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STATUS OF THE NATIVE FLOWERING PLANTS OF THE HAWAIIAN ISLANDS

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ABSTRACT

Estimates of the total number of native Hawaiian plants are widely divergent because of differences in species concepts; our evaluation suggests 1,200-1,300 native species. Hawai'i has the highest number of candidate threatened and endangered plants for the United States (31%), with approximately 10% of the native flowering plants already extinct. Although a modern taxonomic review of the Hawaiian flora will reduce the number of taxa considered valid, roughly 50% of the flora will still be considered threatened or endangered. Currently 11 Hawaiian plants are listed as endangered, one has been proposed as endangered, and the documentation for an additional 9 is currently under review.

An evaluation comparing the number of candidate taxa on each island and in each major ecological zone shows that the islands with the highest percentages of candidate taxa are O'ahu (27.3%), followed by Hawai'i (18.3%), Maui (16.8%), and Kaua'i (14%). The low numbers on islands such as Ni'ihau (1.5%) and Kaho'olawe (0.7%) are apparently partly a reflection of the loss of most of the native vegetation prior to study of these islands, and partly because of lower physiographic diversity. The ecological zones most severely degraded are mixed mesophytic forest, which harbors nearly 33% of the total candidate taxa, and low elevation rain forest with 24%. Not indicated by this analysis is the severe degradation of lowland vegetation (with 14% of total candidate taxa) and coastal vegetation (with 9.5%) that occurred prior to their scientific study. The communities that harbor the majority of candidate taxa on each island are as follows: Kaua'i and O'ahu -- mixed mesophytic forest (56% and 36.4%), low elevation rain forest (14.3% and 40%); Moloka'i and Lana'i -- dryland sclerophyll woodland (21% and 23%), mixed mesophytic forest (37% and 26%); Maui and Hawai'i

-- dryland sclerophyll woodland (16.7% and 13%), mixed mesophytic forest (26% and 20%), low elevation rain forest (16% and 25%), montane rain forest (11% and 10%), subalpine forest and scrub (5% and 10%).

Although the differences among islands and habitats is partly due to the history of man's impact on each island, it probably is more a reflection of an island's age, which affects its topography and the diversity within communities. Topography, in turn, relates to species distributions; that is, the older and more dissected an island, the more local are species distributions. The primary contributing factors to the degradation of native Hawaiian ecosystems are the elimination of habitat through agricultural uses, such as cattle ranching and sugar cane and pineapple cultivation; through urbanization; and through the activities of hoofed animals. Numerous alien plant species in genera such as Psidium, Lantana, Passiflora, and Pennisetum, which dominate habitats formerly occupied by native vegetation, are responsible for smothering existing native species and preventing their regeneration. A myriad of other problems contributes to the deterioration of the Hawaiian flora, including the loss or decline of pollinators, inbreeding depression, and introduced insects such as the black twig borer (Xylosandrus compactus).

Evaluation of the current status of the Hawaiian species of Amaranthaceae, Fabaceae, and Malvaceae clearly shows that members that occur in coastal areas, dryland sclerophyll scrub, and mixed mesophytic forest are currently vulnerable, endangered, or even presumed extinct. Moreover, since nearly all members of these families are in some state of decline, we might generalize that if other families were examined, we would find a similar situation. A chronicle of man's activities in the 'Ewa Plains area on O'ahu is reconstructed as an example of the rapid degradation of a natural community by man.

Public education is one of the principal requirements for initiating adequate conservation programs. There is also a critical need for an adequate classification and inventory of the flora. A project initiated in 1982 at the Bernice P. Bishop Museum to produce a Manual of the Flowering Plants of Hawai'i will provide a modern framework for further in-depth studies of Hawaiian plants. At the same time, it is essential to establish and maintain natural and semi-natural areas in as many community types as possible. Studies of population biology, ecology, and biosystematics are needed in order to develop effective management and conservation programs.

INTRODUCTION

The Hawaiian Archipelago is a great chain of 132 volcanic islands, seamounts, shoals, atolls, and reefs that stretches 2,451 km southeast to northwest across the Tropic of Cancer. The 8 main islands, Hawai'i, Maui, Kaho'olawe, Lana'i, Moloka'i, O'ahu, Kaua'i, and Ni'ihau, make up over 99% of the total land area of 16,641 km^2. The remaining 1%, less than 15 km^2, is comprised of small islets off the shores of the main islands and the Northwestern Hawaiian Islands (Armstrong 1973). The main islands range in age from about 400,000 years at Mauna Kea on the island of Hawai'i to 5 million years on Kaua'i and 3 million years on Ni'ihau. Midway Islands, near the northwestern end of the chain, are about 27 million years old (see summary in Olson and James 1982). If the Emperor Chain of seamounts, which extends northward to Meiji Guyot near the Aleutian trench, is also considered to have arisen over the Hawaiian hot spot (Morgan 1972; Dalrymple, Lanphere, and Jackson 1974), then land could have existed in the vicinity of the present main Hawaiian Islands for over 70 million years, which is the apparent age of Meiji Guyot (Scholl and Creager 1973).

The great diversity of climates in Hawai'i supports a wide range of vegetation types including coastal, dryland sclerophyll scrub and woodland, mixed mesophytic woodland and forest, subtropical rain forest and cloud forest, and xeric alpine scrub.

The Hawaiian Islands have long been known for their remarkable diversity of ecological environments and high level of endemism in their fauna and flora. The disharmonic nature of the flora is directly related to the extreme isolation of the islands; Hawai'i is in fact the most isolated major island group in the world. The native flora consists entirely of waif elements derived by long-distance dispersal. From approximately 270 flowering plants that successfully colonized the islands, evolution has led to roughly 1,200 species of flowering plants, about 95% of which occur only in Hawai'i (Fosberg 1948). Approximately 32 genera (several of questionable status) are endemic, and a few others, such as Charpentiera, have a limited distribution elsewhere, resulting in approximately 16% endemism at the generic level. Interestingly, about 22% of the flowering plant families of the world are found in Hawai'i and none are endemic.

Isolated islands are well known to be vulnerable to the influences of man, both directly through development and habitat destruction, and indirectly through animal and plant introductions (Carlquist 1974). This vulnerability results directly from the evolution of a native biota in the complete absence of man and grazing mammals. In Hawai'i, the introduction of feral animals has been extremely detrimental to the native flora. The decline or elimination of native plant populations is compounded by their often localized distributions and small population sizes.

About 1,600 years ago Polynesian explorers arrived on the pristine shores of these islands (Kirch 1982). They burned and cleared much of the lowlands for their crops and villages (Kirch 1982); pigs (*Sus scrofa* ssp.) and rats (*Rattus exulans*) were introduced (Kirch 1982); and some of the introduced plants, such as kukui (*Aleurites moluccana*), began to compete with the native ones for available space. Undoubtedly some native plant species became extinct, but there is no way of knowing how many. Destruction of native plants greatly increased with the introduction of goats (*Capra hircus*) and European pigs (*Sus scrofa*) by Captain James Cook in 1778. Fifteen years later another English sea captain, George Vancouver, brought sheep (*Ovis aries*) and cattle (*Bos taurus*). Goats and cattle probably have caused more destruction than any other creature save man in Hawai'i. A kapu (taboo) placed on the killing of cattle allowed the growth of enormous herds, until the destruction of native forests was so great that man was forced to contain or destroy the animals. Weedy plant species undoubtedly followed the animals, taking advantage of the disturbance they made.

In this paper we attempt to summarize, based on existing information, the status of the native flowering plants of the Hawaiian Archipelago. The relative endangerment of the Hawaiian flora is evaluated by comparing the numbers of candidate threatened and endangered taxa occurring on each island and in each major ecological zone. The data compiled by the U.S. Fish and Wildlife Service (1980) is derived from the most recent comprehensive list of endangered and threatened plants. Principal past and present threats to native habitats are reviewed for each island. Then the current status of the Hawaiian members of the families Amaranthaceae, Fabaceae, and Malvaceae are discussed to emphasize not only the wide extent to which our flora has deteriorated (especially in this century), but also to indicate the range of factors responsible for its degradation. Finally, the examination of a specific locality ('Ewa Plains) through time is made to obtain a perspective on the sequence and rate of destruction of native habitats in the Hawaiian Islands.

TAXONOMIC PROBLEMS

In order to assess the status of the native flowering plants of Hawai'i, we must first classify and inventory the taxa. A comparison of various estimates of the number of taxa in the Hawaiian flora shows a very wide difference of opinion. The great disparity in the estimates of the number of native Hawaiian plants and their delimitation has been due largely to differences in individual interpretation of observed variability and the paucity of population studies of Hawaiian plants. The extremes in number range from that presented in Hillebrand's flora (1888) which included 705 species, to estimates by St. John (1973), of 1,394 native species (with a fair number described since 1973) and even 20,000-30,000 species as suggested by Degener and Degener (1975). Work currently in progress at the Bishop Museum to produce a _Manual of the Flowering Plants of Hawai'i_ suggests that there are roughly 1,200-1,300 native species. Most studies of Hawaiian plants have been descriptive and taxonomic in nature, based primarily upon the comparison of gross morphological characters of individual plants. Some Hawaiian botanists have maintained to the present day a tradition of describing most variations in plant species in a formal sense, resulting in very large numbers of species, varieties, and forms, many of which are clearly artificial. In order to perform meaningful scientific studies and formulate effective management practices for the remaining Hawaiian flora, we must first have classifications that enable information retrieval and formulation of general biological principles. Indeed, the soundness and utility of a classification can be tested by the ease with which it accommodates information derived from new characters as well as new populations or species.

Modern methods of delimiting species are firmly founded in comparative morphology but are applied in the context of populations and reproductive systems, not merely for cataloging differences between specimens. A great range of techniques and methods is currently employed by systematists in their investigations of the classification, reproduction, and evolution of flowering plants, including chemical analysis, cytology, genetics, hybridization, analysis of breeding systems, common garden experiments, and demographic studies. These techniques and methods also can be exceedingly useful in discerning evolutionary, genetic, and ecological principles that govern the dynamics of plant populations, as well as in formulating realistic management guidelines.

RARE AND ENDANGERED SPECIES OF HAWAIIAN FLOWERING PLANTS

Rare and Endangered Species of Hawaiian Vascular Plants by Fosberg and Herbst (1975) was the first published attempt to give a comprehensive summary of the status of our native vascular flora. This work formed the basis for the Hawaiian taxa included in the Smithsonian Institute's report to Congress published in 1975. It was accepted under the Endangered Species Act and was published by the U.S. Fish and Wildlife Service (1975) as a "Notice of Review." Subsequently, the Service (1976) published a proposal to list some 1,700 plants as endangered, of which 895 are native to Hawai'i. The latest complete revision by the Service was published on December 15, 1980 in the Federal Register.

In the 1980 summary, plants were grouped into 3 categories: 1) plants for which sufficient information exists to support listing the species as endangered or threatened (includes taxa which possibly are extinct); 2) species probably endangered or threatened, but for which more information or research is required to support listing; and 3) plants believed extinct (3A), those with taxonomic problems (3B), and those no longer thought to be endangered or threatened, based on new information (3C). In the 1980 list there are 793 candidate taxa from Hawai'i out of 2,560 candidates for the entire United States, representing 31% of the total taxa listed. California has nearly as many (30%) but has a flora with many times more species. No other state has anywhere near the magnitude of Hawai'i's problem. Although taxonomic review of the Hawaiian flora will reduce the number of taxa considered valid entities, roughly 50% of the vascular flora will still be considered candidate threatened and endangered plants. This problem is discussed further below. In fact, 177 native vascular plants (ca. 10% of the Hawaiian flora) are already known or thought to be extinct, whereas only 106 taxa (0.5%) are extinct from the entire continental United States, including Alaska. The numbers of presumed extinct plants in Hawai'i should be viewed with caution, however, since some Hawaiian species presumed extinct may still be extant. The principal reasons for this are: 1) most of these taxa may have very local and poorly understood distributions, making them very difficult to locate; or 2) many species are exceedingly difficult to identify unless examined during the brief periods when they are in flower and/or fruit. These problems are often compounded by the inaccessibility of many areas in the Islands, either because of the terrain or because scientists increasingly have difficulty obtaining access to private lands.

The fact that there are a large number of highly technical or artificial taxa currently recognized in Hawai'i creates a very serious problem in making an overall evaluation of threatened and endangered species for the Hawaiian Islands. When a contemporary taxonomic review of all the native Hawaiian plants is completed, it is fully expected that the actual number of native species recognized will fall to between 1,200 and 1,300, and we project that the number of taxa recognized on the current list of candidate threatened and endangered plants published by the U.S. Fish and Wildlife Service (1980) will be reduced by about 25-35%. A revised list thus would contain approximately 550-600 taxa, representing roughly half of the total flora using the revised total of 1,200-1,300 species. When we compare these figures to those obtained with the number of native taxa on the 1980 list and previous estimates of native species of 1,500-2,000, the result is a similar percentage of 42-56%. Therefore, it appears very unlikely that a contemporary taxonomic review and subsequent reduction in the numbers of plant species recognized in Hawai'i will have any effect on any overall conclusions drawn from existing lists to establish percentages of candidate taxa on each island and in each major plant community type.

<u>Endangered Species Program</u>

The Federal government presently has 11 Hawaiian plants listed as endangered, 1 has been proposed as endangered, and the documentation for an additional 9 is under review by the U.S. Fish and Wildlife Service's Washington office (table 1). Habitat modification for agricultural or urban development and foraging by introduced herbivores, both past and present, probably are the 2 greatest threats to our native flora.

All the species listed in table 1 are comprised of small, restricted populations. This, too, is a major threat to the continued existence of the plants, but only specific threats have been included in the table. Small numbers of individuals and a restricted distribution make a species particularly vulnerable to environmental disturbances, since a single action such as a fire or natural fluctuation in the population could eliminate the taxon. The presence of small populations also leads to inbreeding, which may result in a loss of reproductive vigor and evolutionary potential due to the concomitant reduction of genetic recombination in normally outcrossing or dioecious species.

<u>Distribution of Threatened and Endangered Plants</u>

Are there discernible patterns to the distribution of threatened and endangered plants in the Hawaiian Islands? Do plants occur in specific habitats or on specific islands? What are the proportions on each island? In order to begin to answer such questions, we examined, by island and ecological zone, the distribution of each taxon included in the 1980 list. The ecological distribution of each taxon was based on a subjective analysis of known collection sites in the plant

Table 1. Native Hawaiian plants listed as endangered (L), proposed to be listed (P), or candidates under review by the Washington office, U.S. Fish and Wildlife Service (C). Data on threats from U.S. Fish and Wildlife Service.

Taxon	Distribution by Island[1]	Status	Threats
Abutilon menziesii	H,L	C	Herbivory by axis deer, cattle, goats, Chinese rose beetle (*Adoretus sinicus*); conversion of habitat for agricultural purposes; fire potential (Funk and Smith 1982).
Achyranthes splendens var. *rotundata*	O	C	Modification of habitat, in the past for agricultural purposes, at present with the development of the harbor, parks and industrial complex at Barber's Point; competition by alien species (Nagata 1981)
Argyroxiphium sandwicense var. *sandwicense*	H	C	Browsing by alien feral mouflon sheep damages the plants and, secondarily, its habitat; adverse management practices as removal of unnecessarily large quantities of fruit for propagation purposes; present exclosure ineffective against sheep (Carr 1981b).
Bidens cuneata	O	L	Soil compaction; erosion promotion; trampling due to hikers; alien species competition; overcollection (Herbst and Takeuchi 1982; Herbst 1984).
Chamaesyce skottsbergii var. *kalaeloana*	O	L	Construction of Barber's Point deep draft harbor; competition with alien vegetation (Fay 1980, 1982).

Taxon	Distribution by Island	Status	Threats
Cyanea superba	O	C	Habitat disturbance by feral cattle, goats, and pigs; invasion of habitat by aggressive alien plants; fire potential from Makua Valley military hikers, hunters, or from impact area (Obata and Smith 1981).
Gardenia brighamii	O, Mo, L, M, H	P	Fire; grazing by introduced herbivores; habitat modification in early and recent times for agricultural purposes; invasion of habitat by alien plants; fruit and seeds eaten by rodents; damage by black twig borer and other alien insects (Gagne 1982).
Gouania hillebrandii	M	L	Browsing, grazing, trampling by feral and domestic livestock; removal of native vegetation with its replacement by alien species; predation by the hibiscus snow scale Pinnaspis strachani (Herbst 1983a).
Haplostachys haplostacha var. angustifolia	H	L	Invasion of fountain grass and other alien species; fire; browsing by feral goats and sheep; military training operations (Herbst and Fay 1979).
Hibiscadelphus distans	K	C	Browsing by feral goats; vandalism or accidental damage from hikers and hunters; fire and damage by rats and the Chinese rose beetle are potential threats (Herbst 1978).

Table 1. Continued.

Taxon	Distribution by Island	Status	Threats
Kokia cookei	Mo	L	Extinct in the wild, 4 grafted plants at Waimea Arboretum, one sapling at Kew (Fay 1979).
Kokia drynarioides	H	L	Grazing and habitat modification by livestock and browsing of plants; invasion and modification of habitat by fountain grass; range fire; destruction of seeds by rodents (Herbst 1983b).
Lipochaeta venosa	H	L	Threats same as Haplostachys (Herbst and Fay 1979).
Mezoneuron kavaiense	K, O, M, H	C	Grazing and browsing by domestic and feral animals; habitat modification by introduced plants; seeds eaten/destroyed by rodents; damage by alien insects as the black twig borer; harvesting of wood (Lamoureux 1982)
Panicum carteri	O	L	Pedestrian traffic; potential vandalism; fire; habitat modification (Herbst and Fay 1981, 1983).
Remya mauiensis	M	C	Browsing, grazing, trampling by feral and domestic animals; now fenced by State (Herbst 1979).
Santalum freycinetianum var. lanaiense	L, M	C	Modification of habitat by domestic and feral animals; conversion of habitat to agricultural land; introduction of alien

Taxon	Distribution by Island	Status	Threats
			plant species; fruit predation by rats (Carr 1981a).
Scaevola coriacea	L, M, O, K, Mo, Ni, H	C	Conversion of habitat into pastures and cane fields, housing and commercial tracts, recreational parks and golf courses; use of Mokuho`onihi Islet as a bombing site (Carr 1981c).
Schiedea adamantis	O	L	Fire potential; overcollection; hikers; alien species invasion and competition (Herbst and Takeuchi 1982; Herbst 1984).
Stenogyne angustifolia var. angustifolia	H	L	Threats same as Haplostachys (Herbst and Fay 1979).
Vicia menziesii	H	L	Cattle; logging; reforestation project; pigs; rodents eat seeds and cut stems (McManus, Altevogt, and MacBryde 1978).

[1] H = Hawai`i; K = Kaua`i; L = Lana`i; M = Maui; Mo = Moloka`i; N = Ni`ihau; O = O`ahu.

community classification scheme presented in table 2. If a particular taxon occurred in more than one plant community, it was counted in each category; thus the total number of taxon occurrences in the table is somewhat higher than the number of taxa evaluated. The results of this evaluation are summarized in table 3, which includes only the flowering plant taxa. The data clearly show that candidate threatened and endangered plants have definite distribution patterns both by island and habitat type. O'ahu has the highest percentage (27.3%) of candidate rare taxa, followed by the islands of Hawai'i (18.3%), Maui (16.8%), and Kaua'i (14.0%). Ni'ihau (1.5%) and Kaho'olawe (0.7%) have low numbers not only because of the low habitat diversity of these islands compared to others, but also because the native biota already largely was gone by the time these islands were first studied. The data also show, as is well known, that in Hawai'i the ecological zones most severely degraded are mixed mesophytic forest (C), which harbors nearly one-third of the total candidate taxa, and low elevation rain forest (D1), with nearly 24% of the total. Not indicated by this analysis was the severe, early degradation of coastal (with 9.5%) and lowland (with 14.7%) vegetation that occurred prior to their scientific study. Moreover, the percentage of endemism of coastal plants is much less than in other ecosystems and thus a coastal plant usually would not appear in a threatened and endangered species list unless threatened throughout its entire range.

Let us now discuss on an island-by-island basis the patterns of distribution of candidate threatened and endangered plants (including those presumed extinct) and the past and current threats to native vegetation on each.

Ni'ihau. This island has been poorly studied. The principal early collections from Ni'ihau were made by Lay and Collie, 1826-27; Remy, 1851-55; and Brigham, 1865 (Forbes 1913). Most of the native vegetation was destroyed by cattle, sheep, and goats prior to the collections made by St. John in 1947 and 1949 (St. John 1959, 1982), when the remaining native vegetation was restricted to cliffs, perched rocks, and a small fenced area around a spring (H. St. John, pers. comm.). At one time Ni'ihau probably had coastal, dryland sclerophyll forest, and based on single collections of *Cheirodendron trigynum* and *Delissea undulata*, some elements of mixed mesophytic forest. Since the latter type of habitat is the most species-rich in Hawai'i, the total number of species listed in table 3 for Ni'ihau most likely is not representative of the diversity of the original flora nor of the number of extinctions that have occurred.

Table 2. Overview of ecological zonation scheme for the high Hawaiian Islands* (letter symbols adapted to Ripperton and Hosaka 1942 map).

I. Zonal Ecosystems [controlled primarily through macroclimate]

1. Xerotropical (leeward lowland to submontane)

A. Savannah and dry grassland [Prosopis savannah and Heteropogon-Rhynchelytrum grassland]

B. Dryland sclerophyll forest (or scrub) [Metrosideros-Diospyros open forests; replacement vegetation: Leucaena scrub and forest]

C. Mixed mesophytic forest (woodland or scrub). [Open Acacia forests; replacement vegetation Psidium guajava, Eugenia cumini forests or woodland]

2. Pluviotropical (windward lowland to upper montane)

D1. Lowland rain forest [Metrosideros forests]

D2. Montane rain forest [Metrosideros-Cibotium and dominantly Cibotium forests]

D3. Upper montane rain or cloud forest [Cheirodendron or Acacia-Metrosideros mixed forests]

3. Cool tropical [upper montane to alpine; only on Maui and Hawai'i]

E1. Mountain parkland and savannah [Acacia-Sophora tree communities, Deschampsia tussock grassland]

E2. Subalpine forest and scrub [Sophora-Myoporum tree communities, Styphelia-Vaccinium-Dodonaea-Metrosideros scrub communities]

E3. Sparse alpine scrub [Styphelia, Vaccinium] and moss desert [Rhacomitrium lanuginosum var. pruinosum]

Table 2. Continued.

II. Azonal Ecosystems [controlled primarily through edaphic factors]

4. Coastline
   - windward beach, dune and rock-substrates [Scaevola scrub, Pandanus and Hibiscus tiliaceus forests]
   - leeward beach, dune and rock-substrates [Prosopis scrub and woodland]

5. Bogs
   - low- and mid-elevation bogs
   - montane bogs

6. Geologically recent
   - vegetation on new volcanic materials [e.g., Metrosideros-Sadleria, Gleichenia, and Lycopodium]
   - lava tubes and other recent geological features

7. Aquatic
   - fresh water lakes
   - streams
   - coastal brackish and marine ponds

8. Cliffs

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* Synthesized by Gagne and Mueller-Dombois (n.d.) from earlier works (Egler 1939; Ripperton and Hosaka 1942; Krajina 1963, Knapp 1965; Mueller-Dombois and Krajina 1968; Fosberg 1972).

Table 3. Occurrence by island and ecological zone of the flowering plant taxa listed in the December 15, 1980 <u>Federal Register</u>. Ecological zone symbols are those listed in Table 2.*

	Ecological Zone															
	4	A	B	C	D1	D2	D3	E1	E2	E3	5	6	8	?	Total	%
Main Islands (HI):																
Ni`ihau (Ni)	3	5	3	1	--	--	--	--	--	--	--	--	2	2	16	1.5
Kaua`i (K)	6	0	12	87	22	1	9	--	--	--	8	--	4	5	154	14.0
O`ahu (O)	23	0	17	109	120	4	11	--	--	--	1	--	3	11	299	27.3
Moloka`i (Mo)	13	0	23	39	13	11	1	--	--	--	0	--	1	4	105	9.6
Lana`i (L)	9	3	24	28	27	2	9	--	--	--	--	--	0	4	106	9.6
Maui (M)	14	3	31	48	30	20	5	1	10	6	2	1	1	13	185	16.8
Kaho`olawe (Ka)	1	1	6	--	--	--	--	--	--	--	--	--	0	0	8	0.7
Hawai`i (H)	14	3	26	41	50	20	7	4	20	2	2	0	0	12	201	18.3
Offshore Islands:																
Mokoli`a	1	--	--	--	--	--	--	--	--	--	--	--	--	--	1	0.1
Ka`ula	1	--	--	--	--	--	--	--	--	--	--	--	--	--	1	0.1

Table 3. Continued.

	Ecological Zone														
	4	A	B	C	D1	D2	D3	E1	E2	E3	5	6	8	?	Total	%
Northwestern Hawaiian Islands (NWI):																
Kure (Ku)	5	--	--	--	--	--	--	--	--	--	--	--	--	--	5	Ø.4
Midway (Mi)	3	--	--	--	--	--	--	--	--	--	--	--	--	--	3	Ø.3
Pearl & Hermes (PH)	1	--	--	--	--	--	--	--	--	--	--	--	--	--	1	Ø.1
Lisianski (Li)	1	--	--	--	--	--	--	--	--	--	--	--	--	--	1	Ø.1
Laysan (La)	7	--	--	--	--	--	--	--	--	--	--	--	--	--	7	Ø.6
Necker (Ne)	1	--	--	--	--	--	--	--	--	--	--	--	--	--	1	Ø.1
Nihoa (N)	1	--	4	--	--	--	--	--	--	--	--	--	--	--	5	Ø.4
Total	1Ø4	15	146	353	262	58	42	5	3Ø	8	13	1	11	51	1Ø99	
%	9.5	1.4	13.3	32.1	23.8	5.3	3.8	Ø.5	2.7	Ø.7	1.2	Ø.1	1.Ø	4.6		

* The question mark (?) on the habitat type axis indicates that habitat is unknown; hyphens (--) indicate that a particular community type does not occur on that island.

Kaua'i. More than one half (56%) of the candidate threatened and endangered species on Kaua'i occur in the mixed mesophytic forest of the Koke'e region. Currently, this entire area is very vulnerable, largely due to present land management practices. The area has been developed for agricultural uses such as grazing cattle and also has been impacted by the development of water collecting systems for sugar cane fields at lower elevations. Another major threat to the native plants is competition with alien plant species such as the blackberry (Rubus argutus, incl. R. penetrans), introduced for its fruit; the faya tree (Myrica faya), for reforestation (Neal 1965); the banana poka (Passiflora mollissima), as an ornamental; and the karakanut (Corynocarpus laevigata) which was broadcast by air over the Koke'e area after World War I. Development for recreation also has had a very great impact on the area through extensive hiking trails; construction of vacation cabins; the deliberate introduction of animals such as horses for riding, and the black-tailed deer (Odocoileus hemionus) and Guinea fowl (Numida meleagris) for hunting; as well as the maintenance of populations of feral goats and pigs for hunting.

Mixed mesophytic and rain forest ecosystems on Kaua'i are still not fully known and have not been recently studied. The rediscovery of species presumed extinct, such as 2 populations of Remya kauaiensis and new populations of Isodendrion forbesii (T. Flynn, pers. comm.), indicates that our knowledge of Kaua'i is yet incomplete.

Kaua'i has the highest number of candidate threatened and endangered bog species (8) for Hawai'i, primarily due to the fact that it has the most extensive bog system in the Islands. Since most alien plant species are not adapted to bog environments, bogs are among the least disturbed habitats in the Islands. In bogs alien species are principally confined to hiking trails and their immediate vicinity. Other than hiking trails the only significant disturbance to the bogs appears to be from invasion by pigs, but this can be a considerable disruptive factor as seen in parts of the Alaka'i Swamp (W. Takeuchi, pers. comm.).

O'ahu. Like Kaua'i, this older island is highly dissected; as a result, ecological zones in mountainous areas often have abrupt transitions and therefore species often have very localized distributions. Nearly 75% of the total candidate threatened and endangered plant taxa on O'ahu occur in mixed mesophytic forest and low elevation rain forest, the predominant montane communities on O'ahu. Nearly 30% of the total candidate taxa on O'ahu (70% of the low elevation rain forest category) are in the genus Cyrtandra. The large number of Cyrtandra species (83) is partly the result of a detailed study of the O'ahu species by St. John (1966) and the description of a large number of artificial taxa, including species based on minor morphological features and species known from single specimens which now appear to represent hybrids. Despite these problems, a large number of Cyrtandra species on O'ahu resulted from the isolation of Cyrtandra populations in many dissected valleys. Wind direction is the same as the long axes of the valleys, so the spread of plants with low dispersibility such as Cyrtandra is primarily up and down the valleys. Moreover, the narrow ecological range of most Cyrtandra species (mixed mesophytic forest to low elevation rain forest) further limits dispersal into adjacent valleys. Careful evaluation of Cyrtandra on O'ahu is needed after a more conservative taxonomy is established and possible hybrids are removed from consideration. On other islands the situation for speciation is different. Either they are geologically too young to have developed such intricate valley and gulch topography with low elevation rain forest (East Maui and Hawai'i), or they are too highly eroded (Kaua'i).

The remaining 37 candidate threatened and endangered taxa of low elevation rain forest of O'ahu (30% of O'ahu rain forest category) occur primarily in the Ko'olau Mountains, where the situation is among the most critical in the Islands; the list of threats here is almost endless. Degradation of habitats in the Ko'olau Mountains began with the development of trails by early Hawaiians that presumably allowed movement of naturalized species up into the range. Low elevation areas were altered even more by prehistoric Hawaiians through cultivation of taro and sweet potatoes in many valleys such as Manoa and Nu'uanu (C. Lamoureux, pers. comm.). Impacts in this area have been far greater since the arrival of western man. Severe damage has resulted from urbanization, cattle, fires, military use, and introduction of alien plant species. The grazing of cattle probably has been the most detrimental to the native biota; for example, the remaining forests of the lower slopes of Manoa Valley were essentially denuded by cattle and woodcutters during the earlier parts of this century (Campbell 1920). Areas such as Manoa are now reforested entirely with introduced species such as Psidium cattleianum, Eucalyptus spp., Eugenia spp., and Persea americana. More recently, the military has leased large areas of the Ko'olau Mountains for training, resulting in many plants being trampled in military exercises and destroyed in fires from the explosion of ordnance. Fires also have altered many areas of native vegetation that are not especially fire resistant and subsequently have encouraged invasion by alien species (Smith, this volume).

Introduced plants now constitute the bulk of the vegetation below 600 m elevation. In addition to the alien plants mentioned above, other species such as Koster's curse (Clidemia hirta) have severely impacted the rain forest vegetation of the Ko'olau Mountains since introduction prior to 1941 (Wester and Wood 1977). Clidemia has since colonized the Wai'anae Mountains, where it probably will have the same impact. Other plants such as Citharexylum caudatum, which currently is spreading into the Ko'olau Mountains out of Manoa Valley, may repeat the pattern exhibited by Clidemia. In summary, almost no undisturbed native plant communities occur below 600 m elevation other than a few scattered patches of native coastal strand vegetation. Only a few hardy native species such as Canthium odoratum and Alyxia olivaeformis still occur in small patches mixed in the forests and scrub vegetation consisting of alien species.

Approximately 36% of the O'ahu taxa listed in the 1980 list occurs in mixed mesophytic vegetation. The extant species in this category occur primarily in the Wai'anae Mountains, the oldest on O'ahu, where a very diverse mixed mesophytic forest and perhaps the best development of this type in the Islands occurs. Mixed mesophytic vegetation formerly also was in areas above Honolulu where much early collecting was done; however, the forest now has been nearly eliminated there. There are many threats to the unique vegetation of the Wai'anae Mountains, including the construction of military installations such as radar tracking stations and Nike missile sites, feral animals, and introduced plants such as guava (Psidium spp.) and koa haole (Leucaena leucocephala).

The low elevation and coastal zones of O'ahu have fared even worse than the uplands. Most coastal and dryland sclerophyll vegetation has been completely eliminated by land development.

Moloka'i and Lana'i. The distribution and total number of candidate threatened and endangered taxa are very similar for these 2 islands. Most of the lower elevation vegetation on both islands has been largely replaced by grazing land and pineapple fields. Feral animals also have played a major role in the degradation of the native ecosystems. Forestry plantings of alien tree species such as Eucalyptus spp., paper bark (Melaleuca quinquenervia), Alnus spp., and Pinus spp. for erosion control at higher elevations have prevented the return of native rain forest species to many areas of East Moloka'i. A few pristine and nearly inaccessible areas such as Oloku'i Plateau still exist on Moloka'i. The Nature Conservency recently purchased conservation rights to a portion of the remaining native rain forest on East Moloka'i and created the Kamakou Preserve. It presently is developing a management system that includes removal of alien vegetation and exclusion of feral animals from the preserve (Holt and Fox, this volume).

In the lowlands of Lana'i almost all native ecosystems have been eliminated and only small pockets of native vegetation still remain, such as at Kanepu'u. A few native plants such as Lipochaeta heterophylla, Gossypium sandvicense, Erythrina sandwicensis, and Chamaesyce celastroides persist in these areas.

Roughly 62% of the Lana'i taxa in table 3 are restricted to the Lana'ihale area, which harbors the only mixed mesophytic and rain forest on the Island. Lana'ihale formerly was degraded by feral goats, which were essentially eliminated in the 1930's. More recently, as the goat population increased, they were again reduced significantly. Another important impact to Lana'ihale has been caused by the planting of alien species along the crest. Good remnants of native vegetation still exist in the deep gulches of this area; however, a continuing major threat is the presence of axis deer (Axis axis).

Maui and Hawai'i. The distribution and total number of threatened and endangered plants on these 2 islands are very similar but differ from the other islands. Apparently fewer endangered species occur on Maui and Hawai'i in each habitat. The age, elevation, and geological structure of each island govern the types of habitats that develop, which in turn influences floristic diversity. The younger islands of Maui and Hawai'i are topographically less dissected and thus the transitions from habitat to habitat are generally more gradual. Therefore, specific plant community types and species distributions are often wider and more continuous on the younger islands. In contrast, topography of the older islands of Kaua'i and O'ahu is more varied and highly dissected, resulting in more opportunities for speciation as well as narrower species distributions.

Mountains on Maui and Hawai'i are high enough to extend above the inversion layer and thus have 3 ecological zones not present on the older, lower islands: mountain parkland, subalpine forest, and alpine scrub (table 2). These islands also have the largest areas of montane rain forest. Although the factors mentioned above may partially explain the numbers of threatened and endangered species and their distribution (table

3), another factor may be our lack of knowledge of Maui and Hawai'i. Both islands had large areas altered by cattle and other agricultural practices long before their floras were extensively studied (Stone, this volume). Therefore, it seems likely that some plant species were extinct before they could be discovered and described (St. John 1976, 1978). Extinctions have been well documented for birds at least on Kaua'i, O'ahu, and Moloka'i (Olson and James 1982). They found that the fossil avifauna consists of between 2 and 3 times as many species as that known historically.

As a direct result of man's use of the land, there are candidate threatened and endangered plants in nearly every habitat type on these 2 islands. Some examples of man's impact are discussed below.

1. Agriculture. Prehistoric Hawaiians cleared and intensively cultivated large tracts of land in the Waimea area on the island of Hawai'i (Clark and Kirch 1983). Cattle were introduced in the 1790's and protected by a kapu (taboo). This resulted in large herds of feral cattle and led to the establishment of large ranches such as Parker Ranch, among the largest privately owned ranches in the United States. On Maui several large ranches cover extensive areas of Haleakala. Sheep ranches such as the one at Humu'ula, Hawai'i, also were established on these islands, but none are still in operation.

Crop cultivation also has irreversibly changed some areas. Hawaiians cleared extensive lowland areas prior to Cook's arrival. Beginning in the middle 1800's, large tracts of land were cleared on Maui for wheat, Irish potatoes, pineapple, and vegetable crops. Small vegetable and flower truck farms still exist, including those of Kula, Maui, and Waimea (Kamuela), Hawai'i. Sugar cane and more recently macadamia nut trees occupy extensive acreage on both islands. The largest known population of *Neowawraea phyllanthoides* (formerly, *Drypetes*), an endemic species which is nearly extinct, was greatly reduced when new land was cleared for a macadamia nut farm on the Kapu'a tract, Hawai'i.

2. Silviculture. Although logging in the past has been a relatively minor industry in Hawai'i, silviculture has already had a major impact on the native vegetation, and it may be important in the future if native trees are used for energy production. Native species, primarily koa (*Acacia koa*), are harvested, and plantations of eucalyptus and other aliens have frequently been established by replacing the native vegetation. In the past, tree ferns (*Cibotium* spp.) have been harvested for their starch, and the scales on the

fronds were used for stuffing mattresses and furniture. Currently, croziers are still harvested as a vegetable, and the trunks are used as a growth medium in the large orchid industry and whole plants in landscaping.

3. Introduced species. Fountain grass (Pennisetum setaceum) is a good example of an alien weed that has had a great impact on the environment on the island of Hawai'i. Originally introduced as an ornamental in the early 1920's on the Hu'ehu'e Ranch, fountain grass is an aggressive invader and now is becoming widespread and abundant primarily in dry areas. This species creates a fire hazard by adding large amounts of organic matter to the ecosystem. Moreover, it is a fire climax species and among the first pioneers to quickly move into an area after a fire. This appears to prevent other plants from becoming established (Smith, this volume).

Openings or disturbances of an area, as from the browsing and grazing of feral animals, activities by man, or a phenomenon like 'ohi'a (Metrosideros polymorpha) dieback (Mueller-Dombois, this volume), allows the entry of alien species into native communities. In addition to directly destroying native plants, feral animals also spread introduced plants. For example, it is probable that introduced game birds recently have spread the European olive (Olea europea) near Waimea on the island of Hawai'i. Passiflora mollissima and Myrica faya have been spread by feral pigs and game birds in Hawai'i Volcanoes National Park and other areas (Warshauer et al. 1983; L. Stemmermann, pers. comm.).

4. Development. Urbanization has occurred rapidly in areas such as Kihei and Ka'anapali, Maui, and Waimea, Hawai'i. The principal impact of urbanization in these areas has not been the direct destruction of native communities, since most of the development is in already severely disturbed areas (primarily from sugar cane agriculture); rather, the effects have resulted indirectly from the continued demand on an area's resources, such as for the disposal of wastes and from the loss of natural water percolation.

Kaho'olawe. The current low number of candidate threatened and endangered taxa on Kaho'olawe may be due to our lack of knowledge of the original vegetation. Collections by Jules Remy sometime between 1851 and 1855, as well as studies of charcoal from archaeological excavations (G. Murakami, pers. comm.), give some indication that there once was coastal and dryland sclerophyll forest on Kaho'olawe. The discovery of charcoals of species never otherwise recorded from the

Island indicates that the prehistoric Hawaiians may have cleared much of the existing vegetation (G. Murakami, pers. comm.). Soon after their introduction, cattle, goats, and sheep largely eliminated the remaining native vegetation. Goats, however, continue to roam the island in large numbers and presumably prevent the return of any significant amount of native vegetation.

Northwestern Hawaiian Islands. With the exception of Laysan (Schauinsland 1899; Lamoureux 1963), the flora of these islands was not extensively studied prior to heavy human impact. Human use includes military operations (principally on Kure, Midway Islands, and French Frigate Shoals), guano mining and feather harvesting (Lisianski and Laysan), pearl oyster harvesting (Pearl and Hermes Reef), and introduction of rabbits probably for food (Lisianski and Laysan). In addition, archaeological evidence from Necker and Nihoa indicates that these islands were used by prehistoric Hawaiians.

With the exception of Nihoa, the flora is essentially coastal, consisting primarily of widespread strand species. There are 13 presently recognized taxa endemic to the Northwestern Hawaiian Islands. Among these, 4 are presumed extinct, *Achyranthes atollensis*, *Cenchrus laysanensis*, *Phyllostegia variabilis*, and *Pritchardia* sp. (undescribed from Laysan); the remainder are considered endangered or threatened.

STATUS OF HAWAIIAN AMARANTHACEAE, FABACEAE, AND MALVACEAE

In this section we examine the current status of native Hawaiian species of Amaranthaceae, Fabaceae, and Malvaceae. These families were arbitrarily selected as representative of the flora because we thought it would be useful to survey the status of several taxonomic groups in their entirety. In view of the space and time limitation only families that are small to medium-sized in Hawai'i were selected. Moreover, we selected families that occur predominantly in dryland sclerophyll to mixed mesophytic forest because it was clearly demonstrated in the previous section that these communities have been the most severely degraded so far in Hawai'i. Other examples of plants occurring primarily in rain forest will be given in the discussion. The analysis of the status and principal causes for the decline of the species in these families (table 4) is based primarily on observations by the authors and other Hawaiian biologists.

This summary clearly shows that most species in these families that occur in coastal, dryland sclerophyll scrub or forest and mixed mesophytic forest are

Table 4. Status and some causes of the decline of species in Amaranthaceae, Fabaceae, and Malvaceae in the Hawaiian Islands. Island symbols for distributions are those given in table 3

Taxon	Distribution by Island	Status[1]	Possible Reasons for Degradation
AMARANTHACEAE			
Achyranthes (3 spp.)	dryland scrub and coastal		
A. atollensis	NWI	Ex	Reasons for decline unknown.
A. mutica	K, H?	Ex	Probably severely impacted in pre-Cook times; known only from two collections.
A. splendens	O, M, Mo, L	V	Some populations appear stable, others severely depleted or lost by development.
Amaranthus brownii	N, dryland scrub	E	Perhaps below critical population size, gene pool severely reduced; low germination; perhaps may have been impacted in pre-historic times.
Charpentiera (5 spp.)	HI, mixed mesophytic forest	V	The black twig borer has severely reduced the numbers of plants of this genus (Hara & Beardsley 1979). A native insect in the endemic genus Mapsidius with no close relatives also affects the growing tips; it is unclear whether this is part of a natural cycle or the result of an

Taxon	Distribution by Island	Status	Possible Reasons for Degradation
			ecological imbalance (F. Howarth, pers. comm.).
Nototrichium (2 spp.)	dryland scrub		
N. humile	O	V	Very local species, could easily become extinct from habitat loss and competition with weeds.
N. sandwicense	HI	V	Decline due to habitat destruction.
FABACEAE			
Acacia (2 spp.)			
A. koa	HI, dryland to rain and subalpine forest	S	Currently widespread; however, fast-growing aliens such as *Passiflora mollissima* probably are outcompeting seedlings in certain localities and decreasing fecundity of adults. It was severely depleted in the past when land was converted to pastures. Introduced insects are also a periodic problem, e.g., *Uresiphita polygonalis* which defoliates plants, and the black twig borer (Hara & Beardsley 1979). Other threats include logging and increased infestation by koa rusts, *Uromyces* spp., now vectored by the alien insect *Psylla uncatoides* (Leeper & Beardsley 1973; Howarth, this volume), and

Table 4. Continued.

Taxon	Distribution by Island	Status	Possible Reasons for Degradation
			seed predation by such insects as the koa haole seed weevil, Araecerus levipennis (Stein 1983a, 1983b).
A. koaia	Mo, M, H, dryland forest	E	Severely depleted due to habitat degradation from feral and domestic animals, competition with introduced grasses, and fires. Also, it was popular with Hawaiians for making spears and canoe paddles (Rock 1913).
Canavalia (ca. 10 spp.)	HI, coastal to mixed mesophytic forest	S	Most of the species of this genus appear to be relatively stable. Canavalia kauensis, only recently described, first appeared in an experimental exclosure on Hawai`i, clearly indicating past degradation primarily by goats (Mueller-Dombois and Spatz 1972).
Cassia gaudichaudii	HI, dryland forest	V	Uncommon at the present time, primarily due to dryland forest destruction.
Erythrina sandwicensis	HI, coastal and dryland forest	S	Previously more widespread; possibly being replaced by Prosopis pallida or Leucaena leucocephala in parts of its range. Original bird pollinator presumed to be rare or extinct, but it currently is pollinated extensively by the Japanese white eye (D. Neill, pers. comm.).

Taxon	Distribution by Island	Status	Possible Reasons for Degradation
Mezoneuron kavaiense	HI, dryland to mixed mesophytic forest	R	Current low numbers are primarily due to conversion of much dryland and mixed mesophytic forest habitat to pasture and agricultural land, browsing by feral and domestic animals, rodents that eat its seeds, black twig borer infesting young wood, and fires. Perhaps depleted by previous use by Hawaiians for spears and in fishing (Rock 1913). It is currently under review by U.S. Fish & Wildlife Service for listing.
Sesbania (ca. 8 spp.)	HI, coastal and dryland forest	E or S	All species have been drastically impacted. Their habitat, low dry coastal areas, has deteriorated due to development of resorts, browsing by feral animals, and off-road vehicle traffic. The only populations which appear stable are those on Nihoa and Necker.
Sophora chrysophylla	HI, dryland to rain forest and subalpine forest	V	The single native species in this genus is common, but much less so than in the past, especially in subalpine scrub of Haleakala and Mauna Kea. In these areas its decline has primarily been caused by browsing of goats and sheep (Scowcroft 1983; Scowcroft and Sakai 1983) and specifically from the destruction of seedlings, thus preventing

Table 4. Continued.

Taxon	Distribution by Island	Status	Possible Reasons for Degradation
			regeneration (Scowcroft and Giffin 1983). With the eventual removal of sheep and feral goats from Mauna Kea, this population may be improving (Scowcroft 1983).
<u>Strongylodon</u> <u>ruber</u>	K, O, Mo, M, H, mixed mesophytic forest	?	This genus serves as an example of a group for which very little is known at present; thus we are unable to evaluate its current status.
<u>Vicia</u> <u>menziesii</u>	H, montane rain forest	E	It is an extremely rare species that is listed as endangered by the Endangered Species Act but currently is threatened by ungulates, rodents, and by bulldozing, logging, and conversion of its habitat to pasture (Warshauer and Jacobi 1982; Ralph, Pearson, and Phillips 1980). An estimate of 1,500-2,000 individuals was made prior to 1981. A recent survey by the State Division of Forestry and Wildlife showed a serious decline in the populations. Its taxonomic relationships were reviewed by Lassetter and Gunn (1979).
<u>Vigna</u> (3 spp.)			
<u>V.</u> <u>marina</u>	HI, coastal	S	An indigenous, widespread, successful strand plant. The Hawaiian populations currently are stable.

Taxon	Distribution by Island	Status	Possible Reasons for Degradation
V. o-wahuensis	K, O, Mo, coastal (to dryland scrub?)	R	Extremely rare; its severe decline is due to habitat loss: most of former habitat is now pasture, resorts, or beach parks.
V. sandwicensis	L, M, H, coastal	R	Same problem as V. o-wahuensis.
MALVACEAE			
Abutilon (4 spp.)			
A. eremitopetalum	L, dryland scrub	Ex	Extinction due to habitat destruction.
A. incanum	HI, coastal to dryland scrub	S	Apparently stable or only slowly declining.
A. menziesii	L, H, dryland scrub	E	Decline due to habitat destruction; presently only a few individuals known.
A. sandwicense	O, mixed mesophytic forest	R	Reasons for decline unknown. Seedlings have not been observed recently, perhaps due to rodent predation.
Gossypium sandvicense	HI, coastal	S	Situation of relative stability may rapidly change as coastal areas are developed.
Hibiscadelphus (6 spp.)	K, L, M, H, dryland to mixed mesophytic forest	E & Ex	Relictual at time of first collection in 1868; habitat destruction and rodents feeding on any seeds produced and

Table 4. Continued.

Taxon	Distribution by Island	Status	Possible Reasons for Degradation
			stripping the bark of stems perhaps will lead to extinction of entire genus relatively soon. Also, its unknown bird pollinator is probably rare or extinct. Presently 14 individuals are known collectively of H. distans, H. hualalaiensis, and H. crucibracteatus (Hobdy 1984), while H. bombycinus, H. giffardianus (2 wild seedlings in cultivation), and H. wilderanus are extinct.
Hibiscus (ca. 10 spp.)	HI, coastal to rain forest	S	Populations have been degraded in past; presently most species appear rather stable, with a few exceptions.
H. brackenridgei	O, Mo, L, M, H, dryland scrub	E	Extremely endangered due to habitat destruction and grazing by cattle.
Kokia (4 spp.)	K, O, Mo, H, mixed mesophytic to dryland forest	E or Ex	Situation very much like Hibiscadelphus; K. cookei (in cultivation) and K. lanceolata are extinct while K. drynarioides and K. kauaiensis are known from only small relictual populations. Principal causes for depletion are habitat destruction, stripping of bark and leaves by cattle, sheep, goats, and perhaps by previous use by Hawaiians to dye fishing nets (Rock 1913), and rodents destroying seeds.

Taxon	Distribution by Island	Status	Possible Reasons for Degradation
Sida (ca. 10 spp.)	HI, coastal to mixed mesophytic forest	S	Currently rather stable since this group grows fairly well in disturbed habitats, although it probably was more common in pre-contact times.

[1] The symbols in the status category, Extinct (Ex), Endangered (E), Vulnerable (V), and Rare (R), are adapted from *IUCN Plant Red Data Book* categories (Lucas and Synge 1977) and elaborated by Synge (1981, Appendix 3) except Stable (S), which is used for species that are known to be reproducing and apparently have relatively stable numbers.

currently vulnerable, endangered, or even presumed extinct. Moreover, most of the taxa classified as presently "stable" appear to have been more common in the past, but at the present time are either declining rather slowly or in some cases appear to be maintaining their present status. Other species, such as Vigna marina, which is an indigenous widespread strand plant, seems able to persist in severely altered habitats. Since nearly all members of these families are in some state of decline, we might generalize that if other families were examined, we would find a similar situation. It is possible that if the current threats are not removed, a great majority of the native Hawaiian ecosystems will be forever altered or destroyed in the next few decades. A great number of native species, however, appear to be able to persist in the face of extreme alteration of their habitat. For example, so far, with a hundred years of disturbance, about 10% of the known native species have become extinct. Fifty percent of the known extant species are candidates for threatened or endangered species classification. It is inevitable that if the native ecosystems continue to deteriorate, a much greater rate of extinction will occur in the near future.

The principal cause of decline, at least of the species in these families, is the outright loss or severe alteration of their habitat (table 4). The grazing and browsing of feral animals is perhaps the next greatest cause of destruction, as is shown here and outlined in the previous section on an island-by-island basis. Beyond these very obvious reasons for the deterioration of the Hawaiian flora, the myriad of other problems perhaps only touched upon in this analysis are much less obvious and usually more difficult to assess. For example, we presume that the original bird pollinators of species such as Erythrina sandwicensis and species of Hibiscadelphus are rare or extinct. Most of our present knowledge of pollination mechanisms is based primarily on floral morphology; direct observational studies are almost entirely lacking. We have suggested that there may be inbreeding depression resulting from extreme reduction of population size in plants such as Amaranthus brownii; however, there may be a dormant seed pool which could dramatically increase the population size in a favorable year. Again, we lack data that contribute to understanding the situation. Another problem requiring detailed study is the interaction between introduced insects and native plants. For example, the black twig borer, Xylosandrus compactus, is known to be a problem on many native plants such as Neowawraea phyllanthoides (Samuelson 1981; Howarth, this volume). This pest apparently was introduced prior to 1931, when H.L. Lyon collected it on elderberry plants imported from Singapore; 30 years later the species was collected again and was obviously spreading onto native plants (Samuelson 1981). Situations in which native insects are herbivorous on native plants, such as the insects that attack the young tender growth and meristems of Charpentiera species, are especially important to understand. We do not know if these situations are naturally cyclic or result from ecological imbalances triggered by perturbations of the ecosystems. The detection of some of these problems requires the careful, detailed field studies that are critically needed for most Hawaiian plants.

Another problem requiring detailed, long-term study is the dynamics of populations composed of native and alien species. The successional sequence that commences after a catastrophic event such as Hurricane Iwa, which hit Kaua'i in November 1982 and devastated a large portion of the koa forests in the Koke'e area, is unknown. Fast-growing naturalized species such as Passiflora mollissima and Rubus argutus that rapidly invade newly opened areas may largely replace the numerous koa seedlings that have begun to grow in devastated areas. The Hurricane has provided a rare opportunity for study.

Rain forest ecosystems have not been as greatly altered as other ecosystems and they are currently declining at a slower rate. If present land use practices and associated threats continue, however, these montane communities undoubtedly will ultimately suffer the same fate as lower elevation ecosystems. Although many rain forest species are currently "stable" or appear to have slow rates of decline, many others have been more severely affected. For example, some rain forest species of Campanulaceae are already extinct, such as Cyanea giffardii, which previously occurred only in low elevation rain forest near Glenwood on the windward slope of Kilauea, Hawai'i, and apparently was eliminated by development. Other problems contributing to the decrease in the number of many Campanulaceae include rats that girdle the soft woody stems, overcollection of certain rare taxa, and possibly genetic inbreeding. The invasion of many rain forest areas by feral pigs rapidly contributes to the degradation of the whole ecosystem through rooting activities, opening the habitat for alien species, and dispersing certain alien plants. Another Campanulaceae genus, Delissea, was rare and, for reasons that are unclear, was apparently already declining at the time of its original discovery.

HISTORY OF THE FLORA OF 'EWA PLAINS

Unless otherwise indicated, the information presented here was adapted from the 'Ewa Plains botanical survey by Char and Balakrishnan (1979). This work is an unpublished report prepared for the U.S. Fish and Wildlife Service to map and census the rare and endangered plant species found on the 'Ewa coastal plains.

Setting and History

'Ewa Plains is located on the southwestern, leeward side of the island of O'ahu. It is bounded on the west and south by the Pacific Ocean, the east by Pearl Harbor, and the north by the southern end of the Wai'anae Mountains and the Schofield Plateau. The Plains extend from sea level to an elevation of 30 m, 6-8 km inland. The area lies in the rain shadow of the Ko'olau Mountains and has an average annual rainfall of 508 mm, most of it from southerly kona and winter storms. As a result, the climate has been classified as summer drought, an arid climatic condition characterized by long dry periods interrupted by periods of rain. The mean annual temperature ranges between 22.2 and 25.5 C with a relative humidity range of 60-70% (Kartawinata and Mueller-Dombois 1972; Richmond and Mueller-Dombois 1972).

The Plains were formed during the Pleistocene when the rise and fall of sea levels, which fluctuated approximately 120 m (Gascoyne, Benjamin and Schwarcz 1979), alternately created, flooded and exposed fringing coral reefs, allowing the valleys to cut into the exposed reefs. They are composed of a hard but extremely permeable calcareous substrate with deposited erosional products from the Wai'anae Mountains.

The Hawaiian Islands were first occupied by prehistoric settlers as early as 1,600 years ago (Kirch 1982). The eastern, Pearl Harbor end of 'Ewa Plains was populated and was a center for aquacultural activities as well as inshore fishing (Handy and Handy 1972). The western, Barbers Point area was sparsely settled, primarily by transient or seasonal fishing populations originating from the Pearl Harbor area. However, long-term or permanent occupation of the same area has been suggested by recent archaeological finds at a number of sites, and some subsistence agriculture may have been practiced. Dates of basaltic-glass samples from 2 cultural sites from this area yielded dates of 1612-1650 A.D. +/- 30 years (Sinoto 1978).

The area was observed by Western man very early in the historical period (Vancouver 1801). By the mid-1800's, it was occupied by a number of cattle ranches. The drilling of the first artesian well on O'ahu in Honouliuli in 1879, in conjunction with the construction of a rail line from Honolulu to western O'ahu in 1888, encouraged further settlement of 'Ewa Plains. In 1890, the 'Ewa Sugar Plantation was started and in 1893 a 20,000-plant sisal (Agave sisalana) plantation was started. By the mid 1920's the area contained many truck farms, piggeries, poultry farms, and a coconut plantation.

Military development began first with a mooring station for airships in the 1930's and continued with upgrading the facilities to include an airstrip and support structures. By the 1950's the area contained an airbase, an ammunition facility, and military housing and covered nearly 33% of the Plains area.

By the 1970's, besides the presence of the military and agricultural development, the area also contained several tracts of residential housing, quarries, recreational, commercial, and industrial areas, including an oil refinery. Today, agriculture and occupied land cover 88% of 'Ewa Plains, of which sugar cane fields occupy 36%; military lands, 33%; and 19% is composed of residential, recreational, and commercial areas and agriculture other than sugar. The remaining 12% of the Plains still contains native species in highly modified ecosystems.

The Flora of 'Ewa Plains

'Ewa Plains is an example of an area where the flora has been drastically changed by the alteration of natural ecosystems. The pre-contact flora of this area and others like it is not well known. However, a flora can be reconstructed from observations and collections from the remnant populations of native plants from Barbers Point and other similar areas (table 5). Corroborative evidence from the analysis of fossil snails also gives credence to the reconstruction (Christensen and Kirch, in prep.).

There is some question as to how extensively prehistoric Hawaiians altered the native 'Ewa Plains flora. Direct evidence from descriptions and collections of the area from this period is lacking, as in most places in Hawai'i. However, indirect evidence from archaeological and faunal finds suggests that prehistoric man might have had a substantial impact.

The species composition of land snails may serve as an indicator of the type of environment that existed in an area (Kerney 1966; Evans 1972; Bobrowsky 1984). Recent archaeological excavations conducted in the Barbers Point area have yielded an abundance of avian and terrestrial molluscan remains (Olson and James 1982; Sinoto 1978), many of which were extinct (Olson and James 1982; Christensen and Kirch, in prep.). Changes in species composition of the snail and avifauna found in pre-man, pre-Cook, and historic archaeological strata have suggested that these animals may

Table 5. Reconstruction of the major elements of the flora of 'Ewa Plains.[1]

Coralline area strand vegetation

Achyranthes splendens var. *rotundata*
Fimbristylis pycnocephala
Jacquemontia sandwicensis
Lycium sandwicense
Myoporum sandwicense var. *stellatum*
Portulaca cyanosperma
Sesuvium portulacastrum

Sand dunes strand vegetation

Cuscuta sandwichiana
Heliotropium anomalum var. *argenteum*
Heliotropium curassavicum
Ipomoea pes-caprae
Nama sandwicensis
Scaevola coriacea
Scaevola taccada
Sida fallax
Sporobolus virginicus
Tribulus cistoides
Vitex ovata

Estuaries and marshes

Bacopa monnieria
Cyperus laevigatus
Scirpus paludosus
Scirpus validus

Inland open savannah - dryland sclerophyll forest

Abutilon incanum
Canavalia spp.
Capparis sandwichiana
Cassytha filiformis
Cocculus ferrandianus
Eragrostis paupera
Erythrina sandwicensis
Gossypium sandvicense
Heteropogon contortus
Ipomoea congesta
Marsilea villosa
Myoporum sandwicense
Ophioglossum concinnum
Panicum spp.
Panicum torridum
Plumbago zeylanica
Santalum ellipticum
Santalum freycinetianum
Sapindus oahuensis
Sicyos microcarpus
Sida spp.

[1] Summarized from Char and Balakrishnan (1979).

have become extinct prior to the arrival of Cook in 1778.

This evidence suggests that the composition of the indigenous flora may have been more substantially altered by prehistoric man than previously thought (Kirch 1982, 1983; Christensen and Kirch, in prep.). Evidence of such changes also can be found in numerous other areas of Hawai'i and Polynesia (Kirch 1982, 1983). The reconstruction of the native flora of the 'Ewa Plains area and similar strand and dryland sclerophyll forests suggests that some plants were useful to the natives (Rock 1913; Hatheway 1952; Char and Balakrishnan 1979). Moreover, the practice by the Hawaiians and other Pacific cultures of extensive clearing by burning may have occurred here (Kirch 1982). Clearing may have allowed naturalized plant species brought intentionally or unintentionally by settlers to establish themselves.

The historical changes in the flora are more easily documented. In their vegetation survey, Char and Balakrishnan (1979) found that of 396 species of vascular plants recorded, 347 or 88% were introduced and of the 49 that were native, 17 were endemic.

The present strand vegetation is dominated by the introduced Cynodon dactylon and the native Sporobolus virginicus, both of which grow well in disturbed areas. Native strand species such as Ipomoea imperati, I. pes-caprae, Tribulus cistoides, Sesuvium portulacastrum, Vitex ovata, and Scaevola taccada still occur in less disturbed areas. The range of these native strand species, however, has been decreased considerably due to the elimination of populations by clearing areas for housing and recreational sites.

The wetland areas near Pearl Harbor, once covered with Scirpus sp. and Bacopa monnieria, are slowly being dominated by mangrove (Rhizophora mangle), introduced in 1902 (Neal 1965). Above the mangrove is Batis maritima followed by the Polynesian-introduced Thespesia populnea and the presumably native Hibiscus tiliaceus. Along the margins of the strand and wetland areas, Pluchea indica and P. symphytifolia and their hybrid (P. xfosbergii) can be found.

The inland ecosystems have been more severely disturbed than the strand areas. The introduction of cattle in the middle 1800's aided in dispersing Prosopis pallida throughout the area, where it has since become the dominant tree. Localized sisal and coconut plants remain as remnants of now defunct sisal and coconut plantations. The shrub Leucaena leucocephala forms dense thickets along roadsides and a sub-canopy layer in Prosopis forests. These plants, along with Acacia farnesiana, Pithecellobium dulce, and Schinus terebinthifolius, are the dominant shrubs in open savannahs. Marsilea villosa in the past was one of the common groundcover plants in the Prosopis pallida forests, but this species now has been replaced by grasses such as Setaria verticillata. Pennisetum setosum and Chloris inflata can be found in recently disturbed areas. Sida fallax, Malvastrum coromandelianum, and Asystasia gangetica also occur in localized areas.

Native species such as Capparis sandwichiana, Myoporum sandwicense, and Chamaesyce skottsbergii var. kalaeloana are very localized. Others such as Santalum ellipticum, Sapindus oahuensis, and Gossypium sandvicense are rare. Other plants like Chamaesyce skottsbergii var. skottsbergii and Scaevola coriacea were not collected by Char and Balakrishnan (1979), although these species occurred there in the past. These species which probably were found throughout the inland plains area evidently have decreased considerably in their ranges.

Sugar cane now is the dominant species in the area and is intensively cultivated. Clearing natural areas for cane fields causes substantial disturbance to the native ecosystem. The substrate is further modified by agricultural byproducts for soil improvement and by water used in irrigation. The change in the growing conditions, caused by the absence of trees, additional soil and moisture, and soil improvements, perhaps enabled alien species to colonize the area instead of the original native plants. Further encroachment on the range of native species occurred when large tracts of land were covered by residential, industrial, and military sites, as discussed above.

The history of the flora of 'Ewa Plains illustrates what has happened to the native strand and dry sclerophyll forests in Hawai'i. Although precise dates are not available, it is clear that the changes occurred within the tenure of man's occupation. The emerging archaeological evidence from land snail and avifaunal analyses indicates the increasing role of prehistoric man in the acceleration of the modification of species composition and range to an area. This change was accelerated by several orders of magnitude with the arrival of modern man and his technology.

RESEARCH AND MANAGEMENT NEEDS

The basic requirement for the preservation of the Hawaiian flora is conservation of native communities by developing natural area protection policies and then setting up an adequate network of ecosystem reserves in all of our vegetation types. It is essential to have adequate research and education to successfully implement conservation policies. We also desperately need a modern flora to have a scientific basis for understanding individual groups. It has been nearly a century since the last complete flora of Hawai'i was published (Hillebrand 1888). This leaves the Hawaiian flora, which doubtless is one of the most interesting in the United States, without any significant modern inventory of its plants. As we have outlined above, the situation in Hawai'i is critical; thus a modern flora is viewed as one of the principal research priorities for further study of the Hawaiian flora.

A project initiated in 1982 by S.H. Sohmer and funded by the Irwin Charity Foundation of San Francisco is now under way at the Bishop Museum to produce such a modern framework. Manual of the Flowering Plants of Hawai'i will form a firm basis on which much-needed in-depth studies of specific groups of Hawaiian plants can be made. The philosophy of the Manual is to bring together, with a uniform treatment, the existing knowledge of the native flora pertinent to their identification, classification, distribution, and status. The project also has sought knowledgeable specialists to contribute treatments of specific groups to the book and has encouraged scientists to initiate more detailed research programs on difficult Hawaiian genera. The completion of this project will be a significant step towards an overall evaluation of our native flora; however, it should be followed by more detailed systematic studies as well as studies of pollination ecology, autecology, physiological ecology, genetics, and population biology. The Manual will be a single volume manual to the flowering plants of the Hawaiian Archipelago. It will contain keys and descriptions of the families, genera, and species, both native and naturalized, occurring throughout the Islands. The treatment of each species will include accepted scientific name, Hawaiian and English common names, list of synonyms, literature citations for relevant publications, statement of geographical and ecological ranges, available chromosome numbers, and brief notes on taxonomic problems. The principal source of information for this project is the approximately 70,000 specimens in the Hawaiian section of the herbarium at Bishop Museum; but the field knowledge of the authors, a large number of participating local botanists, and knowledgeable specialists of specific groups will also be incorporated.

The majority of studies made during the past 100 years on the Hawaiian flora has been based principally on descriptive taxonomy. Recently a number of detailed studies of cytology and experimental hybridization (Carr 1977, 1978; Carr and Kyhos 1981; Gardner 1976, 1977, 1979; Gillett 1966; Gillett and Lim 1970; T.

Lowrey, unpubl. data; Rabakonandrianina 1980; Rabakonandrianina and Carr 1981) have shed new insight into our understanding of genera such as Dubautia, Bidens, Scaevola, Tetramolopium, and Lipochaeta, and have provided examples of adaptive radiation patterns in Hawaiian plants. Physiological ecological studies such as those on Chamaesyce and Scaevola (Pearcy, Osteryoung, and Randall 1982; Pearcy 1983; Robichaux and Pearcy 1980a, 1980b, 1984) or studies of ecological distribution of C_3 and C_4 grasses (Rundel 1980) are very important in gaining insight on the ecological tolerances of different plant species, and thus shedding some light on how closely related organisms have adapted to and function in their habitat. Studies of comparative anatomy by Carlquist on a variety of Hawaiian plants (1957a, 1957b, 1959, 1962; Carlquist and Bissing 1976) and Stemmermann on Santalum (1980), as well as research on developmental anatomy by Herbst on Chamaesyce (1971, 1972), also have been valuable in understanding adaptation. Techniques for studying variation in proteins, such as the use of gel electrophoresis, are just beginning to be applied to Hawaiian plants, such as for Tetramolopium (T. Lowrey, unpubl. data). Population genetic and autecological studies, particularly regarding inbreeding suppression, are needed.

Studies of population dynamics and community level interactions are perhaps of even greater importance in the conservation of the native flora. For example, quantitative analysis of the impact of goats on various plants such as koa (Spatz and Mueller-Dombois 1973) and Sophora (Scowcroft and Giffin 1983; Scowcroft and Sakai 1983), and exclosure studies (Mueller-Dombois 1981) are critical in understanding the full effects of feral animals. Even more important are multidisciplinary studies directed towards understanding the structure and function of Hawaiian ecosystems. The U.S. International Biological Program (IBP) Island Ecosystems project (Mueller-Dombois, Bridges, and Carson 1981) used a team approach to study the structural biological organization in certain natural ecosystems in Hawai'i.

The following points can be made in summary of overall priorities and research needs (see also Smith, this volume).

1. Public education is essential to the acceptance of the concept of conservation and preservation of plant species. Education must be the foundation upon which all of our efforts are built. Only with long-term financial commitment that would result from such acceptance can a serious commitment be made to preservation (Raven 1976).

2. We must have a complete review of the native and naturalized plants of Hawai'i, such as the Flora

Project currently under way at the Bishop Museum. We also need local field surveys of specific areas such as those made by the Nature Conservancy of Hawai'i and Haleakala National Park (e.g., A.C. Medeiros, unpubl. data) and the Hawaiian Forest Bird Survey (Jacobi and Scott, this volume).

3. We have an immediate and critical need to establish through legislation and maintain through enforcement natural or semi-natural areas in as many of the native ecosystems of the Islands as possible. Excellent examples of this type of endeavor are Hawai'i Volcanoes National Park, Haleakala National Park, and The Nature Conservancy preserves.

4. Detailed biosystematic and ecological studies should be performed on carefully selected groups of organisms and communities. Especially critical for Hawaiian plants are studies of pollination ecology, for which we presently have extremely little information, and studies of demography and autecology of individual organisms, which are essential in seeking explanations for the requirements, tolerances, and responses in a community of organisms. Studies of physiological ecology are very important in gaining insight into the tolerances of plant species and how the organisms function and have adapted to their environments. These studies are of special importance, since they are concerned with the documentation and explanation of changes in the number of individuals and phenotypic and genotypic changes in populations over time. The information obtained is essential in the development of predictive models that can be used to implement successful management programs and to understand plant species and the communities that they comprise; it is fundamental to the overall study of any ecosystem.

5. Interactions between field biologists and horticulturists are very important in situations in which many species face imminent extinction. Botanical gardens form a network in which materials can be cultivated, propagated, and distributed to various other cultivation sites and perhaps can be reintroduced to native ecosystems. Interactions between horticulturists can lead to the development of new methods of cultivation. This kind of interaction seems to be especially fruitful in Hawai'i with the relatively large number of botanical gardens.

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