PROCEEDINGS
SECOND CONFERENCE IN NATURAL SCIENCES
HAWAII VOLCANOES NATIONAL PARK

held at
Hawaii Field Research Center
Hawaii Volcanoes National Park
on
June 1 - 3, 1978

Edited by
C. W. Smith, Director, CPSU/UH
PREFACE

The Second Conference in Natural Sciences was held from June 1-3, 1978, at the Hawaii Field Research Center in Hawaii Volcanoes National Park. The Research Center has expanded quite dramatically since the first Conference in 1976. First the Mauna Loa Field Station was moved into the area at which time the U. S. Fish and Wildlife Service erected a separate laboratory and office building. Shortly thereafter the U. S. Forest Service also built their own facility. In the meantime, the large greenhouse was erected and the Avian Disease Laboratory was set up in one of the old YCC buildings. The dormitory building opposite Magma House was converted into offices and laboratories while some small dormitories were retained and renovated. The herbarium is located in this building. The facilities, probably the best field station in Hawai'i, are available to the public. Dormitory fees are $4.00 a night and should be booked in advance by writing to the Research Biologist, Hawaii Volcanoes National Park, Hawaii 96718.

During the Conference a questionnaire was distributed concerning future meetings. There was a unanimous vote to continue the conferences. Fifty-two percent of the respondents preferred annual meetings, 40% biennial meetings with the remainder undecided about the frequency. Sixty percent of the participants prefer June meetings, 30% had no opinion, and 10% liked August. Three-quarters of those attending felt that three days was sufficient, the remainder had a number of other options. Concerning the length of papers, half the respondents felt 15 minutes was adequate, 25% thought 10 minutes were enough, the remainder wanted longer presentations. Three-quarters of those responding felt 5 minutes was sufficient time for questions. Fifty-five percent of the participants would prefer topic-oriented sessions, 30% preferred contributed papers.

In the comments and suggestion section numerous complaints about the Conference room were aired. Other common suggestions included restricting each participant to a single paper, broadening the scope of disciplines able to participate, and sending out the abstracts and time table before the Conference.

We will endeavor to correct all the deficiencies noted. We appreciate the time and effort put into your responses which we think illustrates your interest in these meetings.

C. W. Smith
Director, CPSU/UH
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Reference</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apple, Russell A.</td>
<td>THE WHITNEY LABORATORY OF SEISMOLOGY (1912-1963)</td>
<td>1</td>
</tr>
<tr>
<td>Baker, James K., and Melinda S. Allen</td>
<td>ROOF RAT DEPREDATIONS ON <em>HIBISCADELPHUS</em> (MALVACEAE) TREES</td>
<td>2</td>
</tr>
<tr>
<td>Banko, Paul C.</td>
<td>NENE REINTRODUCTION PROGRAM AND RESEARCH IN HAWAIIAN NATIONAL PARKS</td>
<td>6</td>
</tr>
<tr>
<td>Banko, Winston E.</td>
<td>SOME LIMITING FACTORS AND RESEARCH NEEDS OF ENDANGERED HAWAIIAN FOREST BIRDS</td>
<td>17</td>
</tr>
<tr>
<td>Beardsley, John W., Jr.</td>
<td>BIOLOGICAL CONTROL OF WILDLAND WEED PESTS IN HAWAII--IS IT A FEASIBLE SOLUTION?</td>
<td>26</td>
</tr>
<tr>
<td>Beardsley, J. W., R. Burkhart, M. L. Goff, A. Hará, and G. Teves</td>
<td>HALEAKALÁ NATIONAL PARK CRATER DISTRICT RESOURCES BASIC INVENTORY: INSECTS AND OTHER TERRESTRIAL ARTHROPODS</td>
<td>30</td>
</tr>
<tr>
<td>Bridges, Kent W.</td>
<td>HAWAII IBP SYNTHESIS: 5. SHORT-TERM TEMPORAL PATTERNS AMONG ISLAND BIOTA</td>
<td>34</td>
</tr>
<tr>
<td>Callaham, Robert Z.</td>
<td>SECOND CONFERENCE ON NATURAL RESOURCES REMARKS BY ROGER SKOLMEN AT DEDICATION OF THE HAWAII FIELD RESEARCH CENTER ON BEHALF OF STATION DIRECTOR CALLAHAM</td>
<td>35</td>
</tr>
<tr>
<td>Carr, Gerald D.</td>
<td>HYBRIDIZATION IN THE HAWAIIAN SILVERSWORD COMPLEX</td>
<td>37</td>
</tr>
<tr>
<td>Carson, Hampton L.</td>
<td>HAWAII IBP SYNTHESIS: 6. GENETIC VARIATION AND POPULATION STRUCTURE IN ISLAND SPECIES</td>
<td>41</td>
</tr>
<tr>
<td>Chan, John G.</td>
<td>SOME ASPECTS OF A SHELL DISEASE IN THE HAWAIIAN FRESHWATER SHRIMP, <em>ATYA BISULCATA</em> (RANDALL)</td>
<td>42</td>
</tr>
</tbody>
</table>
Clarke, Garvin
THE DISTRIBUTION OF MYRICA FAYA AND OTHER SELECTED PROBLEM EXOTICS WITHIN HAWAII VOLCANOES NATIONAL PARK

Collins, Mark S., and Robert J. Shallenberger
FOREST BIRD POPULATIONS ON O'AHU

Conant, Patrick
LEK BEHAVIOR AND ECOLOGY OF TWO HOMOSEQUENTIAL SYMPATRIC HAWAIIAN DROSOPHILA: DROSOPHILA HETERONEURA AND DROSOPHILA SILVESTRIS

Conant, Sheila
HAWAII IBP SYNTHESIS: 3. THE KILAUEA RAIN FOREST ECOSYSTEM

Conant, Sheila
BIRDS OF THE KALAPANA EXTENSION

Conant, Sheila, and Maile Stemmermann
HALEAKALA NATIONAL PARK CRATER DISTRICT RESOURCES BASIC INVENTORY: BIRDS OF THE CRATER DISTRICT

Corn, Carolyn A.
EXPERIMENTAL HYBRIDIZATIONS IN HAWAIIAN METROSIDEROS

Croft, Lisa K., and Paul K. Higashino
THE RARE AND THREATENED PLANTS IN THE AHUPUA'A OF MANUKA, KAULANAMAUNA, AND KAPU'A, SOUTH KONA, HAWAII

Davis, Bertell D.
HUMAN SETTLEMENT AND ENVIRONMENTAL CHANGE AT BARBERS POINT, O'AHU

Davis, C. J.
ESTABLISHMENT OF SOME RECENT IMMIGRANT INSECTS IN HAWAII VOLCANOES NATIONAL PARK

Evenson, William E.
A MATHEMATICAL MODEL OF 'OHI'A DIEBACK AS A NATURAL PHENOMENON

Gardner, Donald E.
EVALUATION OF A NEW TECHNIQUE FOR HERBICIDAL TREATMENT OF MYRICA FAYA TREES

Gerrish, Grant
FACTORS CONTROLLING THE DISTRIBUTION OF EXOTIC PLANTS IN THE KO'OLAU MOUNTAINS, O'AHU

Goff, M. Lee
RESOURCE TRACKING PATTERNS IN ACARI ASSOCIATED WITH BIRDS IN HAWAII VOLCANOES NATIONAL PARK: A PRELIMINARY REPORT
Gon, Samuel M., III
ALTITUDINAL EFFECTS ON THE GENERAL DIVERSITY OF ENDEMIC INSECT COMMUNITIES IN A LEEWARD HAWAIIAN FOREST SYSTEM, MANUKA FOREST RESERVE, SOUTH KONA, HAWA'I 134

Hoe, William J.
HALEAKALA NATIONAL PARK CRATER DISTRICT RESOURCES BASIC INVENTORY: MOSSES OF THE CRATER DISTRICT 150

Howarth, F. G.
HAWAII IBP SYNTHESIS: 4. THE HAWAIIAN LAVA TUBE ECOSYSTEM 155

Jacobi, James D.
DESCRIPTION OF A NEW LARGE-SCALE VEGETATION MAPPING PROJECT IN HAWAI'I 165

Kaschko, Michael W., and Melinda S. Allen
THE IMPACT OF THE SWEET POTATO ON PREHISTORIC HAWAIIAN CULTURAL DEVELOPMENT 177

Kilgore, Bruce M.
DEDICATION ADDRESS FOR HAWAII FIELD RESEARCH CENTER 184

Kjargaard, John I.
THE STATUS OF THE HAWAIIAN DARK-RUMPED PETREL AT HALEAKALA 193

Lamoureux, Charles H.
HAWAII IBP SYNTHESIS: 7. IMPACT OF EXOTIC PLANTS AND ANIMALS IN HAWAI'I 198

Lee, Ah Fat
POHAKULOA PROPAGATION PROJECT: A CONTINUING SUCCESS STORY 199

Lee, Barbara
STUDIES IN THE LIFE HISTORY OF THE 'ALALA IN CAPTIVITY 207

Merlin, Mark David
HUMAN PERCEPTION OF THE HAWAIIAN ENDANGERED SPECIES: A PRELIMINARY REPORT ON A THREE-YEAR RANDOM SURVEY 208

Miller, John M., and Alan M. Yoshinaga
ACID RAIN IN HAWAI'I 217

THE SEPTEMBER 1977 ERUPTION OF KILAUEA VOLCANO, HAWA'I 218

Mueller-Dombois, Dieter
HAWAII IBP SYNTHESIS: 1. BRIEF INTRODUCTORY SURVEY 219
Stemmermann, Lani
HALEAKALA NATIONAL PARK CRATER DISTRICT
RESOURCES BASIC INVENTORY:
THE VASCULAR FLORA OF HALEAKALA
297

Tabor, Kimo
THE ACQUISITION OF NATURAL AREAS IN HAWAI'I
304

Tomich, P. Quentin
STUDIES OF LEPTOSPIROSIS IN NATURAL HOST POPULATIONS:
I. SMALL MAMMALS OF WAIPU'O VALLEY, ISLAND OF HAWAI'I
308

van Riper, Charles, III, and Sandra Guest van Riper
A NECROPSY PROCEDURE FOR SAMPLING DISEASE
IN WILD BIRD POPULATIONS
309

Walters, Gerald A.
BRINGING BACK THE MONARCH OF HAWAIIAN FORESTS--
ACACIA KOA
333

Whiteaker, Louis D.
HALEAKALA NATIONAL PARK CRATER DISTRICT
RESOURCES BASIC INVENTORY:
VEGETATION MAP OF THE CRATER DISTRICT
337

Wolfe, Claire M., C. John Ralph, and Paul K. Higashino
FOREST BIRD POPULATION VARIATION AS RELATED TO
HABITAT TYPES
345

Yoshinaga, Alvin Y.
VEGETATION OF THE HANA RAIN FOREST,
HALEAKALA NATIONAL PARK
346

Ziegler, Alan C.
PREHISTORIC HAWAIAN BIRDS
349

LIST OF PARTICIPANTS
350

SUBJECT INDEX
354
THE WHITNEY LABORATORY OF SEISMOLOGY (1912-1963)*

Russell A. Apple
State Director's Office
National Park Service
Honolulu, Hawaii 96813

The Whitney vault was built in 1912 on the rim of Kilauea crater to begin the resident study of the volcanic and seismic activity of Kilauea and Mauna Loa volcanoes. In 1912 and 1913, standard seismometers were imported from Japan and Germany. By 1928, these instruments had been modified and new ones designed and built by the Hawaiian Volcano Observatory to deal with three local volcanic phenomena: near quick-period earthquakes, harmonic tremor, and ground tilting. Hawaiian-type seismometers, based on designs evolved in the Whitney laboratory, were manufactured in the Observatory's machine shop and installed in a network of stations on the Big Island of Hawai'i. Hawaiian-type seismometers and trained personnel were also sent to Lassen volcano in California and to the Aleutian Islands to institute seismic studies in these regions.

The structural history of the vault and its seismometers and other instruments are given. Abandonment of vault and instruments came in 1963. By this time, its mechanical seismometers were technologically obsolete and replaced by electronic instruments whose ground-movement magnification capabilities were hundreds of thousands of times greater. The Whitney laboratory and its instrumentation ca. 1950 are being rehabilitated as a historical exhibit by the National Park Service and the U. S. Geological Survey's Hawaiian Volcano Observatory.

* Abstract
ROOF RAT DEPREDATIONS
ON HIBISCADELPHUS (MALVACEAE) TREES

James K. Baker and Melinda S. Allen
Mauna Loa Field Station
Hawaii Volcanoes National Park
Hawaii 96718

INTRODUCTION

The genus Hibiscadelphus Rock (Malvaceae) is endemic to the Hawaiian Islands. It is one of the world's rarest (genera) groups of trees. Of six described taxa, *H. bombycinus* Forbes (1920), from the island of Hawai'i, and *H. wilderianus* Rock (1911), from the island of Maui, are believed to be extinct. *H. hualalaiensis* Rock (1911), from the island of Hawai'i, and *H. distans* Bishop and Herbst (1973), from the island of Kaua'i, still survive in the wild but both species are few in numbers.

*H. giffardianus* Rock (1911), from the island of Hawai'i, the type species for the genus, is extinct in the wild but four trees are growing under cultivation in arboreta, and seven others are growing in the type locality in Kipuka Puaulu (Bird Park) in Hawaii Volcanoes National Park.

A hybrid, *H. X puakuahiwi* Baker and Allen (1976, 1977) originated in Kipuka Puaulu where its parent species, *H. giffardianus* and *H. hualalaiensis*, grow in close proximity. The hybrid has been cultivated widely in arboreta and in private gardens around Hawai'i.

It was during observations on the damage to a number of Hibiscadelphus trees by roof rats, *Rattus rattus* L., that the hybrid trees were discovered in 1973. This series of observations on rat utilization of bark, buds, flowers, nectar, and seed pods followed that initial study.

**Feeding on bark**

Roof rats were sporadically observed feeding on bark on three trees in close proximity to one another in Kipuka Puaulu. Two of these trees are *H. giffardianus* and the third a hybrid. Bark feeding on trees was first noticed in the late 1960's when a number of major limbs were girdled and killed on the oldest of the living Hibiscadelphus trees. Efforts were made at that time to control the problem by placing rat guards around some of the limbs; by poisoning the rats with warfarin; and by catching them in snap traps. Warfarin was the most successful control technique.
Bark consumption in ensuing years seems to have occurred principally during summer dry seasons when it is believed that the soft, succulent bark was consumed largely for its moisture content.

Feeding on nectar

Nectar feeding was found to occur largely on flowers of H. giffardianus and hybrid trees, probably because of their larger flowers and quantities of nectar. Nectar feeding was not observed on any of the smaller blossoms of H. hualalaiensis and H. distans.

In order to reach nectar deep within the tubular corollas of the larger flowered species, rats chew holes through the base of the calyxes. The feeding on flower nectar occurs in all parts of the trees, even out on twigs the diameters of match sticks in the upper reaches of the canopy, demonstrating the agility of roof rats.

In April and May 1976, we examined 317 flowers from a F₁ hybrid tree for evidence of nectar feeding. A total of 239 (75%) were rat damaged. We also examined 1967 flowers in June through August of which 538 (27%) were rat damaged. Then in March through May 1977, we determined that of 1525 flowers observed 977 (64%) were damaged. In June, 412 of 590 (69%) flowers examined were also damaged. In total, 4399 flowers were examined and 2164 (49%) were found to have been fed upon by rats.

Feeding upon buds and flower parts

Roof rats also eat the staminal column which includes the anthers and pollen. They not only eat the staminal column of mature blossoms, but they will also chew open buds to reach the anthers and pollen inside. Most of what we observed of this feeding behavior occurred in April and May 1976, when we noticed that 68 (21%) out of 317 blossoms had missing staminal columns.

It appears that rats are after the relatively large amounts of pollen present. Individual pollen grains in Hibiscadelphus are large, up to 220μ, which can be seen easily with the naked eye. We smeared and dried quantities of pollen and then stained them with ninhydrin producing a deep, purple-colored response indicating the presence of relatively large amounts of amino-acids (after the staining techniques of Baker and Baker, 1973). The nectar also stains a deep purple, more so than nectars of any other native Hawaiian flower we have analyzed so far. This may suggest that the pollen and nectar of Hibiscadelphus is especially nutritious both to rats and bird utilizers.
Feeding upon seed pods

Immature seeds are normally consumed. Each of the five carpels is opened and the two to five seeds present removed. Only the endosperm of the seeds is eaten; the outer husk is discarded. In 1976, we placed a 1 m² seed catching tray under the canopy of a hybrid tree for 30 days and collected the husks of approximately 150 seeds. A total of 21 uneaten seeds were present, obviously dropped by the rats, indicating an 88% destruction of the seed crop during this one period of observation.

There is an obvious difference in the seed feeding habits between two particular rat populations feeding on two different but nearby trees. On one tree the empty pods are left dangling by their peduncles, indicating the rats feeding in that tree are eating the seeds, in situ. On the other tree the rats chew through the peduncle and carry the pod down the tree to a nearby feeding station. A cache of 136 empty seed pods was found in this feeding area in 1976, and another 120 pods were found in 1977.

We estimated that the total 256 fruits destroyed represented about 90% of the total seed production, and that about 3000 seeds were eaten in the two seasons of seed production.

Also, in 1976, we estimated that there were about 300 empty pods in a large cache found near the base of one of the two living H. hualalaiensis trees on Mt. Hualalai. It appeared that all of the remaining pods would be taken for a total destruction of that year's seed crop.

SUMMARY

All of our observations indicate that roof rats cause serious damage to Hibiscadelphus trees by eating bark, buds, flowers, nectar, and seeds, and one has to consider the possibility that introduction(s) of roof rats into Hawai'i sometime around the mid-1800's may have been an additional reason, among several, for the present rarity of these trees. Indications are that as much as 50% or more of the flowers on a tree, and as much as 90% of the seed crop, may be destroyed.

The climbing agility of roof rats in Hibiscadelphus trees suggests that these non-native animals are capable of foraging in a similar manner through the canopies of any native tree, and that the nectar feeding habits of the rats probably compete with native nectar feeding birds.
LITERATURE CITED


The reduction of range and numbers of Nene (*Branta sandvicensis*), the Hawaiian Goose, within historic times has been an international concern of conservationists since P. H. Baldwin published the results of his literature and field survey 33 years ago (Baldwin 1945). At that time the wild population was estimated at about 50 individuals, but by 1951 only 30 were thought to exist in the wild (Smith 1952). A portion of this remnant population was breeding immediately adjacent to Hawaii Volcanoes National Park (HAVO) at high elevation—about 1980 m (6500 ft) (Elder & Woodside 1958). Nene have historically occupied high and low elevation habitats within HAVO (Baldwin 1945). However, traditional lowland nesting grounds have never been positively identified within the Park. The existence of Nene on Maui within Haleakala National Park (HALE) is less well documented than in HAVO, but the species was believed to have been breeding within Haleakala Crater prior to 1890 (Henshaw 1902; Perkins 1903).

Long before the need for conservation measures became apparent, Nene had been bred in captivity. The first record of successful captive propagation of the species was in 1834 when Lord Stanley, Earl of Derby, reared one gosling out of a clutch of four eggs laid at Knowsley, England (Stanley 1834). Young Nene were soon distributed to other private collections and zoos throughout Europe and eventually became fairly common in captivity (Delacour 1954). However, Nene had become rare in European collections after 1900 (Blaauw 1904) and finally disappeared when the last specimen, a 42-year-old gander, vanished during the German invasion of France in 1940 (Delacour 1954).

The Hawaii Board of Agriculture and Forestry (now Department of Land and Natural Resources) began a captive breeding program in 1927 at the territorial Game Farm, Mokapu, O'ahu, having received a pair of Nene from Mr. Leighton Hind of Pu'u Waawaa Ranch (Smith 1952). Mr. Hind and Mr. Herbert Shipman of Hilo, who had been maintaining and breeding Nene since 1918, contributed additional birds to the territorial program and by 1935
the captive flock had grown to 42. In 1935, the flock was disbanded, and the birds were distributed to various individuals who were to continue captive propagation efforts. However, within 15 years, all but one had died, vanished, or had been released to the wild (Smith 1952).

The Board of Agriculture and Forestry began a new captive propagation project in 1949 at Pohakuloa which has eliminated the immediate threat of extinction and bolstered the number of Nene living in the wild through the release of captive-reared birds (DLNR 1966, 1968, 1970, 1974, 1974a). That the present population can increase or remain stable without additional annual releases has yet to be determined.

In fulfilling its mission to protect, manage, and restore native wildlife presently or historically found within Park boundaries, the National Park Service (NPS) began Nene propagation and release programs in HAVO and HALE in 1972. The goals of the HAVO program are to reestablish breeding populations in suitable low and mid-elevation habitats, to maintain and manage habitat at all elevations, and to control or reduce factors which are inimical to Nene survival. At HALE the objectives are similar, but the habitat available is restricted to high elevations. Research begun in 1976 is being integrated with NPS propagation-release programs to guide management decisions and to answer basic questions regarding Nene life history and ecology. Since I have been more directly involved in the HAVO research and management program, I will confine my remarks to this park.

The primary justification for directing propagation and release efforts at low and mid-elevations in HAVO has its basis in the observations of the naturalists of the 1890's. H. W. Henshaw (1902) commented on the lowland breeding range of Nene as follows:

It has been stated and seems to be the general impression that the nene rears its young in the uplands where it is found in summer, but such is not the fact. The greater number, probably all, leave the upper grounds beginning early in the fall, and resort to lower altitudes, from about 1,200 feet downwards. There are barren lava flats near the sea in Puna, Kona, Kau and Kohala, rarely indeed visited by man, and it is to these deserted solitudes that the nene resorts at the beginning of the love season.

The cause of the desertion of the uplands by the geese for the low-lying lava flats near the sea is doubtless the failure of the food supply in the former, at least of such as is adapted to the wants of the young. At high altitudes there is but a scanty crop of berries in winter, and most of the pualele dies; whereas near the sea there is an abundance of this plant and of freshly sprouted grasses during the winter and spring months.
R. C. L. Perkins (1903) also believed that Nene bred primarily in the lowlands:

As is well-known the Goose, like many other native birds, changes its abode at different seasons of the year, being no doubt chiefly influenced by the food supply. In the summer months it affects the open upland region, which is covered with a scrubby vegetation and traversed by many lava flows, such for instance as parts of the plateau between the three great mountains of Hawaii, at an elevation of four or five thousand feet above the sea. Near the crater of Kilauea about two miles from the Volcano House hotel flocks of some size may be occasionally seen in the later summer. In such situations it feeds on the abundant Ohelo berries (Vaccinium), on the wild strawberry (Fragaria chilensis) where the cattle still allow this to exist, and still more commonly on the black berries of the creeping Coprosma, one of the commonest plants in some of its favourite localities. In the winter months large numbers of these upland geese resort to the lowlands and remain there for such time as the vegetation is fresh and green, and they are said to breed during this season.

G. C. Munro (1944) provides further documentation of lowland breeding, as follows:

It [Nene] had become accustomed to semiarid waterless country where it obtained the moisture it needed from the upland berries on which it fed in the summer and the rich soft plants of the lowland lava flows where it wintered and raised its young ... The sparse vegetation on the open lava flows is rich, especially on the lowlands in the wet season, hence the birds migrated to the lowlands to breed. These we collected there were much fatter than the specimens we took at about 2,000 feet elevation.

We hunted this goose in December 1891 on the rough lava flow of 1801, down nearly to sea level, and up the side of the mountain on the Huehue ranch to about 2,200 feet elevation. It was open shooting season and a party of hunters went over ground at the higher elevation where we had taken specimens a few days before. They found a nest with four eggs, caught two very young chicks and shot a young bird nearly full grown.

When the following record, reported in Baldwin (1945), is considered in the context of the observations of Henshaw, Perkins, and Munro, there is little doubt that the Nene was once a breeding resident of low and mid-elevations in HAVO:
An old Hawaiian resident of Puna, Sam Konanui, who traveled across the Puna lowlands to Kau around 1894, says Nene were plentiful above the inshore cliffs around 1,500 to 2,000 feet but not on the flats which line the shore. He saw them as far to the east as Panau.

In light of what was known about Nene in the 1890's, there is ample justification for attempts to reestablish a breeding population at lower elevations in HAVO. Further, since Hawaii State Division of Fish and Game (HSDFG) has operated its restocking program exclusively at high elevations--above 1525 m (5000 ft)--there is even a greater need for the HAVO program to concentrate on lowland population restoration. The overall effect of both state and federal programs will hopefully be to complimentarily repopulate the full altitudinal range of Nene habitat, at least in Puna and Ka'u.

Besides focusing management efforts at different elevations, the HSDFG and HAVO programs differ fundamentally in the methods of propagation and release. HSDFG employs a "game farm" approach. Captive birds are intensively bred by incubating eggs artificially and naturally (by the goose) and by removing eggs of the first clutch so that a second or third clutch will be laid. Goslings are brooded artificially and naturally and are kept at Pohakuloa until their distribution to release pens prior to fledging. Once their wing feathers have fully emerged, the young are free to leave the release pen and begin their life in the wild.

At HAVO Nene are bred in pens which are already situated in habitats where wild populations are to be reestablished. The eight pens so far in use are located from 213 m to 1219 m (700-4000 ft) elevation and range in size from about 0.11 ha to 1.47 ha (0.27-3.63 acres). Pens 1, 2, and 3 are stationed in upper 'Ainahou where Mr. Herbert Shipman temporarily maintained his flock of semi-domesticated Nene from which the original stock was obtained for the HSDFG program in 1949. Pen 4 is situated near Kilauea Crater, 5 is stationed at Pu'u Kaone, 6 is found at Kualalau'ula Pali, and 7 and 8 are situated along the top of Hilina Pali in lower 'Ainahou.

Breeding inside HAVO is unmanipulated in that eggs are not removed for artificial incubation nor for obtaining a second or third clutch. Parents brood and rear their own goslings during the entire period prior to fledging. Once the young are capable of flight they depart from and return to the pen many times before becoming fully independent. By employing this method of propagation and release, young Nene have full contact with their parents and siblings, as well as free-living birds which frequently visit the pens. The young inside the pens also become quickly acquainted with the habitat which they will inhabit as fledglings and adults. In addition, the young are thoroughly acclimatized to the temperature and rainfall regimes with which they must cope in the wild.
Although Nene in HAVO pens are exposed to conditions similar to those in the wild they are not totally self-sufficient. Prolonged occupancy in the pens results in depletion of food plants, so a commercially available game bird ration is supplied regularly. Fresh drinking water is continually available, but Nene are prevented from bathing in the water and fouling it. Potential predators such as mongooses and feral cats, are trapped outside of the pens and are further discouraged from entering the pens by small-mesh, buried wire along the bottom portion of the pens. However, rats and mice occur in all of the pens and Barn Owls are present regularly at Pu'u Kaone.

HAVO breeding stock has been obtained from two sources, HSDFG and U. S. Fish and Wildlife Service (USFWS). HSDFG has contributed three pairs, one each in 1972, 1973, and 1976, plus three unpaired females and a male in 1976. All were raised at Pohakuloa. USFWS has contributed eight females and four males reared at Patuxent Wildlife Research Center, Patuxent, Maryland, and three females from Northern Prairie Wildlife Center, Jamestown, North Dakota. All USFWS birds were less than one year old when received in 1974. USFWS has since distributed its breeding flock to various U. S. zoos.

In any program involving penned birds there are deaths and escapes which deplete the stock. Opportunities for losses are probably higher in the type of program operating in HAVO because birds are unattended most of the time and predators, disease, or other factors may not be detected or prevented from occurring before damage is done. Eight captives have died and one has escaped from pens since 1972. In 1973, the only pair of Nene in HAVO died, apparently as the result of predation by feral cats which were trapped at the pen soon after the incident. One of the females obtained from Jamestown died of exhaustion in December 1974 while trying to free herself from a piece of fence wire which had become caught on her leg band. A pair of Patuxent birds died with one of their juveniles in August 1976. A predator may have been involved but the actual cause of death was impossible to determine since the carcasses were already decomposing when found. Two other juveniles were found unharmed in the pen. A Pohakuloa male died in a pen accident in January 1978. Again in January a Pohakuloa male and Patuxent female died in their pen. Both were emaciated although food was plentiful in the pen and the intestines and gizzards were nearly full. Results of autopsy have revealed no clues as to causes of death.

To determine if coccidia might be present in the captive birds, fecal samples were sent to Hawaii State Department of Agriculture laboratories for analysis in 1976, but results were negative.

One Pohakuloa female escaped from her pen in November 1976 and was never resighted. Pohakuloa and Jamestown birds have temporarily escaped in the past despite clipped primary feathers. When strong winds are blowing, as frequently occurs at Pu'u Kaone and Kukalau'ula Pali, even wing-clipped birds are sometimes able to clear the pen fence which stands nearly 2 m (6 ft). They are
usually recaptured near the pen and returned. Patuxent Nene have not escaped, because they have been tenectomized or tenotomized as youngsters and are consequently unable to fully extend one wing. Their primary feathers do not require clipping.

Breeding results at HAVO are summarized in Tables 1 and 2. Of 21 nesting attempts since 1974, one was initiated in October, four in November, nine in December, two in January, one in February, and four in March. The one February and two of the March nests represent renest efforts. A total of 77 eggs have been laid in the pens, 56 (73%) of which have hatched. The mean number of eggs laid per female, including renests, is 4.28 (range 2 to 12), while the mean clutch size is 3.67 (range 2 to 6).

Of the 56 eggs which have hatched, 21 goslings (37%) have died, almost all within four weeks after hatching. Causes of gosling mortality have been difficult to assess; however, predation cannot be implicated in at least 13 cases where carcasses which showed no wounds were recovered. Disease or nutritional deficiencies may have been involved in some fatalities.

Of the 35 goslings which fledged successfully only three are known to have died. As mentioned during the discussion of adult mortality, one juvenile died with its parents inside a pen while its two siblings survived. Another juvenile died of injuries sustained when it flew into the water catchment system at the pen. The third known fatality occurred when a juvenile was struck by a car on Hilina Pali Road at night.

Twenty-six of the 32 surviving juveniles have been sighted since November 1977 and the majority of these have been seen very recently. Only two pen-reared birds have not been sighted since July 1977. Most fledglings remain with their parents until the following breeding season when finally they appear to leave the vicinity of the pen and begin wandering. By the time they are one-and-a-half to two years old, pen-reared birds usually reappear at or near their natal pen. They may be accompanied by a mate from another pen, or by one or more siblings, or they may be alone. Females have proven to be more faithful than males in returning to the vicinity of their natal pen. Only one individual, a male, has been sighted more than a few kilometers from his natal pen. This bird was accompanying an unbanded female at about 2010 m (6600 ft) elevation near the terminus of Mauna Loa Strip Road. All pen-reared Nene are sexed and banded before fledging, using unique combinations of colored plastic and serially numbered aluminum leg bands. Birds released by HSDFG are banded using plastic leg bands only.

One of the problems affecting the early stage of the HAVO propagation-release program has been the lack of mates available to birds produced during the first three years. The problem has been compounded by the great distance between most pens. Consequently, the initial broods produced in the pens have been widely separated from other broods and have not had the opportunity to contact previously released birds which would be expected to be found in the vicinity. As a result, independent, pen-reared
birds have been forced to mate with siblings and even captive individuals inside the pens. Three free-living, pen-reared females have returned to pens and mated with captive ganders. Two of these nests resulted in goslings while the eggs failed to hatch in the third nest. One sibling mating occurred in the wild in 1977, resulting in two offspring, but this pair bond dissolved and the female nested with another male in 1978, producing one fledgling. Ironically, this new male partner is a brother of the female which was hatched in a different pen. Captive stock is rotated annually in the pens so that different localities will be seeded by more than one pair. In any case, sibling pair bonds will prevail for a few more years until fledglings have been produced to provide mates for newly released birds.

To obtain information concerning the breeding biology of wild populations in and near HAVO, field work was begun during the 1977-8 breeding season at high elevations--1675 m to 2134 m (5500-7000 ft)--with the objective of locating and monitoring nesting success. Six nests were found between 1860 m and 1980 m (6100 & 6500 ft) elevation in the state Keauhou Nene sanctuary, while five nests were found between 1920 m and 1950 m (6300 & 6400 ft) elevation in the adjacent lands of Kapapala within HAVO. One wild nest was located at 1160 m (3800 ft) elevation near Kilauea Crater. Eight of these nests were active when found and the remaining four had been vacated not long before their discovery. The progress of the active nests was followed for as long as possible, but after the eggs hatched, broods were difficult to locate. Four of six pairs that were known to have produced viable offspring lost one or more of their young within four weeks after hatching. In addition, three pairs were observed with young, but nests were not located.

At least 28 pairs were identified which did not breed successfully, although some apparently made nesting attempts, judging from the brood patches evident on a few females. Poor nesting results in the wild and in HAVO pens was perhaps partly due to extraordinarily dry weather occurring throughout the breeding season.

Additional research is being conducted on breeding biology, food habits, habitat utilization, behavior, population dynamics, and inimical factors of wild and captive Nene in conjunction with Park breeding-release programs. The objectives of this research are to contribute to the restoration of viable, wild populations of Nene and to explore the biology of this unique species of goose.
LITERATURE CITED


Blaauw, F. E. 1904. On the breeding of some of the waterfowl at Goolust in the year 1903. Ibis, 8th Ser., 4: 67-75.


TABLE 1. Individual results of Nēnē breeding in HAVO pens (* = wild-release female which bred with captive male; + = died).

<table>
<thead>
<tr>
<th>Breeding Season</th>
<th>Male</th>
<th>Female</th>
<th>Pen</th>
<th>Approx. Date</th>
<th>1st Egg Laid Clutch</th>
<th>Eggs Produced Clutch</th>
<th>Eggs Hatched Clutch</th>
<th>Gosling Mortality Clutch</th>
<th>Fledglings Produced Clutch</th>
<th>Fledgling Mortality Clutch</th>
</tr>
</thead>
<tbody>
<tr>
<td>1974-75</td>
<td>962</td>
<td>917</td>
<td>2</td>
<td>29 Nov</td>
<td>4</td>
<td>4</td>
<td>0</td>
<td>4</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>8088</td>
<td>283</td>
<td>5</td>
<td>8 Dec</td>
<td>-</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>8087</td>
<td>8093</td>
<td>1</td>
<td>16 Dec</td>
<td>-</td>
<td>4</td>
<td>4</td>
<td>0</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>8090</td>
<td>285</td>
<td>3</td>
<td>24 Dec</td>
<td>-</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>+8094</td>
<td>+8081</td>
<td>4</td>
<td>7 Mar</td>
<td>-</td>
<td>3</td>
<td>3</td>
<td>0</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>1975-76</td>
<td>8089</td>
<td>8092</td>
<td>4</td>
<td>8 Mar</td>
<td>-</td>
<td>4</td>
<td>4</td>
<td>0</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>962</td>
<td>917</td>
<td>2</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>8083</td>
<td>4</td>
<td>4</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>8080</td>
<td>-</td>
<td>4</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>8082</td>
<td>-</td>
<td>4</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>8084</td>
<td>-</td>
<td>4</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

17 15 4 11 2
<table>
<thead>
<tr>
<th>Breeding Season</th>
<th>Male</th>
<th>Female</th>
<th>Pen</th>
<th>Approx. Date 1st Egg Laid</th>
<th>Eggs Produced Clutch 1 2</th>
<th>Eggs Hatched Clutch 1 2</th>
<th>Gosling Mortality Clutch 1 2</th>
<th>Fledglings Produced Clutch 1 2</th>
<th>Fledgling Mortality Clutch 1 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>1976-77</td>
<td>8088</td>
<td>283</td>
<td>5</td>
<td>19 Nov</td>
<td>4 3</td>
<td>4 3</td>
<td>4 0</td>
<td>0 3</td>
<td>- 0</td>
</tr>
<tr>
<td></td>
<td>962</td>
<td>917</td>
<td>8</td>
<td>12 Dec</td>
<td>-</td>
<td>4 -</td>
<td>4 -</td>
<td>0 -</td>
<td>4 -</td>
</tr>
<tr>
<td></td>
<td>8089</td>
<td>8092</td>
<td>1</td>
<td>13 Dec</td>
<td>6 6</td>
<td>4 6</td>
<td>4 0</td>
<td>0 6</td>
<td>- 0</td>
</tr>
<tr>
<td></td>
<td>8087</td>
<td>8093</td>
<td>6</td>
<td>29 Dec</td>
<td>-</td>
<td>3 -</td>
<td>2 -</td>
<td>2 -</td>
<td>0 -</td>
</tr>
<tr>
<td></td>
<td>8090</td>
<td>*403</td>
<td>3</td>
<td>30 Dec</td>
<td>-</td>
<td>3 -</td>
<td>3 -</td>
<td>0 -</td>
<td>3 -</td>
</tr>
<tr>
<td></td>
<td>8090</td>
<td>285</td>
<td>3</td>
<td>24 Jan</td>
<td>-</td>
<td>3 -</td>
<td>0 -</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>576</td>
<td>8083</td>
<td>3</td>
<td></td>
<td>0 -</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>8080</td>
<td>929</td>
<td>7</td>
<td></td>
<td>0 -</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>8084</td>
<td>912</td>
<td>2</td>
<td></td>
<td>0 -</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>511</td>
<td>922</td>
<td>5</td>
<td></td>
<td>0 -</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>8082</td>
<td></td>
<td>6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>32</td>
<td>26</td>
<td>10</td>
<td>16</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>1977-78</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>8088</td>
<td>283</td>
<td>6</td>
<td>30 Oct</td>
<td>4 4</td>
<td>2 0</td>
<td>0 -</td>
<td>2 -</td>
<td>0 -</td>
</tr>
<tr>
<td></td>
<td>8082</td>
<td>*406</td>
<td>4</td>
<td>4 Nov</td>
<td>3 -</td>
<td>3 -</td>
<td>3 -</td>
<td>0 -</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>8087</td>
<td>8093</td>
<td>5</td>
<td>30 Nov</td>
<td>4 -</td>
<td>2 -</td>
<td>1 -</td>
<td>1 -</td>
<td>0 -</td>
</tr>
<tr>
<td></td>
<td>962</td>
<td>917</td>
<td>1</td>
<td>4 Dec</td>
<td>4 -</td>
<td>3 -</td>
<td>3 -</td>
<td>0 -</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>8090</td>
<td>285</td>
<td>3</td>
<td>12 Dec</td>
<td>3 -</td>
<td>1 -</td>
<td>0 -</td>
<td>1 -</td>
<td>0 -</td>
</tr>
<tr>
<td></td>
<td>8084</td>
<td>*401</td>
<td>2</td>
<td>24 Dec</td>
<td>2 -</td>
<td>0 -</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>8084</td>
<td>912</td>
<td>2</td>
<td></td>
<td>0 -</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>8089</td>
<td>8092</td>
<td>8</td>
<td></td>
<td>0 -</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>8080</td>
<td>929</td>
<td>7</td>
<td></td>
<td>0 -</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>+576</td>
<td>+8083</td>
<td>3</td>
<td></td>
<td>0 -</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>+511</td>
<td>922</td>
<td>4</td>
<td></td>
<td>0 -</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>24</td>
<td>11</td>
<td>7</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>77</td>
<td>56</td>
<td>21</td>
<td>35</td>
<td>3</td>
</tr>
<tr>
<td>Breeding Season</td>
<td>1974-75</td>
<td>1975-76</td>
<td>1976-77</td>
<td>1977-78</td>
<td>Total</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-----------------</td>
<td>---------</td>
<td>---------</td>
<td>---------</td>
<td>---------</td>
<td>-------</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>No. Pairs</strong> Available</td>
<td>1</td>
<td>6</td>
<td>10</td>
<td>11</td>
<td>28</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>No. Pairs Bred</strong></td>
<td>1</td>
<td>5</td>
<td>6</td>
<td>6</td>
<td>18</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Eggs Produced</strong></td>
<td>4</td>
<td>17</td>
<td>32</td>
<td>24</td>
<td>77</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Mean No. Eggs/Female</strong> (range)</td>
<td>4.0 (3-4)</td>
<td>3.4 (3-12)</td>
<td>5.33 (2-8)</td>
<td>4.0 (2-12)</td>
<td>4.28</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Mean Clutch Size</strong> (range)</td>
<td>4.0 (3-4)</td>
<td>3.40 (3-6)</td>
<td>4.0 (2-4)</td>
<td>3.43 (2-6)</td>
<td>3.67</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Eggs Hatched (%)</strong></td>
<td>4(1.0)</td>
<td>15(.88)</td>
<td>26(.87)</td>
<td>11(.46)</td>
<td>56(.75)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Gosling Mortality (%)</strong></td>
<td>0(0)</td>
<td>4(.27)</td>
<td>10(.38)</td>
<td>7(.64)</td>
<td>21(.37)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Fledglings Produced (%)</strong></td>
<td>4(1.0)</td>
<td>11(.73)</td>
<td>16(.62)</td>
<td>4(.36)</td>
<td>35(.63)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Fledgling Mortality (%)</strong></td>
<td>0(0)</td>
<td>2(.18)</td>
<td>1(.06)</td>
<td>0(0)</td>
<td>3(.08)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1 Includes free-living females which voluntarily occupy and breed inside pens with captive males.

2 18 females nesting, 3 of which were involved in renesting efforts.

3 21 clutches
SOME LIMITING FACTORS AND RESEARCH NEEDS OF ENDANGERED HAWAIIAN FOREST BIRDS

Winston E. Banko
U. S. Fish & Wildlife Service
Hawaii Volcanoes National Park
Hawaii 96718

It is well known that Hawaiian birds are particularly susceptible to depopulation and extinction. Twenty-three of 69 endemic species or races have disappeared since discovery of Hawai'i by Europeans 200 years ago.

Except for Warner (1968) and Atkinson (1977), only superficial inquiries have been made into historical aspects and underlying factors of the Hawaiian forest bird decline. After several years of field and laboratory investigation, Warner explained the disappearance of forest birds as being caused primarily by disease. Atkinson advanced a theory based on historical evidence that arboreal predation by rats was a leading factor.

The object of my long-term historical investigation is to document and compare the salient facts on the geography and chronology of Hawaiian bird loss, species by species; to chronicle what is known about all factors of depopulation—predation, disease, habitat alteration, and food competition; and to draw such conclusions as seem warranted.

At the First Conference in Natural Sciences two years ago, Banko and Banko (1976) reported on the potential significance of food depletion in the decline of Hawaiian forest birds. The role played by the Big-headed ant (Pheidole megacephala) in destroying much of the endemic insect fauna at elevations generally less than 3000 feet (914 m) before 1890 was sketched at that time. (The term "insect" will be used hereafter as including other arthropods as well).

I now wish to elaborate on the possible impact of foreign parasitic flies and wasps in depleting native insect foods important to the small Hawaiian forest birds at higher elevations. It is acknowledged at the outset that all of the information in the historical literature dealing with habitat alteration, predation, disease, and food competition as they relate to bird decline, has not yet been fully extracted or analyzed. However, the effects of habitat destruction are in evidence almost everywhere around us, while claims that disease and predation were leading factors in bird depopulation are now being systematically studied by Charles van Riper and James K. Baker, respectively. It may
therefore be of interest to review some historical facts indicating parasitism of bird food-insects by foreign flies and wasps played a prominent role in depopulating birds through depletion of food supplies. If this theory is correct, foreign parasites may be a major factor limiting population size and range of forest birds today.

In considering the significance of insect foods to forest birds, it is first necessary to point out that insects are important, if not essential, in the diets of the young of all species, irregardless of food preferences of adults. Though specific foods of nestling and newly-fledged forest birds have not been studied extensively, judging from what has been recorded in the literature, their diets appear to consist principally if not entirely of insects.

The history of events in a forest ecosystem above 3000 feet (914 m) elevation illustrates the destructive impact of foreign parasites on native insect foods and indirectly on populations of endemic forest birds, thereby serving as a model of typical effects which have occurred in Hawaiian National Parks and elsewhere. A suitable case history is provided by the Acacia koa forest which extends some 40 miles (64 km) along the Kona Coast, at approximately 4000 to 7000 feet (1219-2134 m) elevation.

Eighty-five years ago this Kona Koa forest supported substantial populations of the 'Oma'o (Phaeornis obscurus obscurus), 'O'u (Psittirostra psittacea), and Greater Koa Finch (Psittirostra palmeri), to mention but a few of the dozen or so species of small forest birds which formed the avifauna of that particular region. Perkins (1903: 375, 433, 437) noted the 'Oma'o to be "almost ubiquitous throughout the forest . . . . from the lower limits to the upper"; the 'O'u in Kona "in countless numbers," moving seasonally upwards into the Koa woods; and the Greater Koa Finch seen in "hundreds" between 4000 and 5000 feet (1219 and 1524 m) in the Koa belt.

Today, judging from a review of the literature and from personal observation, populations of the 'Oma'o, 'O'u, and Greater Koa Finch are either absent or in low numbers in the Kona Koa forest, exemplifying what has happened to other native Hawaiian forest birds in Kona and elsewhere.

Consider the following ecological relationships and history of events. Acacia koa, especially old decadent stands, is of paramount importance to Hawaiian forest birds as a source of insect food. Beginning in 1887 a long procession of naturalists and ornithologists found more kinds of birds in Koa woods than in any other type of Hawaiian forest. In retrospect, the most obvious rationale for avian diversity in Koa forests is that Acacia koa harbored a greater variety of endemic insects than any other generic group of Hawaiian trees (Swezey 1954: 1).
Of all the insects hosted by Acacia koa none were apparently as important as food to more kinds of forest birds than the endemic moth genus Scotorythra spp. (Geometridae). After years of observing feeding behavior and investigating stomach contents of many species of Hawaiian forest birds, Perkins (1913: clii) concluded that Scotorythra spp. "form a most important part of the food supply of endemic birds, and are supplied by the parents to the young of nearly all the species, while they are a favorite food of many adult birds as well." The historical record is replete with references to the prominence of Scotorythra spp., and other caterpillars, in diets of Hawaiian forest birds.

While Scotorythra spp. moths and larvae were found on Hawaiian trees and shrubs other than Koa, it was the species that fed on Koa that were in such demand. Some species of Scotorythra hosted by Koa were very abundant in the 1890's, and occasionally erupted, defoliating entire forests.

In Kona, the 'Oma'o, 'O'u, and Greater Koa Finch had special affinities for Scotorythra spp., or looper caterpillars as they were commonly called. Perkins (1903: 374) mentions several instances of the 'Oma'o feeding on Koa loopers and adds that these birds "also continue to feed the young on these for some time after they have left the nest." Perkins (1903: 433-434) also documented the seasonal dependence of 'O'u on caterpillars after fruiting of its normal food, 'Ie'ie (Freycinetia arborea), had terminated. On several occasions, Perkins observed excursions of the 'O'u out of its usual haunts into Koa woods for the purpose of obtaining (Scotorythra spp.) caterpillars. Likewise, Perkins (1903: 437) noted that the Greater Koa Finch displayed an affinity for Koa looper caterpillars.

Unfortunately, Scotorythra caterpillars are also preyed upon by foreign parasitic insects which began arriving in the Islands about 1890 and continued to become established until at least 1942. While the impact of foreign organisms on insect foods of native birds has never been systematically studied in the field, at least four kinds of exotic flies and wasps are known to attack Scotorythra spp. What little is known of the arrival and status of foreign parasites in the Islands, and their relationships to Scotorythra spp., is condensed in Tables 1 and 2.

According to various authorities quoted in Table 1, two foreign tachinid flies arrived before 1900 and, one at least, was universal in mountain forests about 1892. An ichneumonid wasp was first discovered on O'ahu in 1925 and by 1931 had become very numerous at times. A braconid wasp was introduced in 1942 and not long thereafter was found well into the native forests of the six major Hawaiian Islands. Some foreign fly and wasp parasites apparently have high reproduction and dispersal characteristics.

By the 1940's it was known from impromptu investigations by authorities cited in Table 1, that the two tachinid flies attacked one and three species of Scotorythra spp., respectively. The ichneumonid wasp was discovered to hit seven species of Scotorythra spp., four host-specific to Acacia koa. The braconid
wasp was found to parasitize the larvae of one species of Scotorythra spp. moth hosted by Acacia koa.

Most, if not all of the prey-parasite relationships cited by E. C. Zimmerman in Table 2 were discovered by an economic entomologist, O. H. Swezey. During a long life of work in the field and laboratory, from about 1904 to the late 1930's, Swezey spent what time could be spared from his official duties in the forest studying Hawaiian insects.

In the 40 years since Swezey ceased to be active in the field, other potential parasites of Scotorythra spp. have arrived, creating a need for revision and possible expansion of host relationships shown in Table 2. For example, Bianchi (1959: 993) documented the introduction to Hawai'i of three braconid wasps, including Apanteles marginiventris and Meteorus laphygmae, in addition to the apparently accidental arrival of another tachinid fly, Eucelatoria armigera. Bianchi reported that it was not long after arrival of these parasites in 1942 that they became abundant in the lowlands and then spread to the upland grass ranges and even well into native forests where he theorized they might parasitize native caterpillars unrecorded as hosts. Whitesell (1964) stated, from a forester's viewpoint, that Scotorythra spp. appeared to be under good control biologically and seldom built up to "damaging levels."

Reduction of Scotorythra spp. populations by continental flies and wasps is not the only example which might be cited of depletion of a valuable insect food by foreign parasites. Another large group of endemic moths extensively parasitized by foreign insects is the family Pyralidae. Pyralids were major foods of the Palila (Psittirostra bailleui) and Greater Koa Finch (Psittirostra palmeri), and a general food of the Hawaii Creeper (Loxops maculatus mana), according to Perkins (1903: 436, 437; 1913: clx). In Kona, Perkins (1903: 414, 435) found the Hawaii Creeper "extremely common" at about 3500 feet (1067 m) upwards, and the Palila "extremely numerous" from below 4000 to at least 6000 feet (1219-1829 m).

Commenting on the biological control of species in one genus of Pyraustidae, Hedylepta, Zimmerman (1958b[8]: 66, 68-69) states:

... eight foreign wasps and three foreign flies are extremely active parasites, and parasitism now commonly exceeds 90 per cent ... Two of the species of this genus (Hedylepta) break the general rule that endemic Hawaiian insects are not pests of economic importance, because (H.) accepta is the well-known sugarcane leafROLLER, and (H.) blackburni is the common coconut leafroller. The introduction of parasites to control these species, especially the sugarcane leafroller, have resulted in mass destruction of the endemic Lepidoptera and have greatly altered the composition of the insect fauna of the islands.
Today the Palila is not known to inhabit the Mamane (Sophora chrysophylla) zone of the Kona Koa forest and the Hawaii Creeper appears to be much less common than in the past.

Foreign flies and wasps were not the only organisms depleting foods of forest birds. Other continental and Hawaiian organisms also compete with endemic forest birds for food. But continental parasites appear to have played a dominant role in many areas.

It is clear from the historical record that endemic Lepidoptera were the most heavily utilized food resources of the small Hawaiian forest birds in the 1890's. Concerning their general depletion in the past 80 years, Zimmerman (1958a[7]: 28) has this to say:

When Dr. Swezey laid down his pen and left Hawaii (in 1952) a golden era of Hawaiian entomology closed . . . Swezey was the last of the entomologists to have seen many of the endemic Hawaiian Lepidoptera in a semblance of their natural abundance. The importation of parasites to control various moths of economic importance, together with the accidental importation of other parasites has resulted in wholesale slaughter and near or complete extermination of countless species. It is now impossible to see the Hawaiian Lepidoptera in the natural proliferation of species and individuals of Perkins day. Many are lost forever.

From an analysis of the historical literature, it may therefore be argued that depletion of insect foods by waves of foreign parasites was a significant factor in depopulation of endemic Hawaiian forest birds. If true, such a theory would have serious contemporary implications. Many continental ants, flies, wasps, and other foreign organisms are well established in native forests, and others continue to arrive. Wherever endemic birds are constrained to share food with continental fauna, superior competition by foreign species possess perhaps overlooked potential to significantly restrict population sizes and ranges of Hawaiian birds.

It is my contention that the overall predicament of endangered forest birds is primarily the result of dissolution of the natural Hawaiian ecosystem by continental fauna, and that the challenge of preserving what remains can best be accomplished by efforts to learn more about, maintain, and reestablish long neglected but vital interdependencies. Viewed in this light, research to determine the role of food supply in first reducing and then limiting population size of endemic Hawaiian forest birds is seen as an urgent conservation necessity.
In line with this thinking, immediate inquiry is needed to shed light on the following questions:

1. What is the present distributional relationships between availability of insect foods and endemic forest bird populations, especially during and after the critical nesting and fledging periods?

2. What proportions of diets of the various forest bird species are composed of foods of foreign origin?

3. Are foreign organisms limiting the quantity and quality of food presently available to forest birds? If so, which exotics are the most influential and where are they exerting the most competitive pressure?

4. Are Scotorythra spp. populations under biological control by foreign organisms as has been asserted?

5. What is the contemporary role of predatory ants in reducing food supplies of forest birds?

These and many other high priority questions face contemporary research ecologists charged with preserving endangered birds and maintaining native Hawaiian ecosystems.
LITERATURE CITED


### TABLE 1. Arrival and status of foreign parasites of *Scotorythra* spp. in Hawai'i.

<table>
<thead>
<tr>
<th>TACHINID FLIES</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
</table>
| Chaetogaedia monticola | universal in mountain forests about 1892 | still generally distributed over the Archipelago in 1931 | Perkins (1913: clxxxiv, clxxxv)  
Williams (1931: 291) |
| Frontina archippivora | probably introduced in 1898 | very common in Hawai'i | Williams (1931: 292) |

<table>
<thead>
<tr>
<th>ICHNEUMONID WASP</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Hyposoter exiguae</td>
<td>first discovered on O'ahu in 1925</td>
<td>at times very numerous</td>
<td>Williams (1931: 268-269)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>BRACONID WASP</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
</table>
| Apanteles marginiventris | introduced in 1942 | well into the native forest of 6 forested islands | Beardsley (1961: 364)  
Bianchi (1959: 993-994) |
<table>
<thead>
<tr>
<th>TACHINID FLIES</th>
<th>Specific Host Caterpillar</th>
<th>Host Plant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chaetogaedia monticola</td>
<td>S. corticea</td>
<td>Acacia koa</td>
</tr>
<tr>
<td>Frontina archippivora</td>
<td>S. paludicola</td>
<td>Acacia koa</td>
</tr>
<tr>
<td>ICHNEUMONID WASP</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hyposoter exiguae</td>
<td>S. rara</td>
<td>Acacia koa</td>
</tr>
<tr>
<td></td>
<td>S. caryopis</td>
<td>Acacia koa</td>
</tr>
<tr>
<td>BRACONID WASP</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Apanteles marginiventris</td>
<td>S. paratactis</td>
<td>Dodonaea spp.</td>
</tr>
<tr>
<td></td>
<td>S. trapezias</td>
<td>Dodonaea spp.</td>
</tr>
<tr>
<td></td>
<td>S. sp.?</td>
<td>Dubautia spp.</td>
</tr>
</tbody>
</table>

BIOLOGICAL CONTROL OF WILDLAND WEED PESTS IN HAWAI'I--IS IT A FEASIBLE SOLUTION?1

John W. Beardsley, Jr.
Department of Entomology
University of Hawaii at Manoa
Honolulu, Hawaii 96822

The problem of aggressive exotic weed species invading native Hawaiian ecosystems and overwhelming or out-competing endemic plants has been a recurrent one since man's arrival in these islands. The Polynesians brought with them the hau and the kukui, among others, which have since become widespread and abundant elements of the Hawaiian flora. These at least are plants which at the time were useful. Since the arrival of the Europeans, we have seen Hawai'i's forests invaded in successive waves by lantana (Lantana camara), the guavas (Psidium guajava and P. cattleianum), rose myrtle (Rhodomyrtus tomentosa), the fire-tree (Myrica faya), blackberries (Rubus spp.), melastoma (Melastoma malabathricum), banana pokā (Passiflora mollissima), Koster's curse (Clidemia hirta), and New Zealand tea (Leptospermum scoparium), to mention a few of the more obnoxious species. Several of these are still rapidly extending their ranges and some, such as banana pokā and Koster's curse, appear to be causing the rapid decline and disappearance of elements of the endemic flora in those areas which they have invaded. I am sure that the botanists could name additional species which invaded wildland ecosystems within the past few decades, and I am almost certain that we will be seeing other species, which are not yet considered to be problems, developing into serious pests in the future.

Biologists concerned with the preservation of native Hawaiian ecosystems and the individual elements thereof, are faced with a serious dilemma. The cost of physically or chemically removing or killing invading weed species which threaten native ecosystems is generally prohibitive, given the budgetary limitations under which most of us must operate, and excepting incipient infestations which involve relatively small and accessible areas. Furthermore, physical and chemical methods often have undesirable side effects such as the inadvertent destruction of native plants. Also, such methods are rarely 100% effective, which means that within a few years the treated area, in all probability, will have been reinvaded from adjacent untreated

1 Published with the approval of the Director of the Hawaii Agricultural Experiment Station as Journal Series No. 2249.
lands; or a few surviving plants, or their seeds, will have reestablished the weed infestation. In most situations, it seems to me, the application of physical methods or herbicides to combat well-established aggressive weed species in Hawaiian wildland ecosystems is, in the long run, doomed to failure. I believe that the biological method of control offers a practical alternative to physical and chemical methods which can be successfully utilized against many of the weed pests in Hawaii which compete with native plants.

It has been repeatedly observed that in those areas in which they are endemic, plant species which have become aggressive weeds in Hawaii are, in general, relatively minor and innocuous elements of the floras in which they occur. Thus, in Mexico, the exploratory entomologist Albert Koebele found Lantana camara occurring only sparingly as scattered shrubs, but not in continuous stands (Perkins & Swezey 1924). Similarly, it has been stated that in tropical America Passiflora species, such as P. mollissima, occur primarily as scattered individuals in forest environments, not as overwhelming canopies (Gilbert, pers. comm.).

There is an increasing body of evidence that, in many instances, the distribution and abundance of a particular plant species is determined not only by parameters of the physical environment and by competition from other plants, but also by the predators and parasites which feed upon it (i.e., herbivorous animals and pathogenic microorganisms). In the case of tropical passion vines, for example, Gilbert (1975) has shown that heavy herbivore pressure from the larvae of Heliconius butterflies has resulted in the hyperdispersion of Passiflora populations in Central American forests. Furthermore, in the case of many, perhaps most, phytophagous arthropods and plant diseases, long coevolution between the plant and its natural enemies has resulted in highly specific host/herbivore and host/parasite relationships.

When a potential weed species is brought to Hawaii, usually in the form of seed, it leaves behind virtually all of these specific types of associated arthropods and disease organisms. Thus, freed from the constraints exercised by these specific natural enemies, it is able to flourish and reproduce far beyond what would be possible in those areas where it is endemic, out-competing and overwhelming native species which bear their own burdens of specific native herbivores and parasites.

The classical biological control strategy for combating an introduced pest organism, be it arthropod or weed, involves seeking out natural enemies of the pest in those areas where it is endemic, and establishing these in areas which the pest has invaded. The method has worked extremely well against several very serious range and pasture weeds (e.g., Opuntia spp. in Australia and Hawaii; Hypericum perforatum in Australia and California; Lantana camara in several tropical areas, including Hawaii). Lantana, although it cannot be said to have been completely controlled in all situations in Hawaii, is today, with
15 species of introduced insects established on it, under a great deal of herbivore pressure which did not exist prior to these introductions, and is far less prevalent than it was at the turn of the century (Perkins & Swezey 1924).

I believe that the reason why the majority of the serious weeds which affect native ecosystems in Hawai'i have not been brought under biological control is simply that, for most of them, little or no effort has yet been expended. Work which has been done on controlling Lantana and Clidemia, was directed at these species primarily as range pests; hence the natural enemies best suited to control these species in non-rangeland ecosystems may still be undiscovered.

A major concern, often expressed by biologists and non-biologists alike, is that organisms which are imported for biological control of weeds will themselves become pests by attacking economic plants, ornamentals, or elements of the native flora. Careful research and testing carried out in the areas of origin, and under quarantine at the destination, can almost completely eliminate this possibility. About 40 species of phytophagous insects have been successfully introduced into Hawai'i to combat weeds since this phase of biological control was initiated in 1902. Of these, one of the earliest introductions, made before adequate procedures for testing candidates for introduction had been developed, became a very minor pest of eggplant, and another, also among the first introductions, has twice been reported feeding on a native tree (Myoporum). These are the only exceptions I know of to an otherwise unblemished record. The generally high degree of host specificity which is characteristic of many phytophagous arthropods and disease organisms, plus the fact that many of the important forest weeds have no close relatives among the endemic flora, reduces the chance of unforeseen host transfer by well selected biological control organisms to the realm of a remote possibility. Even in the case of a weed such as banana poka, where a member of the same genus is a food plant of minor economic importance, there is still a good possibility of achieving biological control without materially affecting commercial passion fruit production. Species-specific insects or diseases may exist which will not affect the cultivated passion. Furthermore, ecological isolating mechanisms may exist which would prevent species introduced to combat a wildland weed from attacking a related crop plant growing in an agricultural or urban environment. Thus, among Heliconius the specific ecological and host requirements (i.e., ovipositional stimuli) of the adult butterflies limits their oviposition to specific Passiflora species within certain forest environments, even though the larvae themselves may be capable of feeding on other species of Passiflora.

In the case of weeds such as the introduced grasses which grow in environments similar to those of native grasses, or the introduced Rubus species which may occupy habitat similar to that of the endemic R. hawaiiensis, there is perhaps less chance of achieving satisfactory biological control without some damage to
the native flora, although the possibility of finding phyto-
phagous forms with a sufficiently high degree of host specificity
still exists. For example, the various species of smut fungi
which attack grasses usually are highly host specific.

The biological method of weed suppression is, of course, no
panacea. Even in the most successful programs the target weed
remains present in the environment, although reduced to the
status of a relatively minor element of the flora, limited to
those special sites where it can survive and compete successfully
despite the pressure of its introduced natural enemies. However,
barring some major ecological upset, control, once achieved, is
permanent and self-perpetuating. In achieving control we will
have added some additional elements to the total biota, even
though these elements are restricted to close association with
the target weed. These consequences must be accepted if a
biological control program is to be undertaken.

To me, the choice, with respect to many of our more aggres-
sive wildland weeds, is obvious. Either we opt for biological
control, or we accept the fact that there is no economically
feasible control available. I believe that biological control is
an acceptable, and perhaps the only practical alternative for
controlling many of the more serious wildland weed pests in
Hawai'i.

LITERATURE CITED

Gilbert, L. E. 1975. Ecological consequences of a coevolved
mutualism between butterflies and plants. Pages 210-240 in
L. E. Gilbert and P. H. Raven, eds. Coevolution of animals
and plants. Univ. of Texas Press, Austin.

Perkins, R. C. L., and O. H. Swezey. 1924. The introduction
Hawaiian Sugar Planters Assoc., Entomol. Series no. 16,
83 pp.
HALEAKALA NATIONAL PARK CRATER DISTRICT
RESOURCES BASIC INVENTORY:
INSECTS AND OTHER TERRESTRIAL ARTHROPODS

J. W. Beardsley, Jr., R. Burkhart,
M. L. Goff, A. Hara, and G. Teves
Department of Entomology
University of Hawaii at Manoa
Honolulu, Hawaii 96822

During the past three summers (1975-77) RBI collections of insects and other terrestrial arthropods were made at numerous sites within Haleakala National Park, primarily along established RBI transects. The most intensive collecting was done in the relatively dry higher elevation areas of the Park above 1800 m, within the crater and on the western rim between Hosmer Grove and the summit, and in Kaupo Gap at 1500 m elevation and above. These collections contain approximately 20,000 specimens, most of which have been mounted and labeled for study. Much of the material has been identified by the authors and collaborators, and a preliminary checklist has been prepared. The ultimate objective of this study is to produce, in as complete a form as possible, a checklist of the terrestrial arthropods of Haleakala National Park, annotated with data on host relationships, distribution, and other pertinent ecological information. However, several important major taxa are as yet either unstudied or only partly identified, and it is anticipated that the checklist will require several years for completion.

On the basis of material which has been identified to date, we estimate that our Haleakala collections contain well over 400 species of insects and other arthropods, of which approximately 250 species are Hawaiian Island endemics (greater than 60% of the total fauna), and at least 50 species are known only from Haleakala. The collections contain a substantial number of undescribed endemic insects, several of which had not been collected previously (e.g., a new flower-infesting tephritid fly associated with the Maui wormwood, Artemesia mauiensis). On the other hand, several endemic species previously described from Haleakala are not represented in our material.

We estimate that our collections contain around 70-80% of the terrestrial arthropod species which occur in the highlands of

1 Published with the approval of the Director of the Hawaii Agricultural Experiment Station as Journal Series No. 2253.
Haleakala. However, the wetter environments found within the Park are relatively poorly represented in our material. Collections from Paliku and vicinity contain a number of rain forest associated elements which were not taken elsewhere within the Park, but the Paliku fauna appears to be a relatively depauperate segment of the richer wet forest insect faunas which occur outside the Park boundaries, and, probably, within the Kipahulu extension. Should collections from the Kipahulu area become available for study, we anticipate that the present checklist would have to be greatly expanded.

Collecting Methods and Results

The beating net proved to be the most productive tool for sampling the insect faunas associated with various species of shrubs and small trees which dominate the flora of the higher elevation ecosystems of Haleakala. Hand picking, while sorting through leaf litter and bunch grasses, and searching beneath loose stones were most effective for sampling the litter and soil associated forms, many of which are flightless. Pitfall traps proved useful in some situations for sampling nocturnally active ground dwellers such as carabid beetles. Aerial nets were used to some extent to sample diurnal flying insects such as the Odonata, Diptera, Aculeate Hymenoptera, and diurnal Lepidoptera. A malaise trap proved to be productive of flying forms in some areas where suitable sites for erection of the trap were available. A battery-powered ultraviolet light trap was operated at a number of sites, both within the crater and on the west rim, with generally good results. The light trap yielded primarily noctuid moths, both endemic and introduced species, frequently in large numbers. In comparison to similar traps which have been operated elsewhere, relatively small numbers were obtained of species belonging to such moth families as the Geometridae and Pyralidae, which normally are attracted to light in large numbers, except at Paliku where some night-flying rain forest-associated elements occurred. It appeared that, except for the Noctuidae, there was relatively little nocturnal flight activity in most of the areas sampled. This may have been a consequence of the relatively low night temperatures which prevail on Haleakala at elevations above 1800 m. Some species which belong to groups that are usually night fliers, appear to be primarily day fliers on Haleakala. For example, Eupithecia scoriodes (Meyrick), a geometrid moth endemic to Haleakala, was often taken while flying in daylight, but never taken in our light trap.

The endemic insect fauna of the Hawaiian Islands is characteristically disharmonic, with many of the major taxa very poorly represented or completely absent (Perkins, 1913; Zimmerman, 1948). The fauna endemic to the higher elevations of Haleakala is particularly depauperate as some elements which are better represented in endemic faunas of lower elevations (e.g., many of the endemic weevil genera; the orthopteroid families Gryllidae and Tettigoniidae) are virtually or completely absent in the higher and drier ecosystems of Haleakala. Some of the more successful groups which have been able to occupy these high altitude
areas include the planthoppers (Delphacidae) and mealybugs (Pseudococcidae), the seed bugs (Lygaeidae), plant bugs (Miridae), and the predaceous Nabidae, among the Hemiptera; the Hemerobiidae (Neuroptera); the Carabidae (Coleoptera); the Tephritidae (Diptera); certain elements of the Lepidoptera, particularly the Noctuidae but also some of the Geometridae, Pyralidae, Xylorictidae, and Cosmopterygidae; and the Aculeate Hymenoptera, represented by the Eumenidae (Odyneurus) and Sphecidae (Ectemnius) and the Hylaeidae (Nesoprosopis).

It is possible to make some further generalizations concerning the endemic arthropods of the high elevation ecosystems of Haleakala, based upon collections and associated ecological data obtained during the RBI survey, plus information derived from earlier collections and publications.

1) The non-native insect fauna (recent adventives) of Haleakala includes a number of temperate climate (Holarctic or Nearctic) species which do not occur in lowland areas of the state, although many are found at the higher elevations on other islands (e.g., the syrphid fly, Eristalis tenax (L.); the vespid wasp, Vespula vulgaris (L.); the brown lacewing, Hemerobius pacificus Banks; and the ensign scale, Arctorthezia occidentalis (Douglas), and several species of aphids.

2) Among the endemic phytophagous insects, particularly the Hemiptera, most groups exhibit a high degree of host specificity. Thus, among the mealybugs (Pseudococcidae), planthoppers (Delphacidae), plant bugs (Miridae), and seed bugs (Lygaeidae) most species appear to be restricted largely to one or a few closely related species of native hosts. There are exceptions, such as the mealybug Pseudococcus nudus Ferris, which, although restricted in distribution to elevations above 1800 m, infests several unrelated native plants (i.e., Dubautia, Styphelia, and Vaccinium).

3) Many of the most precinctive endemics are flightless insect species which belong to groups that are usually capable of flight. For example, the flightless endemic ground beetle genus Mecyclothorax Sharp (Carabidae) attains its greatest diversity on East Maui with 36 described species on Haleakala (out of 86 known species), only one of which is known elsewhere (West Maui). Other unusual flightless elements of the Haleakala insect fauna include the xyloricid moth, Hodegia apatella Walsingham; the flightless lacewings (Hemerobiidae) Pseudospectra lobipennis Perkins, P. cookeorum Zimmerman, and Nesothauma haleakalae Perkins; a flightless dolichopodid fly, Campsicnemis haleakalae Zimmerman; and a flightless reduviid bug, Saicella smithi Usinger. It should be pointed out that most of the genera mentioned contain other flightless species which occur elsewhere in Hawai'i.
4) There are many similarities between the high altitude endemic insect fauna of Haleakala and those of Mauna Loa, Mauna Kea, and Hualalai on Hawai'i. Many species are common to both islands. Other elements of the Haleakala fauna are represented on Hawai'i by closely related species which occur in similar environments (e.g., the large endemic Haleakala ground beetle, Barypristus rupicola [Blackburn] and its Hawai'i counterpart, B. incendarius [Blackburn]). However, there are some elements of the Haleakala fauna which appear to be unique to that mountain, and for which homologues apparently do not exist on Hawai'i; for example, the large day-flying geometrid moth Megalotica (Megalotica) holombra (Meyrick). The high altitude insect fauna of Haleakala seems to be slightly more diverse than that of Hawai'i, although this may be due, in part, to more thorough collecting.

LITERATURE CITED


Analyses have been undertaken to determine the extent to which temporal patterns can be seen in the biota sampled in the IBP studies. Particular attention has been given to the quantitative analysis of these trends to test their correspondence to temporal and general climate patterns and specific climatic events. These patterns will be discussed relative to specific organism groups.

Conclusions will be drawn as they relate interspecific relationships and temporal phasing to problems of island ecosystem stability.

* Abstract
I am delighted to be here this morning representing Director Callaham, our Station Director. He regrets being unable to be here but sends his greetings and enthusiastic endorsement of the development of this Center, which includes the new field laboratory for our Experiment Station. Everyone in the Forest Service had planned and hoped to have our building in place by the time of this dedication. But our building is now on a boat somewhere this side of Oakland. Ordered from the factory in Oakland last March, it is expected to arrive at any moment.

Ours will be a carbon copy of the building purchased by the Fish and Wildlife Service. Attractive siting was planned by Tom Fake of the National Park Service. Only by piggybacking on the order for a building by the Fish and Wildlife Service and having strong support by the Park Service were we able to get this new facility. Their cooperation and help made it all possible.

This new field lab will provide space for eight of our scientists and technicians who will work here most of the year. They belong to one of the four research projects of our Institute of Pacific Islands Forestry. The aim of this project is to provide technology for maintaining native Hawaiian forest ecosystems. Their particular purpose is to learn more about the habitat requirements of endangered forest birds on the Big Island. Emphasis so far has been in the Kilauea Forest Reserve--Keahou land area. We are starting new work on the Hawaiian Crow and endangered plants. C. J. Ralph, leader of this research project, and his associates will be speaking on these subjects today.

This new field laboratory certainly will expedite our research. Most of the researchers' time is spent in the field, establishing plots, capturing and examining birds, and carefully monitoring them as they feed, rest, seek cover, and nest. The lab will give our research team a place to work on equipment, analyze data, and do some bench-related research. Most important, its location here in this Research Center will enable our people to share experiences, ideas, and resources with others. Such a place is vital to the success of our research program.
We in the Forest Service are excited about joining our research forces with others who will work here at the Hawaii Field Research Center. The National Park Service is to be commended for its initiative and hospitality which brought us all together. The environment is bound to be synergistic, causing each to produce more than if we were working alone. Such synergism is essential, for there is a greater need for knowledge than there is a research capacity to produce it. We expect and know that this Center will foster cooperation, coordination, and mutual concern, enabling all of us to find the answers we seek.
HYBRIDIZATION IN THE HAWAIIAN SILVERSWORD COMPLEX

Gerald D. Carr
Department of Botany
University of Hawaii at Manoa
Honolulu, Hawaii 96822

The Haleakala silversword (Argyroxyphium macrocephalum) Gray is one of Hawai'i's most well-known and publicized endemic plants. Each year it is in fact sought out by hundreds of tourists including many botanists from all parts of the world. However, the 'ahinahina (A. macrocephalum) is only one of six species in the genus Argyroxiphium which includes plants called greenswords as well as those called silverswords. The silver-sword ordinarily produces a basal rosette of leaves for a number of years before it finally produces a single massive, elongated capitulescence and dies. The floral heads of sword plants are characteristically large and provided with rays. They are found on Hawai'i and Maui, growing in cinder or, as in the case of A. virescens Hbd., in boggy areas like greensword meadow in the upper Hana rain forest on Maui.

Wilkesia, the iliau, is a related bitypic genus which has a growth pattern similar to that of sword plants. It is endemic to dry slopes in and near Waimea Canyon, Kaua'i.

In marked contrast to Argyroxiphium the related Hawaiian endemic genus Dubautia (including Railliardia) is comprised largely of woody, branching shrubs that produce small, rayless heads year after year. However, the genus shows a truly remarkable spectrum of variation from largely herbaceous, low-growing forms like D. scabra (DC.) Keck in dry, pioneer habitats as well as rain forest situations through woody shrubs or small trees like D. linearis (Gaud.) Keck and D. arborea (Gray) Keck in dry sites; and D. raillardioides Hbd. and D. knudsenii Hbd. in wet sites to larger trees like D. reticulata (Sherff) Keck in the vicinity of Pu'u Nianiau. One striking species (D. latifolia [Gray] Keck) from Kaua'i is a large liana with a basal diameter of up to three inches. Altogether there are about 25 species of Dubautia including those called na'ena'e or kupaoa and collectively they are distributed from Kaua'i to Hawai'i.

Field Observations

Dubautia scabra is a widespread species with considerable ecological amplitude and thus comes into contact with several other species of Dubautia. Often the result is spontaneous hybridization as is the case in the upper Hana rain forest. Here the diminutive D. scabra is sympatric with an undescribed large
shrubby Dubautia and numerous hybrids between the two have become established. These hybrids have been given at least four names (Raillardiella ternifolia Sherff, R. thyrsiflora Sherff var. cernua Sherff, R. coriacea Sherff, and R. demissifolia Sherff var. dolichophylla St. John). The hybrid plants have an intermediate morphology and pale lemon-yellow flowers, a color that readily distinguishes all known hybrids involving the white-flowered D. scabra.

A second hybrid combination occurring in large numbers also involves D. scabra. In several areas on Hawai‘i, including Hawaii Volcanoes National Park, D. ciliolata (DC.) Keck and D. scabra are sympatric. In these instances hybrids between the two have invariably been found. The hybrid morphology is intermediate between the shrubby D. ciliolata and the subherbaceous D. scabra and again the flower color is pale lemon-yellow. These plants have been referred to as D. ciliolata var. laxiflora (DC.) Keck.

A third instance of hybridization involving D. scabra occurs in the vicinity of Pu‘u Nianiau, Maui, where one hybrid with the large tree, D. reticulata, has been detected. The hybrid is a very diffuse, spreading plant about 2 m tall. As one would expect it also has pale lemon-yellow flowers.

In the same area, within 50 m of the previous hybrid occur two hybrids between D. scabra and D. plantaginea Gaud., a large shrubby, wide-leaved species. The hybrids are somewhat pendulous and viney with ascending shoot tips and lemon-yellow corollas. They have been given the name Raillardiella lonchophylla Sherff var. stipitata (Sherff) Sherff and I suspect that plants of this hybrid combination also occur elsewhere and have been ascribed other names.

Only one hybrid Dubautia combination has been documented from O‘ahu. Two individuals of the combination D. sherffiana Fosb. x D. plantaginea have been detected in widely separated locations in the Wai‘anae Mts. Both parents are shrubs with orange-yellow flowers and as one might expect, the hybrids are not as morphologically distinct as in the previous cases.

The most spectacular instance of hybridization in this complex occurs in Haleakalā on Maui. There, Argyroxiphium macrocephalum, an essentially monocarpic rosette plant with large, radiate heads hybridizes spontaneously with the scrubbly, woody Dubautia menziesii (Gray) Keck having small rayless heads that are produced annually. The hybrid is somewhat intermediate in appearance (cf. Kobayashi, 1973). It produces tufts of leaves usually on three or more branches, each of which eventually flowers and dies independently. The hybrid has heads of intermediate size with small yellowish distorted rays.
Cytology

The difference between this and other studies of hybridization involving Hawaiian taxa is that in these instances hybrids can be identified with certainty through an analysis of chromosome pairing during meiosis in floral buds. In each of these cases the parents are differentiated chromosomally and these differences can be positively detected at meiosis. In every hybrid except D. scabra x D. plantaginea the diploid chromosome number is 2n = 27, indicating in these instances that one parent furnished 13 chromosomes and the other parent furnished 14. In all cases the chromosome numbers of the parents are consistent with this argument (cf. Carr, 1978). Although D. plantaginea and D. scabra both have 14 pairs of chromosomes, hybrids between the two can be readily recognized at meiosis by virtue of the fact that their genomes are differentiated by two reciprocal chromosome translocations resulting in the appearance of two chains of 4 chromosomes each (cf. Table 1).

These meiotic perturbations result in the inviability of some of the gametes formed. This depression of fertility can be assessed by the staining reaction of pollen grains in certain dyes like cotton blue. Genetic differentiation between parents can also cause low viability and thus low pollen stainability in hybrid plants. Pollen stainability in the hybrids discussed herein ranges from 6 to 86% (Table 1).

Conclusion

In spite of the spectacular morphological and ecological diversity exhibited by these genera, the occurrence of many intergeneric, intersubgeneric, and interspecific hybrid combinations under field conditions attests to the fact that they form a thoroughly natural, genetically cohesive group that has in all probability resulted from rapid evolutionary differentiation of a single colonizing progenitor. Collectively, these plants constitute what may be considered an unparalleled example of adaptive radiation and as such are exceedingly interesting to students of evolutionary phenomena.

LITERATURE CITED


TABLE 1. *Dubautia* and *Argyroxyphium* spontaneous hybrids.

<table>
<thead>
<tr>
<th>Combination</th>
<th>Number Examined/Seen</th>
<th>Pollen Stainability</th>
<th>Diploid (2n) Chromosome Number</th>
<th>Meiotic Configuration</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>D. scabra</em> x <em>D. n. sp.</em></td>
<td>5/many</td>
<td>57</td>
<td>27</td>
<td>$12_{II} + Ch_3$</td>
<td>Maui</td>
</tr>
<tr>
<td><em>D. scabra</em> x <em>D. ciliolata</em></td>
<td>12/many</td>
<td>76</td>
<td>27</td>
<td>$12_{II} + Ch_3$</td>
<td>Hawai'i</td>
</tr>
<tr>
<td><em>D. scabra</em> x <em>D. reticulata</em></td>
<td>1/1</td>
<td>86</td>
<td>27</td>
<td>$12_{II} + Ch_3$</td>
<td>Maui</td>
</tr>
<tr>
<td><em>D. scabra</em> x <em>D. plantaginea</em></td>
<td>1/2</td>
<td>35</td>
<td>28</td>
<td>$10_{II} + 2 Ch_4$</td>
<td>Maui</td>
</tr>
<tr>
<td><em>D. plantaginea</em> x <em>D. sherffiana</em></td>
<td>2/2</td>
<td>41</td>
<td>27</td>
<td>$10_{II} + Ch_4 + Ch_3$</td>
<td>O'ahu</td>
</tr>
<tr>
<td><em>A. macrocephalum</em> x <em>D. menziesii</em></td>
<td>2/14</td>
<td>6</td>
<td>27</td>
<td>$9_{II} + 3 Ch_3$</td>
<td>Maui</td>
</tr>
</tbody>
</table>
Evolution is an extremely active process on islands, even in highly isolated archipelagos like Hawai'i and Galapagos. Species formation is frequently exuberant and, in many cases, wholly novel adaptations have developed. At first glance, it seems remarkable that this should be true because it is clear that in many relevant instances the lineage which evolves actively in the islands can be traced ultimately to one or only a few continental founder individuals. Even more founder effects appear to occur as new species are formed within an archipelago. On the surface, this appears to be a system which might deplete genetic variability and thus reduce evolutionary potential. Precise data on genetic variation within island species of Drosophila flies have been accumulating now for about 15 years. Modern methods of analysis of genetic variability (biochemical, chromosomal, and polygenic) have been employed to assay genetic variability in various endemic and introduced species. Virtually without exception, these species have local populations which are fully as polymorphic genetically as those of widespread continental species. Accordingly, such populations are highly competent for adaptive evolution. Most island species, however, have small total populations. Thus, even though the local populations may be rich in genetic variability, the total variability sequestered within continental species is certainly much larger, but this does not appear to be a crucial difference. In high-altitude archipelagos like Hawai'i, many factors promote isolation. The serial isolations to which island populations are subjected have a profound effect on their genetic structure. This is true not only for populations between islands (species formation is by interisland founder effects) but also for local populations within an island or even a volcano.

As long ago as 1932, Sewall Wright proposed that the conditions most favorable for rapid evolutionary change exist within a species which is subdivided into local semi-isolated populations, some of which have quite small effective sizes. Many island species appear to reflect precisely this dispersive type of population structure and this may explain their observed evolutionary momentum.

In addition to IBP support, this work has been supported by grants GB 27586, 29288, and BMS 22532 from the National Science Foundation.
INTRODUCTION

A disease syndrome characterized by dark necrotic areas of the exoskeleton has been reported in a number of aquatic crustaceans (Rosen 1970). The syndrome has been called black spot disease, brown spot disease, rust disease, burnt disease, and shell disease. Shell disease was reported in the American lobster, Homarus americanus, by Hess (1937). The disease in this species was thought to be promoted by crowded condition of the lobster holding pens. Similarly, Alaskan king crabs, Paralithodes sp., often developed necrotic "rust" spots when held in captivity. The "rust" appeared to be superficial infections occurring most commonly on the ventral body area at natural breaks and abraded surfaces (Bright, Durham, & Knudsen 1960). Rosen (1967) described a necrotic shell disease of American blue crab, Callinectes sapidus, collected from shedding pens in Crisfield Harbor, Maryland. The crabs had been crowded into enclosures until ecdysis yielded the more desirable "soft-shell" crabs. While the shell disease syndrome is most discernible among crustaceans held in captivity, its occurrence has been reported among crustaceans in their natural habitat. More (1969) reported severely eroded carapaces among blue crabs, C. sapidus, caught in Galveston Bay, Texas. And recently Iversen and Beardsley (1976) reported shell disease among marine crustaceans of South Florida. They found pitted, darkened carapaces among the commercially important stone crab Menippe mercenaria, and several other species.

Shell disease has also been reported in a freshwater prawn, Macrobrachium rosenbergii (Sindermann 1974) and is believed to occur among pond reared specimens in Hawai'i (R. Nakamura, pers. comm.). The presence of shell disease in M. rosenbergii is not surprising since Kubota (1972) reported a severe necrotic shell disease in a closely related species, the Tahitian prawn, M. lar in Kahana Stream on O'ahu.

This study describes the shell disease syndrome in the Hawaiian freshwater atyid shrimp, Atya bisulcata, with emphasis on the frequency of occurrence, the nature of the lesion, and its etiology.
MATERIALS AND METHOD

Collection and Examination of Shrimp

Shrimp specimens were captured from various coastal streams in an area bounded by Hilo to the south and Waikamalo Stream to the north. In this area, characterized by high annual rainfall, streams run throughout the year and support some of the largest populations of atyid shrimps on the island. The majority of our specimens were collected from the Wailuku River, which borders Hilo, and Pukihae Stream a few miles to the north.

In the Wailuku River with its deep pools, shrimps were captured by diving with hand-held scoop nets of 0.25-inch mesh. In smaller, shallow streams, the net was simply held underwater and rocks immediately upstream were overturned. The dislodged shrimps were then swept into the nets and captured. Specimens were transported back to the laboratory in Styrofoam chests for examination before returning them to the stream. In some cases, specimens were preserved in 2% formalin for later examination.

Examination of Specimens for Lesions

All specimens brought into the laboratory were initially examined with a Nikon SMZ Stereomicroscope at 10X magnification with an attached ring lamp for illumination. Live specimens had to be cooled in ice water at 5-7°C to facilitate handling of the otherwise very active shrimp. The numbers, size, and location of lesions were noted along with the size and sex of each shrimp. Specimens selected for scanning electron microscopy (SEM) were dissected, dehydrated in an alcohol/acetone series and followed by critical-point drying in amyl acetate or acetone to minimize shrinkage and distortion (Hayat 1978). Specimens were then mounted on aluminum stubs with colloidal silver paint and coated with evaporated gold. Examination was made with an ETEC Autoscan Model U-1 at 20 kv accelerating voltage.

Isolation of Chitinoclastic Bacteria

Lesions selected from newly captured shrimp were aseptically excised and macerated in a sterile mortar and pestle to form a fine slurry. The resultant slurry was diluted 10-fold in sterile water and a 0.1 ml aliquot inoculated onto chitin overlay agar by the spread plate method. Inoculated plates were incubated at 25°C for a minimum of a week and observed for signs of chitin digestion. Chitinoclastic colonies showed a clear halo around the colony as a result of the dissolution of the opaque chitin particles (Skerman 1959). Colonies showing distinct chitinoclastic activity were isolated, purified, and maintained on nutrient agar.
Induction of Lesions

To induce lesions, specimens were abraded carefully to remove just the epicuticle. This was accomplished by using a high speed hand drill fitted with a fine abrasive bit. To facilitate handling, the shrimps were first cooled in ice water at 5-7°C for 10 min and strapped onto a polyethylene foam sheet (Nalgene) with nichrome wire hoops. Just prior to abrading, the shell was swabbed with 70% ethanol.

Abraded animals were then rinsed in tap water and transferred to 500 ml of sterile stream water in 1-liter beakers and covered with aluminum foil. Usually, 3 to 5 animals were contained in each beaker. A buffered washed suspension of a 48-hour culture of chitinoclastic bacteria was added to each beaker to achieve an initial cell density of about $10^5$ cells per ml. As a control, an identical beaker was used without inoculated bacteria. Also, a control was set up with $10^{-5}$ M thimerosal added as a bacterial inhibitor.

To determine whether cuticle abrasion was necessary for lesion formation, the wounds of some specimens were sealed immediately after abrasion. These specimens, sealed with Cutex clear nail polish, were subjected to the same incubation conditions as specimens with fresh abrasions.

The test animals were maintained in their containers at ca. 25°C for up to a month with inspection for lesions initiating after one week.

RESULTS AND DISCUSSION

A total of 3423 specimens were collected from various Hilo coast streams. Lesions were found in 582 (17%) of the specimens. Table 1 is representative of lesion incidence found in three streams during March 1976. The Wailuku River site yielded the highest incidence of lesions. Ka'ie'ie Stream, the smallest of the three, had the lowest incidence. Of the three streams, Wailuku River sites consistently yielded the highest incidence of shell lesions. This may be related, in part, to the physical-chemical characteristics of the stream. The greatest volume, water velocity, and silt load are found in the Wailuku River. High silt load and lesion incidence might be related since it has been suggested that abrasive action in the environment could lead to lesion formation (Bright et al. 1960).

The data in Table 1 also shows a significantly higher proportion of female shrimp developing lesions. Not only did female shrimp develop lesions more frequently, they also had more lesions per individual. In this sample period, some females had as many as 30 lesions. Almost all had more than one. By contrast, males often had but a single lesion.
This difference may be explained in part by the observation that most of the females were bearing eggs. During their ovigerous condition, the females do not molt. Hence, lesions have a longer period in which to develop and to become visible. By contrast, the males have no such constraint and molt more frequently. Upon ecdysis, the animal is generally freed of its lesions. In some individuals, however, previous infection is evidenced by a "scar" or a deformation of the new exoskeleton at the site of the former lesion. This deformed cuticle is often the site of subsequent infection.

Extensive sampling of Wailuku River sites revealed a definite seasonal trend in lesion incidence. While lesions occurred among specimens throughout the year, the highest incidences were found in the winter months. A peak of 92% lesion occurrence was reached in February when the water temperature was 14°C. The lowest incidence of 4.7% was recorded in July when water temperature was 24°C. It appeared that the trend in lesion occurrences was inversely related to stream temperature. This unexpected observation may be explained by the fact that lower water temperature would retard the rate of molting, i.e., the intermolt period was lengthened. Again, longer retention of the exoskeleton allows for greater development of the necrotic lesions.

The distribution of lesions on the body surface of *A. bisulcata* is shown in Table 2. The areas most frequently affected were the cephalothorax and the abdominal segments. This is not surprising since these two body parts offer the greatest exposed surface areas. What is surprising is that the vast majority of lesions occurred on the dorsal or lateral surfaces of the shrimp. Rosen (1967) had shown the ventral surfaces of the blue crab to be the site of intense necrotic lesions. Similarly, Bright et al. (1960) attributed the intensity of lesions occurring on the ventral surfaces of Alaskan king crab to mechanical abrasion by the substrate. It appears that the ventral surfaces and appendages of *A. bisulcata* are relatively protected from abrasive water-borne silt particles and are, therefore, less susceptible to damage and lesion formation.

Current opinion indicates that exoskeletal lesions in crustacea are in part due to chitin-digesting microorganisms—particularly bacteria. Rosen (1970) and Cook and Lofton (1973) have suggested a causal role for chitinoclastic bacteria. In their studies, the bacteria with chitin-digesting ability had been isolated from diseased hosts. However, controlled reinfection experiments were lacking. In this study, chitinoclastic bacteria were consistently isolated from lesions of *A. bisulcata* (Table 3). For comparison, lesions of *M. lar* from the same stream were also examined and found to consistently yield chitinoclastic bacteria. It was found that even the "normal" cuticle of the atyid shrimp would occasionally yield chitinoclastic bacteria. The chitinoclastic bacteria isolated from normal cuticle may have been associated with undetected early stage
lesions. Or they may be part of the normal microflora. Chitinoclastic bacteria are anything but rare in the stream environment. At times they reached over 50,000 per ml of stream water and made up a substantial proportion of all the bacteria present in streams we sampled.

The chitinoclastic bacteria isolated from A. bisulcata were of two types. The majority of isolates were gram negative rods, motile by polar flagella, facultatively anaerobic, and glucose fermentors. These isolates appear to fit the description of the genus Beneckea as proposed by Baumann, Baumann, and Mandel (1971). The other isolate was characterized by bright orange colonies on agar plates and consisted of gram negative, slender rods with gliding motility. The gliding motility is typical of members of the genus Cytophaga. Both the Beneckea and Cytophaga type of isolates showed strong chitinoclastic activity under aerobic condition, but none when incubated anaerobically.

To establish the etiology of the necrotic lesions, pure cultures of chitinoclastic bacteria were used in reinfection experiments. A particularly active Beneckea type, designated WCh-1, was used for the induction of lesions. Table 4 shows that A. bisulcata, abraded to damage the outer cuticle surface, always developed necrotic lesions when confined in a system with abundant chitinoclastic bacteria. Likewise, abraded shrimp confined in raw stream water also consistently developed lesions. Water as taken directly from the stream always contained numerous chitinoclastic bacteria. It was believed that these autochthonous bacteria serve as an infectious reservoir in the stream. When stream water was sterilized (Millipore membrane filter, 0.45 μm pore) or thimerosal added as a bacteriocidal agent, necrotic lesion formation was markedly suppressed. In the few instances where lesions did form in supposedly "sterile" conditions, chitinoclastic bacteria were subsequently found. It appears that residual fecal pellets were a source of the bacteria which contaminated the system and overwhelmed the suppressive capability of the thimerosal.

To show that epicuticular damage was indeed necessary for the initiation of lesions, as suggested by Rosen (1970), abraded test animals were compared to similarly treated specimens in which the abrasions were sealed water tight with clear nail polish. The results in Table 5 show a striking difference. Damaged cuticle when exposed to raw stream water containing chitinoclastic bacteria invariably developed necrotic lesions. Those with sealed wounds never developed lesions unless the seals were faulty and leaking.

In all attempted isolations, the artificially induced lesions yielded chitinoclastic bacteria—almost exclusively of the Beneckea type. Scanning electron microscopy of the naturally occurring lesion and artificially induced lesion showed a remarkable similarity. In both cases, extensive erosion of the cuticle is evident and large aggregations of bacteria are seen. By contrast, areas free of abrasive damage or erosion are essentially
free of bacteria. The activity of these bacteria on the chitinous substrate very closely resembles that described by Akin and Amos (1975) for cellulolytic bacteria and their degradation of cellulosic plant material. In both cases, the production of exoenzymes is likely responsible for hydrolytic degradation of the substrate.

This study has shown that necrotic exoskeletal lesions are common to the endemic Hawaiian freshwater shrimp, A. bisulcata. The causal agent of these lesions have been shown to be chitinoclastic bacteria which are ubiquitous in the stream environment and probably a component of the shrimp's microflora. Stream conditions which lead to damage of the cuticle—primarily the epicuticle layer—exposed the cuticle to bacterial invasion. Establishment of chitinoclastic bacteria on the cuticle and subsequent degradation of the chitinous substrate result in formation of a necrotic lesion. The dark coloration characteristic of these necrotic areas is due to melanization of hemocytes which aggregate underneath the developing lesion.

ACKNOWLEDGEMENTS

The author wishes to acknowledge the support provided by the National Institute of Health Minorities Biomedical Support Grant No. 5 S06 RR 08073-06 GRS and an additional grant from the Environmental Center, University of Hawaii. I am grateful to Messrs. Alfred Menino, Jr., Jason Moniz, Mark H. K. Greer, Rory Murata, and Miles Nagata for their assistance in various phases of this study. Mr. Ken Lesch, San Francisco State University, provided invaluable assistance in scanning electron microscopy.
LITERATURE CITED


TABLE 1. Occurrence of exoskeletal lesions in *Atya bisulcata* from selected Hawai‘i Island streams (% in parentheses).

<table>
<thead>
<tr>
<th>Sampling Site</th>
<th>Number of Specimens</th>
<th>Specimens with Lesions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total Female Male</td>
<td>Total Female Male</td>
</tr>
<tr>
<td>Wailuku River</td>
<td>242 30 212</td>
<td>163 27 136 (67.4) (90.0) (64.2)</td>
</tr>
<tr>
<td>Ka'ie'ie Stream</td>
<td>243 45 198</td>
<td>17 9 8 (7.0) (20.0) (4.0)</td>
</tr>
<tr>
<td>Pukihae Stream</td>
<td>363 146 216</td>
<td>135 64 71 (37.3) (43.8) (32.9)</td>
</tr>
</tbody>
</table>

TABLE 2. The location of exoskeletal lesions in *Atya bisulcata* from Wailuku River, Hawai‘i.

<table>
<thead>
<tr>
<th>Body Part</th>
<th>Number* of Lesions</th>
<th>Percent of Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cephalothorax</td>
<td>27</td>
<td>33.8</td>
</tr>
<tr>
<td>Abdomen Segments</td>
<td>47</td>
<td>58.8</td>
</tr>
<tr>
<td>Telson &amp; Uropod</td>
<td>2</td>
<td>2.5</td>
</tr>
<tr>
<td>Walking Legs</td>
<td>2</td>
<td>2.5</td>
</tr>
<tr>
<td>Swimmerets</td>
<td>2</td>
<td>2.5</td>
</tr>
<tr>
<td>Total</td>
<td>80</td>
<td></td>
</tr>
</tbody>
</table>

* 36 lesions on left side, 30 lesions on right side, and 14 lesions located medially.
### TABLE 3. Isolation of chitinoclastic bacteria from exoskeletal lesions.

<table>
<thead>
<tr>
<th>Source</th>
<th>Number of Lesions Sampled</th>
<th>Lesions Yielding Chitinoclasts Number</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atya bisulcata lesion</td>
<td>24</td>
<td>23</td>
<td>95.8</td>
</tr>
<tr>
<td>Macrobrachium lar lesion</td>
<td>17</td>
<td>14</td>
<td>82.3</td>
</tr>
<tr>
<td>A. bisulcata normal cuticle</td>
<td>24</td>
<td>4</td>
<td>16.7</td>
</tr>
</tbody>
</table>

### TABLE 4. Induced exoskeletal lesions in Atya bisulcata.

<table>
<thead>
<tr>
<th>Test Conditions</th>
<th>Total Specimens</th>
<th>With Lesion</th>
<th>Percent Without Lesion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chitinoclastic Bacteria in sterile stream water</td>
<td>33</td>
<td>100</td>
<td>0</td>
</tr>
<tr>
<td>Raw stream water</td>
<td>16</td>
<td>94</td>
<td>6</td>
</tr>
<tr>
<td>Sterile stream water with Thimerosal, $10^{-5}M$</td>
<td>20</td>
<td>15</td>
<td>85</td>
</tr>
</tbody>
</table>

### TABLE 5. The development of exoskeletal lesions in Atya bisulcata with abrasions. (Specimens were held in raw stream water at 25°C for a minimum of 8 days.)

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Total Number of Specimen</th>
<th>Number of Specimens Developing Lesions</th>
<th>Number of Specimens Without Lesions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abraded only</td>
<td>25</td>
<td>25</td>
<td>0</td>
</tr>
<tr>
<td>Abraded and sealed</td>
<td>15</td>
<td>1</td>
<td>14</td>
</tr>
</tbody>
</table>
Myrica faya was introduced to the Hawaiian Islands sometime in the late 1800's. In the mid-1940's the Territorial government had recognized the plant as an aggressive weed and a threat to pasture land. Intense eradication measures and bio-control efforts were instigated by the Territorial and State governments throughout the years, but by 1962 infestation had affected over 21,000 acres with over 80% of the acreage situated on Hawai'i Island. Recently, M. faya has come of interest to Hawaii Volcanoes National Park as a possible threat to native forest systems, and is now being evaluated for various control methods.

A survey of M. faya distribution within the Park was undertaken during a seven-week period from December 1977 to January 1978. Data collection was accomplished through direct field observation, helicopter surveillance, and to a lesser degree aerial photographs.

Findings revealed that M. faya distribution constitutes a horizontal band between 2200 feet and 4000 feet elevation from Namakanipaio southeast to Panau. Infested areas were mapped and estimated densities established. Information concerning dispersal mechanism, germination rates, control measures, and habitat diversity are noted. Other aggressive exotics were recorded as observed during M. faya mapping.

M. faya was detected to be a very formidable foe to the native ecosystems within the Park. The ability of this tree to cover large areas within a matter of years is recorded. A realistic approach coupled with applicable research is needed in an effort to understand and control this problem.

* Abstract
FOREST BIRD POPULATIONS ON O'AHU

Mark S. Collins¹ and Robert J. Shallenberger²

For the past three years Ahuimanu Productions has conducted various environmental assessments that have led to a greater understanding of the abundance and distribution of O'ahu's forest birds. Beginning in June of 1976 with a brief survey of South Halawa Valley, a series of four avifaunal surveys was conducted in consideration of the alternate routes for the proposed H-3 trans-Ko'olau highway (1, 2, 3, 5). The most intensive as well as extensive survey of the series was initiated on December 19, 1977, and was completed on March 9, 1978. This most recent survey involved 200 man-days in the field and was conducted in eight central Ko'olau valleys and ridges extending from Moanalua Valley in the south to Poamoho Trail in the north. In addition a bird and mammal survey of Army lands on O'ahu and Hawai'i was conducted during 1976 to 1977 under contract to the Army Engineers Division, Pacific Ocean (5). As a part of this contract, a significant portion of the Northern Ko'olau Range and a less extensive area in the Wai'anae Range were surveyed for forest birds. The compilation of these avifaunal surveys represents the most intensive study of O'ahu's forest birds ever conducted.

In addition to extensive data on abundance and distribution of O'ahu's common forest birds, significant information gathered from these avifaunal studies include:

1) Observations that confirm the substantial range extension of three exotic species (Vanikoro Swiftlet, Red-vented Bulbul, Yellow-faced Grassquit) (3, 4, 5);

2) Three separate observations of the endangered O'ahu Creeper in the central Ko'olau Range (5);

3) The first nesting record for the Vanikoro Swiftlet in Hawai'i (5);

4) The probable sighting of a female O'ahu 'Akepa at the summit of Schofield-Waikane Trail (4);

¹ U. S. Forest Service, Hawaii Volcanoes National Park, Hawaii 96718.
² President, Ahuimanu Productions, Kailua, Hawaii 96734.
5) The observation of the "Mystery Garrulax" on Poamoho Trail, a bird that had not been seen in nearly two decades (5);

6) The discovery of a substantial population of 'I'iwi in the Wai'anae Range below Ka'ala (4).

Copies of these contracted survey reports are not currently available for mass distribution. However, the compiled data are now being prepared for future publication.


LEK BEHAVIOR AND ECOLOGY OF TWO
HOMOSEQUENTIAL SYMPATRIC HAWAIIAN DROSOPHILA:
DROSOPHILA HETERONEURA AND DROSOPHILA SILVESTRIS

Patrick Conant
Department of Entomology
University of Hawaii at Manoa
Honolulu, Hawaii 96822

According to Loiselle and Barlow (1978), "Lekking is the temporary synchronous aggregation of sexually active males for reproduction." It is a type of communal display. Theoretically, males displaying communally are more conspicuous and have a better chance of encountering females. Until recently, most of the research on lek behavior has been done on birds, especially grouse (Tetraonidae) and mannikins (Pipridae). Lekking in fish has only begun to be investigated (Loiselle & Barlow 1978) and reports of work on insect lek behavior are not numerous (Wilson 1975).

Spieth (1968) was the first to describe lek behavior in Hawaiian Drosophila. Two species of Hawaiian Drosophila that Spieth found to engage in lek behavior are Drosophila heteroneura and D. silvestris. Carson and Stalker (1968) found these two species to be homosequential, that is, the banding patterns on the polytene chromosomes are identical, indicating they are very closely related. They also found that heteroneura and silvestris share a polymorphic inversion, although silvestris has six other paracentric inversions.

Ahearn et al. (1974) found that in the laboratory, ethological isolation between heteroneura and silvestris was strong although incomplete. Unfortunately, quantitative comparisons of the action patterns observed in the courtships of these two species have not been made. Spieth (pers. comm.) has, however, found some qualitative differences.

Hybrid progeny of successful pairings in the laboratory are vigorous and fertile (Carson & Kaneshiro 1976). Recently, Kaneshiro has even collected hybrids in the wild at Kahuku Ranch on the island of Hawai'i (Kaneshiro & Val 1977).

The two flies belong to the Planitibia complex of picture wing Drosophila and are widely sympatric on the island of Hawai'i. The other two species that belong to this complex are differens found on Moloka'i and planitibia on Maui. Morphological, ethological, and chromosomal data indicate that these two flies are ancestral to heteroneura and silvestris (Kaneshiro 1976). It is most likely that planitibia is ancestral to silvestris. D. heteroneura may be derived from planitibia but differens is the more probable ancestor.
My objectives in this study were to observe and describe the lek behavior and ecology of these two species, and to determine if there were differences in these aspects of their systematics that would explain their reproductive isolation in the wild.

Two primary study areas were established on Kealakekua Ranch in Kona to study differences in habitat preference. The lower of the two sites (1067 m/3500 ft) was called Ha'au'u. It is in an 'ohi'a (Metrodiosideros sp.) forest with a dense tree fern (Cibotium sp.) understory. The higher study site (1304 m/4280 ft), called Oiki, was in a remnant 'ohi'a forest with scattered Acacia koa and diverse tree strata interspersed with open pasture.

Two other sites where observations were made were on Keauhou Ranch at 1432 m (4700 ft) near Hawaii Volcanoes National Park and Kahuku Ranch near South Point. The habitats where the flies occur on these two ranches are similar. Both sites are open pasture with small clumps of dense remnant 'ohi'a-tree fern forest. Observations were made at two separate elevations on Kahuku Ranch, 1058 m (3800 ft) and 1235 m (4050 ft).

Observations were also made in 'Ola'a forest at 1237 m (4060 ft) adjacent to the University of Hawaii Volcano Experiment Station. This forest is similar to the hapu'u study area; it is an 'ohi'a forest with a dense understory of tree ferns.

My observations of the behavior of heteroneura on food supported Spieth's contention that predation by birds acts as a selection pressure favoring the evolution of lek behavior in Hawaiian Drosophila. That is, courtship is not on the food as with most Drosophila, but on branch-territories nearby.

Mark-release experiments showed that marked flies often occupied the same branch when consecutive sightings of them were made. At morning and afternoon sightings, and at afternoon and the following morning sightings, marked flies had moved only small distances (about 0.5 m).

Field observations suggested that the morning temperature threshold for feeding behavior for both species is about 10°C (50°F). Males of both species alight on their branch-territories presumably after feeding. Males of both species were active at the lek if weather conditions remained optimal. Conditions outside these limits caused flies to remain inactive or to leave their branch-territories. Males of both species leave their territories near sunset. Temperature decrease below a threshold probably stimulates this behavior if decreasing sunlight does not do so first. No temporal differences in tendencies of the two species at their respective leks were evident.

The initial response of a heteroneura male to the approach of another arthropod moving on its territory is usually an approach, and is often followed by patrolling behavior, the repeated walking of a distance of 10 to 80 cm over a section of vegetation. Patrolling behavior is most often observed (in
either species) after an encounter with another arthropod; however, the frequency and duration of walks appears to decay with time. While on their territories male heteroneura frequently make short flights in an erratic path away from and back to their territory.

Patrolling behavior may perform three different functions. The visual stimuli of a patrolling male may serve to keep the males together, interacting and competing for territories. It may also attract females. Finally, patrolling may be a means by which the most fit males may defend territories and insure that they inseminate the females that alight there.

Female heteroneura (and presumably silvestris) are usually found at about the same height as the males (about 2 m) resting on the undersides of branches. Many hours of observations of male heteroneura on their territories revealed that females alighted on the territories infrequently.

Premating isolation can be maintained through two different means. Behavioral isolation between two species prevents them from exchanging genetic material. Through ecological isolation species are kept separate by the influence of environmental factors.

Differences in body color between the two species suggested they might be adapted to different levels of incident light under the forest canopy. However, the analysis of incident light level data measured on flies suggested that flies do not seek different light levels in their habitat. Instead the results lend support to the hypothesis that differences in body color (particularly abdomen color) may be most important as stimuli in mate recognition.

Observations on Kealakekua Ranch, Kahuku Ranch, and 'Ola'a forest did not reveal any differences between leks of the two species. Heights of male silvestris in vegetation at the different sites were all found to be about 2 m off the ground.

Observations at "shared lek sites" (leks under the same continuous canopy in close enough proximity that interspecific interactions were possible) did not reveal any differences in the leks of the two species at these shared sites. There was no species-specific preference for plants on which territories were defended. In fact, where branches or fern stipes were long enough, I occasionally saw males of both species "on station" (Spieth 1966) on the same branch or stipe. At certain of these shared lek sites some spatial separation of the two leks was evident. One possible explanation at certain sites might be that behavioral interactions might cause the flies to congregate where they only infrequently encounter the other species on the territories. Species-specific pheromones released into the air might also serve to keep both sexes of both species together at the lek but no evidence of this has been reported. Another resource, besides leks, these species shared was food. Often, both species were seen interacting on the same food.
Further evidence for resource sharing was found when both species were reared from the same decaying Clermontia branches collected on Kahuku Ranch.

The only ecological variables to which the two flies appeared to respond to differently were changes in moisture and pressure (that is, lapse rate) associated with elevation. Results of past collections of these species from different elevations on Kahuku and Keauhou ranches, Kilauea Forest Reserve, 'Ola'a forest, and kipukas on the Saddle Road, suggest that silvestris is more common at higher elevations. It is possible, however, that silvestris may just have a wider range of elevational distribution since it is always found where heteroneura occurs.

LITERATURE CITED


HAWAII IBP SYNTHESIS:
3. THE KILAUEA RAIN FOREST ECOSYSTEM*

Sheila Conant
Department of General Science
University of Hawaii at Manoa
Honolulu, Hawaii 96822

The analysis of this rain forest was focussed on its structure and dynamics with regard to both plant and animal life. Species were assessed quantitatively according to their life forms and ecological roles which they have assumed in the various general niches of this forest.

The structure and behavior of the forest plant community will be briefly characterized and the activity patterns of the birds, tree arthropods, and introduced mammals will be highlighted. A few conclusions will be drawn as to the maintenance trends of this ecosystem under natural conditions.

* Abstract
INTRODUCTION

In recent years the National Park Service has been working to develop a feasible and sound management program for lands included in the approximately 49,000 acres of the Kalapana Extension (Fig. 1), which was acquired by Hawaii Volcanoes National Park between 1938 and 1960 (National Park Service 1974). The first step in planning analysis has consisted largely of inventory-type research aimed at identifying and locating the resources of the Kalapana Extension. An up-to-date inventory of the avifauna was called for as part of this research.

Most of the information on birds presented in the Draft Planning Analysis (National Park Service 1974: Map D, henceforth Fig. 2 of this report) was based on data gathered by Baldwin (1953) more than 25 years ago. Surveys by Dunmire (1962) and Berger (1972), as well as verbal communications from other researchers, provided some additional data. It should be noted that the map shows only what were called "unimpaired" bird habitats. Presumably, some forest birds had and still have today more extensive distributions than is suggested by this map.

MATERIALS AND METHODS

In 1976 I began field surveys under contract with the Cooperative National Park Resources Studies Unit (CPSU). This report summarizes data collected through December of 1977, including observations reported to me by other researchers.

Censuses of birds were conducted using either Emlen's (1971) transect count method or Reynolds et al. (in press) variable circular plot method. For the rarer species not often detected during censuses, such as the 'Io (Buteo solitarius), sighting locations were recorded. Although I was unable to exhaustively survey all parts of the Kalapana Extension, I attempted to inventory the avifauna of the major habitats, concentrating my field work in the closed Metrosideros rain forests near Napau Crater where Baldwin (1953) had reported several endangered species. I was interested to know if these species still occurred in the areas listed as "unimpaired habitats" as of 1974 (Fig. 2).
RESULTS AND DISCUSSION

Fifteen exotic (63%), two indigenous (8%), and seven endemic (29%) bird species were observed during this study or by other researchers during the study period (Table 1).

Four native forest birds previously reported in or near the Kalapana Extension were not recorded there during this study. They are the 'O'ū (Psittirostra psittacea), the 'Akiapola'au (Hemignathus wilsoni), the Hawai'i 'Akepa (Loxops coccineus coccineus), and the 'I'iwi (Vestiaria coccinea). The first three are endangered species, and all belong to the Hawaiian Honey-creeper Family (Drepanididae). It seems doubtful that the 'Akiapola'au or the Hawai'i 'Akepa may still occur there, but recent sightings of the 'O'ū (W. E. Banko, pers. comm.) in the 'Ola'a Tract and near Park Headquarters and residences suggest that this species could still be found, very rarely, in the northernmost parts of the Kalapana Extension. In a brief, one-person survey such as mine, the species could easily be missed.

Because the native forest bird distribution plotted in Figure 2 included only "unimpaired habitats," it is impossible to determine whether or not the extent of native bird distribution has really changed. I suspect that present-day native forest bird distribution (Fig. 3), regardless of habitat quality, is essentially the same as it was in 1974. No doubt volcanic activity has reduced bird distribution since Baldwin's (1953) and Dunmire's (1962) studies due to habitat destruction. This change, as well as extensive alteration in forest habitats wrought by feral pig and goat activity and exotic plant invasion, may account, at least in part, for the disappearance of several forest bird species from the Kalapana Extension. There are virtually no "unimpaired" habitats remaining. It should be noted that the National Park Service (1974) report must have inadvertently omitted Hawai'i 'Oma'o (Phaeornis obscurus obscurus) from the forest birds listed in Map D.

Whether or not absolute densities of native birds have decreased or increased is not known because this information has not been available previously. If the indigenous Kolea (Pluvialis dominica) and Noio (Anous tenuirostris melanogenys) are included, native birds have been observed in virtually every type of habitat in the Kalapana Extension (Table 2).

Although rain forests of the Extension appear to be suitable habitats for most of the Hawai'i Island forest birds, these areas were unusually low in avian diversity, with 'Apapane (Himatione sanguinea sanguinea) and Hawai'i 'Oma'o dominating the avifauna, although Hawai'i 'Elepaio (Chasiempis sandwichensis sandwichensis) and 'Io also occurred there. In fact, the Kalapana Extension harbors the most extensive population of 'Oma'o to be found within Hawaii Volcanoes National Park. It is the only form of Phaeornis (Hawaiian thrushes) not yet considered endangered.
Notably and inexplicably absent from rain forests were the 'I'iwi and the Pueo (Asio flammeus sandwichensis). I feel these species may occur there, but because of their very low numbers, were not observed. Hawai'i 'Amakihi (Loxops virens virens) were present in mesic and dryland forests above 400 feet elevation, and Pueo and 'Io were recorded in lowland scrub. Kolea are likely to be found in any open grassy area between approximately September and April, and Noio can be seen regularly along the coastline.

The endemic passerines reached relatively low elevations, some of which were recorded by observers other than the author. Low elevation records for native passerines were: 'Elepaio 400 feet; 'Oma'o 1600 feet; 'Amakihi 50 feet; and 'Apapane 400 feet. East of Mauna Ulu flows, 'Amakihi were observed no higher than 1600 feet, nor lower than 400 feet, except occasionally (J. Jacobi & F. R. Warshauer, pers. comm.). However, west of Mauna Ulu flows they were consistently observed in suitable habitat, regardless of elevation. While the 'Amakihi does not regularly inhabit homogeneous closed rain forest in substantial numbers, it can usually be found in openings and edges. This was not the case in the forests east of Mauna Ulu flows. Perhaps the lack of understory diversity characteristic of much of this feral pig-disturbed area reduces available resources for birds, giving the much more abundant 'Apapane a competitive edge. This question is in need of further study.

No specific searches were made for the nocturnal 'Ua'u (Pterodroma phaeopygia sandwichensis), which was previously reported to nest in Makaopuhi Crater, on the northern border of the Extension (U. S. Fish & Wildlife Service 1974).

The Nene (Branta sandvicensis) was recorded in western portions of the Extension during this study and by P. Banko (pers. comm.) and J. and Z. Jacobi (pers. comm.). P. Banko (in prep.) is presently working with the National Park Service on a new recovery program aimed at reintroducing a breeding population of Nene to lowland habitats in Hawaii Volcanoes National Park.

The only widespread endangered species in the Extension was the 'Io, which has been observed in or over most habitats, except for the very dry scrub and grassland communities, east of Mauna Ulu flows either during this study or by other workers.

The Japanese White-eye (Zosterops japonicus) was by far the most abundant and widely distributed bird species (Table 3). Only the Cardinal (Cardinalis cardinalis) was as widely distributed as the Japanese White-eye, and it was much less abundant (Table 3). The House Finch (Carpodacus mexicanus) was the only other exotic bird that was either very common or widely distributed. Several species of game birds (Tables 1 & 3) were observed during this study and by J. and Z. Jacobi (pers. comm.). With the exception of the Ring-necked Pheasant (Phasianus colchicus), recorded from lowland scrub, game birds seem to have entered Kalapana Extension habitats from the 'Ainahou Ranch area. These species were probably introduced to the Ranch before it became part of the National Park.
One exotic bird not found but previously recorded in the Kalapana Extension was the Red-billed Leiothrix (Leiothrix lutea). This species has undergone a rapid decline, for unknown reasons, in its Hawaiian Islands range during the last decade (Hawaii Audubon Society 1978).

CONCLUSION

Four species (including three endangered forms) of native birds apparently no longer occur in the Kalapana Extension where they were reported about 25 years ago (Baldwin 1953). However, all the habitat types in the Extension are still occupied by some native bird species, with closed Metrosideros rain forests, open Metrosideros forests, including scrub forests, harboring the greatest diversities of native birds. The closed Metrosideros rain forests provide the best and most extensive habitats available in Hawaii Volcanoes National Park for the Hawai'i 'Oma'o, the only unendangered form of Phaeornis (Hawaiian thrushes). Furthermore, should populations of endangered Hawai'i Island forest birds (e.g., 'O'u, 'Akiapola'a, 'Akepa, Hawai'i Creeper) stage a comeback in the Park, it would most likely occur in extensive tracts of rain forest, such as those found in the 'Ola'a Tract and the Kalapana Extension. For these reasons forest habitats should be managed to protect their integrity. Of extreme importance in this regard is the control of feral pigs and exotic plants.

When the natural features of the Kalapana Extension, especially those geological and botanical, but also ornithological and archaeological, are measured against its questionable value as homestead land (e.g., high volcanic risk, unsuitability for agriculture and ranching), it seems clear that management of these lands should have conservation of natural resources as its highest priority.

ACKNOWLEDGEMENTS

I thank June Saito for typing the manuscript. Terry Parman, Maile Stemmermann, and Rick Warshauer assisted with field work. The National Park Service has been particularly helpful with logistics. I appreciate Dr. Cliff Smith's assistance with several aspects of the project.
LITERATURE CITED


<table>
<thead>
<tr>
<th>Scientific Name</th>
<th>Vernacular Name</th>
<th>Hawaiian</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>* Branta sandvicensis</td>
<td>Hawaiian Goose</td>
<td>Nene</td>
<td>E</td>
</tr>
<tr>
<td>* Buteo solitarius</td>
<td>Hawaiian Hawk</td>
<td>'Io</td>
<td>E</td>
</tr>
<tr>
<td>Lophortyx californicus</td>
<td>California Quail</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Francolinus erckelli</td>
<td>Erckel Francolin</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Francolinus adsperus</td>
<td>Closebarred Francolin</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Phasianus colchicus</td>
<td>Ring-necked Pheasant</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Phasianus versicolor</td>
<td>Green Pheasant</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Pluvialis dominica</td>
<td>Golden Plover</td>
<td>Kolea</td>
<td>I</td>
</tr>
<tr>
<td>Anous tenuirostris melanogenys</td>
<td>Hawaiian Noddy</td>
<td>Noio</td>
<td>I</td>
</tr>
<tr>
<td>Streptopelia chinensis</td>
<td>Spotted Dove</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Geopelia striata</td>
<td>Barred Dove</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Asio flammeus sandwichensis</td>
<td>Hawaiian Owl</td>
<td>Pueo</td>
<td>E</td>
</tr>
<tr>
<td>Alauda arvensis</td>
<td>Skylark</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Garrulax canorus</td>
<td>Melodious Laughing-thrush</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Phaeornis obscurus obscurus</td>
<td>Hawai'i Thrush</td>
<td>'Oma'o</td>
<td>E</td>
</tr>
</tbody>
</table>
| Scientific Name             | Vernacular Name            | Hawaiian       | Status |}
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Chasiempis sandwichensis</em></td>
<td><em>Hawai'i 'Elepaio</em></td>
<td>'Elepaio</td>
<td>E</td>
</tr>
<tr>
<td><em>Zosterops japonicus</em></td>
<td>Japanese White-eye</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td><em>Acridotheres tristis</em></td>
<td>Common Myna</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td><em>Loxops virens virens</em></td>
<td><em>Hawai'i 'Amakihi</em></td>
<td>'Amakihi</td>
<td>E</td>
</tr>
<tr>
<td><em>Himatione sanguinea</em></td>
<td><em>'Apapane</em></td>
<td>'Apapane</td>
<td>E</td>
</tr>
<tr>
<td><em>Lonchura punctulata</em></td>
<td>Spotted Munia</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td><em>Passer domesticus</em></td>
<td>House Sparrow</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td><em>Cardinalis cardinalis</em></td>
<td>Cardinal</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td><em>Carpodacus mexicanus</em></td>
<td>House Finch</td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>
### TABLE 2. Densities (birds/40 ha) of native bird species in the different vegetation types of the Kalapana Extension ($P = < 1$ bird/40 ha; $+ =$ irregularly present). Vegetation types are based on Mueller-Dombois and Fosberg (1974).

<table>
<thead>
<tr>
<th>Species</th>
<th>cM</th>
<th>cM(ns)</th>
<th>oM</th>
<th>oM(C)</th>
<th>MD</th>
<th>olf</th>
<th>s</th>
<th>HEAn</th>
<th>r</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>'Io</td>
<td>P</td>
<td>P</td>
<td>P</td>
<td>P</td>
<td>P</td>
<td>P</td>
<td>P</td>
<td>P</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kolea</td>
<td></td>
<td></td>
<td>P</td>
<td>P</td>
<td>P</td>
<td>P</td>
<td></td>
<td></td>
<td></td>
<td>(shoreline)</td>
</tr>
<tr>
<td>Noio</td>
<td></td>
<td></td>
<td>P</td>
<td></td>
<td></td>
<td>P</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pueo</td>
<td></td>
<td></td>
<td>P</td>
<td>P</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>'Oma'o</td>
<td>23</td>
<td>18</td>
<td>4</td>
<td>11</td>
<td>P</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>above 1600 ft</td>
</tr>
<tr>
<td>'Elepaio</td>
<td>4</td>
<td>2</td>
<td>2</td>
<td>+</td>
<td>13</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>above 400 ft</td>
</tr>
<tr>
<td>'Amakihi</td>
<td>+</td>
<td>+</td>
<td>5</td>
<td>+</td>
<td>47</td>
<td>P</td>
<td></td>
<td></td>
<td></td>
<td>400-1600 ft E of Mauna Ulu flows</td>
</tr>
<tr>
<td>'Apapane</td>
<td>100</td>
<td>102</td>
<td>106</td>
<td>42</td>
<td>65</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>above 400 ft</td>
</tr>
</tbody>
</table>

- cM = closed *Metrosideros* forests, various understory types
- cM(ns) = closed *Metrosideros* forests with native shrub understory
- oM = open *Metrosideros* forests, various understory types (includes scrub *Metrosideros* communities)
- oM(C) = open *Metrosideros-Cibotium* forests
- MD = *Metrosideros-Diospyros* forests, various understory types
- olf = open mixed lowland forests
- s = mixed lowland scrub communities
- HEAn = lowland *Heteropogon-Fragrostis-Andropogon* grasslands, sometimes with mixed shrubs
- r = rockland communities with scattered grasses and shrubs, includes salt spray communities
TABLE 3. Densities (birds/40 ha) of introduced bird species in different vegetation types of the Kalapana Extension (P = < 1 bird/40 ha; + = irregularly present). Vegetation types are based on Mueller-Dombois and Posberg (1974).

<table>
<thead>
<tr>
<th>Species</th>
<th>CM</th>
<th>CM(ns)</th>
<th>OM</th>
<th>OM(C)</th>
<th>MD</th>
<th>olf</th>
<th>s</th>
<th>HEAn</th>
</tr>
</thead>
<tbody>
<tr>
<td>California Quail¹</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Erckel Francolin¹</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Closebarred Francolin¹</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ring-necked Pheasant</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Green Pheasant¹</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spotted dove</td>
<td>P</td>
<td>15</td>
<td>P</td>
<td>P</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Barred Dove</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Skylark</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Melodious Laughing-thrush</td>
<td>P</td>
<td>P</td>
<td>P</td>
<td>P</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Japanese White-eye</td>
<td>78</td>
<td>156</td>
<td>266</td>
<td>193</td>
<td>149</td>
<td>213</td>
<td>80</td>
<td>64</td>
</tr>
<tr>
<td>Common Myna</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spotted Mynia</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cardinal</td>
<td>P</td>
<td>3</td>
<td>P</td>
<td>6</td>
<td>22</td>
<td>7</td>
<td>P</td>
<td>3</td>
</tr>
<tr>
<td>House Finch</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

¹ These species probably limited to plant communities in the northwestern corner of the Kalapana Extension, adjacent to upper portions of the 'Ainahou Ranch.

CM = closed *Metrosideros* forests, various understory types
CM(ns) = closed *Metrosideros* forests with native shrub understory
OM = open *Metrosideros* forests, various understory types (includes scrub *Metrosideros* communities)
OM(C) = open *Metrosideros-Cibotium* forests
MD = *Metrosideros-Diospyros* forests, various understory types
olf = open mixed lowland forests
s = mixed lowland scrub communities
HEAn = lowland *Heteropogon-Eragrostis-Andropogon* grasslands, sometimes with mixed shrubs
FIGURE 1. A map showing the locations of the main Hawaiian Islands, the Island of Hawai'i, Hawaii Volcanoes National Park, and the Kalapana Extension.
FIGURE 2. A map of the known (as of April 1974) "unimpaired habitats" of native forest birds in the Kalapana Extension, according to National Park Service (1974: Map D).
FIGURE 3. A map showing native forest bird distribution in the Kalapana Extension according to this study. Includes many habitats considered to be impaired by feral animals and exotic plants.
HALEAKALA NATIONAL PARK CRATER DISTRICT
RESOURCES BASIC INVENTORY:
BIRDS OF THE CRATER DISTRICT

Sheila Conant
Department of General Science
and
Maile A. Stemmermann
Department of Zoology
University of Hawaii at Manoa
Honolulu, Hawaii 96822

INTRODUCTION

Field studies of avian distribution and abundance were undertaken in Haleakala National Park between June 1976 and April 1978. We conducted most of the field work during the summer months, but also took several trips into the study area at other times of the year to evaluate seasonal changes in bird activity. Most species densities for different habitat types have been derived from censuses using the transect count method described by Emlen (1971), or the circular plot method of Reynolds et al. (in press). Some species densities could not be calculated by these methods (e.g., game birds, House Finch): in such cases, we estimated densities by averaging census totals per unit area covered.

Although this survey encompassed the entire Crater District, certain regions received particular attention due to high density or diversity of birds. These areas included scrub habitats in the eastern end of the Crater, the Paliku area, the eastern boundary of Kaupo Gap, and Pu'u Mamane.

RESULTS AND DISCUSSION

Twenty-two species of birds representing 14 families were found in the Crater District during this survey. Thirteen of these species (approx. 60%) were exotic. Of the native species about 30% are endemic to Maui and two species (the Nene, Branta sandvicensis, and the 'U'au, Pterodroma phaeopygia sandwichensis) are considered endangered. Table 1 shows the approximate densities of bird species in five general habitat types within the Crater District.
Several patterns in avian distribution and diversity are apparent from our data. Species diversity in the Crater is strongly affected by vegetation patterns. Bird diversity generally increases with increasing plant cover, with the lowest number of species occurring in the arid western region of the Crater, and the highest number occurring in mesic forest, particularly those along the eastern boundary of the Crater District. In a similar fashion, species diversity on the outer Crater slopes increases with decreasing altitude, reflecting a corresponding increase in vegetative cover and plant species diversity down the altitudinal gradient.

Specific distribution patterns are highly reflective of the niche components (especially the feeding niche) of the birds in question. Distributions of native and non-native species are broadly separable on this basis. Exotic species generally have wide distributions; each species may have a distribution encompassing several different habitat types and may be common throughout most of its range. This tendency towards wide distributions shown by exotics is in many cases reflective of their generalized ecologies. As Ralph (1978) has found, the broad feeding niches of many of these birds enable them to utilize diverse habitat types.

The distributions of two common exotics, the Japanese White-eye (Zosterops japonicus) and the House Finch (Carpodacus mexicanus) are good examples of these patterns. Both species occur in habitat types between the extremes of arid scrub and grasslands, and wet forests. As shown in Table 1, both species occur in fairly high densities even outside their optimal habitats. The House Finch seems to have a greater ability to use marginal habitats than does the White-eye, possibly because of its greater flocking tendency and mobility.

Other exotic species have broad ranges similar to those of the White-eye and House Finch, but occur in lower densities. These species typically occur in fewer habitat types than their more abundant counterparts, and may have more specialized feeding habits. Among the species showing such distributions are the Ring-necked Pheasant (Phasianus colchicus), the Mockingbird (Mimus polyglottos), and the Skylark (Alauda arvensis). Each of these birds occurs over a large area of the Crater, but as indicated in Table 1, none occurs in very large numbers in any one habitat type.

Some exotic species are rare in the Crater District, either because their ranges are expanding into the area, or because they are poorly adapted to Crater habitats. The Grey Francolin (Francolinus pondicerianus) is an example of the first category: it is uncommon in the Park and has localized distribution in the west side of Kaupo Gap. The bird is common in Kaupo ranchlands, but was not recorded in the Park prior to this study. Other exotics, mostly non-game species such as the Melodious Laughing-thrush (Garrulax canorus) and the Cardinal (Cardinalis cardinalis) have been sighted on a sporadic basis, generally on the periphery of the Crater District. These birds are unable to
persist in Crater habitats as yet, possibly due to feeding limitations or an inability to cope with the rigorous climatic conditions.

Native species show distribution trends similar to the exotics, although they show more restricted distributions and are often uncommon outside limited areas. The dietary specificity of the native forest birds limits them to small areas of suitable habitat. Table 1 illustrates the restricted ranges of these birds. The generalized native forest birds (e.g., the 'Amakihi, [Loxops virens wilsoni] and the 'Apapane [Himatione sanguinea sanguinea]) have larger distributions in the Crater District and are in less danger of extirpation from the area than the more specialized Maui Creeper (Loxops maculatus newtoni) and 'I'iwi (Vestiaria coccinea). The ranges of the latter species within Haleakala are limited and are highly sensitive to seasonal shifts in resource abundance, much more so than the more generalized Drepanids.

Native non-passerines tend to have broader ranges than do the honeycreepers, but no natives are as abundant as the broad-ranged exotics such as the Chukar (Alectoris chukar) or Pheasant. As illustrated in Table 1, the ranges of the Nene and the Pueo (Asio flammeus sandwichensis) are similar in many respects to those of the broad-ranged exotics, except as regards density values. The low densities of native non-passerines may be attributed to several factors, among them, competition between native and exotic species, and the resulting exclusion of natives from sub-optimal habitats, habitat destruction, and predation by exotic mammals.

Management recommendations for the two endangered species in the Park center on the last two problems mentioned above. We feel strongly that control and elimination programs for nest predators should continue, and be expanded during the breeding seasons of both the 'Ua'u and Nene. Predation, especially by rats (Kjargaard 1978), is a serious threat to the nesting success and continued survival of both species in the Crater. In addition, populations of both the 'Ua'u and Nene should be carefully studied in order to define not only the sizes of breeding populations, but also the nesting success of both species.

In keeping with Park goals, ecosystem management and maintenance of native habitats of these species should be of high priority. Elimination of exotic organisms in the Park (particularly feral mammals and the more aggressive exotic plants) will significantly contribute to the enhancement of native bird habitats in Haleakala.
LITERATURE CITED


**TABLE 1. Density values (birds/40 ha) in five Crater District habitats. (P = present at a density less than 1 bird/40 ha).**

<table>
<thead>
<tr>
<th>Scientific Name</th>
<th>Hawaiian or Vernacular Name</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Pterodroma phaeopygia sandwichensis</em></td>
<td>'Ua'u</td>
<td>P</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Phaethon lepturus dorotheae</em></td>
<td>Koa'e-kea</td>
<td>P</td>
<td>P</td>
<td>P</td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Branta sandvicensis</em></td>
<td>Nene</td>
<td>5-10</td>
<td>1-5</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Alectoris chukar</em></td>
<td>Chukar</td>
<td>1-20</td>
<td>5</td>
<td>1-10</td>
<td>2-4</td>
<td></td>
</tr>
<tr>
<td><em>Francolinus pondicerianus</em></td>
<td>Gray Francolin</td>
<td>P</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Phasianus colchicus</em></td>
<td>Ring-necked Pheasant</td>
<td>3-4</td>
<td>5</td>
<td>1</td>
<td>1-25</td>
<td></td>
</tr>
<tr>
<td><em>Pluvialis dominica</em></td>
<td>Kolea</td>
<td>5</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Asio flammeus sandwichensis</em></td>
<td>Pueo</td>
<td>2</td>
<td>P</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Tyto alba</em></td>
<td>Barn Owl</td>
<td>2</td>
<td>P</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Columba livia</em></td>
<td>Rock Dove</td>
<td>P</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Alauda arvensis</em></td>
<td>Skylark</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Garrulax canorus</em></td>
<td>Melodious Laughing-thrush</td>
<td>P</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Leiothrix lutea</em></td>
<td>Red-billed Leiothrix</td>
<td>1-18</td>
<td>3-20</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Mimus polyglottos</em></td>
<td>Mockingbird</td>
<td>P</td>
<td>1</td>
<td>1-4</td>
<td>1-2</td>
<td></td>
</tr>
<tr>
<td>Scientific Name</td>
<td>Vernacular Name</td>
<td>Hawaiian or Density (bird/40 ha)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>--------------------------------------</td>
<td>--------------------------</td>
<td>--------------------------------</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zosterops japonicus</td>
<td>Japanese White-eye</td>
<td>P 7 1-8 P-13 15-275</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acridotheres tristis</td>
<td>Common Myna</td>
<td>P</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Loxops virens wilsoni</td>
<td>Maui 'Amakihi</td>
<td>1 1-6 20-130</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Loxops maculata newtoni</td>
<td>'Alauwahio</td>
<td>P-3 P-12</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Himatone sanguinea sanguinea</td>
<td>'Apapane</td>
<td>6 P-40 4-330</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vestiaria coccinea</td>
<td>'I'iwi</td>
<td>P-6 1-8</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lonchura punctulata</td>
<td>Spotted Munia</td>
<td>P 1-6</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cardinalis cardinalis</td>
<td>Cardinal</td>
<td>P-2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carpodacus mexicanus</td>
<td>House Finch</td>
<td>P 1-40 P-35 P-45 1-25</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Habitat types:

1) Rock, cinder, open native scrub communities; crater floor; crater slopes
2) Grasslands
3) Savannah
4) Closed native scrub
5) Native rain forest
EXPERIMENTAL HYBRIDIZATIONS IN HAWAIIAN METROSIDEROS

Carolyn A. Corn
Hawaii State Division of Forestry
Department of Land & Natural Resources
Honolulu, Hawaii 96813

The genus Metrosideros of the family Myrtaceae is native, but not endemic to Hawai'i. The genus occurs scattered from eastern Australia through the high islands of the Pacific Ocean, with the largest number of species located in New Zealand. If New Zealand is considered to be the probable center of origin for the genus because it has the largest number of extant species, then the high islands of the Pacific to the east and north could have served as "stepping stones" in the migration of the genus to Hawai'i by long distance dispersal (Corn 1972b). The most common species occurring on oceanic islands of the Pacific is M. collina (J. R. & G. Forst.) Gray, whose distribution ranges from the New Hebrides on the west to Pitcairn Island on the east to the Hawaiian Islands on the north. The species is fairly uniform in the western part of its range (i.e., Tahiti and Marquesas) and reaches its greatest variability in the Hawaiian Islands (Smith 1973). This species in Hawai'i is presently called M. polymorpha Gaud. (St. John 1979).

The genus is abundant in the relatively undisturbed portions of the six largest Hawaiian Islands. It occurs in diverse edaphic, topographic, and climatic habitats as either a tree or shrub. The plants are variable in height, shape, vegetative and floral characteristics. Taxonomic treatments of the genus (Hillebrand 1888; Rock 1917; Skottsberg 1944; Porter 1972; St. John 1979) are difficult since the taxon may be best described as a polymorphic group of plants. Sastrapradja and Lamoureux (1969) found no distinct patterns of variation in wood variation. Anatomical and morphological evidence of leaf variation in mature plants along an altitudinal and rainfall transect on Mauna Loa, Hawai'i, often suggests clinal patterns of variation commonly found among outbreeding forest trees (Corn 1979).

This paper includes information from observations and field hybridizations of seven varieties of M. polymorpha present on Mauna Loa, Hawai'i. A basic number of \( n = 11 \) chromosomes was described by Niimoto (1950), Skottsberg (1955), and Carr (1978), which corresponds to the basic count for New Zealand material by Mousel (1965). However, Skottsberg also noted counts of \( n = 12 \) and \( n = 13 \) in material from the Island of Hawai'i for varieties incana and glabrifolia, respectively. Carpenter (1976) in a paper on plant-pollinator interactions described two yellow-flowered plants as self-compatible, but the red-flowered plants as being partially self-incompatible.
The objective of this paper is to ascertain if hybridization can occur between plants that are morphologically different.

METHODS

Pollen samples were obtained by two methods. The first method involved coating glass slides with either vasoline or scotch tape and placing them around and under blooming Metrosideros trees for four days and nights to see if Metrosideros pollen was wind-dispersed. The second method was devised to see if birds were transmitting Metrosideros pollen between trees at 1220 to 2012 m elevation in Hawaii Volcanoes National Park and Kilauea Forest Reserve. Birds were caught in mist nets, their head feathers around their beaks were sampled with scotch tape, and the scotch tape was fastened to microscope slides and viewed for Metrosideros pollen.

Experimental field hybridizations were prepared by removing all but five to seven buds in an inflorescence and emasculating the remaining buds. A wire frame was erected around the prepared inflorescence which was covered by an organdy bag, so that the bag did not touch the elongating styles during windy weather. The bag was secured by cotton and string at its base to prevent ants and other insects from crawling into the bag. A small plastic umbrella was erected above the inflorescences used in nectar production studies to prevent rain from diluting the nectar. Some of the prepared bags with emasculated flowers served as controls which were not crossed. Other bagged inflorescences were crossed with pollen from select plants about 10 days after emasculation. Pollination bags were again secured after the flowers were crossed and labelled. Approximately four to seven months later when the capsules were mature, the labelled bags were clipped off the female parent plant and brought into the laboratory for analysis.

Each bag containing mature capsules was air-dried until the capsules opened. One hundred seeds from each cross were placed into petri dishes, given light and water for germination trials. After one month the percent seed germination for each cross was tallied. The seedlings were then planted into soil and grown.

RESULTS

Metrosideros grows as a tree or shrub which bears conspicuous flower clusters at the terminal portions of its branches. Although it flowers most commonly during the spring and summer, sporadic blooms may be seen on a few trees throughout the year. The inflorescence is composed of a flower cluster that may vary in number from several to about 30, but normally between 18 and 24 flowers.
Flowers normally have no scent and are red in color. However, their color on different trees may vary from deep red to various shades of red, salmon, orange, yellow, and very rarely white. The flowers are perfect with five small petals and numerous protruding stamens which are the showiest portion of the flower. The flowers open with the modified floral cup facing upward which allows the secreted nectar to be retained within the cup. The height of the stamens in relation to the style varies, as does the space between the row of stamens and the central style.

Nectar production begins as the petals and stamens unfold, and is greatest several days later when the anthers begin to dehisce. It ceases three to five days later when the anthers and petals abscise. The receptive period of the stigma may vary from one to two days after the stamens begin to exert (Carpenter 1976) to several days after the anthers begin to dehisce (Corn 1972a). Within an inflorescence it is common to have flowers in all stages of the blooming cycle.

Nectar is 10 to 15% solid (by refractometer measurements) when flowers are enclosed within a plastic bag. However, these same flowers when exposed to wind, low humidity, and no nectar-gathering animals, may have nectar concentrations of >60% (Corn 1979). Analysis of nectar yields low protein (or histidine) content.

The stamens produce abundant sticky pollen which attract various hymenopterans, including native and introduced bees and wasps. These hymenopterans may also obtain nectar on sunny, hot days. Other insects seen on the flowers are nocturnal caterpillars that live in the flower buds during the day and emerge at night. They feed on the anthers and young succulent portions of the flower buds. Moths, crickets, ants, and even centipedes have been seen on the blossoms. No wind-dispersed Metrosideros pollen was obtained using sticky slides placed under and around blooming trees.

Although the flowers are open and relatively unspecialized, their dimensions and position on the branch are probably best suited to bird pollination. Various native and introduced birds visit the flowers for nectar and/or insects. The pollen adheres to the feathers and beaks of birds visiting the flowers. Twenty-three of 27 sampled birds had Metrosideros pollen (Table 1). Species carrying pollen include: 'Amakihi (Loxops virens), 'Apapane (Himatione sanguinea), Hawaiian Creeper (Loxops maculatus mana), Japanese White-eye (Zosterops japonica), House Finch (Carpodacus mexicanus frontalis), and House Sparrow (Passer domesticus). Since the birds commonly flit from tree to tree visiting the flowers, they can serve as active and efficient cross-pollinators. Carpenter (1976) found more capsules produced on trees that birds were visiting the blossoms, than on trees where insects but no birds were visiting the blossoms.
Selective field hybridizations yielded mixed results. None of the uncrossed emasculated flowers produced seed or mature capsules. Since apomixes is not usually associated with diploidy, it is probably safe to assume that apomixes plays no role in seed production.

Hybridizations were made between trees within one site and between varieties at various sites. In some cases successful crosses were made in one direction between two plants, but the reciprocal cross was not successful. Carpenter (1976) suggested a partial self-incompatibility system was present in red-flowering plants. Of nine self-pollinated red-flowering plants, four of these (36%) set no seed. When these same plants were outcrossed, five of 36 crosses (or 14%) produced no seed. Seed germination from selfed individuals commonly yielded few seedlings.

Crosses were attempted among the seven varieties found on Mauna Loa (Fig. 1). All but one possible combination was attempted. Of the 20 combinations tried, seven of them did not produce capsules and seed. Many factors could have contributed to these failures. For example, some bags were broken off the trees between the time of pollination and capsule maturity; sometimes the style was injured during emasculation; the timing of the cross was poor; the pollen too old; or climatic factors unfavorable. Before self-incompatibilities are attributed to these failures, additional trials and cytological studies need to be made.

Not all successful crosses diagramed in Figure 1 had their capsules collected at the proper time. Some capsules had dehisced and the seeds exposed to rain. When this happened the seeds became darker in color and did not germinate.

A subset of data shown in Figure 1 (Fig. 2) illustrates those instances where seed germination could be tabulated. Some of the 55 crosses that were tried on 16 trees failed to produce capsules. Where capsules were produced, germination varied from <1% to 42%. Additional crosses may result in higher seed germination, due to various factors that affect crossability.

DISCUSSION

Certain varieties occur more commonly in certain localities (Corn 1979). M. polymorpha varieties imbricata, incana, and polymorpha occur together in seasonally dry sites. At higher elevations var. imbricata is absent, but var. nuda is found in association with var. polymorpha and var. incana. In rain forests at mid-elevations the other three varieties, newellii, macrophylla, and glaberrima, are common, although some var. incana, var. polymorpha, and var. imbricata may also exist in these sites.
Therefore, the occurrence of these varieties in certain habitats may limit their chances of crossing with other varieties that are not present in the immediate area. However, these varieties may still be able to hybridize if given the opportunity. A good example of this can be seen in a cross I made two years ago between a plant from the Marquesas Islands and a plant from O'ahu. The Marquesas Island plant which is growing at Lyon Arboretum, is distinctly different in appearance from the O'ahu plant. Although no seed was produced using the O'ahu tree as the female parent, 22% seed germination was obtained using the Marquesas Islands tree as the female parent.

In summary, various crosses have been attempted among the seven recognized varieties found on Mauna Loa, Hawai'i. Some of these crosses produce viable seeds with the hybrids now being grown for future analysis and crosses. Other crosses did not result in seed set. The reasons for these failures are not known. Additional work needs to be done to verify if these crosses are genetically incompatible.

ACKNOWLEDGMENTS

Support for research of the paper was made possible by research grants from Island Ecosystems IRP, US/IBP Hawaii (NSF GB 23230) and Pacific Tropical Botanical Garden. Travel to the conference was furnished by Hawaii Division of Forestry.

LITERATURE CITED


TABLE 1. The amount of *Metrosideros* pollen found on bird species at three localities on the Island of Hawai‘i.

<table>
<thead>
<tr>
<th>Bird Species</th>
<th>Hawaii Volcanoes National Park Residential Area 1220 m</th>
<th>Kīlauea Forest Reserve 1615 m</th>
<th>Mauna Loa Strip Road 2012 m</th>
</tr>
</thead>
<tbody>
<tr>
<td>House Finch (<em>Carpodacus mexicanus frontalis</em>)</td>
<td>3, 2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>House Sparrow (<em>Passer domesticus</em>)</td>
<td>3, 3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Japanese White-eye (<em>Zosterops japonicus</em>)</td>
<td>0, 1, 1, 1, 3</td>
<td>1, 2</td>
<td></td>
</tr>
<tr>
<td>'Amakihi (<em>Loxops virens</em>)</td>
<td>0, 3, 1</td>
<td>1, 0, 1, 1</td>
<td></td>
</tr>
<tr>
<td>'Apapane (<em>Himatione sanguinea</em>)</td>
<td>2</td>
<td>1, 2</td>
<td></td>
</tr>
<tr>
<td>Hawaiian Creeper (<em>Loxops maculatus mana</em>)</td>
<td></td>
<td>3, 2, 2, 1</td>
<td></td>
</tr>
<tr>
<td>Hawaiian Thrush (<em>Phaornis obscurus</em>)</td>
<td>0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1 Amount of *Metrosideros* pollen present: 0 = no pollen grains/slide; 1 = 1 to 10 pollen grains/slide; 2 = 11 to 50 pollen grains/slide; 3 = 51 or more pollen grains/slide.
Figure 1. Field hybridizations attempted between Metrosideros polymorpha varieties.
Figure 2. Seed germination for a subset of field hybridizations shown in Figure 1 of Metrosideros polymorpha varieties.
There is no simple description for a typical community within the ahupua'a of Manuka, Kaulanamauna, and Kapu'a, as a consequence of climatic patterns in South Kona. Within this location there is a mosaic of communities.

Subalpine, pioneer communities on lava, kipukas, "fog inversion layer" rain forests, mixed mesophytic forests, dry transitional forests, and coastal strand communities are all found within this one area.

This paper focusses on the rare and threatened plants that are located within each of these zones, as identified by the project systematists. For species that have been identified on certain lists as rare and endangered, preliminary information—habitat, condition (vigor, regeneration), and general observations—has been compiled. This research was sponsored by the National Science Foundation under the Student Originated Studies Program to conduct a baseline survey of the archaeological and natural resources in the ahupua'a of Manuka, Kaulanamauna, and Kapu'a, during the summer of 1977.

---

* Abstract
HUMAN SETTLEMENT AND ENVIRONMENTAL CHANGE
AT BARBERS POINT, O'AHU

Bertell D. Davis
Archaeological Research Center Hawaii, Inc.
Honolulu, Hawaii 96765
and
Department of Anthropology
University of Hawaii at Manoa
Honolulu, Hawaii 96822

ABSTRACT

Recent studies at Barbers Point, O'ahu, have demonstrated an unparalleled potential there for coordinated research on human settlement and environmental change in leeward "marginal" regions of the Hawaiian Islands. The following paper presents some of the more significant results: the available data are summarized, and several interpretive models from different sources are offered.

The current level of knowledge is tantalizing to say the least. Clearly our principal limitation is one of sampling. It is expected, however, that with the definition of specific research goals this limitation can be overcome.

Preliminary environmental impact studies at Barbers Point, O'ahu, have demonstrated the unique potential there for significant contributions to the cultural and natural history of the Hawaiian Islands. Several areas of investigation are of particular interest: the survival of rare and endangered species, the extinction of endemic Hawaiian avifauna, the structure of the leeward lowland forest prior to man's arrival in the islands, and the native Hawaiian settlement of a presumed "marginal" environment. To better accommodate such diverse but parallel concerns, continuing research is coordinated in phases, beginning with intensive survey of the terrestrial biology and archaeological resources. Fieldwork for this Phase I study was completed over the past 12 months, and a detailed report is now in preparation (Davis & Griffin 1978).

The following paper summarizes the findings of the current study. Using data collected from the cultural survey, together with that recovered from excavation by the Bishop Museum (Sinoto 1976, 1978), I suggest a tentative model for interpreting the archaeological remains at Barbers Point. The model focuses on patterns of settlement and subsistence, and several alternatives are considered as testable hypotheses. This paper is of course necessarily quite preliminary. My purpose here is primarily to
open ideas for consideration and to stimulate discussion for developing and refining the direction of future research.

To begin with, the study area is located along the south-western coast of O'ahu on a broad plain of emergent fossiliferous coral-algal reef (Fig. 1). Because the seaward portions of the region are relatively isolated from alluvial encroachment, the exposed limestone has weathered to form a shallow karst landscape. The area is characterized by numerous solution sinkholes, irregular rock masses, and poor soil development. Local climate is generally arid with intense sunshine, warm dry winds, and low annual rainfall. However, the coral plain is a major aquifer, and many of the sinkholes in the study area penetrate to the water table. Thus despite superficially arid conditions, the availability of fresh water alone is not the principal constraint on human settlement and subsistence. Indeed, as is typical of atoll environments in the tropical Pacific, the more significant factors are those resulting from the alkaline substrate and the general paucity of inorganic sediments. It is these conditions which placed particular requirements upon the adaptive strategies employed by the former inhabitants of Barbers Point.

The intensive botanical survey described and mapped the modern vegetation zones of the study area, and complementary wildlife studies defined primary habitats. The presence of a second threatened plant species, Achyanthes splendens var. rotundata Hb., was confirmed in addition to the originally identified Euphorbia skottsbergii var. kalaeloana Sherff. The population and distribution of both species have been determined and pertinent recommendations presented (Miura & Sato 1978). An uncommon terrestrial shrimp, Halocaridina rubra, was also found in a large, flooded cave, and is briefly reported on by Miura and Sato (1978).

From this baseline study we can now begin to consider the nature of the former environment at Barbers Point. Excavations by the Bishop Museum yielded extensive remains of terrestrial mollusca and extinct avifauna as well as cultural material. In addition to known coastal, forest, and predatory species, the avian assemblage includes several new taxa, two of which are flightless forms (Sinoto 1976; Ziegler 1978). Continuing analysis of the avifauna should yield substantial information regarding the birds themselves and their habitats. The potential for paleoenvironmental reconstruction has been especially enhanced with the recovery of terrestrial mollusca. Because they are habitat specific, these snails are highly responsive to local conditions. Although sampling for land snails has been somewhat limited, the available collection indicates a varied population in which eleven species have been identified to date (Kirch 1978). Morgenstein (1978) observes that the mollusca occur in a complete and continuous biostratigraphic profile. Preliminary sediment analyses—including pollen, spores, and phytoliths—correlate with the inferred deposition of avian and molluscan remains, and attest to significant changes in the vegetation of the study area. It is suggested that an initial reduction in the resident aviary probably occurred prior to a major transition
from small-shrubbery to heavy-forest vegetation, and before human settlement of the area (Morgenstein 1978). What factors precipitated these events, however, are still uncertain. Clearly more extensive sampling will be needed before further assessments are possible.

Discussion of the archaeological remains may be initiated with three simple observations. (1) The settlement at Barbers Point was one of functionally integrated, multi-household residence groups. (2) The settlement was minimally long-term, recurrent occupation of the same habitation areas. And (3) the local subsistence pattern focused on the exploitation of marine-strand resources integrated with limited horticulture involving tree and/or root crops. Let us now consider these propositions in detail.

What is the evidence for functionally integrated, multi-household residence groups?

I have defined the archaeological evidence for such a group as the occurrence of functionally different, but contemporaneous features clustered in close spatial association. Here the assumption is that at the time of occupation, the various features of the cluster served a range of uses which, when combined, encompassed a set of activities that defined the residence group. I now suggest that the minimal group was an extended family incorporating several households similar to that outlined by Handy and Pukui (1972). The similarity is not complete, however. This is, first, because Handy and Pukui's description of the Hawaiian family is based on ethnohistoric material gathered during the 1930's in Ka'u, Hawai'i; and secondly, because many of the structural features listed for their residence group are apparently missing from the Barbers Point settlement. Specific features of this model include separated cooking and eating houses for men and women, sleeping houses, storage facilities, work areas, and a menstrual house or other place of seclusion for women (Handy & Pukui 1972: 7-11). This model clearly reflects the segregation of sexes according to the kapu system. Such proscriptions, however, may not necessarily have operated uniformly throughout the islands, among all levels of society, or during all periods of cultural development. Indeed, while Malo (1951: 118-126) describes a similar residential organization for "respectable" people, he nevertheless observes that "no accounts" often followed no such proprieties.

The habitation features recorded at Barbers Point were subjected to metric analysis using total area, interior floor area, and maximum wall width as the principal discriminating variables. Frequency distribution curves of the combined variables distinguished three classes of structures ultimately based on overall size (Fig. 2). Except for three anomalous enclosures, Class I features are C-shaped structures less than 10 m² in total area. Class II features include both C-shapes and walled enclosures of 17±5 m². And finally, Class III features are rectangular enclosures 24 m² or more in area.
Presence-absence trait analysis further defined these classes in functional terms. Because of their small size, shape, and virtual absence of other distinctive attributes, Class I structures are inferred to be for the storage of tools and materials, or possibly for such produce as yams and sweet potatoes. Class II features are the ordinary dwellings of individual households. Class III enclosures also appear to be ordinary dwellings. Although these enclosures are rather large when compared to other habitation features in the study area, none approach the usual size range or structural complexity to indicate more specialized features, such as men's houses.

A fourth class of habitation feature is defined from the trait analysis. These are distinguished by the presence of scattered midden and large mounds of burned coral associated with open, elevated floors. Class IV features are therefore inferred to be cooking areas using surface imu, or ovens, although oven pits may be found under the raised floors.

Extensive disturbances in the study area have left few probable clusters intact. Of the remaining examples, one cluster especially, includes seven Class I storage features, six Class II dwellings, and five Class IV cooking features in two separate areas within the cluster (Fig. 3). The habitation features are associated with structurally modified sinkholes and clearings of soil-humus deposits—both inferred to be garden areas, and with other unmodified sinkholes used as refuse dumps. The entire cluster is situated on a slight rise of limestone outcropping immediately adjacent to an area of surface drainage. Despite considerable evidence for surface runoff, the relatively minor difference in elevation does not seem sufficient to explain this location as a direct response to flooding alone. What is of interest is that shallow, but numerous pockets of silt are found in these drainages. The proximity of the habitation area to the accumulated sediments suggests that the drainages were also utilized. This may have been for additional gardening, or perhaps as a source of alluvial materials for use in mulched garden pits (sinkholes).

The one feature conspicuously missing from this cluster is the Class III enclosure. Although a Class II or several Class I features may be located nearby, the larger enclosures are in fact quite dispersed throughout the study area without any apparent pattern to their location. It is possible that these enclosures are the residences for individual households, and that the "clusters" may have functioned as communal foci for a larger settlement group. If so, then the whole nature of the residence group in terms of spatial distribution may require rethinking. Alternatively, the Class III enclosures may not be contemporaneous with the feature clusters, and their distribution may reflect changes occurring in the settlement of the area. Trait analysis suggests that Class III features are either very late prehistoric, or wholly historic phenomena. Although precontact dates of A.D. 1666±41 and 1743±41 were obtained from one such enclosure tested by the Bishop Museum (Sinoto 1976: 87), the
artifact assemblage was clearly historic. This was true also of surface remains recorded in an adjacent feature during the present study.

Whether these or other changes, and the conditions which may have induced these changes, were occurring at Barbers Point during the period of settlement are intriguing and important questions for investigation.

What is the evidence that the settlement was minimally long-term and recurrent occupation of the same habitation areas?

Adequate temporal controls have yet to be established. Nevertheless, that feature clusters initially conforming to my definition of a residence group are present in the study area indicates that the resident population must have included whole families. This would not likely have been the case if Barbers Point were merely the temporary campsite of itinerant specialists. In the one instance where a range of dates are available from a single feature (a Class II enclosure), the span of occupation is over 250 years (Sinoto 1976: 87). At least two separate events altered the nature of this site: the filling of a sinkhole adjacent to a living floor followed by the building of the present enclosure wall. Whether or not this represents continuous occupation has not been resolved. But it does suggest that use of the site may have become more formalized through time. Again, this does not seem to be consistent with short-term, or transient habitation.

It is evident that an argument can initially be made for extended, recurrent residence in the study area. The possibility of permanent habitation, however, remains an open question. Tight stratigraphic control within and temporal control between habitation features are minimally essential for resolving these and other crucial questions raised by the available data.

What is the evidence for local subsistence based on the exploitation of marine-strand resources integrated with limited horticulture?

The artifact and midden assemblage clearly shows the use of marine and strand resources. Shellfish were collected from the shoreline and the reef. Octopus was taken from the reef on hook and line using cowrie-shell lures. And in-shore fishing was done with lines using small rotating and jabbing fishhooks. Off-shore line fishing is also indicated by large, one-piece rotating fishhooks (Sinoto 1976), by fragments of large points probably for two-piece trolling lures (Lewis 1970; Sinoto 1978), and by the remains of tuna in the midden (Sinoto 1978).

Although the availability of fresh water is not considered a major obstacle to the growth of cultivated plants, the present evidence for horticulture is largely circumstantial. The numerous walled sinkholes, enclosed humus-filled depressions, and
small clearings of soil-humus deposits are inferred to be garden areas. Ethnographic correlates for the walled sinkholes are found elsewhere across the tropical Pacific. On the low coral-line atolls tree and root crops are frequently grown in mulched garden pits to utilize the limited ground water, and to overcome the excessive alkalinity of the carbonate substrate (Barrau 1961). Similar strategies for conserving moisture, such as low-walled windbreaks and intensive mulching, have been documented from arid localities elsewhere in Hawai'i. Then there is the continued survival of several native economic plant species, particularly noni and ti, found thriving in the study area.

Depending upon the plants involved, gardening at Barbers Point would potentially have been a labor-intensive activity. Tree crops, for instance, probably required only occasional tending once they were well started. The persistence of noni, ti, and others in the deeper sinkholes indicates that these plants are capable of supplying sufficient natural mulch in the form of leaf litter to ensure continued growth. On the other hand, the level of mulching required to reduce excessive alkalinity and provide a suitable medium for productive growth of root crops would have been a demanding activity. If indeed root crops were grown in the study area, then this point can be taken further to suggest that at least a part of the population at Barbers Point was permanently resident there.

To obtain direct evidence for cultivation, or indirect evidence of the potential for cultivation, will require largely a comparative approach. Both the inferred horticultural features and the "natural," or unmodified, features must be sampled to meet two criteria. It must be demonstrated (1) that the deposits in the culturally modified features are consistently similar from one feature to the next, and (2) that the deposits in the modified features are significantly different from those in the unmodified features. Once these conditions are fulfilled, it must be further established that plant cultivation is the most reasonable explanation accounting for the differences between the two sample groups. Direct evidence may include macrofossils like yam or sweet potato tubers, or more likely, microfossils such as the pollen, spores, or phytoliths from the cultivated plants. Although less satisfying, indirect evidence would largely be based on first determining the proper growth medium required by the presumed cultivated plants. Secondly, it must be shown that the proper conditions are, or were present in the modified features, and not in the unmodified features.

The most intriguing question, and the one for which the least empirical data is currently available, is the relationship between the remains of the extinct avifauna and that of the human settlement. It has already been suggested that the major reduction in the Barbers Point aviary apparently occurred prior to human settlement. However, this is a very preliminary assessment requiring further confirmation. Direct affects of human predation, or significant disruption of habitat resulting from other unassociated events, cannot yet be discounted as possible contributive factors in the extinction of selected bird species.
SUMMARY

Barbers Point is a geologically unique area for the high volcanic islands of Hawai'i. Located on the coast of an extensive raised coral-reef plain and isolated from alluvial encroachment, the exposed limestone has weathered to form a shallow karst landscape. Karst environments are alkaline, ideal for the preservation of bone and vegetal debris. Yet the area had received little serious attention and was generally viewed as too marginal to have supported a significant precontact population. Routine environmental impact studies in conjunction with a proposed harbor development have since reversed this opinion.

Intensive cultural surveys indicate that Barbers Point was more extensively settled than had previously been considered. Pending detailed excavations, the initial data suggest a settlement of multi-household residence groups over a time span of c. A.D. 1600 to 1870. Local subsistence was based in part on marine-strand resources, and apparently integrated with limited cultivation adapted to make use of the many sinkholes that characterize the area. Other relationships have yet to be determined.

For the natural sciences, biological surveys have identified an uncommon endemic terrestrial shrimp and rare and endangered plant species. Of greater significance is the potential for paleontological and paleoenvironmental studies, particularly regarding the bird life and forest structure of the leeward lowlands prior to man's arrival in the islands. Limited test excavations have recovered the remains of several new taxa of extinct birds, including flightless forms. Varieties of land snails have also been identified from the excavations. Highly responsive to local conditions, these snails attest to significant changes in the vegetation at Barbers Point.
LITERATURE CITED


FIGURE 1. Map of O’ahu and the Hawaiian Islands showing the location of the Barbers Point Study Area.
FIGURE 2. Frequency distribution graphs for total area, interior floor area, and width of largest wall for habitation features from the Barbers Point Study Area.
FIGURE 3. Topographic map of a portion of the Barbers Point Study Area showing the distribution of habitation features and the location of surface drainages. Stippled area indicates feature cluster discussed in text.
ESTABLISHMENT OF SOME RECENT IMMIGRANT INSECTS
IN HAWAII VOLCANOES NATIONAL PARK

C. J. Davis
Hawaii Field Research Center
Hawaii Volcanoes National Park
Hawaii 96718

Between 1961 and 1978 over 300* new immigrant arthropods were recorded in the State of Hawaii. Most of these were discovered on O'ahu but a few were first recorded from the neighbor islands such as the false dandelion gall wasp which was discovered on the Mauna Loa Strip Road in June 1966 and the bristly rose "slug" which was discovered in Volcano on 6 October 1973.

While most of these newly reported organisms were insects, some were mites and miscellaneous arthropods.

Between 1966 and 1978, 11 of these immigrant insects were recorded in Hawaii Volcanoes National Park. Undoubtedly there are others which have not been detected in the Park to date or reported by other sources not available to the writer.

With the exception of a sphingid, Theretra nesus (Drury), most of the Park immigrants are firmly established.

A summary of exotic insects which reached Hawai'i Island from O'ahu is presented in Table 1 and their relationship to the Park flora and other organisms is discussed.

1) **Xylosandrus compactus** (Eichhoff). (Black twig borer)

This is a tiny black beetle that bores into the twigs, branches, and boles of living trees. The male is brownish in color, smaller than the female, and about 1 mm or less in length. The female excavates a small chamber in the pithy portion of the twig or stem and deposits 30 or more white eggs in this niche. Upon hatching, the legless larvae feed on ambrosia fungus which is stored in dorsal pouches of the female and liberated for the developing brood.

Together with this fungus the black twig borer has become an important enemy of fruit trees, ornamentals, orchids, and native and exotic forest trees in Hawai‘i. Over 100 hosts have been recorded.

This beetle has strong host preferences and will attack vigorous seedlings as well as mature trees. Often young trees are top killed and gradually succumb. Trees that have been weakened by drought or other factors are readily susceptible to borer and associated fungus organisms.

The first host record in the Park was at Waha‘ula in October 1975, where it was found infesting twigs and branches of the native lama, *Diospyros ferrea*.

The altitudinal range of *X. compactus* is sea level to 914 m elevation and of the 11 new Park insects listed in this paper, this beetle has the greatest plant pest potential.

2) **Coptosoma xanthogramma** (White). (Black stink bug)

The black stink bug was collected at Kukalau‘ula anti-goat enclosure, 244 m elevation on *Canavalia kauensis*, 18 March 1977--a new host and Park record. It is the first known representative of the family Plataspidae to become established in the Hawaiian Islands (Beardsley 1967).

The adults are black in color, broadly oval in shape, about 2 mm long, and odiferous when handled.

The nymphal stages vary in color and, like the adults, prefer to feed on the succulent growth of host plants. Both adults and nymphs have sucking mouth parts.

With one or two exceptions, legumes are the principal hosts and both exotic and native species are represented in the coastal areas of Hawaii Volcanoes National Park.

The bugs are gregarious with as many as 1000 adults and nymphs being observed on a four foot branch of a *Sesbania* tree on windward O‘ahu.
An egg parasite*, Trissolcus sp., was reared from parasitized eggs collected on O'ahu in January 1968, and at Hilo, Hawai'i, in February 1968. It is very likely established in the Park and hopefully keeping the black stink bug below pest levels.

According to P. M. Marsh, United States Department of Agriculture Taxonomist, this parasite probably came in with its host from the Philippine Islands.

3) **Psylla uncatoides** (Ferris & Klyver). (Acacia psyllid)

In July 1970 this important pest of koa (Acacia koa) was found at high population levels on terminal foliar growth, Mauna Loa Strip Road, 1645 m elevation. This was also the first record of this forest pest on Hawai'i Island.

It is a native of Australia and occurs in New Zealand and California. The major hosts are Acacias and Albizzias. In addition to koa, another species (A. koaia) occurring at Kawaihae Uka, Mt. Kohala, was heavily attacked in the early 1970's by *P. uncatoides*.

The adults are small, about 1 mm or less in length and resemble a tiny cicada. There are five nymphal instars and both nymphs and adults are gregarious and have sucking mouth parts.

Leeper and Beardsley (1973, 1976) studied the Acacia psyllid in Hawaii Volcanoes National Park and at the A. koaia sanctuary, Kawaihae Uka, Mt. Kohala, and concluded in their initial study that imported natural enemies were needed for the control of this new immigrant pest.

This was subsequently accomplished with the introduction of two species of lady bird beetles, *Harmonia conformis* and *Diomus pumilio*. To date, *Diomus* has not been recovered and since the aforementioned authors' last publication, *Harmonia* was found on koa at Hilina Pali and clustered in a weather shelter off the Mauna Loa Strip Road, 1646 m elevation on 25 October 1977—an indication that this beneficial lady bird beetle is well established in the Park. A number of these beetles were also found on the summit of Mauna Kea, 4205 m elevation on 21 August 1976. These were most likely wind borne.

4) **Gilletea taraxaci** Ashmead. (Dandelion gall wasp)

The dandelion gall wasp was collected from false dandelion (*Hypochaeris radicata*) on the Mauna Loa Strip Road, 1818 m elevation in June 1966, a new State record. It was subsequently found on Mt. Haleakala, Maui, at 3030 m elevation on the same host, 22 May 1969.

Since the false dandelion is an exotic weed, the gall wasp can be regarded as a beneficial immigrant.

5) Pollenia rudis (Fabricius). (Cluster fly)

This calliphorid parasite of earthworms was first observed at Kamuela, Hawai‘i, in April 1968 and by 1969 had spread rapidly around the Island becoming very abundant in Hawaii Volcanoes National Park and vicinity.

The adults are nuisance pests of buildings, usually entering in late afternoons. Between 1969 and 1971, thousands of these flies were observed in the tack room of the stables located near the Tree Molds and in various homes.

In recent years cluster fly populations have been at low population levels except for brief upsurges. The reasons for this are not fully understood. Lowering of earthworm populations and adult predation by plovers, spiders, skinks, and other organisms may have been responsible.

6) Antianthe expansa (Germar). (Solanaceous treehopper)

The plant hosts of the solanaceous treehopper include Cestrum, Solanum, and Acnistus.

On 31 August 1977, nymphs of this insect were found on potted Nothocestrum by tree nursery personnel at Ainahou Nursery, 914 m elevation. This was the first record of the solanaceous treehopper in the Park as well as a new host record.

These are small bizarre insects having the head vertical and the nymphs are queerly ornamented with spines. The adults will sometimes move behind a leaf or around a branch to escape capture.

Both adults and nymphs have sucking mouth parts, occur in large numbers, and may have pest potential.

7) Papilio xuthus Linnaeus. (Citrus swallowtail)

According to the literature, the caterpillars of the citrus swallowtail butterfly feed on various kinds of citrus trees, lime berry, Triphasia trifolia, prickly ash, Zanthoxylum americana, and Fagara spp., all members of the family Rutaceae.

The attractive butterflies were first sighted in Volcano residential area in January 1974, and were officially recorded in Kailua, Kona, in June 1974.

In October 1977, National Park tree nursery personnel found citrus swallowtail caterpillars feeding on kawa‘u‘kua-kulu-kapa, Fagara (Zanthoxylum dipetalum), a new Hawai‘i host record. The
caterpillars were found on young nursery stock in the old tree nursery.

Eggs were found on plants that were transferred to the new tree nursery but were not viable.

Three mature larvae pupated and two normal adults were placed in the Park collection.

8) **Cladius difformis** Panzer. (Bristly rose slug)

The bristly rose slug was found severely damaging rose foliage on 6 October 1973, in the Volcano residential area. The adults are small black wasps and are known as sawflies. They are parthenogenetic and oviposit in the petioles and midribs of the leaves. The caterpillars are slug-like in appearance and have chewing mouth parts.

This was the first record of the Hymenopterous family Tenthredinidae in the State of Hawai'i and it was observed at Kilauea Military Camp in January 1977. The bristly rose slug is restricted to roses.

A similar sawfly is found on wild blackberry and is well established in Volcano, Kipuka Ki, Kipuka Puaulu, and in other Park localities. Blackberry is the preferred host but it will feed on 'akala, *Rubus hawaiiensis*. It was purposely introduced for biological control of wild blackberry.

9) **Anua indiscriminata** (Hampson). (Myrtaceous moth)

10) **Theretra nessus** (Drury). (Yam sphingid)

11) **Macroglossum pyrrhostictum** Butler. (Maile pilau hornworm)

The last three immigrants are among the most recent arrivals in the Park and their relationship to the Park flora has not been determined. The myrtaceous moth is a noctuid whose caterpillars feed on guava, eucalyptus, and possibly 'ohi'a foliage. The yam sphingid is doubtfully established and the maile pilau hornworm has not been found feeding on native Rubiaceae. Under laboratory conditions, however, the caterpillars have been reared to maturity on pilo, *Coprosma* sp. The adults are attracted to light and are frequently observed in the Park as well as Volcano District feeding on honeysuckle and impatiens flowers.


<table>
<thead>
<tr>
<th>Insect</th>
<th>First Record</th>
<th>Kaua'i</th>
<th>O'ahu</th>
<th>Moloka'i</th>
<th>Lana'i</th>
<th>Maui</th>
<th>Hawai'i</th>
<th>Hawaii Volcanoes National Park</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>black twig borer</em></td>
<td>O'ahu</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>black stink bug</em></td>
<td>O'ahu</td>
<td>(Oct)</td>
<td></td>
<td>(Sept)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Acacia psyllid</em></td>
<td>O'ahu</td>
<td>(Jun)</td>
<td></td>
<td>(Mar)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4) <em>Gilletea taraxaci</em> Ashmead</td>
<td>1966</td>
<td></td>
<td></td>
<td>1969 (May)</td>
<td>1966 (Jun)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>dandelion gall wasp</em></td>
<td>Hawaii'i</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>cluster fly</em></td>
<td>O'ahu</td>
<td>(Jul)</td>
<td></td>
<td>(Sept)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>solanaceous treehopper</em></td>
<td>O'ahu</td>
<td>(Jun)</td>
<td></td>
<td>(Jun)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>citrus swallowtail</em></td>
<td>O'ahu</td>
<td>(Apr)</td>
<td></td>
<td>(Jul)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8) <em>Cladius difformis</em> (Panzer)</td>
<td>1973</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1973 (Jan)</td>
<td>1977 (Jan)</td>
</tr>
<tr>
<td><em>bristly rose slug</em></td>
<td>Hawaii'i</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>myrtaceous moth</em></td>
<td>Oa'hu</td>
<td>(Dec)</td>
<td></td>
<td>(Aug)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>yam sphingid</em></td>
<td>O'ahu</td>
<td>(Nov)</td>
<td></td>
<td>(Aug)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>maile pilau hornworm</em></td>
<td>O'ahu</td>
<td>(Nov)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
A MATHEMATICAL MODEL OF 'OHI'A DIEBACK 
AS A NATURAL PHENOMENON

William E. Evenson*
Department of Botany
University of Hawaii at Manoa
Honolulu, Hawaii 96822

INTRODUCTION

By means of a very general model system, the possibility of interdependent dying, as contrasted to individual, random dying, in large areas of forest is investigated. In particular, insight is provided into the possible roles of natural mechanisms in producing such interdependent collapse behavior and what the properties of such mechanisms must be. In this study, mechanisms of change in the forest are characterized as "natural" if they have been part of the forest environment over an evolutionary time scale. Otherwise, they are characterized as "introduced."

This model is applied to the problem of dieback in the native 'ohi'a (Metrosideros collina subsp. polymorpha) forests of Hawai'i. The focus of the model is on the "trigger" of the dieback. That is, we look only at the transition of trees from a healthy to a declining state (or vice versa). Mechanisms at work in the subsequent death or reinvigoration of trees are beyond the scope of this model.

The model allows separate examination of the effects of interaction between trees, external factors affecting growth, and physiological factors. Thus, it gives insight into the relative importance of various features of the 'ohi'a dieback phenomenon.

It is of especial interest for 'ohi'a dieback to know whether natural factors could produce interdependent decline or whether an "introduced" epidemic (e.g., disease or insects or some combination of introduced factors) is necessary to explain the field observations. The model presented here, while very general, deals with the plausibility of these various types of mechanisms for interdependent dieback.

Before discussing the model considered in this paper and its application to 'ohi'a dieback, the value of such models from physics in biological problems and the kind of information they

* Permanent address: Department of Physics and Astronomy, Brigham Young University, Provo, Utah 84602
can be expected to provide will be considered (Weidlich 1971; Callen & Shapero 1974).

Problems of the sort considered here concern the behavior of "incompletely-specified systems." That is, they deal with systems (e.g., a forest) for which there is either insufficient data to predict the behavior of each individual or incomplete knowledge of the laws which govern individual and system behavior, or both. In fact, these systems are intrinsically incompletely specified since we are not really interested in predicting the detailed behavior of each individual and since the data necessary for that task is impossibly extensive. Incompletely specified systems are probabilistic systems by their nature. The sub-discipline of statistical mechanics in physics is directed at such problems in Hamiltonian systems (Hobson 1971), and both models and methods originally developed in physics may be applicable to problems of incompletely-specified systems arising in other contexts.

In particular, while the causes of interdependent behavior among atomic spins in magnets and interdependent behavior among 'ohi'a trees in a dying forest are obviously rather different, the statistical behavior of these two systems does show interesting similarities.

The most serious objection to the approach taken in this paper is that models from physics, like the one discussed below, are such an oversimplification of reality that their results cannot be relied upon. While this is always a danger, such difficulties can be minimized by focusing attention on features which are insensitive to specific details of the model. It is argued that the collapse behavior in the present study is such a feature. In addition, if detailed simulation is desired, it is often possible to add specifics to such models and successively improve the simulation of reality.

DESCRIPTION OF THE MODEL

Imagine a forest of \( N \) uniform-age, essentially identical trees. Let each tree be in one of two states: healthy or declining. (The effect of modifying this model to include individual differences in trees and continuous variation in vigor will be discussed below.) This simple, very general model shows the important features of transition from healthy to declining in a manner which is qualitatively the same as a more realistic model.

The forest of identical trees in two possible states can be modelled as a spin-\( \frac{1}{2} \) classical magnet in two dimensions—the Ising model in statistical mechanics (Weidlich 1971; Callen & Shapero 1974). We use this analogy to analyze the behavior of our model forest. There are three important classes of variables in this problem:
(1) Tree interaction parameters which represent the effects of the trees on each other. We label these parameters $I_{ij}$, for the interaction between trees $i$ and $j$. Since we consider only a single species in this model, the $I_{ij}$ represent only intra-specific competition. Interspecific competition is treated as an individual (negative) growth factor in its effects on the trees. These parameters are analogous to spin-spin interactions in magnets.

(2) Individual growth factors which influence the tree toward the healthy or declining state. These factors represent the net effect on each tree of such influences as limiting resources, disease or insect attacks, moisture relations, and interspecific competition. They may be favorable or unfavorable. We label these factors $G_i$ for tree $i$, $i=1,...,N$. These factors are analogous to local magnetic fields in the magnetic systems.

(3) A stand condition parameter which represents the relative susceptibility of trees to stresses which might induce dieback. We label this parameter $S$. Large $S$ characterizes stands which are resilient in meeting stress and resist the transition from healthy to declining. The magnitude of $S$ will depend on tree physiology, including maturity and other factors which affect resistance to stress. Such factors may include environmental restrictions to a tree's ability to respond to stress; for example, substrate limitation of root development. This parameter plays a roll in the model analogous to inverse temperature in the magnetic system.

We study the simplest case: i.e., we assume that the individual growth factors are the same for all $N$ trees in the stand; and we assume that there is no tree interaction except for pairs of trees which overlap in canopy, rhizosphere, etc. (i.e., close neighbors). Hence, $G_i = G$, independent of which tree is considered, and $I_{ij} = I$ if trees $i$ and $j$ overlap, while $I_{ij} = 0$ otherwise.

So the picture is of $N$ trees interacting with close neighbors and under the influence of a growth factor, which may either induce or retard growth. Some of these trees are healthy, and some are declining. The susceptibility of trees to transition from healthy to declining is governed by a stand condition parameter.

MODIFICATIONS AND RELEVANCE TO 'OHI'A DIEBACK

The two basic assumptions of the model are that the trees are identical and that there are two discrete states for the trees: healthy or declining. It is, however, possible to relax these assumptions. Since 'ohi'a is a pioneer species on new lava flows in Hawai'i, often with a readily available seed source from an adjacent, older lava flow, and since it does not regenerate in its own shade, it tends to grow in uniform-age stands (Mueller-
Dombois 1977). Of course the trees are still not identical: there are genetic and micro-environmental differences which produce differences in trees. However, since these variations are limited by the nearly uniform seed source, age, and macro-environment of a stand, they can be accounted for by allowing our parameters, $I_{ij}$, $G_i$, and $S$, to vary from tree to tree (i.e., to vary with $i$ and $j$) with a limited distribution.

The assumption of two discrete states for the trees can be replaced by a continuous spectrum of tree vigor or by the possibility of a tree's state being described as a mixture of the healthy and declining states. The latter suggestion actually seems most reasonable since trees do die in stages and sections -- e.g., the crown may die but leave vigorous trunk sprouts (Mueller-Dombois 1977).

It is clear that the model, even with relaxed assumptions, oversimplifies the description of a stand of 'ohi'a trees in nature. For this reason, we only address questions of general behavior which are not likely to depend critically on the details of the model. In particular, the presence or absence of widespread decline (i.e., of interdependent collapse behavior like a phase transition) is insensitive to the modifications described above, with the possible exception of allowing the stand condition parameter, $S$, to vary from tree to tree. (Allowing $S$ to vary removes the concept of an equilibrium "temperature" and suggests that the forest is not in internal equilibrium.) However, $S$ should only vary over a narrow range through a given even-aged stand and hence can be treated as approximately constant in the systems of interest to this study. The effect of variations of $S$ with a restricted distribution will be to broaden the "phase transition" so that it does not occur so sharply in time and space. But interdependent collapse behavior will still be evident in such a system.

In sum, then, the modifications needed to make the proposed model more realistic will not affect the qualitative nature of any interdependent collapse which occurs. Hence, one can with some confidence draw conclusions from this model relative to the plausibility of various possible trigger mechanisms for 'ohi'a dieback.

**BEHAVIOR OF THE MODEL**

In the steady state, we can express the behavior of the model described above in terms of the steady-state probability, $P(h)$, that the forest stand consists of $h$ percent healthy trees. In detailed analysis of the model, we find that $P(h)$ depends on the three parameters, $I$, $G$, $S$, only in the two combinations $G$ times $S$ and $I$ times $S$. So we introduce two new parameters: $q = GS$, and $k = IS$. That the state of the forest depends on the parameters of the model in these combinations accords well with our expectations for biological systems: the effect of a given
environmental stress (negative $G$) depends not only on the magnitude of the stress but also on the resilience of the forest (i.e., on stand condition, $S$). And similarly for the effects of competition.

Figure 1 shows a sequence of $P(h)$ for $N = 100$ with relatively large $k$ and three values of $g$. These curves illustrate the possibility of interdependent change of a stand from healthy to declining condition.* Such a situation could occur if the effect of the trees on each other (through nutrient depletion for example) were quite strong, while the conditions for growth measured by $G$ fluctuated from favorable to unfavorable in an extreme year.

When the individual growth factors or the stand condition parameter are neutral, so $g = 0$ (Fig. 1[b]), the forest stand is in a critical state. The probability that the stand will be predominantly declining is the same as that it will be predominantly healthy. So small fluctuations could cause a collapse from healthy to declining. The converse is also possible: the use of fertilizers, thinning, or similar techniques to make growth more favorable could revive a stand which has begun to die back. An alternative outcome might be the growth of separate healthy and declining regions within the larger stand. For the case where $g = 0$, one could have about equally large clumps of dying trees and of healthy trees. The establishment of such clumps will be a function of microenvironment. This may be what happens in a "hot spot"--the small patches of dieback in dryland areas.

For contrast, Figure 2 shows a similar sequence of $P(h)$ but with $k = 0$. There is no bimodality here because there is no interdependent response. Rather, examination of the model shows that the change from a healthy to a declining stand takes place randomly by individual trees in this case, resulting in random thinning. To get as strong a dieback condition (or as strong a healthy condition) as in Figures 1(a) and (c) requires much larger values of $g$ ($g = 1.0$ when $k = 0$ gives about the same condition as $g = 0.02$ when $k = 2.5$). So the swings in growth factors have to be much greater to produce a recognizable dieback when interaction between trees does not play a significant role. An introduced disease could produce such a large change in $g$. However, relatively light environmental stress may be sufficient to produce collapse when it is associated with interactions between the trees. Such light stress could easily be produced by changes in nutritional status, moisture, or other environmental constraints.

* The mathematical expression of the model and its analysis to produce the curves discussed here are being prepared for separate publication. The analysis and results are very similar to Weidlich (1971).
We see from the two figures that interactions between trees introduce an interesting kind of stability, with an associated fragility, into the forest system. The stability comes from the tendency of the forest to maintain its state even for relatively small \( g \). However, once \( g \) becomes negative, there is a tendency for the whole system to "collapse." Hence a fragility, when close to critical values of the growth factors and stand condition parameter, is closely connected with the stability of the forest.

**DISCUSSION AND CONCLUSIONS**

The motivation for this work has been to examine the plausibility of the hypothesis that natural mechanisms within the 'ohi'a forest ecosystem can produce an interdependent collapse of a forest stand.

As illustrated in the previous section, the simplified model discussed here does show such behavior. It has been noted that the modifications required to make the model realistic do not change the qualitative behavior of the collapse, which is the focus of our interest. We see that collapse due to a natural mechanism is a possible outcome which is an alternative to random thinning, or, in a more extreme case, to introduced epidemic. The reason that collapse occurs rather than random thinning is related to the way in which 'ohi'a stands are established as pioneer, uniform-age stands on new lava flows with no regeneration in their own shade.

The fact that dieback in 'ohi'a forests seems to occur only in fairly mature forests, perhaps at intervals of several hundred years, suggests that the magnitude of environmental stress (i.e., the reduction in \( g \)) required to produce collapse is quite large and hence unusual. This fact also suggests that the interaction parameter, which increases as the trees get larger and more able to affect one another, must be fairly large. In addition, \( S \) will be larger for mature trees than, for example, for seedlings. So the requirements for collapse (i.e., that \( k \) be large and \( g \) go from a significant positive value to a significant negative value) are associated with the long time scale of several hundred years from establishment of the stand to dieback. This long time scale has made the collapse more difficult to recognize as a natural phenomenon in the sense addressed here. Similar phenomena on a shorter time scale have been much easier to recognize.* For example, one could apply the same type of model to the yearly dieback of annual plants. Annual life-forms provide a mechanism to respond to environmental stress (sharp decrease in \( G \)).

* The example given here was originally suggested to me by N. Balakrishnan.
decrease in $G$ (perhaps accompanied in some cases by a decrease in $S$) leads to a very rapid transition of a stand from healthy to declining. The response pattern which has been illustrated in Figure 2 would serve for this example as well.

This study also suggests that it would be profitable to seek out ways of measuring the interaction parameter, $I$, in the field to verify the interaction mechanism suggested here for 'ohi'a dieback. This parameter will include all factors which cause of environment. For example, nutrient competition will bring about similar deficiencies in neighboring trees when nutrients are depleted below a critical level. Since this effect is due to interaction between trees, it is one of the components of the parameter $I$. All such components must be considered.

SUMMARY

The possibility of collapse of the 'ohi'a forest from healthy to dying condition due to natural factors is investigated by means of a very general mathematical model. The model is closely related to the Ising model of magnetism. The role of interactions between the trees, i.e., intraspecific competition, is contrasted with the roles of environmental stress, disease, or insect epidemic in producing a collapse of the model forest. It is argued that the collapse behavior persists through modifications of the model which bring it into closer correspondence with reality. Study of the model leads to the following conclusions: (1) Canopy collapse can plausibly be triggered by natural mechanisms including competition, as well as by introduced epidemic factors. (2) Collapse is an alternative to random thinning or external epidemic, any of which can occur in the model under appropriate conditions. (3) Investigation of interaction mechanisms between trees in the 'ohi'a forest is an especially important and potentially rewarding avenue for further research.

LITERATURE CITED


FIGURE 1. Probability distribution for healthiness of forest stands with strong interactions between trees.
FIGURE 2. Probability distribution for healthiness of forest stands with no interactions between trees.
EVALUATION OF A NEW TECHNIQUE FOR HERBICIDAL TREATMENT OF MYRICA FAYA TREES

Donald E. Gardner
Hawaii Volcanoes National Park
Hawaii 96718

Among the many exotic plant species occurring within Hawaii Volcanoes National Park, the firetree (Myrica faya Aiton) is well recognized as being among those which pose the greatest threat to the composition of the Park's native ecosystems. Because of its demonstrated ability to quickly and aggressively become established in many Park habitats occurring roughly between 2000 and 4000 feet elevation, and since its current abundance is such that the species threatens to exceed the limits of practical control, high priority has been placed by resource management personnel upon developing efficient eradication methods. The present exotic plant control program, which is directed largely at the firetree, involves direct uprooting of smaller individuals and spraying the stems or trunks of larger plants with a diesel-Kuron (silvex) mixture, often facilitated by cutting into the bark. Large trees are routinely cut down and their stumps treated with the herbicide mixture to prevent resprouting. While herbicide treatment in this manner has proven to be effective in killing trees, certain disadvantages are also inherent in this method:

1) Diesel as a solvent for Kuron is in general more difficult to obtain and to work with in comparison with water. Application equipment is difficult to clean following use as is the protective clothing of the workers themselves. Accidentally spilled material presents greater cleanup problems.

2) Storage of large quantities of diesel presents a potential fire hazard.

3) The herbicide must be sprayed entirely around the lower tree stem for best results, often in combination with stem scoring. Access to the complete circumference of the stem is often limited by bushy lower growth, heavy surrounding vegetation, or rough terrain.

4) The spraying process inevitably results in accidental spray contact with native vegetation types growing close to target trees. Care that must be taken to avoid such contact lessens the efficiency of control work. Fire-trees in some habitats are often associated so closely with 'ohi'a trees that effective treatment of the exotic without affecting the native tree is extremely difficult.
5) Although spraying is generally limited to the lower stem as compared to the entire crown, rather large quantities of herbicide solution are required per tree. Transporting such quantities to remote areas of infestation is often costly.

To define and evaluate possible alternate methods of chemical control of M. faya, the herbicide Roundup (a product of the Monsanto Company) was selected for testing. Although at the time experimentation was begun Roundup had not been approved for routine application in a park exotic plant control program, the lack of approval was due to the relatively recent entry of the product on the market rather than to any demonstrated undesirable qualities. Roundup has since received this approval and is in use in the Park's efforts to control infestations of the exotic fountain grass (Pennisetum setaceum).

Qualities of Roundup which led to its consideration were its demonstrated systemic activity in target plants other than M. faya and the relative ease with which it is handled due to its water solubility. The current higher cost of the product compared to diesel-Kuron on an equal volume basis presents a recognized disadvantage to its use. This factor is the basis for the non-use of Roundup by the State of Hawaii Exotic Plant Control Division in M. faya control. Another product, Tordon 22K, which is available for use by the State gives satisfactory control (Walters & Null 1970; Robert Kami, Noxious Weed Specialist, Hawaii State Department of Agriculture, pers. comm.). A mixture of Tordon 212 and 2,4,5-T amine has also proven effective in killing firetree in Hawaiian state forest reserves (Kim 1969).

The above-mentioned ease with which Roundup is taken up and translocated offers potential for use through methods other than those conventionally utilized. The advantages of such techniques may include reduction in time and effort required per treated tree, ability to transport equipment and material to treat trees in difficult to reach areas, and avoidance of damage to other vegetation in the vicinity of the target tree.

MATERIALS AND METHODS

The Byron Ledge area of Hawaii Volcanoes National Park was selected as a suitable study area due to its accessibility and the large number of firetrees growing in a relatively open area unencumbered by heavy undergrowth.

Trees for the preliminary tests fell within a size range from approximately 1.5 m high and 2 cm basal diameter to 2.5 m and 4.5 cm. One branch per tree of approximately 0.75 to 1 cm diameter, depending upon tree size, was clipped off and a small plastic vial containing 20 ml of either 0.5, 1, 2, 5, or 10% aqueous Roundup solution was attached to the cut branch end of each tree such that the cut surface extended through a hole cut
in the vial cap and was immersed in herbicide solution. Actual amounts of solution absorbed by each tree were not determined since initial attempts at sealing the vials upon the branches often allowed leakage to occur. Results of these tests indicated, however, the feasibility of killing firetrees with Roundup through a single application point. In subsequent tests, treatment variables including dosage in relation to tree size, growth form of the tree, and effect of position of application on the tree were considered. Other factors such as influence of phenological or seasonal states upon treatment time were considered, although the observed lack of distinct dormant and growing seasons among trees in the study area resulted in less emphasis being placed upon the latter.

Thirty-two test trees were selected and separated into two size classes: the smaller ranged from 16.3 cm basal circumference to 25 cm and from 2.55 m tall to 5 m; the larger included basitome growth forms (several equally large branches at the base), and heights up to 6.5 m. Crown cover (bushiness) was also visually evaluated as a size class factor.

Four treatment locations upon trees were selected and test trees were further placed into categories accordingly: the upper portion of the crown; the lowest branch of suitable diameter on the mainstem (or of a major branch in a basitome tree); distal from the mainstem (the treatment branch was clipped off no less than 90 cm from the mainstem); proximal (the branch was clipped as near the mainstem as possible). Two herbicide concentrations, 2 and 5%, were superimposed upon the size and treatment location categories. These concentrations were selected on the basis of preliminary test results as reasonable experimental dosages.

Fifty-ml syringe barrels from which the plungers had been removed were fitted to lengths of bicycle inner tubing such that the rubber was stretched over the larger barrel opening. The cut branch end of each treated tree was inserted into the syringe barrel through the tube section immediately following clipping and the rubber was tightened securely around the branch with a screw-clamp. Petroleum jelly was also applied around the clamped area to insure the seal. The combined volume of the syringe barrel and rubber tubing was approximately 60 ml after displacement by the approximately 1 cm diameter cut branch.

The syringe barrel attached to each tree was filled with the appropriate Roundup concentration immediately upon the attachment of the latter to the cut branch. The herbicide was introduced with a 50-ml syringe provided with an 18-gauge needle. All trees of this experiment were treated in February 1978.

A test to determine the effectiveness of undiluted Roundup relative to that of 2 or 5% aqueous dilutions was conducted simultaneously with the latter. Smaller (12-ml) syringe barrels were sealed to freshly cut branch ends of trees with waterproof silicone rubber caulking compound. Trees of similar size range to those described above were selected. Proximal or distal
treatment locations were again chosen for each tree and the position of application along the mainstem axis was again considered.

Trees were treated with either 1.2 or 3 ml of undiluted herbicide, the equivalent amount of 60 ml of 2 and 5% dilutions, respectively. Periodic observations were conducted and treatment results were recorded in May 1978.

RESULTS AND DISCUSSION

Reactions to treatment of firetrees with Roundup by the above-described methods varied from slight effects to complete death of trees. The results of the 2 and 5% dilution treatments are summarized in Table 1.

Although variation existed among individual trees, these results indicate a trend toward increased effectiveness among those trees treated through a lower branch cut near the mainstem. The latter treatment resulted in general death of the tree with most branches being affected, whereas treatment in an upper distal location usually resulted only in localized death. Movement of the herbicide throughout the tree was evident only through limited terminal dieback of other branches. Basitone trees were more difficult to treat effectively through single-site herbicide introduction than were trees with dominant mainstem growth forms since the former required substantial downward movement of the herbicide through the treated branch to reach the vascular system of the other major branches. The apparent greater efficiency of herbicide distribution in an upward direction indicated a close correlation with xylem transport of water and in some instances a high degree of early selection for individual branches along the mainstem.

Variation in rates of diluted herbicide absorption was noted among individual trees. Complete absorption of the entire 60 ml quantity occurred among some trees within 2 days, although most required somewhat longer for complete uptake. A few trees (Table 1) never completely absorbed the available amount during the test period. Dosage comparisons involving the latter trees are therefore difficult to make, although effects of the solution amounts actually taken up were noted.

Trees treated with small quantities of undiluted Roundup reacted in a manner comparable to that described for Roundup dilution treatments. Again, herbicide introductions proximal to the mainstem and in the lowermost possible position tended to be most effective, although variation in percentage of death among individual trees was again noted, presumably resulting largely from inconsistencies in effectiveness of internal vascular connections. Complete absorption of undiluted Roundup quantities into fresh cut branch ends was markedly and uniformly rapid,
usually requiring only a few minutes. In contrast to tests utilizing Roundup dilutions, in no case did undiluted Roundup remain unabsorbed.

To discover the extent to which firetrees were able to absorb undiluted Roundup, 12-ml syringe barrels or sections of half-inch inside diameter rigid-walled plastic tubing were sealed to cut branch ends of smaller and larger trees, respectively, with caulking compound. These containers were regularly replenished with quantities of herbicide such that during a 45-day period in excess of 100 ml of Roundup were absorbed by each smaller tree and in excess of 300 ml by each larger tree over a 32-day period. Rapid uptake continued even after portions of trees near treatment areas had developed severe visual signs of poisoning. These results dispel former concerns that attempts to introduce concentrated Roundup through a single cut branch may cause immediate death of the branch with subsequent inhibition of further uptake, resulting in ineffectiveness of the treatment method.

Treatment with undiluted Roundup therefore offers no apparent disadvantage compared to the use of various dilutions, whereas the relatively small quantities required per tree and rapid absorption of the former through a single treatment site present obvious advantages. In no case was a tree killed or severely affected by either a diluted or an undiluted Roundup treatment observed to show any regenerative activity through root or lower stem sprouting.

Further experimentation emphasizes determination of effective treatment methods and herbicide quantities for trees larger than those here described and for those growing in other Park elevations and habitats. Also, alternate methods for effective treatment of trees unsuitable for the cut branch method are under investigation.

LITERATURE CITED


TABLE 1. Effects of Roundup absorbed through cut branch ends of firetrees.

<table>
<thead>
<tr>
<th>Tree size class &amp; herbicide concentration</th>
<th>Lower Proximal</th>
<th>Lower Distal</th>
<th>Upper Proximal</th>
<th>Upper Distal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Large</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2%</td>
<td>4, 7&lt;sup&gt;a&lt;/sup&gt;</td>
<td>4, 3</td>
<td>3, 1</td>
<td>1, 3</td>
</tr>
<tr>
<td>5%</td>
<td>8, 9</td>
<td>6, (5)&lt;sup&gt;b&lt;/sup&gt;</td>
<td>3, (2)</td>
<td>1, (2)</td>
</tr>
<tr>
<td>Small</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2%</td>
<td>10, 2</td>
<td>4, 3</td>
<td>1, (2)</td>
<td>2, 1</td>
</tr>
<tr>
<td>5%</td>
<td>9, 10</td>
<td>9, 4</td>
<td>2, 4</td>
<td>2, 9</td>
</tr>
</tbody>
</table>

<sup>a</sup> a number scale from 0 (unaffected) to 10 (completely dead) indicates the approximate degree to which each tree was affected.

<sup>b</sup> parentheses indicate a lack of complete absorption of herbicide solution from the container. In all other cases the solution (approx. 60 ml) was completely taken in by the tree.
FACTORS CONTROLLING THE DISTRIBUTION OF EXOTIC PLANTS IN THE KO'OLAU MOUNTAINS, O'AHU

Grant Gerrish
Department of Botany
University of Hawaii at Manoa
Honolulu, Hawaii 96822

A study of native and exotic plants was conducted in two rain forest communities in the Ko'olau Mountains, O'ahu. One study area is on Mt. Tantalus in the southern Ko'olau's; the other, 24 miles to the north, is at Pupukea. The study areas are between approximately 1500 and 2000 feet in elevation and are within the 'Ohi'a Vegetation Zone as described by Egler (1939). Eighteen 400 m² plots were sampled in the more natural vegetation of Tantalus, 16 such plots were placed at Pupukea. All species of vascular plants growing in the sample plots were recorded and their abundance estimated.

Of the 110 species of vascular plants found in the sample plots of either study area, 38 are exotic. Of these 38 exotic species, only a few are important in determining the structure and appearance of the vegetation. If frequent is taken to mean "occurring in at least half of the sample plots of one or the other study area," and abundant to mean "having cover greater than twenty percent in at least one sample plot," then only seven species of exotics are both frequent and abundant in these study areas. These seven are the trees: Psidium guajava, P. cattleianum, and Citharexylem spinosum; the smaller woody plants: Cordyline terminalis and Clidemia hirta; and the two grasses: Andropogon virginicus and Setaria palmaefolia. These species often dominate their respective vegetation layers and locally give the vegetation the appearance of being dominated by exotic plants.

Concern about the impact of exotic plants on Hawaiian ecosystems and the detrimental effects that these introductions may have on the endemic flora necessitates the examination of the ecology and behavior of exotic species and to ask the question "Why of the more than 4000 species of exotic plants found in Hawaii (St. John 1973) have these seven species become frequent and abundant in these rain forest communities?" Species which are obviously "trailside weeds," such as Erechites hieracifolia, will not be discussed in detail, since any damage to the native vegetation associated with the presence of these plants can be more directly attributed to the disturbance that allowed them to become established. At the same time, it is not realistic to discuss these ecosystems under conditions of no human-induced disturbance. The presence of pigs and goats in the southern Ko'olau's, and at least occasional human presence throughout the
range insure that the vegetation will always be subjected to some disturbance. Exotic plants which can exploit this minimal level of disturbance are of prime interest.

The occurrence of 11 exotic species at Tantalus which do not occur at Pupukea supports the hypothesis that more exotics are found in the southern Ko'olau's because the effects of man are greater at that end of the range, especially in the Honolulu area, to which Mt. Tantalus is adjacent. This hypothesis proposes that the distribution of exotic plants is largely a function of seed availability and disturbance of the vegetation by man or recently introduced animals. Observations and research indicate that now, as well as in the past, the Tantalus study area is subjected to more disturbances of these kinds than is the Pupukea study area, and that Tantalus has available to it a greater source of potential exotic invaders in the form of ornamentals and other introduced plants grown in botanic and private gardens in the Honolulu area.

The presence of escaped cultivars on Tantalus, such as Cinnamomum zeylanicum and Ilex paraguariensis, and of the ornamentals Ardisia crispa and Tropaeolum majus, clearly indicates that proximity to Honolulu is a controlling factor of these species distributions. None of these exotic species are reported elsewhere in the Ko'olau's. Citharexylum caudatum was introduced into Lyon Arboretum at the foot of Mt. Tantalus. This tree now forms dense stands on Tantalus and elsewhere on the periphery of Manoa Valley and has been reported as "occasional" in the Schofield Barracks area (USACH, unpublished).

However, there are species of exotic plants which have distribution patterns that do not fit the hypothesis that the spread of exotics is mediated by man alone. There are exotics which are found in the Tantalus study area and near, but not in, the Pupukea study area; and exotics that occur at Pupukea and in the vicinity of, but not in, the Tantalus study area. These distribution patterns would not be found if seed availability were the only factor governing the distribution of exotic species.

The common guava, Psidium guajava, is the most abundant exotic tree on Tantalus, but only a few scattered individuals of this species occur in the Pupukea study area. Guava occurs on all sides of the Pupukea study area, indicating that unavailability of seeds is not the reason this species is not abundant there. The distribution of Schinus terebinthifolius is similar to that of the guava.

On the other hand, the noxious shrub Clidemia hirta, another melastomaceous weed, Pterolepis glomerata, and the grass Andropogon virginicus, are very common in the Pupukea study area and elsewhere in the Ko'olau's. These three exotics are found near Tantalus, but not in the Tantalus study area. Considering the great dispersability of the seeds of all three of these species, it is not possible that unavailability of seed is responsible for the absence of these three species on Tantalus.
With respect to the distribution of some exotic plants, it would appear that each study area is an island surrounded by these species, but free of them. Distribution patterns of some native plants coincide with these exclusive distributions of exotics. On Tantalus and at lower elevations in the Pupukea area, Acacia koa is a co-dominant in the 'ohi'a forest. Koa is lacking in the Pupukea study area. Metrosideros tremuloides is the most common species of the genus at Tantalus; only one individual of this species was found in the Pupukea study area. Many native species which are common at Pupukea are absent or of low frequency at Tantalus. These include Cibotium chamisssoi, Alyxia olivaeformis, Scaevola gaudichaudiana, Wikstroemia cahuensis, Lycopodium cernuum, Pelea clusiaefolia, Clermontia oblongifolia, and Tetraplasandra pupukeensis.

These differences in the native and exotic floras of the two areas suggest that important environmental differences exist. According to published meteorological data (Voorhees 1929; Taliaferro 1959), the annual amount and the monthly distribution of rainfall is quite similar in both areas. No major climatic differences exist.

Analyses of the soils of the sample plots of the study areas were conducted. The soil at Pupukea is mapped as the Kapaa Series (USDA 1972). These highly weathered clays are classified as Oxisols. They are derived from Ko'olau basalt and have a high gibbsite content. Analyses showed the mean pH to be 4.6. Available phosphorous was undetectable in most samples. Bases, especially calcium and magnesium, were present only in very low concentrations. All analyses indicated that the soils of the Pupukea study area are extremely infertile.

In the Tantalus study area, two very distinct soils were found. A majority of the study area is on cinder-derived soils of the Tantalus Series. This inceptisol is derived from ash and cinder of the Tantalus eruption (USDA 1972) which is dated to less than 100,000 years age (MacDonald & Abbott 1970). These soils are youthful and were found to retain higher concentrations of calcium and magnesium than the soils of Pupukea. Mean A horizon pH is 5.6 and available phosphorous was detected in all samples.

Several sample plots in the Tantalus study area were found to be on soils derived from the ancient Ko'olau basalt rather than Tantalus cinder. These highly weathered clays have a mean pH of 4.6 with no detectable available phosphorous or calcium in the A horizon. These lava-derived soils, like the lava-derived soils of Pupukea, are extremely infertile.

The influence of soil fertility on the vegetation structure and quantity of biomass supported at each study area can be seen. At Pupukea, the canopy above 2 m high is rarely more than 50% closed and above 5 m is approximately 70% closed. Thus, the forest at Pupukea can be called "open," while the canopy at
Tantalus is "closed" and of higher stature. While no measurement of biomass was made, it is evident that a larger standing crop is maintained on the more fertile cinder-derived soils of Tantalus than at Pupukea.

In some cases, the distribution of exotic species can be directly correlated with the canopy characteristics of the community. For example, shade-loving *Setaria palmaefolia* and *Commelina diffusa* are found on the forest floor of Tantalus. Neither species occurs in the open forest of the Pupukea study area. At Pupukea, *Andropogon virginicus* locally dominates the ground cover under the open tree canopy, but this grass is not found on Tantalus. The distributions of these and other species appear to be controlled by biotic characteristics of the ecosystems, and only secondarily by the environmental factors which determine the general structure of the community.

In other cases, the effect of environmental factors is directly expressed. The near absence of the common guava, *Psidium guajava*, from the Pupukea study area is not a result of seed unavailability, lack of vegetation disturbance, or an unsuitable vegetation structure. The most reasonable explanation is that this tree can not tolerate the stress of the acid, infertile soil of Pupukea. Similarly, *Clidemia hirta* is in the vicinity of Tantalus and has been shown to be relatively shade tolerant (Wester & Wood 1977) but it is not found in the Tantalus study area. This species is very tolerant of infertile soil but lacks the genetic attributes needed to compete with faster growing plants on a less stressful site. This tree appears to be both tolerant of soil infertility and capable of competing on more fertile sites.

That soil fertility is a controlling factor in the distribution of both native and exotic plants is supported by the finding that the vegetation of the infertile lava-derived soils of Tantalus is more like the vegetation of Pupukea than like that of the more fertile soils of Tantalus. The vegetation of these lava-derived soils of Tantalus exhibits an open canopy; lacks a number of species common in other Tantalus communities, such as *Psidium guajava*; and possesses several species common at Pupukea but rare elsewhere on Tantalus, such as *Dicranopteris linearis*.

In conclusion, it has been found that a number of exotic species have escaped cultivation into the native vegetation around Honolulu. Some of these do not appear to be aggressive; others, such as *Citharexylum caudatum*, do. Some exotic species, especially grasses and forbs, have distribution patterns determined by community biotic factors, such as degree of canopy cover. The distribution of other species is controlled by soil fertility.

It is suggested that the difference in soil fertility between the Tantalus and Pupukea study areas is one of several or many environmental barriers that can be found within a climatically similar zone of the Ko'olau Mountains. These barriers may effectively prevent the spread of an exotic species through the
native rain forest. However, the several exotic species that are capable of crossing all or most of these barriers are the plants that must be considered a threat to the integrity of native vegetation and to the existence of local endemics. From this study it has been found that the most threatening exotic plants in the rain forests of the Ko'olau Mountains are Psidium cattleianum, Citharexylem caudatum, and Clidemia hirta.

LITERATURE CITED


RESOURCES TRACKING PATTERNS IN ACARI ASSOCIATED WITH BIRDS IN HAWAII VOLCANOES NATIONAL PARK: A PRELIMINARY REPORT*

M. Lee Goff
Department of Entomology
Bernice Pauahi Bishop Museum
Honolulu, Hawaii 96818

For some time now, host-parasite relationships have been an area of important and frequently controversial inquiry among systematists. Studies of Mallophaga infesting birds by Clay (1949, 1950, 1957); the streblid batflies by Wenzel et al. (1966); and the Macronyssidae and Laelapidae of bats by Radovsky (1967, 1969) have provided examples which have led to the somewhat optimistic statement: "parasite phylogeny parallels host phylogeny" (Kethley & Johnston 1975). In more rigorous terms this may also be expressed: "parasite inter-relationships are congruent with host inter-relationships" (Kethley & Johnston 1975). Recently Acari infesting birds have been studied with some emphasis given to host-parasite co-evolution (Kethley 1971). These Acari may be divided into three groups based on their interaction with the bird host (Fig. 1). Group I contains the host-dwelling mites. Here, most or all of the life cycle of the mite is spent on the host. Group II contains the nest-dwelling ectoparasites. These mites visit the host only to feed and spend the remainder of their life cycle in the nest. Group III mites are the field parasites. These mites, most notably the chiggers and ticks, are associated with the host only for feeding. Wide host ranges are typically associated with Group III mites.

Group I parasites have been the primary source of data for the construction of patterns of radiation, as shown in Figure 2 for the Acaridei, and for tentative phylogenies, as shown in Figure 3 for the parasitic Gamasina (after Radovsky 1969). It is of interest that in the Acaridei (Fig. 2) there is an actual difference in the life cycle corresponding to the difference in habitat, as the deutonymphal stage, or hypopus, is absent from parasitic forms. A tendency toward reduction in stages in the life cycle, or tachygenesis, is common among parasitic forms. The house dust mites (family Pyroglyphidae) are placed in an intermediate position between the nest habitat and the parasitic habitat in Figure 2. This results from the belief that these

* Studies upon which this report is based were supported in part by Cooperative National Park Resources Studies Unit Contract CX 8000-7-0009 to the University of Hawaii and in part by National Institutes of Health Grant AI 13893 to Bishop Museum.
mites are parasitic forms which have secondarily reverted to the nest habitat (Wharton 1976). In both Figures 2 and 3, the nest habitat is shown to be an intermediate step toward parasitism. The nest serves as a stable food source for nidicolous mites as well as a concentrating mechanism for their mating. In many instances, this association has been shown to be a forerunner of parasitism, for example, in the parasitic Gamasina (Radovsky 1969). It is also of some interest to note that the bird-infesting Rhinonyssidae are believed derived from the bat-infesting Macronyssidae (Fig. 3). In this instance, strict adherence to the previously stated concept of host-parasite congruence would require that one derive the birds from the bats. With relative safety, I feel that I can say this is slightly unreasonable. In the past such non-congruencies have been explained by invoking either the "accidental transfer" or "historical accident," which imply some form of selection error on the part of the parasite.

The possibility that something other than an accidental transfer was operating was suggested by Kethley and Johnston (1975), based on studies of quill mites of the family Syringophilidae (Kethley 1971). They observed that the mites had not tracked their hosts as a unit through their evolution, but instead, topographic sub-units of the host. In the case of the Syringophilidae the parameters of quill diameter and wall thickness were the major determining factors in the mite population. Thus distantly related, or in some instances apparently non-related, hosts which had structurally similar feathers were observed to support closely related mite populations.

With this background, it might be expected that similar patterns would be found in mites infesting the external portions of feathers. The feather mites of the superfamily Analgoidea comprise a complex of over 50 families. These are highly derived mites with varying degrees of host specificity (Krantz 1971). Feather mites are primarily grazers on the surface of the feather and do not normally appear to cause any injury to the host, thus large numbers of mites per host are common. Members of the family Analgidae are frequently noted from a wide range of hosts (Krantz 1971), but generally from hosts with similar feathers. Among species of Proctophyllodidae, most notably the genus Proctophyllodes, a high degree of host specificity is noted, with 38% of the species reported from a single host species (Atyeo & Braasch 1966). Thus in the feather mites, there are indications that both co-evolution and resource tracking are present. Due to the relative isolation of the Hawaiian Islands, and the number of endemic birds present, Hawaii Volcanoes National Park presents an ideal situation for the study of these patterns in the birds. At present both endemic and introduced birds are being collected and processed for ectoparasites in conjunction with a study of avian malaria, sponsored by the Cooperative National Park Resources Studies Unit (CPSU).
Identifications completed to date are presented in Tables 1 and 2. While conclusions cannot be drawn at this time, several undescribed taxa have been encountered and new records for hosts and localities are present in the data. Prior to this study only the families Analgesidae and Proctophyllodidae had been reported from the Hawaiian Islands (Garrett & Haramoto 1967). In the Proctophyllodidae, only the genus Proctophyllodes was reported. All other feather mite records are new. The recovery of specimens of cytoditids from the Red-billed Leiothrix constitutes a new host record. The recovery of Neharpyrhynchus sp. from an 'Amakihi constitutes both a new host record and the first record of this genus from Hawai'i.

Following completion of taxonomic studies, host-parasite relationships will be studied to determine which patterns are present in the feather mites associated with endemic birds and these results compared to currently available taxonomic structures for the species involved.

ACKNOWLEDGEMENTS

I am indebted to Dr. Warren T. Atyeo, University of Georgia, for providing identifications of feather mites. Harpyrhynchidae were identified by Dr. Wayne W. Moss, Philadelphia Academy of Sciences. Birds were collected and processed under the direction of Dr. Charles van Riper III.
LITERATURE CITED


<table>
<thead>
<tr>
<th>Bird</th>
<th>Mites Recovered Family</th>
<th>Genus &amp; Species</th>
</tr>
</thead>
<tbody>
<tr>
<td>'Amakihi</td>
<td>Rhinonyssidae</td>
<td>Ptilonyssus sp.</td>
</tr>
<tr>
<td>(Loxops virens)</td>
<td>Harpyrhynchidae</td>
<td>Neharpyrhynchus sp.</td>
</tr>
<tr>
<td>'Apapane</td>
<td>Laelapidae</td>
<td>Androlaelaps sp.</td>
</tr>
<tr>
<td>(Himatione sanguinea)</td>
<td>Rhinonyssidae</td>
<td>Ptilonyssus sp.</td>
</tr>
<tr>
<td>'Oma'o</td>
<td>Rhinonyssidae</td>
<td>Ptilonyssus sp.</td>
</tr>
<tr>
<td>(Phaeornis obscurus)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Red-billed Leiothrix</td>
<td>Cytoditidae</td>
<td>Cytodites sp.</td>
</tr>
<tr>
<td>(Leiothrix lutea)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Japanese White-eye</td>
<td>Cheyletidae</td>
<td>Neocheyletiella sp.</td>
</tr>
<tr>
<td>(Zosterops japonicus)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### TABLE 2. Feather mites recovered from endemic and introduced Hawaiian birds.

<table>
<thead>
<tr>
<th>Bird</th>
<th>Mite Family</th>
<th>Mite Genus &amp; Species</th>
</tr>
</thead>
<tbody>
<tr>
<td>'Amakihi (Loxops virens)</td>
<td>Analgidae</td>
<td>Analges sp.</td>
</tr>
<tr>
<td></td>
<td>Proctophyllodidae</td>
<td>Proctophyllodes sp.</td>
</tr>
<tr>
<td></td>
<td>Trouessartiidae</td>
<td>Trouessartia sp.</td>
</tr>
<tr>
<td></td>
<td>Xolalgidae</td>
<td></td>
</tr>
<tr>
<td>'Apapane (Himatione sanguinea)</td>
<td>Analgidae</td>
<td>Analges sp.</td>
</tr>
<tr>
<td></td>
<td>Proctophyllodidae</td>
<td>Proctophyllodes sp.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pterodectes sp.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>House Finch (Carpodacus mexicanus)</td>
<td>Proctophyllodidae</td>
<td>Proctophyllodes pinnatus</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>House Sparrow (Passer domesticus)</td>
<td>Proctophyllodidae</td>
<td>Proctophyllodes troncatus</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>'I'iwi (Vestiaria coccinea)</td>
<td>Analgidae</td>
<td>Analges sp.</td>
</tr>
<tr>
<td></td>
<td>Proctophyllodidae</td>
<td>Proctophyllodes sp.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Laysan Finch (Psittirostra cantans)</td>
<td>Analgidae</td>
<td>Analges sp.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Red-billed Leiothrix (Leiothrix lutea)</td>
<td>Pteronyssidae</td>
<td>n. gen. &amp; n. sp.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>'Ôma'o (Phaeornis obscurus)</td>
<td>Analgidae</td>
<td>Analges sp.</td>
</tr>
<tr>
<td></td>
<td>Proctophyllodidae</td>
<td>Proctophyllodes sp.</td>
</tr>
<tr>
<td></td>
<td>Trouessartiidae</td>
<td>Trouessartia sp.</td>
</tr>
<tr>
<td></td>
<td>Xolalgidae</td>
<td>n. gen. &amp; n. sp.</td>
</tr>
<tr>
<td>Pueo (Asio flammeus)</td>
<td></td>
<td>Onychalges sp.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rice Bird (Lonchura punctulata)</td>
<td>Analgidae</td>
<td>Anhemialges sp.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Streikovilarus sp.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mouchetia dolichosikya</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Calcealges yunkeri</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Trouessartia sp.</td>
</tr>
<tr>
<td>Japanese White-eye (Zosterops japonicus)</td>
<td>Analgidae</td>
<td>Anhemialges sp.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Streikovilarus sp.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mouchetia dolichosikya</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Calcealges yunkeri</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Trouessartia sp.</td>
</tr>
</tbody>
</table>
NASAL MITES
RHINONYSSIDAE
ASCIDAE (PHORETIC)
EREYNETIDAE
TROMBICULIDAE
CYTODITIDAE
TURBINOPTIDAE

SKIN MITES
CHEYLETIDAE
HARPYRHYNCHIDAE
EPIDERMOPITIDAE
KNEMIDOCOPTIDAE

WING MITES
ANALGOIDEA (50+ FAMILIES)

QUILL MITES
SYRINGOPHILIDAE
DERMOGYPHIDAE
SYRINGOBIIDAE
CHEYLETIDAE (PREDATORY)

DOWN MITES
ANALGOIDEA

OTHER MITES
DERMANYSSIDAE
MACRONYSSIDAE
ARGASIDAE
IXODIDAE &
TROMBICULIDAE &

HOST DWELLING
NEST DWELLING
FIFID PARASITES
FIGURE 2. Proposed radiation of the Acaridei.
INTRODUCTION

The amazing diversity of form and habitat in the Hawaiian native insect fauna is currently an object of review and study. Perhaps 4000 species of endemic insects have been described, and new species are often encountered in general collections of remoter areas. Thus, a pioneering stage still prevails in Hawaiian forest entomology.

Many species of introduced insects (especially those of economic importance) have been well studied, and aspects of their taxonomy, physiology, behavior, and ecology are relatively well known. In contrast, many of the Hawaiian insects are so poorly understood that all the information available may be a type specimen and general collection information. Some species holotypes are defined from as little as wing fragments from a single specimen, never again re-encountered (Zimmerman 1948).

One of the recent trends in Hawaiian entomology is the utilization of transect techniques along altitudinal gradients. These studies have demonstrated that species are often restricted to well-defined altitudinal ranges (Gagné 1976). There are usually habitat limitations related to altitude which define optimal ranges and distribution boundaries.

This study examines the distribution of endemic insect families along an altitudinal gradient between 1670 and 580 m, and investigates differences in the diversity of the families at various elevations. The trends uncovered would provide insight to environmental and biotic factors related to altitude, affecting the distribution of the Hawaiian insect fauna.
STUDY SITE

The ahupua'a of Manuka, Kaulanamauna, and Kapu'a lie upon the southwestern flank of the Mauna Loa shield volcano in the South Kona district of the island of Hawai'i. These triangular sections of land extend downslope from their common apex at Pu'u Ohohia (1690 m) along the Southwest Rift Zone of Mauna Loa, fanning outward to include a 12 km expanse of shoreline at their bases (USGS topographic quadrangles 1957).

METHODS

Transects and sample stations

Field study was conducted from June 15 to July 31, 1977. The survey of insect fauna was one aspect of a holistic ecosystem baseline survey of the Manuka area conducted under the auspices of the National Science Foundation.

Twelve sampling stations were established along two parallel transect access lines in altitudinal increments of 290 m running from Pu'u Ohohia downslope. The arrangement of sampling stations is illustrated in Figure 1. This placement established two replicate stations at the 1440, 1150, and 875 m elevations, and one replicate at the 585 m elevation. The study area boundaries precluded establishing replicates at the 1690 m level, while commercial agriculture at one of the 585 m plotsites made considerations of sampling at that location moot.

Whenever possible, the entomology sampling station plotsites coincided with that of the Manuka Research Project vegetation ecology survey sites, in order to have available detailed vegetation data.

Sampling techniques

In this study, only the night fauna was considered. Night collection commenced at 7:00 PM and ran continuously to 10:00 PM. Each night collection utilized a simple sheet light trap. A Coleman-type lantern provided attractive illumination. All insects that came to rest upon the sheet were collected during the 3-hour period, and kept for identification. Large insects were collected with sweep nets, while smaller insects were aspirated into vials.

Data analysis

The number of families encountered at each plot were cumulated, and mean values for isoaltitudinal plots were computed. The trends in the diversity of insect communities at the family
level were analysed against altitude distributions of the sample station plotsites via correlation coefficients generated by:

\[ r = \frac{s_{xy}}{s_x s_y} \]

where \( s_{xy} \) (covariance) = \( \frac{1}{n-1} \left( \sum x_i y_i - \frac{1}{n} \sum x_i \sum y_i \right) \),

and \( s_x = \sqrt{\frac{\sum x_i^2 - (\sum x_i)^2}{n-1}} \) \( s_y = \sqrt{\frac{\sum y_i^2 - (\sum y_i)^2}{n-1}} \)

where \( s_x \) and \( s_y \) are standard deviations, \( x \) and \( y \) being values of two discrete and changing factors: altitude and the number of insect families encountered.

RESULTS

There was a general linear increase in the number of families collected with decreasing altitude (Table 1). Correlation coefficients calculated using the mean number of families collected at isoaltitudinal plots substantiated this linear relationship \((r = -0.72, n = 5)\).

With decreasing altitude, greater numbers of families appeared during the first half of the collection periods. At the 1690 m station, 50% of families encountered were collected by the midpoint of the collection period. At 1150 m, this figure had increased to 70%, while at 875 m it was 79% and at 585 m, the insects collected by the first half of the collecting period amounted to 84% of the total yield. The rise in this temporal packing correlated with altitude \((r = -0.74, n = 12)\).

An interesting exception to the linear relationship of both family diversity and temporal packing trends occurred at the 1440 m elevation, where both diversity and packing exceeded figures characteristic of the 1150 m plots, and were only slightly lower than values at the 875 m level. This "hump" is easily seen in Figure 2. If the data from the 1440 m plots are deleted, and correlation coefficients are again calculated, the linear fit against altitude is far more precise (family diversity/altitude \( r = -0.82, n = 9 \); temporal packing/altitude \( r = -0.91, n = 9 \)).

The distribution of entomology sites, vegetation ecology relevé stations, habitat descriptions, and climatic observations along the altitudinal gradient are presented in Figure 3. The number of vascular plant species and insect families encountered at identical sites are compared in Figure 4. The data is utilized in the discussion to assess vegetational correlations and to incorporate several situations to interpret both general trends and the "hump" phenomenon.
DISCUSSION

The trend of increasing diversity in insect communities with lower altitude that was uncovered in the study area was expected by this author. Major dimensions critical to the survival and fitness of insect species, such as temperature and moisture, approached more favorable conditions with decreasing altitude. In addition to these environmental aspects, the effect of vegetational diversity can be considered.

Environmental Aspects

Temperature

On the even, lee slope of the Mauna Loa shield volcano, mean temperature decreases with altitude. It is not unusual to find morning frost at the 2000 m level, while at sea level, nights are often uncomfortably warm. There is some evidence that temperature effects contributed to limiting the upper range of many insect species in this study. The total number of specimens per collection increased with decreasing altitude, and the numbers of insect families which appeared by the first half of the collection period increased from five families (50% of the total families collected) at 1690 m, to 18 families (84% of the total families collected) at 585 m. Clearly, not only were there more insect families encountered, but more total specimens collected, and a much greater relative activity at lower elevations. The difference in activity was especially notable. At 1690 m, less than 100 specimens were collected, and long periods of inactivity were prevalent by the end of the collection period, when night temperature was estimated at 5°C. In contrast, at the 585 m plotsites, several hundred specimens were collected, and near the end of the collecting period, the collectors were hard-pressed to keep up with the insects clustered on the sheet and swarming around the light. The estimated temperature at the end of the night collection there was 15°C.

Beetles in the family Scolytidae were not encountered except below 875 m, where they were quite common. Scolytid beetles are known in Metrosideros wood, and Metrosideros sp. exists as the dominant macrophanerophytic species in the entire study area. Thus, food limitations cannot be imposed. Increasing moisture conditions toward 1150 m is not a limiting factor. Scolytids are known from rain forests as well as mesophytic forests. Predation is a factor to consider; however, bird species such as Loxops and Himatine exist at both low and higher altitudes, and the incidence of predacious and parasitic insects increases with lower altitude. It seems likely that temperature is the limiting factor. Little is known of the temperature tolerances of the Hawaiian insects, and because no systematic temperature readings were taken in this study, no conclusions can yet be made.
Moisture

The climatic pattern along the Kona Coast of the island of Hawai‘i is clearly defined from the predominant tradewind situation in the Hawaiian Islands. Due to the massive obstacle of the Mauna Loa shield volcano which negates tradewind influences, the Kona (leeward) flank climate is determined largely by a diurnal convective cycle.

In the day, land heat-induced winds pull moisture-laden ocean air up the slope of Mauna Loa. An inversion layer near 1100 m induces cloud formation in a band above this level, where highest precipitation occurs. Above and below this level, average rainfall decreases along gradients (Blumenstock & Price 1967). From the barren cinder above 1700 m, moisture levels increase downslope toward fog forest at 1440 m, and mixed mesophytic forest below this to approximately 300 m, where near-xeric conditions prevail. Within the altitude range of the study, however, moisture conditions are seen to increase downslope. If moisture is considered as a limiting factor, then the good agreement between moisture gradients and insect family diversity leads to the conclusion that the increase in moisture and the increase in insect diversity are related.

In a study of the distribution of canopy-associated arthropods along a transect on the windward slope of Mauna Loa, Gagné (1976) suggested that factors contributing to the distribution of the more restricted arthropods would appear to be related to climate. For example, in his study, the exotic detritivorous roach, Allacta similis, was apparently excluded from higher montane environments, a phenomenon which Gagné attributed to cooler temperature and greater moisture in the lower rain forest (below 1800 m). In the same manner, he noted that the detritivorous tree cricket, Paratrigonidium spp., predominated in moister, warmer sites at the lower portions of the transect (below 1500 m). In a more general trend, Gagné found that arthropod species diversity in Acacia koa tree canopies was relatively high at low and mid-elevations, but decreased markedly with altitude, which he attributed to climatic causes.

In the Manuka study, moisture conditions were considerably different from the Mauna Loa findings, where tradewind influences push the inversion layer higher, and mesic conditions prevail to about 200 m, with rain forest environments restricted to below 1400 m. In the Manuka study area, rain forest environment does not exist, and mesic conditions exist in a band of precipitation largely below 1400 m and above 400 m. We would expect that the upper altitudinal limit, if it is determined by relative humidity, would be lower than those observed along the Mauna Loa transect.

In the day collections at Manuka, Allacta similis was not found above 1150 m plotsites. In nocturnal collections, the crickets, Paratrigonidium spp., likewise were limited to below 1150 m. A rarer, brachypterous ground cricket, Leptogryllus sp., was found only at 860 m, despite concerted searches of leaf
litter habitats at lower and higher altitudes. Although both Paratrigonidium and Leptogryllus are poorly scleroterized, Leptogryllus is an especially soft-bodied insect. The tendency toward hot, xeric conditions at lower elevations, and the tendency toward colder, xeric conditions at higher elevations seem to have restricted the range of this fragile, wingless, detritivorous cricket.

Desiccation pressure and the alleviation of this factor at lower altitudes seems likely to play a role in determining the increase of diversity seen in the study area. However, until determinations can be made about the optimum moisture conditions for any Hawaiian insect species, we have no quantitative indication of moisture-related limitations of insect distribution in the Hawaiian systems.

Biotic Aspects

Vegetational diversity

Temperature and moisture regimes determine the distribution of endemic plant species. Krajina (1963) described 14 biogeoclimatic zones, elaborating on the works of Rock (1913), Ripperton and Hosaka (1942), Fosberg (1961), and others, compiling ecological observations and studies of topographic, geological, climatic, and biotic factors. Five of these zones exist in the Manuka study area, reflecting a leeward forest pattern. At lower altitudes (300-470 m) open mixed xerophytic and mesophytic forest grades into closed mixed mesophytic and xerophytic forest (470-850 m) which in turn gradually passes into mesophytic marine tropical and subtropical forest (850-1470 m) and rather suddenly passes into open mixed mesophytic and xerophytic scrub forest (1470-1690 m) and finally to open xerophytic scrub (1690 m to subalpine and alpine elevations). The area has been largely characterized as a "dry transitional forest," based upon the vegetational community gradients, but the diversity of the communities is affected by differences in substrate, making the area far more complex.

Aerial photographs of the study area taken in 1962 show that the substrate varies in both age and basic composition. Unweathered 'a'a and cinderfalls may be found alongside sections of older, weathered substrates with good soil development. Differential vegetation type is seen to correspond to differing substrates.

Results of a vegetation survey and ecological study conducted concurrently with the entomology collections of this study show that vegetational diversity changed with altitude. For example, at the 1690 m site, a plant species count tallied a maximum of 15 vascular plant species. At 1440 m, 52 vascular plant species were collected, and at 1150 m, 35 vascular plant species were encountered. At 875 m, 37 vascular plant species were tallied, and at 585 m, 39 vascular plant species were
counted at the main transect relevés. When the correlation coefficient $r$ was computed for insect family diversity and plant species count, a strong correlation was seen ($r = 0.811$, $n = 10$). The relationship between the number of plant species and the number of insect families at identical plotsites reflects the correlation (Fig. 4).

Two major factors may be responsible for the relationship: trophic relationships between insects and plants, and the effect of spatial heterogeneity on species diversity.

The major relationship between insects and plants is trophic, and thus the ecology of the vegetation has a direct bearing on insect ecology. This would be most evident in stenophagous insects (i.e., insects with narrowly limited diets). Swezey (1954) compiled an annotated checklist of the insect faunas of Hawaiian forest plants, making note of stenophagous species. The percentage of stenophagous insects ranged from an 11% incidence of stenophagy (on *Acacia koa*), to a 72% incidence of stenophagy (on *Pelea* spp.). For the majority of endemic plant species, however, the incidence of stenophagy ranged between 30% and 45%, and the mean incidence of stenophagy in the Hawaiian herbivorous insects in 36.55%, a sizeable percentage.

The various Hawaiian plant species are host to a diverse number of insect species, ranging from eight known associated species on *Osteomeles* sp. to more than 128 known to feed on *Acacia koa*. Each plant species in the vegetational community could "contribute" its complex of associated insects to the total insect fauna. In the same manner, the absence of a plant species in a given area would mean that its stenophagous insect complement would be missing from the fauna. In our study area, the coleopteran families Bostrichidae, Cerambycidae, and Carabidae were restricted to the 875 m plotsites and lower. The homopteran families Cicadellidae and Cixiidae likewise become extremely common below 875 m. Both families' predominance seem to be related to a change in vegetation below 940 m. *Psychotria*, a tree species in the family Rubiaceae becomes common in the canopy. Various dryland tree species such as *Antidesma*, *Drypetes*, and *Diospyros* make their appearance below 800 m and occur in their highest frequency just below 600 m. The increase in the number of tree species may explain the appearance of the coleopteran families, notable wood borers of various Hawaiian trees. The prevalence of the homopteran families may be related to the prevalence of *Psychotria*, from which both cixiids and cicadellids were collected in large numbers in day collections.

The predatory families Chrysopidae, Braconidae, and Bethylidae become prominent in the lower altitude plotsites, although the chrysopid lacewings and the braconid wasps were present at much lower numbers at higher plotsites. It is likely that either prey species became more numerous at lower altitudes, or that biomass of the prey population became greater. Both situations were seen to occur. The increase in predatory and parasitic families can be considered an indirect result of the increase in
plant species diversity. The more diverse the vegetational community, the greater is the potential for species packing in the consumer community and likewise in the entire trophic network.

In addition to trophic relationships, increased vegetational diversity results in an increased spatial heterogeneity. There is an increase in the complexity of the physical environment. For example, the higher abundance of Psychotria sp. in lower altitude plotsites means that there are differences in the trophic niche, habitat changes in the litter layer, unique resilience opportunities for day-inactive insect species, a new bark habitat for the pscopteron and orthopteran families, etc. In short, the more complex the physical environment becomes, the more complex the plant and animal communities supported, and the higher the species diversity. MacArthur (1965) suggested that between-habitat diversity is a major scheme in determining tropical species packing. For example, MacArthur and MacArthur (1961) determined that the extent of foliage stratification in a forest community was more important than the species diversity of the vegetational community alone in affecting the faunal diversity. In the Manuka study, foliage stratification increased with lower altitude, as conditions improved for tree species. At the 1150 m plotsites, the canopy of Metrosideros was non-interlocking and rose to about 6 m. Forest conditions developed by 875 m, however, with densely interlocking canopies of Metrosideros and Psychotria, reaching crowns at 25 m. The substantially tall canopy created adequate room for a well-developed middle-story of Cibotium tree ferns, Myrsine lessertiana, and Vaccinium calycinum, and an understory of ferns and small vascular plants. In the 585 m plotsites, species diversity was even higher, and the complexity of foliage stratification was very well developed. It is not surprising that the increase in species diversity and foliage stratification downslope in the study area is paralleled by a correspondant increase in the diversity of the insect community.

Combination of factors

All of the factors discussed this far cannot be realistically considered independently. The combination of environmental aspects and biotic factors is a dynamic process, the synthesis of which is the final characteristics of insect distribution we have observed. For example, moisture characteristics probably determined the basic vegetational diversity at 675 m; however, the presence of vegetation can create microclimates in which moisture and temperature conditions are quite different from adjacent, barren areas at the same altitude. As a result, the increase in the complexity of the environment created by microclimates would allow for a higher potential in species diversity. What will be discussed next is an example of the resultant effect of a combination of environmental and biotic factors: the "hump" phenomenon at 1440 m.
The "hump" phenomenon

The exceptionally high diversity of the 1440 m plotsite collection can be considered in terms of the interaction of several factors which exist at that elevation. It can be seen that perhaps three aspects unique to the 1440 m plotsites could contribute to the "hump" phenomenon: moisture conditions, vegetational diversity, and kipuka effects.

An inversion layer fog belt which exists from 1080 to 1860 m creates a high humidity situation without heavy precipitation. It has been suggested that for some species of Hawaiian insects, the physical effect of rain showers may restrict their presence in zones of precipitation (Gagné 1976). In addition, high air moisture creates favorable conditions for the growth of fungus, and results in suitable habitats for detritivorous and fungivorous insects, which constitute a considerable percentage of Hawaiian forest insect communities (Gagné 1976). In our study, the dipteran families Dolichopodidae and Cecidomyiidae were restricted between 1160 and 1500 m.

The importance of fog drip as a major mode of water uptake in the Hawaiian forest has been documented (Juvick & Perreira 1973). In the Manuka study, we found that not only is there a more luxuriant vegetational situation created, but vegetational diversity is highest in the fog zone.

In addition, the 1440 m plotsite sampling was conducted in a kipuka of moderate size. Generally, a kipuka, or regional unconformity (Pukui & Elbert 1971) is a section of vegetation surrounded by the relative infertility of fresher lava substrate. In many cases, the change in species diversity and community structure of vegetation moving from barren lava to within the lush kipuka environment promises to show consistent patterns, allowing the kipuka concept to be defined ecologically. Yoshinaga and Anderson (1977, unpub. ms.) studied the kipuka systems of the Manuka-Kapu'a area and found that because of the insular character of kipukas, their habitat differs from continuous stands of old substrata as well as from that of the surrounding fresh lava. Compared to the open lava, the more weathered kipuka substrate has better moisture-holding capacity, more available nutrients, and better rooting opportunities. The more closed canopy offers shelter for species unable to tolerate the hot, dry open environment of the surrounding undecomposed lava. Litter may collect more effectively than in the open. Along the perimeter of a kipuka exists a strip of edge habitat, which can support species which might be unable to grow in closed forest. Just outside the kipuka is a boundary habitat, where the harsh environment of the lava flow may be somewhat ameliorated by the effects of the kipuka such as shade, fog drip, and leaf litter. The plant species list for soil kipukas in our study area was similar to a combined species list for open lava and continuous stand vegetation on soil. Thus, in the kipuka situation, a combination of high plant species complement, higher potential
vegetational situation, and habitats unavailable to both surrounding lava and continuous stand forest, can be considered as factors contributing to an increased insect diversity.

In summary, Figure 3 illustrates the diversity of habitat and climatic conditions which contribute to the "hump" phenomenon at 1440 m: fog conditions, general vegetational diversity, and kipuka effects. In addition, Figure 3 demonstrates gradients in moisture and vegetation that are pertinent to the general relationship of altitude and insect diversity uncovered in this study.

CONCLUSION

In the Manuka-Kapu'a study, nocturnal insect diversity at the family level increased as altitude decreased, with the exception of a disproportionately high diversity at the 1440 m elevation. The general altitude effect was attributed to the interrelation of three major factors: temperature, moisture, and vegetational diversity. Although it is clear that temperature and moisture conditions contributed indirectly to insect distribution by determining vegetational diversity and structure, it is not known what direct limiting effect they have on the Hawaiian insect species. It is recommended that physiological studies be conducted, focusing on the tolerances of Hawaiian species to a wide range of temperature and moisture conditions, determining survivorship thresholds and optimum ranges. The information from such studies could be used to test whether temperature and moisture limitation is a mechanism directly determining the distribution of Hawaiian insects in field studies.

The exceptionally high diversity at 1440 m was attributed to three major factors not present at other-plotsite locations: fog belt conditions, unique vegetational species complement, and the effects of kipukas.
LITERATURE CITED


Ripperton, and Hosaka. 1942.


Swezey. 1954.


<table>
<thead>
<tr>
<th>Transect Plotsite</th>
<th>Total Families</th>
<th>$\bar{X}$ by Altitude</th>
<th>Total by 8:30 P.M.</th>
<th>$\bar{X}$ by Altitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>1690A</td>
<td>10</td>
<td>10.00</td>
<td>5</td>
<td>5.00</td>
</tr>
<tr>
<td>1440A</td>
<td>18</td>
<td>15.67</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1440B</td>
<td>13</td>
<td>15.67</td>
<td>10</td>
<td>12.67</td>
</tr>
<tr>
<td>1440K</td>
<td>16</td>
<td></td>
<td>13</td>
<td></td>
</tr>
<tr>
<td>1150A</td>
<td>14</td>
<td>14.67</td>
<td>10</td>
<td>10.33</td>
</tr>
<tr>
<td>1150B</td>
<td>13</td>
<td>14.67</td>
<td>11</td>
<td>10.33</td>
</tr>
<tr>
<td>1150K</td>
<td>17</td>
<td></td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>875A</td>
<td>15</td>
<td></td>
<td>11</td>
<td></td>
</tr>
<tr>
<td>875B</td>
<td>16</td>
<td>17.67</td>
<td>13</td>
<td>14.00</td>
</tr>
<tr>
<td>875K</td>
<td>22</td>
<td></td>
<td>18</td>
<td></td>
</tr>
<tr>
<td>585A</td>
<td>24</td>
<td>21.50</td>
<td>18</td>
<td>18.00</td>
</tr>
<tr>
<td>585B</td>
<td>19</td>
<td></td>
<td>18</td>
<td></td>
</tr>
</tbody>
</table>
FIGURE 1. Arrangement of transect lines and plotsites, Manukā Forest Reserve, South Kona, Hawai'i.

Altitudinal replicate plotsites occur at the 1440 m, 1150 m, 875 m, and 575 m elevations. Note that land boundary restrictions preclude replicates at the apical plotsite (1690 m), while commercial agriculture (shaded area) limited sampling to areas above this zone in the ahupua'a of Kapu'a.
FIGURE 2. The number of insect families encountered in night collections of isoaltitudinal plotsites, Manuka Forest Reserve, South Kona, Hawai'i. Immediately notable is a general decrease of family diversity with increase in altitude. However, data collected from the 4600 ft (1400 m) plotsites do not fit well in the trend, creating a "hump" phenomenon. This "hump" is most pronounced in data from the main transect collections, but is present in all transect collections. The solid lines connect mean values from all plotsites and demonstrate both the general trend and the deviance in the 4600 ft (1400 m) plotsites. The blackened data points demonstrate that the percentage of families appearing by the midpoint of the collection period decreases with altitude, and is similarly discordant at the 4600 ft (1400 m) level.

KEY:
- Number of families collected from:
  - Kapu'a transect
  - Auxiliary (B) transect
  - Main transect

- Number of families collected from all transects appearing by 8:30 PM (midpoint of collecting period)

- Vertical solid and hatched lines denote range of values.
A comparison of the numbers of plant species and insect families collected at identical plotsites, Manukā Forest Reserve, South Kona, Hawai'i.

The similarity of both trend and "hump" phenomena in the number of plant species and the number of insect families suggests that there is a strong relationship between vegetational diversity and insect diversity. Studies of stenophagy in Hawaiian insect species, demonstrating that nearly 40% of known species are strictly monophagous is evidence that vegetational diversity is an important determiner of insect diversity in this Hawaiian ecosystem.
HALEAKALA NATIONAL PARK CRATER DISTRICT
RESOURCES BASIC INVENTORY:
MOSSES OF THE CRATER DISTRICT

William J. Hoe
Department of Botany
University of Hawaii at Manoa
Honolulu, Hawaii 96822

The biological distinctiveness and the lack of serious bryological collecting in Hawaiian alpine areas was recognized as long ago as 1930. At that time Edwin B. Bartram, who would later publish the Manual of Hawaiian Mosses (1933), wrote to Otto Degener (dated September 30) and expressed the opinion that "The most likely places for new and interesting additions will be around the rim of Haleakala and above 6 or 7000 ft on Mauna Loa and Mauna Kea..." Since then, collections by Degener and others, primarily in conjunction with more generalized surveys, have tended to bear out these predictions.

The Resources Basic Inventory (RBI) surveys, conducted during the summers of 1975 through 1977, have provided an opportunity to study the moss flora of upper Haleakala as well as the distribution of the taxa. The intensive collecting in 55 representative sites has yielded what is probably a complete picture of the moss flora. With the taxonomic basis now understood, future research could include investigations of the moss communities present and their relationships to the general vegetation as well as physiological adaptations to the rigors of Hawaiian alpine conditions.

Identification of the mosses collected during the survey is virtually completed, and will result in a technical report summarizing the taxa present, their general distribution and phytogeographic relationships. It would perhaps be most appropriate at this time to summarize general relationships of the mosses of upper Haleakala and to discuss a few of the phytogeographically significant species.

Bartram, in introductory remarks to his Manual, concluded that the affinities of the Hawaiian moss flora lay almost exclusively with the region to the southwest, i.e., to the Indo-Pacific region. Gemmell (1955), in further analysis of Bartram's data, came to the same conclusion. Based upon the incomplete data then available, these conclusions were certainly correct. However, availability of more recent collections, particularly from the poorly-known Hawaiian alpine areas, has shown that the desert-like areas above the tree line contain a surprisingly large and diverse flora. The sometimes abundant representation of genera such as Andreaea, Encalypta, Grimmia, Ptychomitrium,
Racomitrium, and Tortula are not at all reminiscent of Indo-Malesian or even of tropical floras but of the northern and southern hemisphere temperate regions instead. The non-endemic species and close relationship of many of the endemics further suggest Boreal relationships. The purely Austral elements are, in fact, represented by only a few taxa. Table 1 summarizes the phytogeographic relationships of Haleakala's alpine species. Of the 36 taxa which can be identified with confidence, 15 (42%) are represented in both the North and South temperate areas, 13 (36%) are Boreal, with only 3 (8%) Austral. With the possible exception of three endemic species in the "unknown" category, there is no relationship with the Indo-Pacific floras. This suggestion should not be as surprising as it may first seem. In terms of dispersal distance the Hawaiian Islands are considerably closer to Boreal than to possible Indo-Pacific or Austral sources of diaspores for its alpine flora. Both the jet stream and the trade winds originate in the Boreal regions.

One may reasonably ask, then, about the origins of the three austral Haleakala taxa. **Amphidium tortuosum**, although widely distributed in the temperate Southern Hemisphere, seems to have migrated northward along the American cordilleras, reaching into Central America. The local populations, therefore, may well be descendent from American rather than Austral sources. **Tortella fragilis var. tortelloides**, originally described from Antarctica, both there and in Hawai'i may simply represent stress forms resulting in similar morphological responses rather than one being derived from the other. That is, the two populations are probably not the result of long distance dispersal. **Andreaea acutifolia**, known from such Austral areas as the Falkland Islands, Auckland Islands, Campbell Island, New Zealand, Kerguelen, and southern South America, is generally considered to be variable and very close to the extremely variable and cosmopolitan **Andreaea rupestris**. Whether it deserves specific or even varietal recognition is being investigated.

The Boreal representatives clearly outnumber the Austral (>4:1) in the Hawaiian alpine. The odds, then, would seem to favor Boreal origins for the majority of the mosses of cosmopolitan-temperate affinities. If this hypothesis is correct, then Haleakala's alpine flora is basically of Boreal origin and has little relationships with the downslope, primarily Indo-Pacific rain forest species.

The Crater District of Haleakala National Park is interesting to a bryologist not only because of its alpine flora but because it contains upper rain forest representatives in areas such as Paliku. Areas such as Paliku are, in many ways, clearly transitional. They serve as the upper boundary for the many taxa of the lowland forest which are only sparingly represented and as the lower limit for alpine taxa which are present only in exposed sites. There is, however, a surprisingly large number of Boreal forest elements present. New Maui or Hawaiian Islands records of this type discovered during the past three summers include
Isopterygium elegans, Plagiothecium cavifolium, Trichostomum tenuirostre, Leptodontium flexifolium and Orthodontium pellicens, among others. The first three are new state records, and may eventually be found on other islands as well.

The lower and middle Hawaiian rain forests are undoubtedly the best known regions bryologically. The mosses of such areas are often obvious and abundant. Historically, these forests have been the easiest of access. The phytogeographic affinities of these species generally lie with Oceania and SE Asia. In very simple terms, these species require all but brief periods of constant moisture and high humidity. They are probably also frost intolerant. Although the Paliku area is probably sufficiently wet for at least most of these rain forest taxa, the cold air draining from the Crater and the surrounding slopes may well represent the single most important factor in limiting their presence. The rain forest taxa will be discussed in the technical report; I would like to emphasize that they are only sparingly present and are never as abundant as they would be further downslope in rain forest areas.

The remnant dryland forest of eastern Kaupo Gap has a number of structural similarities with the dryland forest of the Wai'anae Mountains of O'ahu. Both have a well-developed canopy cover, with a nearly absent understory and herbaceous ground cover. Several moss species, common in the Wai'anae Mountains, in the Park are confined to the Kaupo Gap dry forests. These include Entodon solanderi and Fissidens intermedius.

In addition to the Boreal forest elements discussed and the locally attenuated lower and middle rain forest taxa, the Paliku area contains an upper rain forest montane element. This general habitat and associated species assemblage is found on all of the Hawaiian Islands between 4000 to 6000 feet. In the absence of quantitative data, about all that one can say is that there is a clear change in the genera and species which predominate when compared with the lowland forest. This difference is sufficiently marked to be noticed in the field by a person familiar with the lower forests. Unlike the alpine, in which Boreal representatives predominate, and the lowland-middle elevation forests in which the Indo-Malesian elements are the most important, the upper rain forest is comprised of species from American, continental Asian as well as Indo-Pacific sources.

These remarks on the mosses of Haleakalā are clearly only introductory. They are intended primarily to point out the uniqueness and the value of the Crater District from a scientific as well as a resource management point of view and to encourage future studies. At this time, it is impossible to provide definitive answers to the questions this brief review must have raised.
LITERATURE CITED


TABLE 1. Phytogeographic relationships of Haleakala's alpine moss flora. Taxa preceded by an asterisk are considered endemic.

<table>
<thead>
<tr>
<th>A. Cosmopolitan</th>
<th>B. Boreal</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. <em>Amphidium tortuosum</em></td>
<td>1. Orthotrichum hawaiiicum</td>
</tr>
<tr>
<td>2. <em>Andreaea rupestris</em></td>
<td>2. <em>Bartramia baldwinii</em></td>
</tr>
<tr>
<td>3. <em>Bartramia halleriana</em></td>
<td>3. <em>Brachythecium hawaiiicum</em></td>
</tr>
<tr>
<td>4. <em>Brachythecium rutabulum</em></td>
<td>4. <em>Pabronia ciliaris</em></td>
</tr>
<tr>
<td>5. <em>Desmatodon convolutus</em></td>
<td>5. <em>Grimmia apocarpa</em> var. pulvinata</td>
</tr>
<tr>
<td>10. <em>Grimmia pulvinata</em></td>
<td>10. <em>Orthotrichum diaphanum</em></td>
</tr>
<tr>
<td>11. <em>Grimmia trichophylla</em></td>
<td>11. <em>Plagiopus oederi</em></td>
</tr>
<tr>
<td>15. <em>Tortella fragilis</em> var. tortelloides</td>
<td></td>
</tr>
</tbody>
</table>

C. Austral

| 1. *Amphidium tortuosum* |
| 2. *Andreaea acutifolia* |
| 3. *Tortella fragilis* var. tortelloides |
| 4. *Ptychomitrium mauliense* (Central American) |
| 5. *Bryum ceramiocarpum* (Andean Venezuela) |

D. Unknown or Other
How and why an animal would lose its eyes, color pattern, and other characters, and restrict itself perpetually to the rigorous environment of caves has long intrigued biologists. Much is known of the ecology of limestone caves in temperate regions (Vandel 1965; Barr 1968). The realization that lava tubes also harbor an analogous specialized fauna is more recent (Torii 1960). In addition to Hawai'i, significant lava tube faunas are now known from the Galapagos (Leleup 1967, 1968), Japan (Ueno 1971), and North America (Peck 1973). In Hawai'i the fact that at least seven native groups have independently evolved troglobitic species on at least two islands indicates that adaptation to lava caves is a general process.

Troglobites (obligatory cavernicoles) are restricted to the true dark zone of caves. The dark zone environment, as outlined by Howarth (1973) is similar to that described by Poulson and White (1969) for temperate limestone caves. It is a rigorous one defined by the absence of light; the relative constancy of temperature at or near the average annual temperature of the region and of relative humidity above the physiological limits of most terrestrial animals; and the absence of many environmental cues. There is generally a rocky substrate and often an illusion that food is scarce.

Lava tubes are destroyed by erosion in a relatively brief geologic time. However, they are continually being created during volcanic eruptions since oceanic volcanoes are characteristically built with vesicular basalts which often flow as pahoehoe, and such flows almost always build lava tubes (Peterson & Swanson 1974). Lava tubes are a common land form on younger oceanic islands. Further, since the voids in basaltic lavas offer some avenues for subterranean dispersal from older caves to younger caves, we can expect that a specialized cave fauna will develop wherever new basaltic lava flows continually cross older flows over a long enough period of time, and the climate allows the continuous colonization of caves.
In Hawai'i rain water percolates rapidly into the young porous basalt. Only where the water table is near the surface is significant water found in the cave. This occurs near the coast and a remarkable aquatic fauna, including many troglobites, inhabits isolated coastal pools of brackish water (anchialine habitat) in young lava flows (Holthuis 1973; Maciolek & Brock 1974).

In younger lava tubes the substrate is usually barren lava rock. However, this can vary considerably in texture, e.g., a polished glazed surface, irregular pile of breakdown blocks, highly vesicular porous lava, and even ashy rubble. The absence of organic detritus is often surprising. Lava tube slimes which represent insipient soil formation often cover large areas. In the oldest caves clay and soil have filled most smaller voids and cover the floor in many areas.

Limestone caves also have a rocky substrate, often as irregular blocks, but there is a greater variety of minerals including crystals, biogenic minerals, and alluvial sediments. A fine residual silt from solution of limestone is characteristic, and is closely associated with terrestrial troglobites (Barr & Kuehne 1971).

The main energy sources in Hawaiian lava tubes are plant roots, especially 'ohi'a (Metrosideros collina var. polymorpha), slimes deposited by organically rich percolating ground water, and accidentals which are those animals that blunder in. In contrast, the main energy sources in continental limestone caves are trogloxenes, especially bats and crickets, and debris washed in with sinking streams, especially during floods. Additional energy is supplied by accidentals, percolating ground water, autotrophic bacteria, and aerial plankton.

The greater overburden of limestone caves often precludes the importance of tree roots and, except for Paulian and Grjebine (1953) who discovered an intermediate cave-adapted cixiid in Madagascar (Synave 1954), most biospeleologists have disregarded roots in their surveys. However, the discovery in Hawai'i of a cave cixiid (Howarth 1972) stimulated other researchers to check roots in caves. Recently Fennah (1973b) described three species of troglobitic fulgoroids, two from Mexico and one from Australia, and Peck (1975) listed an undescribed species from Jamaica caves.

The absence of native trogloxenes in Hawai'i may be related to the absence of winter and of a need to hibernate, and also to the fact that the continental trogloxenic groups did not colonize Hawai'i. Hawai'i's only bat and only native land mammal (Lasiurus cinereus semotus) is a forest species and is not known to enter caves.

Sinking streams are not important energy sources in Hawaiian lava tubes. It is unusual for a stream to enlarge a lava tube; rather, it speeds the siltation and erosion processes. The few
lava tubes visited that had captured a temporary stream were shortly blocked with silt, had signs of periodic flooding, and had a poor fauna.

**Cave Fauna**

Native cavernicolous animals are predominantly arthropods. In Kazumura Lava Tube, 10 troglobitic and seven native troglophilic (facultative cavernicoles) species occupy nine general niches: three primary consumer niches, feeding on living and dead roots; one omnivore; two predatory niches differing in strategies (i.e., with and without snares); one sarcophagous niche; and two saprophagous niches, one feeding on fungus and one generalist. There is broad niche overlap as underscored by omnivore niche occupied by the troglobitic cricket.

Only one species of root penetrates into Kazumura Lava Tube to any great extent, and five native and four exotic arthropods feed on it. The troglobitic cixiid which is probably the most abundant arthropod in the cave is a sapsucker. The living root chewers are represented by three species of moths of the genus Schrankia. One of these is a weak flier and appears to be troglobitic. An undescribed troglobitic millepede occupies the living and dead root feeding niche.

At the top of the food chain is a large striking troglobitic wolf spider which stalks its prey and does not build a web. The other five native predators are less well known and probably live in cracks and rarely enter larger passages. A troglobitic terrestrial water treader scavenges on dead arthropods. The two saprophagous niches are occupied by four troglophilic taxa.

To date no native organisms have been found boring into or specifically feeding on large diameter roots, and this is possibly an empty niche. However, in arthropod surveys it is difficult to generalize on negative evidence, i.e., I can only say I have not found it, not that it does not exist. As explained by Janzen (1977) natural functioning ecosystems have few if any empty niches unless there is a major new disturbance, such as that created by an exotic species.

Even though 15 exotic species have colonized Kazumura Lava Tube, with one exception (snare building predators) they do not appear to have invaded the niches to a great extent.

On the younger flows on Hawai'i Island the troglobites have a wide distribution, but many lowland troglobites have not been found above 1000 to 1500 m where other species often occur. Roots are more important in higher caves. The few lava tubes on Maui are significant because their fauna provides a control group for Hawai'i Island studies. At least six native groups have independently evolved troglobitic species on the two islands.
Most continental troglobites are considered relicts of past climatic changes, especially glaciation and changes in sea level (Vandel 1965; Barr 1968; Mitchell 1969). However, many of the Hawaiian troglobites have close surface relatives still extant. Three such species pairs, Caconemobius varius--C. fori; Oliarius polyphemus --O. inaequalis; and Nesidiolestes ana--N. selium have been recognized (Fennah 1973a; Gagné & Howarth 1975; Gurney & Rentz 1978; Howarth 1979). This strongly suggests that troglobites are relicts only if the surface species have become extinct, not that they become caveadapted after extinction of the surface population. There are many examples of adaptive radiation among continental cave animals, but most apparently are true relicts due to the more complex geological history of the continents.

Cave Perturbations and Maintenance Trends

Continental caves are often viewed as islands and their ecosystems share an apparent fragility in response to perturbations. Cave ecosystems on islands may be in double jeopardy and several of the newly discovered arthropods are candidates for endangered species status. What then is the future of this unique ecosystem, not even recognized before 1971? If perturbations had caused its demise sometime during the last 200 years, biologists would have continued to believe no such fauna had ever existed in Hawai'i.

On Hawai'i Island there are still many avenues of dispersal between lava tubes and continual new flows can be expected; therefore, one can expect the survival of the cave fauna, barring any major catastrophes. On the older islands of Maui and Kaua'i the caves are eroded remnants, many of the avenues of dispersal are closed through erosion, and the cave animals lead a tenuous, threatened, or endangered existence.

The major perturbations facing the Hawaiian cave ecosystems are as follows: (1) destruction of the forest by grazing animals, fire, exotic plants, agriculture, and urbanization; (2) creation of new entrances and increased siltation and filling of caves by the erosion resulting from the above activities; (3) colonization by exotic animals; (4) use of caves for refuse disposal; and (5) direct disturbance by human visitation.

(1) Since the main energy source is plant roots, the destruction of the overlying forest removes this energy source. The obligatory primary consumers die off rapidly and the food web shrinks to a few scavengers and predators feeding on accidentals. A few primary consumers, notably Schrankia and the millepede, can switch to some exotic root species.

(2) Troglobites are restricted to the true dark zone where the relatively constant environmental conditions are maintained. New entrances introduce surface climatic influences and the cave
fauna is destroyed. Further, the erosion of the surface causes rapid filling of the voids in the lava and eventually the cave itself.

(3) The introduction of exotic species, or biological pollution, is perhaps the most insidious perturbation because it is normally irreversible and it often pervades the ecosystem in unforeseen ways. The impact of exotic species will be discussed below.

(4) Using caves for refuse dumps hastens the filling of the cave and introduces large amounts of food that alters the cave food web in several ways. (a) In relatively closed caves it can foul the air and kill the inhabitants. (b) By composting it can raise the cave temperature and dry the cave. (c) Most importantly, it often allows the colonization of the cave by opportunistic scavengers and predators. The high populations of these being supported on refuse can swamp the endemic biota.

Kaua'i has few extant lava tubes and the two known troglobites are among the most bizarre discoveries to date. Regrettably, the fields with the largest caves known on Kaua'i were covered by 5 m of sugarcane bagasse shortly before I visited the area. The caves are now gone, the fauna extinct, and no one will ever guess what that fauna might have been!

The entrance to Offal Cave, a relatively large lava tube on Haleakala Volcano, Maui, was used as an offal pit by the local slaughterhouse, and the tallow, rotting bones, and other garbage are piled high near the entrance and scattered throughout the downslope portion of the cave. The cave is no longer used for this purpose, but even now the cave ecosystem approaches that reported for large bat caves in tropical continental areas, where a huge amount of animal matter is introduced into the cave and supports a large population of many troglophiles. In Offal Cave these troglophiles are almost all exotic carrion feeders, scavengers, and predators, including such groups as cockroaches, earwigs, ants, moths, spiders, millipedes, and isopods. This is the only cave where many of these organisms have invaded any significant distance from the entrance, and it is assumed that it is the rich, novel food supply that allows them to colonize the cave environment. Only one endemic troglolobe, the omnivorous cricket Caconemobius howarthi, occurs in this section of the cave.

Unfortunately, grazing has destroyed all native trees over Offal Cave and no roots now penetrate into the deep cave, so that it remains hypothetical whether other troglobites may have survived the influx of offal and associated biota if the rest of the ecosystem were intact. I believe most would not have survived, as such a large amount of organic matter would have heated the cave and dried or otherwise affected the environment. Such a large influx of exotic predators, sustained by the high population of exotic scavengers, also would have preyed on any cave species so that few endemics would have survived.
Caves are fragile ecosystems and, like other discrete geologically defined habitats such as montane bogs and sand dunes, are easily disturbed by human visitation. Normal weathering processes are so changed and attenuated that even footprints can remain for centuries. In Hawai'i careless or destructive visitors kill or break tree roots, mark walls, litter the cave, and trample animals and their habitats. Tobacco smoke is a strong insecticide and smoking in the enclosed cave environment may be lethal to the fauna. The heat from both the body and a torch, if used, can dry the cave. Any smoke also introduces a large number of condensation nuclei to the saturated cave atmosphere. Littering is related to the using of caves as refuse dumps as discussed above. Cave visitation by the public should be discouraged until adequate protection of sample caves and ecosystems is assured.

Impact of Exotics

Many of the arthropods recently introduced by man, especially household pests and soil forms coming in with plant materials, have successfully colonized certain Hawaiian lava tubes. Such animals as the cockroaches, centipedes, millepedes, isopods, spiders, and other groups have been successful in lowland caves. Some of these exotics have surely altered the ecology of the caves, but it is unknown whether any replaced native species in the cave ecosystem. This is the region most disturbed by man. Many exotic species of roots penetrate these caves and mostly exotic species occupy these exotic niches. These are also the caves littered by visitors and used for dumps, as explained above.

Exotic scavengers also exploit the dead accidental exotic mammals (roof rat and mongoose) in Kazumura Cave. Barr and Kuehne (1971) reported a similar phenomenon in Mammoth Cave, Kentucky. They felt that litter from human activities has allowed the colonization of the cave by troglophiles that would not otherwise be able to do so.

Of the nine niches found in Kazumura Lava Tube the two predatory niches showed the greatest intrusion by exotics, followed by the saprophagous niches. In this cave only one species of root is present and so restricts potential phytophagous invaders. With an increase in species diversity there is a greater chance of an exotic or native species finding a suitable niche.

Thus those secondary and tertiary consumers that are generalists have the highest diversity of prey or food to choose from, and it follows that these niches would have the most species, both native and exotic, in most habitats. The invasion by an exotic does not imply that there had been an empty niche but that the invader was able to create one.

One exotic spider, Nesticus mogera from Japan, is common in mid- to high elevation caves on Hawai'i Island where its sloppy inverted webs are found between adjacent protuberances and in
cracks in the walls in nearly the same situation as one sometimes finds the rare troglobite *Erigone stygius*. Both species are about the same size and both build similar sized webs. Although their webs are quite different, they probably capture similar prey. Even though *N. mogera* may not be as well adapted to the cave environment as *E. stygius* its cave population is constantly being augmented by individuals from surface habitats. As the prey is depleted the native spider loses. This circumstantial evidence implies that *N. mogera* is replacing the endemic species.

Other exotic troglophiles have not colonized Hawai'i's caves. For example, the predatory snail *Euglandina rosea* is a common troglophile in its home region in Florida. In Hawai'i its shells are common in low to mid-elevation caves but apparently the absence of both calcium for its shells and suitable prey have prevented this species from colonizing island caves. Other examples from Offal Cave are discussed above.

With one exception exotic trogloxenes have not yet become established. Attempts to introduce cave bats to Hawai'i in the 1920's were unsuccessful (Tomich 1969). The Edible Nest Swiftlet was released in 1962 and is now established in a small area on O'ahu (Shallenberger 1976).

Five main groups of trogloxenes exist in the world. Bats and rhaphidophorine crickets are nearly worldwide in caves except at high latitudes and on a few oceanic islands. Cave rats (*Neotoma* spp.) are widespread in North America. The Oilbird (*Steatornis caripensis*) inhabits some Neotropical caves, and certain Swifts (family Apodidae) nest in caves of the Old World tropics. These groups carry in organic matter as food, excrement, nesting material, and dead bodies.

The advent of trogloxenes in Hawai'i will result in a major new energy source in the caves and the establishment of a new food web, drawing almost entirely on exotic organisms for its cycle.

Had a trogloxene colonized Hawai'i naturally before man, the cave ecosystem would certainly have been greatly altered, but native species would have eventually adapted to exploit the new niches. The present situation is quite different, as a great many potential exotic troglophiles that live in guano caves elsewhere are already established as inquilines of man or his domestic animals or as soil animals. These species will be able to invade and flourish in Hawai'i's caves when a food source is there, and few native animals will have a chance to adapt to the new conditions. A preview of this phenomenon was described above for a cave that was used for an offal dump, and the ecosystem was drastically altered with only one native species surviving.

I suggest that the apparent fragility and instability of island ecosystems when compared to continental ecosystems is more related to the degree, type, or harshness of the perturbation, than to some inherent weakness in the workings of the system. Evolution dictated that island ecosystems functioned well before
the current onslaught. It is true that given the disharmonic nature of island biota, those missing groups that exploit their environment in an innovative way will drastically alter the island ecosystem when they are introduced. Examples are troglobiontes in Hawai'i's caves and grazing mammals which convert forest to grassland. But these groups were missing once on the continents, too. Did not the forests of the eastern great plains of North America give way to the bison and man, as did the eastern Mediterranean forests to the goat? Most examples on the continents have been obscured because of the complex geological and evolutionary history there.

One of the reasons islands are so interesting biologically is that they have not had as complex a biological and geological history as the continents. Islands can be studied as experimental controls for the evolutionary and ecological processes which are occurring but are obscured on the continents.

ACKNOWLEDGEMENTS

This work was supported by NSF Grant No. GB23075 ISLAND ECO-SYSTEMS IRP/IBP HAWAII and by separate grant to the author, NSF Grant No. DEB75-23106. I thank Dr. D. Mueller-Dombois, Department of Botany, University of Hawaii at Manoa, for assistance in analyzing the data.


DESCRIPTION OF A NEW LARGE-SCALE
VEGETATION MAPPING PROJECT IN HAWAI'I

James D. Jacobi
U. S. Fish and Wildlife Service
Office of Endangered Species
Honolulu, Hawaii 96850
and
Department of Botany
University of Hawaii at Manoa
Honolulu, Hawaii 96822

INTRODUCTION

Vegetation mapping is a method which is often used to display the distribution of plant communities or vegetation types in a two-dimensional format. It entails the delineation and description of more-or-less homogeneous patterns of the vegetation as interpreted usually either from aerial photographs or on the ground. The degree of homogeneity in the map units depends on what types of vegetation characteristics are being viewed, and what the overall purpose of the map is.

Two research projects are currently being conducted in the native forests of Hawai'i, for which it was considered essential to have an adequate map of the vegetation patterns in the different study areas. One of these projects, the Hawai'i Forest Bird Survey conducted by the U. S. Fish and Wildlife Service (USFWS), is attempting to determine the status and distribution of the native forest birds, with emphasis on the listed rare and threatened species on all of the islands. Field work for this survey is presently being conducted on the island of Hawai'i.

In the second project, the 'Ohi'a Forest Study, aspects of the dynamics of the native montane rain forests are being examined in detail, with particular emphasis on the phenomenon known as the 'ohi'a dieback. This project, directed by Dr. Dieter Mueller-Dombois of the University of Hawaii, was funded from 1975-1977 by a grant from the National Park Service.

An attempt was first made to utilize existing vegetation maps for these two projects. However, none of the available maps were found to be suitable for this purpose. Therefore, a new vegetation mapping project was initiated which will eventually cover the native forest areas on all of the major islands. This mapping project is supported primarily by the USFWS; however, additional support has come from the 'Ohi'a Forest Study for work on the windward side of the island of Hawai'i where the study areas overlapped.
In the following paper, a quick summary is made of the types of vegetation maps which currently exist, particularly for the island of Hawai'i, and the new mapping project is described in detail.

Discussion of Map Scale

A major factor to be considered when working with vegetation maps is the scale at which they were produced. A small-scale map shows units which are rather generalized and includes a considerable amount of variation. A large-scale map, on the other hand, shows map units which are quite detailed and includes considerably less variability. Table 1 gives a general summary of the different ranges of map scales and indicates the kinds of information which each can display.

Review of Some of the Vegetation Maps Which Have been Published for Hawai'i

There have been numerous different vegetation maps published for Hawai'i, some depicting the general vegetation on all of the islands, while many others deal with small specific areas in greater detail.

Probably the most familiar map is one published by Ripperton and Hosaka (1942) entitled Vegetation Zones of Hawai'i. This map fits into the intermediate-scale range of maps with all of the islands except Hawai'i mapped at approximately 1:500,000. The island of Hawai'i was mapped at the scale of 1:1.5 million, so all of the islands could be included on a single small map sheet.

Ten different vegetation zones are distinguished on this map which depict a combination of both actual and potential vegetation coverage as determined mainly by climatic and edaphic conditions. This map is useful for getting a general overview of the vegetation; however, it is difficult to work with in any detail on the ground.

Several other maps are available at this general scale which are very similar to Ripperton and Hosaka's, most notable being maps published by Knapp (1965) and Lamoureux (1973).

At the large map scale range, all areas on all of the major Hawaiian Islands were mapped at 1:62,500 by Honda and Klingensmith (1963), as part of the Hawaii Forest Type-Map series produced by the U. S. Forest Service and the Hawaii Division of Forestry. The map units in this case describe (a) land use class, (b) forest type (i.e., tree species composition), (c) density of tree cover, and (d) tree stand size class in terms of sawtimber classes. These vegetation types were interpreted from aerial photographs taken in 1954, but were compiled with only a minimal amount of ground verification.
Another large-scale map was published by Mueller-Dombois and Fosberg (1974) which describes the vegetation types of Hawaii Volcanoes National Park (HVNP). The vegetation patterns in this case were also interpreted from the 1954 photographs, and were ground checked in detail in the more accessible area. The map units were based primarily on dominant species and structural criteria (such as plant spacing and height) of the vegetation.

Both the Hawaii Forest Type-Maps and the HVNP map are at the map scale at which actual patterns of the vegetation are displayed with sufficient detail to serve as base maps for the Fish and Wildlife Service Forest Bird Survey and the study of the dynamics of the 'ohi'a rain forest. Unfortunately, the Hawaii Forest Type-Maps were not ground checked adequately and are, therefore, too inaccurate for practical use. The HVNP map, on the other hand, is much more accurate for what is displayed. However, it covers only a small portion of the forests in which we were interested. Additionally, since it was based on photographs taken nearly 25 years ago, it is unusable in areas in which the vegetation has changed considerably, particularly as the result of land clearing, and of 'ohi'a dieback in the 'Ola'a Tract forest section of the Park.

We, therefore, decided that the best way to approach the problem at hand was to produce a new vegetation map series, also at the large-scale level.

The Current Mapping Project

In the current project the vegetation types in most habitats dominated by native species on all of the major Hawaiian Islands will be mapped. The Fish and Wildlife survey was initiated in the summer of 1976 on the island of Hawai'i, and we expect to finish field work on Kaua'i in the summer of 1981. An attempt is being made to keep the vegetation mapping running concurrently with the field survey work for each of the different study areas.

Figure 1 shows the areas which will be mapped for the island of Hawai'i. To date, the map for one area, the Ka'u Forest, has been finished and is currently being published (Jacobi, in press). The preliminary mapping has been completed for the Hamakua, Waiakea, 'Ola'a, and Mauna Kea sections, and the final versions for each of these areas will be completed in the very near future. Currently, field work is being concentrated in the Hualalai and Kona regions.

Description of the Map Units

In this new map series, the vegetation is displayed at two levels of resolution. The first level shows the distribution of the general plant associations which in this case are defined by the predominant species composition of the dominant vegetation layer. So far at least 10 different general plant associations
have been identified which include, for example, alpine and sub-
alpine scrub, grassland, 'ohi'a forest, 'ohi'a-koa forest, and
tree fern dominated communities. For this purpose, the tree
layer was considered to be dominant in open and closed forest
stands.

The second level of resolution describes the vegetation in
much greater detail. In this case, four major components of the
vegetation are taken into account in determining the map units:
(1) tree canopy crown cover, (2) tree canopy height, (3) dominant
species composition of the tree layer, and (4) understory or
groundcover composition. Tables 2 and 3 show the possible attri-
butes for each of the vegetation components. An example of a
vegetation type symbol is shown in Table 4.

**Mapping Procedure**

Preliminary map units are first delineated on aerial photo-
graphs with the aid of a mirror stereoscope. Several types of
aerial photos have been used for the different areas mapped so
far. For the Ka'u Forest and Mauna Kea maps, the 1965 black and
white EKL series photos (Soil Conservation Service) at the
approximate scale of 1:24,000 were used. For the Hamakua,
'Ola'a, and Waiakea maps, two sets of photographs were used, one
being a set of true color photos at the approximate scale of
1:12,000 taken in 1972 for the State Division of Forestry, and
the other a set of color infrared photos, roughly at the scale of
1:50,000, taken by NASA in 1974-1975. Recently the U. S. Geolog-
ical Survey has released an excellent set of air photos covering
all of the island of Hawai'i and most of the other islands.
These black and white photos were taken in 1976-1977, and are at
the approximate scale of 1:40,000. We plan to use this series of
photographs for most of the future mapping work on this project.

Once the preliminary mapping for an area has been completed,
the boundaries on the photographs are compiled into an undis-
torted map overlay at the scale of 1:24,000. This involves
optically transferring the vegetation boundaries onto a rectified
(i.e., corrected for photo distortion) base map.

**Field Verification of the Map Units**

One of the most important steps in preparing any type of map
is verification of the map units in the field. For this project,
the preliminary map units are checked in two ways: from the air
in a small airplane or helicopter, and on the ground. The air
reconnaissance has proved to be extremely valuable for getting a
tree-top view of the different vegetation types. Many of the
problem areas identified in the preliminary air photo mapping can
be resolved in this way.
Verification on the ground is carried out along transects running mauka-makai at 2-mile intervals through the study area (Fig. 2). These are the same transects on which the bird census is conducted by the Fish and Wildlife survey teams (Scott 1979). The advantage to working along these transects, besides increased access into the forest, is that sampling points called "stations" have been regularly and accurately located along each line (12 stations/mile).

Once the preliminary maps have been corrected, new overlay maps are drawn which will be overlain onto USGS topographic quadrangle maps for final publication. For ease of use, the scale of the final printed maps will be reduced to 1:48,000.

Applications of the Vegetation Maps to Other Studies in the Native Forests

The major objective in producing this new series of vegetation maps is to relate forest bird distribution to vegetation types, and to provide a framework on which to study the dynamics of the 'ohi'a rain forest. I expect, however, that the map series will be useful to other persons and agencies whose work involves the native forests, particularly in such areas as ecological and geological research, and land use planning, most notably connected with preservation of our natural areas.

The major reason for this paper, therefore, is to make more people aware of this project, and to solicit additional suggestions which may increase the overall applicability of the maps to other types of studies.

Jacobi, J. D. 1978. Vegetation map of the Ka'u Forest and adjacent lands, island of Hawai'i.


TABLE 1. Summary of ranges of map scales and the types of vegetation information which they can display. (Adapted from Mueller-Dombois and Ellenberg 1974).

<table>
<thead>
<tr>
<th>MAP SCALE TYPE</th>
<th>SCALE RANGE</th>
<th>TYPES OF INFORMATION DISPLAYED</th>
<th>(approx.) MINIMUM UNIT SIZE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Small scale</td>
<td>1: &gt; million*</td>
<td>Generalized potential vegetation</td>
<td>&gt; 2500 ha</td>
</tr>
<tr>
<td></td>
<td>(*1 cm = &gt;10 km)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Intermediate</td>
<td>1:1 mill to 1:100,000*</td>
<td>Regional maps, potential vegetation associations</td>
<td>2500-25 ha</td>
</tr>
<tr>
<td></td>
<td>(*1 cm = 1 km)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Large</td>
<td>1:100,000 to 1:10,000*</td>
<td>Generalized actual plant associations</td>
<td>25-2.5 ha</td>
</tr>
<tr>
<td></td>
<td>(*1 cm = 100 m)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Very large</td>
<td>1:10,000 to 1:100*</td>
<td>Detailed plant associations, Individual trees</td>
<td>2500 m²-1 m²</td>
</tr>
<tr>
<td></td>
<td>(*1 cm = 1 m)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. Chart maps</td>
<td>1:&lt;100*</td>
<td>Individual plant cover for shrubs and herbaceous species</td>
<td>&lt; 1 m²</td>
</tr>
<tr>
<td></td>
<td>(*1 cm = &lt;1 m)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
TABLE 2. Components for the tree layer which are used in the vegetation map symbols.

<table>
<thead>
<tr>
<th>TREE CANOPY CROWN COVER</th>
<th>TREE CANOPY HEIGHT</th>
</tr>
</thead>
<tbody>
<tr>
<td>d = Dense; &gt;85% cover</td>
<td>1 = Short-stature trees; 3-5 m tall</td>
</tr>
<tr>
<td>c = Closed; &gt;60-85% cover</td>
<td>2 = Moderate-stature trees; 5-10 m tall</td>
</tr>
<tr>
<td>o = Open; &gt;20-60% cover</td>
<td>3 = Tall-stature trees; &gt;10 m tall</td>
</tr>
<tr>
<td>s = Scattered trees; &lt;20% cover</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>TREE SPECIES COMPOSITION FORMAT</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
</tr>
<tr>
<td>A, B</td>
</tr>
<tr>
<td>A-B</td>
</tr>
<tr>
<td>A-B, C</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>TREE SPECIES NAME ABBREVIATIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ac = Acacia koa</td>
</tr>
<tr>
<td>Ch = Cheirodendron trigynum</td>
</tr>
<tr>
<td>Eu = Euphorbia sp.</td>
</tr>
<tr>
<td>Is = Introduced species</td>
</tr>
<tr>
<td>Me = Metrosideros collina</td>
</tr>
<tr>
<td>Mr = Myrsine lessertiana</td>
</tr>
<tr>
<td>My = Myoprun sandwicense</td>
</tr>
<tr>
<td>So = Sophora chrysophylla</td>
</tr>
</tbody>
</table>
TABLE 3. Components for the ground cover which are used in the vegetation map.

FORMAT

1. The format for listing ground cover is the same as for listing tree species composition.

2. Unless otherwise noted, the ground cover is assumed to cover >60%.

3. If the ground cover is <60%, it is indicated by the symbol "o:" placed before the ground cover symbol(s); (e.g., "o:ds-mg").

SPECIES GROUPS

bg = sedges, rushes, grasses, and herbs in boggy situations

ds = native alpine or subalpine shrubs, (Styphelia, Vaccinium, Dodonaea, Geranium, Dubautia, etc.)

il = introduced lianas (primarily Passiflora spp.)

is = introduced shrubs (Rubus, Buddleja, Pluchea, Eupatorium)

mf = matted ferns (Dicranopteris spp., Sticherous, Micriopteris)

mg = mixed grass complex (both native and introduced species)

ng = native grass complex (Deschampsia, Trisetum, Panicum)

rs = native rain forest shrubs (Broussaisia, Vaccinium, Clermontia, Pelea spp., etc.)

pg = pasture grasses

tf = tree ferns (Cibotium spp.)

INDIVIDUAL SPECIES

An = Andropogon spp.

De = Deschampsia australis

Pa = Paspalum conjugatum

Ps = Psidium cattleianum

Se = Setaria palmaefolia

Sp = Sphagnum sp.
TABLE 4. Example of a vegetation type symbol showing the interpretation of the different symbol components.

<table>
<thead>
<tr>
<th>1. Tree Crown Cover</th>
<th>3. Dominant Tree Species Composition</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>o3Me</td>
</tr>
<tr>
<td></td>
<td>(rs-bg, tf)-d</td>
</tr>
<tr>
<td>2. Tree Canopy Height</td>
<td>5. Other Information</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Ground Cover</td>
<td></td>
</tr>
</tbody>
</table>

1. Tree crown cover >20-60%.
2. Canopy height >10 m.
3. Tree canopy dominated by *Metrosideros collina*.
4. Ground cover codominated by native rain forest shrub species and herbaceous plants growing in boggy situation with some tree ferns.
5. Canopy trees in "dieback" condition at time of mapping (i.e., with many standing dead or defoliated trees).
FIGURE 1. Location of the vegetation map sections for the island of Hawai‘i.
FIGURE 2. Location of the U. S. Fish and Wildlife Service's Forest Bird Survey transects on the island of Hawai'i.
THE IMPACT OF THE SWEET POTATO
ON PREHISTORIC HAWAIIAN CULTURAL DEVELOPMENT

Michael W. Kaschko and Melinda S. Allen
Department of Anthropology
University of Hawaii at Manoa
Honolulu, Hawaii 96822

ABSTRACT

Recent research in Hawaiian archaeology suggests that commencing about 1000-1100 A.D. substantial change and development occurred in various aspects of prehistoric Hawaiian culture, and this trend continued in at least some respects to European contact. It is clear that the sweet potato was of increasing importance to Hawaiian agriculture during this time. The New World origin of the sweet potato, as opposed to the Asiatic nature of the other Oceanic cultigens, further presents the possibility of a separate and post-initial settlement introduction of this crucial crop into the prehistoric Hawaiian agricultural complex.

The possible temporal alternatives for the arrival of the sweet potato in Hawai'i are considered. The predictable effects of sweet potato introduction at various points in the prehistoric sequence are examined in relation to the actual evidence for major cultural developments: agricultural expansion-intensification, population growth, increasing social complexity, etc. Specific methods are suggested for incorporation into future archaeological research to provide data relevant to the role of the sweet potato in the prehistoric Hawaiian adaptation.

Early Western explorers, beginning with Captain James Cook in 1778, commented repeatedly on the extent, intensity, and quality of native Hawaiian sweet potato (Ipomoea batatas [L.] Lam.) production, particularly in contrast to other areas of Polynesia (Yen 1974: 311-317). As late as 1823 the Reverend William Ellis described extensive agricultural field systems on the island of Hawai'i where sweet potato was the primary crop (Newman 1970: 112-120). These early accounts clearly attest to the importance of sweet potato in the Hawaiian economy at European contact. Late prehistoric Hawaiian culture was characterized by a complex ranked society, high population density, and an economy primarily reliant upon well-developed agricultural systems. The possible role of the sweet potato in the development of these cultural features is our concern.
The sweet potato is unique in that it is the only Polynesian cultigen of American origin (Brand 1971; Yen 1971, 1974). All other Polynesian cultigens are of Asian derivation. Although taro is characterized as the preferred food of the Hawaiians, as a crop sweet potato has several advantages (Handy & Handy 1972: 124-128):

1) It can be grown in less favorable locations with respect to sunlight and soil.

2) The tubers mature in three to six months as opposed to the nine to 18 months required for taro.

3) It requires less labor in planting and less care in cultivation.

4) The tubers will keep in the ground without rotting for several months after maturing.

5) The sweet potato is not seasonally restricted.

Present evidence indicates that the sweet potato was introduced to Eastern Polynesia from South America sometime after initial settlement, about the first to third century A.D., but prior to the colonization of New Zealand which occurred before 1000 A.D. (Green 1975: 604-624). Carbonized sweet potato fragments have been recovered from archaeological sites in New Zealand (Leach 1976: 145), Easter Island (Rosendahl & Yen 1971: 379), and Hawai'i (Rosendahl & Yen 1971: 383) with dates of 1650-1850 A.D.; 1526±100 A.D.; and 1425-1725 A.D., respectively. In these areas sweet potato was of major agronomic importance. In contrast, sweet potato was a minor crop and dietary element in central East Polynesia at contact where it was used primarily for pig feed (Yen 1974).

Studies at Palliser Bay provide the earliest indirect evidence for sweet potato cultivation in New Zealand (Leach 1976). Intensive examination of environmental conditions past and present, in conjunction with archaeological excavations, showed sweet potato to be the only possible crop for that particular area. These field systems date to the 12th century A.D., and it is assumed that the arrival and dispersal of the sweet potato predates the systems by a hundred years or more. For Easter Island it has been suggested that the sweet potato arrived with the initial colonizers (Yen 1974: 294) in the fifth century A.D. (McCoy 1976: 10). In Hawai'i evidence for swidden agriculture has been substantiated early in the temporal sequence (Kirch 1975; Green, in press). However, in these Hawaiian sites the specific cultigen has not been identified. Until more direct evidence is available, the possibility of sweet potato introduction subsequent to initial settlement but prior to the establishment of the major dryland field systems remains viable. The necessary agronomic techniques were already an integral part of the Hawaiian's cultural knowledge, but if a more adaptable plant was introduced it could have allowed for intensive exploitation of previously unused land.
In 1823 Ellis described five dryland agricultural field systems on Hawai'i where sweet potato was the primary cultigen (Newman 1970: 114-115). These were located in leeward North Kohala, in Kona between Kailua and Ka'awaloa, at Waiohinu and Kapapala in Ka'u, and near Kamaili in Puna. Two of these areas have been investigated archaeologically: the North Kohala system at Lapakahi (Newman 1970; Rosendahl 1972; Tuggle & Griffin 1973) and the Kona system at Kealakekua (Soehren & Newman 1968; Newman 1970: 123-137). Research in Makaha Valley, O'ahu (Green, in press) and Halawa Valley, Moloka'i (Kirch 1975) provide additional data on dryland cultivation in prehistoric Hawai'i.

The earliest indirect evidence in Hawai'i for sweet potato cultivation is from Makaha Valley. Field shelters dated at 1100 to 1300 A.D. were found in stratigraphic association with evidence for swiddening (slash and burn agriculture) (Green 1970: 101). It is assumed that these fields were used for either sweet potato or dry taro cultivation. This initial swidden agriculture was followed by more permanent inland pondfield systems with associated dryland farming (Green, in press). In Halawa Valley, geological and malacological evidence suggest a sequence of forest burning resulting in slope instability and erosion by 1200 A.D. Based on this data, in conjunction with the cultural remains, Kirch (1975: 175-176) suggests that swiddening was probably a major agricultural activity in the valley from the date of initial settlement (ca. 650 A.D.) onward. It was concluded that a quantitative shift in relative emphasis from swidden to pondfield cultivation gradually took place. The extensive field system at Lapakahi dates from the late 1400's to historic contact. It is in this area that the first direct evidence of sweet potato was found. Carbonized sweet potato tuber fragments were excavated from a field shelter in upland Lapakahi with associated dates ranging from 1425 to 1725 A.D. (Rosendahl & Yen 1971; Rosendahl 1972). Less directly, some coastal Lapakahi sites date to about 1300 A.D. (Tuggle & Griffin 1973: 58) and may indicate the initial stages of sweet potato cultivation. Sweet potato tuber skin has also been tentatively identified from one of the Mauna Kea Adze Quarry rockshelters (B.P. Bishop Museum, current analysis). Only one radiocarbon date has been obtained for the rockshelter, 1492 A.D. (corrected), and the identified material is from a layer that is stratigraphically more recent, but definitely prehistoric.

Recent research has led some archaeologists to hypothesize a prehistoric expansion of permanent settlement into the dry leeward areas of Hawai'i beginning as early as 1000 to 1100 A.D. (Cordy 1978). It is suggested that this settlement was accompanied by inland agricultural expansion and substantial population increase, as exhibited by the extensive remains of dryland field systems and numerous coastal habitation sites. There were also certain social developments that took place which resulted in the formation of complex ranked societies during the late 1400's (Hommon 1976). This is in part documented by the appearance of large house sites and heiau (temples) which represent social stratification. The areas affected are notably those in which the sweet potato would be the most productive crop. It is
tempting to suggest that the introduction of this adaptable cultigen was an important factor in these developments. However, evidence to support such an inference has been elusive thus far.

Three alternative time periods are suggested for the introduction of sweet potato to Hawai'i:

1) With initial settlement ca. 600 to 750 A.D. (Yen 1973: 81), or possibly as early as 300 A.D. (Cordy 1978: 25). This would mean that the sweet potato was involved with but not the catalyst for the previously mentioned cultural developments.

2) At a later date, about 1000 A.D. or somewhat later. The sweet potato could have precipitated or been directly requisite for certain cultural developments (Hommon 1976: 258-269).

3) By a historically unrecorded Spanish vessel in the 1500's (Dixon 1932; Stokes 1932). In this case the sweet potato would have been introduced after major cultural developments had taken place.

There is a paucity of both direct and indirect data relevant to the prehistoric presence or absence of sweet potato in Hawai'i. Only the third possibility noted above is seriously questioned by present archaeological evidence. We suggest the following research methods may assist in defining the chronology of sweet potato introduction and establishment in the Hawaiian horticultural complex, as well as identifying the effects this cultigen may have had upon the development of prehistoric Hawaiian culture:

1) The controlled archaeological sampling of prehistoric dryland agricultural field systems can be improved. This would be accomplished in part by obtaining consistent samples along two lines of variation in an individual field system, that is, along the longitudinal axis and the inland-seaward axis. Such a sampling procedure, combined with comprehensive absolute dating, should result in a complete view of the development of an agricultural system from its initial stages through European contact.

2) Direct evidence is obtainable in the form of sweet potato macrofossils. Archaeological excavations could be concentrated on those sites, structures, and features which will most likely contain preserved sweet potato remains. In addition, specific field recovery techniques can be developed.

3) The techniques of macrofossil identification need refinement, and comparative collections and keys should be developed.
4) Microfossil identification and analysis is not fully developed in Hawai'i and previous attempts at isolation of archaeological pollen have been relatively unsuccessful for a variety of reasons. However, pollen analysis may still prove productive, particularly in dry areas. It should be noted that for sweet potato pollen low percentages would be expected as the pollen is not windborn and the plant usually was harvested before flowering occurred.

5) Climatic-edaphic conditions of a specific micro-environment can be compared to the physical requirements of a particular cultigen as was done by Leach (1976).

Ultimately all of these methods depend on the accurate and reliable dating of archaeological sites through basaltic glass hydration rind measurement and radiocarbon dating techniques.

This very brief discussion of the possible role of the sweet potato in prehistoric Hawai'i is clearly quite preliminary and incomplete. All of the data relevant to this topic have not been recounted nor have all the possible interpretations been noted. However, recent archaeological research and dating in Hawai'i, combined with minimal direct evidence presently available on the sweet potato, is rather enticing. It is possible that a focus on the role of this adaptable food plant could have major explanatory potential in future interpretations of the prehistoric development of Hawaiian culture. Until new data more clearly defines the prehistoric position of the sweet potato, in terms of the time of introduction and the effects upon Hawaiian culture, the concerns raised here remain a legitimate area of inquiry for archaeological research in Hawai'i.
LITERATURE CITED


DE DICATION ADDRESS FOR HAWAII FIELD RESEARCH CENTER*

1 June 1978

Bruce M. Kilgore
Associate Regional Director
Resource Management and Planning
Western Region, National Park Service
San Francisco, California 94102

When Bob Barbee asked me to offer some comments this morning, I thought about my past role as a park scientist and my present role as a manager of professional programs. I felt I should not miss this opportunity to comment on some issues that concern me very much dealing with the National Park Service (NPS) science programs and scientists and their relationship to resource management programs and managers.

During our first century of managing national parks, we took it upon ourselves to "play God" because we decided which natural processes were "good" and which were "bad." But how did we assign such moral qualities to fire in the forest or to predators among species of wildlife?

In 1963 we were reminded by the Leopold Report that "playing God" was not what our mission was all about. And as scientists and managers, I find it useful from time to time to look at some of its major points again. You remember the catch phrases: "National Parks should be a vignette of primitive America," and "A reasonable illusion of primitive America can be recreated . . . using the utmost in skill, judgment, . . . and ecologic sensitivity."

But there were other important ideas, too:

1. It pointed out the folly of tinkering with natural processes without understanding these processes.

2. It said that the NPS must recognize the enormous complexity of ecologic communities and the diversity of management procedures required to perpetuate them.

3. It said that management without knowledge would be a dangerous policy.

* Portions of this paper were adapted from the Keynote Address at the NPS Pacific Northwest Region's Science/Resource Management Workshop, April 18, 1978.
When I began my present assignment in the Western Region, I wrote a memo to my boss, Howard Chapman, in which I raised several basic questions about science and scientists and attitudes of managers toward them. I said that perhaps the first question we must ask ourselves and answer honestly is: "Do we really want professionals and scientists in the NPS?" If we do, we must pay for this service, both through adequate funding and through strong commitment to the highest standards of professional activity. Such activity must include: (1) high-quality, in-house research to provide essential facts to guide management programs; and (2) publication of these results in professional journals.

Our past performance, while it has been improving recently, still has a long way to go, as both the Robbins and Leopold Reports in 1963 pointed out. In summary, these reports said four things:

1. We need a permanent, independent, identifiable research unit within the National Park Service.

2. Most of the research by the Park Service should be mission-oriented.

3. The NPS should itself plan and administer its own mission-oriented research program.

4. The results of research undertaken by the Park Service should be publishable and should be published.

Such concepts form the basis for my personal philosophy of what our objectives and goals ought to be for a natural science research organization in the Park Service. But I think there are differences in approaches between some managers and researchers on these points.

The Manager Needs the Sound, Scientific Support of the Scientist

While many managers may sense they need information upon which to base their management of forest resources or wildlife resources or fisheries resources, they do not always think they need a real scientist.

"Just get me the data," some say. "Give it to me in a report with management recommendations I can understand. But don't bother to write it up for those ivory-tower scientific journals. That's just the scientist doing his thing with his scientific peers. That's for his own personal benefit. It doesn't help me."
I want to say that I strongly disagree with this philosophy. And I want to tell you why. There is no way that a manager can be assured his scientist's information is solid unless he operates like a scientist and is recognized by his peers and the scientific community as a scientist. And for this to happen, there are few viable shortcuts to the process of careful design of a research project, careful review of that design by the most knowledgeable professional peers, careful gathering of data (often by research technicians, not the scientist himself), and professional analysis of the results and drawing of conclusions which are then subjected to a number of review processes, with publication as the final product.

This is a point I have trouble with in discussions with many managers and some researchers. Yet, I feel strongly that if a field research scientist does not publish, the research mission of the Park Service will certainly perish in the sense that it will come to have zero influence in or out of the Service.

So, what I am saying is the National Park Service must increasingly learn to support your local scientist and your local Cooperative National Park Resources Studies Unit (CPSU) when they seek to establish a reputation for solid scientific achievement. We must learn to support the process of presenting papers at scientific meetings and preparing the results for publication in the best possible scientific journals.

**Attitude of the NPS Scientist**

On the other hand, let me warn the National Park Service field-area scientist and the CPSU scientist that a part of the reason we lack management support for science stems from attitudes of some Service scientists and research biologists. There are those scientists--few, I hope--who are inclined to use fancy equipment and procedures to do a job that less sophisticated procedures could do equally well and with better management support and understanding. If you need computers and sophisticated equipment, use them. But do not play science games. And do not try snow jobs on managers.

The National Park Service scientist, who does not fully understand that the primary function of Service scientists is to produce mission-oriented results for those problems identified by management as being top priority problems, has done great damage to the image of science in the NPS. Such an individual may feel he is free to study whatever strikes his fancy, because anything he learns will benefit society and hence, the NPS. While most basic research has some interpretive value, there is no quicker way to lose support of the hard-pressed manager with a tight budget and an early deadline than to operate this way.
But we can make it over this hump if we have two things: (1) greater understanding on the part of the manager that good solid science is costly and takes some optimum minimum time, and that following through to publication is a worthwhile investment both for the scientist and the manager; (2) greater commitment on the part of the NPS scientist to working with the manager at the outset to select his highest priority projects to study, and then a continuing effort to gain a mutual understanding of what both hope to achieve by the research. This should sometimes include how data gathering—whatever is decided upon—will help the manager make a decision. In other words, we need desperately to better understand one another. We need better bridging of the communications gap that exists between manager and scientist.

**Bridging the Gap Between Scientist and Manager:**
**The Role of the Resource Management Specialist**

I feel that bridging the communications gap between the scientist and the Superintendent or manager is a key role that resources management specialists can and must play. This role is vitally important, and they need background experience and professional training as nearly equivalent to that of the scientist as possible. As I would see it, researchers and resources management specialists relate to each other in the following way:

1. The scientist develops the basic strategy—a sound rationale for ecological action programs of prescribed burning or goat and pig reduction or reintroduction of extirpated species.

2. Then the resources management specialist—the second half of an essential team—deals with the tactical operations of actually doing controlled burning in a regular way or guiding rangers in reducing exotic animal herds.

An extremely important need in the Service now is to develop a solid, professional resources management program. We need a career ladder for resources management specialists, an effective training program for such specialists, and a separate grade evaluation system to encourage them to become highly skilled specialists and not have to transfer to line management or to research in order to advance professionally. We should be able to recruit prospective resource management specialists directly from universities or from other assignments where their background experience qualifies them well.

I would see scientists and resources management specialists forming essential teams in larger parks, splitting the strategy and tactics of resources management, while in smaller parks, the scientist part of the team would be provided by scientists stationed at CPSU's.
We will see how far these ideas get in the next few years in the NPS. But some effective system for bridging the research-management gap must be found because managers need mission-oriented research. But not just the short-term brush fire efforts. Once you have identified a major issue, you need to go into in-depth studies of the various aspects of the ecosystem that are related to that particular problem. In no way can we be superficial in our approach.

**Where the Researcher Fails the Manager...**

**And the Manager Fails the Researcher**

All too often, researchers fail in their job to assist managers, and managers fail in their job to support researchers. The researcher most often fails the manager when he:

---carries out overly-sophisticated studies that are unrelated to management;

---makes little effort to communicate the results of his research to the manager (including recommendations for action);

---does not set up mutually agreed upon objectives at the beginning of the project and then follow through with reports and publications that are of value to the manager.

The researcher owes a manager at least two things: a solid study that leads to publication; and recommendations on how his research relates to management.

The manager may fail the researcher when he:

---undercuts the researcher's efforts to work steadily on primary projects, often by involving him in "brush fire" projects;

---does not communicate management problems he needs research answers for in a timely way, or does not seek a researcher's input on whether a given resources problem should have priority consideration for limited research funding;

---puts research at the bottom of the priority list for funding (maybe cutting it first in order to fill chuckholes in his road);

---discourages a researcher's papers at professional meetings or discourages him from finishing publications.
Hawaii Volcanoes: A Success Story

But with all its problems and controversies, resource management and research at Hawaii Volcanoes National Park has been a real success story, and the research center we are dedicating here today is a concrete example of the tremendous progress being made. Looking back briefly at where we have been in research in the National Park Service during the past 50 years, gives us some perspective. Lack of knowledge about natural resources and natural processes in parks has been a serious threat to the ecological health of many parks. Such was the case here in Hawai'i in the early 1960's with the two large park areas of Hawaii Volcanoes and Haleakala.

It is well documented that more species of native Hawaiian plants and animals have become extinct in these islands—and more are threatened with extinction—than in any other biological province on earth. We in the National Park Service are especially concerned with the problems in Hawai'i since the Service is the largest Federal land agency in the State, and because the Service is charged with a Congressional mandate to conserve the scenery, natural objects, and wildlife on all national park lands.

Research programs in the Service really began in the late 1920's when an advisory committee on problems in the national parks recommended a research program to fill some of the gaps in scientific information needed to administer and interpret the nation's national parks. In response, a Branch of Research and Education was created in 1930, headed by Dr. Harold Bryant, a student of Joseph Grinnell. Two years later, the Wildlife Division of the NPS was established as the first organization created solely for the purpose of ecological research and management of biological resources. It was led by George Wright, another Grinnell student.

At about this time, the Civilian Conservation Corps (CCC) presented the Park Service with a unique opportunity for expanding its conservation role on the national scene. CCC Camps were established all over the country; many were placed in national and State parks. The National Park Service administered portions of the CCC Program, and was able to acquire a large sum of Federal funds for research and management activities in national parks. (The site of the present Hawaii Field Research Center was at one time a CCC Camp.)

Unfortunately, George Wright was killed in 1936 and the CCC Program was abolished in the early 1940's. This led to a definite drop in NPS research efforts. It was not until nearly 25 years later, in the early 1960's, that the biological problems of the parks were again recognized as needing extensive NPS research commitment. In 1958, the Service obtained its first official budget solely for research—a meager sum of $28,000 for the entire NPS.
While the $28,000 would not even build a single comfort station for one national park, the money had some real psychological and fiscal pump-priming effects. Several Regional Offices and a few parks added their own funds to materially augment this initial sum. As such, this stimulated research institutions to produce several dozen reports by 1962 on critical ecological situations in a number of parks.

In the early 1960's, the Secretary of the Interior requested two surveys. The first was the "Leopold Report" I mentioned earlier. The second survey was one by the National Academy of Sciences on Research needs in national parks. It outlined the steps necessary to set up an effective research organization to handle park management problems.

Part of the Academy of Sciences Report stated that research centers should be established in national parks when justified by the nature of the park, and that such research centers should not only serve the staff of a national park but should be used jointly by personnel from universities, other organizations, and other Government agencies.

The late 1960's signaled the end of the 25-year period of frustration for biological research and management in the national parks, and the beginning of a new period of opportunity and hope for a better future.

Today, 10 years later, the annual research budget for Hawaii Volcanoes alone totals about $250,000. Considering our sister agencies, in the latter 1960's the Fish and Wildlife Service assigned a biologist to Hawai'i to research the probable causes for the decline of Hawaiian birdlife, and in 1969 the two agencies jointly established the Mauna Loa Field Station in Hawaii Volcanoes, manned by one research biologist from each agency.

Then in 1970, ecosystem research in Hawai'i received a tremendous "shot-in-the-arm" with a several-million-dollar grant from the International Biological Program (IBP). Many of the 5-year studies undertaken wholly or in part in the Hawaiian national parks required adding space for offices and laboratories.

These present facilities of the Hawaii Field Research Center were used at that time by the Kilauea Job Corp Camp, but when the camp was vacated in 1973, plans were immediately formulated to use the buildings (1) for needs of the IBP Program; (2) for other scientists including personnel from the Cooperative National Park Resources Studies Unit at the University of Hawaii; and (3) to expand the operations of the Mauna Loa Field Station into a several-person facility for research on endangered Hawaiian ecosystems. Since 1973, there has been increasing momentum in the development of the Center as a major facility for research in Hawaii and in the national parks.
In 1977, the U. S. Forest Service joined the ranks of the National Park Service and the U. S. Fish and Wildlife Service as the third Federal agency in Hawai'i to be concerned with research and management of endangered Hawaiian biotas. Total funding for the three agencies approaches about $750,000 a year.

The combined research efforts of the three agencies will make this one of the really significant interagency efforts in the country. The combined total of more than 20 permanent and seasonal employees from the three agencies should enable us to carry out a far more effective program of research on the decline and present status of endangered flora and fauna than would be possible by any single agency effort. We hope there will be the synergistic interactions which will help us all, and that some critical mass has been achieved that will ensure that this research facility, with these biennial conferences, with monthly seminars attended by leading scientists in Hawai'i, and with ongoing research carried out by staffs of three Federal agencies will become the leading research facility of its kind in the State.

It is appropriate, therefore, at this stage of development that we officially recognize the potential for the Hawaii Field Research Center to become Hawai'i's leading facility for research and management of natural resources, and as one of the best institutions of its kind in interagency cooperation anywhere in the nation.

In doing so, I want to express my personal commendation, and --I think I can safely say--that of the Western Region and the Washington Office of the National Park Service, for the heroic research and resource management efforts which have been made at Hawaii Volcanoes and in Hawaiian parks generally.

This is a tribute to the dedicated and long-standing efforts of:

--Bob Barrel, Hawaii State Director of the National Park Service;

--Bryan Harry, Past Superintendent, and Bob Barbee, Present Superintendent of Hawaii Volcanoes;

--The researchers, past and present,...who have contributed immensely to knowledge needed for active management programs--Ken Baker, Garrett Smathers, Dieter Mueller-Dombois, Cliff Smith, their graduate students, and many others from the University of Hawaii;

--and perhaps one of those who has contributed most has been Don Reeser, Resource Management Ecologist at Hawaii Volcanoes, who with his dedicated staff has contributed immensely to the positive values of the resources management program at Hawaii Volcanoes which is recognized as one of the finest active resource management programs in the Western Region and the National Park Service as a whole.
By no means, however, do I imply that our work is done! There is much left to do, including several items about which there is much controversy, and where we will need productive interchange between scientists and resource managers to resolve the issues. But I feel we all have two common objectives, as stated in the Master Plan which was recently approved. Namely:

(1) Protect the park's remnant Hawaiian ecosystems— including endangered species—from further depredation and competition by those exotic animals and plants introduced by modern man.

(2) Reestablish the park's endemic species into their former ranges, concentrating efforts on those species which are in danger of extinction, and those that are key components of major native ecosystems.

It is my honor on behalf of the National Park Service to declare the Hawaii Field Research Center as an official function of the National Park Service research and management effort, and to acknowledge that the Center is a facility for use and cooperation by other Federal agencies and educational institutions concerned with the conservation of Hawai'i's natural flora and fauna.
THE STATUS OF THE
HAWAIIAN DARK-RUMPED PETREL AT HALEAKALA

John I. Kjargaard
Haleakala National Park
Maui, Hawaii 96768

The Hawaiian Dark-rumped Petrel, or 'Ua'u (Pterodroma phaeopygia sandwichensis), a rare and endangered oceanic seabird, has probably been nesting at Haleakala continuously for many centuries. The eggs and young were considered a delicacy by the Hawaiians who learned to excavate a hole in the burrow through which they could "harvest" the birds every year. Dogs were also sometimes used to locate the burrows and dig out their occupants.

Although the species was rediscovered to science at Haleakala by Richardson and Woodside in 1954, it was heard by Ted Rodrigues and other CCC personnel in the mid-1930's and observed as well as heard by Clifford McCall and other Park Rangers in the late 1940's.

A history of the Hawaiian Dark-rumped Petrel compiled by Winston E. Banko in 1971 is the most complete study of the population status and distribution of the species in Hawai'i. Between 1966 and 1971 James Larson, Warren King, Jitsumi Kunioki, and others initiated work to locate and monitor the Haleakala population (Appendix A). From 15 known burrows in 1966 the total has now risen to 437; of the original 15 known burrows only 47% were active, and of that number active one-third failed to produce fledglings. Predation by rats and cats were considered the major problem.

Monitoring records prior to 1970 are limited; however, since that time fairly complete reports have been made on population studies, banding predator control, and bird mortality. Since 1968 the percent of activity in known burrows has ranged from 39% in 1969 to 95% in 1970, with recent years averaging about 69%. With the beginning of a predator trapping program in 1968 the nesting success rose to 93% and went as high as 99.9% in 1973. The average has been 96.5%.

Since 1969, 22 dead adults and six juveniles have been recovered. Most adult deaths have been attributed to collisions with rocks and, in a couple of instances, with automobiles whose lights appear to attract and blind the birds. Juvenile mortality has been attributed primarily to predators although other factors such as parent death, adverse weather, and burrow collapse undoubtedly contribute.
Due primarily to lack of personnel Haleakala National Park has done very little work on the breeding biology of the species and has instead concentrated on population studies. Access to the primary nesting areas on White Hill and Kilohana Pali is difficult and hazardous due to the steep unstable terrain which has helped to limit work on the species. The other major problem in conducting research on the Petrel at Haleakala has been the difficulty in locating burrows, even known ones. Each located burrow is numbered with white spray painted numerals and one or more white spots which serve both to catch the eye and to indicate the entrance.

Magnetic disturbances are evident in many places on the "Petrel slopes" and even with the use of an artificial north, conventional mapping techniques cannot be applied to determining exact locations of individual burrows. Prior to the development of the Haleakala Petrel Burrow Location System in 1977 burrows were frequently plotted by "guestimate" and although they were occasionally close to their actual location, more often they were many yards off.

To rectify this situation a photographic based burrow plotting system was produced with the aid of a grant from the Hawaii Natural History Association. The tactic was to photograph all the "Petrel slopes" from the air from three different angles. Four series of pictures totaling 67 photographs were produced with each burrow plotted on at least two photos. The system is cross referenced by area and burrow number to increase versatility and although it takes about a day's practice to become familiar with the methods involved, the accuracy is so high that the location time has been cut significantly.

Last year 290 successful breeding pairs were recorded in the primary nesting area and it is safe to estimate that there are at least another 20 pairs in more remote areas of Haleakala. It has been estimated that the population that nests at Haleakala, including all those birds that have not yet reached breeding maturity, is somewhere in the vicinity of 1600±500 individuals. Although the breeding population has remained more or less stable during the last 10 years there is little cause for optimism. Feral animal predation remains the largest single problem. Recently feral pigs moving up from Ko'olau Gap have dug up burrows in the Holua area. Dogs have never been observed but cats, mongoose, rats, and mice have all been trapped in the primary nesting areas. Perhaps one of the greatest problems is the almost total lack of breeding biology data which makes it difficult to accurately assess all the factors that may be involved in the survival of this species.


Huber, L. N. Survey of a breeding colony of Dark-rumped Petrels in Haleakala Crater, Maui, Hawaii.

King, W. Haleakala Crater Maui.


____. 1977. The Haleakala Petrel Burrow Location System.


APPENDIX A

Summation of Haleakala Petrel data compiled by King, Guth, Larson, Kunioki, Kjargaard, and Others

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Known Burrows</td>
<td>15</td>
<td>15</td>
<td>15</td>
<td>36</td>
<td>226</td>
<td>?</td>
<td>344</td>
<td>344</td>
<td>344</td>
<td>362</td>
<td>428</td>
<td>437</td>
</tr>
<tr>
<td>Total Burrows Checked</td>
<td>15</td>
<td>0</td>
<td>15</td>
<td>36</td>
<td>210</td>
<td>113</td>
<td>322</td>
<td>250</td>
<td>275</td>
<td>315</td>
<td>334</td>
<td>415</td>
</tr>
<tr>
<td>Percent Active</td>
<td>47</td>
<td>--</td>
<td>60</td>
<td>39</td>
<td>95</td>
<td>71</td>
<td>82</td>
<td>76</td>
<td>62</td>
<td>65</td>
<td>67</td>
<td>71</td>
</tr>
<tr>
<td>Percent Failed</td>
<td>33</td>
<td>--</td>
<td>7</td>
<td>8</td>
<td>5</td>
<td>1</td>
<td>3</td>
<td>0.1</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Total Rats Trapped</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>15</td>
<td>4</td>
<td>24</td>
<td>?</td>
<td>?</td>
<td>12</td>
<td>6</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>Rattus norvegicus</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>2</td>
<td>4</td>
<td>?</td>
<td>--</td>
<td>--</td>
<td>0</td>
<td>0</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>Rattus rattus</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>11</td>
<td>0</td>
<td>?</td>
<td>--</td>
<td>--</td>
<td>11</td>
<td>1</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Rattus exulans</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>2</td>
<td>0</td>
<td>?</td>
<td>--</td>
<td>--</td>
<td>1</td>
<td>5</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Total Mice Trapped</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>0</td>
<td>0</td>
<td>3</td>
<td>?</td>
<td>?</td>
<td>17</td>
<td>0</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Total Cats Trapped</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>6</td>
<td>0</td>
<td>0</td>
<td>0*</td>
<td>0*</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Total Mongoose Trapped</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Dead Adults Recovered</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>6</td>
<td>2</td>
</tr>
<tr>
<td>Dead Juveniles Recovered</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>0</td>
<td>?</td>
<td>2</td>
<td>3</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Recorded Bandings by the Park</td>
<td>--</td>
<td>--</td>
<td>1</td>
<td>1</td>
<td>5</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>2</td>
<td>3</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Banded by Maui Zoo</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>7</td>
</tr>
<tr>
<td>successfully released died in captivity</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>5</td>
</tr>
</tbody>
</table>

* observed but not trapped
Although biologists have long assumed that the influx of exotic plants and animals reaching Hawai'i in the past 200 years has caused severe disturbances in natural ecosystems and to native organisms, few reliable data have been obtained. Some such data have been obtained in recent years, mostly in connection with Hawaii IBP and with the National Park Service. This paper will discuss a number of different effects of introduced species, including their roles in destruction or displacement of native species, spreading fire, biological control, changes in moisture regimes, and disease introduction and spread. The literature will be summarized and gaps in our knowledge requiring further work will be indicated.

It is postulated that the rate of introduction of exotic species, and hence the rate at which perturbations have been imposed on Hawaiian ecosystems, has been an important factor in accounting for the magnitude of change which has occurred in these ecosystems.
POHAKULOA PROPAGATION PROJECT:
A CONTINUING SUCCESS STORY

Ah Fat Lee
Wildlife Branch
Hawaii State Division of Fish & Game
Department of Land & Natural Resources
Honolulu, Hawaii 96813

INTRODUCTION

In the latter part of the 18th century, the population of Nene, (Branta sandvicensis) was estimated at 25,000. In 1902, Henshaw predicted that "the time will inevitably come, and that soon, when this goose will need protection from sportsmen (and introduced predators) to save it from its otherwise inevitable fate of extermination." The Board of Agriculture and Forestry of the Territory of Hawaii operated a restoration project on O'ahu from 1927 to 1935. Nene were distributed to various interested people at the close of the project. By 1950, only one of these birds, a gander, was still alive and accounted for. The present Nene Restoration Project was started in Pohakuloa, Hawai'i, in 1949, with wildlife staff personnel in charge of the flock. At that time the world population was estimated to be approximately 50 Nene. Thirty of the 50 were estimated to be free flying in the fields; 20 were in captive flocks in three different locations. The captive flocks carried the same blood lines. The original two pairs at Pohakuloa were obtained on a breeding loan from Mr. Herbert Shipman, a cattle rancher from 'Ola'a, Hawai'i. Because the Shipman flock was the only one available, it was very likely that they were of an inbred line.

Captive Rearing

The inbreeding continued in the Project with poor results. Our records show that a high percentage of the inbred ganders were sterile. Embryos were of weak vitality and a high percentage died in the shell. Between 1953 and 1962 eight Nene were obtained from the fields. They included captured adults, young goslings, and a stray egg. Since they were not all taken from the same geographical area it is assumed that they were not too closely related. With this infusion of wild stock from the fields, the fertility and hatchability greatly improved in the Project (Table 1). The percent fertility of all eggs laid by Shipman strain geese was 54.5%; fertility of eggs laid by geese of different ages ranged from a low of 7.4% to a high of 75%. The percent fertility of all eggs laid by Wild strain geese was 76.7%; fertility of eggs laid by geese of different ages ranged from a low of 41.4% to a high of 100.0% (Table 2).
Management Techniques

The first clutch of eggs were removed from each goose at the completion of the clutch. This encouraged the goose to produce a second clutch of eggs during the breeding season.

Several methods of incubation have been tried in the Project. The use of setting Muscovy ducks, Silky bantam chickens, and mechanical incubators were tried. Ducks and bantams proved satisfactory as incubators; however, since the Nene laying season is between November and March, we had difficulty finding enough available setting hens and ducks. Fall and winter are, of course, the normal times for domestic fowl to go into molt. We have not had a high degree of success with mechanical incubators (Table 3).

Our best results have been to permit the goose to incubate her eggs. When the goslings of the first clutch begin to pip, the eggs are taken away from the goose and placed in an incubator-hatcher. The nest of the goose is broken up, and we have been successful in having Nene lay second clutches of eggs during the season. Three to five eggs are laid with an average clutch size of four. We have had a few six-egg clutches, and one successful hatching of six goslings out of six eggs. The incubation period for Nene eggs is 30 to 32 days.

The goslings of the first clutches are hand-reared. The parent pair are permitted to raise the goslings of the second clutch.

The diet of the Nene goslings consists primarily of greens, commercial poultry feeds, and vitamin/mineral supplements. The favorite choice of greens is Sow thistle (Sonchus oleraceus), and we go out of our way to collect it in the lower elevations for the flock. In Pohakuloa a rye grain-barley cross, Zetra petra, is planted during the fall and winter months when frost kills the local vegetation. This has proven to be very acceptable to the Nene; however, they will also graze on any green grass, including kikuyu (Pennisetum clandestinum), chickweed (Stellaria media), and varieties of clover.

We keep accurate pedigree records of all Nene bred, raised, or kept at Pohakuloa. Pairs of Nene are mated as long as they are productive and compatible. We have pairs of producing Nene in the breeding flock that are 14 years of age. Most Nene breed in their second year, but we had one goose that produced young her first year. Mated pairs have been successfully broken up, when the need arises, and mated to other mates.

The strain of "hairy down" goslings has been successfully bred out of the flock during the past three years.

At six weeks of age, the goslings are cloacally sexed and banded with numbered aluminum U. S. Fish and Wildlife Service bands. Goslings are capable of flight at 10 weeks, so their primaries are clipped while they are in the pens. Prior to release,
each Nene is banded with colored plastic leg bands. The order of the color bands is a "color band combination" for a specific individual, and no two Nene are banded alike. As many as three color bands have been placed on each leg of an individual Nene. The aluminum U. S. Fish and Wildlife Service bands are removed before release, and our records contain the given serial number as well as the color band combination. Biological studies in the field are facilitated by this method of record keeping.

Goslings are taken out to the gentle-release pen in the fields between two and eight months of age. In years when we produce a large number of goslings, the young are sent out in groups of about the same age. In years when production is smaller, the goslings are held until the last broods are ready for flight, for a single yearly release.

The development of techniques for captive breeding and rearing Nene for successful release has been a challenge to all of us associated with the Project. Between 1949 and 1978, we have been successful in raising 1699 Nene at Pohakuloa (Table 4). 1225 have been released on the Island of Hawai'i; 268 have been released on the Island of Maui in Haleakala Crater (198 Nene were shipped to Hawai'i from the Wildlife Trust in England, and those birds, as well as seven Nene from a private breeder in Connecticut, have been released on Maui).

Now, as the Endangered Species Propagation Project, we continue our work with Nene, Koloa (Anas wyvilliana), Laysan teal (Anas laysanensis), and the 'Alala (Corvus tropicus).

LITERATURE CITED


<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>No. Breeding Pairs</td>
<td>6</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>6</td>
<td>15</td>
<td>14</td>
<td>15</td>
<td>16</td>
</tr>
<tr>
<td>No. Producing</td>
<td>4</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>6</td>
<td>15</td>
<td>14</td>
<td>15</td>
<td>16</td>
</tr>
<tr>
<td>First Clutch</td>
<td>4</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>6</td>
<td>15</td>
<td>14</td>
<td>15</td>
<td>16</td>
</tr>
<tr>
<td>Second Clutch</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>5</td>
<td>12</td>
<td>13</td>
<td>14</td>
<td>16</td>
</tr>
<tr>
<td>Third Clutch</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>4</td>
<td>6</td>
<td>8</td>
<td>10</td>
<td>9</td>
</tr>
<tr>
<td>Fourth Clutch</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Total Eggs</td>
<td>14</td>
<td>16</td>
<td>27</td>
<td>46</td>
<td>76</td>
<td>118</td>
<td>149</td>
<td>174</td>
<td>181</td>
</tr>
<tr>
<td>Eggs per Clutch</td>
<td>3.5</td>
<td>3.2</td>
<td>3.8</td>
<td>4.1</td>
<td>4.4</td>
<td>3.3</td>
<td>4.3</td>
<td>4.4</td>
<td>4.4</td>
</tr>
<tr>
<td>Eggs per Goose</td>
<td>3.5</td>
<td>4.0</td>
<td>5.4</td>
<td>7.7</td>
<td>12.6</td>
<td>7.9</td>
<td>10.6</td>
<td>11.6</td>
<td>11.3</td>
</tr>
<tr>
<td>No. Fertile, LG*</td>
<td>6</td>
<td>4</td>
<td>18</td>
<td>22</td>
<td>15</td>
<td>28</td>
<td>56</td>
<td>97</td>
<td>87</td>
</tr>
<tr>
<td>No. Fertile, DC**</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>4</td>
<td>5</td>
<td>18</td>
<td>18</td>
</tr>
<tr>
<td>No. Infertile</td>
<td>8</td>
<td>10</td>
<td>8</td>
<td>16</td>
<td>47</td>
<td>76</td>
<td>86</td>
<td>49</td>
<td>68</td>
</tr>
<tr>
<td>No. Damaged 1</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>8</td>
<td>13</td>
<td>10</td>
<td>2</td>
<td>10</td>
<td>8</td>
</tr>
<tr>
<td>Percent Eggs with</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fertile, LG</td>
<td>42.8</td>
<td>35.0</td>
<td>66.7</td>
<td>47.8</td>
<td>19.7</td>
<td>23.7</td>
<td>37.5</td>
<td>55.7</td>
<td>48.1</td>
</tr>
<tr>
<td>Percent Eggs Fertile</td>
<td>42.8</td>
<td>31.2</td>
<td>61.7</td>
<td>47.8</td>
<td>21.1</td>
<td>27.1</td>
<td>40.9</td>
<td>66.2</td>
<td>58.1</td>
</tr>
<tr>
<td>No. Hatched</td>
<td>4</td>
<td>4</td>
<td>8</td>
<td>14</td>
<td>8</td>
<td>11</td>
<td>27</td>
<td>40</td>
<td>52</td>
</tr>
<tr>
<td>Percent Hatchability2</td>
<td>66.8</td>
<td>100.0</td>
<td>44.5</td>
<td>63.7</td>
<td>53.3</td>
<td>39.2</td>
<td>48.2</td>
<td>41.2</td>
<td>59.8</td>
</tr>
<tr>
<td>Mortality3</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>4</td>
<td>1</td>
<td>8</td>
<td>7</td>
<td>6</td>
</tr>
<tr>
<td>Percent Mortality</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>14.3</td>
<td>50.0</td>
<td>9.1</td>
<td>29.6</td>
<td>17.5</td>
<td>11.5</td>
</tr>
<tr>
<td>Goslings per Goose*</td>
<td>1.0</td>
<td>1.0</td>
<td>1.6</td>
<td>2.3</td>
<td>0.7</td>
<td>0.7</td>
<td>1.9</td>
<td>2.7</td>
<td>3.2</td>
</tr>
</tbody>
</table>

1. Percent Hatchability = (No. Hatched / Total Eggs) x 100
2. Percent Mortality = (No. Mortality / Total Eggs) x 100
3. Goslings per Goose = (No. Hatched / No. Fertile)
### TABLE 1—Continued.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>No. Breeding Pairs</td>
<td>17</td>
<td>17</td>
<td>20</td>
<td>24</td>
<td>30</td>
<td>40</td>
<td>30</td>
<td>29</td>
<td>26</td>
</tr>
<tr>
<td>No. Producing</td>
<td>16</td>
<td>16</td>
<td>20</td>
<td>23</td>
<td>27</td>
<td>38</td>
<td>30</td>
<td>29</td>
<td>21</td>
</tr>
<tr>
<td>First Clutch</td>
<td>16</td>
<td>16</td>
<td>20</td>
<td>23</td>
<td>27</td>
<td>38</td>
<td>30</td>
<td>29</td>
<td>21</td>
</tr>
<tr>
<td>Second Clutch</td>
<td>15</td>
<td>15</td>
<td>16</td>
<td>19</td>
<td>18</td>
<td>26</td>
<td>13</td>
<td>25</td>
<td>18</td>
</tr>
<tr>
<td>Third Clutch</td>
<td>13</td>
<td>8</td>
<td>11</td>
<td>7</td>
<td>2</td>
<td>0</td>
<td>1</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>Fourth Clutch</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Total Eggs</td>
<td>202</td>
<td>176</td>
<td>197</td>
<td>208</td>
<td>196</td>
<td>259</td>
<td>180</td>
<td>260</td>
<td>185</td>
</tr>
<tr>
<td>Eggs per Clutch</td>
<td>4.5</td>
<td>4.5</td>
<td>4.2</td>
<td>4.2</td>
<td>4.2</td>
<td>4.0</td>
<td>4.1</td>
<td>4.5</td>
<td>4.5</td>
</tr>
<tr>
<td>Eggs per Goose</td>
<td>12.6</td>
<td>11.0</td>
<td>9.9</td>
<td>9.1</td>
<td>9.1</td>
<td>6.8</td>
<td>6.0</td>
<td>8.6</td>
<td>8.9</td>
</tr>
<tr>
<td>No. Fertile, LG*</td>
<td>106</td>
<td>121</td>
<td>138</td>
<td>143</td>
<td>151</td>
<td>200</td>
<td>145</td>
<td>191</td>
<td>139</td>
</tr>
<tr>
<td>No. Fertile, DG**</td>
<td>28</td>
<td>22</td>
<td>18</td>
<td>10</td>
<td>6</td>
<td>7</td>
<td>12</td>
<td>28</td>
<td>4</td>
</tr>
<tr>
<td>No. Infertile</td>
<td>56</td>
<td>26</td>
<td>32</td>
<td>43</td>
<td>26</td>
<td>36</td>
<td>19</td>
<td>29</td>
<td>29</td>
</tr>
<tr>
<td>No. Damaged1</td>
<td>11</td>
<td>7</td>
<td>9</td>
<td>12</td>
<td>13</td>
<td>16</td>
<td>10</td>
<td>12</td>
<td>13</td>
</tr>
<tr>
<td>Percent Eggs with</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fertile, LG</td>
<td>52.7</td>
<td>68.7</td>
<td>70.1</td>
<td>68.7</td>
<td>77.0</td>
<td>77.2</td>
<td>80.6</td>
<td>73.5</td>
<td>75.0</td>
</tr>
<tr>
<td>Percent Eggs Fertile</td>
<td>66.3</td>
<td>81.3</td>
<td>79.2</td>
<td>73.7</td>
<td>80.2</td>
<td>80.0</td>
<td>88.3</td>
<td>84.2</td>
<td>77.0</td>
</tr>
<tr>
<td>No. Hatched</td>
<td>47</td>
<td>50</td>
<td>81</td>
<td>93</td>
<td>121</td>
<td>176</td>
<td>122</td>
<td>145</td>
<td>111</td>
</tr>
<tr>
<td>Percent Hatchability2</td>
<td>44.3</td>
<td>41.3</td>
<td>58.7</td>
<td>65.0</td>
<td>80.1</td>
<td>88.0</td>
<td>78.7</td>
<td>66.2</td>
<td>77.6</td>
</tr>
<tr>
<td>Mortality3</td>
<td>5</td>
<td>6</td>
<td>11</td>
<td>1</td>
<td>5</td>
<td>13</td>
<td>8</td>
<td>13</td>
<td>7</td>
</tr>
<tr>
<td>Percent Mortality</td>
<td>10.6</td>
<td>12.0</td>
<td>13.6</td>
<td>1.1</td>
<td>4.1</td>
<td>7.4</td>
<td>6.5</td>
<td>8.9</td>
<td>5.0</td>
</tr>
<tr>
<td>Goslings per Goose4</td>
<td>2.9</td>
<td>3.1</td>
<td>4.1</td>
<td>4.0</td>
<td>4.5</td>
<td>4.6</td>
<td>3.8</td>
<td>5.0</td>
<td>4.0</td>
</tr>
</tbody>
</table>

1 These are eggs broken in the nest; soft-shelled; abnormally small, etc. Fertility undetermined.
2 Percent of eggs with fertile, live germs that were successfully hatched.
3 Only post-hatch mortality (occurring within the first two weeks) is included here.
4 This represents production per goose of goslings successfully hatched.

**LG** means live germ at 10 days of incubation.

**DG** means dead germ at 10 days of incubation.
TABLE 2. Fertility of eggs in relation to the age of geese.

PART A: Shipman Strain Geese (14 Geese)

<table>
<thead>
<tr>
<th>Age</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of Geese</td>
<td>8</td>
<td>12</td>
<td>10</td>
<td>10</td>
<td>9</td>
<td>9</td>
<td>8</td>
<td>6</td>
<td>6</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>No. of Eggs</td>
<td>68</td>
<td>111</td>
<td>119</td>
<td>119</td>
<td>118</td>
<td>110</td>
<td>94</td>
<td>70</td>
<td>60</td>
<td>59</td>
<td>46</td>
</tr>
<tr>
<td>No. Fertile</td>
<td>5</td>
<td>30</td>
<td>65</td>
<td>62</td>
<td>79</td>
<td>66</td>
<td>56</td>
<td>56</td>
<td>43</td>
<td>43</td>
<td>29</td>
</tr>
<tr>
<td>Percent Fertile</td>
<td>7.4</td>
<td>27.0</td>
<td>54.7</td>
<td>52.1</td>
<td>67.0</td>
<td>60.9</td>
<td>59.6</td>
<td>71.4</td>
<td>71.7</td>
<td>72.8</td>
<td>63.1</td>
</tr>
</tbody>
</table>

PART B: Wild Strain Geese (29 Geese)

<table>
<thead>
<tr>
<th>Age</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of Geese</td>
<td>27</td>
<td>15</td>
<td>9</td>
<td>7</td>
<td>4</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>No. of Eggs</td>
<td>212</td>
<td>143</td>
<td>83</td>
<td>66</td>
<td>29</td>
<td>17</td>
<td>4</td>
</tr>
<tr>
<td>No. Fertile</td>
<td>164</td>
<td>121</td>
<td>66</td>
<td>43</td>
<td>12</td>
<td>15</td>
<td>4</td>
</tr>
<tr>
<td>Percent Fertile</td>
<td>72.4</td>
<td>84.7</td>
<td>79.5</td>
<td>65.2</td>
<td>41.4</td>
<td>88.3</td>
<td>100.0</td>
</tr>
</tbody>
</table>
Table 3. Hatching success as related to method of incubation.

<table>
<thead>
<tr>
<th>Method of Incubation</th>
<th>Muscovy Ducks(^1)</th>
<th>Silky Bantam Hens(^2)</th>
<th>Mechanical(^3)</th>
<th>Nene(^*)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Eggs(^*)</td>
<td>61</td>
<td>201</td>
<td>393</td>
<td>419</td>
</tr>
<tr>
<td>Number with Fertile, Live Germs</td>
<td>43</td>
<td>156</td>
<td>294</td>
<td>335</td>
</tr>
<tr>
<td>Number with Fertile, Dead Germs</td>
<td>1</td>
<td>16</td>
<td>43</td>
<td>10</td>
</tr>
<tr>
<td>Number Infertile</td>
<td>11</td>
<td>22</td>
<td>55</td>
<td>49</td>
</tr>
<tr>
<td>Number Damaged</td>
<td>6</td>
<td>7</td>
<td>1</td>
<td>22</td>
</tr>
<tr>
<td>Number Incubated Full-Term</td>
<td>43</td>
<td>156</td>
<td>294</td>
<td>335</td>
</tr>
<tr>
<td>Number Hatched</td>
<td>17</td>
<td>78</td>
<td>88</td>
<td>294</td>
</tr>
<tr>
<td>Percent Hatchability (^*)</td>
<td>39.6%</td>
<td>50.0%</td>
<td>29.9%</td>
<td>88.0%</td>
</tr>
</tbody>
</table>

\(^*\) All eggs are from first and second clutches.
\(^1\) Ducks were used from 1957-58 through 1959-60.
\(^2\) Hens were used from 1961-62 through 1964-65.
\(^3\) Mechanical incubation was used from 1960-61 through 1966-67.
\(^*\) Data for incubation by Nene is from 1958-59 through 1968-69.

Note: Ducks were used to supplement Nene for incubating eggs during the early stages of the propagation program. The hatchability was comparatively poor because the geese were predominantly Shipman strain geese. These blood lines had been found to have low fertility and hatchability.

| Year Number | Year Released | Kealakeku | Kealakeku 2 | Kahuku | 'Ainahou | Kipuka | Total | From Pōhakuloa | Connec- | Total | Nēnē Released |
|-------------|---------------|-----------|-------------|--------|----------|--------|-------|----------------| ticut   |       | Released      |
| 1949-50     | 2             |           |             |        |          |        | 20    |                |         |       |               |
| 1950-51     | 3             |           |             |        |          |        | 31    |                |         |       |               |
| 1951-52     | 2             |           |             |        |          |        | 35    |                | 5       | 35    |               |
| 1952-53     | 1             |           |             |        |          |        | 30    | 5              | 5       | 29    |               |
| 1953-54     | 4             |           |             |        |          |        | 42    | 19             | 5       | 29    |               |
| 1954-55     | 4             |           |             |        |          |        | 20    | 8              |         | 28    |               |
| 1955-56     | 8             |           |             |        |          |        | 49    | 24             | 8       | 34    |               |
| 1956-57     | 12            |           |             |        |          |        | -     | 25             |         | 25    |               |
| 1957-58     | 3             |           |             |        |          |        | -     | 5              |         | 5     |               |
| 1958-59     | 15            |           |             |        |          |        | -     | 75             |         | 75    |               |
| 1959-60     | 17            | 20/60     | 20          |        |          |        | 20    | -              |         | 20    |               |
| 1960-61     | 32            | 11/61     | 20          |        |          |        | 31    | -              |         | 31    |               |
| 1961-62     | 45            | -         | 35          |        |          |        | 35    | 30             | 5       | 35    |               |
| 1962-63     | 54            | -         | 42          |        |          |        | 42    | 19             | 5       | 29    |               |
| 1963-64     | 38            | -         | -           |        |          |        | -     | 20             | 8       | 28    |               |
| 1964-65     | 41            | 30/65     | 19          |        |          |        | 49    | 24             | 8       | 34    |               |
| 1965-66     | 69            | -         | -           |        |          |        | -     | -              | 25      | 25    |               |
| 1966-67     | 84            | -         | -           |        |          |        | 75    | -              |         | 75    |               |
| 1967-68     | 123           | -         | -           |        |          |        | 85    | -              | 20      | 20    | 105            |
| 1968-69     | 156           | -         | 33          |        | 122      |        | 155   | 50             | 22      | 72    | 227            |
| 1969-70     | 114           | 106       | -           |        |          |        | 106   | 55             | -       | 55    | 161            |
| 1970-71     | 131           | 94        | -           |        |          |        | 94    | -              |         | 94    |               |
| 1971-72     | 104           | -         | -           |        |          |        | 37    | -              | 44      | 44    | 81             |
| 1972-73     | 109           | 13        | -           |        |          |        | 61    | 74             | -       | 50    | 124            |
| 1973-74     | 134           | -         | -           |        |          |        | 123   | -              |         | -     | 123            |
| 1974-75     | 141           | -         | -           |        |          |        | 135   | -              |         | -     | 135            |
| 1975-76     | 160           | -         | 164         |        |          |        | 164   | -              | 34      | 34    | 198            |
| 1976-77     | 47            | -         | -           |        |          |        | -     | -              | 48      | 48    | 48             |
| Totals      | 1653          | 276       | 348         | 282    | 319      | 1225   | 198   | 269            | 7       | 474   | 1699           |

* All of the Nēnē released on Hawai'i were reared at Pōhakuloa.
STUDIES IN THE LIFE HISTORY OF THE 'ALALA IN CAPTIVITY*

Barbara Lee
Division of Fish and Game
State Department of Land & Natural Resources
Honolulu, Hawaii

This illustrated report describes observations on behavior of hand-reared 'Alala (Corvus t. tropicus) maintained as captive breeding stock at the State of Hawaii's Endangered Species Project, Pohakuloa, Hawai'i. The development of husbandry techniques and the problems and experiences related to establishing and maintaining a breeding population of 'Alala in captivity will be briefly discussed as well as the objective study of social, instinctive, and reproductive activities of the only six 'Alala in captivity.

* Abstract
INTRODUCTION

The rare and endangered species of Hawai'i represent one of the major problems facing those interested in preserving the exceptional natural heritage of the Hawaiian archipelago. It is well known that the Hawaiian Islands have a diverse and unique native biota. Most regretfully, a relatively large number of endemic species have already become extinct within historic times and several more are on the verge of disappearing forever.

There are a number of reasons for the extraordinary demise of so many of the native Hawaiian species. Exploitative land use, the impact of large feral herbivore populations, the introduction of aggressive weed species, fires, predatory and pathogenic organisms, and general habitat destruction have all taken their toll on the unique and vulnerable endemic species of Hawai'i. The impact of these problems has become increasingly acute in recent years.

OBJECTIVES

The basic assumption underlying the research discussed below is that a general consensus regarding the importance of the rare and endangered species is lacking. In order to determine citizen attitudes relevant to this issue, an ongoing research effort was initiated in 1976 to survey human perception of the problem. The goal of this project has been two-fold in nature: on one hand, there has been an attempt to quantify perception of the real or potential economic, scientific, aesthetic, ecological, and biological value of the rare and endangered species; on the other hand, it has also been the aim of this research to stimulate more study into the problem so that an objective measurement of the public's attitudes can become known. In other words, this is basically a pioneering effort to monitor popular feelings about an issue of growing concern and urgency. Furthermore, it has been hoped that the survey process will in some way elevate public awareness of the problems so that educated decisions affecting the future of the native Hawaiian plants, animals, and habitats can be made.
In order to measure the public's attitudes regarding the real or potential value of the species in question, a series of random surveys was taken of citizens from various parts of the Island of O'ahu. Over a three-year period, some 15 undergraduate students administered random surveys throughout the island as partial fulfillment of a course requirement in the General Science Department of the University of Hawaii at Manoa.

The sample survey size for each student was approximately 200. In 1976, eight students (Arthur Horibe, Rose Souza, Cynthia Hara, Jean Higa, Ronna Hazel, Mary Sniffen, Lori Fowler, & Diane Rose) completed their field work. In 1977, three students (Alva Young, Bobbie Daniels, & Ann Kagawa) completed their field work. And in 1978, four more students (Harold Yap, Debra Yuen, Joni Tanonaka, & Terry Tamura) completed their field work. The combined effort so far has compiled a sample size of approximately 3000.

The majority of the individual surveys were taken at various shopping centers located on O'ahu. Randomness and general objectivity in survey procedure were stressed. However, although these aspects were crucial to the usefulness of the data and the validity of the interpretations, common problems facing the social scientist may not have been under satisfactory control. For example, many people refused to answer the survey; and as in many surveys of human perception, there is always the question as to whether or not the persons surveyed did respond to the questions according to their true attitudes rather than socially acceptable ones. Moreover, one can argue that the structure of the questions themselves may have influenced the respondents to answer in a socially approved way.

Indeed it is hard to study the attitudes in question without biasing the responses in favor of preservation. This is a particularly difficult problem when there is no "price" involved in giving the "right" answer. In fact, this difficulty (i.e., personal financial commitment) is generally problematic in studies of quality of life (Dr. Earl Babbie, pers. comm. 1976). With this basic problem in mind, we revised the original survey administered in 1976 so that those taken in 1977 and 1978 had (what we considered to be) less ambiguity and better research design.

Copies of the 1976 and revised 1977-1978 surveys are presented in the Appendix. Note that data regarding age, length of residency in Hawai'i, educational background, ethnicity, and sex was also solicited from those answering the survey. Generally these showed relatively close correlations to these same characteristics manifested in the overall state population. Cross tabulation analysis of these characteristics (of the people surveyed) and the attitudes reflected in their answers to the first nine questions regarding their perceptions of the importance of the endangered species may reveal some interesting aspects of
public opinion concerning the issues at hand. This data is still in the process of being analysed.

RESULTS

Combined tabulations for the individual years 1976, 1977, and 1978 are presented in Tables 1 and 2. It should be noted that questions 4, 5, and 6 for 1976 have been shifted to questions 5, 6, and 7, respectively, in the 1977 and 1978 surveys; and question "7" for 1976 has been shifted to "4" in the 1977 and 1978 surveys.

A cursory examination of the data reveals an apparently strong concern for the protection of Hawai'i's endangered plants and animals. The majority of those surveyed over the three-year period feel that these species have an important research potential, have significant roles in the Hawaiian ecosystems, serve useful purposes, are important parts of Hawai'i's heritage, and have significant aesthetic value. However, non-native plants are also considered to be of equal value and the percentages of undecided responses to some questions tends to reduce the overall positive response of the public to the questions regarding the protection of the endangered species of Hawai'i.

The general difficulties of social survey research notwithstanding, it is hoped that this preliminary effort will stimulate other students, scientists, and concerned citizens to improve on the research design and possibly produce a more complete description and explanation of the public's attitudes pertinent to this problem.
<table>
<thead>
<tr>
<th>Variables</th>
<th>Strongly Agree</th>
<th>Agree</th>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Uncertain</th>
<th>No Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Question)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1976</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>781(52%)</td>
<td>606(40%)</td>
<td>19(1%)</td>
<td>31(2%)</td>
<td>52(3%)</td>
<td>14(1%)</td>
</tr>
<tr>
<td>2</td>
<td>62 (4%)</td>
<td>232(15%)</td>
<td>334(22%)</td>
<td>593(39%)</td>
<td>207(14%)</td>
<td>75(5%)</td>
</tr>
<tr>
<td>3</td>
<td>284(19%)</td>
<td>732(49%)</td>
<td>41(3%)</td>
<td>99(7%)</td>
<td>271(18%)</td>
<td>76(5%)</td>
</tr>
<tr>
<td>4</td>
<td>42 (3%)</td>
<td>101(7%)</td>
<td>673(45%)</td>
<td>517(34%)</td>
<td>91(6%)</td>
<td>79(5%)</td>
</tr>
<tr>
<td>5</td>
<td>748(50%)</td>
<td>630(42%)</td>
<td>13(1%)</td>
<td>38(3%)</td>
<td>58(4%)</td>
<td>16(1%)</td>
</tr>
<tr>
<td>6</td>
<td>184(12%)</td>
<td>735(49%)</td>
<td>75(5%)</td>
<td>188(13%)</td>
<td>266(15%)</td>
<td>95(6%)</td>
</tr>
<tr>
<td>7</td>
<td>575(38%)</td>
<td>696(46%)</td>
<td>11(1%)</td>
<td>34(2%)</td>
<td>94(6%)</td>
<td>93(6%)</td>
</tr>
<tr>
<td>8</td>
<td>64 (4%)</td>
<td>204(14%)</td>
<td>288(19%)</td>
<td>612(41%)</td>
<td>237(16%)</td>
<td>98(7%)</td>
</tr>
<tr>
<td>9</td>
<td>865(58%)</td>
<td>561(37%)</td>
<td>10(1%)</td>
<td>19(1%)</td>
<td>37(2%)</td>
<td>11(1%)</td>
</tr>
<tr>
<td>1977</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>347(71%)</td>
<td>128(26%)</td>
<td>--</td>
<td>4(1%)</td>
<td>4(1%)</td>
<td>4(1%)</td>
</tr>
<tr>
<td>2</td>
<td>11 (2%)</td>
<td>61(13%)</td>
<td>130(27%)</td>
<td>165(34%)</td>
<td>113(23%)</td>
<td>7(1%)</td>
</tr>
<tr>
<td>3</td>
<td>152(31%)</td>
<td>218(45%)</td>
<td>8(2%)</td>
<td>25(5%)</td>
<td>79(16%)</td>
<td>5(1%)</td>
</tr>
<tr>
<td>4</td>
<td>224(46%)</td>
<td>144(30%)</td>
<td>64(13%)</td>
<td>33(7%)</td>
<td>20(4%)</td>
<td>2(0%)</td>
</tr>
<tr>
<td>5</td>
<td>56 (11%)</td>
<td>50(10%)</td>
<td>127(26%)</td>
<td>204(42%)</td>
<td>48(10%)</td>
<td>2(0%)</td>
</tr>
<tr>
<td>6</td>
<td>262(54%)</td>
<td>170(35%)</td>
<td>10(2%)</td>
<td>22(5%)</td>
<td>17(3%)</td>
<td>6(1%)</td>
</tr>
<tr>
<td>7</td>
<td>122(25%)</td>
<td>225(46%)</td>
<td>12(2%)</td>
<td>50(10%)</td>
<td>74(15%)</td>
<td>4(1%)</td>
</tr>
<tr>
<td>8</td>
<td>16 (3%)</td>
<td>117(24%)</td>
<td>43(9%)</td>
<td>157(32%)</td>
<td>143(29%)</td>
<td>11(2%)</td>
</tr>
<tr>
<td>9</td>
<td>300(62%)</td>
<td>152(31%)</td>
<td>3(1%)</td>
<td>8(2%)</td>
<td>14(3%)</td>
<td>10(2%)</td>
</tr>
<tr>
<td>1978</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>383(60%)</td>
<td>232(36%)</td>
<td>4(1%)</td>
<td>5(1%)</td>
<td>6(1%)</td>
<td>10(2%)</td>
</tr>
<tr>
<td>2</td>
<td>25 (4%)</td>
<td>78(12%)</td>
<td>173(27%)</td>
<td>268(42%)</td>
<td>85(13%)</td>
<td>11(2%)</td>
</tr>
<tr>
<td>3</td>
<td>159(25%)</td>
<td>382(60%)</td>
<td>15(2%)</td>
<td>17(3%)</td>
<td>56(9%)</td>
<td>11(2%)</td>
</tr>
<tr>
<td>4</td>
<td>214(33%)</td>
<td>351(55%)</td>
<td>6(1%)</td>
<td>23(4%)</td>
<td>36(6%)</td>
<td>10(2%)</td>
</tr>
<tr>
<td>5</td>
<td>12 (2%)</td>
<td>27(4%)</td>
<td>323(50%)</td>
<td>226(35%)</td>
<td>40(6%)</td>
<td>12(2%)</td>
</tr>
<tr>
<td>6</td>
<td>286(45%)</td>
<td>283(44%)</td>
<td>11(2%)</td>
<td>13(2%)</td>
<td>36(6%)</td>
<td>11(2%)</td>
</tr>
<tr>
<td>7</td>
<td>135(21%)</td>
<td>329(51%)</td>
<td>16(3%)</td>
<td>70(11%)</td>
<td>82(13%)</td>
<td>8(1%)</td>
</tr>
<tr>
<td>8</td>
<td>34 (5%)</td>
<td>198(31%)</td>
<td>69(11%)</td>
<td>189(30%)</td>
<td>137(21%)</td>
<td>13(2%)</td>
</tr>
<tr>
<td>9</td>
<td>323(50%)</td>
<td>264(41%)</td>
<td>2(0%)</td>
<td>8(1%)</td>
<td>29(5%)</td>
<td>14(2%)</td>
</tr>
<tr>
<td>Variables</td>
<td>1976</td>
<td>1984</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-----------</td>
<td>------</td>
<td>------</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No Response</td>
<td>69</td>
<td>157</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.6%</td>
<td>15.2%</td>
<td>22.3%</td>
<td>25.2%</td>
<td>13.4%</td>
<td>19.2%</td>
<td></td>
</tr>
<tr>
<td>No Response</td>
<td>113</td>
<td>219</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7.5%</td>
<td>14.6%</td>
<td>16.4%</td>
<td>10.6%</td>
<td>21.4%</td>
<td>29.5%</td>
<td></td>
</tr>
<tr>
<td>No Response</td>
<td>99</td>
<td>196</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6.6%</td>
<td>13.0%</td>
<td>37.5%</td>
<td>37.0%</td>
<td>5.8%</td>
<td>22.8%</td>
<td></td>
</tr>
</tbody>
</table>

**TABLE 2. Survey of perception of endangered species (1976-1978).**
TABLE 2—Continued.

<table>
<thead>
<tr>
<th>Variables</th>
<th>No. Response</th>
<th>1977</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Under 15</td>
</tr>
<tr>
<td>10</td>
<td>9</td>
<td>24</td>
</tr>
<tr>
<td></td>
<td>2%</td>
<td>5%</td>
</tr>
<tr>
<td>11</td>
<td>94</td>
<td>34</td>
</tr>
<tr>
<td></td>
<td>19%</td>
<td>7%</td>
</tr>
<tr>
<td></td>
<td>Intermediate Sch</td>
<td>High Sch</td>
</tr>
<tr>
<td>12</td>
<td>24</td>
<td>233</td>
</tr>
<tr>
<td></td>
<td>5%</td>
<td>48%</td>
</tr>
<tr>
<td>Japanese</td>
<td>97</td>
<td>79</td>
</tr>
<tr>
<td></td>
<td>20%</td>
<td>16%</td>
</tr>
<tr>
<td>Caucasian</td>
<td>79</td>
<td>138</td>
</tr>
<tr>
<td>Chinese</td>
<td>138</td>
<td>20</td>
</tr>
<tr>
<td>Hawaiian</td>
<td>20</td>
<td>37</td>
</tr>
<tr>
<td>Filipino</td>
<td>37</td>
<td>27</td>
</tr>
<tr>
<td>Korean</td>
<td>27</td>
<td>11</td>
</tr>
<tr>
<td>Samoan</td>
<td>11</td>
<td>57</td>
</tr>
<tr>
<td>Other</td>
<td>57</td>
<td>21</td>
</tr>
<tr>
<td>No Response</td>
<td>21</td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>197</td>
<td>184</td>
</tr>
<tr>
<td>Female</td>
<td>40%</td>
<td>38%</td>
</tr>
</tbody>
</table>

TABLE 2—Continued.

<table>
<thead>
<tr>
<th>Variables</th>
<th>No. Response</th>
<th>1977</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Under 15</td>
</tr>
<tr>
<td>10</td>
<td>9</td>
<td>24</td>
</tr>
<tr>
<td></td>
<td>2%</td>
<td>5%</td>
</tr>
<tr>
<td>11</td>
<td>94</td>
<td>34</td>
</tr>
<tr>
<td></td>
<td>19%</td>
<td>7%</td>
</tr>
<tr>
<td></td>
<td>Intermediate Sch</td>
<td>High Sch</td>
</tr>
<tr>
<td>12</td>
<td>24</td>
<td>233</td>
</tr>
<tr>
<td></td>
<td>5%</td>
<td>48%</td>
</tr>
<tr>
<td>Japanese</td>
<td>97</td>
<td>79</td>
</tr>
<tr>
<td></td>
<td>20%</td>
<td>16%</td>
</tr>
<tr>
<td>Caucasian</td>
<td>79</td>
<td>138</td>
</tr>
<tr>
<td>Chinese</td>
<td>138</td>
<td>20</td>
</tr>
<tr>
<td>Hawaiian</td>
<td>20</td>
<td>37</td>
</tr>
<tr>
<td>Filipino</td>
<td>37</td>
<td>27</td>
</tr>
<tr>
<td>Korean</td>
<td>27</td>
<td>11</td>
</tr>
<tr>
<td>Samoan</td>
<td>11</td>
<td>57</td>
</tr>
<tr>
<td>Other</td>
<td>57</td>
<td>21</td>
</tr>
<tr>
<td>No Response</td>
<td>21</td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>197</td>
<td>184</td>
</tr>
<tr>
<td>Female</td>
<td>40%</td>
<td>38%</td>
</tr>
<tr>
<td>Variables</td>
<td>No Response</td>
<td>Under 15</td>
</tr>
<tr>
<td>-----------</td>
<td>-------------</td>
<td>----------</td>
</tr>
<tr>
<td>10</td>
<td>11</td>
<td>16</td>
</tr>
<tr>
<td></td>
<td>2%</td>
<td>3%</td>
</tr>
<tr>
<td>No Response</td>
<td>Less Than 1 Yr</td>
<td>1-4</td>
</tr>
<tr>
<td>11</td>
<td>19</td>
<td>52</td>
</tr>
<tr>
<td></td>
<td>3%</td>
<td>8%</td>
</tr>
<tr>
<td>No Response</td>
<td>Inter. Sch</td>
<td>High Sch</td>
</tr>
<tr>
<td>12</td>
<td>1</td>
<td>244</td>
</tr>
<tr>
<td></td>
<td>0%</td>
<td>38%</td>
</tr>
<tr>
<td>No Response</td>
<td>Japanese</td>
<td>Caucasian</td>
</tr>
<tr>
<td>13</td>
<td>16</td>
<td>186</td>
</tr>
<tr>
<td></td>
<td>3%</td>
<td>29%</td>
</tr>
<tr>
<td>No Response</td>
<td>Male</td>
<td>Female</td>
</tr>
<tr>
<td>14</td>
<td>8</td>
<td>309</td>
</tr>
<tr>
<td></td>
<td></td>
<td>50%</td>
</tr>
</tbody>
</table>
APPENDIX 1. Questionnaires used during the perception of endangered species study (1976 & 1977-78).

This is a survey to find out how the people of Hawaii feel about the rare native plants and animals of Hawaii. All questions are optional; but please answer as best you can. Mahalo.

Can you guess how many native Hawaiian plants and animals are in danger of disappearing completely from the Hawaiian environments? _____ (How many?) (Please check the appropriate box for each of the following questions.)

SA = strongly agree  SD = strongly disagree
A = agree  U = undecided (no opinion)
D = disagree

1. The endangered species, like all species, have a right to live.
   SA □ A □ D □ SD □ U □

2. Economic progress is more important than the native plants and animals.
   SA □ A □ D □ SD □ U □

3. The species provide important research potential.
   SA □ A □ D □ SD □ U □

4. Native plants and animals serve no useful purpose.
   SA □ A □ D □ SD □ U □

5. The native plants and animals are an important part of Hawaii's natural heritage.
   SA □ A □ D □ SD □ U □

6. Non-native plants and animals are equally desirable.
   SA □ A □ D □ SD □ U □

7. The ecological functions of the native plants and animals should be protected.
   SA □ A □ D □ SD □ U □

8. The protection the native plants and animals would limit recreational needs.
   SA □ A □ D □ SD □ U □

9. The native plants and animals add to the environmental beauty of Hawaii.
   SA □ A □ D □ SD □ U □

What should be done about the endanger plant and animal situation? Suggestions? Use the back of this paper.


11. How long have you lived in Hawaii? _____

12. Educational Background: Intermediate School _____ High School _____
    College _____

13. What ethnic background best describes you? __________________________
This is a survey to find out how the people of Hawaii feel about the endangered native plants and animals of Hawaii. All questions are optional; but please answer as best you can. Mahalo.

(Please check the appropriate box for each of the following questions.)

SA = strongly agree       SD = strongly disagree
A = agree                 U = undecided (no opinion)
D = disagree

1. The endangered plants and animals, like all species, should be protected by man.  
   SA A D SD U
2. Economic progress is more important than the preservation of the endangered native plants and animals.  
   SA A D SD U
3. The endangered plants and animals may have an important research potential.  
   SA A D SD U
4. The endangered plants and animals may have an important role in Hawaii's Ecology.  
   SA A D SD U
5. The endangered plants and animals serve no useful purpose.  
   SA A D SD U
6. The endangered plants and animals are an important part of Hawaii's natural heritage.  
   SA A D SD U
7. Non-native plants and animals are just as valuable as the endangered ones.  
   SA A D SD U
8. The protection of the endangered plants and animals would limit recreational use of their habitats.  
   SA A D SD U
9. The endangered plants and animals of Hawaii add to her environmental beauty.  
   SA A D SD U

11. How long have you lived in Hawaii? __________
12. Educational Background: Intermediate School _____ High School _____
    (Highest level completed) College _____
13. Of which ethnic background do you consider yourself?  
    Japanese Filipino  Chinese Korean  Caucasian Samoan  Hawaiian Other ________
14. Your sex: Male Female
Precipitation samples have been collected for chemical analysis on the island of Hawai'i since June 1975. Though the number of collection sites varied from 5 to 10, the permanent sites included Kapoho (sea level), Hilo (60 m), Kulani Mauka (2500 m), and Mauna Loa Observatory (3400 m). Samples were collected either on an event basis or every three days depending on the accessibility of the site. The pH and conductivity tests were performed immediately after collection of all samples. Anion analysis was made on selected samples using an ion chromatograph. The results show that pH values in precipitation ranged from 3.7 to 5.5 with an all-island average of 4.5. The acidity of the precipitation increased with elevation from sea level to 3400 m. Analysis in terms of air trajectories and surface winds at the Mauna Loa site indicates the more acidic rains come from the northern quadrant. The effects of the volcano on the acidity will also be discussed.

* Abstract
THE SEPTEMBER 1977 ERUPTION OF KILAUEA VOLCANO, HAWAI'I

Richard B. Moore, Daniel Dzurisin, Gordon P. Eaton, Robert Y. Koyanagi, Peter W. Lipman, John P. Lockwood, Gary S. Puniwai, and Rosalind Tuthill Helz

The latest eruption of Kilauea Volcano began on 13 September 1977, after a 21-month period of quiescence. Harmonic tremor in the central east rift zone and rapid deflation of the summit occurred for 22 hours prior to the outbreak of surface activity.

The first spatter cones formed along a discontinuous, en echelon, 7-km-long fissure system trending N 70°E between two prehistoric vents, Kalalua and Pu'u Kauka. During the first week, eruptive activity was concentrated at two spatter cones, one near the center and one at the west end of the new fissure.

The most voluminous phase of the eruption began late on September 25. An irregular spatter rampart formed along a 500-m segment near the center of the new fissure, but within 24 hours activity became concentrated at the east end of this segment. One flow from the new, breached, 40-m-high cone at this site moved rapidly (up to 300 m/hr) southeast, eventually reaching a point 700 m from the nearest house in the evacuated village of Kalapana. The total volume of material produced during this 19-day eruption is estimated to be 25-50×10^6 m.

Samples from active flows and vents indicate that a differentiated tholeiitic basalt was erupted. Plagioclase is the only significant phenocryst, and augite and minor olivine accompany it as microphenocrysts. This mineralogy, although uncommon in Kilauea lavas, is similar to that of the 1955 basalt. Some variation in bulk composition occurred throughout the eruption, but the last basalt produced also appears to be differentiated, suggesting that the magma involved in summit deflation has not erupted.

---

1 Abstract

HAWAII IBP SYNTHESIS:
1. BRIEF INTRODUCTORY SURVEY

Dieter Mueller-Dombois
Department of Botany
University of Hawaii at Manoa
Honolulu, Hawaii 96822

IBP, the International Biological Program was the first internationally coordinated, multi-disciplinary ecological research program which focussed on the ECOSYSTEM as the study object. Officially, the research objective was to study the biological basis of organic production in the world's major ecosystems. About 60 nations participated in the Program. Rather large research teams were organized in Russia, Japan, East and West Germany, England, France, Canada, Australia, and the U. S. The operational phase lasted a decade, from 1965 through 1975.

In the U. S., two major component programs were developed, a Human Adaptability component, concerned with the study of human populations living in extreme environments, and an Environmental component, concerned with the natural science aspects, particularly with the structure and function of major ecosystems. Teams of each 80-150 natural scientists were organized to study five mainland biomes in the U. S.: Tundra, Grassland, Desert, Eastern Deciduous Forest, and Western Coniferous Forest. The research emphasis of the Biome studies was on ecosystem metabolism, i.e., Photosynthesis, Respiration, Decomposition, Consumer Relations, and Mineral Cycling. In addition, three smaller research projects, with teams of 20-50 scientists were organized on the theme of Ecosystem Structure and Evolutionary Biology. Two of these worked on comparisons of similar ecosystems in geographically disjunct places: one was the Mediterranean Scrub ecosystem comparison between California and Chile; the other, the Desert Scrub and mesquite ecosystem comparison between Arizona and Venezuela. Ours was the third, focussing on Island Ecosystem Stability and Evolution.

By legislative mandate, the National Science Foundation received an annual allotment of about $6 to 10 million. Of this, the mainland biome studies received $1 to 2 million per year. The three Ecosystem Structure and Evolution Study programs received from $200,000 to $500,000 per year.

The funds were highly competitive. We got the first slice in 1970 after three times rewriting our proposal, and then managed to maintain approximately a $300,000 per year budget for our suggested five-year program from 1970-75.
General Conclusions

1. Zonal (or community) boundaries are evident from our data on species distributions, but boundary criteria need to be defined.

2. Different organism groups show different gradient sensitivities which are peculiar to the organism group.

3. Spatially associated species groups occur in nearly all organism groups.

4. Native species show a higher degree of spatial integration than introduced species among plants, birds, and Drosophilids. However, the origin (whether a species is native or non-native) is not a general predictor for species distribution patterns. These depend on the species ecological properties and the degree of naturalization (i.e., habitat saturation) among the exotics.

5. There is not only one generalized pattern of species distribution as Whittaker has claimed for temperate mountain gradients. Instead we can recognize at least three dominant patterns:

   1) Individually distributed species

   2) Spatially associated, but overlapping species groups

   3) Various forms of widely distributed species. The dominance of the latter groups are probably a characteristic related to biota distribution on young island mountains.
FIGURE 1. Map of Hawaii Volcanoes National Park showing the six environmental sections, the 14 Mauna Loa Transect sampling sites, and the Kilauea Rain Forest site.
FIGURE 2. Distribution of the three rodent species sampled along the Mauna Loa transect (Oct. 71 through Sept. 73). Abundance scale in equal units of 5 animals trapped per year: Maximum is 9 units = 41-45 animals (M. musculus at site 4), 8 units = 36-40 animals, 7 units = 31-35, 6 = 26-30, etc., horizontal line = 1 animal (e.g., R. rattus at site 12). K = closed kipuka forest in savannah zone IV. Origin: TeC = Temperate-continental Asia, TeL = Temperate-littoral Asia, TrP = Tropical-Pacific Asia.
<table>
<thead>
<tr>
<th>ORIGIN</th>
<th>TRANSECT ZONES</th>
<th>I</th>
<th>II</th>
<th>III</th>
<th>IV</th>
<th>V</th>
<th>VI</th>
<th>VII</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>IBP SITES</td>
<td>14</td>
<td>13</td>
<td>12</td>
<td>11</td>
<td>10</td>
<td>9</td>
<td>8</td>
</tr>
<tr>
<td>TeC</td>
<td>Mus musculus</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TeL</td>
<td>Rattus rattus</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TrP</td>
<td>Rattus exulans</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**ALTITUDE DISTANCE**

- 11,000
- 9,000
- 7,000
- 5,000
- 3,000
- 1,000

- (foot)
- (meters)

- 24
- 12
- 6
- 4
- 2

**DISTANCE (km)**
FIGURE 3. Distribution diagram of populations of selected fungal species from soils along the Mauna Loa transect. Curve heights are based on relative population levels rated from very low to high. Dashed lines imply presence at very low levels. Species group numbers along the right-hand column refer to spatially associated groups in the two-way table (50/10 rule). Ungrouped species are at the bottom of the diagram. FI = Fungi Imperfecti, P = Phycomycete, S = Sterile Isolate.
<table>
<thead>
<tr>
<th>SOIL FUNGUS ZONES</th>
<th>SET 1</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>IBP SITES</td>
<td>I</td>
<td>I</td>
<td>I</td>
<td>I</td>
<td>I</td>
<td>I</td>
</tr>
<tr>
<td>F1</td>
<td>Fusarium lateritium</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P</td>
<td>Mortierella hygrophila v. minuta</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P</td>
<td>Mucor fragilis</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P</td>
<td>Absidio spinosa</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>F1</td>
<td>Fusarium oxysporum</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>F1</td>
<td>Gliocladium deliquescent</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>F1</td>
<td>Pseudozymes corneus</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>F1</td>
<td>Fusarium solani</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>F1</td>
<td>Gliocladium roseum</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>F1</td>
<td>Gliocladium vermoosen</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P</td>
<td>Mucor strictus</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>F1</td>
<td>Penicillium atramentosum</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>F1</td>
<td>Cylindrocarpon magnusianum</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S</td>
<td>Sterile 77</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P</td>
<td>Mortierella ramanniana</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>F1</td>
<td>Trichoderma viride</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

ALTITUDE DISTANCE (km)
HAWAII IBP SYNTHESIS:
8. ISLAND ECOSYSTEMS: WHAT IS UNIQUE ABOUT THEIR ECOLOGY?

Dieter Mueller-Dombois
Department of Botany
University of Hawaii at Manoa
Honolulu, Hawaii 96822

We may now ask the question whether we have found anything unique or different in the ecology of island ecosystems from our studies. This is not an easy question.

It is clear that the biological evolution of our island ecosystems has been rather unique. Four factors stand out which contribute to the unique biological evolution of ecosystems here. These are the extreme isolation of the island group, the small size of the island habitats, the recency of the oceanic islands as a group, and their perturbation history in connection with volcanism.

The extreme isolation had a significant "screening effect" on what organism groups could get here and establish themselves successfully. This screening effect excluded any plants with large seeds or small seeds of short longevity. It also excluded among animals, all terrestrial mammals (except the hoary bat), large reptiles, and primates, except man.

The small size of the island habitats is the result of small island land masses jutting high out of the ocean. Thus, we have distinct altitudinal segregations of habitats with their own temperature regimes. Furthermore, these small land masses are segregated into windward (pluvio tropical) and leeward (xerotropical) habitats with their own rainfall regimes. The habitats are further fractioned by great variations in substrate, ranging from recent volcanic flows to old, scelitzed, and nutrient-depauperated latosols. This island habitat mosaic brings about another factor of important ecological consequences, and that is the very limited recurrence of similar habitats across the island chain. These narrow habitat dimensions strongly limit the population sizes of the island biota.

The recency of oceanic islands as a group is undoubtedly of evolutionary significance also. They originated in the Tertiary, when the modern angiosperm flora had already evolved. In contrast, some of the continental tropical ecosystems evolved without major geological disturbances forming a primary succession from seed fern forests to primitive gymnosperm and angiosperm forests to modern angiosperm forests. These continental ecosystems developed during a much greater evolutionary time span.
The high tree species diversity of some continental tropical forests may be largely attributable to this.

Volcanism causes major geological disturbances. These perturbations are a significant part of island ecosystem development from the highest mountain top to sea level. Volcanic perturbations are of many kinds and differing degrees and are erratic or unpredictable. They were once effective on each island and left their traces long after individual volcanoes became extinct. As such they had and still have a great effect on the evolution of the island biota.

There is little doubt then, that the island biota evolved under unique environmental conditions. Much has been written also about their adaptive characteristics, which sometimes resulted in the development of rather bizarre island life forms. But has this also made the ecology of island ecosystems different?

The answer, as revealed from our studies, appears to be that ecological principles do not differ for island ecosystems. However, our studies have brought out some new dimensions to island ecosystem ecology, which should add to both their scientific understanding and appropriate management.

**Distributional Characteristics of Island Biota**

The spatial distribution analysis along the Mauna Loa mountain gradient confirmed Whittaker's individualistic species distribution model established for temperate mountains. It also confirmed the spatial association model of species distribution which is, in part, an affirmative answer to MacArthur's question on species and community patterns in the tropics. However, spatially associated species groups along environmental gradients are not to be considered unique for tropical areas, since such patterns have been demonstrated many times also in temperate environments. They are, like Whittaker's individualistic species distribution patterns, a universal phenomenon applicable to islands and continents, temperate and tropical environments alike.

However, we found a number of other distribution trends, all of them more or less wide-ranging (e.g., bimodal, multi-modal, and broadly overlapping). These all reflect generalistic tendencies of species behavior. The high proportion of these generalists in our biota groups are perhaps characteristic for geologically young areas or those relatively poor in species. This tendency may not be found in geologically older areas, and thus also not so much on older volcanic islands.

An island characteristic, which may have interesting applications, is that soil fungi, soil algae, and soil arthropods are probably mostly indigenous. This would imply as a hypothesis that they may form a community-similarity link with continental
mountain habitats in similar climatic and soil regimes. Conversely, the other island community members, the higher plants, birds, canopy arthropods, tree borers, and Diptera flies all form much more unique species compositions.

Community Structure and Niche Differentiation

Island communities have the same gross-structural characteristics as found in continental communities. For example, montane tropical rain forests and lava tube ecosystems are also found on continents. At the species level, our island communities are almost totally unique. But they are not so unique at the higher taxon level. At this higher level one can find interesting similarities and departures from continental ecosystems.

In our community structure analysis we focussed on the general niche level, a functional ecological unit concept, intermediate between the individual species and the total ecosystem. We identified general niches by species of closely similar function and structure, i.e., by life-form types (i.e., synusiae in plants, guilds in animals).

We did not really find "empty niches" in the sense of absence of important life forms among the native species. The life-form spectra appeared complete in all organism groups analyzed, i.e., plants, birds, canopy arthropods, and cave animals. This does not mean that "empty niches" may not be found in other island ecosystems, but it may imply that the empty niche phenomenon is probably an exception rather than a rule in developed island ecosystems. What appeared to be a departure from continental ecosystems of similar kind was that several important life-form groups had only one or a few native species, often with high quantitative importance. These appeared to occupy the more stable positions (or general niches) in the ecosystems in the sense that few exotics had invaded them. Conversely, exotic species invasion appeared to occur more readily in those general niches or life-form groups in which several native species occur with relatively small populations. However, this is a new hypothesis, which needs further testing. We have not yet given special attention to the ecology and relative stability of rare and endangered native species, which as a rule are probably more specialized.

Instead our studies brought out the ecological versatility of some of the dominant native island biota. For example, in the Kilauea rain forest, all native tree species can grow on mineral soil and as epiphytes. The same applies to most of the herbaceous native ferns. This phenomenon argues for the stability of native species composition under temporarily adverse forest floor conditions (e.g., pig disturbance, flooding, ash blanket deposits).
It is probable that ecological generalists among the native species prevail in the island ecosystems, which we analyzed. Both the Kilauea rain forest and the lava tubes are relatively young ecosystems, which support biota which are able to survive perturbation effects associated with volcanism. Frank Howarth mentioned the underground dispersal modes for the Hawaiian cave fauna. Thus, here we are dealing largely with biota, which are still displaying pioneering traits, a characteristic which all island biota must have had for becoming successfully established in the new island environment.
VARIABILITY IN DORSAL PATTERNING AMONG POPULATIONS OF HAWAIIAN "HAPPY-FACE" SPIDERS (THERIDION SP. OR SPP.) ON THE BIG ISLAND*

William P. Mull
Department of Entomology
Bernice Pauahi Bishop Museum
Honolulu, Hawaii 96818

Since the December 1972 discovery on O'ahu of an apparently undescribed comb-footed spider (Theridiidae) with a striking "happy-face" design on its back, close relatives have been found on Maui and the Big Island. Preliminary surveys of Big Island forests have produced over 100 specimens and revealed a remarkable spectrum of dorsal patterning variation among populations of these tiny (3-4 mm body length) Hawaiian leaf-dwelling spiders. Pending study by a specialist, it is unclear whether these populations represent a single very variable species or several species. They are tentatively assignable to the widespread genus Theridion, which includes 10 described species (plus one subspecies) endemic to Hawai'i, only one of which bears resemblance to the "happy-face" group. These previously unknown Hawaiian spiders seem to be another example of the extremes of "genetic plasticity" and "evolutionary flux" expressed among other closely-related groups of Hawaiian organisms (e.g., Anomalochrysa lacewings, Achatinella tree snails, Metrosideros trees) in response to generous ecological opportunities and minimized inhibiting pressures presented to those groups by the unique Hawaiian environment.

* Abstract
THE ROLE OF THE HAWAIIAN TWO-LINED 'OHI'A BORER, PLAGITHMYSUS BILINEATUS SHARP, IN THE DECLINE OF 'OHI'A-LEHUA FORESTS ON THE ISLAND OF HAWAI'I*

Richard P. Papp
Department of Entomology
Bernice Pauahi Bishop Museum
Honolulu, Hawaii 96818

Plagithmysus bilineatus Sharp (Coleoptera: Cerambycidae), the Hawaiian two-lined 'ohi'a borer, is an integral part of the 'ohi'a forest decline. This insect has been closely associated with the onset of decline symptoms (crown chlorosis and crown loss) in 'ohi'a trees at eight widely differing sites on the island of Hawai'i. Experimental implantation of P. bilineatus larvae has also produced severe crown symptoms in otherwise healthy trees. Our data analyses indicate that P. bilineatus is a secondary invader of physiologically weakened trees, but it is of primary importance as the only organism yet to be both consistently associated with decline and experimentally proven to be capable of producing decline symptoms in healthy trees. Although abiotic factors continue to be suspect in the initiation of 'ohi'a forest decline, the role of this organism is now clear as an accelerating factor. Furthermore, since this species appears to be symptomatic rather than incitative in the demise of the 'ohi'a forest overstory, it can be regarded as a beneficial organism. P. bilineatus hastens the destruction of the declining forest canopy, opens the forest floor to light, and promotes the rapid resurgence of the shade-intolerant native understory, thus helping to preserve the integrity of the rain forest ecosystem.

* Abstract
As part of the U. S. International Biological Program, rodents were trapped seasonally during a two-year period at 14 primary sites from 840 to 2440 m on a transect along the southeastern slope of Mauna Loa; rodents were also intensively collected in the Kilauea Forest near the transect. Three of the four murine species present in the Hawaiian Archipelago were taken: *Mus musculus*, *Rattus rattus*, and *R. exulans*. Ectoparasites were recovered from rodents by a standardized washing technique. Mammalogical and parasitological data were analyzed by computer. The occurrence, host associations, and spatial distribution of some Acari are treated here. The occurrence of some parasitic mites was found to be partially independent of host factors and associated with local differences in climate.
In the native forests on the island of Hawai'i there is a species assemblage of 10 common passerine birds. Two of them are introduced, and six of the remainder are honeycreepers (three of these are endangered). All species except one are primarily insectivores. Four species utilize nectar sources to some extent and four utilize fruit.

Detailed observations of habitat use and foraging behaviors coupled with indices of abundance of flowering and fruiting, as well as population estimates of the birds, provide a preliminary estimate of a wide variety of niche components. Introduced species appear to have a somewhat broader foraging niche than native species in the same guild. Competitive interactions seem to play a role in limiting populations of one of the endangered species, while another appears to be limited by its rather narrow niche.

Interrelationships between phenology, abundance, and spatial distribution of food plants are all critical factors in determining habitat utilization by the birds. Interspecific interactions appear to play a secondary role at most times.

* Abstract
PLANTING, A TOOL FOR NATIVE ECOSYSTEM RESTORATION

Don Reeser
Hawaii Volcanoes National Park
Hawaii 96718

Natural Resources Management objectives for Hawaii Volcanoes National Park are to protect and restore native Hawaiian ecosystems. Making progress towards these objectives is a difficult task primarily because of introduced non-native agents competing with or directly destroying native conditions. We are making some headway, however.

The primary tool at the command of the resource manager is "extraction," i.e., the removal or control of non-native elements. Priority is given to those species which are considered to be the most destructive and competitive and for which techniques for control or elimination are feasible. Freeing Park ecosystems of goats, pigs, mongooses, feral cats, and certain exotic plants is the logical course of action where management emphasis has been placed in recent years and where it will probably remain in the future. Unfortunately extraction alone, regardless of how effective, will not counteract over 150 years of disturbance many areas of the Park have sustained. Large areas will continue to be dominated by exotic flora and fauna, and many rare or endangered species will continue to decline.

Besides extraction, the only other significant tool the resource manager has left to pursue established objectives is the reintroduction of appropriate native species, primarily plants, where and when conditions are suitable. Propagating and reintroducing native plants is an integral and vital component of Hawaii Volcanoes National Park's Natural Resources Management Plan and is consistent with National Park Service Management policy which is:

The reintroduction of native species into parks is encouraged, provided that:

--the species being reintroduced most nearly approximates the extirpated subspecies or race;

--the species disappeared, or was substantially diminished, because of human-induced change--either directly or indirectly--to the ecosystem.

The planting program is not new at Hawaii Volcanoes National Park. It has been a sporadic activity since the 1920's. Only in recent years, however, has it become a full time operation. Nearly a year ago a modern greenhouse was built here at the
Hawaii Field Research Center. The planting program is in its infancy, relative to its potential to contribute to the restoration and maintenance of native Hawaiian ecosystems. Some of the ways this program is or will be contributing are as follows:

1. **Restoration of man-made scars**

Following a disturbance such as rerouting the Crater Rim Road at Waldron Ledge an ugly scar has been created. If left alone, natural succession will produce a swath of exotic grasses through which it is unlikely 'ohi'a or other native trees can become established. We are planting this area to advance succession so that the scar will blend into the adjacent terrain.

An ugly scar near the research center was created during the 1930's by bulldozing probably for the purpose of a recreation site for Civilian Conservation Corp. We are now raising 'ohi'a trees which will be transplanted here in an attempt to return this area to a more nearly native condition.

2. **Restoration of selected lowland sites following goat removal**

Significant changes are taking place in once goat-infested areas. Many areas of the lowland are dominated by exotic shrubs and grasses. Historical accounts and examination of remnant vegetation and natives which have reappeared provide clues to the original flora of the area. We are making some experimental plantings of selected areas to see if natives can be reestablished and to what extent succession following goat removal can be influenced to produce a more native flora.

On the slopes of Makahanu Pali several wiliwili trees survived 150 years of goat browsing. As a result of this goat browsing and a 7.2 earthquake in 1975, only one is left representing the last gene pool from this site. We hope to reestablish a population in this area.

Canavalia first appeared inside a goat enclosure at Kukalau'ula and has also come up at Kaone several miles away. We planted Canavalia on the top of Pu'u Kapukapu on a site composed entirely of exotic grasses to see if it will produce a native cover and give competition to the exotic grass.

3. **Exotic Plant Control**

Much effort and money is spent on trying to control certain aggressive plants. For some, mechanical cutting and/or herbicidal treatment is possible, but for others...
this technique is futile. Native plantings could be used to compete with exotic species now that goats are removed and the thorniness or natural herbivorous defenses of many exotic plants do not necessarily give them the advantage.

For example, Lantana is a noxious weed for which the State of Hawaii has introduced many insects for biological control. One technique which we are exploring is the feasibility of removing the problem exotic and immediately replacing it with a native before exotics can reinvade.

4. Preservation and protection of rare and endangered species

Possibly several dozen plants considered to be rare and endangered are not reproducing in the wild. We are hopeful that with the control of goats and pigs they will begin to reproduce. It appears there are other regeneration problems such as exotic grass cover, destruction of seeds by rats, and exotic insects. Therefore, until solutions to these problems are found it is imperative that we continue to propagate and learn as much about these plants as possible so that their survival is ensured.

5. Historical restoration and interpretation

Greenhouse plant propagation can assist reestablishment of the historical scene and reestablish native or Polynesian plants used by early Hawaiians. These are located at archeological sites primarily along the Kalapana coast and are planted out in consultation with the Pacific archeologist and historian.

Plantings are recorded in books maintained at Park Headquarters and at the greenhouse. All the vital information on each planting is recorded and each site is pinpointed on maps. These records are always available for use by other researchers, or other interested persons. Monitoring of plantings is done on a sporadic basis whenever greenhouse personnel have an opportunity to get to the site. Size, condition, and mortality are recorded of a random sample of a given planting. More precise monitoring is planned to be able to follow the effectiveness of the program. As a side benefit of the planting program, an enormous amount of information is being collected and recorded such as location of rare and endangered species, flowering and fruiting times, etc. Insect collections are continuously made which are being identified and mounted by Mr. Cliff Davis. In the greenhouse, germination techniques and a host of other information are being recorded which will contribute to the overall program.
It is understandable that there is concern that the program does, in fact, truly enhance native ecosystems as intended. We fully recognize that there have been mistakes made in the past such as bringing in species which were never suspected of occurring in the Park or planting species outside of their natural range. However with the evolving comprehensive ecosystem restoration plan, rather than just a part time-greenhouse operation as it was a few years ago, errors of this kind should be avoided. A primary safeguard, however, is that the program be open to scientific scrutiny. The present resources management plan list of species to be propagated was compiled through consultation with ecologists, botanists, taxonomists, and other interested persons so species, propagating material source, and planting locations can be evaluated, and input on the desirability of same can be received. It has been suggested that we go even further than this in encouraging scientific input and expertise on the program by developing a discussion group composed of scientists from many disciplines who would meet regularly with Park personnel. This would be a more formal method of receiving advice and suggestions, and we are interested in discussing further the practicability of forming such a group. Another safeguard is to continually keep sight of the goal and to evaluate the impact of any resource management action on the native flora and fauna. It is native ecosystems which continue to decline islandwide. Hawaii Volcanoes National Park is one of the few places in Hawai'i where objectives for ecosystem preservation and restoration are clear and unencumbered by conflicting land use policy. In this Park we have the opportunity to make some lasting headway in native ecosystem preservation and it will be done through ecologically sensitive resource manipulation. The reintroduction of native species is an important tool needed for doing the job.
Despite Hawai'i's relatively small size, much of its flora and fauna may still be undescribed or undiscovered. A new genus of bird was discovered as recently as 1973 (Casey & Jacobi 1974) and many plants and insects remain to be described. Basic information on distribution, abundance, and biology is lacking even for many of the most common birds. This lack of information, combined with the limited area of natural vegetation, multiple and often conflicting demands for the land, and the vulnerability of island ecosystems in general, makes it imperative that we learn as much as possible about the native birds of Hawai'i now.

A survey of the distribution and abundance of birds and their habitats on all the major islands was begun in 1976 by the U. S. Fish and Wildlife Service in cooperation with the Hawaii Division of Fish and Game, Hawaii Division of Forestry, U. S. Forest Service, National Park Service, and Private landowners. The objectives of the survey are to determine:

1) the distributional areas for all forest birds in the study area;

2) the density (birds/km²) by vegetation type and elevational strata for all birds within the study area;

3) the population size for all forest birds for each vegetation type, elevational strata, and study area;

4) habitat preferences for all forest birds in study area;

5) occurrence of major vegetation types relative to the distributional patterns of birds;

6) land use patterns and stability of habitats within each distributional area; and

7) areas in which more detailed studies can be undertaken to clarify distributional anomalies and to identify limiting factors for endangered species.
To accomplish the objectives of the survey, transects are laid at intervals of 3.2 km (2 miles) on the Island of Hawai'i (Fig. 1), and at 1.6 km (1 mile) intervals on the other major islands. Stations are placed every 134 m along these transects. The vegetation at each station is characterized according to tree height, canopy cover, species composition of the canopy and understory, and the presence of major habitat modifiers such as 'ohi'a dieback, pig damage, banana pokā (Passiflora mollissima), browsing, grazing, and logging. In addition, the fruiting and/or flowering of the olapa (Cheirodendron spp.) and 'ohi'a (Metrosideiros collina) is recorded for 10 plants at each station. The occurrence of birds at each station is determined during eight minute count periods conducted during the first 4 hours after first light. By recording all birds heard and seen at each station and their initial detection distance it is possible to determine the density for each species encountered at a station. The area surveyed is a circle whose diameter varies with the species being censused as well as with the observer and vegetation type (Ramsey & Scott 1979; Reynolds et al., in press). The information on the occurrence of birds is related to the vegetation; multivariate statistics are used to determine habitat correlates.

Additional information is obtained on the occurrence of rare plants and birds as a result of incidental observations made after the regular census period.

The forest bird survey is conducted by a team of six trail cutters, 11 avian biologists, four botanists, and one statistician. On site observations as well as aerial photographs and direct aerial observations are used to conduct the various studies. To date, 815 km of trail have been laid, censuses have been conducted at 6247 stations, the vegetation characterized at 3100 stations, and over 3000 man-days of work expended in our efforts to quantify the distribution and abundance of Hawai'i's birds and their habitats. Transects 1 to 75 (Fig. 1) have been censused and it is anticipated that all the islands will be surveyed by September 1981.

Preliminary analyses of the data have greatly changed our understanding of the distribution and abundance of the rare and endangered birds on Hawai'i. Revised priorities for research and management have been adopted as the result of these findings. Threats to native birds and their habitats have been identified as well as possible ways to reduce or eliminate their impact. Distributional anomalies for endangered birds have been identified which, when studied in detail, should assist us in determining the limiting factors for these species. New study areas are being located and important information on breeding biology and habitat preferences is being obtained. Additionally, it should be possible to stratify sampling effort in future studies of Hawai'i's plants and animals, thus significantly reducing the time and money necessary to complete future studies.
When analysis of the data is completed it will be possible to state, for each species, its habitat preferences, area occupied (ha), the acreage of each habitat type within its range, relative stability of habitat types within its range as well as the density and population size for any subdivision of elevation, vegetation, or geography that is of interest. It is hoped that all this information will be used by land managers as well as researchers in their efforts to better understand and protect the plants and animals of Hawai'i.

LITERATURE CITED


FIGURE 1. Map of the island of Hawai'i showing locations of transects used during Forest Bird Survey.
Most of you are familiar with the mamane (Sophora chryso-phylla) and mamane-naio (Myoporum sandwicense) forest ecosystems of the Mauna Kea Forest Reserve. I need not recount the history of this reserve—you know it as well as I. Suffice it to say that feral herbivores have been major contributors to the degradation of these ecosystems.

Since 1970, the number of feral sheep (Ovis aries) has averaged 1500 animals. Mouflon sheep (Ovis musimon) have totaled 200 to 300 head. And feral goats (Capra hircus) have numbered about 150 to 200 animals. Today, the number of browsing animals in the mamane and mamane-naio ecosystems is about 1/20th of what it was in the mid-1930's.

Despite these relatively small populations, regeneration of mamane has not occurred in some areas while in others it has occurred at a slower rate than I would expect. This situation would probably persist even if all browsing pressure were eliminated. Such has been the case within several sheep exclosures, two of which are 15 years old. Elimination of browsing pressure within the exclosures has not been followed by an increase in mamane seedlings. Regenerating such areas with mamane would, therefore, involve the planting of seedlings and/or direct sowing of seeds (i.e., artificial regeneration). In my opinion, these efforts would fail if sheep still roamed the area.

If browsing pressure is eliminated from the ecosystems, thus making artificial regeneration of mamane a practical management option, information about successful regeneration methods will be needed. The study reported here deals with artificial regeneration by direct seeding. The objective was to determine the effect of seed coat treatment and sowing depth on mamane seedling emergence, survival, and growth under field conditions.

The 1-ha Wailuku River sheep exclosure located at 2750 m elevation on the east flank of Mauna Kea (Fig. 1) was selected for the experiment because mamane regeneration was lacking in a nearby exclosure built in the early 1960's.
Old mamane seed pods were collected from Hale Pohaku, 2750 m elevation. Seeds were extracted by hand and sorted to remove damaged ones. Intact seeds were kept in sealed plastic bags at room temperature until sowing.

The two factors examined in this study were seed coat treatment and sowing depth. Four seed coat treatments were tested:

1. Acid soak: Seed immersed in concentrated sulfuric acid for 60 minutes.
2. Sanded: Seed abraded between two sanding blocks for about 1 minute.
3. Hot water soak: Seed immersed in water at 100°C and allowed to soak until the water reached room temperature (overnight).

Seeds were sown at six depths: broadcast over the surface, spot sown at 1.3 cm, and at every 2.5 cm thereafter to a depth of about 11 cm.

Three blocks, each divided into four plots, were laid out within the Wailuku exclosure. Seed coat treatments were randomly assigned to the plots in each block. Plots were further divided into six subplots each and sowing depths were randomly assigned to them (split-plot design). Movement of surface sown seeds was restricted by means of buried hardware cloth around the perimeter of the appropriate subplot.

Eighty treated seeds were sown in each subplot during the first week of March 1974 when the upper 13 cm of soil were moist to sight and touch. Seed spots were made by inserting a reinforcing rod to the desired depth. Spacing was 10 by 10 cm. Only one seed was sown in each spot after which soil was poured into the hole and lightly tamped.

As seedlings emerged, numbered plastic markers were stuck nearby in the ground. The condition and height of each seedling were recorded.

Weekly measurements were made for the spring test to the 15th week after sowing. Thereafter, measurements were made every 4 weeks through the 54th week when the test was terminated.

Differences in seedling emergence, survival, and height due to seed coat treatment and sowing depth were examined by standard ANOVA techniques and multiple range tests using appropriate transformations. In addition, height-age regressions were fitted to the data and the coefficients were compared.
RESULTS

None of the seed sown on the soil surface germinated during the test. Therefore, I did not include this sowing depth in the analyses.

Seedling emergence

Analysis revealed that both seed coat treatment and sowing depth significantly \( p<0.01 \) affected seedling emergence. Significant interaction was also detected.

Table 1 shows the results of comparisons of means. Several conclusions can be drawn from these:

1. At all depths except 1.3 cm, emergence was significantly greater for acid and sanded treatments than for control and hot water.

2. For the acid and sanded treatments, emergence from the 1.3 cm depth was significantly poorer than from the other depths.

3. Emergence from acid treated seed sown at the 3.8 cm depth was significantly greater than any other treatment/depth combination.

4. For the control treatment, emergence from the 3.8, 6.4, and 8.9 cm depths was significantly greater than from the 1.3 cm depth.

5. Seedling emergence from hot water treated seeds was not significantly affected by sowing depth.

Emergence began the fifth week after sowing with a single seedling, originating from an acid-soaked seed buried at 1.3 cm (Fig. 2). The two greatest seedling increments occurred between the fifth and sixth weeks; 52 new seedlings emerged from acid-soaked seed at 3.8 cm and 32 seedlings from sanded seed, also at 3.8 cm. Seedlings were not observed from the 8.9 cm and 11.4 cm depths until the 7th and 8th weeks, respectively. In both cases, sanded seed produced seedlings first.

Seedlings from hot water-treated seed emerged slowly. The first seedlings came from the 1.3 cm and 6.4 cm depths 12 weeks after sowing. The first and only seedling from the 3.8 cm depth emerged between the 30th and 34th week after sowing.

Most of the seedlings emerged between the 5th and 14th week after sowing. In the case of the acid and sanded treatments, more than 80% of the emergence was complete by the 14th week at all sowing depths.
Seedling survival

Seedling survival was low. Of the 602 seedlings that emerged, only 99 (16%) were still alive 54 weeks after sowing.

Was survival affected by sowing depth? By type of seed coat treatment? After looking at my data, I decided I could not answer these questions for the control and hot water treatments because so few seedlings emerged from these. Therefore, I only compared seedling survival between acid and sanded treatments (Table 2).

Depth at which seed were sown did not significantly affect end-of-test seedling survival. However, seedling survival was affected by type of seed coat treatment; significantly greater survival was observed for seedlings originating from sanded seed.

I examined the relationship between percent survival and week of emergence and found that survival was not dependent on week of emergence. Seedlings that emerged relatively early had just as good a chance of surviving as those that emerged later.

Another expression of survival is seedling age—that interval between the time a seedling was first seen and the time it was declared dead or the test ended. Analysis showed that seedling age was not significantly affected by week of emergence, seed coat treatment, or sowing depth.

One unexpected discovery was that some seedlings tallied as dead suddenly reemerged, one as much as 24 weeks later. Of the 602 seedlings that emerged, 57 exhibited this behavior. Thirteen of these were still alive at the end of the test, thus accounting for about 13% of the surviving seedlings.

Seedling height

Height-age regression curves were fitted to my data (Fig. 3). Comparisons of the regression coefficients for the acid seed coat treatment showed that growth was significantly greater for seedlings from the 11.4 cm depth than for those from other depths. The same was true for the sanded treatment. Regression curves for the control treatment—3.6, 6.4, and 8.9 cm depths only—were significantly different from each other with seedlings from the 6.4 cm depth growing tallest.

The effect of seed coat treatment on seedling height was not clear from my data.

The coefficients of determination ($r^2$) for the regressions were low. Obviously, factors other than seedling age, seed coat treatment, and sowing depth were affecting height growth.
About 70% of the seedlings died back either prior to their death or prior to the end of the study. The greatest proportion of seedlings exhibiting dieback (77%) came from the 3.8 cm depth followed in order by the 6.4 cm (71%), 8.9 cm (70%), 11.5 cm (64%), and 1.3 cm depth (47%).

DISCUSSION

The management implications of these results are clear; direct sowing is not viable regeneration technique on sites similar to the one I used. Maximum emergence was only 54%. Survival was low and height growth slow.

Compared to planting of nursery-grown seedlings, direct sowing is not effective for regenerating mamane. About the time the test began, 36 containerized seedlings with an average height of 24 cm were planted in the Wailuku exclosure. Survival was 47% in April 1978 compared to 3% for seedlings from this study. Average height of survivors was 52 cm for the planted seedlings and 31 cm for the others. Planting was clearly the superior regeneration method.
TABLE 1. Comparisons of percent seedling emergence means for each combination of seed coat treatment and sowing depth.

<table>
<thead>
<tr>
<th>Seed Coat Treatment</th>
<th>Sowing Depth (cm)</th>
<th>Percent Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acid</td>
<td>1.3</td>
<td>6d</td>
</tr>
<tr>
<td></td>
<td>3.8</td>
<td>54a</td>
</tr>
<tr>
<td></td>
<td>6.4</td>
<td>34b</td>
</tr>
<tr>
<td></td>
<td>8.9</td>
<td>15c</td>
</tr>
<tr>
<td></td>
<td>11.4</td>
<td>15c</td>
</tr>
<tr>
<td>Sanded</td>
<td>3.8</td>
<td>32b</td>
</tr>
<tr>
<td></td>
<td>6.4</td>
<td>34b</td>
</tr>
<tr>
<td></td>
<td>8.9</td>
<td>22bc</td>
</tr>
<tr>
<td></td>
<td>11.4</td>
<td>15c</td>
</tr>
<tr>
<td>Control</td>
<td>6.4</td>
<td>4de</td>
</tr>
<tr>
<td></td>
<td>8.9</td>
<td>3def &lt; lefg</td>
</tr>
<tr>
<td></td>
<td>11.4</td>
<td>&lt; lefg</td>
</tr>
<tr>
<td>Hot Water</td>
<td>1.3</td>
<td>&lt; lfg</td>
</tr>
<tr>
<td></td>
<td>3.8</td>
<td>1defg</td>
</tr>
<tr>
<td></td>
<td>6.4</td>
<td>1defg</td>
</tr>
<tr>
<td></td>
<td>8.9</td>
<td>&lt; lfg</td>
</tr>
<tr>
<td></td>
<td>11.4</td>
<td>&lt; lfg</td>
</tr>
</tbody>
</table>

1 Means followed by the same letter are not significantly different (Duncan's Multiple Range Test).

TABLE 2. Average percent survival of mamane seedlings by sowing depth for acid and sanded seed coat treatments.

<table>
<thead>
<tr>
<th>Seed Coat Treatment</th>
<th>Sowing Depth (cm)</th>
<th>Percent Survival</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acid</td>
<td>1.3</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>3.8</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>6.4</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>8.9</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>11.4</td>
<td>11</td>
</tr>
<tr>
<td></td>
<td>Average</td>
<td>10</td>
</tr>
<tr>
<td>Sanded</td>
<td>1.3</td>
<td>33</td>
</tr>
<tr>
<td></td>
<td>3.8</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td>6.4</td>
<td>24</td>
</tr>
<tr>
<td></td>
<td>8.9</td>
<td>21</td>
</tr>
<tr>
<td></td>
<td>11.4</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>Average</td>
<td>24</td>
</tr>
<tr>
<td></td>
<td>Average</td>
<td>14</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td></td>
</tr>
<tr>
<td></td>
<td>16</td>
<td></td>
</tr>
<tr>
<td></td>
<td>17</td>
<td></td>
</tr>
<tr>
<td></td>
<td>--</td>
<td></td>
</tr>
</tbody>
</table>
Figure 1--Map of Mauna Kea, island of Hawaii, showing the location of the Wailuku exclosure study site.
Figure 2--Cumulative number of emerged mamane seedlings over time for each sowing depth and seed coat treatment during the test period, March 7, 1974 to March 18, 1975.

**Cumulative Number of Emerged Seedlings**

- **1.3 cm depth**
- **3.8 cm depth**
- **6.4 cm depth**
- **8.9 cm depth**
- **11.4 cm depth**

- **Acid**
- **Sanded**
- **Control**
- **Hot water**

*Acid and sanded curves coincide*

*Weeks Since Sowing*
FIGURE 3—SEEDLING HEIGHT OVER TIME FOR EACH SOWING DEPTH WITHIN A GIVEN SEED COAT TREATMENT DURING THE SPRING TEST.

**ACID**

<table>
<thead>
<tr>
<th>SOWING DEPTH (CM)</th>
<th>R²</th>
<th>EQUATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.743</td>
<td>1.289 + 1.169N(X)</td>
</tr>
<tr>
<td>3</td>
<td>0.310</td>
<td>4.223 + 0.266N(X)</td>
</tr>
<tr>
<td>5</td>
<td>0.363</td>
<td>2.813 + 0.563N(X)</td>
</tr>
<tr>
<td>7</td>
<td>0.263</td>
<td>6.038 + 4.598N(X)</td>
</tr>
<tr>
<td>11</td>
<td>0.331</td>
<td>5.422 + 3.969N(X)</td>
</tr>
</tbody>
</table>

**SANDED**

<table>
<thead>
<tr>
<th>SOWING DEPTH (CM)</th>
<th>R²</th>
<th>EQUATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.707</td>
<td>1.545 + 1.097N(X)</td>
</tr>
<tr>
<td>3</td>
<td>0.343</td>
<td>3.755 + 0.764N(X)</td>
</tr>
<tr>
<td>5</td>
<td>0.410</td>
<td>3.872 + 0.313N(X)</td>
</tr>
<tr>
<td>7</td>
<td>0.388</td>
<td>4.637 + 1.794N(X)</td>
</tr>
</tbody>
</table>

**CONTROL**

<table>
<thead>
<tr>
<th>SOWING DEPTH (CM)</th>
<th>R²</th>
<th>EQUATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>0.265</td>
<td>7.454 + 5.479N(X)</td>
</tr>
<tr>
<td>5</td>
<td>0.317</td>
<td>3.243 + 4.137N(X)</td>
</tr>
<tr>
<td>7</td>
<td>0.263</td>
<td>2.923 + 2.879N(X)</td>
</tr>
</tbody>
</table>

**HOT WATER**

<table>
<thead>
<tr>
<th>SOWING DEPTH (CM)</th>
<th>R²</th>
<th>EQUATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>0.147</td>
<td>7.265 + 1.660N(X)</td>
</tr>
<tr>
<td>5</td>
<td>0.001</td>
<td>10.848 + 0.341N(X)</td>
</tr>
</tbody>
</table>
COMMUNICATIONS TECHNIQUES AND THE SCIENTIST

Jerry Y. Shimoda
City of Refuge National Historical Park
Kona, Hawaii

(Write word SEX on the Board)

Now that I have your attention, let me tell you why I think I am here. Perhaps the reason for having me present my paper first has something to do with Superintendent Barbee's notice of April 10 to all participants of this Science Conference. In it, he appealed to us to transmit our research into easily understood language so that our papers can be enjoyed by the highly mixed group of persons here today.

I consider myself a layman in the midst of scientists, so let me express some of my concerns. Most of you will be using what you think is the easiest form of public communications—the lecture. Actually, although it is the fastest and easiest form to use, it is the most difficult one to transmit messages with. Many lay people shudder at the thought of attending a Science Conference because they will not understand what is going on. But if the scientist needs public support for his research projects, he must somehow be able to arouse the interest of these people and help them to understand. A good communicator always looks at his presentation with this key thought: "How can I help my listeners to better understand what I am saying?"

The scientist often uses scientific names of plants, birds, and animals without giving the common name. I suggest writing it out: Colocasia esculenta—Taro! (Write scientific name on flip chart). Then, use the word "taro" for the rest of the presentation. One of the dangers that any group of people can fall into is the "in-house language." Anyone who communicates with the public needs to be aware of this. For example, (write on board) I work for the NPS, DI, our central office is WASO, and it establishes policies that are interpreted and comes to CIRE through WRO and HISD. Permit me to explain those terms. NPS is National Park Service, DI is Department of the Interior, WASO is the Washington, D. C., Office, CIRE is City of Refuge National Historical Park, WRO is Western Regional Office, HISD is Hawaii State Director's office.

Permit me to present another example of "in-house talk." Some years ago, I worked at Saratoga National Historical Park, a Revolutionary War Battlefield, in upstate New York. We sold a booklet about the battle there. One day, I noticed some visitors looking at the booklet and chuckling among themselves. I found out why! For those of you who are not familiar with the Battle
of Saratoga, it occurred in the fall of 1777. The American army was commanded by General Horatio Gates and the British army by General John Burgoyne. The passage in question in the booklet was describing the advance of Burgoyne's army toward the American position. It said, "Burgoyne's right and left flanks lay in the woods, but his front was open." We quickly revised that passage, of course!

In good communications we must SIMPLIFY (write on board)! But this does not mean reducing your presentation to a childish one. Perhaps the scientist needs to look at things in the following ways. He needs to be bilingual and at the same time have a good understanding of objectives, human relations, and the techniques of presentations—both verbal and non-verbal.

Let us look at each of these items separately. Be BILINGUAL (write on board)—like knowing a second language. Learn the language of the communicator, e.g., use the active voice—"I went to the woods" instead of "I had gone to the woods." "We decided" instead of "It had been decided by us." Concentrate on short sentences instead of those long ones with 40, 50, or more words. Your listener will find it easier to follow your presentation, instead of having to follow you through all of the semicolons, commas, adjectives, and adverbs, until you finally get to your point.

Use words that touch your listener's emotions so that he will become involved in what you are saying. For example, it may be better to say "stink" instead of "odoriferous," or "home" instead of "house," and "killed" instead of "dispatched." Graphic words are better in public communications, but not to the point of nausea.

One may say, "But there is no simple word for that flower or that animal." My reaction to that is, "Use the word, but explain it. Write it on the board!" (Point to Colocasia esculenta written on flip chart). Speaking of words, a speaker should avoid profanity or delving into the gory as a shock treatment for they tend to turn off a good part of his audience, and cause them to become negative toward him and what he is saying.

In speaking, leave out as many "I's" as possible, like "I did this" and "I did that." When you do even little things like this, you are "removing the static so that your listeners can hear the music."

In preparing a speech, decide your objective for giving it, even before you start your outline. For example, in preparing for this paper, "Communications Techniques and the Scientist," the first thing I did was to decide that my objective would be change. I would try to change your thinking so that you would think of your listeners, and try to help them to better understand what you are saying, instead of telling your listeners of the great things you have accomplished, in language they cannot understand.
In a ten-minute paper like today's, a clear objective is needed because you do not have much time to reach one. Choice of words and thoughts also become important. As the presentations are made today and in the following two days, you will notice that some of the ten-minute papers will seem short and others will seem long. That will be because of the way they are written and the way they are presented. Remember that there is not a boring subject in the world. It is all in how you tell it!

To make a good speech, it is necessary to understand human relations. Sensitivity to the listeners' feelings is important. Remember that without the listeners, there is no need for a speaker! Try to relate what you are saying to your listeners' experience as much as possible. Do not present the same paper you presented last night at the dinner meeting of botanists, to a luncheon meeting of the local Lions Club today. Too many times this happens because we are not interested enough in having the listeners understand what we are saying, but are interested only in having our names in the newspaper that says we made a speech somewhere.

Now, let us review a few of the things any speaker should be aware of, and look at some new things. A person who is going to present a paper or give a talk on a particular subject must be willing to pay the price of preparation. He must have an objective in mind and must use an outline. The beginner should write his talk out, re-write until he is satisfied, then practice out loud on lay persons (with graphics if he is going to use any). Then, re-write again based on their feedback.

Arrive early at the meeting place to set up your equipment, and to look at the layout of the room. It is always better to provide your own equipment, e.g., movie projector, slide projector, or tape recorder, because you are more familiar with it than with one that the facility provides.

When you come up to the stand, be ready to speak. Do not play with your papers, your glasses, etc. Take ten deep breaths to help pull yourself together, then begin.

In making your presentation, relax, be natural, and throw your voice out to the people in the last row. Eye contact with the audience is also very important. Movements help, but not distracting movements, like playing with your glasses, shifting your weight from one foot to the other, or playing with the coins in your pocket. Use gestures, but they must look natural. People say "But I can't do gestures because when I try them they feel forced." Then practice! I am doing gestures deliberately right now to show you that deliberate gestures need not appear forced.

In communicating with the public, the burden is on you, the speaker. Keep in mind that the hardest parts of a day to give a speech are: bright and early in the morning, right after lunch, and right after a dinner. You need to use all the tricks in the book to keep the audience's attention.
under grass than in roots exposed to direct sunlight. Most roots with suckers show no obvious scars of damage.

**Rooting of cuttings under mist**

Mist rooting of cuttings provided a higher percentage of rooting than did air layering, but the rooted cuttings had a much lower percentage of survival after transplanting than did the air layers. Therefore, it is difficult to determine which of these two successful methods of propagation is the better.

Most of the successes occurred when perlite was used as the rooting medium and 3000 mg/kg IBA in talc as the rooting substance (Table 4). Rooting was obtained only once on a phyllo-dinous cutting. One experiment (Nos. 7, 8, 9) indicated that rooting could be improved by supplying nutrients to the cuttings while they were under mist. In the potassium nitrate (KNO₃) solution portion of this experiment, one phyllo-dinous cutting in addition to half of the true-leaf cuttings rooted. Unfortunately, these results could not be duplicated when the experiment was repeated on two occasions. The difference may have been that in the first test the cuttings were placed under mist the same day that they were obtained. The other experiments were started with 1- to 2-day-old material.

Although an average of 20% of cuttings rooted when IBA and perlite were used, only 14 propagules survived transplanting. The low percentage resulted because koa cuttings were very slow to root and produced very few roots per cutting. Rooting usually took 2 months or longer. By the time the cuttings rooted, almost all the leaflets had dropped and when they were transplanted, the rest of the leaflets were usually lost.

The methods we found most successful were to collect root suckers that had reached the round rather than square stem stage. These were placed under mist the same day they were collected. We rubbed the freshly cut end in 3000 mg/kg IBA in talc and put the cuttings in individual styrofoam cups of perlite to reduce fungus contamination. Cuttings that rooted were transplanted as soon as discovered to black plastic bags containing a mixture of mica-peat and perlite. The bag was then closed and sealed around the stem to reduce moisture entry. The packaged transplant was then held under mist for about 3 weeks before transfer to a shade house.

Recently, we have obtained an excellent source of stool shoot and root sucker material from one superior tree that was mistakenly cut by loggers and using the methods described we have twice achieved the usual 20% rooting, and have increased the ultimate survival rate to 12% of the original cuttings started.

Seven rooted cuttings have been planted at Laupahoehoe and five at Keauhou. The seven at Laupahoehoe have grown in a very similar fashion to the air layers. One died a few months after planting. Three others have become infested with *Uromyces koae,*
but are now growing in a normal upright fashion. Two others show plagiotropism. All have formed phyllodes, but all are so far much less vigorous than seedling trees growing in the same area.

**Clonal variation**

The percentage of rooting of cuttings and air layers indicates a possible pronounced clonal variation in rootability (Table 5). These data are only for rooting, not for ultimate survival of the propagules and are, of course, strongly weighted by the variation in numbers of cuttings worked. Only those trees that produced propagative material were listed. Six trees--numbers 1, 10, 18, 19, 20, and 22--provided a fair size sample of material which did not root. They can be compared with the quite good rooting performance of material from trees 2, 8, 9, 15, and 26. These results are only indicative of possible differences. They cannot be validly compared statistically because of the differences in conditions at each attempt in rooting.

Since these data were obtained, we have started more than 100 cuttings from tree number 2 of which 10 to 12 will survive. The key to success in all this propagation work is to use large amounts of material, and this has proved to be impossible with the superior trees up to now.

**CONCLUSION**

*Acacia koa* can be propagated by air layering or rooting of cuttings under mist. However, neither procedure has yet been developed sufficiently so that it can be considered a practical method of propagating forest-grown superior trees. So far only a few propagules of such trees have been produced, and many of them are showing slow growth, disease susceptibility, plagiotropism, or poor form.

The only practical way of propagating the species is from seed. This has several obvious disadvantages for tree improvement. Few seeds are produced by the tall, well-formed superior trees which have crowns above the general forest canopy where they are subjected to strong winds and, probably, low populations of insect pollinators. The seeds are open pollinated, so progeny expresses only a portion of the genotype.

Most of our tree improvement work with *koa* will be concentrated on seedlings. We are gradually building up a supply of sufficient superior tree seed to do a progeny test which will become a future seed orchard. We can also collect seedlings from beneath the trees to transplant to progeny tests.
We are continuing to explore ways of improving vegetative propagation of the species. The latest technique we are trying is to air-layer root suckers in the field and then bring them in as cuttings to root under mist once swelling has occurred above the girdle. This works well with southern hardwoods, but our trials of the method are not yet far enough along to report on.

LITERATURE CITED


Table 1--Grafting trials of Acacia koa

<table>
<thead>
<tr>
<th>Reference number</th>
<th>Grafts</th>
<th>Type of graft</th>
<th>Scions</th>
<th>Stocks and age</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>36</td>
<td>Side veneer</td>
<td>Shoot tip (juv. &amp; mature)</td>
<td>Seedling 4 mo.</td>
<td>18 (9 of each scion) kept under mist</td>
</tr>
<tr>
<td>2</td>
<td>30</td>
<td>Side veneer</td>
<td>Root sucker tip (juv.)</td>
<td>Seedling 5 mo.</td>
<td>One-half kept under mist</td>
</tr>
<tr>
<td>3</td>
<td>29</td>
<td>t-bud</td>
<td>Root sucker lateral (juv.)</td>
<td>Seedling 5 mo.</td>
<td>One-half kept under mist</td>
</tr>
<tr>
<td>4</td>
<td>12</td>
<td>Side veneer</td>
<td>Stem sprouts (juv.)</td>
<td>Seedling 6 mo.</td>
<td>Sprouts girdled, graft at swell above girdle</td>
</tr>
<tr>
<td>5</td>
<td>6</td>
<td>t-buds</td>
<td>Root sucker lateral (juv.)</td>
<td>Seedling 7 mo.</td>
<td>Raffia and grafting wax, expert grafter</td>
</tr>
<tr>
<td>6</td>
<td>6</td>
<td>Side veneer</td>
<td>Root sucker tip (juv.)</td>
<td>Seedling 7 mo.</td>
<td>Raffia and grafting wax, expert grafter</td>
</tr>
<tr>
<td>7</td>
<td>7</td>
<td>Top cleft</td>
<td>Root sucker tip (juv.)</td>
<td>Seedling 8 mo.</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>15</td>
<td>Patch buds</td>
<td>Root sucker lateral (juv.)</td>
<td>Seedling 9 mo.</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>15</td>
<td>Side veneer</td>
<td>Root sucker tip (juv.)</td>
<td>Seedling 9 mo.</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>6</td>
<td>Side veneer</td>
<td>Seedling branch (10 mo. old)</td>
<td>Seedling 10 mo.</td>
<td>Scion and stock same plant</td>
</tr>
<tr>
<td>11</td>
<td>10</td>
<td>Top cleft</td>
<td>Seedling tip (juv.)</td>
<td>Forest trees to 1 yr.</td>
<td>Seedling tips to forest-grown tree stumps</td>
</tr>
<tr>
<td>12</td>
<td>4</td>
<td>Approach</td>
<td>Root sucker propagule</td>
<td>Seedling 5 mo.</td>
<td>Scions were potted cuttings and air layers</td>
</tr>
<tr>
<td>13</td>
<td>6</td>
<td>Side tongue</td>
<td>Seedling tip (juv.)</td>
<td>Seedling 7 mo.</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>10</td>
<td>Whip</td>
<td>Seedling tip (mature)</td>
<td>Seedling 10 mo.</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>8</td>
<td>Side veneer</td>
<td>Root sucker tip (juv.)</td>
<td>Seedling 10 mo.</td>
<td></td>
</tr>
</tbody>
</table>

1/ Descriptive terms follow those by Hartmann and Kester (1975).
2/ Juvenile indicates juvenile or true-leaf stage; mature indicates phyllode stage.
Table 2--Rooting and survival of air layered root suckers and stem sprouts of superior trees

<table>
<thead>
<tr>
<th>Tree number</th>
<th>Air layers</th>
<th>Rooted</th>
<th>Surviving</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>13</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>5</td>
<td>18</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>8</td>
<td>32</td>
<td>6</td>
<td>4</td>
</tr>
<tr>
<td>9</td>
<td>6</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>10</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>12</td>
<td>7</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>14</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>15</td>
<td>57</td>
<td>9</td>
<td>5</td>
</tr>
<tr>
<td>19</td>
<td>6</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>20</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>22</td>
<td>3</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>23</td>
<td>5</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>26</td>
<td>2</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>35</td>
<td>3</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>36</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>159</strong></td>
<td><strong>25</strong></td>
<td><strong>13</strong></td>
</tr>
</tbody>
</table>
Table 3—Treatments applied to *Acacia koa* roots intended to induce suckering

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Trees</th>
<th>Treatments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Knife wounding (deep)</td>
<td>65</td>
<td>195</td>
</tr>
<tr>
<td>Knife wounding (shallow)</td>
<td>65</td>
<td>195</td>
</tr>
<tr>
<td>Expose root to sun</td>
<td>65</td>
<td>65</td>
</tr>
<tr>
<td>&quot;Chew&quot; with pliers</td>
<td>20</td>
<td>40</td>
</tr>
<tr>
<td>Pound with hammer</td>
<td>20</td>
<td>40</td>
</tr>
<tr>
<td>Heat with torch</td>
<td>20</td>
<td>40</td>
</tr>
<tr>
<td>Girdle root</td>
<td>32</td>
<td>32</td>
</tr>
<tr>
<td>Raise root on rock</td>
<td>9</td>
<td>18</td>
</tr>
<tr>
<td>Bury exposed root</td>
<td>11</td>
<td>11</td>
</tr>
<tr>
<td>Wound - kinetin (100 mg/L)</td>
<td>31</td>
<td>48</td>
</tr>
<tr>
<td>Wound - NAA (500 mg/L)</td>
<td>27</td>
<td>35</td>
</tr>
<tr>
<td>Wound - Ethrel (100 mg/L)</td>
<td>15</td>
<td>17</td>
</tr>
<tr>
<td>Wound - B (500 mg/L)</td>
<td>31</td>
<td>48</td>
</tr>
<tr>
<td>Wound - IAA (200 mg/L)</td>
<td>15</td>
<td>17</td>
</tr>
<tr>
<td>Wound - GA (500 mg/L)</td>
<td>31</td>
<td>48</td>
</tr>
<tr>
<td>Air layer (untreated)</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>Air layer B (500 mg/L)</td>
<td>6</td>
<td>6</td>
</tr>
</tbody>
</table>

1/ IAA = indoleacetic acid; NAA = napthaleneacetic acid; 
B = benzyladenine; GA = gibberellic acid.
<table>
<thead>
<tr>
<th>Ref. No.</th>
<th>Number Cuttings</th>
<th>Ontogenetic Stage</th>
<th>Source</th>
<th>Auxin</th>
<th>Auxin Strength</th>
<th>Application Method</th>
<th>Rooting Medium</th>
<th>Number</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>50</td>
<td>Succulent phylloide</td>
<td>Large trees</td>
<td>IBA</td>
<td>3000 mg/kg</td>
<td>Talc</td>
<td>1:1 vermiculite-perlite</td>
<td>0</td>
<td>One-half with bottom heat</td>
</tr>
<tr>
<td>2</td>
<td>50</td>
<td>Succulent phylloide</td>
<td>Large trees</td>
<td>IBA</td>
<td>100 mg/l</td>
<td>1 hr soak</td>
<td>1:1 vermiculite-perlite</td>
<td>0</td>
<td>One-half with bottom heat</td>
</tr>
<tr>
<td>3</td>
<td>50</td>
<td>Succulent phylloide</td>
<td>Large trees</td>
<td>None</td>
<td>--</td>
<td>--</td>
<td>1:1 vermiculite-perlite</td>
<td>0</td>
<td>One-half with bottom heat</td>
</tr>
<tr>
<td>4</td>
<td>25</td>
<td>Phylloide</td>
<td>Stem sprouts</td>
<td>IBA</td>
<td>3000 mg/kg</td>
<td>Talc</td>
<td>Perlite</td>
<td>0</td>
<td>--</td>
</tr>
<tr>
<td>5</td>
<td>25</td>
<td>True-leaf</td>
<td>Stem sprouts</td>
<td>IBA</td>
<td>3000 mg/kg</td>
<td>Talc</td>
<td>Perlite</td>
<td>9</td>
<td>35% rooted</td>
</tr>
<tr>
<td>6</td>
<td>54</td>
<td>True-leaf &amp; phylloide</td>
<td>Root suckers</td>
<td>IBA</td>
<td>3000 mg/kg</td>
<td>Talc</td>
<td>Perlite</td>
<td>8</td>
<td>15% of true-leaf rooted</td>
</tr>
<tr>
<td>7</td>
<td>20</td>
<td>True-leaf &amp; phylloide</td>
<td>Root suckers</td>
<td>IBA</td>
<td>10 mg/l</td>
<td>In medium</td>
<td>0.002 M KNO₃ and perlite</td>
<td>6</td>
<td>50% true-leaf, 1% phylloide rooted</td>
</tr>
<tr>
<td>8</td>
<td>20</td>
<td>True-leaf &amp; phylloide</td>
<td>Root suckers</td>
<td>IBA</td>
<td>10 mg/l</td>
<td>In medium</td>
<td>0.002 M KH₂PO₄ and perlite</td>
<td>0</td>
<td>--</td>
</tr>
<tr>
<td>9</td>
<td>10</td>
<td>True-leaf &amp; phylloide</td>
<td>Root suckers</td>
<td>IBA</td>
<td>10 mg/l</td>
<td>In medium</td>
<td>Hoagland's solution and perlite</td>
<td>3</td>
<td>30% of true-leaf rooted</td>
</tr>
<tr>
<td>10</td>
<td>10</td>
<td>True-leaf &amp; phylloide</td>
<td>Root suckers</td>
<td>None</td>
<td>--</td>
<td>--</td>
<td>Water and perlite</td>
<td>0</td>
<td>--</td>
</tr>
<tr>
<td>11</td>
<td>30</td>
<td>True-leaf</td>
<td>Root suckers</td>
<td>IBA</td>
<td>3000 mg/kg</td>
<td>Talc</td>
<td>Perlite</td>
<td>10</td>
<td>30% rooted</td>
</tr>
<tr>
<td>12</td>
<td>10</td>
<td>True-leaf</td>
<td>Root suckers</td>
<td>NAA</td>
<td>2000 mg/kg</td>
<td>Talc</td>
<td>Perlite</td>
<td>0</td>
<td>--</td>
</tr>
<tr>
<td>Ref. No.</td>
<td>Number Cuttings</td>
<td>Ontogenetic Stage</td>
<td>Source</td>
<td>Auxin(^1)</td>
<td>Auxin Strength</td>
<td>Application Method</td>
<td>Rooting Medium</td>
<td>Number</td>
<td>Remarks</td>
</tr>
<tr>
<td>---------</td>
<td>-----------------</td>
<td>-------------------</td>
<td>----------------</td>
<td>-------------</td>
<td>----------------</td>
<td>-------------------</td>
<td>----------------</td>
<td>--------</td>
<td>---------------</td>
</tr>
<tr>
<td>13</td>
<td>62</td>
<td>True-leaf</td>
<td>Root suckers</td>
<td>IBA</td>
<td>3000 mg/kg</td>
<td>Talc</td>
<td>Perlite</td>
<td>7</td>
<td>11% rooted</td>
</tr>
<tr>
<td>14</td>
<td>37</td>
<td>True-leaf</td>
<td>Root suckers</td>
<td>IBA</td>
<td>3000 mg/kg</td>
<td>Talc</td>
<td>Perlite</td>
<td>10</td>
<td>27% rooted</td>
</tr>
<tr>
<td>15</td>
<td>9</td>
<td>True-leaf</td>
<td>Stem sprouts</td>
<td>IBA</td>
<td>1000 mg/kg</td>
<td>Talc</td>
<td>Running water</td>
<td>0</td>
<td>-</td>
</tr>
<tr>
<td>16</td>
<td>9</td>
<td>True-leaf</td>
<td>Stem sprouts</td>
<td>IBA</td>
<td>3000 mg/kg</td>
<td>Talc</td>
<td>Running water</td>
<td>0</td>
<td>-</td>
</tr>
<tr>
<td>17</td>
<td>9</td>
<td>True-leaf</td>
<td>Stem sprouts</td>
<td>IBA</td>
<td>8000 mg/kg</td>
<td>Talc</td>
<td>Running water</td>
<td>0</td>
<td>-</td>
</tr>
<tr>
<td>18</td>
<td>108</td>
<td>True-leaf</td>
<td>Root sucker</td>
<td>IBA</td>
<td>3000 ml/kg</td>
<td>Talc</td>
<td>Perlite</td>
<td>19</td>
<td>18% rooted</td>
</tr>
<tr>
<td>19</td>
<td>10</td>
<td>True-leaf</td>
<td>Root sucker</td>
<td>IBA</td>
<td>3000 mg/kg</td>
<td>Talc</td>
<td>Perlite after 10 min NaOH</td>
<td>3</td>
<td>-</td>
</tr>
<tr>
<td>20</td>
<td>10</td>
<td>True-leaf</td>
<td>Root sucker</td>
<td>IBA</td>
<td>3000 mg/kg</td>
<td>Talc</td>
<td>Perlite after 10 sec H(_2)SO(_4)</td>
<td>1</td>
<td>-</td>
</tr>
<tr>
<td>21</td>
<td>10</td>
<td>True-leaf</td>
<td>Root sucker</td>
<td>IBA</td>
<td>3000 mg/kg</td>
<td>Talc</td>
<td>Perlite</td>
<td>1</td>
<td>-</td>
</tr>
<tr>
<td>22</td>
<td>10</td>
<td>True-leaf</td>
<td>Stem sprouts</td>
<td>None</td>
<td>-</td>
<td>-</td>
<td>Perlite after 10 min NaOH</td>
<td>0</td>
<td>-</td>
</tr>
<tr>
<td>23</td>
<td>10</td>
<td>True-leaf</td>
<td>Stem sprouts</td>
<td>None</td>
<td>-</td>
<td>-</td>
<td>Perlite after 10 sec H(_2)SO(_4)</td>
<td>0</td>
<td>-</td>
</tr>
<tr>
<td>24</td>
<td>10</td>
<td>True-leaf</td>
<td>Stem sprouts</td>
<td>None</td>
<td>-</td>
<td>-</td>
<td>Perlite</td>
<td>0</td>
<td>-</td>
</tr>
</tbody>
</table>

\(^1\) IBA = Indolebutyric acid; NAA = Naphthaleneacetic acid.
Table 5--Clonal variation in rooting of root suckers and stem sprouts of superior trees

<table>
<thead>
<tr>
<th>Tree number</th>
<th>Air layers</th>
<th>Rooted</th>
<th>Cuttings</th>
<th>Rooted</th>
<th>Rooted methods</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>0</td>
<td>9</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>0</td>
<td>25</td>
<td>5</td>
<td>20</td>
</tr>
<tr>
<td>3</td>
<td>13</td>
<td>2</td>
<td>21</td>
<td>1</td>
<td>9</td>
</tr>
<tr>
<td>5</td>
<td>18</td>
<td>3</td>
<td>33</td>
<td>4</td>
<td>14</td>
</tr>
<tr>
<td>8</td>
<td>32</td>
<td>6</td>
<td>58</td>
<td>11</td>
<td>19</td>
</tr>
<tr>
<td>9</td>
<td>6</td>
<td>2</td>
<td>14</td>
<td>4</td>
<td>30</td>
</tr>
<tr>
<td>10</td>
<td>2</td>
<td>0</td>
<td>7</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>12</td>
<td>7</td>
<td>1</td>
<td>4</td>
<td>0</td>
<td>9</td>
</tr>
<tr>
<td>14</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>15</td>
<td>57</td>
<td>9</td>
<td>74</td>
<td>17</td>
<td>20</td>
</tr>
<tr>
<td>16</td>
<td>0</td>
<td>0</td>
<td>4</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>18</td>
<td>0</td>
<td>0</td>
<td>8</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>19</td>
<td>6</td>
<td>0</td>
<td>10</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>20</td>
<td>2</td>
<td>0</td>
<td>6</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>22</td>
<td>3</td>
<td>1</td>
<td>9</td>
<td>0</td>
<td>8</td>
</tr>
<tr>
<td>26</td>
<td>2</td>
<td>1</td>
<td>11</td>
<td>3</td>
<td>31</td>
</tr>
<tr>
<td>35</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>36</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
STAND ANALYSIS OF AN INVADING FIRETREE (MYRICA FAYA AITON) POPULATION, HAWAI'I

Garrett A. Smathers
CPSU Western Carolina University
Cullowhee, North Carolina 28723
and
Donald E. Gardner
Hawaii Volcanoes National Park
Hawaii 96718

INTRODUCTION

Firetree (Myrica faya), an aggressive, noncommercial, exotic species that is native to the Azores, Madeira, and Canary Islands, has been spreading rapidly in Hawai'i for approximately 80 years. This tree was introduced in Hawai'i for reforestation in the late 1800's, but by 1944 it had become so aggressive in colonizing agricultural and forested land that the Board of Agriculture and Forestry was pursuing a control program to eradicate it (Neal 1965).

Distribution and Controls

Firetree concentration is dense on the islands of Maui and Hawai'i. However, the major efforts of control have been on the island of Hawai'i. In 1961 Kawasaki (unpublished) reported that the major concentrations on the island of Hawai'i were along the Hamakua Coast from Laupahoehoe to Honoka'a, then mauka (toward the mountain) to the Parker and Kukaiau Ranches. A smaller population covering 300-400 acres in the 'Ola'a Forest near Hawaii Volcanoes National Park (HVNP) was also reported in the 1961 survey.

In a 1966 survey Kawasaki (unpublished) estimated that the 'Ola'a Forest infestation had increased to 4500 acres, including 1500 acres on Forest Reserve Land and 25 acres in HVNP. Two additional infestations were observed in the National Park: (1) a 50-acre site on the northeast rim of Kilauea Crater; and (2) a 150-acre site at the intersection of the Chain of Craters Road and the 'Ainahou Escape Road.

Invasion of firetree on the island of Hawai'i has increased exponentially. A 1970 survey revealed that more than 40,000 acres of the island were infested with firetree (Walters & Null 1970). The 225 acres infestation in HVNP in 1966 had increased to approximately 9000 acres in 1977. Infested acreage varied from light (1 tree/acre) to heavy (1000 trees/acre) concentrations,
with the major distribution being in the seasonal dry forest section of the Park. 62,776 firetrees were removed from the Park from 1967 to 1974, and from 1975 to 1978 an additional 30,884 were destroyed, making a total of approximately 100,000 trees removed over a 10-year period (Donald Reeser, Resources Management Biologist, pers. comm.), and yet the plant continues to spread (Smathers 1976). The National Park Service considers the firetree invasion an unnatural phenomenon that threatens and impairs the natural and historic quality of the Park's vegetation.

The United States Forest Service and the Hawaii State Board of Forestry consider firetree to be an aggressive exotic with no commercial value, occupying land which should be utilized for agriculture and commercial forestry purposes. The State of Hawaii has conducted a control program for nearly 20 years, but funding and manpower have caused considerable fluctuations in this effort. Herbicides are the primary means of control. Of the various herbicides, Tordon 22k has proved the most successful in giving complete canopy kill and 99% control of sprouting (Walters & Null 1970; Walters 1973).

Controls by the National Park consist of uprooting small trees and using Kuron herbicide (2,4,5-TP) on medium and large trees. In addition to chemicals, several species of insects have been tested for control of firetree, but none have been successful (Krauss 1964).

Ecological Evaluation

As yet no comprehensive ecological evaluation has been made of the long-term impact of firetree upon the native vegetation. It seems reasonable that such a study should be conducted, considering the long period firetree has been colonizing the island ecosystems, and since its complete eradication is not likely. The latter is especially true in wildlands where agriculture and forestry are not practiced. Such a study would reveal the ecological role that firetree has with native species as well as with other exotic species now naturalized to Hawai'i. Information of this type would provide resource managers a better knowledge of how to evaluate the firetree's presence in light of their agency's mission and policy.

There is now an excellent opportunity to study firetree as it invades a series of ecosystems in Hawai'i. Since 1971, firetree has been invading the Devastation Area of the 1959 Kilauea Iki Crater eruption site in HVNP (Fig. 1) where a similar comprehensive ecological study has been underway for nearly 20 years. A main objective of the Devastation Area study is to determine the competitive relationship between native and exotic plants as they colonize recent volcanic substrates. Results of this study have shown that exotic and native plants have both a competitive and complementary relationship. In all habitats, native woody plants were eventually capable of replacing or holding their own with exotics. The Park manager has now set aside a part of the
Devastation Area for a concentrated study of the invading firetree population.

STUDY AREA

In December 1959 Kilauea Iki, a pit crater on the summit of Kilauea Volcano, erupted and deposited a blanket of pumice over an area of 500 hectares. Later the entire area, which is approximately 1200 m in elevation, became known as the Devastation Area. The latter name was given to the area because of widespread destruction of both a montane rain forest and a seasonal dry forest. With its variety of climates, substrates, and contiguous populations of native and exotic plants, the area provided a unique opportunity to study the formation of new plant communities.

Immediately after the eruption, a study was begun of plant invasion and recovery within the six habitats. These habitats were recognized by kinds of substrate and remains of the former vegetation. A series of permanent photo stations, belt transects (Fig. 2), and quadrats were established to record the chronological sequence of plant succession and recovery. The results of this study have provided information heretofore unknown on the phytosociological relationships of native and exotic plants (Smathers and Mueller-Dombois 1974; Smathers 1976).

During the 15-year observation period (in 1974) a small population of firetree seedlings was recorded in the western part of Habitat 5 near Byron Ledge. It is estimated that the initial invasion started about 1971.

The habitat is characterized by the large number of surviving native 'ohi'a (Metrosideros collina subsp. polymorpha) trees with a pumice layer that varies from approximately 30 cm to 3 m in depth (Habitat 5 in Fig. 3). It is in the lee of the cinder cone that formed during the 1959 eruption and slopes gently in a southwesterly direction. This habitat is somewhat protected from the prevailing northeasterly trade winds. However, it receives greater insolation in the lower sectors because of decreased cloud cover. The approximate mean annual air temperature is 17°C and the mean annual rainfall approximates 2700 mm. Mean evaporative rate from a Livingston atmometer was 6 ml/day/week with a standard deviation of 2.7. The climate is characterized by humid mild winters and warm dry summers (Smathers & Mueller-Dombois 1974).

METHODS

A survey was made of the firetree infestation pattern in Habitat 5 to determine its boundary, homogeneity, and the direction of invasion before placement of transects for stand analysis. Two permanent belt transects at right angles to one another were established in the infested area to meet the above criteria. It was not possible to determine direction of invasion
as size classes (height and diameter) were found evenly distributed throughout the populated area. One transect, C-C', which was 180 m long and consisted of contiguous 10 x 10 m plots, was originally established in 1960 for the Devastation Area study. The other transect W-W', was 70 m long and consisted of 10 x 20 m contiguous plots (Fig. 2).

Ninety-six firetrees were sampled within the transects for height, basal diameter, vigor, and phenological characteristics. A vigor rating of good to average included specimens with dark green to green foliage, mature fruits, and strong to medium terminal growth. A rating of poor included specimens with numerous pale green to chlorotic leaves, defoliated branches, fruit falling before maturity, and terminal die back. Associated plant species were recorded as to their physical position in relation to each firetree. Parameters of density, frequency, and percent cover were determined for the various height and diameter ranges. Unusual growth forms were also recorded.

RESULTS AND DISCUSSION

Stand Structure and Vigor Characteristics

The structure and vigor of the firetree population are shown in Table 1. By totaling both transects (C-C' and W-W') the highest number of trees (61) is in the 2-5 cm range; the second highest (32) is in the < 2 cm seedling range; and the next lowest number (2) is in the 6-7 cm range. The number trend in diameter sizes indicates that firetree is making a steady-progressive invasion of the area, but the small number of trees with mature fruits (Table 2) could not likely be the parent stock of the large number (32) of seedlings (< 2 cm).

Of the 96 firetrees examined, 89 were directly associated with the native 'ohi'a trees by being rooted beneath their crowns. In the < 2 cm diameter range, 27 seedlings, having a height range of 0.20-2.00 meters, grew beneath 'ohi'a trees, and 10 of these over 1 m tall were beginning to interlock with the lower 'ohi'a branches. In the 2-3 cm range, 34 shrubby firetrees were growing beneath 'ohi'a trees, and 25 of these were interlocking with 'ohi'a branches. In the 4-5 cm range and up to the 4 m height range, 25 shrubs grew beneath 'ohi'a with 20 exhibiting strong interlocking of branches with 'ohi'a. In the 6-7 cm small tree range, 100% had interlocking of most branches with both 'ohi'a and firetree seedlings become established beneath 'ohi'a trees and then grow upwards and into the 'ohi'a crown with interlocking branches. This direct aggressive behavior of firetree toward 'ohi'a would appear to end in competitive replacement of the latter. However, in all but one firetree 'ohi'a interlock situation, 'ohi'a was exhibiting average to good vigor. The only interlocking 'ohi'a with low vigor was recorded in plot 8 of transect C-C'. On the other hand, firetree was not faring as well as shown in Table 1. In Transect C-C' its vigor was from average to good in the < 2 cm range. However, this condition
shifted in the 2-3 cm range where 82.4% of the firetrees exhibited average vigor, but on reaching the 4-5 cm range, average vigor had decreased to 54.5%, and 27.3% of the trees exhibited poor vigor. In transect W-W' a similar relationship existed with poor vigor continuing to increase with diameter range. At range 6-7 cm, 50% of the trees showed poor vigor, and at 10-11 cm the single tree recorded in this range had poor vigor.

The foregoing data show that within the area considered in this study firetree tends to lose vigor as it increases in size. Cause of the vigor loss may be a lack of available soil water. The recent pumice soil is exceedingly dry regardless of the high rainfall (2700 mm) for Habitat 5. Available water for plants ranges only from 2% to 3%. Thus, there is less water available in this new volcanic material than in most sands, and plants in open areas will have water for growth only for a short period after showers (Smathers & Mueller-Dombois 1974).

The surviving 'ohi'a trees have created a mesic microhabitat beneath their canopy, in comparison to the xeric soil environment outside the canopy. Beneath each tree an accumulating litter layer has formed that is periodically moistened by through-falling rain, and protected from desiccation by the crown cover. Thus the microhabitat conditions beneath 'ohi'a favors firetree seed germination and seedling development up to a diameter range of 2-3 cm. Further growth causes a drain on the soil water, and this condition is reflected by loss of vigor. When the firetree reaches the 6-11 cm range, soil water is practically unavailable for growth, and thus vigor becomes poor. The fact that firetree has never invaded the dry, barren soil of Habitat 4 tends to support the foregoing hypothesis.

It is not known whether there is competition between the 'ohi'a and firetree root systems. Surviving 'ohi'a were rooted in the old soil layer prior to the 1959 ash fallout layer. In localities where the ash fallout was over 0.5 m, a secondary root system developed on the buried 'ohi'a trees, thus there could be competition between the two trees for water and nutrients. In any case, 'ohi'a would still have the advantage by having a rooting system in the old soil, which still receives water filtering through the new soil.

**Quantitative Characteristics**

The basal diameter, height, density, and frequency of firetrees are shown in Table 3. In transect C-C', the 2-3 cm range had the highest density, frequency, and second highest percentage cover, thus showing its dominance in the community structure (stratification). In transect W-W', the 2 cm class had the highest density (1.64/100 m$^2$) and frequency, but the 2-3 cm and 4-5 cm ranges had the same frequency and also the highest percentage cover (3.88 and 5.72, respectively). The higher total density, frequency, and percent cover of the W-W' transect than the C-C' transect is because 'ohi'a trees are spaced farther apart in the C-C' transect than in the W-W' transect. Therefore,
there were more available microhabitats ('ohi'a crowns) in transect W-W' for firetree to colonize.

**Phenological Characteristics**

Phenological characteristics of this firetree population are shown in Table 2. The following information on flowering and fruiting was obtained in August 1977. Most noticeable was the senescence of staminate flowers and green fruits developing on several plants. Also, considerable defoliation was occurring on the branches of three plants that bore both staminate flowers and fruits. Approximately one-fourth of the fruits observed were purple, which indicated they were ripe. With the exception of defoliation, the flowering and fruiting cycle of firetree in Hawai'i probably approximates that in the plant's native habitat. In Madeira and the Canary Islands, Krauss (1964) observed firetrees in June with an abundance of male flowers and green fruits. However, he noted that the staminate flowers were drying up. From July to September he reported that most of the green fruits had turned purple, and by November there were many ripe fruits with some on the ground.

Flowering and fruiting starts with the Devastation Area firetrees in the 2-3 cm range. Of the trees in transect C-C' 17.6% had staminate flowers or fruits, while in transect W-W' 16.7% had staminate flowers or fruits. The percentage of trees with fruits increased with height and diameter size. At the 4-5 cm range, 53.8% of the trees had staminate flowers or fruits (both C-C' and W-W' combined). At the 6-7 cm range 100% of the trees had staminate flowers or fruits. There were no seedlings beneath those trees that bore fruit, even though the ground beneath some trees was covered with fruits. Overall, 24.0% of the trees had fruits: 4.2% with immature fruits, 6.3% with mature fruits, and 13.5% with both mature and immature fruits.

Thus, firetrees begin to produce seed at an early age, and the seed crop continues to increase as the stand gets older. Therefore, numerous seeds are available for stand regeneration and dispersal. This type of accelerated productivity, associated with horde invasion, tends to characterize some pioneering species, more so than a long-term colonizer. It is not known why defoliation of terminal branches of three trees occurred after producing flowers and fruits. These trees were relatively large ranging from 3.95-5.67 cm in diameter and 3.1-3.9 m in height. Two exhibited poor vigor and one average vigor. Their condition may have resulted from stress brought on by lack of available soil water. It could also indicate a response of conserving energy for fruit development.

The means of dispersing firetree throughout Habitat 5 is still unknown. As previously pointed out, it is not likely that the large number of seedlings were offspring from the small number of trees capable of producing mature fruit. Also, there was
no invasion pattern characterized by a sequential trend of diameter ranges along a directional gradient. The random distribution of diameter sizes suggests a dispersal agent that would be following a similar pattern. In addition, the fact that 93% of the firetrees were established underneath 'ohi'a crowns, suggests a strong correlation with the distributional pattern other than just microhabitat conditions for seed germination.

There is good reason to believe that birds are involved in the dispersal of firetree seed. While collecting field data, the investigators observed numerous Japanese White-eye (Zosterops japonica) foraging in the 'ohi'a trees. The White-eye is an exotic bird in Hawai'i. It is native to Japan, and it has been observed to feed on insects, nectar, and fruits in Hawai'i (Guest 1973). In Australia, Gannon (1936) reported that White-eye spread blackberry, lantana, and several other species of plants. It seems logical that as Japanese White-eye forage among the 'ohi'a flowers for nectar or insects, they could be depositing firetree seeds obtained from trees outside the Devastation Area. The presence of numerous firetree seedling beneath 'ohi'a crowns and oftentimes close to the trunk, tends to support the assumption that seeds are being deposited by birds. Another exotic bird that is common to the area, and may also be capable of spreading firetree is the Red-billed Leiothrix (Leiothrix lutea).

**Growth Form Characteristics**

The growth form characteristics are shown in Table 1. Firetrees in the 2-3 cm and 4-5 cm ranges exhibited a high degree of basitonic branching (multiple branching near base of main stem). It was not determined what produces this type of adventitious budding. It seems likely that the basitonic branching is in response to a stressful condition. For example, one specimen found in the 1974 survey of the Devastation Area (Smathers 1976) is believed to have survived the 1959 ash fallout. This tree had a stem 10 cm in diameter that appeared to have been burned off by the hot falling ash. It was approximately 10 cm below the 1959 ash level, underneath and close to the trunk of a surviving 'ohi'a tree, and with numerous branches sprouted from the burned stump. These branches had been unable to penetrate the dense-basal branches of the surviving 'ohi'a, and thus they had grown outward, prostrate on the ground, beyond the periphery of the crown and then upward. This growth response could indicate firetree's low shade tolerance under high crown densities. A similar condition was also observed in transect C-C' and W-W' where a majority of firetrees grew into 'ohi'a with open crowns; however, where the basal canopy was dense, they grew outward, prostrate on the ground.
CONCLUSIONS

The Devastation Study Area provides a unique opportunity to study firetree ecology. Here, a self-contained population can be eventually studied under six different habitat conditions that range from rain to seasonal dry forests types.

The initial phase of the present study has provided heretofore unknown ecological information on firetree in Hawai'i. Although several factors have been evaluated, the results are preliminary. Additional investigation is needed before definitive conclusions can be made. Notwithstanding, the present results show that the firetree population is not competitively replacing 'ohi'a trees nor any other native vascular plant. On the contrary, firetree shows a decided loss in vigor as it develops into tree size, apparently a function of low availability of soil water for an increasing biomass. However, the close interlocking of 'ohi'a and firetree crowns has a threatening characteristic which must be further evaluated.

To evaluate the apparent close, physical, competitive relationship between 'ohi'a and firetree will require long-term observations on a permanent site. Data derived over an extended period of time will reveal whether firetree can competitively replace 'ohi'a, and in addition whether firetree can regenerate itself on the same site.

Kawasaki's (unpublished) observation that firetree forms a dense-closed canopy forest with nothing growing beneath, seems to indicate that it is a shade intolerant species. In addition, it must be determined whether firetree can recolonize where it was previously eradicated by herbicides or natural succession.

Although the present location of firetree correlates with the foraging pattern of fruit-eating birds, primarily the Japanese White-eye, it cannot be definitely stated that this is the dispersal agency. Considerable observations, seed viability, and germination study will be needed to test this hypothesis.

It is imperative that firetree be observed in its native habitats (Azores, Madeira, and Canary Islands). This would provide a better understanding of its potential ecological role in the various ecosystems of Hawai'i. Now that firetree has become naturalized in Hawai'i, as have hundreds of other exotics, it seems that the prudent course of action would be to learn as much as possible about how it fits into the new vegetation. Knowledge of this type will provide a better understanding of what controls, if any can be effective in eliminating or stabilizing firetree populations. This viewpoint is shared by some of the foremost ecologists who have studied the nature of exotic invasions (Elton 1977).
LITERATURE CITED


**TABLE 1. Habitat 5. Structure and vigor of firetree population.**

**Transect: C-C', 18 plots, 10 x 10 meters. Total cover 1800 m²**

<table>
<thead>
<tr>
<th>Basal Diameter Range (cm)</th>
<th>Number of Trees</th>
<th>Number with Basitonic Branching</th>
<th>Vigor Class</th>
<th>Number of Trees/ % of Diameter Range</th>
<th>Number Interlocking with 'ohi'a</th>
<th>Number growing underneath 'ohi'a</th>
<th>Number Associated with Species other than 'ohi'a</th>
<th>Number Growing in Open</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>9</td>
<td>0</td>
<td>0/0</td>
<td>6/66.7 3/33.3</td>
<td>2</td>
<td>7</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2-3</td>
<td>17</td>
<td>5</td>
<td>1/5.9</td>
<td>1/12.4 2/1.2</td>
<td>11</td>
<td>6</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>4-5</td>
<td>11</td>
<td>2</td>
<td>3/27.3 6/54.5 2/18.2</td>
<td>7</td>
<td>3</td>
<td>0</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Subtotal</td>
<td>37</td>
<td>7</td>
<td>4/10.8 26/70.3 7/18.9</td>
<td>20</td>
<td>16</td>
<td>0</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

**Transect: W-W', 7 plots, 10 x 20 meters. Total cover 1400 m²**

<table>
<thead>
<tr>
<th>Basal Diameter Range (cm)</th>
<th>Number of Trees</th>
<th>Number with Basitonic Branching</th>
<th>Vigor Class</th>
<th>Number of Trees/ % of Diameter Range</th>
<th>Number Interlocking with 'ohi'a</th>
<th>Number growing underneath 'ohi'a</th>
<th>Number Associated with Species other than 'ohi'a</th>
<th>Number Growing in Open</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>23</td>
<td>0</td>
<td>1/4.3</td>
<td>7/36.7 15/65.2</td>
<td>8</td>
<td>10</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>2-3</td>
<td>18</td>
<td>4</td>
<td>3/16.7</td>
<td>10/55.6 5/27.8</td>
<td>14</td>
<td>3</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>4-5</td>
<td>15</td>
<td>4</td>
<td>11/33.3</td>
<td>2/13.3 2/13.3</td>
<td>13</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>6-7</td>
<td>2</td>
<td>0</td>
<td>1/5.0</td>
<td>1/5.0</td>
<td>2</td>
<td>0</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>8-9</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>10-11</td>
<td>1</td>
<td>0</td>
<td>1/100</td>
<td>-</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Subtotal</td>
<td>59</td>
<td>8</td>
<td>17/28.8 20/33.9 22/37.3</td>
<td>38</td>
<td>15</td>
<td>3</td>
<td>3</td>
<td></td>
</tr>
</tbody>
</table>

**Both Transects Combined (Subtotals) 25 plots, 3200 m². Total Cover**

| Totals                    | 96              | 15                             | 21            | 46  | 29  | 58  | 31  | 3  | 4  |
### TABLE 2. Habitat 5. Phenological characteristics of firetree population.

<table>
<thead>
<tr>
<th>Basal Diameter Range (cm)</th>
<th>Number of Trees</th>
<th>Immature Fruits</th>
<th>Mature Fruits</th>
<th>Both Mature &amp; Immature Fruits (8/8/77)</th>
<th>Trees with Fruits (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>9</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2-3</td>
<td>17</td>
<td>1</td>
<td>0</td>
<td>2</td>
<td>17.6</td>
</tr>
<tr>
<td>4-5</td>
<td>11</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>63.6</td>
</tr>
<tr>
<td><strong>Subtotal</strong></td>
<td><strong>37</strong></td>
<td><strong>4</strong></td>
<td><strong>2</strong></td>
<td><strong>4</strong></td>
<td><strong>27.0</strong></td>
</tr>
</tbody>
</table>

**Transect: C-C', 18 plots, 10 x 10 meters. Total cover 1800 m²**

<table>
<thead>
<tr>
<th>Basal Diameter Range (cm)</th>
<th>Number of Trees</th>
<th>Immature Fruits</th>
<th>Mature Fruits</th>
<th>Both Mature &amp; Immature Fruits (8/8/77)</th>
<th>Trees with Fruits (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>23</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2-3</td>
<td>18</td>
<td>0</td>
<td>0</td>
<td>3</td>
<td>16.7</td>
</tr>
<tr>
<td>4-5</td>
<td>15</td>
<td>0</td>
<td>3</td>
<td>4</td>
<td>46.7</td>
</tr>
<tr>
<td>6-7</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>100.0</td>
</tr>
<tr>
<td>8-9</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>10-11</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>100.0</td>
</tr>
<tr>
<td><strong>Subtotal</strong></td>
<td><strong>59</strong></td>
<td><strong>0</strong></td>
<td><strong>4</strong></td>
<td><strong>9</strong></td>
<td><strong>22.0</strong></td>
</tr>
</tbody>
</table>

**Transect: W-W', 7 plots, 10 x 20 meters. Total cover 1400 m²**

**Both Transects Combined (Subtotals) 25 plots, 3200 m². Total Cover**

<table>
<thead>
<tr>
<th>Totals</th>
<th>96</th>
<th>4</th>
<th>6</th>
<th>13</th>
<th>24.0</th>
</tr>
</thead>
</table>

TABLE 3. Habitat 5. Quantitative characteristics of firetree population.

<table>
<thead>
<tr>
<th>Basal Diameter Range (cm)</th>
<th>Number of Trees</th>
<th>Height Range (m)</th>
<th>Density</th>
<th>Frequency (%)</th>
<th>Cover (% of Total Cover)</th>
</tr>
</thead>
<tbody>
<tr>
<td>* 2</td>
<td>9</td>
<td>0.34-1.80</td>
<td>0.50/100m²</td>
<td>38.9</td>
<td>0.48</td>
</tr>
<tr>
<td>2-3</td>
<td>17</td>
<td>1.30-3.20</td>
<td>0.94/100m²</td>
<td>50.0</td>
<td>2.79</td>
</tr>
<tr>
<td>4-5</td>
<td>11</td>
<td>2.10-4.00</td>
<td>0.61/100m²</td>
<td>33.3</td>
<td>3.22</td>
</tr>
<tr>
<td>Subtotal</td>
<td>37</td>
<td></td>
<td>2.05/100m²</td>
<td>72.2</td>
<td>6.49</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Transect: C-C', 18 plots, 10 x 10 meters. Total cover 1800 m²</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Basal Diameter Range (cm)</th>
<th>Number of Trees</th>
<th>Height Range (m)</th>
<th>Density</th>
<th>Frequency (%)</th>
<th>Cover (% of Total Cover)</th>
</tr>
</thead>
<tbody>
<tr>
<td>* 2</td>
<td>23</td>
<td>0.20-2.00</td>
<td>1.64/100m²</td>
<td>85.7</td>
<td>0.88</td>
</tr>
<tr>
<td>2-3</td>
<td>18</td>
<td>1.85-3.60</td>
<td>1.29/100m²</td>
<td>85.7</td>
<td>3.88</td>
</tr>
<tr>
<td>4-5</td>
<td>15</td>
<td>2.40-4.00</td>
<td>1.07/100m²</td>
<td>85.7</td>
<td>5.72</td>
</tr>
<tr>
<td>6-7</td>
<td>2</td>
<td>2.80-4.10</td>
<td>0.14/100m²</td>
<td>28.6</td>
<td>0.76</td>
</tr>
<tr>
<td>8-9</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10-11</td>
<td>1</td>
<td>4.0</td>
<td>0.07/100m²</td>
<td>14.3</td>
<td>1.22</td>
</tr>
<tr>
<td>Subtotal</td>
<td>59</td>
<td></td>
<td>4.21/100m²</td>
<td>100.0</td>
<td>12.46</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Transect: W-W', 7 plots, 10 x 20 meters. Total cover 1400 m²</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Both Transects Combined (Subtotals) 25 plots, 3200 m². Total Cover</th>
</tr>
</thead>
<tbody>
<tr>
<td>Totals/Avg.</td>
</tr>
</tbody>
</table>
Halemaumau

Kilauea Caldera

Rain Forest - cM(c)
Seasonal Forest - cM(ns)

1974 Lava Flow

Habitat No. 1 - Massive Lava with Joint Cracks
Habitat No. 2 - Cinder Cone
Habitat No. 3 - Spatter Area with Tree Snags
Habitat No. 4 - Pumice Area with Tree Snags
Habitat No. 5 - Pumice Area with Surviving Trees
Habitat No. 6 - Thin Fallout Area

X - Weather Stations

Figure 1. Map showing location of Kīlauea Iki crater in reference to Hawaii Volcanoes National Park.
FIGURE 2. Habitat types and study transects of the 1959 Kilauea Iki eruption site (crater floor and pyroclastic deposit).
FIGURE 3. Northeast-southwest profile of eruption site extending from Kilauea Iki crater to upper Ka‘u Desert.
The Crater District of Haleakala National Park lies between latitudes 20°41' and 20°46' N and longitudes 156°08' and 156°15' W. The crater is in fact an erosional feature where two amphitheater-headed valleys, Kaupo and Ko'olau (Keanae), met in the Pu'u Mamane to Kapalaoa area. Later flows of the Hana volcanic series obscured all but the most obvious features of the erosion.

The pre-contact Hawaiians used the crater area mainly as a transisland corridor later to be paved by Kihapiilani. Other uses, particularly religious and adze quarrying, were made of the area. The impact of this usage was minimal, involving minor disturbances of rocks and some fire-building.

After 1788, the impact in the area remained minimal until the Wilkes Expedition's (1840-1841) report described the summit and surrounding areas in somewhat melodramatic terms. The mountain had in fact been climbed 12 years earlier in 1828 by three missionaries. The silverswords were the first to suffer, as tourists collected them to verify their ascent (Bryan 1915). The establishment of the Rest House and later the Silversword Inn resulted in an escalation of the visitor impact on the silverswords. Perhaps the most unfortunate abuse was Maui's entry in Washington's Birthday Annual Floral Parade in 1911 in which a car was completely covered with large silverswords.

Later, cattle grazed in and were driven through the crater. Pasture improvement was encouraged, at least in the Kaupo Gap, by burning the vegetation. Goats have been established in the area for a long time. However, before the Second World War the problem was sufficiently acute that massive goat drives were organized. The impact of goats in Haleakala has been well documented by Yocum (1967). The problem is still as acute today as it was in the recorded past.

The lowest point of the Crater District is just below 4000 feet, the highest just over 10,000 feet. The majority of the area is above the inversion layer and a significant percentage is above the diurnal frost line at 8000 feet. One might ascribe
much of the xeric scrub and open to almost absent plant communities to extensive periods of drought. However, Whiteaker (pers. comm.) has evidence from climate diagrams which indicates that only at the Observatory is there any consistent drought period and then only for the month of June. The Paliku area has a climate diagram typical of a rain forest area. Thus other factors have to be identified to account for the paucity of vegetation. The acute disturbances previously alluded to are undoubtedly part of the explanation. Alpine ecosystems are notoriously slow to recuperate. The alpine edaphic factors and the paucity of soil in many areas are also contributing factors. It is my opinion that what we see today in Haleakala Crater is a meager remnant of the previous ecosystem. Even if the disturbances are eliminated the recovery will be an extremely slow process.

The objective of the Resources Basic Inventory was to identify all the plants and animals in the Crater District which would be presented as annotated lists. Distribution maps of individual species would also be produced. Resource management problems would also be identified and possible remedies discussed. Finally, a detailed vegetation map and description of the vegetation units would be produced.

The methodology of the Inventory was to use seven transects, five along a north-south axis and the other two along an approximately east-west axis. Study sites were established irregularly in areas along the transect which were obviously different from other areas. In all, 55 study sites were established. At each site, all species were recorded or collected, and their relative abundance using the Braun-Blanquet system was estimated. Observations and collections were made in numerous other localities not formally sampled.

The vegetation map and vegetation unit description program was conducted on a more formal basis. Potential vegetation units were later identified, refined, and mapped from aerial photographs. The unit boundaries and authenticity were verified by visiting each delineated area. Formal sampling areas were then established in each vegetation unit, the vegetation sampled and soil and other environmental parameters measured.

Various aspects of these studies will be presented in the following papers. Six areas are covered and I ask you to bear with the very limited scope of information presented in each which is necessitated by the severe time constraints of the Conference.
LITERATURE CITED


INTRODUCTION

The lichens of Haleakala have received scant attention in the past. The only comprehensive collection prior to the Resources Basic Inventory was by Skottsberg during the Hawaiian Bog Survey in 1938. This collection was studied by A. H. Magnusson and forms a significant element of his Catalogue of the Hawaiian Lichens. A few other botanists have collected in the Crater including the Abbe Faurie, J. F. Rock, and O. Degener. However, none of these collectors were specialists in lichens; their collections were incidental to their other interests, mostly flowering plants.

This report is a preliminary investigation of the lichens of the Crater District of Haleakala National Park with notes on the principal lichen associations found in the area. Unfortunately, several groups are very inadequately understood from a taxonomic point of view and the omission of some of them seriously limits the reliability of a few of the assessments. This reservation is particularly true of the rock-inhabiting species at higher elevations. A significant number of species, about 25%, still await determination by specialists. In the majority of instances, their lack of response is the result of their own current uncertainty on these Hawaiian specimens. As further information becomes available the list will be updated and the ecological assessments revised.

WHAT ARE LICHENS?

Lichens are an obligate symbiotic association between a fungus and an alga. The association produces a plant which is uniquely different from that of either the fungus or alga growing alone. Perhaps the single most significant ecological feature of lichens is that they must undergo periodic dessication. If they are not allowed to dry out within a three or four day period they become moldy and die. Thus these plants are ideally suited to areas where water is not continuously available. One may think of deserts in this respect but many situations in more equable
climates experience alternating periods of wet and dry, for example, rock surfaces, leaves, tree trunks, and branches and even the surface of soil.

There are three basic growth forms in the lichens: crustose, foliose, and fruticose. Crustose species form a thin crust or film over the substratum. They are firmly attached to or embedded in the rock or bark. Foliose species lie flat on the substratum and are usually attached to it by hairs or rhizines. Foliose species can generally be separated from the substratum. Fruticose species are generally pendent or erect as in the familiar Usneas and British Soldier lichens. They are normally easily detached from the substratum.

It is generally true to say that the drier an area the more likely you will find crustose species, the wetter an area foliose and fruticose species. This generalization is as true on the microscale as it is on the macroscale. If you look at the twigs on the edge of a tree or bush you will normally find crustose species only. On the larger deeper shaded branches you will probably find foliose or fruticose species. The complicating factor to this generalization in Haleakala National Park is that many areas are frequently inundated in clouds which encourages the growth of the foliose and fruticose species in situations that would normally only support crustose species. On the other hand, in areas where rainfall and fog interception result in infrequent dessication, mosses and liverworts replace the lichens.

lichens ecology

All lichens in the Hawaiian Islands are presumed to be native or endemic. No exotic species are known, a situation which is likely to change in the near future because of the introduction of large numbers of plants from various regions of the world, e.g., orchids introduced to the Foster Botanic Gardens frequently have live lichens associated with them; Christmas trees from the Pacific Northwest nearly always have lichens on their trunks, especially Hypogymnia physodes. On the other hand, endemic and native species previously reported from Haleakala have not been located during this study. For example, the genus Umbilicaria is represented by three endemic species in the literature (Magnusson 1956). None of these species was found on the recent survey. Unfortunately, the type locality of one of these species, U. pacifica, is "at the top of Halemau (sic) Trail." Since the species has been collected from this area only, it may be assumed that it is now extinct or extremely rare in the area. The recent heavy pig impact will have made the former alternative more probable.

The lichen communities generally follow the flowering plant community distributions outlined in Whiteaker (1979) in his Vegetation Map of the Crater District of Haleakala National Park. However, two environmental variables modify the lichen community distributions so that they do not conform precisely to Whiteaker.
The diurnal frostline is of little significance in the distribution of rock-inhabiting lichens though it does have an impact on bark-inhabiting species because of the reduced availability of substrate. Lichens are capable of carrying out their life functions at much lower temperatures, even to freezing point, than flowering plants as long as there is sufficient moisture available. The other environmental variable, cloud inundation, extends the distribution of foliose and fruticose lichens beyond their expected distribution in mesic plant communities. Lichens are extremely efficient at absorbing water from air and can become quite wet in a short period of time when submerged in clouds. As a consequence, their growth and abundance are increased so much that the relative cloud cover can be fairly accurately mapped from the abundance of the epiphytic foliose lichens. For example, the eastern side of the Ko'olau Gap up to and beyond Pu'u Mamane is more frequently immersed in cloud than the western or central portions of the Gap.

Rock Communities

The lichen communities on rock are probably the least disturbed or altered in the study area. A few species have disappeared, for example, Umbilicaria pacifica, and the abundance of others may have been changed by habitat alteration. By and large, the community structure is probably the same now as it was prior to the impact of western man.

At the top of the mountain and in other areas which are predominantly devoid of vegetation, the rocks are colonized by a community in which Acarospora and Lecidea are dominant with occasional specimens of Caloplaca, Candelariella, and Rhizocarpon geographicum. Only the stable rocks and boulders are colonized; the loose cinder is too frequently disturbed by wind and rain for lichens to become established. Even on the rocks the lichens are always in very protected situations where the microenvironmental conditions offer some relief from the rigorous climate of the area. With decreasing elevation, the lichens are found in more exposed situations with increasing frequency and other species, for example, Stereocaulon vulcani and Placopsis gelida begin to appear in the community.

The lichens in this harsh environment do not grow very rapidly. Colony sizes are always small. The activity of lichens as primary colonizers in such situations is very low. Consequently, the rate at which they decompose the rock is low. Rain and other edaphic factors are probably more important in soil formation than are the lichens. At lower elevations or where moisture is more abundant, for example, the summit of Kuiki, the lichens probably play a significant role in soil formation.

Where moisture from cloud or rainwater is more abundant, the lichen communities on rock are more luxuriant in terms of both biomass and species diversity. The species of the genus Stereocaulon show an interesting series of communities which are
correlated with the amount and physical phase of the available water, as well as the age of the rock on which they are growing.

Stereocaulon vulcani, the primary colonizer of most lava flows in Hawai'i, characteristically grows where the annual rainfall is above 30 inches a year. Though one would expect to find it at the summit which supposedly receives this amount of rain each year, it is extremely rare and very poorly developed there. Its near absence is probably because most of the rain comes in two or three major kona storms each year. It is found throughout the rest of the Crater District but below 6000 feet its distribution is regulated by the growth of other organisms. The occurrence of this species in any appreciable quantity below 6000 feet is generally a good indication of the recent disturbance of the community.

Stereocaulon octomerellum grows on large boulders in the high rainfall area of the eastern side of the Kaupo Gap. It is normally found only on well-weathered, exposed rocks.

Stereocaulon ramulosum has an almost intermediate ecological position between the above two species. It favours environments in which cloud inundation is frequent. The height and fertility of the plants is indicative of the frequency of the cloud cover, the lower stature and infertile specimens indicating drier, harsher conditions.

Litter Communities

Where plant litter accumulates and areas where the humus content of the soil is high, the endemic Cladonia leiodea is dominant. The species is not tolerant of shading so it is characteristic of the open scrub communities. The luxuriance and colony size of the plants are an indication of the moisture regime of the area. The largest specimens are found in the wetter areas. The plant is particularly sensitive to mechanical disturbance and may serve as an indicator of past pig activity when absent from an area in which it should logically appear.

A rather unusual litter community occurs under the dead but still standing leaves between Deschampsia clumps. All of the species are very attenuated and none are fertile which is probably due to the suboptimal levels of light filtering down between the leaves. Pseudocyphellaria crocata, Sticta weigeli, Peltigera polydactyla and Cladonia scabriuscula are the most common species in this situation. I know of no similar community type adapted to such low light intensities.

Leaf Communities

In the gullies behind Paliku a fragmentary lichen community is found on the leaves of Pelea. Two species are present and represent the upper elevational limit of a specialized community normally found below 1000 feet. Their occurrence in this highly
protected environment illustrates the unusual nature of these gullies.

**Bark Communities**

The complex chemical nature of bark results in unique lichen communities on each tree or shrub species. Since chemical and physical surface characteristics change with the age of the bark, the associated lichen communities also change. Thus the lichen community on twigs will be different from that on the trunk. For example, the twigs and branches of mamane are colonized by *Ochrolechia pallescens*, *Hypotrachyna sinuosa*, and species of *Candelaria*, *Buellia*, *Rinodina*, and *Lecanora*, whereas the trunk has *Parmelia dominicana*, *Pannaria rubiginosa*, and *Heterodermia speciosa*. Every other tree and shrub has its own spectrum of species. Consequently, it is extremely difficult to describe the general distribution of bark-inhabiting species of lichens in any meaningful manner. Any attempt to do so is beyond the scope of this study which was not designed with this type of analysis in mind.

The distribution of *Usnea* and *Alectoria* on pukiawe and 'ohelo closely parallels the areas inundated by cloud for significant periods. *Usnea* is found where clouds probably cover the area at least half the days of the year whereas *Alectoria smithii* occurs in areas where the cloud cover is significantly less.

**RECOMMENDATIONS**

There are no formally designated threatened or endangered lichens. That does not mean that there are no rare lichens. Even if they were to be listed there would be very little that could be done to promote the species other than habitat protection and conservation. As with many other groups studied during this survey, the removal of the feral herbivores would be a significant management action to preserve the lichen communities in the Park.

**LITERATURE CITED**


HALEAKALA NATIONAL PARK CRATER DISTRICT
RESOURCES BASIC INVENTORY:
THE VASCULAR FLORA OF HALEAKALA

Lani Stemmermann
Department of Botany
University of Hawaii at Manoa
Honolulu, Hawaii 96822

Haleakala includes one of the four alpine ecosystems in the Hawaiian archipelago (the other three being located on the island of Hawai'i). Its flora has been studied by numerous botanists since the first collections in this area were made by members of the United States Exploring Expedition in 1841. Hawaiian alpine ecosystems (only one of the Park's vegetation types) have been recognized in the past as having a high percentage of endemic species (Skottsberg 1931)—plants that grow nowhere else—and even now, despite the presence of numerous exotic species in the Park and the extinction of native taxa (both a result of past and present disturbances), the Park's flora exhibits a large number of endemic species (Table 1).

The Haleakala National Park Crater District Resources Basic Inventory (RBI) integrated research program was undertaken to provide a biological inventory of the Park, and to identify resource management problems. When this report, currently in the final stages of preparation, is finished, a computer print-out will be available which will provide the following information.

1) A general catalogue of the species with notes on general abundance and distribution within the Park, and their status (Indigenous, Endemic, Exotic) within the State;

2) Inclusion of any of the species in any of the Rare and Endangered Species Lists (Fosberg & Herbst 1975; U. S. Fish & Wildlife Service 1976) or the State's noxious weed list (Office of Environmental Quality Control 1972, revised 1976);

3) Scientific, English, and Hawaiian names (when known).

Use of the computer for storage of information facilitates updating the list as new information is gathered.

In addition to an inventory of plants found in the Park, voucher specimens have been collected as reference material for Park personnel with some duplicate materials to be distributed to the Bishop Museum (BISH) and University of Hawaii (HAW) herbaria.
The last comprehensive review of the Park's flora was prepared by Mitchell (1945). Ruhle (1959 revised 1968, 1975) presented a good review of the natural history, but gathered no new information on the Park's flora or vegetation. Our studies during the years 1975-1978 have resulted in the listing of many more species for the Park than previously known, although certain genera, for which Mitchell listed numerous species and subspecific taxa, are not so finely circumscribed. For instance, 17 taxa were recorded by Mitchell for the genus Railliardia, while far fewer are considered in our recent compilation. In such instances this is due to a more conservative interpretation of taxonomically difficult groups, rather than extinction. Unfortunately certain taxa, such as Clermontia haleakalensis, are probably extinct, while others, such as Hillebrandia and Ranunculus, previously reported from the Crater region, are now confined to Kipahulu Valley and Ko'olau Gap.

Over the 30 years between Mitchell's study and the present one, there has been little change in the flora of the Park, but some of those changes are well worth mentioning. Several species which have the potential of being aggressive weeds were not noted by Mitchell (1945). While some of these may have been overlooked (a problem all too familiar to anyone who has attempted to compile species lists), others are no doubt relatively recent introductions. These, and others which were previously reported from the Park and should be considered problematic, are listed in Table 2. Some of these species are officially considered "noxious weeds" (as indicated), but many are not, and only a few are presently under Park management. At present, a number of species with localized populations should be contained to prevent their spread throughout the Park. Table 2 does not include all the weedy species in the Park, but only those which are thought to be most in need of control and not those already hopelessly out of control.

A few rare or new species not previously noted from the Park were located including: Panicum sp. (undescribed); Dryopteris palikuensis (nom. prov.); Bidens sp. (sterile--probably undescribed); Plantago princeps C. & S. var. laxifolia Gray; and Lepechinia hastata (Gray) Epling (previously recorded near Park boundaries).

In conclusion, certain taxa present in the Park are endemic not only to Hawaiian alpine and subalpine ecosystems, but to Haleakala proper such as Artemisia mauiense, Argyroxiphium macrocephalum, Stenogyne crenata (2 varieties), Geranium cuneatum, G. arboreum, Santalum haleakalae, and others. The deleterious effects of feral goats on certain vegetation types within the Park (especially in areas more-or-less inaccessible to hunters) cannot be overemphasized. Since many of the endemic species are of limited distribution, they should be considered threatened by the continued presence of goats. Delays in the implementation of an effective goat control program must be considered a serious threat to the native biological resources of Haleakala National Park.
LITERATURE CITED


TABLE 1. Percentages of the indigenous, endemic, and exotic vascular plant flora of Haleakala National Park Crater District.

<table>
<thead>
<tr>
<th></th>
<th>Pteridophytes</th>
<th>Monocots</th>
<th>Dicots</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Indigenous</td>
<td>44</td>
<td>13</td>
<td>2</td>
<td>11</td>
</tr>
<tr>
<td>Endemic</td>
<td>54</td>
<td>28</td>
<td>51</td>
<td>46</td>
</tr>
<tr>
<td>Exotic</td>
<td>2</td>
<td>59</td>
<td>47</td>
<td>43</td>
</tr>
<tr>
<td>Species</td>
<td>Status</td>
<td>Distribution in Park</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-------------------------------</td>
<td>--------</td>
<td>--------------------------------------------------------------------------------------</td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Cirsium vulgare</em> (Savi) Tenore</td>
<td>1,2</td>
<td>Present especially in heavily goat infested areas.</td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Eupatorium adenophorum</em> Spreng.</td>
<td>*,2,4</td>
<td>Maui pōmākani is found in several large populations at mid-elevations in the Park such as at kipuka S of Laie cave, and S of Hanakauhi. It probably is no longer spreading but nevertheless should be controlled.</td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Eupatorium riparium</em> Spreng.</td>
<td>*,2,4</td>
<td>This species is recorded from the Hosmer Grove area, and while potentially dangerous in lower elevations it is probably not a threat in the Park but should be watched.</td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Lantana camara</em> L.</td>
<td></td>
<td>Though probably not a problem or even a potential problem above 5000 feet in the Park, the presence of <em>Lantana</em> at low elevations in Kaupo Gap within the Park should be watched carefully and controlled when practical.</td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Opuntia megacantha</em> Salm-Dyck</td>
<td>1,7,3,4</td>
<td>Panini is presently known from only two small populations in mid-lower Kaupo Gap, and near Laie Cave. It is probably under control within the Park.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Species</td>
<td>Status</td>
<td>Distribution in Park</td>
<td></td>
<td></td>
</tr>
<tr>
<td>---------------------------------</td>
<td>--------</td>
<td>------------------------------------------------------------------------------------------------------------------------------------------------------</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Passiflora subpeltata Ortega</strong></td>
<td>2,4</td>
<td>A few plants were noted along Kaup Trail, and while the populations are currently not a problem any detected plants of this genus should be controlled.</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Pennisetum clandestinum Hochst.</strong></td>
<td>2,4</td>
<td>Kikuyugrass is found along trails and roads throughout the Park, and at low elevations along Kaup Trail it is the dominant cover species.</td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Pinus</em> spp.</td>
<td>1,2,3</td>
<td>Certain pines and other gymnosperms have spread from their planting sites, notably near Hosmer Grove. Aggressive species should be controlled.</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Poa pratensis L.</strong></td>
<td>2,4</td>
<td>The Kentucky bluegrass is common in damp areas throughout the Park, such as under trees. It is replacing the native Deschampsia grassland in Kaluanui, and work should be done to find a means of controlling its spread.</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Ricinus communis L.</strong></td>
<td>2,4</td>
<td>A large community of castor bean is found along and to the east of the Kaup Trail near the boundary of the Park.</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Rubus penetrans Bailey</strong></td>
<td>*,2,4</td>
<td>The prickly Florida blackberry has become a nuisance in the Paliku Horse Pasture, could spread elsewhere in the Park. It is high on the list of species needing immediate control.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Rubus rosaefolius Sm.  
2 The thimbleberry is found occasionally in lower east Kaupo Gap in damp shaded areas; though perhaps not in danger of spreading its populations should be watched.

Schinus terebinthifolius Raddi  
2,4 A single specimen of Christmas berry was seen in the goat-ridden western part of Kaupo Gap; elevation ca. 4400 feet. It should be removed.

Ulex europaeus L.  
*,1,4 Degener (1930) reports that gorse was planted as a hedge in Olinda to contain sheep but within a decade of it being planted it had become a pest. At one time territorial prisoners were employed to eradicate this plant. Within the Park it is only known from a small patch below Park Headquarters.

* Included in the State's noxious weed list
1 Currently being controlled by Park personnel or volunteer groups
2 Species not presently controlled which are in need of control by the Park
3 Biocontrol agents available but apparently not presently effective
4 Not included in Mitchell's species list

Note: those species thought to be "hopelessly out of control" in the Park, or at least have probably reached their greatest distribution with little probability of control are not listed but include Anthoxanthum, Caryophyllaceae spp., Dactylis, Heterotheca, Holcus, Hypochaeris, Lapsana, Rumex acetosella, etc.
THE ACQUISITION OF NATURAL AREAS IN HAWAI'I

Kimo Tabor
The Nature Conservancy
Honolulu, Hawaii

The Nature Conservancy's acquisition policy in Hawai'i has been shaped by several factors.

Expert advice from knowledgeable individuals who know Hawai'i's uniqueness in specific areas of biological importance is critical to selection of natural areas, a process which is exceedingly intricate. It is desirable to acquire a piece of property of viable ecological significance after the financial and legal tangles are resolved.

Acquisition of a general type of system rather than a specific type of biota was the primary consideration in the acquisition of Maulua Nui. Once the preliminary selection was made from some 40 alternatives, a party of three people did a brief field reconnaissance of the property. Steven Montgomery, for many years scientific assistant to the Natural Area Reserve Systems Commission, and James Jacobi, a botanist and student of Dr. D. Mueller-Dombois with wide experience on the island of Hawai'i, provided a quick scientific assessment of the Maulua property during a three-day field trip in early January 1977 (covering a distance of 11 miles, or 18.2 km).

The location of Maulua Nui on the slope of Mauna Kea provides a classic Hawaiian ahupua'a land form. It faces northeast against the tradewinds, from sea level to an elevation (at the boundary) 1 mile high on Hawai'i's highest mountain, on the State's largest land mass, the island of Hawai'i. This area is accessible to birds and seeds from the North American Continent given the wind patterns of perceived history. It is an area which has a high rainfall and sunshine ratio thus highly desirable from the high growth rates possible; an attraction also to the forest industry. The mouth of the ahupua'a is a large fault valley 21 miles northeast of Hilo. The emerging valley stream provides an interesting, though disturbed, estuarine area. It is also an area of some local historic interest.

Maulua Nui is a unique addition to the inventory of Nature Conservancy lands nationwide. It provided forest habitat for endangered forest birds of the native passerines and the Hawaiian Hawk, or 'Io.
Land availability is necessary to acquisition. An unwilling seller or an exorbitant price would prevent a transaction from occurring. An additional consideration born from the experience of the Kipahulu, Maui, acquisition of The Nature Conservancy is the desirability of getting firm, total, fee simple title for the monies expended. In this case the title was clearly established by one of the Kingdom of Hawai‘i's most astute legal minds. The Nature Conservancy was fortunate in finding an extended family, rapidly changing its priorities, which was anxious to convert their real property into a liquid asset while maintaining the traditional land form of the ahupua'a. Integrating ownership of the ahupua'a with corollary emotional attachments to the family history was a factor also. From this point of view, The Nature Conservancy was the ideal vehicle as economic agricultural lands were not of interest. Continuing revenue and a family memorial of sorts was created while providing the family with some liquidity to assist the changing, and sometimes conflicting, priorities within the extended family.

Remote of the property and the conservation zoning made the property suitable for one other use--forestry. Forestry provides a slow financial return, an eight-year harvest cycle in the most ambitious forecast, and is one which has extant political and biological problems given the intensive exotic cultivation intended. A general economic slowdown also encouraged a reasonable price.

Maintenance of the ecosystem at low cost is a point of debate. The issues are feral pigs and people. Feral pigs are an enormous nuisance to the botanical integrity of an area as they are a biological plow complete with seeder. People from a consumer-oriented expendable economy and their transport systems resemble mechanical plows with not-so-degradable littering systems. While remoteness encourages the pigs, it discourages the people, in a qualified sense. Maintenance costs are therefore subjective and are dependent upon the ultimate use or pressure on the land itself.

Problems in acquisition were highly specific occurrences of some generally discussed situations. In the acquisition of Maulua Nui, orchestrating 15 different individuals in three different families through more-or-less uniform sets of legal documents including an Offer to Option, Option, Conservation Easement, Subdivision Applications, waivers for survey, access improvement, and water system; and deeds on the resulting three subdivided parcels (which are subject to reconsolidation); the swap of fractional interests between parcels and family members, plus the negotiation for, acquisition of, another parcel used in barter for a major percentage interest in two of the Maulua parcels, directly involved at least 50 people, excluding the 12 attorneys representing their clients. Needless to say scheduled closing was delayed.
For many reasons The Nature Conservancy needed fee simple title for expenditure of the donors' money. It was necessary therefore to subdivide the property to receive title to a specific area representing the sum of that donation which incidentally carried with it a conservation easement on the boundary. The remainder of the ahupua'a was to be purchased on an "offer to-option" basis for eventual reintegration of the ahupua'a without unduly extending The Nature Conservancy. To accomplish this, it was necessary to subdivide the property in simultaneous proceedings at State and County level. Each proceeding was contingent upon the other.

Sociological considerations were similarly important. The most immediate reason was to ensure the rapid success of subdivision necessary to the transaction. The other premise was that The Nature Conservancy was to be a long-term member of the Hawaiian community rather than a mainland mentor of local values. Consequently, members of the community closest to the property were informed of the transaction and questions poised were directly and sincerely answered. Community leaders and heads of pertinent special interest groups were similarly informed largely through mutual acquaintances.

The Nature Conservancy is a private organization working with private landowners. Many other organizations also acquire Natural Areas with a view to preserving these. In a small geographical area such as Hawai'i, where competing interests vie with intensity, the size and necessity of natural area acquisition will become an ever increasing question. The question of redundancy appears valid to the layman. The response to the criticism is complicated by the explanation of island by island variations of biota, varying State of Hawaii and Federal Government (Department of Interior, National Parks, Fish & Wildlife Service, U.S. Forest Service, Department of Agriculture) acquisition criteria and responsibilities. Currently these considerations are handled within the community on a consensus basis. The quality of information in each agency's decision-making process varies. The need for similarly evaluated information and standard criteria is apparent. Some areas designated as "Natural Areas" may be too large, too small, or repetitive in maintaining specific ecosystems. Some land may have been designated a natural area about which no one knows anything specific that will prove useful to comparative analysis.

The solution is for specific information of uniform criteria for the entire State of Hawaii to be housed in a single location by type of ecosystem, and by specific location. The Nature Conservancy pioneered the rationalization of such information and has continued to encourage State and Federal governments to introduce this type of information system so that planning departments of highways and other civil works projects can avoid impact on sensitive areas, avoiding the 'snail darter' syndrome and concurrent economic waste, while preserving the remnants of complex ecosystems. Such an information system builds by cataloging the existing information, then begins to fill voids in geographical and biological information through field studies.
Confirmation of existing information validates previously collected information, providing all users firm, dependable "intelligence" which, with one reference location, saves time and enormous frustration.

Additional Natural Area acquisitions will require this type of well-conceived identification and documentation process to enhance the case for acquisition.

The Fish and Wildlife Service of the Department of Interior has already implemented a corollary program through its forest bird survey administered by Mike Scott, and the State of Hawaii has a similar program in its 'Alala (Hawaiian Crow) survey. The Maulua acquisition itself was influenced by information generated in a logical consistent manner by the forest bird survey, as will additional Nature Conservancy acquisitions. A shift to preserving wildlife systems will become the responsibility of the Department of Interior if Senate Bill 1820 or the equivalent House Bill passes during 1978 or 1979. These bills provide for a National Heritage Program, identifying not only flora and fauna, but also within the same information matrix, cultural and prehistoric sites of significance. Each State will be responsible for adhering to the criteria to qualify for Federal funds.

Locally, the State of Hawaii and the County of Hawaii recognize adaptation of their codes to reflect subdivision for non-economic uses may enhance the values which are so frequently sold as Hawai'i. Areas may be left without visible habitation.
STUDIES OF LEPTOSPIROSIS IN NATURAL HOST POPULATIONS:
I. SMALL MAMMALS OF WAIPI'O VALLEY, ISLAND OF HAWAI'I*

P. Quentin Tomich
Research Unit, State of Hawaii
Department of Health, Honokaa

The small Indian mongoose (Herpestes auropunctatus), Carnivora: Viverridae, and the roof rat (Rattus rattus) and Polynesian rat (Rattus exulans), both Rodentia: Muridae, are abundant in Waipi'o Valley, island of Hawai'i. Two other murid rodents, the house mouse (Mus musculus) and the Norway rat (Rattus norvegicus), are sporadic or rare in occurrence. As carriers of serotypes of bacterial leptospires (Leptospira), which are transmissable to man, this assemblage of alien mammals is of public health significance and numerous cases of leptospirosis have been traced to the valley. Population density of the mongoose was estimated at 2.3 per acre; for rats it fluctuated seasonally from 1 to 11 per acre. The serotypes L. icterohemorrhagiae and L. sejroe were found in the mongoose in a 40:60 ratio. Of 33 house mice tested, L. ballum was isolated from 21 and L. icterohemorrhagiae from 2. One isolation of L. icterohemorrhagiae was made from 4 Norway rats examined. For 126 roof rats tested, 68% of adults and 26% of young were infected; and for 175 Polynesian rats, 34% of adults and 26% of young were infected. L. icterohemorrhagiae made up 95% and L. ballum the remaining 5% of infections in the roof rat. For the Polynesian rat the ratio was 75:25. Free-ranging rats under observation for as long as 8 months acquired or lost infections. The wet subtropical climate of Waipi'o Valley supports conditions for transmission of leptospirosis even in times of drought. No prominent differences were observed in the infection rates in the lower valley at 30 feet above sea level and 1.7 miles inland at 120 feet. In the forested watershed of the valley rim at 3000 feet, conditions of infection matched closely those on the valley floor. Tests of 152 water samples from streams, ponds, and taro paddies resulted in isolations only of saprophytic leptospires.

* Abstract
A NECROPSY PROCEDURE FOR SAMPLING DISEASE IN WILD BIRD POPULATIONS*

Charles van Riper III, and Sandra G. van Riper
Cooperative National Park Resources Studies Unit
Hawaii Volcanoes National Park
Hawaii 96718

INTRODUCTION

When the demography of wild birds is analyzed, disease is an important but often overlooked factor. Although disease can be a primary factor of population regulation, its overall importance is probably more closely related to increasing the susceptibility of the host to other mortality factors (Kennedy 1975; van Riper, in prep.). It is therefore important that researchers be able to determine levels of parasites and diseases, if they are to draw meaningful conclusions concerning demographic parameters of a host population. Our purpose is to outline a procedure which would enable an ornithologist, who does not have sophisticated laboratory facilities, to examine birds correctly and to find answers concerning diseases present within an avian population.

For accurate disease diagnosis it is first necessary to establish a definite postmortem sequence, so that each animal is examined in a similar manner and data are organized and easily retrievable. Ornithologists often feel limited in their ability to understand and diagnose diseases, and in many instances pathologists are not readily available for consultation. Furthermore, budgetary constraints frequently limit the number of specimens that can be sent out for diagnosis; of those that are, the time lag before obtaining results is often considerable. It is therefore important that workers be able to perform their own diagnosis, and to do this the development of a necropsy form applicable to wild bird populations is essential.

The majority of avian necropsy techniques available today have been developed for poultry (e.g., Hungerford 1969; Zander 1975). Those designed specifically for other species usually place emphasis upon caged birds (Keymer 1961; Arnall & Keymer 1975), in particular canaries (Serinus sp.) and the Budgerigar (Melopsittacus undulatus) (Stone 1969). Many necropsy procedures are geared for veterinarian use and consist of pages with only general headings after which findings are placed (Ensley et al. 1976; Carpenter, pers. comm.).

* This is a prepublication; anyone wishing to reference the material herein, should first contact the authors.
The necropsy technique discussed herein was developed for small passerine birds, but with slight modifications can be applied to most avian groups. It is based on described disorders present in poultry (Hofstad et al. 1972), pet and caged birds (Petrak 1969; Arnall & Keymer 1975), and wild birds (Davis et al. 1971), and should account for most diseases commonly encountered in birds from the field. Included is a checklist of potential symptoms interspersed with dissection directions (Part I), supplemented with detailed instructions on which parts of a bird to save when a symptom is encountered (Part II). Short sections are presented which (1) outline the materials and facilities necessary to carry out a postmortem analysis; (2) give general handling techniques which should be used during postmortem analysis; and (3) give detailed instructions on how to prepare different materials which are to be sent to laboratories for diagnosis. Diseases and the avian orders in which they have been reported are summarized in tables. Following the procedures outlined in this paper, most ornithologists should now be able to perform their own postmortem analyses.

MATERIALS AND METHODS

Required Materials

The basic equipment required for this postmortem technique is minimal. It is, however, very important that the working area have limited access so as to reduce bio-hazards. Safety is an important consideration in doing postmortem analysis of any avian species, because many organisms that cause disease in birds are also pathogenic to man. Use standard procedures in handling diseased tissue and liberal amounts of a strong detergent (e.g., Tincture Green Soap) and disinfectant (e.g., Phenol or Pine Oil).

Both a dissecting and compound microscope are necessary. Necropsy of small birds is tedious, and unless fine instruments are used much information can be lost. Ophthalmic tools are ideal, and we have found iris microdissecting scissors, watchmakers and microdissection forceps, as well as microprobes invaluable. Other essential equipment should include a small piece of glass for examining the gastrointestinal tract, clean microscope slides and cover slips, sterile swabs and syringes, sterile petri dishes and vials for collecting tissue samples, sterile plastic bags for freezing tissue, and an alcohol lamp.

Required chemicals and solutions for processing necropsy material include: 10% buffered formalin (add a pinch of CaCO₃ per gallon); 70% alcohol glycerine-alcohol (90 parts 70% ethyl alcohol, 10% parts glycerine); F.A.A. (50 parts 95% ethyl alcohol, 10 parts commercial formalin, 2 parts glacial acetic acid, 40 parts distilled water); absolute methyl alcohol; sterile transport medium for fungi (e.g., Sabouraud's agar available from Difco Laboratories, Detroit, Michigan 48201; or Mycotic media available from Baltimore Biological Laboratory, Inc., BioQuest
Division, P. O. Bos 243, Cockeysville, Maryland 20030); sterile transport medium for bacteria (e.g., Stuart's medium, a modified form packaged with a sterile swab available from Culturette, American Hospital Supply Corp., McGraw Park, Illinois 60085); and dry ice. Optional, but often extremely useful supplies include: filters, Lugol's solution (5 g iodine, 10 g potassium iodide, 100 ml distilled water; dilute with 5 times the distilled water before use); Hoyer's mounting medium (30 g gum arabic, 50 ml distilled water, 20 ml glycerol, 200 gm chloral hydrate; mix in order listed and filter through fine gauze); 10% solution of potassium hydroxide or 20% solution of sodium hydroxide; sterile transport medium for viruses (available from Colab Laboratories, Chicago Heights, Illinois 60412).

Postmortem Methods

General handling of the bird. A necropsy should be performed as soon as the bird is received because decomposition of internal organs is rapid and postmortem migration of parasites might occur. Take measurements immediately because weight, in particular, will change. Size measurements are important for aging purposes and may later prove useful as indicators of specific diseases within the population. Feather wear, cloacal protuberance, and brood patch will better define the breeding condition of the specimen. Tag and label the bird, and every sample taken from this animal should have the same necropsy number (recorded on the necropsy form); indicate if samples are "sterile" or "non-sterile" and the type of medium in which it is preserved. Obtain a detailed history of the specimen.

Preparation and examination of smears. Several types of smears are useful in the diagnosis of disease. Direct microscopic examination (such as fecal material) is important because some organisms are much more readily detected when alive. By using Lugol's solution, fungal hyphae and protozoa become more visible. Impression smears of organs or exudate prepared for gram or Ziehl-Neelsen stain (fix by drying over heat) are important for laboratory analysis of bacteria. Blood smears and impression smears of organs stained with Giemsa are essential when searching for blood haematozoa; fix for 30 seconds in absolute methyl alcohol.

Collection of blood serum. Serological tests will require blood serum. Collect blood aseptically from the heart and let clot overnight. Centrifuge for 10 minutes and then transfer serum to sterile vials. Refrigerate or freeze for shipment.

Preparation of tissue samples. There are a variety of fixatives used in preparing tissue (e.g., Zenker's is useful for all except nervous system tissue), but a good general fixative for most histopathological work is 10% buffered formalin. Cut tissue samples in pieces no larger than 1 x 2 x 0.5 cm and place in
10 volume equivalents of formalin. After 24 hours the tissue can be packed with less formalin or left as is. When freezing tissue, use dry ice to rapidly lower the temperature below 60°C. Glass may shatter so plastic bags are best for samples. Ship in a styrofoam container with dry ice.

**Preparation of cultures.** In general, collect samples to be cultured before the intestine is open. If an organ has been collected under nonsterile conditions, sear the surface with a hot spatula, incise tissue, and sample the cut surface. Sample moist membranes and soft organs with sterile swabs. Place the entire swab directly in medium for shipment. Collect joint or nasal exudate with a sterile hypodermic needle or swab. If solid agar is used, place the tissue firmly against agar or embed several small pieces in agar.

**Fixation of helminths.** Nematodes can be fixed directly in glycerine-alcohol solution and shipped. Cestodes, trematodes, and acanthocephalans should be placed in F.A.A. for 24 hours and then transferred to 70% alcohol before shipment.

**Fixation of arthropods.** Mites, lice, and small insects may be placed directly in 70% alcohol; larger organisms (such as fleas) may be killed first by placing in steaming water and then transferring to 70% alcohol. For permanent mounts of ectoparasites, drop the specimen directly into Hoyer's mounting medium, pass over a flame to relax specimen, and then cover with a cover slip. Fungal hyphae should be mounted in 10% potassium hydroxide or 20% sodium hydroxide and heated gently to clear the specimen.

**Sporulation of Coccidian Oocysts.** A fecal suspension should be placed, with a thin layer of 1% formalin, in a petri dish for one to four days so that sporulation will occur and species can be identified. The fecal material may be shipped in this medium.

**Laboratory facilities.** A problem often occurs in trying to find a laboratory which will process the tissue and identify pathogens. There are several agencies that have well-established laboratories which specialize in avian diseases (e.g., Fish & Wildlife Service), but they are usually hesitant to accept material from independent researchers due to lack of time or personnel to process material. Better places to try include the Department of Agriculture, Department of Health, Veterinary Pathology laboratories, and university laboratories in Medical or Veterinary Sciences. Check with the particular laboratory for their preferences of tissue preservation.
Results

Instructions

The following postmortem analysis (Part I) is organized to include initial cataloging of specimen, the history of the specimen, and necropsy and laboratory analysis. The actual examination is outlined with dissection directions. The examiner need only follow the instructions in parentheses until a particular symptom occurs, check the space, circle the disorder (symptom), and then using the number at the right of the line as a guide, turn to Part II. In Part II are instructions for collection of relevant material necessary for laboratory analysis. The numbers on the postmortem form also are listed in Tables I and II under specific diseases; by referring to the tables the examiner can determine possible disorders to suggest to the laboratory for consideration. Underlined numbers in the tables refer to characteristic symptoms. However, disease symptoms were determined from poultry diseases to a large extent and they may differ in other species of birds. Furthermore, many diseases may share common symptoms, especially those that undergo a septicemic phase. Therefore, in most cases it is only by a thorough necropsy analysis supplemented with laboratory tests that a particular disease can be positively identified.
### PART I

**SPECIES:**

**FIELD #:**

**NECROPSY #:**

<table>
<thead>
<tr>
<th>Area collected:</th>
<th>Collector:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Date collected:</td>
<td>Date examined:</td>
</tr>
<tr>
<td>Examiner:</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Age:</th>
<th>Weight: g</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Sex:</th>
<th>Gonad meas.: mm</th>
</tr>
</thead>
</table>

**Fat:**

**P.M.State:**

<table>
<thead>
<tr>
<th>Preserved in:</th>
<th></th>
</tr>
</thead>
</table>

**History of bird:**

### MATERIAL TO LABORATORY

**Smears:**

- peripheral blood
- bone marrow
- heart
- lungs
- liver
- spleen
- kidney
- brain
- fecal
- other

**Tissue:**

- entire bird
- heart
- liver
- spleen
- lungs
- intestine
- proventriculus
- gizzard
- esophagus
- crop
- gall bladder
- pancreas
- kidney
- brain
- gonads
- nerves
- trachea
- bursa of fabricius
- muscle
- endocrine glands
- legs
- feet
- other

**Body Wash:**

**Crop Contents:**

**Parasites:**

- helminths
  - arthropods
  - other

**Cultures:**

**Other:**

### NECROPSY SUMMARY:

### LABORATORY RESULTS:

### DIAGNOSIS:
I. External Analysis
(Examine bird externally for disorders.)

a. HEAD AND BEAK
   - Face: lesions; crusty or scaly scabs (1)
   - Face or sinuses swollen (2)
   - Ear disorder (3)
   (Cut eyelids back and expose eyeball.)
   - Eye: inflamed; swollen; cloudy; exudate; helminths (4)
   (Cut off beak at nostrils; examine with dissecting microscope.)
   - Nasal chamber: lesions; nodules; exudate (5)
   - Nasal parasites (6)
   - Other

b. BODY AND WINGS
   - Keel prominent (7)
   - Vent soiled; diarrhea (8)
   - Feathers: dry, easily broken, or absent; follicles infected (9)
   - Skin: dermatitis, ulceration, swelling; uropygial infected (10)
   - Other

c. LEGS AND FEET
   - Legs or feet: lesions; crusty or scaly scabs (1)
   - Legs or feet: swollen; enlarged bones; inflamed joints (11)
   - Missing appendages (12)
   - Other

d. BODY WASH FOR EXTERNAL PARASITES
   (Tape bill shut, shake in soapy water, let settle, decant to alcohol.)
   Comments:

II. Internal Analysis

a. BODY SURFACE
   (Skin body, neck, head; record fat and skull condition.)
   - Muscles: lesions; discolored; hemorrhage (13)
   - Feather, follicle, or skin parasites (14)
   - Other

b. UPPER DIGESTIVE AND RESPIRATORY SYSTEMS, SKULL, AND BRAIN
   (Cut from mouth down neck exposing trachea and esophagus.)
   - Mouth, pharynx, esophagus: lesions; nodules; cheesy masses (15)
   (Cut esophagus to proventriculus; preserve crop contents in alcohol.)
   - Crop: lining thickened; contents sour (15)
   (Cut up length of trachea; examine with dissecting microscope.)
   - Trachea: lesions; nodules; exudate (16)
   - Tracheal parasites (16)
   (Remove skull; examine brain.)
   - Brain: lesions; nodules; discolored; hemorrhage (17)
   - Other

b. CELOMIC CAVITY AND AIR SACS
   (Cut out breast and slowly lift sternum. Examine air sacs.)
   - Air sacs: lesions; nodules; exudate (18)
   (Examine internal organs and if any suggest infection, process immediately to avoid contamination.)
   - Abdomen: lesions; nodules; exudate (19)
   - Other
d. HEART AND PERICARDIUM
(Examine pericardium and remove.)
   Pericardium: exudate; inflamed; discolored; hemorrhage (20)
(Examine heart; prepare smear from heart blood and fix for Giemsa stain.)
   Heart: enlarged; lesions; nodules; hemorrhage (21)
   Other:

e. LIVER, SPLEEN, GALL BLADDER
(Examine liver, gall bladder; measure spleen: x mm.)
   Liver disorder (22):
   Spleen disorder (23):
   Gall bladder disorder (24):
(Remove liver and spleen.)
f. INTESTINAL TRACT AND PANCREAS
(Examine external appearance of intestinal tract and membranes.)
   Peritoneum: nodules; discolored; inflamed (25)
   Intestine: external ballooning or hemorrhage (26)
(Examine gastrointestinal tract and straighten on glass plate.)
   Intestine length: mm. Separate proventriculus and gizzard.
(Examine down length of intestine and lay open.)
   Intestine: lesions; nodules; hemorrhage: helminths (27)
(Record location of parasites:
   Ceca: lesions; nodules; exudate; hemorrhage; thickened; helminths (27)
   Bursa of Fabricius abnormal (28):
   Other:
(Take intestinal and cecal smears; check for protozoa parasites.)
   Coccidiosis, Trichomoniasis, Histomoniasis, Other (27):
(Cut open proventriculus and gizzard.)
   Proventriculus: lesions; nodules; hemorrhage; erosion; helminths (30)
   Gizzard: lesions; nodules; hemorrhage; erosion; helminths (30)
   Other:
(Examine pancreas.)
   Pancreas: lesions; chalky; hemorrhage (31)

h. LUNGS
(Examine and remove lungs.)
   Lungs: lesions; nodules; exudate; inflamed (32)
   Other:

i. UROGENITAL SYSTEM AND ADRENAL GLANDS
(Measure and remove gonads; record sex; examine adrenals.)
   Gonads or associated structures abnormal (33):
   Adrenal glands abnormal (34)
(Examine and remove kidneys.)
   Kidneys: lesions; nodules; discolored; enlarged (35)
   Other:

j. NERVOUS SYSTEM
(Examine nervous plexus.)
   Nerves: lesions; discolored; swollen (36)
   Other:

k. SKELETAL SYSTEM
(Examine vertebrae; break leg bone and examine bone marrow.)
   Bone marrow abnormal (37):
   Vertebrae or other bones infected (37):
   Other:

l. COMMENTS:
PART II

(1) Face, legs, or feet: lesions; crusty or scaley scabs.

Scrape part of a lesion onto a microscope slide (with water or mineral oil) and examine for mites; preserve in 70% alcohol. If exudate is present, prepare a smear for gram stain. Divide the remainder of infected tissue into three parts; preserve one in 10% formalin, freeze part on dry ice, and culture the rest in a mycotic medium.

(2) Face or sinuses swollen.

Smear a portion of the exudate on two clean slides and fix for gram stain. Either freeze an exudate sample or swab the sinus area and place in a virus transport medium.

(3) Ear disorder.

If the ear is crusty, examine a wet smear for mites. Preserve in 70% alcohol.

(4) Eyes: inflammed; swollen; cloudy; exudate; helminths.

Examine the eyes for helminths; fix and preserve. Smear exudate on a clean slide for gram stain. Fix the infected tissue in 10% formalin, cutting a window through the eyeball so that fixatives can reach the internal structures. Be aware that this is often a secondary symptom and primary disease disorders will probably occur elsewhere. However, if there were nervous symptoms before the bird died, preserve the brain and nerve tissue at end of necropsy by freezing on dry ice.

(5) Nasal chamber: lesions; nodules; exudate.

From the exudate prepare a smear for gram stain and collect two swabs. Place one swab in a transport medium for virus and the other in bacteria transport medium. Preserve half of the infected tissue by freezing and the other half in 10% formalin. This may be a secondary symptom; therefore, examine the remaining respiratory system carefully.

(6) Nasal parasites.

Examine the nasal chamber with a dissecting microscope; preserve and fix parasites.
(7) Keel prominent.

A prominent keel is often indicative of a chronic disease; however, since it is also a secondary manifestation of many disorders, look for other symptoms.

(8) Vent soiled; diarrhea.

A soiled vent indicates diarrhea, a symptom of many diseases. Look for other disorders and be especially careful to examine the digestive tract.

(9) Feathers: dry, easily broken, or absent; follicles infected.

Examine feathers under a microscope for ectoparasites; preserve in 70% alcohol. The entire feather may be placed in alcohol rather than removing the parasite. follicles and inner shaft should be examined for mites. If the skin is dry, or scaley and powdery, preserve a section in 10% formalin.

(10) Skin: dermatitis, ulceration, swelling; uropygial infected.

Proceed as in (1). If possible collect parasites and preserve in alcohol.

(11) Legs or feet: swollen; enlarged bones; inflammed joints.

Using a sterile syringe, collect fluid from joints (including wing joint), and smear for gram stain. Place a portion (or a swab) into a bacteria medium and either freeze (-60°C) the remaining exudate or place in viral transport medium. Preserve some infected tissue by freezing and the rest in 10% formalin.

(12) Missing appendages.

If appendages are missing consider the bird's history in terms of trauma (e.g., freezing) or past viral (e.g., Pox) infections. Be sure to include this in the history of the bird.

(13) Muscles: lesions; discolored; hemorrhage.

If nodules are obvious on pectorals, open one and examine for nematode larvae or mites; preserve in 70% alcohol. Smear necrotic lesions and prepare for a gram stain. If exudate is present (e.g., blood) prepare a swab and place in a bacteria medium. Fix infected tissue in 10% formalin. This is often a secondary symptom so be careful to look for other indications of disease.
(14) Feather, follicle, or skin parasites.

Examine the internal surface of the skin for mites; if present preserve in alcohol. Proceed as outlined in #(9).

(15) Mouth, pharynx, esophagus: lesions; nodules; cheesy masses. Crop: lining thickened; contents sour.

Lesions in the mouth should be smeared for gram stain or preserved in 10% formalin. If cheesy, culture on a mycotic medium for shipment. A wet smear may reveal protozoa (especially if crop lining is thickened); proceed as outlined in #(29). Preserve crop contents and tissue in formalin. Fix and preserve any helminths.

(16) Trachea: lesions; nodules; exudate.

Freeze or swab exudate and place in viral transport medium. Prepare an exudate for gram stain. Preserve lesions and tracheal tissue in 10% formalin and on dry ice. The entire length of the trachea should be examined for nematodes; fix and preserve.

(17) Brain: lesions; nodules; discolored; hemorrhage.

Swab tissue and place in bacteria medium. Make two impression smears (one fixed for gram stain and one for Giemsa). Divide the remaining brain tissue in half; freeze part and place the rest in 10% formalin. Collect a sample of body fat; freeze.

(18) Air sacs: lesions; nodules; exudate.

Make a tissue smear for gram stain and search tissue for mites. Prepare diseased tissue by freezing and in 10% formalin. Also freeze (even though they may appear normal) sinus tissue, trachea, lungs, and cloaca.

(19) Abdomen: lesions; nodules; exudate.

Lesions or exudate in the abdomen should be smeared for gram stain. If the lesions are nodular, examine for mites or nematode larvae; fix and preserve. The remaining diseased tissue should be place in 10% formalin.

(20) Pericardium: exudate; inflamed; discolored; hemorrhage.

Prepare two smears (for gram stain and Giemsa) from exudate. Preserve the remaining tissue in 10% formalin. Since this is often a secondary symptom, samples of tissue from the kidney, bone marrow, bursa of Fabricius, lungs, liver, spleen, and brain should be routinely collected.
(21) Heart: enlarged; lesions; nodules; hemorrhage.

Prepare lesion, organ impression, and heart blood smears for gram stain and Giemsa stain. Swab tissue and place in a bacteria medium. Preserve what remains of the heart in 10% formalin. Tissue from other representative areas of the body (e.g., liver, spleen, kidney, bone marrow, lung, brain—freeze part—and bursa of Fabricius) should also be collected.

(22) Liver disorder.

Prepare two organ impression as well as lesion and exudate smears for gram stain and Giemsa stain. If tubercles are present on the liver smash a small (2 mm) tubercle between two slides and prepare for Ziehl-Neelsen stain. Swab tissue and place in bacteria medium. Divide the remaining tissue, placing part in 10% formalin and freezing the rest on dry ice for shipment. A sample of heart blood should be prepared for Giemsa stain and blood serum collected. Collect spleen, heart tissue, lung, and bone.

(23) Spleen disorder.

Follow the procedure outlined in #(22) and be sure to collect a sample of the liver.

(24) Gall bladder disorder.

Using a sterile syringe collect some bile and place in bacteria medium. Examine the bile ducts for helminths and if present, preserve.

(25) Peritoneum: nodules; discolored; inflammed.

Prepare a gram stain from lesion. If small tubercles are present smash some between two slides and fix for Ziehl-Neelsen stain. The remaining tissue should be placed in 10% formalin.

(26) Intestine: external ballooning; hemorrhage.

Examine carefully without opening the intestine. Prepare smears of any lesions for gram stain.

(27) Intestine: lesions; nodules; hemorrhage; helminths. Ceca: lesions; nodules; exudate; hemorrhage; thickened; helminths.

Before proceeding, prepare a swab from lesions and place in bacteria medium. Omit if intestinal contents have contaminated the area such that lesions cannot be seared and incised.
Examine a wet smear of intestinal contents at several places for intestinal protozoa (see #29). Smears of lesions should be prepared for gram stain. Fix the intestinal and cecal contents in 1% formalin and the tissue in 10% formalin. Freeze sections of the bursa of Fabricius, liver, spleen, bone marrow, and take blood serum. Sections of the heart, lung, kidney, liver, and spleen should be placed in 10% formalin. Examine the length of the intestine for helminths and if present, preserve.

(28) Bursa of Fabricius abnormal.

Divide the organ in half and preserve part in 10% formalin and freeze the rest on dry ice.

(29) Intestinal Protozoa.

To check for protozoa parasites, a wet smear will usually suffice. However, Lugol's solution will often facilitate observation.

(30) Proventriculus: lesions; nodules; hemorrhage; erosion; helminths.
     Gizzard: lesions; nodules; hemorrhage; erosion; helminths.

If lesions are present, swab and place in a bacteria medium. Prepare a smear from heart blood for gram stain. Any cheesy exudate should be transferred to a mycotic medium for culture and/or placed in 10% formalin. Be sure to remove the gizzard lining and examine for helminths; if present, preserve.

(31) Pancreas: lesions; chalky; hemorrhage.

Place the entire organ in 10% formalin.

(32) Lungs: lesions; nodules; exudate; inflamed.

From the exudate prepare two swabs; place one in a bacteria medium and one in a transport medium for viruses. Fix an exudate smear for gram stain. Any cheesy exudate should be cultured on a mycotic medium. Preserve half the remaining tissue in 10% formalin and freeze the rest. Fix a heart blood smear for Giemsa stain and separate serum into a sterile vial.

(33) Gonads or associated structures abnormal.

Prepare a swab for bacteria medium and make two impression smears for gram stain and Giemsa stain. Freeze some of the remaining tissue and place the remainder in 10% formalin. Samples of the bone marrow, heart blood, liver, spleen should also be collected.
(34) Adrenal Glands abnormal.

Look for other disorders, but note especially if shock might be suspected (e.g., hemorrhage of heart).

(35) Kidney: lesions; nodules; discolored; enlarged.

Prepare swabs from lesions for bacteria medium. Make impression smears for gram and Giemsa stain. Divide the remaining tissue in half and freeze part; examine the other half carefully for trememodes and Protozoa and if present, preserve. Collect blood serum in sterile vials and refrigerate. Also collect tissue from the heart, liver, and spleen.

(36) Nerves: lesions; discolored; swollen.

Preserve nerves that are diseased in 10% formalin. Prepare a heart blood smear for Giemsa stain and see #(17) for possible treatment of the brain. Even if brain appears normal, preserve it in 10% formalin.

(37) Bone marrow abnormal; vertebrae or other bones infected.

Prepare two bone marrow smears, one for gram stain and one for Giemsa stain. Freeze part of the tissue and preserve the rest in 10% formalin. If vertebrae are implicated, check carefully for joint involvement and place exudate in bacteria medium.
SUMMARY

More work needs to be done on disease in wild birds, especially studies which delimit the entire parasitic fauna present within a host population. Recording levels of a single pathogen, as most surveys to date have done, cannot possibly determine the impact disease is playing upon wild populations. A multi-disease approach is necessary, one which reveals the inter-relationship between all parasites and diseases within a host population.

We have presented this postmortem technique in hopes that more ornithologists will be inspired to attempt such multi-disease studies. These surveys will hopefully provide enough information so that disease interactions can be defined, possibly simulated in laboratory situations, and control measures can be found which would be applicable to the natural state.
LITERATURE CITED


van Riper, C., III. Environmental productivity as a possible factor regulating parasite levels in the Hawaii Amakihi (Loxops virens) Aves: Drepanididae. (In preparation).

### TABLE 1. Summary of diseases in avian hosts

<table>
<thead>
<tr>
<th>Disease</th>
<th>Pathogen</th>
<th>Major Host Symptoms</th>
<th>Hosts Reported Susceptible</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Bacterial Diseases</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Arizonosis</td>
<td>Arizona sp.</td>
<td>Septicemic; (4,17,18, 19,21,22,27,32,33,36)</td>
<td>A,G,PS,P</td>
</tr>
<tr>
<td>Anthrax</td>
<td>Bacillus anthracis</td>
<td>Nervous</td>
<td>Str,Ci,A,F,C</td>
</tr>
<tr>
<td>Botulism</td>
<td>Clostridium botulinum</td>
<td>Nervous; (17,36)</td>
<td>Pod,Ga,Pel,Ci,A,F,G,Ch,C,St,P</td>
</tr>
<tr>
<td>Chlamydiosis (Ornithosis)</td>
<td>Chlamydia psittaci</td>
<td>Respiratory; Circulatory; (4,17,18,19,20,21,22, 23,24,31,32,33,36)</td>
<td>Ga,Pro,Pel,Ci,A,F,G,Gr,Ch,C,Ps,St,Ap,Cor,Pic,P</td>
</tr>
<tr>
<td>Cholera</td>
<td>Pasteurella multocida</td>
<td>Septicemic; (2,4,5, 15,16,17,18,19,22,25, 27,30,32,33,36)</td>
<td>Sp,Pod,Pro,Pel,Ci,A,F,G,Gr,Ch,C,Psi,St,P</td>
</tr>
<tr>
<td>Clostridia</td>
<td>Clostridium sp.</td>
<td>Wound infection; Digestive; (10,13, 22,27,30,35,37)</td>
<td>G (necrotic enteritis); probably all species susceptible to wound infection or gangrene</td>
</tr>
<tr>
<td>Colibacillosis</td>
<td>Escherichia coli</td>
<td>Various; (1,2,4,5,10, 11,13,16,18,19,20, 21,22,23,25,27,32, 33,35)</td>
<td>Str,A,F,G,Gr,Ch,Ps,St,P</td>
</tr>
<tr>
<td>Erysipelas</td>
<td>Erysipelothrix insidosa</td>
<td>Septicemic; (1,10,11, 13,18,20,21,22,23, 27,30,31,32,33,35)</td>
<td>Sp,Pod,Pel,Ci,A,F,G,Gr,Ch,C,Ps,Cu,St,P</td>
</tr>
<tr>
<td>Infectious Coryza</td>
<td>Hemophilus sp.</td>
<td>Respiratory; (2,4,5, 16,18,32)</td>
<td>G,C</td>
</tr>
<tr>
<td>Disease</td>
<td>Pathogen</td>
<td>Major Host Symptoms</td>
<td>Hosts Reported Susceptible</td>
</tr>
<tr>
<td>-------------------------</td>
<td>-----------------------------------------------</td>
<td>---------------------</td>
<td>----------------------------</td>
</tr>
<tr>
<td>Bacterial Diseases (Cont'd.)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Infectious Serositis</td>
<td><em>Pasteurella anatipestifer</em></td>
<td>Septicemic; (4, 5, 16, 17, 18, 20, 22, 23, 25, 32, 33, 36)</td>
<td>A, G</td>
</tr>
<tr>
<td>(Duck Septicemia)</td>
<td><em>P. septicaemiae</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Listeriosis</td>
<td><em>Listeria monocytogenes</em></td>
<td>Septicemic; (4, 17, 18, 19, 20, 21, 22, 23, 27, 32, 35, 36)</td>
<td>A, F, G, Gr, Ch, C, Ps, St, P</td>
</tr>
<tr>
<td>Mycoplasmosis</td>
<td><em>Mycoplasma sp.</em></td>
<td>Respiratory;</td>
<td>F, G, C, Ps, P</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Skeletal;</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(2, 5, 10, 11, 16, 18, 19, 20, 22, 32, 35)</td>
<td></td>
</tr>
<tr>
<td>Pseudotuberculosis</td>
<td><em>Pasteurella pseudotuberculosis</em></td>
<td>Septicemic; (13, 18, 19, 22, 23, 27, 32)</td>
<td>A, F, G, Gr, Ch, C, Ps, Cu, St, T, Cor, Pic, P</td>
</tr>
<tr>
<td>Salmonellosis</td>
<td><em>Salmonella sp.</em> (over 1000 pathogenic sp.)</td>
<td>Digestive;</td>
<td>Sp, Str, Ga, Pel, Ci, A, F, G, Gr, Ch, C, Ps, Cu, St, Ap, Cor, Pic, P</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Septicemic; (4, 11, 15, 17, 18, 19, 20, 21, 22, 23, 25, 27, 30, 32, 33, 35, 36)</td>
<td></td>
</tr>
<tr>
<td>Spirochaetosis</td>
<td><em>Borrelia anserina</em></td>
<td>Blood; (22, 23, 27, 35)</td>
<td>A, G, C, P</td>
</tr>
<tr>
<td>Staphylococcus</td>
<td><em>Staphylococcus aureus</em></td>
<td>Skeletal; (1, 2, 3, 10, 11, 22, 37)</td>
<td>Str, Ci, A, F, G, Gr, Ch, C, Ps, Ap, C, P (common on skin and mucous membrane)</td>
</tr>
<tr>
<td>Streptococcus</td>
<td><em>Streptococcus sp.</em></td>
<td>Septicemic; (1, 2, 9, 10, 11, 17, 19, 20, 21, 22, 23, 25, 33)</td>
<td>Ci, A, F, G, Gr, Ch, C, Ps, P</td>
</tr>
<tr>
<td>Disease</td>
<td>Pathogen</td>
<td>Major Host Symptoms</td>
<td>Hosts Reported Susceptible</td>
</tr>
<tr>
<td>-------------------------------</td>
<td>-------------------------------</td>
<td>---------------------</td>
<td>---------------------------</td>
</tr>
<tr>
<td><strong>Bacterial Diseases (Con't.)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tuberculosis</td>
<td>Mycobacterium avium</td>
<td>Viscera; (1, 11, 18, 19, 22, 23, 27, 32, 33, 37)</td>
<td>Sp, Str, Rh, Ca, Ti, Ga, Pel, Ci, A, F, G, Gr, Ch, C, Ps, Cu, St, Ap, Cor, Pic, P</td>
</tr>
<tr>
<td>Ulcerative Enteritis</td>
<td>Corynebacterium sp.</td>
<td>Digestive; (22, 23, 27)</td>
<td>F, G, C</td>
</tr>
<tr>
<td>Vibrio Infections</td>
<td>Vibrio sp.</td>
<td>Liver; Digestive; (20, 21, 22, 23, 27, 33, 35)</td>
<td>Sp, Pod, Pro, Pel, Ci, A, F, G, Gr, Ch, C, Ps, St, P</td>
</tr>
<tr>
<td><strong>Fungal Diseases</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aspergillosis</td>
<td>Aspergillus fumigatus</td>
<td>Respiratory; (1, 2, 4, 5, 9, 10, 15, 17, 18, 22, 32)</td>
<td>Sp, Str, Rh, Ti, Ga, Pro, Pel, Ci, A, F, G, Gr, Ch, C, Ps, St, T, Cor, P</td>
</tr>
<tr>
<td>Candidiasis</td>
<td>Candida albicans</td>
<td>Digestive; (15, 27, 30)</td>
<td>Sp, Rh, Ci, A, G, Gr, Ch, C, Ps, Cu, Ap, Pic, P</td>
</tr>
<tr>
<td>Cryptococcus</td>
<td>Cryptococcus neoformans</td>
<td>Meningitis; (17)</td>
<td>G, C, Ps, P</td>
</tr>
<tr>
<td>Favus</td>
<td>Microsporum sp.</td>
<td>Skin; (1, 5, 9, 10, 16, 18, 32)</td>
<td>G, P</td>
</tr>
<tr>
<td><strong>Protozoan Diseases</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coccidiosis</td>
<td>Isospora; Eimeria; and others.</td>
<td>Digestive; (26, 27, 29, 35)</td>
<td>Pro, A, G, C, Ps, P others?</td>
</tr>
<tr>
<td>Haemoproteus</td>
<td>Haemoproteus sp.</td>
<td>Blood; (17, 18, 22, 23, 32)</td>
<td>Pod, Ci, A, F, G, Gr, Ch, C, Ps, Cu, St, Cap, Ap, T, Cor, Pic, P</td>
</tr>
<tr>
<td>Disease</td>
<td>Pathogen</td>
<td>Major Host Symptoms</td>
<td>Hosts Reported Susceptible</td>
</tr>
<tr>
<td>-------------------------------</td>
<td>---------------------------------</td>
<td>---------------------</td>
<td>---------------------------</td>
</tr>
<tr>
<td><strong>Protozoan Diseases (Con't.)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Histomoniasis</td>
<td>Histomonas meleagridis</td>
<td>Digestive; (22,27,29)</td>
<td>G</td>
</tr>
<tr>
<td>Leucocytozoosnosis</td>
<td>Leucocytozoon sp.</td>
<td>Blood; (17,21,22,23)</td>
<td>Ci,A,F,G,Gr,Ch,C,Ps,Cu,St, T,Cor,Pic,P</td>
</tr>
<tr>
<td>Malaria</td>
<td>Plasmodium sp.</td>
<td>Blood; (17,22,23)</td>
<td>Sp,Ci,A,F,G,Gr,Ch,C,Cu,St, Cor,Pic,P</td>
</tr>
<tr>
<td>Other blood Protozoa</td>
<td>Aegyptianella, Lankestrella, Toxoplasma</td>
<td>Blood; (11,17,18, 20,21,22,23,27,32, 35)</td>
<td>Ci,A,F,G,Gr,Ch,C,Ps,Cu,St, Cap,Ap,Cor,Pic,P</td>
</tr>
<tr>
<td>Sarcosporidiosis</td>
<td>Sarcocystis rileyi</td>
<td>Muscle; (13,21)</td>
<td>Ci,A,F,G,St,P</td>
</tr>
<tr>
<td>Trichomoniasis</td>
<td>Trichomonas sp.</td>
<td>Digestive; (5,15,16, 18,19,20,22,27,29, 30,31,32)</td>
<td>Ca,Pel,F,G,C,Ps,P</td>
</tr>
<tr>
<td><strong>Viral Diseases</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Arbovirus</td>
<td></td>
<td>Nervous; (17,21,36)</td>
<td>A,G,C,P</td>
</tr>
<tr>
<td>Bluecomb</td>
<td></td>
<td>Digestive; (26,27,31,35)</td>
<td>G</td>
</tr>
<tr>
<td>Duck Virus Enteritis (Duck Plague)</td>
<td></td>
<td>Septicemic; Digestive; (5,15,16,17,18,19,20,22, 23,27,28,31,32,35,36)</td>
<td>A</td>
</tr>
<tr>
<td>Duck Virus Hepatitis</td>
<td></td>
<td>Liver; (17,22,23,35)</td>
<td>A,G</td>
</tr>
</tbody>
</table>
TABLE 1--Continued.

<table>
<thead>
<tr>
<th>Disease</th>
<th>Pathogen</th>
<th>Major Host Symptoms</th>
<th>Hosts Reported Susceptible</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Viral Diseases (Con't.)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Encephalomyelitis</td>
<td>Nervous; (4,17,30,36)</td>
<td>A,G,C</td>
<td></td>
</tr>
<tr>
<td>Hemorrhagic Enteritis</td>
<td>Digestive; (13,21,23,27,</td>
<td>G</td>
<td></td>
</tr>
<tr>
<td></td>
<td>30,35)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Infectious Bronchitis</td>
<td>Respiratory; (2,5,16,18,</td>
<td>G</td>
<td></td>
</tr>
<tr>
<td></td>
<td>32,33,35)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Infectious Bursal Disease</td>
<td>Bursa of Fabricius; (13,</td>
<td>G</td>
<td></td>
</tr>
<tr>
<td></td>
<td>23,28,30,35)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Influenza</td>
<td>Respiratory; (2,4,5,16,</td>
<td>A,G,Ch,C,Ps</td>
<td></td>
</tr>
<tr>
<td>(over 80 types)</td>
<td>17,18,19,20,22,23,25,32,</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Fowl Plague)</td>
<td>33,35)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Laryngotracheitis</td>
<td>Respiratory; (2,4,5,15,</td>
<td>G</td>
<td></td>
</tr>
<tr>
<td></td>
<td>16)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Monocytosis</td>
<td>Digestive; Viscera</td>
<td>G</td>
<td></td>
</tr>
<tr>
<td>Newcastle Disease</td>
<td>Systemic; Nervous; Respir-</td>
<td>Sp,Str,Rh,Ca,Pel,A,Ci,F,G,</td>
<td></td>
</tr>
<tr>
<td></td>
<td>atory; (4,5,16,17,18,20,</td>
<td>Gr,Ch,C,Ps,Cu,St,Ap,Cor,</td>
<td></td>
</tr>
<tr>
<td></td>
<td>22,23,24,27,30,32,33,36)</td>
<td>Pic,P</td>
<td></td>
</tr>
<tr>
<td>Pox</td>
<td>Skin; Mucous membranes;</td>
<td>probably all species of birds</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(1,5,10,11,12,15,16)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Puffinosis</td>
<td>Skin (feet); Nervous; (1,</td>
<td>A,Ch,C,Pro</td>
<td></td>
</tr>
<tr>
<td></td>
<td>17)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Quail Bronchitis</td>
<td>Respiratory; (2,4,5,16,</td>
<td>A,G,P,P</td>
<td></td>
</tr>
<tr>
<td></td>
<td>18,32)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Disease</td>
<td>Pathogen</td>
<td>Major Host Symptoms</td>
<td>Hosts Reported Susceptible</td>
</tr>
<tr>
<td>---------------------------------</td>
<td>-------------------------</td>
<td>------------------------</td>
<td>---------------------------</td>
</tr>
<tr>
<td><strong>Viral Diseases (Con't.)</strong></td>
<td></td>
<td></td>
<td>G</td>
</tr>
<tr>
<td>Turkey Viral Hepatitis</td>
<td>Liver; (22,31)</td>
<td>G</td>
<td></td>
</tr>
<tr>
<td>Viral Arthritis</td>
<td>Skeletal; (11)</td>
<td>G</td>
<td></td>
</tr>
<tr>
<td><strong>Neoplastic Diseases</strong></td>
<td></td>
<td></td>
<td>G</td>
</tr>
<tr>
<td>Erythroblastosis</td>
<td>Circulatory; (9,10,13,18,22,23,32,35,37)</td>
<td>G</td>
<td></td>
</tr>
<tr>
<td>Hemangioma</td>
<td>Skin; Viscera; (9,10)</td>
<td>G</td>
<td></td>
</tr>
<tr>
<td>Leukosis complex</td>
<td>Viscera; (18,19,21,22,23,28,30,32,33,35,37)</td>
<td>Ci,A,G,C,Ps,P</td>
<td></td>
</tr>
<tr>
<td>Marek's Disease</td>
<td>Nervous; Viscera; (1,4,13,17,19,21,22,23,25,27,28,30,31,33,35,36)</td>
<td>A,F,G,C,Ps,St,P</td>
<td></td>
</tr>
<tr>
<td>Myeloblastosis</td>
<td>Bone marrow; (9,22,23,35,37)</td>
<td>G</td>
<td></td>
</tr>
<tr>
<td>Myelocytomatosis</td>
<td>Skeletal; (11,13,37)</td>
<td>G</td>
<td></td>
</tr>
<tr>
<td>Nephroblastoma</td>
<td>Kidney; (35)</td>
<td>G</td>
<td></td>
</tr>
<tr>
<td>Osteopetrosis</td>
<td>Skeletal; (11,37)</td>
<td>G</td>
<td></td>
</tr>
<tr>
<td>Other Neoplasms</td>
<td>Viscera; Various sites</td>
<td>Str,G,C,Ps,P</td>
<td></td>
</tr>
</tbody>
</table>
Information not our own is from Garnham (1966), Davis et al. (1971), Hofstad et al. (1972), Arnall and Keymer (1975), Greiner et al. (1975), McClure et al. (1978).

2 Numbers refer to symptoms listed on postmortem form and outlined in Part II; these numbers indicate the symptoms most likely to be found when that disease is present, and the underlined numbers are very characteristic symptoms.

3 Letters refer to the orders of birds in which the diseases have been reported. Wild, domestic, cage, and laboratory groups that have shown susceptibility are included. The underlined orders indicate a host group in which that disease is particularly common.

Key to orders: Sp = Sphenisciformes, Str = Struthioniformes, Rh = Rheiformes, Ca = Casuariiformes, Apt = Apterygiformes, Ti = Tinamiformes, Ga = Gaviiformes, Pod = Podicipediformes, Pro = Procellariiformes, Pel = Pelecaniformes, Ci = Ciconiiformes, A = Anseriformes, F = Falconiformes, G = Galliformes, Gr = Gruiformes, Ch = Charadriiformes, C = Columbiformes, Ps = Psittaciformes, Mu = Musophagiformes, Cu = Cuculiformes, St = Strigiformes, Cap = Caprimulgiformes, Ap = Apodiformes, Col = Coliiformes, T = Trogoniformes, Cor = Coraciiformes, Pic = Piciformes, P = Passeriformes.
### TABLE 2. Summary of parasites and other disorders of avian hosts

<table>
<thead>
<tr>
<th>Disease</th>
<th>Major Host Symptoms</th>
<th>Parasite Location</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Helminth and Arthropod Parasites</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Helminth</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acanthocephalans</td>
<td>Digestive; (27)</td>
<td>Intestine</td>
</tr>
<tr>
<td>Cestodes</td>
<td>Digestive; (27)</td>
<td>Intestine</td>
</tr>
<tr>
<td>Nematodes</td>
<td>Digestive; Respiratory; 4, 5, 6, 13 (larvae), 15, 16, 19 (larvae), 22, 23, 24, 27, 30</td>
<td>Intestine, proventriculus, gizzard, trachea, eye, &amp; ceca are most common, but many other sites possible.</td>
</tr>
<tr>
<td>Trematodes</td>
<td>Viscera; (4, 5, 16, 22, 24, 27, 30, 31, 33, 35)</td>
<td>Various sites throughout body.</td>
</tr>
<tr>
<td><strong>Arthropods</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Biting insects</td>
<td>Irritation of skin; (10)</td>
<td>Free-living or in nest; some on the body or the feathers.</td>
</tr>
<tr>
<td>Lice</td>
<td>Feather destruction; (1, 9, 10)</td>
<td>Feathers</td>
</tr>
<tr>
<td>Mites</td>
<td>Various, from feather damage to respiratory symptoms; (1, 3, 5, 6, 9, 10, 13, 16, 18, 19, 32)</td>
<td>Feathers; Respiratory; Skin; Viscera</td>
</tr>
<tr>
<td><strong>Miscellaneous Disorders</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diet deficiencies—not analyzed as they are not usual in wild populations.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Poisoning</td>
<td>Various symptoms; Nervous; (17)</td>
<td>———</td>
</tr>
<tr>
<td>Trauma</td>
<td>Various symptoms; (9, 10, 12, 13, 17)</td>
<td>———</td>
</tr>
</tbody>
</table>

---

1 Specific pathogens and orders of birds susceptible are not included because parasites are often not identified below the taxonomic level given, and probably all species of birds are susceptible.
Koa has been called the "Monarch of Hawaiian Forests." This is a fitting title for a species found on about 500,000 acres in the State. Trees may reach 120 feet tall, 10 feet in diameter, and more than 100 feet in crown spread. Koa is important as a component of the native forest to birds, insects, mollusks, and different plant species with which it grows in association. Its wood is valued highly for furniture, cabinets, veneer, and craft pieces. The technical properties of koa wood are very similar to those of black walnut (Juglans nigra). The koa industry, including harvesting, manufacturing, and sale of finished products, both here and elsewhere, generates about $7,000,000 annually.

Koa forests are not as extensive as they once were. The principal reason is the effect of grazing animals that eat or otherwise damage young trees. Fire, insects, and diseases have destroyed many stands. Harvesting does not necessarily reduce the area of koa forest if natural regeneration that develops after site disturbance is allowed to grow and develop into a new forest. Too often, however, harvesting has been the first step in converting forest to pasture. An estimated 100,000 acres of koa forest have been converted to pasture in the past 50 years. Cattle, of course, are very effective in preventing reestablishment of a koa forest.

In an effort to rehabilitate denuded watersheds, many seedlings of many different species were planted on the Forest Reserves from 1900 to 1940. About 1.1 million koa seedlings were planted, making it the fourth most widely planted species. When the once barren watersheds were revegetated and when labor became scarce because of World War II, interest in reforestation with koa or other species largely ceased. Little reforestation of any kind was done during the 1940's and the early 1950's.

In the late 1950's, people began to realize the multiple values of the trees that had been planted in previous decades. Interest in reforestation was renewed, but not with koa. The Hawaii Division of Forestry built a bare-root nursery in 1961 --principally for growing pine and eucalyptus seedlings. The bare-root system of production, transport, and planting requires a hardy species if it is to work satisfactorily. And koa is definitely not a hardy species. Although interest in forestation with koa has increased during the last 10 years, efforts to use
the bare-root system have failed. Koa seedlings had been successfully raised in and planted from flats and tin cans, but because of the high cost of labor, this method was not economically feasible.

About 5 years ago, in cooperation with the Division of Forestry, I began developing a new system for successfully raising, transporting, and planting seedlings. The system is based on a small, specially designed container called the "Hawaii Dibbling Tube." The container is 5 inches deep and 1-1/8 inches inside top diameter. Four ridges that extend from top to bottom on the inside of the tube prevent root spiraling. The tubes are filled with rooting medium, then seeds are sown and covered. After about 4 months, seedlings are ready for outplanting. Seedlings are removed from the tubes, packed in wax-lined boxes, and shipped to the planting site. Seedlings are planted using a dibble which, when driven into the ground makes a hole the same size and shape as the seedling root system. The tree planter makes the hole and drops in the seedling. The dibbling tube system is proving to be efficient in terms of seedling production, transport, and planting. Its real worth is best measured by the degree of seedling survival after planting. And the bottom line, of course, is that the trees generally survive after planting.

The first planting of dibbling tube seedlings was made about 4 years ago. About 100 koa seedlings were planted in the hapu'u harvest area in the Kilauea Forest Reserve. The seedlings, grown by the green-thumb method, were of reasonable quality. We did not know then, nor do we know now, what constitutes the best seedlings in terms of stem height and diameter, leaf number and area, shoot/root ratio, etc., for maximum survival and growth on a variety of sites under a variety of weather conditions. Nor do we know the cultural treatments, such as fertilizer formulation and concentration, light intensity, temperature, etc., to obtain the best seedlings. Even with these unknowns, this first planting of koa was successful. About 95% survived, and they showed rapid initial growth. About a year later we made another planting with similar results.

Results of these two plantings indicated that koa could be successfully planted in terms of survival, growth, and costs. Reforestation with koa again became feasible.

These first efforts with koa and other species were on a research basis. In other words, we grew a few seedlings of different species and planted them on different sites to test an idea. The idea worked so we expanded from a research basis to a pilot-scale production basis—expanding from a scale of hundreds to a scale of thousands of seedlings. The pilot-scale production nursery was constructed at the Division of Forestry bare-root nursery at Kamuela.

The first crop of 40,000 koa seedlings from the pilot-scale production nursery was contracted for by the Bernice Pauahi Bishop Estate. In growing these trees, we tried to do everything to develop seedlings which would have high survival and growth
potential. For example, we collected nitrogen-fixing nodules from roots of koa seedlings growing in the area where the nursery-grown seedlings were to be planted and isolated the bacterium responsible for nitrogen fixation. The bacterium was applied to all the koa seedlings in the nursery. Seedlings were watered, fertilized, exposed to full sunlight, etc., according to the green-thumb instincts of the nurseryman. When we thought the seedlings were ready for field planting, we packed them in wax-lined boxes and shipped them to the Keauhou-Kilauea Forestry Center for planting.

The Keauhou-Kilauea Forestry Center is a project sponsored by the Bishop Estate. This project, on about 200 acres of cut-over and grazed-over koa-'ohi'a forest, is aimed at restoring koa for eventual sustained-yield management. Technical guidance for the project is being provided by State, private, and Federal organizations.

The 200-acre area was fenced and divided into four 50-acre sections. It was decided to harvest merchantable koa trees, prepare the site, and plant where necessary on 50 acres at a time. That way, if mistakes were made or better methods were developed, other areas would benefit. The area was fenced, of course, to keep out cattle.

Although natural koa reproduction generally develops in adequate numbers following site disturbance, their spatial distribution is often irregular. Seedlings are most common where seed trees once were. Koa seedlings are planted to obtain uniform stocking within an area.

A total of 36,000 seedlings were planted among the natural seedlings to obtain a 5- by 5-foot spacing between all seedlings. The first 18,000-seedling planting was done in August 1977 by Kamehameha School students and several adults. The second planting was done by welfare recipients in November.

We did learn from the first planting as evidenced by the fact that only 56% survived compared to about 98% for the second planting. Seedlings for the second planting were much hardier than those used for the first planting. Also, we were luckier the second time as rainfall was more than adequate. As of May 1978, there were about 2600 natural and planted seedlings per acre. Natural seedlings averaged about 20 inches tall. Seedlings planted in August averaged about 24 inches tall; those planted in November averaged about 16 inches tall.

We had some mortality in both natural and planted seedlings due to frost. Apparently, the opening made in the forest by harvesting and site preparation resulted in greater damage from cold air during periods of freezing temperatures in December and January. Less than 5% of the seedlings were affected.
Results of the efforts on the first 50-acre section were successful enough that work was started on the second 50 acres early in 1978. Seedlings were planted in May 1978. If we get sufficient rain, I feel certain that the survival rates will again be high. Also, because the seedlings were fertilized with 1 ounce of 10-30-10 placed in a hole next to the seedling, initial seedling growth should be rapid. This fertilizer treatment was based on a study we did which indicated that initial growth rate could be more than doubled with just 1 ounce of 10-30-10.

On the basis of results of the first crop from the pilot-scale container nursery, the Division of Forestry plans to develop it into a full production nursery with a capacity of 1 million seedlings per year.

The planting of 36,000 seedlings at Keauhou-Kilauea was the first major koa reforestation project in about 35 years. Now we have just had the second. It is exciting to think that koa reforestation is now biologically and economically feasible. We not only have the potential to bring back the monarch of Hawaiian forests, we have the ability. Now we have to do it.
A vegetation map of the Crater District of Haleakala National Park was produced at a scale of 1:24,000 that can overlay a composite of the USGS topographic quadrangle maps that cover the same area. After an initial field reconnaissance, the mapping was carried out using 1:12,000 aerial photographs. The map units were field checked as to the accuracy of the boundary positions and the structural and floristic composition of the vegetation units. The boundaries were transferred to overlays on 1:12,000 prints of NASA false infrared color aerial photographs. These maps served as a base for the final map which was produced with photographic methods.

The mapped vegetation has been classified into 53 structural-floristic communities that are grouped into four structural vegetation-types: forest communities, scrub communities, grassland communities, and high altitude desert communities. Forest communities were defined as areas with the tallest vegetation layer composed of woody vegetation greater than 5 m tall that had at least 30% crown cover. Scrub communities were defined as areas in which the uppermost vegetation layer consisted of woody vegetation greater than 0.3 m but less than 5 m in height with crown cover greater than 30%. Grassland communities were defined as areas in which grass species had more than 30% cover while woody species had less than 30% cover. High altitude desert communities were defined as areas with less than 30% total plant cover.

Cover has been defined by Mueller-Dombois and Ellenberg (1974) as the vertical projection of the crown or shoot areas of a species to the ground and expressed as a percentage of the reference area. In this study, closed cover was defined as greater than 60%, open cover as between 30%-60%, and sparse cover as less than 30%.

The communities were labeled using a combination of symbols derived from generic names or other predominant surface cover that correspond as closely as possible to and are used in a similar manner as those used in Mueller-Dombois and Fosberg's (1974) vegetation map of Hawaii Volcanoes National Park. A total of 19 symbols were used in combinations to classify the vegetation into the 53 structural-floristic communities that were mapped.
Areas for these vegetation communities were generated using an electronic planimeter. Scrub communities had the largest total area of 3691.7 hectares (9122 acres). High altitude desert communities were next with an area of 3119.7 hectares (7708 acres) and grassland communities covered 568.6 hectares (1405 acres). Forest communities had the smallest total area of 164.9 hectares (407 acres).

Using the map as a base, three topographic vegetation profiles were constructed to aid in the interpretation of the map units. The courses of the profiles are shown in Figure 1. These courses were chosen so as to cross as much of the study area as possible while illustrating as much of the range in vegetation-types and environmental factors as possible. Profile 1 runs from Pu' u Nianiau at the Park boundary on the northwestern outer slope at 2087.5 m (6849 ft) elevation to Kilohana on the western rim of the crater at 2926.1 m (9600 ft). Profile 2 runs from Kilohana, across the crater floor, to the eastern rim above Paliku Cabin that separates Haleakala Crater from Kipahulu Valley at 2133.6 m (7000 ft). Profile 3 runs from the southern Park boundary in Kaupo Gap at 1158.2 m (3800 ft) up over Kalapawili Ridge at 2484 m (8150 ft) to the northern Park boundary on the northern outer slope at 2316.5 m (7600 ft).

Profile 1 (Fig. 2) shows a decrease in both mean annual precipitation and mean annual temperature to be associated with the increase in elevation. An apparent effect of the temperature gradient on the vegetation can be seen at approximately 2590.8 m (8500 ft) where the vegetation becomes very sparse and is termed a high altitude desert. This change may be associated with the diurnal frost boundary, above which freezing temperatures occur at ground level every night of the year. Mueller-Dombois (1967) found the diurnal frost boundary to occur at about this elevation on Mauna Loa.

Profile 2 (Fig. 3) shows an increase in mean annual temperature associated with the decrease in elevation, and an increase in mean annual precipitation associated with the west-east orientation. The increase in rainfall is related to a greater exposure to the effects of the predominant northeasterly trade winds. These factors result in a gradual increase in cover and stature of the vegetation from a low growing very sparse vegetation (high altitude desert), through several variations of scrub communities, to a low stature 'ohi'a rain forest.

Profile 3 (Fig. 4) shows a decrease in mean annual temperature associated with the increase in elevation, and an increase in mean annual precipitation resulting from greater exposure to the effects of the northeasterly trade winds associated with the south to north orientation. Also, the lower end of this profile extends below the inversion layer which occurs between 1700 and 2300 m (5000-7000 ft) elevation (Blumenstock & Price 1967). This complex of factors is associated with the occurrence of several forest communities between 1292 and 1890 m (4240-6200 ft) which are unique to this section in the study area.
This variation of the climatic regimes within the Crater District and along these profiles can be viewed graphically on climate diagrams constructed by the method of Walter (1963) (Fig. 5). Mean annual temperature ranges from 17.6°C (64°F) just below the southern Park boundary in Kaupo Gap at 1088 m (3570 ft) elevation to 8.0°C (46°F) at Haleakala Summit at 3055 m (10,025 ft). Mean annual precipitation ranges from 1077 mm (42.4 in.) at the summit to 4508 mm (177.5 in.) at Paliku Cabin at 1945 m (6341 ft) elevation. All five diagrams have a mean monthly temperature curve that shows little seasonal variation indicating a tropical climate at all elevations. Also, all five diagrams show a similar annual pattern of precipitation with the wettest months being January and December and the driest month being June. Drought conditions are indicated if the mean monthly precipitation curve crosses below the mean monthly temperature curve and is indicated on the diagrams by the stipled areas. This occurs at three stations: Haleakala Summit, Haleakala Ranger Station, and Holua Cabin, but only for a short period in June. The mean monthly precipitation curve for Paliku Cabin is above 100 mm for all months and thus indicates a rain forest climate.

LITERATURE CITED


FIGURE 2. Topographic vegetation profile 1 of the Crater District of Haleakala National Park.
FIGURE 5. Climate diagrams and locations of stations for the Crater District of Haleakala National Park.
A 16-ha site was studied on the Keauhou Ranch, Hawai'i, to determine the interrelationships between vegetation type and presence of native and exotic birds. The area was subdivided into 64 0.25-ha plots and the vegetation sampled on each plot. On a twice-monthly basis, birds were systematically mapped on the study site, and these data compared with the vegetation samples. Birds were identified as to species, and when possible as to sex and age. One year of data has been collected and preliminary analysis shows inter-specific differences in habitat preference.
VEGETATION OF THE HANA RAIN FOREST
HALEAKALA NATIONAL PARK

Alvin Y. Yoshinaga
Department of Botany
University of Hawaii at Manoa
Honolulu, Hawaii 96822

As part of the Hana Rain Forest Project in 1973, the vegetation of the rain forest zone of the northeastern windward slope of Haleakala was studied. The study area included Kalapawili Ridge from below Wai'anapanapa to 1610 m (5400 ft), and part of the Ko'olau Forest Reserve northeast of Pu'u Alaea. The vegetation consisted of 'ohi'a (Metrosideros collina) montane rain forest, with occasional bogs and shrub stands.

At bogs, frequency and cover were measured. At forest sites, the vegetation was sampled separately in three different strata. For trees, densities and basal areas were measured; for saplings and arborescent shrubs, densities and frequencies; for understory, frequencies in 1 m² quadrats. The data were processed by computer. Bray and Curtis ordination was used to interpret the relations between the sites, and a clustering program was used to group the sites into sites according to similarity.

Data for the tree layer were used to divide the sites into four types, arbitrarily called Types 1-4. Understory data were similarly used to identify four site types, called Types a-d. These were related to the site types for trees. For all types, Metrosideros collina was the dominant tree; Cheirodendron trigynum was usually second.

Type 1 included the lowest sites, from about 1670 m (5500 ft), near the Park boundary on Kalapawili Ridge. These were poorly drained, with scrubby forest alternating with open bogs. The tree layer consisted mainly of low (ca. 4 m) Metrosideros collina with a few Cheirodendron trigynum and Ilex anomala. Other tree species, though present, seldom reached full tree size. Tree density, basal area, and cover were low compared to the other types. The understory in some spots was transitional to bogs, at other spots it was of the type described below as Type a.

Type 2 occurred on better drained uplands, mainly from 1710 m to 2010 m (5600-6600 ft) on Kalapawili Ridge. The tree layer consisted mainly of 5 m to 9 m tall Metrosideros collina. Cheirodendron trigynum or, less frequently, Ilex anomala were second in density. Myrsine lessertiana was less abundant than at Type 3 sites. The arborescent shrub layer consisted of Coprosma
spp., Pelea sp., and Vaccinium calycinum. Where the tree layer was open, a layer of large bushes consisting of Broussaisia arguta, Clermontia sp., Labordia sp., and, in places, Rubus hawaiiensis was often present. The understory was mainly Type a. At higher elevation sites the understory was transitional to Type b.

Type 3 sites occurred on well drained uplands from 2010 m to 2070 m (6600-6800 ft) along Kalapawili Ridge, and in most of the Ko'olau sites. The tree layer was 5 m to 8 m tall along Kalapawili Ridge and 8 m to 13 m tall in the Ko'olau Forest Reserve (KFR). The basal areas were generally greater, and the canopies more closed, than in Type 2 sites. Metrosideros collina was the dominant tree, followed by Cheirodendron trigynum or, less often, Myrsine lessertiana. Ilex anomala was less abundant than at Type 2 sites. Coprosma spp., Pelea spp., and Vaccinium calycinum often reached tree size. The understory was more open and poorer in species than at Type 2 sites. Astelia sp., Clermontia sp., Gouldia terminalis, Labordia sp., and Phyllostegia sp. were uncommon or absent. Pteris excelsa, Carex alligata, and Rubus hawaiiensis were more common than at Type 2 sites. At Kalapawili Ridge Type 3 sites, the understory was generally Type b. At lower KFR Type 3 sites, the understory was Type b or Type d; at upper KFR Sites, Type c.

Type 4 included the uppermost sites on Kalapawili Ridge, from 2060 m to 2110 m (6800-6900 ft). The canopy was low, ca. 5 m, and dense. The tree layer consisted of Metrosideros collina with occasional Cheirodendron trigynum. Other tree species occur, but do not reach tree size. Small Metrosideros and Coprosma spp. were particularly abundant in the sapling and arborescent shrub layer. The understory was an open version of Type b.

Common to all four types of understory recognized were Athyrium spp. (incl. A. microphyllum and A. sandwicianum), Dryopteris spp. (incl. D. glabra, D. hawaiiensis, and D. wallichiana), Elaphoglossum hirtum and E. wawrae, Polypodium pellucidum, Sadleria sp., Uncinia uncinata, and Peperomia spp.

Type a, usually associated with a Type 1 or Type 2 tree layer, was both the densest and richest in species. Typical of Type a sites was high frequencies of Asplenium spp., Astelia spp., Gouldia terminalis, and Myrsine lessertiana seedlings.

Type b, generally associated with a Type 3 tree layer and a more closed canopy, was poorer in species and usually more open than Type 2. Carex alligata and Rubus hawaiiensis were present more often than in Type a.

Type c, generally associated with Type 3 tree layer at higher elevation KFR sites, was more open and poorer in species than the other three types. The presence of Pteris excelsa, Carex alligata, and Rubus hawaiiensis was characteristic.
Type d was a catch-all category consisting mainly of lower elevation sites occurring under various types of tree layers. Their main similarity is presence of Carex alligata, Ilex anomala seedlings, Nertera granadensis, Styphelia tameiamelae, and Vaccinium berberifolium.

In general, understories at lower elevation sites have more species than higher elevation sites. There are few species typical of higher elevation sites. Rather than turnover along the gradient, the trend is for species to drop out with increasing elevation, with few new species coming in. For tree species, the trend is different: More arborescent species reach tree size at the higher elevation sites than at the lower ones.

At the time of the study in 1973, there were few if any exotic plants in the understory. Feral pigs were almost absent from Kalapawili Ridge from between 1710 m to 2200 m (5550-7200 ft), although present both above and below those elevations, and in KFR. Since 1973, pigs have become much more common along Kalapawili Ridge. In 1978, the 1973 sites were relocated, marked, and resampled in order to evaluate the pigs' effects on the vegetation. Effects seem small so far; the situation will be monitored to observe any changes as they develop.
Until recently, the prehistoric Hawaiian avifauna was known only by the 1926 find of an extinct goose under 25 m of lava at Pahala on Hawai'i. Since 1971, however, remains of 20 or more previously unknown prehistoric Hawaiian bird taxa have been recovered from Moloka'i and Kaua'i (windblown sand dunes), Maui (lava tube), and O'ahu (solution pits in raised limestone reef). A radiocarbon age of 26,000 years for a Moloka'i goose skeleton is the only date presently available.

A remarkable flightless component of this extinct avifauna comprises several geese and rails, and the first known flightless ibis. Yet-undescribed flighted birds include eagle, owl, and raven, as well as a variety of finch-like passerines. Hawaiian Hawk, Nene, Hawaiian Duck, and Chaetoptila (a meliphagid), or closely related forms, apparently occurred contemporaneously. Present-day native wading and marsh birds are relatively scarce or absent in the prehistoric deposits. Remains of modern Drepanididae seem lacking in all sites except those of Kaua'i, possibly because of a relatively more recent date for these latter deposits.

Absence of terrestrial predators originally allowed survival of flightlessness in Hawai'i, and lowered metabolic requirements of the flightless individuals constituted a selective advantage. Evolution of flightlessness in the Islands probably represents neoteny, rather than the more common long-term incremental selective process. Time and cause of extinction of this prehistoric avifauna is unknown but, although no evidence has thus far been found, it is quite possible that original Polynesian settlers or their associated animals were involved.

* Abstract
LIST OF PARTICIPANTS

Ken Adee, U. S. Forest Service
Gregory A. Ahearn, Zoology Dept., Univ. of Hawaii at Manoa
Jayne N. Ahearn, Genetics Dept., Univ. of Hawaii at Manoa
Rothwell K. Ahulau, Univ. of Hawaii at Manoa,
    and Hawaii Institute of Marine Biology
Barbara F. Allen
Suzy Allen, Hawaii Volcanoes National Park
Russell A. Apple, National Park Service, Honolulu

Ken Baker, Hawaii Volcanoes National Park
Winston E. Banko, Hawaii Volcanoes National Park
Bob Barbee, Hawaii Volcanoes National Park
Bob Barrel, National Park Service, Honolulu
Carmen M. Baybayan, Univ. of Hawaii at Hilo
John W. Beardsley, Entomology Dept., Univ. of Hawaii at Manoa
Marc A. M. Bell, Biology Dept., Univ. Victoria, B. C., Canada
Tim J. Bertrand, U. S. Fish & Wildlife Service
Theodore P. Bodner, U. S. Fish & Wildlife Service
Dawn Breese, U. S. Forest Service
Paul L. Breese, SR CF Kapa'au
Kent W. Bridges, Univ. of Hawaii at Manoa

Gerald D. Carr, Botany Dept., Univ. of Hawaii at Manoa
Hampton L. Carson, Genetics Dept., Univ. of Hawaii at Manoa
Meredith S. Carson
John G. Chan, Biology Dept., Univ. of Hawaii at Hilo
Gar Clarke, Hawaii Volcanoes National Park
Mark S. Collins, U. S. Forest Service
Patrick Conant, Entomology Dept., Univ. of Hawaii at Manoa
Sheila Conant, General Science Dept., Univ. of Hawaii at Manoa
Carolyn A. Corn, Univ. of Hawaii at Manoa,
    and Hawaii Division of Forestry
Lisa K. Croft, Botany Dept., Univ. of Hawaii at Manoa,
    and U. S. Forest Service
Linda W. Cuddihy, Botany Dept., Univ. of Hawaii at Manoa

Gordon Y. Daida, Botany Dept., Univ. of Hawaii at Manoa
Bertell D. Davis, Univ. of Hawaii at Manoa,
    and Archaeological Research Center Hawaii
Clifton J. Davis, Hawaii Volcanoes National Park
Joyce A. Davis, Botany Dept., B. P. Bishop Museum
Isa Degener, New York Botanical Garden
C. H. Diong, Zoology Dept., Univ. of Hawaii at Manoa
Ann E. Dunmire, Cooperative Park Studies Unit, Univ. of Hawaii

Jon W. Erickson, Hawaii Volcanoes National Park
William E. Evenson, Botany Dept., Univ. of Hawaii at Manoa,
    and Dept. of Physics & Astronomy, Brigham Young University
List of Participants (Continued)

Dennis B. Fenn, National Park Service, San Francisco
Evangeline J. Funk, Botany Dept., Univ. of Hawaii at Manoa

Peter C. Galloway, Univ. of Hawaii, Cons. Council for Hawaii
Donald E. Gardner, Hawaii Volcanoes National Park
Ruth A. Gay, Botany Dept., Univ. of Hawaii at Manoa
Grant Gerrish, Botany Dept., Univ. of Hawaii at Manoa
Jon G. Giffin, State Division of Fish & Game
M. Lee Goff, Entomology Dept., B. P. Bishop Museum
Samuel M. Gon, III, Zoology Dept., Univ. of Hawaii at Manoa

Arnold H. Hara, Entomology Dept., Univ. of Hawaii at Manoa
Duane D. Harding, Mauna Loa Observatory
D. Elmo Hardy, Entomology Dept., Univ. of Hawaii at Manoa
Dennis Hashimoto, Hawaii Volcanoes National Park
Mary M. Helfrich, Lyman House Museum
Dorothy S. Henderson, Univ. of Hawaii at Manoa
Derral R. Herbst, U. S. Fish & Wildlife Service
Paul K. Higashino, U. S. Forest Service
Stephen A. Holmes, Hamakua District Development Council
Beverly M. Hookano, Univ. of Hawaii at Hilo
Marcia E. Horner, Entomology Dept., Univ. of Hawaii at Manoa
Frank G. Howarth, Entomology Dept., B. P. Bishop Museum

James D. Jacobi, Botany Dept., Univ. of Hawaii at Manoa,
and U. S. Fish & Wildlife Service
Francis H. Jacot, National Park Service, San Francisco
Terrell J. Jones, Cooperative Park Studies Unit, Univ. of Hawaii

Dina Kageler, Hawaii Volcanoes National Park
Seiso Kamimura, Dept. of Land & Natural Resources,
Division of State Parks
Michael W. Kaschko, Anthropology Dept., Univ. of Hawaii at Manoa
Larry K. Katahira, Hawaii Volcanoes National Park
Cameron B. Kepler, U. S. Fish & Wildlife Service
Bruce M. Kilgore, National Park Service, San Francisco
John I. Kjargaard, Haleakala National Park

Charles H. Lamoureux, Botany Dept., Univ. of Hawaii at Manoa
Ah Fat Lee, Wildlife Branch, Fish & Game, State of Hawaii
Barbara Lee, Wildlife Branch, Fish & Game, State of Hawaii
H. Franklin Little, Univ. of Hawaii at Hilo
Marcia H. Little
Tim K. Lowrey, Botany Dept., Univ. of California - Berkeley

Anna Manis, The Nature Conservancy
Doris Mann
Herber J. Mann, National Oceanographic and Atmospheric Admin.
Marcia May, Univ. of Hawaii at Hilo
Phyllis H. McEldowney, U. S. Fish & Wildlife Service
Hans Megens, B. P. Bishop Museum
Christina B. Meller, Life of the Land
Douglas Meller, Shoreline Protection Alliance
List of Participants (Continued)

Mark D. Merlin, General Science Dept., Univ. of Hawaii at Manoa
John M. Miller, Mauna Loa Observatory
Shirlene S-L. Miyashiro, Dept. of Land & Natural Resources,
Division of State Parks
Geary S. Mizuno, Zoology Dept., Univ. of Hawaii at Manoa
Steve L. Montgomery, Entomology Dept., Univ. of Hawaii at Manoa
Richard B. Moore, USGS--Hawaiian Volcano Observatory
Christine E. Morgan, U. S. Forest Service
Dieter Mueller-Dombois, Botany Dept., Univ. of Hawaii at Manoa
Mae E. Mull, Hawaii Audubon Society
William P. Mull, B. P. Bishop Museum
Gail M. Murakami, Botany Dept., Univ. of Hawaii at Manoa
Timothy G. Myles, Univ. of Hawaii at Manoa

Jean I. Nishida, Dept. of Land & Natural Resources,
Division of State Parks

Timmy J. Ohashi, U. S. Forest Service
Gregory P. Owen, Hawaii Outward Bound School

Richard P. Papp, B. P. Bishop Museum
Carol Pearson, U. S. Forest Service
Dana R. Peterson, Univ. of Hawaii at Manoa,
and Haleakala National Park
Lawrence J. Pinter, Navy Environment Office

C. J. Ralph, U. S. Forest Service
Don Reeser, Hawaii Volcanoes National Park
Faith M. Roelofs, Botany Dept., Univ. of Hawaii at Manoa
Christa A. Russell, Hawaii Volcanoes National Park

Howard F. Sakai, U. S. Forest Service
Simon C. Sanidad, Entomology Dept., Univ. of Hawaii at Manoa
Mike Scott, U. S. Fish & Wildlife Service
Paul G. Scowcroft, U. S. Forest Service
Richard J. Scudder, Governor's Office of Environmental
Quality Control
Deborah A. Shaw, Field Studies Unit
Clara H. Shimoda, City of Refuge National Historical Park
Jerry Y. Shimoda, City of Refuge National Historical Park
Roger G. Skolmen, U. S. Forest Service
Garrett H. Smathers, National Park Service, Biology Dept.,
Western Carolina University
Clifford W. Smith, Botany Dept., University of Hawaii at Manoa,
and Cooperative National Park Resources Studies Unit, U. H.
Linda L. Smith, Botany Dept., Univ. of Hawaii at Manoa
Jim Sorenson, Botany Dept., Univ. of Hawaii at Manoa
Wayne H. Souza, Dept. of Land & Natural Resources,
Division of State Parks
John D. Stein, U. S. Forest Service
Lani Stemmermann, Botany Dept., Univ. of Hawaii at Manoa,
and B. P. Bishop Museum
Maile A. Stemmermann, Zoology Dept., Univ. of Hawaii at Manoa
List of Participants (Continued)

Carol S. Tabata, Coastal Zone Management, Univ. of Hawaii at Manoa
Raymond S. Tabata, Sea Grant, Univ. of Hawaii at Manoa
Kimo Tabor, The Nature Conservancy
Howard A. Takata, Sea Grant, Univ. of Hawaii at Manoa
Avery L. Taylor, U. S. Forest Service
JoAnn Tenorio, B. P. Bishop Museum
Glenn I. Teves, Entomology Dept., Univ. of Hawaii at Manoa
P. Quentin Tomich, State Health Department

Charles van Riper III, Univ. of Hawaii, and Cooperative Park Studies Unit, Univ. of Hawaii
Sandra G. van Riper, Cooperative Park Studies Unit, Univ. of Hawaii

Jerry A. Walters, U. S. Forest Service
John F. Walters, Oceanography Dept., Univ. of Hawaii at Manoa
Richard E. Warner, Field Studies Unit
Rich Warshauer, U. S. Fish & Wildlife Service
Deborah A. Weiner, Cooperative Park Studies Unit, Univ. of Hawaii
Art Whistler, Botany Dept., Univ. of Hawaii at Manoa
Louis D. Whiteaker, Cooperative Park Studies Unit, Univ. of Hawaii
Claire M. Wolfe, U. S. Forest Service
David H. Woodside, Dept. of Land & Natural Resources

Faye Yates
Alvin Y. Yoshinaga, Botany Dept., Univ. of Hawaii at Manoa, and Cooperative Park Studies Unit, Univ. of Hawaii
Ernest R. Yoshioka, State Dept. of Agriculture
Chris J. Yuen, Youth Conservation Corps

Alan, C. Ziegler, Division of Vert. Biology, B. P. Bishop Museum
Nicholas Zimmer, Hawaii Volcanoes National Park
SUBJECT INDEX

Acacia koa, 260, 333
Acari, 125, 237
Acid Rain, 217
'Alala, 207
Animals, 198
Atya, 42
Biological, 26
Bird, 52, 199, 207, 309, 345
Birds, 6, 17, 59, 71, 125, 193
Communications Techniques, 256
Drosophila, 54
Ecosystem, 58
Ecosystem Restoration, 239
Endangered, 17
Endangered Forest Birds, 238
Endangered Plants, 37
Endangered Species, 208
Exotic Plants, 120, 198
Exotics, 51
Geology, 1, 218
Haleakula, 30, 71, 193, 289, 292, 297, 337, 346
Hana Rain Forest, 346
Hawaii Volcanoes National Park, 51, 98, 125
Hawaiian Dark-rumped Petrel, 193
Hawaiian Forests, 333
Hibiscadelphus, 2
Human Settlement, 87
Hybridizations, 37, 77
Insect, 134, 236
Insects, 30, 41, 54, 98, 235, 237
Island Ecosystems, 231
Kalapana, 59
Kilauea Rain Forest, 58
Kilauea Volcano, 218
Lava Tube, 155
Leptospirosis, 308
Lichen, 292
Limiting, 17
Mamane, 247
Mammals, 2, 237, 308
Mauna Loa, 222, 237
Metrosideros, 77
Mosses, 150
Myrica faya, 51, 114, 274
Natural Areas, 304
Necropsy, 309
Nene, 6, 199
O'ahu, 52, 87, 120
'Ohi'a, 105, 236
Planting, 239
Plants, 297
Pohakuloa, 199
Propagation, 260
Rat, 2
Reintroduction Technique, 247
Rodents, 237
Seismology, 1
Shell Disease, 42
Shrimp, 42
Silversword, 37
South Kona, 86, 134
Spiders, 235
Sweet Potato, 177
Temporal Patterns, 34
Threatened Plants, 86
Variation, 41
Vegetation Map, 165, 337
Weed, 26
Whitney, 1