

# PACIFIC SOUTHWEST Forest and Range Experiment Station

FOREST SERVICE  
U. S. DEPARTMENT OF AGRICULTURE  
P.O. BOX 245, BERKELEY, CALIFORNIA 94701



## **OHIA FOREST DECLINE: its spread and severity in Hawaii**

Edwin Q. P. Petteys   Robert E. Burgan   Robert E. Nelson

## CONTENTS

|                                   | <i>Page</i> |
|-----------------------------------|-------------|
| Summary .....                     | 1           |
| Introduction .....                | 3           |
| Methods .....                     | 3           |
| Aerial Photography .....          | 3           |
| Data Analysis .....               | 5           |
| Map Compilation .....             | 7           |
| Results .....                     | 7           |
| Island of Hawaii .....            | 7           |
| Other Islands .....               | 10          |
| Discussions and Conclusions ..... | 10          |
| Literature Cited .....            | 11          |

## THE AUTHORS

**EDWIN Q. P. PETTEYS** has been with the Hawaii Division of Forestry since graduating from Oregon State University with a bachelor's degree in forestry in 1967. As timber survey forester, he is assigned to the Station's Institute of Pacific Islands Forestry at Honolulu, Hawaii. **ROBERT E. BURGAN** has been on the staff of the Institute of Pacific Islands Forestry since 1969. From 1963 to 1969, he served on the timber sales staff of the Union and later Bear-Sleds Ranger Districts in Oregon. He earned bachelor's and master's degrees in forestry at the University of Montana. **ROBERT E. NELSON** has been in charge of the Station's timber and watershed resource development research in Hawaii since 1957. He joined the Forest Service in 1941 after earning a bachelor's degree in forestry at the University of California, Berkeley.

Cover photo: A healthy ohia-lehua tree, *left*, is in sharp contrast to one in severe decline, *right*.

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## SUMMARY

Petteys, Edwin Q. P., Robert E. Burgan, and Robert E. Nelson

1975. **Ohia forest decline: its spread and severity in Hawaii.** USDA

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*Oxford:* 176.1 *Metrosideros collina*: 48(969)

*Retrieval Terms:* ohia decline; forest diseases; epidemics; aerial photography; Hawaii.

Thousands of acres of ohia and ohia-koa rain forest on the windward slopes of the island of Hawaii are suffering a severe epidemic. A high proportion of the trees have died on thousands of acres, and the forest decimation is continuing. The epidemic is affecting all ages of trees and forests on widely different sites. The specific cause (or causes) of the forest decline is not known, although both disease organisms and insects have been found associated with the dead and dying trees.

Scientists from several agencies are using a multi-disciplinary approach to investigate the problem. This paper deals with the determination of the extent, rate of spread, and severity of the forest decline.

Aerial photographs taken in 1954, 1965, and 1972 of the 197,000-acre (80,000 ha) study area on the island of Hawaii provided a means of comparing forest conditions at these three time periods. A grid of 1450 equally spaced 1-acre plots was marked in the same location on each set of photographs. Each plot on the 1954 photographs was studied stereoscopically, and a "decline condition class" rating assigned, along with an estimate of the percent of the plot area covered by healthy tree canopy. On the 1965 and 1972 photographs, only the percent of plot area covered by healthy tree canopy was determined. Information on forest type, average annual rainfall,

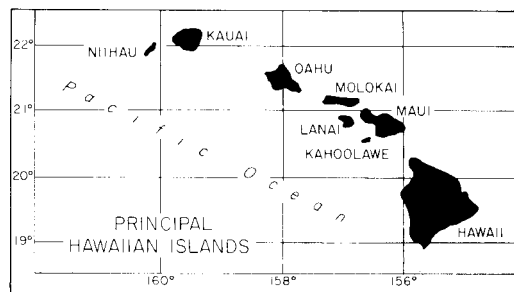
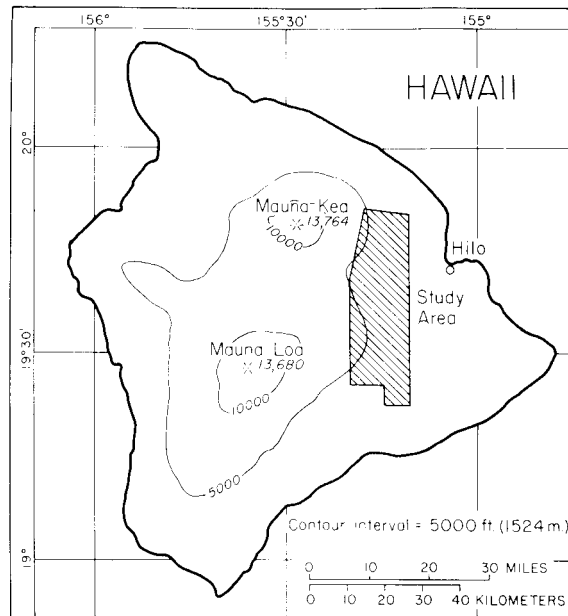
elevation, plot location, and land ownership was also recorded. From these data, maps were developed to show decline severity in each of the 3 years. Statistical correlations of decline severity with elevation and average annual precipitation were also developed.

In 1954, only 300 acres (120 ha) of the forest studied had severe decline, whereas 75,500 acres (30,500 ha) were classed as healthy. By 1972, 85,000 acres (34,400 ha) had severe decline, and only 32,500 acres (13,150 ha) were still classed as healthy. The forest decline is continuing, and extends well beyond the original study area boundaries. Virtual elimination of the ohia forest within the study area is possible within 15 to 25 years if present rate of damage continues.

The most severe decline locations in 1954 were in a roadless area in the northern portion of the study area. The data taken from the 1954 photographs provide, in retrospect, a forecast of the later patterns of spread.

Mean annual precipitation and elevation slightly influence the rate of decline and its current severity.

Forested areas on the islands of Oahu, Maui, Molokai, and Kauai have snag patches and forest remnants indicating the presence of former forests. Recent tree deaths are few and scattered except on Kauai Island, where crown dieback can be considered epidemic in two areas.



**Figure 1**—The study area surveyed by aerial and ground techniques for ohia forest decline covers 197,000 acres (80,000 ha) on the island of Hawaii.

**O**hia-lehua (*Metrosideros collina*) forests on windward slopes of the island of Hawaii are suffering a severe epidemic. A high proportion of the trees have died on thousands of acres, and the forest decimation is continuing. The epidemic is affecting all ages of trees and forests on widely different sites. The specific cause (or causes) of the rapid forest decline is not known, although both disease organisms and insects have been found associated with dead and dying trees. Scientists from several agencies and disciplines are investigating the problem (Burgan and Nelson 1972; Kliejunas and Ko 1973; Laemmlen and Bega 1972; Gressitt, Samuelson, and Davis 1973). One objective of these investigations is to survey the extent, rate of spread, and severity of the forest decline.

Ohia and ohia-koa (*Acacia koa*) forest types occupy nearly 1 million acres (400,000 ha) in the Hawaiian Islands. The island of Hawaii has over 711,000 acres (287,700 ha) of these forest types. These native forest types occupy a significant acreage on all the major islands (table 1).

The ohia forests provide a variety of resource values, including watershed cover, habitat for game

animals and rare wildlife, timber, forage, and recreation opportunities. Loss of the dominant tree cover over large areas of these forests may have serious and long-term consequences. Even if the epidemic stops, regeneration of the native forest is not a certainty. Aggressive adventive plants invading areas of decline may limit or prevent native forest regeneration. Information is needed to help guide management decisions regarding this forest resource. Long-term studies are underway to determine vegetation successional trends.

To evaluate the severity and rate of ohia forest decline, we focused on a 197,000-acre (80,000 ha) portion of the windward slopes of the island of Hawaii (fig. 1). This area was chosen because it contained the major concentrations of identified epidemic decline and because funds were not available to obtain new aerial photography for other parts of the island or other islands.

This paper compares the severity and rate of decline of ohia-lehua forests in the study area from 1954 to 1973; relates this decline to elevation, mean annual rainfall, and forest types; and considers the prospects for the future.

## METHODS

### *Aerial Photography*

Color aerial photography for this study was taken in 1972-73 at a scale of 1:12,000<sup>1</sup>. These photos, hereafter called 1972 *photography* provided the most recent information on decline status. In addition,

black and white aerial photographs were available for the years 1954 (1:38,000) and 1965 (1:24,000).

The aerial photographs enabled us to compare forest conditions in the area at three time periods. We used the following sampling technique:

1. A grid of points, equally spaced, was marked on topographic maps of the study area and on the 1954, 1965, and 1972 photographs. The points totaled 1450, each representing 136 acres (55 ha) for statistical expansion purposes.

2. Each point was assigned a plot number which applied to the same point on all three photos. The points represented centers of 1-acre circular plots.

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<sup>1</sup>Photography had been contracted for by the Hawaii State Division of Forestry in November 1971, but clouds and volcanic haze delayed and interrupted accomplishment of the photo flight missions. The photography was completed in four missions: January 1972, August 1972, September 1972, and February 1973.

Table 1—Total land area and area occupied by ohia and ohia-koa forest types, six main islands of Hawaii

| Island  | Total area   |                 | Ohia and ohia-koa types |                 |
|---------|--------------|-----------------|-------------------------|-----------------|
|         | <i>Acres</i> | <i>Hectares</i> | <i>Acres</i>            | <i>Hectares</i> |
| Hawaii  | 2,584,300    | 1,045,900       | 711,000                 | 287,700         |
| Maui    | 466,000      | 188,600         | 89,500                  | 36,200          |
| Molokai | 167,100      | 67,600          | 23,000                  | 9,300           |
| Lanai   | 89,300       | 36,100          | 500                     | 200             |
| Oahu    | 380,800      | 154,100         | 55,500                  | 22,500          |
| Kauai   | 352,600      | 142,700         | 88,500                  | 35,800          |
| Total   | 4,040,100    | 1,635,000       | 968,000                 | 391,700         |

3. Each photo plot was studied stereoscopically and a "decline condition class" rating was assigned each plot on the 1974 photos, along with an estimate of the percent of plot area (to the nearest 5 percent) covered by healthy tree canopy. The decline condition classes were defined as:

| Condition:  |                                                  | <u>Class</u> |
|-------------|--------------------------------------------------|--------------|
| Severe:     | Over 40 percent of the tree canopy dead or dying | 1            |
| Moderate:   | 11 to 40 percent of canopy dead or dying         | 2            |
| Slight:     | 1 to 10 percent of canopy dead or dying          | 3            |
| No decline: | Entire canopy apparently healthy                 | 4            |

For the 1965 and 1972 photos, we estimated only the percent of plot area (to the nearest 5 percent) covered by healthy tree canopy. "Canopy loss

classes" were developed for the intervals 1954-65 and 1965-72 from calculations from these estimates. Canopy loss classes were as follows:

|                         | <u>Class</u> |
|-------------------------|--------------|
| Canopy loss:            |              |
| None                    | 1            |
| 1 to 10 percent         | 2            |
| 11 to 50 percent        | 3            |
| Greater than 50 percent | 4            |

To aid photo interpretation accuracy, 1972 color photos were studied at various sites in the field. Field checking of the earlier black and white photos was obviously not possible because of changes over time.

Information on forest type, average annual rainfall, elevation, land ownership, and plot location coordinates (X and Y) was also recorded. All data were computer processed.

Table 2—Acres of forest land within the project boundary, by ohia forest decline class and man-disturbed or nonforest areas, island of Hawaii

| Ohia forest decline class        | 1954                   | 1965                   | 1972                   |
|----------------------------------|------------------------|------------------------|------------------------|
| Forest land:                     |                        |                        |                        |
| No decline                       | 75,500                 | 46,300                 | 32,500                 |
| Slight decline                   | 85,400                 | 27,200                 | 10,800                 |
| Moderate decline                 | 17,200                 | 65,300                 | 48,700                 |
| Severe decline                   | 300                    | 39,600                 | 85,200                 |
| Total forest land                | 178,400<br>(72,200 ha) | 178,400<br>(72,200 ha) | 177,200<br>(71,700 ha) |
| Man-disturbed and nonforest land | 18,900                 | 18,900                 | 20,100                 |
|                                  | 197,300<br>(79,800 ha) | 197,300<br>(79,800 ha) | 197,300<br>(79,800 ha) |
| Total project area               |                        |                        |                        |

## Data Analysis

Because decline class was directly interpreted only for 1954, we had to compute the decline class for each plot for the years 1965 and 1972. We used the formula

$$D_y = D_{54} + \left[ \left( 1 + \frac{HC_y}{HC_{54}} \right) 100 \right]$$

in which

$D_y$  = percent of dead or dying forest canopy in year  $y$  (1965 or 1972)

$D_{54}$  = midpoint percentage of decline class in 1954

$HC_y$  = percent of plot covered by healthy tree crowns in year  $y$  (1965 or 1972)

$HC_{54}$  = percent of plot covered by healthy tree crowns in 1954

The value of  $D_y$  was compared with the class intervals for assignment to the proper decline class. As  $HC_y$  did not increase with time on any of the plots, the formula was written so that  $D_y$  would never decrease.

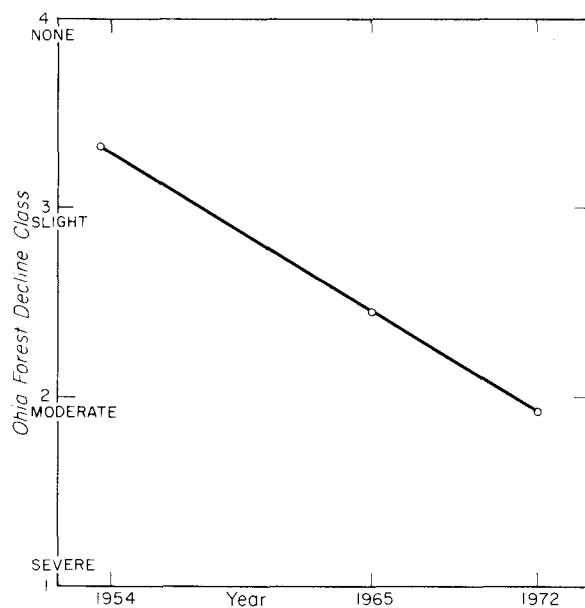
The number of plots in each decline class was summarized and then converted to acreages with an expansion factor of 136 acres (55 ha) per plot. Summaries of areas in each decline class, by year, forest type, and ownership were developed (tables 2, 3, 4).

Table 3—Forest land within the project boundary, by ohia forest decline class, year, and forest type, island of Hawaii

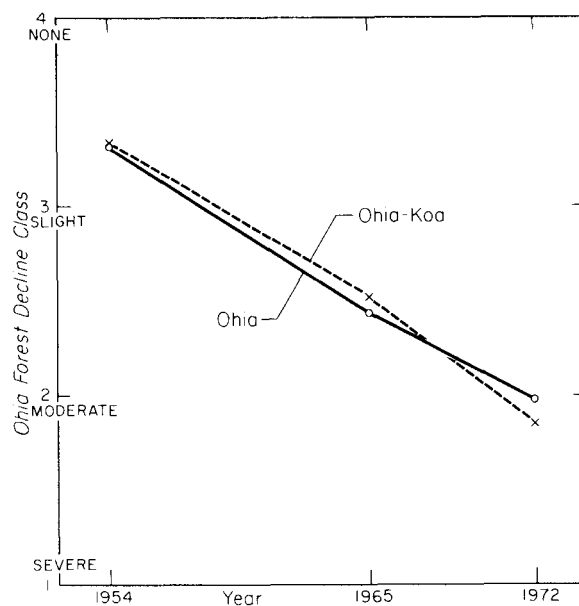
| Year and ohia forest decline class | Ohia                   | Ohia-koa              | Total                  |
|------------------------------------|------------------------|-----------------------|------------------------|
|                                    | <i>Acres</i>           |                       |                        |
| 1954:                              |                        |                       |                        |
| No decline                         | 60,700                 | 14,800                | 75,500                 |
| Slight decline                     | 62,000                 | 23,400                | 85,400                 |
| Moderate decline                   | 15,600                 | 1,600                 | 17,200                 |
| Severe decline                     | 300                    | -0-                   | 300                    |
| Total                              | 138,600<br>(56,100 ha) | 39,800<br>(16,100 ha) | 178,400<br>(72,200 ha) |
| 1965:                              |                        |                       |                        |
| No decline                         | 37,600                 | 8,700                 | 46,300                 |
| Slight decline                     | 18,200                 | 9,000                 | 27,200                 |
| Moderate decline                   | 48,700                 | 16,600                | 65,300                 |
| Severe decline                     | 34,000                 | 5,600                 | 39,600                 |
| Total                              | 138,500<br>(56,100 ha) | 39,900<br>(16,100 ha) | 178,400<br>(72,200 ha) |
| 1972:                              |                        |                       |                        |
| No decline                         | 28,700                 | 3,800                 | 32,500                 |
| Slight decline                     | 7,500                  | 3,300                 | 10,800                 |
| Moderate decline                   | 32,900                 | 15,800                | 48,700                 |
| Severe decline                     | 68,200                 | 17,000                | 85,200                 |
| Total                              | 137,300<br>(55,600 ha) | 39,900<br>(16,100 ha) | 177,200<br>(71,700 ha) |

Table 4—Forest land within the project boundary, by ohia forest decline class, year and ownership

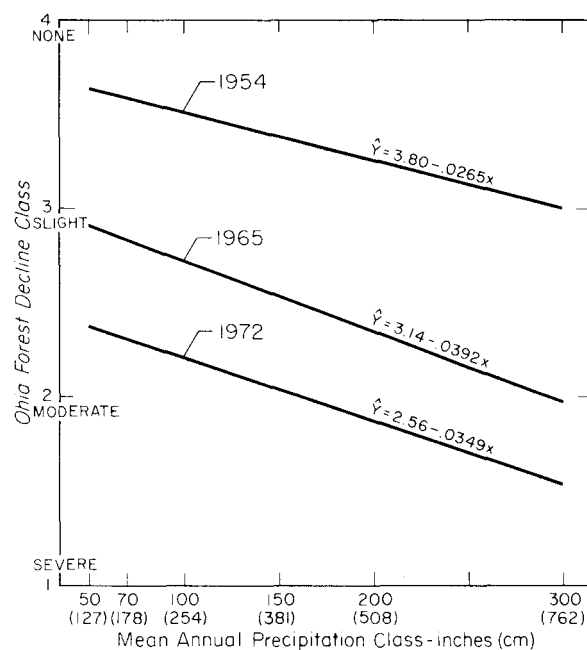
| Year and ohia forest decline class | National Park        | Hawaiian homes  | State                  | Corporate             | Individual           |
|------------------------------------|----------------------|-----------------|------------------------|-----------------------|----------------------|
|                                    | <i>Acres</i>         |                 |                        |                       |                      |
| 1954:                              |                      |                 |                        |                       |                      |
| No decline                         | 9,520                | 140             | 43,670                 | 17,140                | 5,030                |
| Slight decline                     | 8,030                | 140             | 51,830                 | 20,000                | 5,440                |
| Moderate decline                   | 540                  | 0               | 10,200                 | 5,850                 | 540                  |
| Severe decline                     | 0                    | 0               | 140                    | 140                   | 0                    |
| Total                              | 18,090<br>(7,320 ha) | 280<br>(110 ha) | 105,840<br>(42,830 ha) | 43,130<br>(17,450 ha) | 11,010<br>(4,460 ha) |
| 1965:                              |                      |                 |                        |                       |                      |
| No decline                         | 7,480                | 0               | 25,300                 | 11,290                | 2,180                |
| Slight decline                     | 1,090                | 140             | 17,410                 | 6,390                 | 2,180                |
| Moderate decline                   | 3,950                | 140             | 41,080                 | 15,640                | 4,490                |
| Severe decline                     | 5,580                | 0               | 22,040                 | 9,800                 | 2,170                |
| Total                              | 18,100<br>(7,320 ha) | 280<br>(110 ha) | 105,840<br>(42,830 ha) | 43,120<br>(17,450 ha) | 11,020<br>(4,460 ha) |
| 1972:                              |                      |                 |                        |                       |                      |
| No decline                         | 6,670                | 0               | 16,730                 | 7,750                 | 1,360                |
| Slight decline                     | 140                  | 0               | 7,350                  | 2,580                 | 680                  |
| Moderate decline                   | 2,180                | 140             | 28,840                 | 14,010                | 3,540                |
| Severe decline                     | 9,110                | 140             | 52,370                 | 18,230                | 5,300                |
| Total                              | 18,100<br>(7,320 ha) | 280<br>(110 ha) | 105,290<br>(42,830 ha) | 42,570<br>(17,230 ha) | 10,880<br>(4,400 ha) |



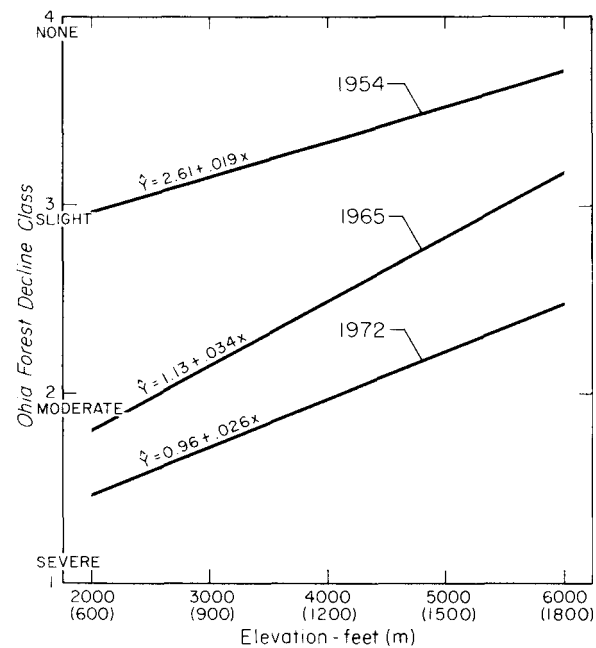
**Figure 2**—"Average health" of ohia forests in the study area changed from a rating of "slight decline" in 1954 to "moderate decline" by 1972.



**Figure 3**—Rate of decline for the ohia forest has been about the same as that for the ohia-koa forests in the study area.



**Figure 4**—As mean annual rainfall increased, the severity of ohia forest decline increased in the study area. In the regression formula, X equals mean annual precipitation (in inches) divided by 10.



**Figure 5**—The greater the elevation of the ohia forest in the study area, the less it was affected by decline. In the regression formula, X equals elevation (in feet) divided by 100.

Area statistics are subject to sampling error. The sampling intensity for this survey was such that, for 95 percent confidence limits, area estimates are liable to these errors:

| Area estimate (acres): | Sampling error (acres $\pm$ ) |
|------------------------|-------------------------------|
| 1,000                  | 720                           |
| 10,000                 | 2,000                         |
| 20,000                 | 3,100                         |
| 50,000                 | 4,400                         |
| 100,000                | 5,100                         |

## Map Compilation

All decline-condition maps were prepared with the aid of a programmable calculator and plotter which performed these functions: (a) reduced the scale of the original project area map; and (b) computed the decline class for each point, selected the mapping symbol appropriate to that class, and plotted this symbol at the location identified by the coordinates of the point. Mapping was completed by differential shading around isodecline symbols.

## RESULTS

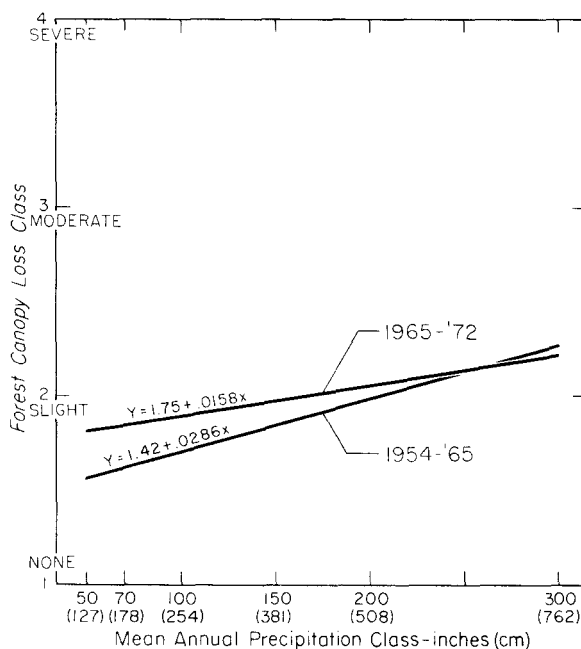
### Island of Hawaii

The average forest decline condition was calculated for the years 1954, 1965, and 1972 to provide a measure of the "health" of the forest within the study area for each year. The results were .

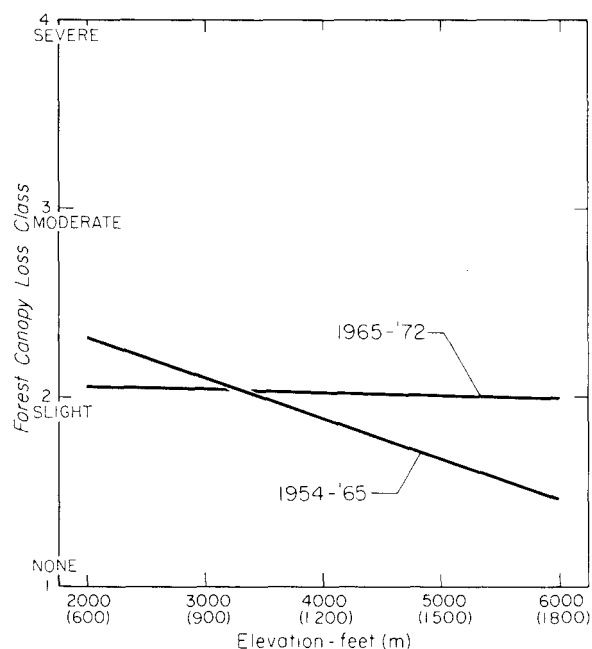
- In 1954, the average condition of the forest in the study area was rated "slight decline" with an index of 3.32 (*fig. 2*). Since then, the forest has declined markedly.
- The ohia forest type declined at about the same rate as the mixed ohia-koa forest (*fig. 3*). Data were

not sufficient to allow a comparison with the koa forest type.

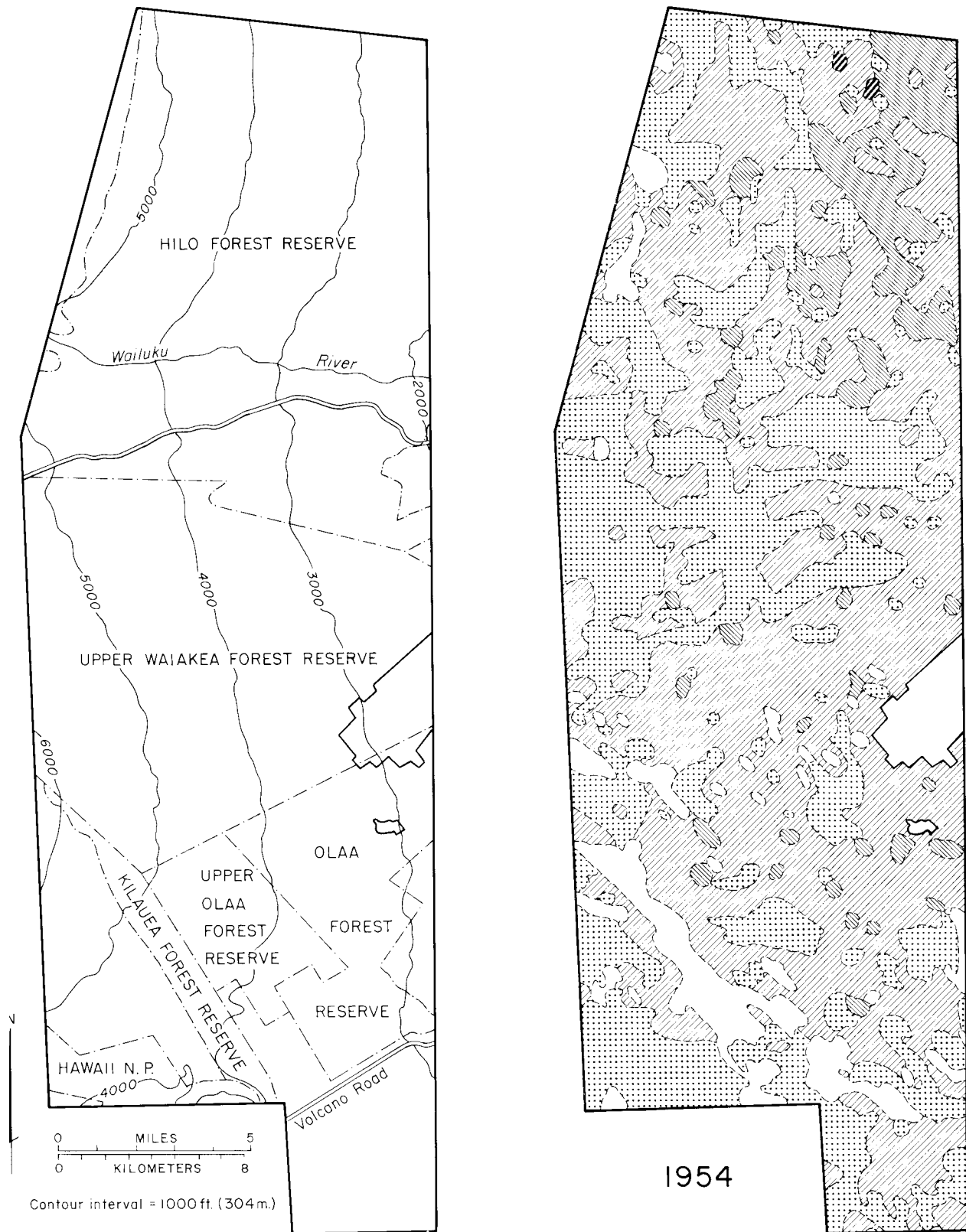
- The "health" status of the forest deteriorated as the mean annual rainfall increased (*fig. 4*). This was true for all 3 years (1954, 1965, 1972). In addition, the regression lines are significantly lower in each of the more recent years, suggesting that the overall average "health" of the forest declines with time.
- The forest was less affected at higher elevations (*fig. 5*). This condition is consistent with the relationship with rainfall because the maximum annual rain-



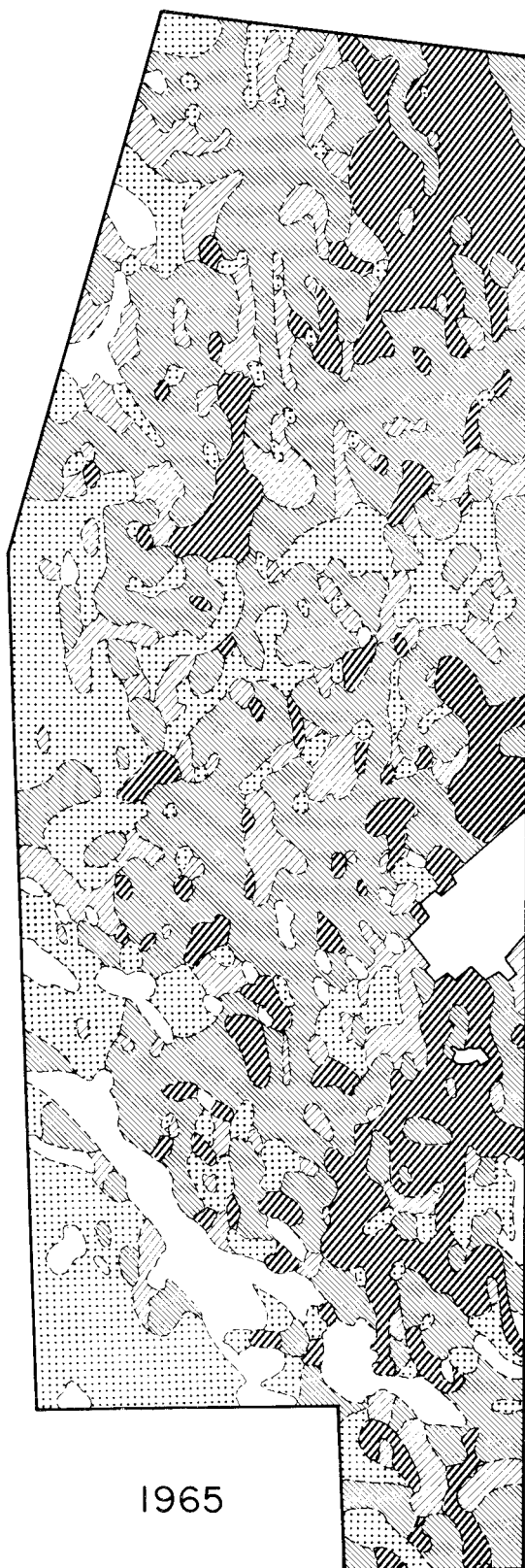
**Figure 6**—The rate of canopy loss due to ohia forest decline was greater in the higher rainfall areas than elsewhere in the study area. In the regression formula, X equals mean annual precipitation (in inches) divided by 10.



**Figure 7**—Rate of forest canopy loss due to ohia forest decline decreased as elevation increased in the study area.



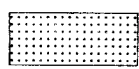
**Figure 8**—Changes in the condition of forests affected by ohia forest decline are evident from a comparison of areas surveyed in 1954, 1965, and 1972, by the four decline condition classes.



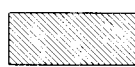
1965



1972



None



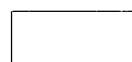
Slight



Moderate



Severe



Not surveyed

fall within the project area occurs near the lower boundary, at 2500 feet elevation (760 m). From there, the mean annual rainfall generally decreases as elevation increases.

- The canopy loss was greater in the higher rainfall areas. This loss occurred at a slightly faster rate during the 1954-65 time interval than from 1965 to 1972 (*fig 6*).

- The periodic loss of forest canopy was also related to elevational levels (*fig 7*). There was less forest canopy loss at higher elevations during the 1954-65 time period. This relationship is consistent with the generally lower rainfall in the higher elevations. However, from 1965 to 1972, the forest was apparently declining at about the same rate at all elevations. Perhaps by then the loss of forest canopy in the lower elevations had already been so severe that the rate of forest decline (canopy loss) had tapered off.

- The severity of decline decreased as elevation increased, although the pattern has anomalies (*fig. 8*). Regressions of forest health class on precipitation and elevation for each of the 3 years (1954, 1965, and 1972) showed that they explained only 4 to 9 percent of the variation of health, i.e.,  $0.043 < r^2 < 0.088$ . Regressions of data (unclassified) for percent of crown canopy loss on precipitation and elevation for the interval 1954-65 produced  $r^2$  values of only 4.8 and 5.4 percent, and for the interval 1965 to 1972, the respective  $r^2$  values were only 0.09 and 0.13 percent. Thus, although mean annual rainfall and elevation may have some effect on the rate of decline, these factors apparently are not limiting—at least within the boundaries of the study area.

The area of principal concern in this investigation was a portion of the forests on windward slopes of the island of Hawaii, but general aerial and ground reconnaissance indicated that forest decline extends outside the study area.

Reconnaissance surveys show that the occurrence

of crown dieback and tree death in the Puna and Ka'u areas is spotty, but extensive. Both single trees and small pockets or clumps of trees are affected. In extensive areas in Ka'u where tree fern is the dominant cover, snags and occasional ohia trees suggest a former ohia forest. These signs point to the possibility of epidemic decline activity in the past.

In the Kohala Mountains there are extensive areas of old top dieback in the scrub ohia forests; but only a few recently dead tree crowns.

Areas in Manuka and North Kona have small patches of presently active decline, especially in the Kahaluu Forest Reserve.

## Other Islands

### Maui, Molokai, Oahu

Reconnaissance of forest areas of Maui, Molokai, and Oahu in 1972 showed a few places where some trees had died recently. On each of these islands, we found large areas where snags and forest remnants indicate forest decimation many years ago. Areas where recent tree deaths have occurred should be visited to determine the cause, or to determine any similarity to the nature of the decline on the island of Hawaii.

### Kauai

Reconnaissance on Kauai revealed that in some places ohia tree death or crown dieback was abnormally frequent. In two areas—the ridge between upper Hanalei and Kalihiwai Valleys, and the Kawai-koi Stream watershed adjacent to Alakai swamp—the forest decline condition could be considered epidemic. Gressitt, Samuelson, and Davis (1973) reported that *Plagithmysus* beetles were fairly consistently associated with tree crown dieback. Further investigations are needed to determine the implications of their findings.

## DISCUSSION AND CONCLUSIONS

From the 1954 photography, 42 percent or 75,500 acres (30,500 ha) of native forest in the study area, island of Hawaii, were classified as "healthy," while only 300 acres (120 ha) were classified as having severe decline (*table 2*). Map portrayal of the 1954 data shows that moderate and severe decline was concentrated in the northern portion of the study area (*fig. 8*). This area has no roads and is cloud

covered most of the time. Therefore, any incipient epidemic decline had little chance of being spotted and interpreted as such at that time.

On the basis of 1965 photography, 26 percent or 46,300 acres (18,700 ha) were classified as "healthy" forest while 39,600 acres (16,000 ha) were classified as having severe decline. Comparison of the 1954 and 1965 data (*fig. 8*) shows that forest decline condi-

tions had extended and intensified. But, and perhaps significantly in retrospect, data from the 1954 photographs forecast the pattern. There was extensive light decline noticeable on the 1954 photos, and decline had intensified markedly in these same areas by 1965. Concentrations of severe decline were generally in the roadless northeast and southern parts of the study area.

The 1972 photographs show that only 18 percent or 32,500 acres (13,200 ha) of the forest were free of decline symptoms, while 85,200 acres (34,500 ha) had severe decline. Much of the area having slight decline in 1954 and moderate decline in 1965 had severe decline in 1972. The extension of forest decline is especially clear when 1954 and 1972 maps and data are compared. The loss of "healthy" forest has been at an average rate of nearly 2400 acres (970 ha) per year. The increase in severe decline acreage

occurred at a rate of about 3600 acres (1450 ha) per year from 1954 to 1965 and 6500 acres (2600 ha) per year from 1965 to 1972. North of the Wailuku River in the study area, spots of "healthy" forest are now extremely rare. The tree cover there has been decimated.

The overriding factor dictating the decline severity class of the forest appears to be time. Analyses of the data show a marked extension and increased severity of the ohia forest decline during the period 1954 to 1972. This study suggests that if decline continues at the present rate, remaining ohia forest in the study area will be virtually eliminated in 15 to 25 years.

Other areas of decline have been found on the island of Hawaii, and on other islands. Because of the potentially great losses, investigators should continue the research to determine the cause of the epidemic decline.

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represents the research branch of the Forest Service in California and Hawaii.

Petteys, Edwin Q. P., Robert E. Burgan, and Robert E. Nelson

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Ohia forest decline—its severity and rate of spread—was studied by aerial photographic techniques on a 197,000-acre (80,000-ha) portion of the island of Hawaii. In 1954, only 300 acres (121 ha) showed signs of severe decline; by 1972, the acreage of severely affected forest had increased to 85,200 acres (34,480 ha). Rate of decline and current severity were related to mean annual precipitation and to elevation. The epidemic is continuing. Some forests on other Hawaiian islands also display decline symptoms.

*Oxford:* 176.1 *Metrosideros collina*: 48(969)

*Retrieval Terms:* ohia decline; forest diseases; epidemics; aerial photography; Hawaii.

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