Technical report #3

THE OHIA DIEBACK PROBLEM IN HAWAII

A Proposal for Integrated Research

Addressed to the

National Park Service Science Center

Mississippi Test Facility
Bay St. Louis, Mississippi

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by

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ABSTRACT

The current status of ohia (Metrosideros collina subsp. polymorpha) forest dieback research in Hawaii is reviewed, and a proposal is made for a relatively small integrated complementary program. This is suggested to consist of five subprojects to be carried out primarily by graduate student dissertation research. The five subprojects are: (1) To determine the percent cover of defoliated crowns in the ohia rain forest by remote sensing techniques and to develop a monitoring program, (2) to develop a large scale vegetation map on the basis of structural criteria, (3) to carry out a detailed floristic sampling by many small sample plots and to study by structural analyses techniques the dynamic trends of the woody species populations in a few, large sample plots, (4) to map and study the substrate variations in terms of soil nutrient and soil water regimes to develop a habitat classification for watershed purposes and (5) to study by experimental procedures in the field and in a glasshouse the response of ohia trees and seedlings to irrigation treatments with natural seepage water from dieback areas. The experimental subproject will be designed further for testing the performance of different Metrosideros ecotypes under different moisture and nutrient regimes.

The program is developed to verify or discard the alternate hypothesis that the ohia dieback is a natural phenomenon of primary succession rather than a pathological disease problem as is pursued by the current ohia dieback research of other institutions.

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INTRODUCTION

Ohia (*Metrosideros collina* subsp. *polymorpha*) is the most widely distributed and abundant native tree species in the Hawaiian Islands. It is the first tree invader on new volcanic substrates in a variety of climatic types and the dominant tree species in the montane rain forests.

A conspicuously large number of dead standing trees (snags) has been noticed in recent years, particularly in the montane rain forest on the east flank of Mauna Kea (Island Hawaii). This phenomenon has become known as the "Ohia Dieback" or "Ohia Decline" Problem. Based on a recent aerial photographic analysis by the Hawaii State Division of Forestry and the U. S. Forest Service, the prediction has been made that the ohia forest will be wiped out by 1985.

This rather dramatic prediction that the Hawaiian rain forests will be completely destroyed in 11 years from now was first publicized in February this year in a newspaper article as a public statement made by the Hawaii State Forester, Tom Tagawa (see APPENDIX 1: Honolulu Advertiser article of February 7, 1974 "Ohia epidemic worsens"). The prediction refers not only to the montane rain forest on Mauna Kea, but also to that on Mauna Loa, which includes the newly acquired rain forest area of Hawaii Volcanoes National Park: the Olaa Rain Forest Tract. It also includes the rain forest around the Park Headquarters, Thurston Lava Tube, the Escape Road and south beyond Napau Crater. In other words, the entire rain forest of Hawaii Volcanoes National Park is included in the dieback prediction. It would therefore seem appropriate that this problem receive the attention of the National Park Service Science Center.

In addition, the problem poses the question of island ecosystem stability in a very fundamental sense.

ABSTRACT

The current status of ohia (*Metrosideros collina* subsp. *polymorpha*) forest dieback research in Hawaii is reviewed, and a proposal is made for a relatively small integrated complementary program. This is suggested to consist of five subprojects to be carried out primarily by graduate student dissertation research. The five subprojects are: (1) To determine the percent cover of defoliated crowns in the ohia rain forest by remote sensing techniques and to develop a monitoring program, (2) to develop a large scale vegetation map on the basis of structural criteria, (3) to carry out a detailed floristic sampling by many small sample plots and to study by structural analyses techniques the dynamic trends of the woody species populations in a few, large sample plots, (4) to map and study the substrate variations in terms of soil nutrient and soil water regimes to develop a habitat classification for watershed purposes and (5) to study by experimental procedures in the field and in a glasshouse the response of ohia trees and seedlings to irrigation treatments with natural seepage water from dieback areas. The experimental subproject will be designed further for testing the performance of different *Metrosideros* ecotypes under different moisture and nutrient regimes.

The program is developed to verify or discard the alternate hypothesis that the ohia dieback is a natural phenomenon of primary succession rather than a pathological disease problem as is pursued by the current ohia dieback research of other institutions.

BACKGROUND

How Ohia Dieback became a Pathological Problem

In September 1970, the writer organized a field trip to the Big Island (Hawaii) for the participants of the Hawaii IBP (International Biological Program). We had just received the first-year funds of a 5-year research program that became known subsequently as the Island Ecosystems IRP (Integrated Research Program) of the US/IBP. The objective of this initiation trip was to familiarize the program participants with the ecosystem transects that were previously established by the writer. Certain ecosystems along these transects were to be selected as future study sites for the Island Ecosystems Research Team.

As we drove upwards on the Saddle Road we made several stops and trips to the Mauna Kea Transect north of the Saddle Road to Wailuku River. At 4,200 ft we walked across the 1855 lava flow into an older ohia rain forest with a large number of dead standing snags. A plant pathologist that had come along (but was not a program participant) immediately diagnosed the situation as a "pathological problem." He expressed the idea that a pathogenic fungus is destroying the ohia forest in this and the surrounding areas.

I had seen this stand earlier in 1965, when I made a comparative analysis of the east-flank vegetations of Mauna Loa and Mauna Kea (Mueller-Dombois and Krajina 1967), and noted the poor drainage in the snag stand. I had also noted on the 1965 air photos that snags were abundant and widely distributed in an area between 3500-5000 feet elevation, where the natural drainage system on the east-flank of Mauna Kea is poor because of insufficient stream channelling. Further down-slope near 3,000 feet, rainfall increases (from about 3000 to 5000 mm/year) and geomorphological development has progressed to a much greater extent with streams and tributaries providing for improved drainage. In this area, from about 3,000 feet down slope, the ohia forest looked generally "healthy." The pathologist pointed out dead standing trees on what appear to be "dry" aa flows in the surrounding area, but I maintained that the ohia dieback phenomenon may have an ecological basis. I suggested that a pathogen may be involved as a secondary agent, building up its population in trees of low vigor in the poor drainage areas and perhaps spreading to a few vigorous trees on surrounding, dryer soil moisture regimes.

The snag-problem was of course an eminently worthwhile topic for research, but we had planned for our IBP research to first concentrate on a "healthy" rain forest (the Kilauea Forest Reserve) to gather base-line data on an intact native rain forest ecosystem, to later branch out into what appear to be "problem areas." A comparative analysis of the two different rain forest ecosystems was planned, but time restraints of the International Biological Program precluded a thorough investigation of the ohia dieback problem.

The plant pathologist carried his "pathological problem" hypothesis to the foresters, who in turn launched a campaign to obtain funds (see Burgan and Nelson 1972).

Status of Current Dieback Research

Fairly large sums of money were obtained by the foresters who began to coordinate research in three areas: (1) air photo analyses (2) disease research and (3) insect research. The latter two areas were contracted to the Plant Pathology Department, University of Hawaii and to the Bishop Museum, respectively. The foresters themselves concentrated on the first area, but also contracted a forest pathologist as a consultant from the Mainland. The results up-to-date can be briefly summarized in: (a) the prediction that the ohia forest will be wiped out by 1985 and (b) pathological research findings.

(a) The prediction

The before discussed "doomsday" prediction of State Forester Tom Tagawa is based on an air photo analysis by two research foresters, one of which (Ed Pettys) presented the finding to a recent meeting of the Hawaiian Botanical Society, which I attended. The analysis consisted of an air photo comparison of three sets taken in 1954, 1965 and 1972. A large belt transect was laid out over the east-flanks of Mauna Loa and Mauna Kea extending from Hawaii Volcanoes National Park and Kilauea Forest Reserve (Mauna Loa) northward across the Saddle Road and the east-flank of Mauna Kea to about Laupahoehoe and covering an elevational range from about 2500 to 5000 feet. In this belt transect, the foresters placed approximately 1450 small, systematically distributed points. On the air photos, the points were made to correspond to a small circle scaled to be 1 acre in size on each air photo set. The percent cover of dead or defoliated crowns was estimated in each circle on each of the three air photo sets. The estimating procedure included three features: live tree crowns, defoliated tree crowns and ground matrix. The latter referred to exposed undergrowth, such as tree ferns, small trees, sedges and such like. Apparently no "ground truth" studies had been conducted in association with the air photo survey. I visited the foresters following Ed Pettys presentation to find out more about their method. It became apparent that: (1) the circles could be displaced laterally by as much as 100 feet, which puts in question the exact reestimate of the same acre from photo set to photo set, (2) the sampling intensity was extremely low, about 2 to 3 circles per 200 acres (i.e. 1%), (3) my checking of two points through the series of air photos did not give me the impression of an objective estimate. In one instance I saw on their excellent 1972 color photo set defoliated tree crowns outside the circle area and none inside, whereas the record showed a severe decline for the same circle. (4) The air photo interpretation permits evaluation of only the canopy trees. It gives no information on Metrosideros regeneration, which however is required also for a prediction of forest decline.

There is no doubt that the snag-covered area on the east-flank of Mauna Kea is very extensive, but it appears highly questionable that the ohia dieback has progressed as rapidly over the past 20 years that one can predict a total dieback to occur within the next 11 years. The air photo study with this prediction is to be published shortly.

(b) Pathological research findings

The ohia decline problem was publicized by Burgan and Nelson (1972) as an alarming disease problem in the Hawaiian rain forest that had suddenly reached epidemic proportions in the east-flank of Mauna Kea, including Hawaii Volcanoes National Park. These authors hinted strongly that the shoestring root rot (Armillaria mellea) might be the cause.

Subsequent research by Bega (1972) gave clear evidence that Armillaria mellea could not be considered the major causative agent of ohia decline.

Instead, other potential fungal pathogens were isolated and in August 1973, Dr. I. W. Buddenhagen wrote an open memorandum (attached as APPENDIX 2) suggesting Phytophthora cinnamomi as the causative agent. Buddenhagen's suggestion was based on isolations of this fungus (made previously by Drs. Ko and Kliejunas) and a renewed field reconnaissance of the ohia dieback area together with a visiting plant pathologist from New Zealand, Dr. Frank Newhook. Newhook saw a great resemblance of the ohia dieback pattern with the jarrah forest dieback in Western Australia, which is caused by Phytophthora cinnamomi (Christensen 1973).

However, prior to Buddenhagen's pronouncement of what he then considered a "major breakthrough," Kliejunas and Ko (1973) had found no correlation of

Phytophthora cinnamomi with ohia decline. They proved that potted seedlings of ohia, when inocculated with this fungus, can be killed. But their field research disproved its function as a major cause of ohia decline. These investigators made root collections from dying and healthy ohia trees on both well-drained and poorly-drained sites. They report that they found a correlation of Phytophthora cinnamomi with poorly-drained sites, but not with dying ohia trees.

Later, Kliejunas and Ko treated declining ohia trees with fertilizer. They found that partly defoliated trees recovered totally with applications of NPK and concluded that ohia trees are declining because of nutrient deficiency (see APPENDIX 3).

In addition, ohia decline research was directed to insects as a possible cause. Dr. J. W. Beardsley studied the effect of ohia psyllids on trees with dieback symptoms. He eliminated the psyllid populations with insecticides and reports no evidence of positive response of insecticide-treated trees.

The ohia borers were investigated by Gressitt, Samuelson and Davis. The black twig borer (Xylosandrus compactus) was found to be associated with dead and dying ohia trees. But to date no evidence has been given that this borer is causatively involved in ohia decline.

The pathological research findings were recently summed up by O. V. Holtzmann in a two page "Status Report on Ohia Decline" (see APPENDIX 4). The problem is revolving back to the basic question of whether the ohia decline is a normal or an abnormal (i.e. pathological) phenomenon.

Ohia Dieback - an Old Phenomenon

Shortly after the turn of the century there was a similar concern about ohia decline in Hawaii. According to Dr. Harold St. John (public communication in a Lyon Arboretum lecture), Dr. H. L. Lyon (a well-known earlier plant pathologist in Hawaii) started what today is known as the University of Hawaii's Lyon Arboretum because of his fear that ohia trees may disappear from the windward slopes of Maui as the result of a disease. He brought various species of tropical rain forest trees to this Arboretum to raise planting stock for replacement of dead ohia trees.

Dr. Lyon devoted a great deal of effort to the ohia decline and also attacked it as a pathological problem. He came to the conclusion (Lyon 1909) that the disease was definitely not caused by a fungal pathogen. He found that the dead and dying trees occurred on the more gentle slopes with poor drainage, whereas trees on steep slopes or well-drained soils remained healthy. He observed not only ohia trees to die in the poor drainage areas but also several associated tree species. He made numerous root isolations and always found them to be of a deep purple or bluish black coloration. He noted what looked like "oil slicks" on the standing water in pools of poorly-drained areas and concluded that hydrogen sulfide was produced by bacteria in the stagnating surface water, which would be toxic to tree growth. Moreover, he said that the free hydrogen sulfide changes harmless ferric (iron) compounds to poisonous ferrous (iron) compounds. He buried a heavily rusted axe head among dying ohia tree roots for 21 days and found after that period that the rust was easily removed by washing, which exposed the bluish black steel beneath. He concluded that hydrogen sulfide in the soil reduced the rust to ferrosolferric hydrate and possible iron sulfide. He also noted that the soil had very little calcium resulting in an unusually high magnesium/calcium ratio.

Although Lyon's findings on the ohia decline on East Maui in the first decade of this century were circumstantial rather than direct, they provide an important working hypothesis that has so far not been followed up. The area on East Maui affected by this earlier ohia dieback extended over about

30 miles (from 5 miles west of Kailua to Nahiku near Hana) in an elevational belt from 1000-3000 feet. Thus, the Maui ohia dieback was similarly as extensive as the present dieback on the Island of Hawaii. Today the Maui area is still occupied with ohia trees in the eastern part, where the trees grow in an open formation (i.e. open ohia forest with staghorn fern) across the Hana Highway at about 2000 feet elevation. Upslope the forest appears denser. The western part of the area near 1000 feet has been locally developed for grazing and in other parts it is covered with introduced bamboo forest and other planted species. The ohia snags have largely disappeared and the healthy ohia trees are relatively low-stature trees with globous crowns of the variety macrocarpus, but very unlike the taller, narrow crowned ohia trees that are dying on the east-flank of Mauna Kea.

Apparently then, large-scale ohia dieback is not a new phenomenon in Hawaii. Dieback of tree groups in otherwise healthy appearing native Hawaiian forests was noted as a peculiarity already in 1875 by F. L. Clarke. He attributed this phenomenon to natural succession. Another earlier record was given by Miller (1900) relating to the area between Volcano House and Olaa Mill, a rain forest terrain within the present boundaries of Hawaii Volcanoes National Park. The diary entry reads: "The cause of the deadening of so many ohia trees is altogether inexplicable. All the way up they seemed to be half leafless almost like an autumnal wood but for the colors and the abundance of the ferns below." Moreover, the present ohia decline on the east-flank of Mauna Kea was prevalent already during the Second World War according to Dr. Ko (personal communication) who was told this by a person travelling the Saddle Road for 40 years.

HYPOTHESES

The phenomenon of large areas with standing snags of ohia trees is not easily explained.

The Disease Hypothesis

The U. S. Forest Service together with the Hawaii State Division of Forestry are still giving strong emphasis to the pathological hypothesis, implying that it must be a fungus or an insect or a combination of these agencies that is causing wide-scale dying of ohia. They have gone even further to say that the whole ohia dominated native forest will be wiped out, implying that the associated vegetation will also become diseased and die.

A more refined version of the pathological hypothesis was stated by Dr. Newhook (from New Zealand) in his write-up made after his short reconnaissance in September 1973. Newhook was aware of Kliejunas and Ko's work and stated the hypothesis that ohia dieback may be caused by root-pruning through a fungus and subsequent nutrient deficiency. If this hypothesis can be verified, ohia dieback can be considered an abnormal phenomenon.

The Succession Hypothesis

However, in view of so many unanswered questions it would not seem wise to merely pursue the pathological hypothesis of ohia dieback. Instead we may study the problem simultaneously with the opposing hypothesis in mind *that the ohia dieback is a normal phenomenon, a developmental stage in primary succession of an isolated island rain forest ecosystem*. In this hypothesis pathogens may be involved as secondary agencies, after the tree vigor is reduced through a non-pathological cause.

This hypothesis was proposed already in the February 1970 IBP proposal by the writer, and it was newly restated in IBP Technical Report #19 (Mueller-Dombois

1973) as a longer-term research goal of explaining the wide ecogeographical amplitude of the Metrosideros species complex on the Hawaiian Islands (see Fig. 1).

Dead standing trees are a normal phenomenon in any natural forest where overmature trees are not harvested. However, the presence of so many dead standing trees as found on windward Hawaii in parts of the ohia rain forest needs more explanation.

It is well known that ohia (Metrosideros collina subsp. polymorpha) is the first tree to arrive in primary succession on new lava flows. But the tree is also the dominant climax species of the rain forest. This is most probably a unique situation among tropical montane rain forests on a world-wide scale. The normal situation is an exchange of pioneer species by different seral and then by different climax tree species. There is evidence to believe that the climax Metrosideros is not the same ecotype as the pioneer Metrosideros. The pioneer Metrosideros is usually of the variety incana, while the later form of the rain forest seems to belong largely to the variety macrocarpa. Moreover, it seems quite possible that the pioneer Metrosideros, which can populate a new volcanic surface over a relatively short time span (say 20-40 years) may also reach senility more or less simultaneously. Thus, a large number of trees may die and occur as snags together for a while, particularly when the species has very tough wood (from slow growth which is true for ohia) and when this is combined with slow decay (cool montane climate, slow fungal activity, no termites). Moreover, after the invasion of the pioneer Metrosideros, there may be a secondary invasion of a seral Metrosideros, which in turn is invaded by a climax Metrosideros. This would explain also the peculiar observation made repeatedly that different varieties of Metrosideros occur side by side on the same habitat. The postulated succession of different

Metrosideros ecotypes would also explain why a tall-growing seral Metrosideros forest may transform into a more open low-growing climax Metrosideros forest as existing today on large areas of windward East Maui. If Metrosideros does not display a clear turn-over of ecotypes in succession, it certainly has a number of unique mechanisms to hold on to a habitat in spite of great environmental changes on the same site. For example, as pioneer, Metrosideros invades the rock crevices on the new lava surfaces (Smathers and Mueller-Dombois 1972). In mature forests, Metrosideros seeds germinate in large numbers on decaying logs (Cooray 1974). In addition, Metrosideros can grow as epiphyte for a while after germinating on the apices of tree fern trunks or on standing old Metrosideros trees (Mueller-Dombois 1966). In addition, Metrosideros can grow vegetatively into new trees from branches of fallen trees. Far from being a "feeble" species on the decline as postulated by the pathological hypothesis, Metrosideros seems a uniquely vigorous species complex that can cope with even basic changes in its habitat. For example, one can see vigorous and dense Metrosideros regeneration in many places along the right-of-ways leading through so-called ohia decline areas.

The observation that Metrosideros individuals of all size classes are dying in the same stand as claimed by some proponents of the pathological hypothesis could not be verified by the writer. In all cases observed so far - and a large number of stands have been visited during repeated reconnaissance - ohia trees only of the upper size group were dead or dying, while undergrowth trees showed no signs of declining except for a few occasional individuals that may be dying in the normal course of stand development. A certain amount of "thinning" is expected as seedlings grow into sapling stage and saplings into mature trees.

It has been claimed by the foresters that wherever ohia dieback occurs that the remaining natural vegetation will deteriorate further into a useless grass cover of broomsedge (Andropogon virginicus). It is quite possible that continued poor drainage may cause swamp formation in certain places where formerly a tall ohia stand was growing, but it is highly unlikely that swamp formation will be so widespread a phenomenon that it will coincide with the current territory of the dieback area. Instead many of the dieback stands will probably remain woody vegetation indefinitely.

PROPOSAL OF 5 INTEGRATED COMPLEMENTARY PROJECTS

In view of the complexity of the ohia dieback phenomenon, I believe it important that the problem is investigated from both the pathological and the nonpathological viewpoints. Since the first sort of inquiry is well covered by the research efforts currently coordinated by the U. S. Forest Service's Pacific Islands Institute, this proposal is made in an area complementary to the first, to be carried out under the auspices of the National Park Service and the University of Hawaii, Department of Botany.

The following integrated subprojects are suggested:

1. Determine the percent cover of defoliated tree crowns by remote sensing techniques and develop a monitoring system as a case example.

The objective of this subproject will be to measure (rather than estimate) the true quantitative distribution of standing snags (i.e. defoliated tree crowns) across the ohia rain forest on Mauna Kea and Mauna Loa by the point-intercept method with a statistically adequate air photo sampling procedure. This should include mapping of the dieback area to determine the spatial outline of snag abundance types. A monitoring system for repeated analysis should be developed as a case example for other forest dieback areas in the world and specifically, to determine the dynamics of the forest dieback.

2. Map the ohia rain forest vegetation by structural criteria across the same area at the scale of 1:12,000 (or near this scale).

The objective of this subproject will be to recognize and clarify the structural variation in the ohia rain forest by a mapping procedure similar to the one developed by Mueller-Dombois and Fosberg (1974) for the vegetation of Hawaii Volcanoes National Park. The new map will be an extension of the Park's vegetation map.

3. Develop detailed floristic and structural analyses of the rain forest vegetation in conjunction with the vegetation mapping by the study of a large number of sample plots.

4. Analyze soils and substrates in the vegetation sample plots with the objective to develop a habitat type classification with particular stress on moisture and nutrient regime variations that are found within the ohia rain forest. Moisture regime variations should be studied with regard to water flow mechanisms and be evaluated in terms of watershed criteria.

5. Experimental studies in the field and in a glasshouse involving irrigation treatments with natural seepage water from ohia dieback areas as contrasted to irrigation treatments with nutrient solutions.

The objective will be to verify Dr. Lyon's earlier working hypothesis as explained on p. 7.

PROCEDURES

The program will be conducted jointly by the writer and Dr. K. W. Bridges, both working as co-principal investigators and research coordinators.

Subprojects 2-5 will form the research projects for four (or five) graduate students working under the supervision of both principal investigators. It is the experience of the writer that carefully executed, detailed and significant research contributions can be obtained with graduate students working towards a degree.

Subproject 1: It is suggested that the snag distribution be measured with the aid of remote sensing techniques as developed and used at the Mississippi Test Facility in Bay St. Louis.

Several ground truth checks will be required to determine to what degree defoliation or snag development can be detected by electronic signal techniques on satellite or high altitude imagery.

The ground truth checks will be carried out by the writer preferably with the aid of a remote sensing specialist from the Mississippi Test Facility. A monitoring system for repeated dieback status analyses should be developed as a case example.

Subproject 2: Large-scale vegetation mapping will become part of a Ph.D. program of a graduate student. The same student will be responsible for the establishment of approximately 100 floristic sample plots, which he will analyze according to the relevé technique (Mueller-Dombois and Ellenberg 1974).

Subproject 3: (a) Floristic analyses of many plots (~100) will be done by the same person who prepares the 1:12,000 vegetation map.

(b) Structural analyses of few (carefully selected) large sample plots will be carried out by a team of two students:

As a model we will use the structural analysis procedures developed under IBP for the Kilauea Forest. The latter project yielded two M.Sc. Theses, one dealing with the pattern of horizontal spatial variation (Maka 1973), the other with the analysis of vertical stand structure for an interpretation of woody plant population dynamics (Cooray 1974). Application of the same analysis technique as used for the IBP work has the added advantage of enabling