportunity for exposure to all of the habitats in which Ryukyu pine grows, and presumably a subsequent exposure to all potential native biocontrol agents.

The possibility of introducing exotic insects to control pine wilt disease exists, but as Mr. Irei is well aware, the potential risks are high. Introductions could simply bring new problems, if exotic insects attacked non-target species. Few examples exist of successful biological control of forest insects. The larch casebearer in North America was brought under control in the 1970's by introduced parasitoids from Europe. There appear to be no negative consequences of these introductions. But even in this example, many species of parasitoids were introduced, and only two species were truly effective. The ineffective species are now also established in North American forests and the consequences of these introductions are not known.

I certainly encourage Mr. Irei to continue studying the potential for biocontrol of pine wilt disease, perhaps by visiting countries where the disease is established but not particularly damaging.

Genetic resistance

Yasuko Nakahira, OPG Forest Experiment Station, Nago, is studying genetic resistance of Ryukyu pine to pine wilt disease. Initial results are quite encouraging: of 400 seedlings inoculated with nematodes, 160 survived. This is an encouraging number of survivors, and I hope Ms. Nakahira continues to test for resistance. Genetic resistance to pine wilt disease in Japanese black pine has also been demonstrated (Toda and Kurinbu 2001).

Ultimately, genetic resistance to pine wilt disease offers few negatives. The drawbacks are those inherent to any program of genetic resistance – it takes a long time to replace the host species in the wild, it is usually not desirable to replace all susceptible host families, and the nematode might adapt to the resistant gene(s) over time.

A “do nothing” alternative, which I have not included in this report, is essentially a test of natural genetic resistance.

Pheromone-based control

I regret not having asked anyone in OPG whether sawyer pheromones have been used in trials. Pheromone strategies have been quite successful in reducing the impact of many species of insects in forests and agriculture.

Mass trapping

Sawyer beetles are attracted to freshly cut pines, so perhaps this approach could be used in conjunction with other strategies.

Forest management

Most established forest pests are best managed not by attempting to eradicate the insect or pathogen, but by growing appropriate tree species in densities suited for the site. Forest management of an insect or disease involves developing and applying a hazard rating system. Several examples from North America are listed in order to clarify this alternative:

White pine blister rust – the introduction of this disease from Europe devastated five-needle pines over much of North America. Western white pine is now managed by a combination of site hazard rating system, planting disease-resistant seedlings, and pruning lower branches of saplings. Disease-resistant western white pine is not planted on high-hazard sites, and where it is planted, the lower branches, which are most likely to become infected, can be pruned to reduce the potential for infection.

Western spruce budworm – high-hazard forests are those in which there is vertical and horizontal continuity of fir foliage, and where the percentage of basal area occupied by fir is high. Thinning these forests and favoring non-host conifers greatly reduces the hazard of defoliation by this native insect.

Douglas-fir beetles – high hazard forests have the following characteristics: Hazard increases as average tree diameter at breast height (dbh) exceeds 14 inches. Hazard increases as tree ages exceed 90 years, however, dbh is a better predictive variable than age, especially later in an outbreak when smaller trees are being attacked. Hazard increases significantly as the proportion of Douglas-fir in a stand exceeds 50%, and as the stand basal area exceeds 150 square feet per acre. Hazard correlates with plant association, a reflection of the biophysical environment. As stand density increases, so does the proportion of successfully attacked smaller trees. The relative abundance of beetles on-site prior to tree blowdown, and adjacent to the site at the time of blowdown, influences the course of the outbreak because beetles may fly from several miles to respond to the latest disturbance. Blowdown or fire in a watershed with extensive root disease will probably result in a larger bark beetle outbreak than in a healthier watershed. Beetle success depends upon the susceptibility of the attacked trees and upon the diameter (larger trees = more phloem; less larval competition for a constant number of attacking adults). As few as 3 to 5 downed Douglas-fir per acre in excess of 10" DBH may be sufficient to start an outbreak of this native insect.

Study Proposal

Available soil moisture is significant in survival of Japanese black pine and Japanese red pine exposed to pine wilt disease on mainland Japan (Kishi 1999, Miki and others 2001). Based upon this and other literature, it is logical to hypothesize that variables affecting available soil moisture influence susceptibility of Ryukyu pine to pine wilt disease.

Two potential studies are described here. This is not an attempt to replace existing management strategies on Okinawa for pine wilt disease. As with most forest insect or disease infestations, the optimal approach is to use a spectrum of tools synergistically. The more tools that are tested and available, the better the chance for minimizing damage. The following two study proposals do not preclude the use of the cut-and-burn approach in the study plots. A forest management approach for pine wilt disease is complicated by the fact that Ryukyu pine forests have had little time to ecologically adapt to the disease. And as with many forest pests, unusually hot and dry weather could temporarily override the forest management approach.

<u>Development of a hazard rating system (no-treatment approach)</u>

Plots would be established prior to sawyer emergence, preferably in February and March. The complete variety of habitats where Ryukyu pine is found on Okinawa would be represented in the plot selection - plots would encompass a range of site factors such as soil type, mean annual temperature, mean annual precipitation, and aspect. Plot density (basal area) would be recorded. Within plots, each tree would be given a numbered metal tag. Tree data to be recorded include height, diameter at breast height, age, canopy position (suppressed, intermediate, codominant, dominant), width of last five years growth and width of last ten years growth (taken by increment borer). A device that records cambial moisture would be used for each tree in the plots. The Shigometer accomplishes this by measuring electrical resistance. Dr. Junko Morimoto of Keio University is interested in Ryukyu pine moisture stress and might have a recommendation for a different instrument. Each plot would consist of a minimum of 20 trees, and this would be a fixed plot size so I can't state at this point what the plot size would be, it has to be determined in the field.

During summer any fading trees would be recorded on the plot list. Because dying and dead trees no longer compete with uninfected pines, they can be removed in a cut-and-burn project if desired.

Data analysis can proceed only after a sufficient number of trees within plots have become infected and died. This will probably vary throughout the range of habitats on Okinawa, but I estimate that it would take three to five years to obtain enough data to develop a hazard rating model. Variables would be re-measured each spring prior to emergence of sawyers.

<u>Simultaneous development and test of a hazard rating system (treatment approach)</u>

Plots would be established in groups of three: a control, a light treatment, and a moderate treatment. A buffer zone of approximately 10 meters would exist between plots to avoid treatment interactions. The control plots would be similar to the plots in the “no-treatment” approach described above. In the light treatment, approximately 25% of the basal area would be removed, and a moderate treatment would remove approximately 50% of the basal area. Plot size would be established following a field survey. The plot size would be fixed, and would be larger than the plot size in the “no-treatment” approach” because the target number of trees to be left in the heavy treatment would be 20. All species of trees would be considered for removal in the treated plots because density measurements are independent of tree species.

Trees to be removed would be those considered the least vigorous, based upon growth measurements, moisture readings, tree height, and a qualitative assessment of overall tree appearance. Some apparently healthy trees would need to be removed from some plots. The same variables listed above in the “no-treatment” approach would be re-measured for each live tree in the treatment and control plots each spring prior to emergence of sawyers.

The number of 3-plot groups to be established depends upon the range of conditions that are found, as well as access and permission to establish the plots. If only one area is available in the first year, and site conditions within this area are similar, I recommend a minimum of five 3-plot groups. More is always better from a statistical standpoint.

The treatment approach to this study potentially gleans much more valuable information than the no-treatment approach, for obvious reasons – you can develop and test a hazard rating system simultaneously. Both approaches allow for a cut-and-burn project to proceed normally, the only requirement is to record the tree number of any cut trees.

As with any research, I cannot anticipate all of the variables that exist in the field until plots are established, so the guidelines I have presented are tentative and will need to be modified. Either study could be conducted by one or more technicians or graduate students. Studies could be adapted to fit either a M.S. or a Ph.D. program in forest ecology, forest entomology, or forest pathology. I am available to assist whoever is selected with plot selection and experimental design, and would be pleased to serve on the graduate committee(s) of student(s) working on either project. I can also assist, if desired, in the selection of the appropriate university(ies), student(s), or technician(s). I am also available to help organize a workshop or conference on pine wilt disease. A meeting, held on Okinawa, could lead to productive dialogue and would enhance our understanding of this disease.

Several people contributed to an enjoyable and productive trip. In particular I wish to thank Mitsugu Sugiyama for his assistance in scheduling, meeting me at the airport, providing a tour on Sunday, driving many miles throughout much of Okinawa, and translating in the various meetings.

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Disclaimer

I am solely responsible for any errors or omissions in this report.

Scientific names

Ryukyu pine	*Pinus luchuensis*
Japanese black pine	*Pinus thunbergii*
Japanese red pine	*Pinus densiflora*
Western white pine	*Pinus monticola*
Douglas-fir	*Pseudotsugae menzesii*
Grand fir	*Abies grandis*
Japanese pine sawyer	*Monochamus alternatus*
Pine wood nematode	*Bursaphelenchus xylophilus*
Asian gypsy moth	*Lymantria dispar ssp.*
European gypsy moth	*Lymantria dispar ssp.*
White pine blister rust	*Cronartium ribicola*
Western spruce budworm	*Choristoneura occidentalis*
Douglas-fir beetle	*Dendroctonus pseudotsugae*
Armillaria root disease	*Armillaria ostoyae*

Consultations

December 9

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◊ Okinawa Prefectural Government Agricultural Experimental Station, Naha:

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◊ Field tour of central Okinawa:

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◊ Department of Environmental Sciences and Technology, Faculty of Agriculture, University of the Ryukyus:

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◊ Okinawa Prefectural Government, Department of Agriculture, Forestry, and Fisheries, Greenery Promotion Division

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◊ Okinawa Prefectural Government, Forest Experiment Station, Nago:

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