IMPACT OF ALIEN PLANTS ON HAWAI'I'S NATIVE BIOTA

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ABSTRACT

Over 4,600 species of plants have been introduced into the Hawaiian Islands over the last 200 years. Only 86, less than 2% of the total, have become serious pests of native ecosystems. Of these, the most significant are _Andropogon virginicus_, _Clidemia hirta_, _Lantana camara_, _Leucaena leucocephala_, _Melinis minutiflora_, _Myrica faya_, _Passiflora mollissima_, _Pennisetum clandestinum_, _P. setaceum_, _Psidium cattleianum_, _Rubus argutus_, and _Schinus terebinthifolius_. All 86 species are discussed with regard to their impact on the ecosystem, dispersal mechanism, fire tolerance, potential for biological control, and their distribution and principal infestation sites. Twenty-eight (32%) are invasive weeds; the remainder generally require some form of disturbance in order to become established.

The lowland ecosystems have suffered the most disruption from alien species because of agriculture, fire, and urbanization. However, all vegetation types have been affected to some degree. The ecosystems least impacted are alpine habitats, rain forests, and bogs, although they are coming under increasing pressure.

A number of strategies are discussed which may help to ameliorate weed problems. Greater effort by government is needed to educate the public on the need for importation control and to enforce regulations. Mechanical and herbicidal control is discounted except in small areas. Biological controls offer considerable hope, but there are many problems associated with this strategy.

The unique flora and fauna of the Hawaiian Islands is seriously threatened by alien plants. Many native species have already been extirpated. Unless importation of aliens and the continuing disturbance of the

native ecosystems is stopped, the prognosis for the remaining native biota is grim.

INTRODUCTION

"The history of weeds is the history of man" (Anderson 1952); the development of the Hawaiian flora is a classical example. Prior to the colonization of the Hawaiian Islands by man, the rate of introduction of plants was very low because of difficulties of dispersal over 3,200 km of ocean and subsequent establishment. The approximately 272 plants that did become established adapted and diversified to produce a flora of 1,729 species and varieties, 95% of which are endemic (Fosberg 1948). The aboriginal Hawaiians accelerated the process of introduction by bringing with them plants necessary for their culture. These plants had a distinct advantage in the process of establishment because they were deliberately cultivated. Most were cultivars and less than 25 escaped, but St. John (1978) listed 7 additional weeds which he believed were introduced inadvertently. The major impact of the Hawaiians was restricted to the lowlands, resulting from the clearing and burning of the native vegetation (Kirch 1982).

On the arrival of Captain Cook in 1778, the rate of plant introductions increased. Each new culture arrived with plants necessary for their cuisine or pleasure. Agricultural interests accelerated the process even more by bringing in pasture grasses and forb seeds which generally were contaminated with weeds from other sources, a common problem until quite recently (Salisbury 1964). Finally, foresters brought in trees, initially to reforest watershed areas devastated by feral cattle (Bos taurus), but later to establish a forestry industry in the Islands. Introductions of horticultural interest continue even today with little control except for a specific ban on a number of drug-producing plants and officially declared "noxious" weeds. Statutes exist which regulate the importation of plants, but they are only cursorily enforced except for those plants that come in under permit. The State's overriding concern is to protect and promote agricultural and other economically attractive interests, and protection of native ecosystems has received little consideration.

There are over 4,600 alien species in Hawaii (St. John 1973), of which over 600 have become naturalized (W.L. Wagner, pers. comm.). In this paper 86 are considered pests in areas not cultivated or urbanized. Many other weeds are confined to agricultural areas (Haselwood and Motter 1983). Although the term "pest" normally connotes social, economic, and biological problems (Norton and Conway 1977), in this paper it is used solely in the context of a weed's disruptive impact on the natural processes of native ecosystems. Species that prevent the reestablishment of native communities are included, along with those which invade disturbed or undisturbed native communities. Several species that may be considered beneficial by agronomists or horticulturists as forage, ornamentals, or for timber are included in this listing because of their negative impact in native Hawaiian ecosystems.

TERMINOLOGY

Six terms (adventive, alien, exotic, introduced, naturalized, and weed) are commonly used to describe species not native to an area. In Hawai'i most people use "exotic" and "introduced", or more rarely "adventive". It may seem overly critical to worry about which term is correct. However, we are discussing not only a problem of communication among scientists, but also with the general public. The semantic confusion, particularly for the non-scientist, could prevent understanding of some essential elements of the problem. The term "exotic", although literally correct, is inappropriate because it also implies something excitingly different. "Adventive" is a word with a specific botanical meaning, i.e., not native to the environment, but it is generally used to refer to accidental introductions which persist for a while and then disappear. It is also somewhat indiscriminate in that it can be used to refer to a species introduced from a neighboring ecosystem. "Introduced" is probably appropriate except that it implies a deliberate action and does not carry the negative implication of the term "alien." The term "naturalized" is unsuitable because it refers to alien species which have become established and self-sustaining in a new geographic area. Not all alien species are naturalized and not all naturalized species are pests.

In many parts of the world, "alien" is the preferred word. "Alien" is appropriate because its meaning is direct and it also has the connotation of not belonging, a strongly desirable implication. The term "weed" refers to the functional role of an organism and is inappropriate in this context because not all alien plants are weeds and native species can also be weeds. Two endemic species, *Cuscuta sandwiciana* Choisy (dodder) and *Hesperocnide sandwicensis* Wedd. (stinging nettle), have been declared noxious weeds by the State of Hawai'i, and an additional 7 endemic and 8 indigenous species have been called weeds (Haselwood and Motter 1983; Hosaka and Thistle 1954). The word alien will be used in this paper and its use is encouraged elsewhere.

Acacia mearnsii Willd. (A. decurrens (Wendl.) Willd. in Hawaiian literature) (Black wattle)

This noxious, evergreen tree often reaches 20 m in height. Apart from producing copious numbers of seeds, it generates numerous suckers resulting in monotypic thickets. The small seeds are not actively dispersed and, although rodents or granivorous birds cannot be totally discounted, man appears to be the principal disseminator. The species resprouts by basal shoots following fire, thereby generally intensifying the infestation. No evaluation of its potential for biological control has been made.

It grows in disturbed, mesic habitats between 600-1,700 m. The major infestation is at Kula, Maui.

Acacia confusa Merr. (Formosan koa)

This evergreen tree is prized by many for its brilliant display of bright yellow, mimosoid flowers and its ability to grow in poor, dry soils. It reaches heights of 15 m and shades out most other plants. The small seeds are passively dispersed. Man has been the principal disseminator through aerial broadcasting. The leaves are apparently allelopathic since the ground underneath these trees is barren except for a few alien weeds, e.g., Stachytarpheta jamaicensis (L.) Vahl (Jamaica vervain). The plant is essentially fire resistant because fire will not carry under the tree due to the lack of fuel. Aerial portions which are only scorched will resprout rapidly. No evaluation of potential for biological control has been made.

It thrives between sea level and 700 m elevation in dry and mesic habitats. Major infestations are found on the windward side and Wai'anae Mountains, O'ahu, and the north shore of East Maui.

Acacia farnesiana (L.) Willd. (Klu, popinac)

This thorny, deciduous shrub grows to 4 m in height, sometimes forming impenetrable thickets, although in most areas it forms a more open cover. The seeds are dispersed by ungulates which eat the pods. Although the aerial portions may be killed by fire, it soon regenerates from basal shoots. It has not been evaluated for biological control.

Acacia grows in dry habitats between sea level and 1,000 m on all islands. There are some dense infestations at Lualualei, O'ahu, and Lihau, Maui; some overgrazed areas on Lana'i; and the Ha'upu area of Kaua'i, particularly Mahalapu.

Albizia falcataria (L.) Fosb. (Molucca albizia)

This elegant, deciduous tree with wide-spreading branches is used as a shade plant for coffee in many parts of the world. It grows very rapidly even on nutrient-poor soils. It is not known how the large seeds are dispersed, although man was initially the principal disseminator when seeds were sown from aircraft. It is not susceptible to control by fire because the trees are rarely subjected to fires of sufficient intensity. The potential for biological control has not been evaluated.

It grows from sea level to 1,500 m elevation but is most common in mesic, lowland areas. It is common in windward O'ahu, in the Mililani area and above Lualualei, O'ahu, and in upper Wailua, Kaua'i. It is still planted as an ornamental and in forest plantations in Hawai'i.

Andropogon glomeratus (Walt.) BSP. (Bush beardgrass)

The problems associated with this species and its ecological preferences are the same as A. virginicus. It is confined to the island of Hawai'i.

Andropogon virginicus L. (Broomsedge)

This perennial bunchgrass sometimes forms continuous cover in boggy, open mesic and dry habitats. It releases highly persistent allelopathic substances (Rice 1972). The dead material provides an excellent fuel for fires. It is fire-stimulated; its cover increases dramatically with each fire (Smith, Parman, and Wampler 1980). In areas where it occurs, both fire intensities and acreage burnt have increased. Because it retains the phenology of its native habitat, the southeastern United States, its growth is out of synchrony with Hawai'i's climatic pattern (Sorensen 1980). It is dormant during the rainy season, which Mueller-Dombois (1973) has shown leads to increased erosion in some areas. The seeds are dispersed by wind. The potential for biological control has been discussed by Gardner and Davis (1982), but attempts to evaluate possible agents in Hawai'i probably will be resisted by the sugar industry.

It is widely distributed from sea level to at least 1,600 m on all major islands. Major infestations occur on the windward plain and Pupukea areas of O'ahu, overgrazed ridges in East Moloka'i, and the Puna and Ka'u regions of Hawai'i.

Anthoxanthum odoratum L. (Sweet vernalgrass)

This small, perennial bunchgrass forms extensive ground cover in open mesic and dry habitats at high elevations. It invades disturbed areas, preventing the reestablishment of native species. The seeds are dispersed by wind. Its cover increases after fire, but this increase appears to be the result of reduced competition rather than stimulation. It has not been evaluated for biological control.

It occurs between 1,500-3,000 m on Haleakala, Maui, and Mauna Kea and Mauna Loa, Hawai'i. Some scrubland habitats on Haleakala have almost pure stands of this grass between the bushes.

Ardisia humilis Vahl (Shoebutton ardisia)

This shade-tolerant, evergreen tree grows rapidly, forming dense monotypic stands that prevent establishment of all other species. Alien frugivorous birds are the principal dispersal agent. The red-vented bulbul (*Pycnonotus cafer*) is attracted to its numerous red to blackish fruit. It will be interesting to note the impact of this recently established frugivorous bird on the distribution and infestation levels of this tree on O'ahu. The tree is probably not resistant to fire, and the potential for biological control has not yet been evaluated.

The species is confined to wet, lowland areas. The principal infestations are Waikane-Waiahole, O'ahu and Hana, Maui.

Asystasia gangetica (L.) Anders. (Chinese violet)

Chinese violet is a rapidly growing perennial, shrubby herb which grows to 1 m height but can grow over shrubs up to 3 m tall. It can smother all vegetation in the herbaceous layer. The seeds are dispersed from explosive capsules but long-distance dispersal is effected by man. Although aerial portions may be killed by fire, the plant soon regenerates from basal shoots or seeds. It has not been evaluated for biological control.

Chinese violet grows in dry habitats between sea level and 300 m on all islands. There are dense infestations at Lualualei, 'Ewa Plains, Diamond Head, and Koko Head, O'ahu.

Bambusa sp. (Bamboo)

This large bamboo forms extensive, impenetrable thickets. It spreads into adjacent areas, overshadowing all but the tallest trees. The species has not yet reproduced in Hawai'i, so we do not know whether it will set viable seed. Fires rarely carry through stands because of the lack of sufficient fuel. Though aerial shoots at the edge of the colony are destroyed by fire, the stand recovers rapidly by means of subterranean shoots. Since the species name is not known with certainty and it is a useful plant to many, it has not been evaluated for biological control.

There are major infestations in the northern valleys of Kaua'i, e.g., Limahuli Valley, the forests above Honolulu from 'Aiea to Niu and from Kailua to Kipahulu, Maui. It is confined to elevations below 400 m.

Bidens pilosa L. (Beggar's tick)

This annual to almost perennial shrubby herb forms dense cover along roads, trails and open lowland areas. It is dispersed on human clothing and animal coats. It is not fire tolerant but quickly invades burnt areas. Biological control of this species could be complicated by the presence of endemic species in this genus.

The plant is widely distributed and common in open areas up to 1,300 m. There are several areas on the south slope of Haleakala and the central valley of Maui where carpets of this species inhibit the establishment of native species during the rainy season.

Bocconia frutescens L.

This evergreen shrub to small tree forms dense stands in dry habitats. The seeds are wind-dispersed. Its fire tolerance in Hawai'i is unknown. It has not been evaluated for biological control.

It grows at elevations between 300-1,000 m in dry habitats on Maui and Hawai'i. There is a significant infestation above 'Ulupalakua, Maui.

Brachiaria mutica (Forsk.) Stapf (California grass)

This perennial grass can reach heights of 2 m. It forms dense monotypic stands by layering from trailing stems. It will overgrow most shrubs and trees in its habitat. It has mild allelopathic activity (Chou and Young 1975). Man is the principal dispersal agent. Fire is rare in its habitat but the dense stands rapidly regenerate from any damage that they suffer. It has not been evaluated for biological control because it is a valued pasture grass in lowland areas.

The species grows in wet habitats between sea level and 700 m. Open marshy areas, such as Kawainui Swamp, O'ahu, are the principal habitat.

Brassaia actinophylla Endl. (Octopus tree)

This fast-growing, evergreen tree with few branches reaches heights of 15 m. It is a shade-tolerant plant capable of invading undisturbed forests. The seeds are dispersed by alien frugivorous birds. It is not tolerant of fire. It has not been evaluated for biological control.

It grows up to 1,000 m elevation in wet lowland habitats on all islands. There are major infestations in the northern valleys of Kaua'i, particularly Limahuli Valley, and in Nu'uanu and Waiahole Valleys, O'ahu.

Caesalpinia sepiaria Roxb. (Cats claw, Mysore thorn)

This deciduous, sprawling, noxious shrub, with numerous spines, forms impenetrable thickets. The medium-sized seeds may be dispersed by rodents and granivorous birds, but man is almost certainly the principal dispersal agent in Hawai'i. Fire tolerance in Hawai'i is unknown, and the potential for biological control has not been evaluated.

The plant is confined to dry to mesic lowland habitats. There are several infestations along the Honouliuli trail of the Wai'anae Mountains and on the windward side of O'ahu, the upper pastures and adjacent forest of much of northeastern Kaua'i, and Kakipi Gulch, Maui.

Casuarina equisetifolia Stickm. (Common ironwood)

This rapidly growing tree can reach heights of 40 m or more. It forms monotypic stands under which little else grows. The lack of undergrowth beneath trees suggests the release of an allelopathic agent, although Neal (1965) suggested that it exhausts the nutrients in the soil. The seeds are wind-dispersed. The lack of undergrowth prevents very hot fires from burning in the vicinity of these trees. When fires do sweep through stands, trees regenerate rapidly from basal shoots. The species has not been evaluated for biological control because it is still considered a beneficial tree for windbreaks, erosion control, and nitrogen fixation.

It is common in all but the driest and wettest coastal areas of all islands up to 500 m.

Casuarina glauca Sieb. in Spreng. (Swamp oak)

This species is very similar to C. equisetifolia. However, it forms suckers prolifically, producing dense stands. It is the most aggressive ironwood in the Islands.

It has a similar distribution to C. equisetifolia.

Cecropia peltata Sandmark (Trumpet tree)

This very rapidly growing but short-lived tree attains a height of no more than 10 m. It forms dense stands which seriously impede the growth of other plants. The seeds are dispersed by alien frugivorous birds. It is destroyed by fire and has not been evaluated for biological control.

It grows in wet lowland habitats of all major islands, but there is a major infestation in Manoa Valley, O'ahu, and the Waiakea area, Hawai'i.

Cenchrus ciliaris L. (Buffelgrass)

This small, perennial bunchgrass forms continuous cover in arid habitats. The dried shoots provide an excellent fuel for fire, from which the plant recovers rapidly by basal shoots. It is a fire-enhanced species as its cover increases with each succeeding fire. The seeds are dispersed by wind. It has not been evaluated for biological control, because of its extensive use in erosion control.

The species is confined to arid habitats between sea level and 150 m elevation. There are major infestations at Lualualei, O'ahu; Kihei, Maui; on Kaho'olawe; and at Kawaihae, Hawai'i. It has recently become the dominant grass on Molokini Island.

Citharexylum caudatum L. (Juniper berry)

This evergreen shrub to small tree forms dense thickets in wet habitats. It has many characteristics in common with C. spinosum.

It recently escaped from the Lyon Arboretum in Manoa Valley, O'ahu and has since moved rapidly into the Ko'olau Mountains in that region.

Citharexylum spinosum L. (Fiddlewood)

This evergreen, medium-sized tree does not have the spines that its scientific name suggests. It forms crowded stands even in undisturbed habitats and is dispersed by alien frugivorous birds. Its fire response in Hawai'i is unknown. It has not been evaluated for biological control.

The tree has escaped only recently and is a pest only on O'ahu. Gerrish and Mueller-Dombois (1980) describe 2 infestations at Tantalus and Pupukea. However, extensive use as an ornamental by landscapers on other islands will result in infestations there also.

It grows in wet habitats generally below 500 m. There is a population at the bottom of the cliffs in Waimanalo in a very dry habitat. This population is deciduous during the dry season, and it can be seen from a considerable distance when the leaves turn red prior to fall.

Clerodendron japonicum (Thunb.) Sweet (Glorybower)

This ornamental shrub has escaped on Kaua'i in the Oma'o area, where it is becoming a serious pest. It has recently escaped in Wailau Valley, Moloka'i. The fruit is dispersed by alien frugivorous birds. Its susceptibility to fire is not known, and it has not been evaluated for biological control.

<u>Clidemia hirta (L.) D. Don (Koster's curse)</u>

This noxious weedy shrub grows up to 2 m tall in pastures and forest. It is an aggressive invader which shades out all vegetation below it (Wester and Wood 1977). The seeds are principally dispersed by alien frugivorous birds, but any organism moving through the thickets will carry seeds away with it. It is probably not resistant to fire, an unlikely event in its habitat, but it rapidly colonizes burned areas. Several expeditions for potential biological control agents have been made in Trinidad, and a number of insects are being screened currently.

This plant is a serious pest in mesic and wet environments on O'ahu and more recently in Wailau, Moloka'i, as well as Nahiku and Kailua areas, Maui. It has also become established on Kaua'i, West Maui, and Waiakea, Hawai'i. There is increasing evidence that many of the new infestations are inadvertently established by marijuana growers.

<u>Corynocarpus laevigatus J.R. & G. Forst. (New Zealand laurel)</u>

This evergreen tree reaches heights of 15 m. It forms a dense shade excluding other species. The fruit, which is very poisonous to man, is dispersed by alien frugivorous birds. Its fire tolerance is unknown, and it has not been evaluated for biological control.

It grows in mesic habitats between 700-1,500 m. There is a major infestation in Koke'e, Kaua'i.

<u>Eugenia cumini (L.) Druce (Java plum)</u>

This large evergreen tree forms a dense cover, excluding all other species. The large black fruit are dispersed by alien frugivorous birds and perhaps occasionally by feral pigs (<u>Sus scrofa</u>). Although it is not an aggressive invader of undisturbed forest like the closely related roseapple, it prevents the reestablishment of native lowland forest. It is not really fire resistant, but fires are rarely intense enough in the stands to produce other than peripheral damage. This tree has not been evaluated for biological control.

It is found in dry to mesic and more rarely wet lowland areas up to 700 m on all major islands. There is a heavy infestation at Kalalau Valley, Kaua'i, and Kalaupapa, Moloka'i.

Eugenia jambos L. (Roseapple)

This medium-sized deciduous tree forms dense thickets which shade out native species. It invades undisturbed forest. The fruit is dispersed by humans and perhaps feral pigs. It is not known to be fire resistant. It has not been evaluated for biological control.

It is found in wet lowland habitats up to about 500 m elevation on most major islands. There is a major infestation in the Manuka Natural Area Reserve on Hawai'i.

Ficus microcarpa L.f. (Chinese banyan)

This evergreen tree produces a very dense shade excluding all other species. It does not invade undisturbed forest but once established it will displace all other trees in its shade. The fruit are dispersed by alien frugivorous birds. Although it is susceptible to fire, it is only marginally affected because fire will not carry under the tree for lack of fuel. It has not been evaluated for biological control. There are a number of insects which attack it, most notably the Cuban laurel thrip (Gynaikothrips ficorum), but they do not reduce the vigor of most trees.

This species grows in all but the wettest and driest habitats on all of the major islands, most commonly on cliffs and rocky outcrops. It has the potential to grow up to 1,500 m but rarely grows much above 700 m. There are some particularly large trees along the Hana coastline, Maui.

Fraxinus uhdei (Wenzig) Lingelsheim (Mexican ash)

This tall, deciduous tree has been planted extensively by foresters. It is among the most successful trees for reforestation and has spread into adjacent areas, forming dense stands from which most native species are excluded. The seeds are dispersed by wind. Its response to fire in Hawai'i is unknown. Because of its use in forestry, it is very unlikely that it will be evaluated for biological control.

The most extensive infestations are along the Honouliuli trail, O'ahu; on Moloka'i; and in the Makawao Forest Reserve and Olinda areas, Maui. It grows best between 1,000 and 1,750 m but also grows up to 2,000 m.

Furcraea foetida (L.) Haw. (Mauritius hemp)

This large, rosette plant rarely grows above 1.5 m though the inflorescence may reach 5 m. The inflorescence produces bulbils rather than seeds which are dispersed locally, forming dense monotypic thickets. The plants are not susceptible to fire, which does not move through concentrations of this plant. It has not been evaluated for biological control.

This plant grows between sea level and 1,000 m in dry habitats. There are major infestations along the Napali coast, Kaua'i, and near Wailuku, Maui.

Grevillea banksii R. Br (Kahili flower)

This noxious, medium-sized, evergreen tree is similar to silky oak in most features. There is a major infestation in the Ka'u District, Hawai'i.

Grevillea robusta A. Cunn. in R. Br. (Silky oak)

This large, evergreen tree has been used extensively in reforestation programs. The leaves produce an allelopathic substance which inhibits the establishment of all species, including itself. The seeds are wind-dispersed, and adaptation to fire in Hawai'i is unknown. Because of its use in forestry and as a shade tree by some ranchers, it has not been evaluated for biological control.

It is quite widespread in dry areas between 350-1,600 m elevation on all major islands.

Hedychium coronarium Koenig (White ginger)

The problems with this fragrant-flowered species are very similar to those for H. gardnerianum. However, reproduction by seeds, which are not produced in large numbers, is localized because they are rarely displayed conspicuously. Long-distance dispersal is effected vegetatively by man. Its adapatation to fire is unknown but unless the fire is intense enough to harm the rhizomes it will recover. The potential for biological control is poor because of the extensive use of this species in gardens and lei making.

This species is widely distributed in wet habitats on all islands. There are major infestations in Nahiku, Maui; and Puna and Kohala Mountains, Hawai'i.

Hedychium flavescens Carey in Roscoe (Yellow ginger)

The problems associated with this species are identical to those of H. coronarium.

This species is very common in the wetter northern valleys of Kaua'i but is also found in many of the same habitats as the white ginger.

Hedychium gardnerianum Roscoe (Kahili ginger)

This showy ginger grows just over 1 m tall. Each plant grows rapidly by stolons, displacing all other plants. The conspicuous, fleshy, red seeds are dispersed by alien, and perhaps native, frugivorous birds as well as man. Adaptation to fire is unknown, but unless the fire is intense enough to harm the rhizomes, it will recover. Gardner and Davis (1982) discussed the potential for biological control of this species but noted the almost certain opposition from horticulturists to any move in this direction.

The plant grows in wet habitats on all islands between sea level and 1,700 m. There are major infestations at Koke'e, Kaua'i; Nahiku, Maui; and Volcano, Hawai'i.

Heliocarpus popayanensis HBK. (White moho)

This tall tree, planted extensively by foresters, has escaped into wet forests at low to mid elevations. The seeds are dispersed by wind. Its response to fire is unknown, and it has not been evaluated for biological control.

There are some potentially troublesome infestations at the base of Kaua in the Wai'anae Mountains, and Manoa Valley, O'ahu, as well as Mountain View, Hawai'i.

Holcus lanatus L. (Velvetgrass)

This perennial bunchgrass invades disturbed sites rapidly. It forms dense stands which shade out seedling establishment, but allelopathic activity is also suspected (Watt 1978). Seeds are produced abundantly and dispersed by wind. Seedling growth is much more rapid than in native species. As with most bunchgrasses, this species tolerates fires and regenerates rapidly from basal shoots. Holcus has not been evaluated for biological control but potential agents and the effectiveness of some herbicides are noted by Watt (1978). The sugar industry will probably resist any move to import biocontrol agents.

This plant is widely distributed in all but the most xeric habitats above 1,300 m. Jacobi (1981) suggested that, once disturbance is eliminated, Holcus will remain stable in a native grassland community.

Hypochoeris radicata L. (Hairy cats-ear)

This small rosette herb is very common above 2,000 m on Maui and Hawai'i. It has a deep, succulent taproot favored by feral pigs, which dig up large areas searching for the roots. Seeds are produced in large numbers and dispersed by wind. It regenerates rapidly from the crown of the taproot after fire. It has not been evaluated for biological control.

Lantana camara L. (Lantana)

This thorny shrub is a noxious weed. It can form impenetrable thickets which crowd out other plants. The fruit are dispersed by alien frugivorous birds. It is capable of surviving all but the hottest fires, regenerating from basal shoots. Allelopathic substances are produced by shoots and roots (Achhereddy and Singh, in press). The plant has been subjected to biological control which has been quite effective in some areas (Gardner and Davis 1982). Further control agents are being sought.

Lantana is found up to 600 m on all islands, principally in dry areas. It has infested both mesic and wet habitats as well.

Leptospermum ericoides A. Rich. (Tree manuba)
This tree is similar to L. scoparium. It is confined to Lana'i.

Leptospermum scoparium J.R. & G. Forst. (New Zealand tea)
This small, scrubby tree forms thickets which crowd out other plants. On Lana'i, it has infested goat (Capra hircus)-eroded ridgetops, resulting in their stabilization. It appears to have allelopathic activity like many other members of the Myrtaceae. The seeds are dispersed by wind. Its response to fire in Hawai'i has not been established, nor has it been evaluated for biological control.

It is found in mesic habitats between 300-700 m elevation. The principal infestations are on Lana'i and above La'ie in the Ko'olau Mountains, O'ahu.

Leucaena leucocephala (Lam.) de Wit (Koa haole)
This thornless tree forms dense thickets, excluding all other plants. It is grown for fodder, but unless severely grazed or controlled, it spreads rampantly throughout adjacent areas. The seeds are not actively dispersed except occasionally by rodents and alien granivorous birds. It regenerates rapidly from basal shoots after fire. There is also a flush of new seedlings produced following fire, but whether this is the result of normal germination or breaking dormancy by fire is not known. In mature monotypic stands fire is suppressed because of the low fuel load. The potential for biological control has been evaluated by Gardner and Davis (1982), but no action is likely to be taken because of its use in agriculture and use of closely related species as fuel crops. In fact, the State Department of Agriculture may import parasites of the recently introduced Heteropsylla cf. incisa (Nakahara and Lai 1984) which has considerable potential as a control agent of koa haole.

Koa haole is found in dry to mesic habitats on all islands up to 700 m, having been deliberately broadcast over lowland habitats approximately 50 years ago. It is also present in severely disturbed wet areas but not as a dominant species.

Linociera intermedia Wight (Olive) (? = L. ligustrina)

This shrubby, evergreen tree forms dense, monotypic thickets between 500-1500 m elevation. It may have allelopathic activity. The seeds are dispersed by alien frugivorous birds. Its adaptation to fire is unknown, and it has not been evaluated for biological control.

The major infestations are at Waimea, Hawai'i and 'Ainahou, Hawai'i Volcanoes National Park.

Melaleuca leucadendra (Stickm.) L. (Paperbark)

This evergreen tree reaches heights of 12 m and has been planted extensively in reforestation projects. It invades open swampy areas. The leaves appear to have allelopathic activity, probably of a similar nature to that of other members of the Myrtaceae. The seeds are dispersed by wind. Like many other members of its family, it is adapted to fire, which generally results in an intensification of the infestation. It has not been evaluated for biological control.

Paperbark infests wet habitats between 100-1,000 m. The principal infestations are above Kalaheo, Kaua'i; in the Ko'olau Mountains, O'ahu; and in the Metrosideros dieback area on the north slope of Haleakala, Maui.

Melastoma malabathricum L. (Indian rhododendron)

This noxious, spreading shrub forms tangled brush up to 2 m tall which crowds out all other species. Its berry-like fruit is dispersed by frugivorous birds. There is no information on its adaptation to fire. Although Gardner and Davis (1982) suggested that it has been partially controlled by Selca brunella Hampson caterpillars, there is little evidence of any decrease in population levels.

There are heavy infestations on Kaua'i and the Puna and Hamakua Districts of Hawai'i from sea level to 700 m. In some areas of Kaua'i, particularly in Kilohana Crater, it is being replaced by Rhodomyrtus tomentosa.

Melia azedarach L. (Pride of India)

This fast-growing, deciduous tree reaches 20 m in height. Its wide-spreading branches form a deep shade. There does not appear to be a natural seed dispersal agent present in the Islands; it is thought that man is responsible for dispersal. Adaptation to fire in Hawai'i is unknown, and it has not been evaluated for biological control.

It grows between sea level and 700 m in open dry habitats. There are major infestations in Waimea Canyon, Kaua'i; Nu'u and lower Kula, Maui; and Kona, Hawai'i.

Melinis minutiflora Beauv. (Molassesgrass)
This spreading, perennial mat grass smothers everything around it. Once established, it forms monotypic stands from rooted runners. It is considered a good forage grass and therefore is not a candidate for biological control. The seeds are dispersed by wind. It is adapted to fire, and the dense mats are generally only partly consumed. Regeneration from the remaining portions is rapid, and colony expansion into adjacent burned areas generally follows.

It is found on all islands from sea level to 1,500 m in dry and mesic environments.

Melochia umbellata (Houtt.) Stapf. (Melochia)
This small, fast-growing, shrubby tree was originally introduced to produce shade for young forest trees and perhaps coffee. It rapidly fills any available space after disturbance, displacing the slower growing native species. The seeds are dispersed by wind. Adaptation to fire is unknown, and it has not been evaluated for biological control.

The major infestations are in Puna and Hilo, Hawai'i.

Merremia tuberosa (L.) Rendle (Woodrose)
This light-loving, perennial vine can smother tall forest canopies. The seeds are almost exclusively distributed by man, who introduces it to new areas principally as a source of material for dried flower arrangements. The aerial portion of the plant is killed by fire, but a new vine is soon produced from its underground tuber. It has not been evaluated for biological control.

Woodrose grows in open mesic forests from sea level to 1,400 m. Many areas of Kaua'i are infested, e.g., Puhi, west of Lihu'e.

Miconia magnifica (Triana)
This evergreen tree escaped from a local garden very recently. It forms densely shaded, monotypic stands. We know little about its local biology but anticipate that it will have the same impact in Hawai'i as it has had in Tahiti, where it has rapidly invaded native forests with disastrous consequences for the native flora. Its adaptation to fire is not known, and it has not been evaluated for biological control.

There is a population established in the Hilo area which should be eliminated immediately. Unfortunately, it is still being sold by garden shops. The species should be classified as noxious.

Microlaena stipioides (Labill.) R. Br. (Meadow rice-grass)

This wiry, perennial tufted grass is common in moist and wet habitats. It invades disturbed sites rapidly. The awned fruit are dispersed on clothing or animal fur. It is a fire-stimulated grass and in Hawai'i carries fires over larger areas than normal. It has not been evaluated for biological control.

It grows between 100-1,500 m in dry to mesic areas. There are major infestations from Puna to South Kona on Hawai'i.

Myrica faya Ait. (Fayatree, firetree)

This rapidly growing, noxious, evergreen tree, reaching up to 15 m in height, invades mesic and wet habitats where it forms dense, monotypic stands. The leaves are suspected of some allelopathic activity. The fruit is dispersed by alien and native frugivorous birds (La Rosa 1983) and feral pigs (C. Stone, pers. comm.). Trees are normally killed by fire, although regeneration from basal sprouts is possible. It has been and still is being evaluated for biological control (Gardner and Davis 1982). Exploration for potential biological control agents was made in 1984.

Myrica grows between 300-1,700 m elevation. The principal infestations are in Koke'e, Kaua'i; Wai'anae Mts., O'ahu; lower Kula, Maui; Ko'ele, Lana'i; and Hamakua, Hualalai, and Volcano Golf Course and Hawai'i Volcanoes National Park, Hawai'i.

Panicum maximum Jacq. (Guinea grass)

This coarse, perennial grass reaches heights of more than 2 m. It has a strong allelopathic activity (Chou and Young 1975). The seeds are dispersed by wind, and it can survive long periods of drought. Fire will sweep through stands of this grass but it regenerates rapidly from underground rhizomes. It has not been evaluated for biological control.

It grows in dry areas between sea level and 1,200 m on all major islands.

Paspalum conjugatum Berg. (Hilo grass)

This perennial, stoloniferous grass rapidly invades wet habitats from sea level to 2,000 m. It forms a dense ground cover even on acidic, low-nutrient soils. Neal (1965) noted that "some native forests have become extinct due to this pest." The small seeds are probably distributed by man and animals on clothing and fur. This species is generally susceptible to fire, an unlikely event in the rain forest. No serious effort has been made to evaluate this pest of native ecosystems and ranchlands for biological control.

It is found in wet habitats on all islands.

Passiflora ligularis Juss. (Sweet granadilla)

This vine is a weed with many similarities to P. mollissima. The major infestation is at Ka'upulehu, Hualalai, Hawai'i.

Passiflora mollissima (HBK.) Bailey (Banana poka)

This light-loving vine can rapidly reach and smother the forest canopy when the sub-canopy vegetation is disturbed either naturally, by hurricanes and other high winds, or by man or feral pigs (La Rosa 1983). Feral pigs are the principal short-distance dispersal agents (Warshauer et al. 1983). Alien frugivorous and granivorous birds as well as man act as long distance dispersal agents. Adaptation to fire is not known. This pest is the subject of an exploration for biological control agents supported by the State Department of Land and Natural Resources (DLNR). Studies on the biocontrol potential of Fusarium oxysporum f. sp. passiflorae are in progress.

There are 3 major infestations on Hawai'i at Hualalai, Laupahoehoe, and Volcano, and another on Kaua'i at Koke'e (Warshauer et al. 1983). A population at upper Waiakoa, Maui, which had been thought to be eradicated has recently been relocated in several adjacent gullies.

Passiflora suberosa L. (Huehue-haole)

This vine does best in the subcanopy layers where it smothers shrubs, small trees and the ground layer. In some areas it also smothers the upper canopy layer. The seeds are dispersed by alien frugivorous birds. Adaptation to fire is not known, and it has not been evaluated for biological control.

This passionfruit is found in dryland habitats on all islands between sea level and 600 m. There are major infestations throughout the Wai'anae Mountains, O'ahu and along the Kahoma Ditch trail, Maui.

Pennisetum clandestinum Hochst. ex Chiov. (Kikuyugrass)

This rapidly growing, partially scrambling, rhizomatous plant is a favored, but overrated, rangeland grass. It is a serious pest in forests because, apart from shading out shrubs and herbs, it releases allelopathic substances which kill almost all other species in the vicinity (Sanchez and Davis 1969). It burns very slowly and generally retards fire. It has been evaluated for biological control but no action will be taken because of its agricultural importance (Gardner and Davis 1982). A rust (Phakospora apoda (Har. and Pat.) Mains) has recently become established on all islands but its impact is not yet known (Gardner 1984). The grass can be eradicated by spraying with 0.5% glyphosate (Gardner and Kageler 1983) or Dalapon (Hosaka 1958).

It is found on all major islands from 500-2,000 m in dry and mesic habitats. It will also invade wet environments when the forest is disturbed. It has been classified as a noxious weed by the U.S. Department of Agriculture in all states except Hawai'i.

Pennisetum setaceum (Forsk.) Chiov. (Fountaingrass)

This bunchgrass is a noxious weed, crowding out other herbs and seedlings. It is a fire-stimulated grass which carries intense fires throughout its range. The seeds are dispersed by wind. Any attempt to evaluate its potential for biological control will be undoubtedly opposed by the sugar industry.

It is present on all major islands with the major infestation on the Kona side of Hawai'i.

Phormium tenax J.R. and G. Forst. (New Zealand flax)

This rosette-like lily forms dense thickets from which other species are excluded. Man is probably the principal dispersal agent but granivorous birds cannot be completely discounted. Adaptation to fire is unknown, and it has not been evaluated for biological control.

The species is found principally in gullies in mesic areas below 300 m, e.g. Moloka'i, and the northern Hamakua coastline, Hawai'i.

Pinus caribaea Morelet (Slash pine)

This evergreen tree can form dense monotypic stands reaching 15 m in height displacing all other plants. The seeds are dispersed by wind, and it is rapidly destroyed by fire. Control in native ecosystems is by felling. It has not been evaluated for biological control because it is still hoped that it will produce timber for a forest industry.

The principal infestation is on Moloka'i.

Pinus patula Schlecht. and Cham. (Mexican weeping pine)

The problems with this pine are very similar to P. caribaea. The principal infestation is in the area adjacent to Hosmer Grove, Haleakala National Park, Maui.

Pinus pinaster Ait. (Cluster pine)

The problems with this pine are very similar to those with P. caribaea. The principal infestation is in the Polipoli area, Maui between 1,600-2,200 m elevation.

Pithecelobium dulce (Roxb.) Benth. (Opiuma)

This thorny, deciduous tree grows up to 10 m tall, forming impenetrable thickets. The seeds are dispersed by alien frugivorous birds. It is relatively resistant to fire and resprouts rapidly by basal or aerial shoots. The tree has not been evaluated for biological control, a strategy that would probably be opposed because of its use in landscaping.

It is found from sea level to 300 m elevation in dry habitats. Major infestations are at Mokule'ia, O'ahu; the east end of Moloka'i; the gulches east of Lahaina, Maui; and South Kona, Hawai'i.

Pluchea indica (L.) Less. (Indian fleabane)

The problems associated with this species are similar to P. odorata. This plant is confined to lowland habitats, particularly wetlands and fishponds. There is a major infestation at Kanaha pond, Maui.

Pluchea odorata (L.) Cass. (Sour bush)

This 1-2 m tall, fast-growing shrub forms thickets in dry habitats. The seeds are wind-dispersed. Its resistance to fire depends on the intensity of the fire. It generally regenerates from basal shoots. Some biological control agents have been introduced but they have not been effective.

It is found on all major islands from sea level to 1,000 m elevation.

Prosopis pallida (Humb. and Bonpl. ex Willd.) HBK. (Kiawe, mesquite)

This deciduous, thorny tree grows up to 20 m tall. It overshadows other vegetation but also desiccates an area by using all available water. Deep root systems tap ground-water. There is no known disseminator of the seeds but mesquite was planted in arid areas for shade and reforestation. The pods were used extensively for fodder, resulting in further dissemination or intensification of stands. This species is generally killed by intense fires, although a small proportion of the trees will survive if the bases are partially protected. It has not been evaluated for biological control. It has many uses (Simpson 1977) and is locally favored by bee-keepers.

The plant is found in arid regions on all islands between sea level and 700 m. In dry areas dense populations are found over subterranean water courses.

Psidium cattleianum Sabine (Strawberry guava)

This medium-sized tree forms dense thickets, later forming forests under which very few other plants grow. It is the worst pest in Hawai'i's rain forests. It is favored by pigs which move into infested areas during the fruiting season in the fall. The seeds pass through digestive tracts unharmed and are often deposited in soil disturbed by pigs. Alien frugivorous birds also disperse the seed, often in areas without soil disturbance. In this case, infestations spread very slowly. Adaptation to fire is unknown. The prospects for biological control are slim because the commercial exploitation of the common guava would require rigorous species specificity of the control agent. However, the extent of the infestation of this species precludes any other approach.

Strawberry guava is found on all major islands between 150-1,300 m, principally in rain forest habitats.

Psidium guajava L. (Guava)

This evergreen tree reaches heights of 8 m. It invades disturbed sites and forms dense thickets. The leaves are suspected of allelopathic activity. The seeds are dispersed by alien frugivorous birds as well as rats and feral pigs. Guava can survive moderately intense fires by regenerating from basal sprouts. It has not been evaluated for biological control and is unlikely to be because of commercial orchards on Kaua'i and Hawai'i.

It is distributed in mesic to wet areas below 500 m on all major islands, and in gulches, even in dry areas.

Rhizophora mangle L. (Red mangrove)

This evergreen tree grows up to 25 m tall in coastal marshes and streams. The monotypic stands form a very dense cover, excluding all other species. On O'ahu and Moloka'i, these infestations have significantly altered almost all brackish water ecosystems as well as many fishponds. The seedlings are dispersed by water. Red mangrove forests are generally destroyed by fire, but the species has not been evaluated for biological control.

It is confined to brackish waters around all major islands.

Rhodomyrtus tomentosa (Ait.) Hassk. (Rose myrtle)

This noxious evergreen shrub rarely grows above 3 m but forms dense thickets. The seeds are dispersed by alien frugivorous birds. Its adaptation to fire is unknown, and it has not been evaluated for biological control.

The plant grows in lowland mesic habitats. There is a major infestation on Kaua'i, particularly in Kilohana Crater. It is displacing Melastoma malabathricum in some areas.

Ricinus communis L. (Castorbean)

This fast-growing tree can reach heights of 10 m. It forms somewhat ephemeral thickets which can shade out other species. Although rodents and granivorous birds may disperse some seeds, man is the principal agent. Castorbean is destroyed by fire; it has not been evaluated for biological control.

It grows in dry and mesic habitats from sea level to 1,200 m on all major islands.

Rubus argutus Link (R. penetrans Bailey in Hawaiian literature) (Florida prickly blackberry)

This thorny scrambler is a noxious weed which rapidly invades disturbed areas between 1,000-2,300 m. It forms impenetrable thickets which expand by the rooting of aerial shoots where they bend over and touch the ground. Alien frugivorous birds are the principal dispersal agents. The aerial portions of a plant are normally destroyed by fire but the plant quickly recovers from basal and subterranean shoots. Several biological control agents have been introduced but they are not very effective. Two rust diseases are currently under investigation by the National Park Service (NPS) and U.S. Forest Service (USFS). Some biocontrol agents introduced to control this species have adversely affected the 2 native Rubus species.

The species is well established in mesic to wet forests on all major islands.

Rubus ellipticus Sm. (Yellow Himalayan raspberry)

This prickly, semi-deciduous shrub invades native forests principally in pig-disturbed areas. The plants spread into neighboring forest from underground shoots. The seeds are dispersed by alien, and perhaps native, frugivorous birds. The species regenerates rapidly from underground shoots after fire. It has not been evaluated for biological control except collectively with other Rubus species (Gardner and Davis 1982).

It is found in wet habitats between 700-1,700 m, and there is a major infestation at Volcano, Hawai'i.

Rubus glaucus Bth. (Raspberry)
This species is similar in many respects to R. ellipticus. It was introduced at Volcano and Pa'auilo Agricultural Experimental Stations, where it grew but did not provide commercially exploitable fruit crops. The canes were abandoned but the seeds were dispersed by birds; the plant is now threatening the 'Ola'a Tract of Hawai'i Volcanoes National Park.

Rubus moluccanus L.
This species is a very serious pest similar to R. argutus. There is a major infestation at Koke'e, Kaua'i.

Rubus nivalis Doug. ex Hook.
This species is also a very serious pest similar to R. argutus. There are major infestations at Polipoli, Maui, and Humu'ula, Hawai'i.

Sacciolepis indica (L.) Chase (Glenwood grass)
This slender, annual grass invades disturbed and open areas in wet habitats. The seeds are dispersed by sticking to animal fur. Its response to fire, an unlikely event in the rain forest, is unknown. It has not been evaluated for biological control.

Glenwood grass occurs on all major islands. There is a large infestation moving into Wahiawa Bog, Kaua'i and above Nahiku, Maui.

Schinus terebinthifolius Raddi (Christmasberry)
The low-growing, evergreen, deciduous tree is an aggressive invader of most mesic to wet lowland environments. It shades out other plants, as well as prevents reestablishment of other species due to the release of allelopathic substances (Gogue, Hurst, and Bancroft 1974). The fruit is especially favored by alien frugivorous birds. Schinus is killed by high intensity fires but regenerates rapidly where there is a large seed bank. A defoliating insect has been introduced but has not been effective. Further attempts at biological control can be expected to be met with stiff opposition from bee-keepers.

The species is widely distributed in lowland areas of all major islands.

Senecio mikanioides Otto ex Walp. (German ivy)
This noxious, light-loving vine grows rapidly into the emergent layers of forests where it festoons the vegetation. The seeds are wind-dispersed. The degree

of adaptation to fire is unknown, and it has not been evaluated for biological control.

Senecio grows in open, wet habitats between 800-2,000 m. There are several infestations along the Saddle Road, e.g., Pu'u Huluhulu, Hawai'i, and it is becoming established at upper elevations on Mauna Kea and Manuka. The infestations there are local and could still be controlled with mechanical methods.

Setaria palmaefolia (Koen.) Stapf (Palmgrass)

This large-leaved, perennial grass reaches heights of almost 2 m, shading out other herbaceous vegetation. The seeds are distributed passively or by granivorous birds. The young shoots are eaten by feral pigs, which intensify infestations by uprooting neighboring vegetation, creating new areas for establishment. Palmgrass is well-adapted to fire. It has not been evaluated for biological control.

It is found in wet areas on all major islands from 300-2,000 m elevation. There are major infestations in the 'Ola'a, Hilo, Kohala, and Wai'akea Forest Reserves, Hawai'i, and the Ko'olau Forest Reserve, Maui.

Spathodea campanulata Beauv. (African tuliptree)

This showy, shade-tolerant, evergreen tree reaches heights of 25 m. It invades abandoned agricultural land and closed forest where the wind-dispersed seeds germinate rapidly. These seedlings continue growing, forming thickets from which a few saplings may reach the canopy. Adaptation to fire is unknown, and it has not been evaluated for biological control.

Tuliptree occurs in wet habitats from sea level to 1,000 m on all major islands. There are major infestations tucked away in almost every rain forest valley along the northern and eastern slopes of Kaua'i, O'ahu, and East Maui.

Tagetes minuta L. (Marigold)

This noxious, rapidly growing herb forms a dense ground cover at higher elevations. The seeds cling to hair and are dispersed by domesticated and feral animals. It is killed by fire, but new colonies are formed rapidly from the seed bank. Marigold has not been evaluated for biological control.

The plant is confined to dry and mesic areas on Mauna Kea between 1,700-3,000 m.

Terminalia catappa L. (False kamani)

This evergreen tree rarely reaches heights over 15 m. It shades out all other species. The seeds are dispersed by man and probably by water. Adaptation to fire is unknown. It has not been evaluated for biological control and is considered a desirable shade tree by many people.

The plant is confined to mesic and wet coastal habitats on all major islands.

Tibouchina urvilleana (DC.) Cogn. (Glorybush)

This semi-deciduous shrub reaches heights of 4 m. It forms thickets in wet habitats. The seeds are mechanically dispersed from a capsule with sufficient force to enable this species to form expanding thickets in suitable habitats. Adaptation to fire is unknown. Gardner and Davis (1982) suggested that it had been partially controlled by Selca brunella Hampson, but no control has been effected at the principal infestations. Apart from that, the potential for biological control has not been exploited.

Tibouchina is confined to wet habitats between 200-1,700 m on Kaua'i, O'ahu, and Hawai'i. There is a major infestation in Volcano, Hawai'i.

Ulex europaeus L. (Gorse)

This noxious, spiny shrub reaches heights of 2 m. It forms impenetrable, monotypic thickets. The seeds are forcibly ejected up to 3 m from the parent plant. Long-distance dispersal is effected by man or by capsules attached to branches entangled in mammal pelage. Although much of the aerial portion of the plant may be destroyed by fire, the remaining portions regenerate rapidly. Fire also aids in breaking the dormancy of the seeds. Gorse has been subjected to biological control, the effectiveness of which has been reviewed by Markin (1984).

It grows in mesic habitats between 200-2,100 m on Maui and Hawai'i. The infestations at Olinda, Maui and Humu'ula, Hawai'i are a considerable problem and beyond economically feasible mechanical or chemical control.

Verbascum thapsus L. (Common mullein)

This wooly, biennial, rosette plant forms a dense ground cover displacing slower-growing native species. The seeds are wind-dispersed. Fires are retarded in stands of this plant under normal conditions. Mullein has been partially controlled by a gall-forming insect which has reduced population size and range significantly.

The plant is found between 2,200-3,100 m on Mauna Kea, Hawai'i.

Additional Species

The following species now found in Hawai'i need to be monitored because their behavior elsewhere suggests that they could become serious pests.

- Acacia melanoxylon R.Br. (Australian blackwood)
- Ailanthus altissima (Mill.) Swingle (Tree of Heaven)
- Anisomeris fasciculata K. Schum.
- Athyriopsis japonica (Thunb.) Ching
- Blechnum occidentale L. (Blechnum fern)
- Brugeria gymnorhiza (L.) Lam. (Oriental mangrove)
- Buddleja madagascariensis Lam. (Butterfly bush)
- Caesalpinia bonduc (L.) Roxb. (Yellow knickers)
- Castilloa elastica Cerv. (Panama rubber tree)
- Cecropia obtusifolia Bertol. (Guaramo)
- Cinchona succirubra Pav. ex Klotsch. (Quinine tree)
- Cordia glabra L. (Broad-leaved cordia)
- Eleagnus multiflora Thunb. (Gumi)
- Eucalyptus globosus Labill. (Blue gum)
- Euphorbia ?antiquorum L. (Cactus-like spurge)
- Flindersia brayleyana F. Muell. (Silkwood)
- Haematoxylon campechianum L. (Logwood)
- Heterocentron subtriplinervium (Link and Otto) A. Br. & Bouche (Pearl flower)
- Hunnemannia fumariaefolia Sweet (Mexican tulip poppy)
- Mimosa invisa Mart.
- Montanoa hibiscifolia (Benth.) C. Koch (Montanoa)
- Oxyspora paniculata (D. Don) DC.
- Passiflora edulis Sims (Liliko'i)
- Passiflora laurifolia L. (Yellow granadilla)
- Samanea saman (Jacq.) Merr. (Monkeypod)
- Swietenia mahogani (L.) Jacq. (Mahogany)
- Terminalia myriocarpa Heurck and Muell.-Arg. (Jhalna)
- Thunbergia alata Bojer ex Sims (Black-eyed Susan)
- Thunbergia grandiflora Roxb. (Large-flowered thunbergia)
- Thunbergia laurifolia Lindl. (Laurel-leaved thunbergia)
- Trema orientalis (L.) Bl. (Charcoal tree)
- Urena lobata L. (Aramina)
- Wedelia trilobata (L.) Hitchc. (Wedelia)
- Wisteria sinensis Sweet (Chinese wisteria)

PROBLEM WEEDS IN HAWAI'I BY ISLAND

The determination that any weed is a pest is somewhat subjective. However, there is usually a general consensus about the most important weeds on each island. Seven species (Florida prickly blackberry, Christmasberry, common guava, Guinea grass, koa haole, lantana, and molassesgrass) are serious pests on all islands (table 1). They all occur in dry to mesic lowland environments, but lantana and molassesgrass are also found at higher elevations and in wetter habitats. Another 5 (common ironwood, swamp oak, Java plum, kiawe, and strawberry guava), although present on all islands, are a problem only on 5 islands. With the exception of swamp oak, they are not a problem on Lana'i because it is too dry for their proper development. Another 7 species (bamboo, Chinese banyan, faya tree, Indian fleabane, roseapple, Glenwood grass, and sourbush) are a problem on 4 islands only, but they may be present on all islands. Again these are species which prefer wetter habitats and are therefore excluded from Lana'i and some other islands.

All 19 species just noted are serious threats to native ecosystems or their reestablishment. They all smother vegetation, displacing the native species or preventing their reestablishment. Egler (1942) has suggested that koa haole will enhance recolonization of native species by ameliorating the habitat. There is little evidence to support this hypothesis. In fact, it appears that the native species are being excluded from these environments and their seed banks exhausted.

Fourteen other species (African tuliptree, ardisia, banana poka, bush beardgrass, broomsedge, cats-claw, fountaingrass, Indian rhododendron, kahili ginger, kikuyugrass, Kosters curse, palmgrass, velvetgrass, and white ginger) are a serious problem on 2 or 3 islands but have not yet filled their potential range. With the exception of bush beardgrass, cats-claw, fountaingrass, and velvetgrass, they all infest wet habitats. Broomsedge and kikuyugrass infest dry, mesic, and wet habitats.

Seven species (buffelgrass, gorse, hairy cats-ear, kahili flower, Rubus nealus, sweet vernalgrass, and white ginger) are problems only on Maui and Hawai'i. Hairy cats-ear, Rubus nealus, and sweet vernalgrass are confined to high elevations. Gorse was introduced to the higher elevations of Haleakala and Mauna Kea only but would grow in mesic habitats above 200 m on all islands. Buffelgrass is a serious weed in very dry areas. It is not clear why white ginger infestations are confined to Maui and Hawai'i, as suitable habitat exists on other islands.

Table 1. List of weed pests in Hawai`i, showing distribution by island; whether or not noxious, allelopathic, or able to fix N_2; why introduced and where from; susceptibility to fire; and growth form. [(+) = present but not a pest; + = pest].

Scientific Name (Common Name)	Island						Nox-ious	Allel-opath	N_2 Fix.	Why Intro.	Where From	Fire Sus.	Growth Form
	Kau	Oah	Mol	Lan	Mau	Haw							
Acacia mearnsii (black wattle)	(+)	(+)	(+)	(+)	+	(+)	Y[1]	(Y)	Y	Eros[2]	Aust[3]	A[4]	Ph[5]
A. confusa (Formosan koa)	(+)	+	(+)	(+)	+	(+)		Y	Y	Eros	SEAs	C	Ph
A. farnesiana (Klu)	+	+	(+)	(+)	(+)	(+)			Y	Inad	TrAm	A	Ph
Albizia falcataria (Molucca albizia)	+	+	(+)	(+)	(+)	+			Y	Fsty	SEAs		Ph
Andropogon glomeratus (Bush beardgrass)						+		Y		Inad	NoAm	B	Ch
A. virginicus (Broomsedge)	(+)	+	+	(+)	(+)	+		Y		Inad	NoAm	B	Ch
Anthoxanthum odoratum (Sweet vernalgrass)					+	+				Fodd	Eurp	A	HC
Ardisia humilis (Shoebutton ardisia)	(+)	+			+	(+)				Hort	Asia		Ph
Asystasia gangetica (Asystasia)										Hort	Asia	B	Ch

Table 1. Continued.

Scientific Name (Common Name)	Island						Nox-ious	Allel-opath	N_2 Fix.	Why Intro.	Where From	Fire Sus.	Growth Form
	Kau	Oah	Mol	Lan	Mau	Haw							
Bambusa sp. (Bamboo)	+	+	+		+	(+)				Hort	Asia	C	Ph
Bidens pilosa (Beggar's tick)	(+)	(+)	(+)	(+)	+	(+)				Inad	TrAm	A	Th
Bocconia frutescens					+	(+)				Hort	TrAm		Ch
Brachiara mutica (California grass)	(+)	+	(+)	(+)	(+)	(+)		Y		Fodd	Afrc	B	HC
Brassaia actinophylla (Octopus tree)	+	+	(+)		(+)	(+)				Hort	Aust	D	Ph
Caesalpinia sepiaria (Cats-claw)	+	+			+	(+)	Y		?	Hort	Asia		Li
Casuarina equisetifolia (Common ironwood)	+	+	+	(+)	+	+		Y	Y	Eros	Aust	C	Ph
C. glauca (Swamp oak)	(+)	+	+	+	+	+		Y	Y	Eros	Aust	C	Ph
Cecropia peltata (Trumpet tree)	(+)	+	(+)		(+)	+				Hort	TrAm	D	Ph
Cenchrus ciliaris (Buffelgrass)	(+)	(+)	(+)	(+)	+	+				Eros	Afrc	B	HC

Scientific Name (Common Name)	Island						Nox-ious	Allel-opath	N_2 Fix.	Why Intro.	Where From	Fire Sus.	Growth Form
	Kau	Oah	Mol	Lan	Mau	Haw							
<u>Citharexylum caudatum</u> (Juniper berry)		+								Hort	TrAm		Ph
<u>C. spinosum</u> (Fiddlewood)	(+)	+			(+)	(+)				Hort	TrAm		Ph
<u>Clerodendron fragans</u> (Glorybower)	+		(+)			(+)				Hort	SEAs		Ch
<u>Clidemia hirta</u> (Koster's curse)	+	+	+		+	+	Y			Eros	TrAm		Ch
<u>Corynocarpus laevigatus</u> (New Zealand laurel)	+					(+)				Hort	NZ		Ph
<u>Eugenia cumini</u> (Java plum)	+	+	+	(+)	+	+		(Y)		Hort	SEAs	C	Ph
<u>E. jambos</u> (Roseapple)	+	+	(+)		+	+				Hort	TrAm	C	Ph
<u>Ficus microcarpa</u> (Chinese banyan)	+	+	(+)	(+)	+	+		(Y)		Hort	SEAs	C	Ph
<u>Fraxinus uhdei</u> (Mexican ash)	(+)	+	+	(+)	(+)	(+)				Fsty	TrAm		Ph
<u>Furcraea foetida</u> (Mauritius hemp)	+	+	(+)	(+)	(+)	(+)				Hort	SoAm	C	Ph

Table 1. Continued.

Scientific Name (Common Name)	Island						Nox-ious	Allel-opath	N_2 Fix.	Why Intro.	Where From	Fire Sus.	Growth Form
	Kau	Oah	Mol	Lan	Mau	Haw							
Grevillea banksii (Kahili flower)	(+)	(+)	(+)		+	+	Y	Y		Inad	Aust	A	Ph
G. robusta (Silky oak)	(+)	(+)	(+)	(+)	+	+		Y		Fsty	Aust	A	Ph
Hedychium coronarium (White ginger)	(+)	(+)	(+)		+	+				Hort	Asia		Ge
H. flavescens (Yellow ginger)	+	(+)	(+)		(+)	+				Hort	Asia		Ge
H. gardnerianum (Kahili ginger)	+	(+)	(+)		+	+				Hort	Asia		Ge
Heliocarpus popayensis (White moho)	(+)	+				+				Fsty	TrAm		Ph
Holcus lanatus (Velvetgrass)	(+)	(+)	(+)	(+)	+	+				Fodd	Eurp	A	HC
Hypochoeris radicata (Hairy cats-ear)					+	+				Inad	Eurp	A	Ge
Lantana camara (Lantana)	+	+	+	+	+	+	Y	Y		Hort	TrAm	A	Ch
Leptospermum ericoides (Tree manuba)				+				(Y)		Hort	NZ	A	Ph

Scientific Name (Common Name)	Island Kau	Island Oah	Island Mol	Island Lan	Island Mau	Island Haw	Nox-ious	Allel-opath	N_2 Fix.	Why Intro.	Where From	Fire Sus.	Growth Form
L. scoparium (New Zealand tea)		+		+	(+)	(+)		Y		Hort	NZ	A	Ch
Leucaena leucocephala (Koa haole)	+	+	+	+	+	+			Y	Fodd	TrAm	B	Ph
Linociera intermedia (Olive)						+		(Y)		Hort	Asia		Ph
Melaleuca leucadendra (Paperbark)	(+)	+	(+)	(+)	+	+		Y		Fsty	Aust	A	Ph
Melastoma malabathricum (Indian rhododendron)	+	+				+	Y			Hort	Asia		Ph
Melia azedarach (Pride of India)	(+)	+	(+)	(+)	(+)	(+)				Hort	Asia		Ph
Melinis minutiflora (Molassesgrass)	+	+	+	+	+	+				Fodd	Afrc	B	HC
Melochia umbellata (Melochia)	(+)	(+)				+				Fsty	Asia		Ph
Merremia tuberosa (Woodrose)	+	(+)	(+)	(+)	(+)	(+)				Hort	SEAs	B	Li
Miconia magnifica						+				Hort	SEAs?		Ph

Table 1. Continued.

Scientific Name (Common Name)	Island Kau	Oah	Mol	Lan	Mau	Haw	Nox-ious	Allel-opath	N_2 Fix.	Why Intro.	Where From	Fire Sus.	Growth Form
Microlaena stipioides (Meadow ricegrass)	(+)	(+)	(+)	(+)	(+)	+				Inad	Aust	A	HC
Myrica faya (Fayatree, Firetree)	+	+		+	(+)	+	Y	Y		Eros?	Eurp	A	Ph
Panicum maximum (Guinea grass)	+	+	+	+	+	+		Y		Fodd	Afrc	B	Ch
Paspalum conjugatum (Hilo grass)	(+)	(+)	+		+	+		(Y)		Fodd	SoAm		HC
Passiflora ligularis (Sweet granadilla)	(+)					+				Hort	TrAm		Li
P. mollissima (Banana poka)	+				+	+				Hort	TrAm		Li
P. suberosa (Huehue-haole)	(+)	+			+					Hort	TrAm	D	Li
Pennisetum clandestinum (Kikuyugrass)	+	(+)	(+)	(+)	+	+		Y		Fodd	Afrc	C	HC
P. setaceum (Fountaingrass)		(+)			(+)	+	Y	(Y)		Hort	Afrc	B	HC
Phormium tenax (New Zealand flax)	(+)		(+)	(+)	(+)	+				Hort	NZ	C	Ph

Scientific Name (Common Name)	Island						Nox-ious	Allel-opath	N_2 Fix.	Why Intro.	Where From	Fire Sus.	Growth Form
	Kau	Oah	Mol	Lan	Mau	Haw							
Pinus elliottii (Slash pine)	(+)		+	(+)	(+)	(+)				Fsty	TrAm	D	Ph
P. patula (Mexican weeping pine)		(+)			+	(+)				Fsty	TrAm	D	Ph
P. pinaster (Cluster pine)			(+)	(+)	+	(+)				Fsty		D	Ph
Pithecelobium dulce (Opiuma)	(+)	+	+		(+)	+			Y	Hort	TrAm	A	Ph
Pluchea indica (Indian fleabane)	+	+	(+)	(+)	+	+				Inad	Asia	B	Ch
P. odorata (Sourbush)	+	+	(+)	(+)	+	+				Inad	TrAm	B	Ch
Prosopis pallida (Kiawe)	+	+	+	(+)	+	+			Y	Fodd	TrAm	D	Ph
Psidium cattleianum (Strawberry guava)	+	+	+	(+)	+	+		(Y)		Hort	TrAm		Ph
P. guajava (Common guava)	+	+	+	+	+	+		Y		Hort	TrAm		Ph
Rhizophora mangle (Red mangrove)	(+)	+	+	(+)	(+)	+		(Y)		Eros	TrAm	D	Ph

Table 1. Continued.

Scientific Name (Common Name)	Island Kau	Oah	Mol	Lan	Mau	Haw	Nox-ious	Allel-opath	N_2 Fix.	Why Intro.	Where From	Fire Sus.	Growth Form
<u>Rhodomyrtus tomentosa</u> (Rose myrtle)	+	(+)					Y			Hort	SEAs		Ph
<u>Ricinus communis</u> (Castor bean)	+	(+)	(+)	(+)	(+)	+				Hort	Afrc	D	Ph
<u>Rubus argutus</u> (Florida prickly blackberry)	+	+	+	+	+	+	Y			Hort	NoAm	A	Ch
<u>R. ellipticus</u> (Yellow Himalayan raspberry)						+				Hort	Asia	A	Ch
<u>R. glaucus</u> (Raspberry)						+				Hort	TrAm	A	Ch
<u>R. moluccana</u>	+									Hort	SEAs	A	Ch
<u>R. nivalis</u>					+	+				Hort		A	Ch
<u>Sacciolepis indica</u> (Glenwood grass)	+	+	(+)		+	+				Fodd	SEAs		HC
<u>Schinus terebinthifolius</u> (Christmasberry)	+	+	+	+	+	+		Y		Hort	TrAm	A	Ph
<u>Senecio mikanioides</u> (German ivy)						+	Y			Hort	Afrc		Li

Scientific Name (Common Name)	Island: Kau	Oah	Mol	Lan	Mau	Haw	Nox-ious	Allel-opath	N_2 Fix.	Why Intro.	Where From	Fire Sus.	Growth Form
Setaria palmaefolia (Palmgrass)	(+)	(+)	(+)		+	+		(Y)		Hort	Asia	A	Ch
Spathodea campanulata (African tuliptree)	+	+	(+)	(+)	+	(+)				Hort	Afrc		Ph
Tagetes minuta (Marigold)						+	Y			Inad	SoAm	A	Th
Terminalia catappa (False kamani)	(+)	+	(+)	(+)	(+)	(+)				Hort	SEAs		Ph
Tibouchina urvilleana (Glorybush)	+	(+)			(+)	+				Hort	SoAm		Ph
Ulex europaeus (Gorse)					+	+	Y		Y	Hedg	Eurp	B	Ch
Verbascum thapsus (Common mullein)						+				Inad	Eurp		Ge

Table 1. Continued.

Scientific Name (Common Name)	Island Kau	Oah	Mol	Lan	Mau	Haw	Nox-ious	Allel-opath	N_2 Fix.
Total	66	64	53	42	67	76	13	26	10
Total weeds present as pests	36	43	20	11	44	54			
Island area (sq km)	1,624	1,574	676	361	1,887	10,458			

[1] Y = Yes, (Y) = Suspected.

[2] Eros = erosion control or ground cover, Fodd = fodder plants, Fsty = forestry, Hedg = animal control, Hort = horticulture, Inad = inadvertent.

[3] Afri = Africa, Asia = India to China, Aust = Australia and Melanesia, Eurp = Europe, NoAm = North America, NZ = New Zealand, SEAs = South-east Asia, TrAm = Tropical America.

[4] A = Resprouts quickly; B = stimulated, cover increases; C = fire spread slowed; D = destroyed.

[5] Ch = Chamaephgytes; Ge = Geophytes; HC = Hemicryptophytes; Li = Lianes, Ph = Phanaerophytes; Th = Therophytes.

Twenty-eight species appear to be a problem on one island only. Fourteen (50%) of them occur on Hawai'i, 5 (18%) on Kaua'i, 4 (14%) on Maui, 3 (11%) on O'ahu, and 1 each (4%) on Lana'i and Moloka'i. Most of these species occur on other islands but have not escaped, probably because they have not been introduced into a suitable environment.

It is somewhat surprising that O'ahu does not have the highest number of problem weeds. It is the principal port of entry for the Islands as well as the location of 3 botanical gardens. It is the most probable area where weeds would become established. Gerrish and Mueller-Dombois (1980) found some support for this hypothesis in that an area close to the metropolitan area (Tantalus) did have more weeds present than a more remote area (Pupukea). Also, juniper berry and several other plants which now infest the southern Ko'olaus appear to have dispersed from the Lyon Arboretum. However, the largest number of weeds occur on the island of Hawai'i. Although no obvious single explanation is available, it is known that several ranchers on Hawai'i have introduced large numbers of plants and birds for various reasons, particularly at elevations between 800-1,700 m. The recent formation and volcanic activity of much of the Island and the large expanses of open forest may provide favorable conditions for alien plant establishment.

Like most Pacific islands, the northwestern Hawaiian Islands have been affected by man--either by guano mining or World War II. Nihoa and Necker have not been disturbed (Clapp, Kridler, and Fleet 1977). Some aliens are established on Pearl and Hermes Reef and French Frigate Shoals, but they are not doing well (Amerson, Clapp, and Wirts 1974; Amerson 1971). Laysan and Lisianski were devastated by rabbits. Some alien species, including _Casuarina_, were planted but they have not spread (Clapp and Wirtz 1975; Ely and Clapp 1973; Lamoureux 1963). Kure Atoll, on the other hand, has a predominantly alien flora (Woodward 1972).

PROBLEM WEEDS IN HAWAI'I BY VEGETATION ZONE

It is quite obvious that lowland ecosystems in Hawai'i have suffered the most disruption from alien species because of agriculture, fire, and urbanization. These disturbances have created ideal conditions for the establishment of weeds. The lowlands are also the principal points of entry of most introductions to the Islands. Therefore, unless weeds survive in the tropical lowlands, they rarely become established. Occasionally, plants originally cultivated as ornamentals at lower elevations reach higher elevations, where they escape, e.g., _Senecio mikanioides_. This generalization will not be tenable for much longer as larger communities become established in the cooler upper elevations at Koke'e, Kaua'i; Kula, Maui; and Volcano, Hawai'i. Typical ornamentals will be introduced and then escape, e.g. the recent escape of nasturtium, Tropaeolum majus, at Hawai'i Volcanoes National Park.

It is not possible to make any meaningful assessment of weed invasions of Hawaiian ecosystems on the basis of elevation because of the significant differences in climatic conditions around the major islands. Ripperton and Hosaka (1942) in an early description of Hawai'i's vegetation subdivided it into 10 zones. Krajina (1963) later refined this system into 14 zones, principally by further subdividing the high rainfall categories. These vegetation zones provide a convenient framework for a discussion of the impact of alien plants on Hawaii's vegetation (table 2). Because disturbance in each zone has varied quite considerably, the following remarks are generalizations illustrating trends.

Land below 300 m elevation receiving less than 500 mm of rain each year (Ripperton and Hosaka's Zone A) is now almost totally dominated by alien forbs and shrubs (table 2). Formerly open native scrub grasslands, these areas were the principal habitation of the aboriginal Hawaiians. The lands were greatly disturbed by fire and in many instances have been severely eroded. When fires were suppressed as western civilization took hold, the native vegetation began to recover. However, the introduction of koa haole and its subsequent aerial broadcasting resulted in its rapid colonization and ultimate domination of these areas. Other species which are common in this zone include Formosan koa, Indian fleabane, klu, Java plum, and sourbush. In areas with subsurface water, kiawe is dominant. Along the west coast of Hawai'i fountaingrass has become a serious pest and dominates many coastal and upland areas. Where cheap irrigation water is available and the soil is reasonably deep, sugar cane or other crops are grown. In the driest areas of most islands (e.g. Diamond Head and Ka'ena Point, O'ahu) a few native species still predominate.

Zone B, land below 1,000 m with an annual rainfall from 500-1,000 mm, has suffered a fate very similar to Zone A in areas where there is insufficient soil for agriculture. However, below 350 m and where irrigation water is available, sugar cane plantations, or more recently papaya and macadamia nut farms, have been developed. Above 200 m pineapple is cultivated where irrigation is not feasible. On land too steep for plantations, various timber trees were planted,

Table 2. List of weed pests in the Hawaiian Islands by vegetation zone (Krajina 1963). (+ = present as a pest, (+) = present but not a pest).

Scientific Name (Common Name)	Vegetation Zone									
	A	B	C1	C2	D1	D2	D3	E1	E2	E3
Acacia mearnsii (Black wattle)		(+)	+	+						
A. confusa (Formosan koa)	+	+	+							
A. farnesiana (Klu)	+	+	+							
Albizia falcataria (Molucca albizia)		(+)	+		+					
Andropogon glomeratus (Bush beardgrass)		+	+	+				+		
A. virginicus (Broomsedge)	+	+	+	+	(+)			+		
Anthoxanthum odoratum (Sweet vernal grass)							+	+	+	
Ardisia humilis (Shoebutton ardisia)			(+)		+					
Asystasia gangetica (Asystasia)	+	+								
Bambusa sp. (Bamboo)			+		+					
Bidens pilosa (Beggar's tick)	+	+	+	+	(+)					
Bocconia frutescens			+	+				+		
Brachiaria mutica (California grass)	(+)	(+)	+		+					
Brassaia actinophylla (Octopus tree)			+		+					

Table 2. Continued.

Scientific Name (Common Name)	Vegetation Zone A	B	C1	C2	D1	D2	D3	E1	E2	E3
Caesalpinia sepiaria (Cats-claw)		+	+		(+)					
Casuarina equisetifolia (Common ironwood)	+	+	+		+					
C. glauca (Swamp oak)	+	+	+		+					
Cecropia peltata (Trumpet tree)			+		+					
Cenchrus ciliaris (Buffel grass)	+	(+)								
Citharexylum caudatum (Juniper berry)		+	+		+					
C. spinosum (Fiddlewood)		+	+	(+)	+					
Clerodendron fragrans (Glorybower)					+					
Clidemia hirta (Koster's curse)			+	(+)	+					
Corynocarpus laevigatus (New Zealand laurel)			+	+						
Eugenia cuminii (Java plum)	(+)	+	+		+					
E. jambos (Roseapple)			(+)		+	+				
Ficus microcarpa (Chinese banyan)		+	+		+					
Fraxinus uhdei (Mexican ash)		(+)	+	+	+	+				
Furcraea foetida (Mauritius hemp)	+	+								

Scientific Name (Common Name)	Vegetation Zone									
	A	B	C1	C2	D1	D2	D3	E1	E2	E3
Grevillea banksii (Kahili flower)		+	(+)	+						
G. robusta (Silky oak)		+	(+)	+						
Hedychium coronarium (White ginger)			+	+	+	+	(+)			
H. flavescens (Yellow ginger)			+	+	+	+	(+)			
H. gardnerianum (Kahili ginger)			+	+	+	+	(+)			
Heliocarpus popayensis (White moho)			+		+					
Holcus lanatus (Velvet grass)						+	+	+	+	
Hypochoeris radicata (Hairy cats-ear)							+	+	+	
Lantana camara (Lantana)	(+)	+	+	(+)	(+)					
Leptospermum ericoides (Tree manuba)			+		+					
L. scoparium (New Zealand tea)					+	+				
Leucaena leucocephala (Koa haole)	+	+	+							
Linoceria intermedia (Olive)		+	+	+						
Melaleuca leucadendra (Paper bark)			(+)	(+)	+	+				
Melastoma melabathricum (Indian rhododendron)			+	+	+					

Table 2. Continued.

Scientific Name (Common Name)	Vegetation Zone									
	A	B	C1	C2	D1	D2	D3	E1	E2	E3
Melia azedarach (Pride of India)	+	+								
Melinis minutiflora (Molassesgrass)		(+)	+	+	+	+				
Melochia umbellata (Melochia)			+		+					
Merremia tuberosa (Woodrose)		(+)	+		+					
Miconia magnifica					+					
Microlaena stipioides (Meadow ricegrass)							+	+	(+)	
Myrica faya (Fayatree, firetree)			(+)	+		+	+			
Panicum maximum (Guinea grass)		+	+		(+)					
Paspalum conjugatum (Hilo grass)				+	+	+	(+)			
Passiflora ligularis (Sweet granadilla)						+				
P. mollissima (Banana poka)						+	+			
P. suberosa (Huehue-haole)	+	+	+							
Pennisetum clandestinum (Kikuyugrass)		(+)	(+)	+				+	(+)	
P. setaceum (Fountaingrass)	+	+		(+)						
Phormium tenax (New Zealand flax)					+					

Scientific Name (Common Name)	Vegetation Zone									
	A	B	C1	C2	D1	D2	D3	E1	E2	E3
Pinus elliottii (Slash pine)					(+)	+				
P. patula (Mexican weeping pine)							+			
P. pinaster (Cluster pine)								+	(+)	
Pithecelobium dulce (Opiuma)	+	+								
Pluchea indica (Indian fleabane)	(+)	(+)	+		+					
P. odorata (Sourbush)	+	+	+		(+)					
Prosopis pallida (Kiawe)	+	+	(+)							
Psidium cattleianum (Strawberry guava)			+		+	+				
P. guajava (Common guava)		(+)	+		+					
Rhizophora mangle (Red mangrove)	(+)	(+)	(+)		(+)					
Rhodomyrtus tomentosa (Rose myrtle)			+		+					
Ricinus communis (Castor bean)	(+)	+	+							
Rubus argutus (Florida prickly blackberry)				+		+	+	(+)	(+)	
R. ellipticus (Yellow Himalayan raspberry)					+	+	+			
R. glaucus (Raspberry)					+					

Table 2. Continued.

Scientific Name (Common Name)	Vegetation Zone									
	A	B	C1	C2	D1	D2	D3	E1	E2	E3
R. moluccana				+		+	(+)			
R. nivalis						+				
Sacciolepis indica (Glenwood grass)				+	+	+	(+)			
Schinus terebinthifolius (Christmasberry)	+	+	+		+					
Senecio mikanioides (German ivy)						+	+	+		
Setaria palmaefolia (Palmgrass)					+	+				
Spathodea campanulata (African tuliptree)					+	+				
Tagetes minuta (Marigold)								+	+	
Terminalia catappa (False kamani)			+		+					
Tibouchina urvilleana (Glorybush)			+		+	+				
Ulex europaeus (Gorse)				+		+	+		+	
Verbascum thapsus (Common mullein)									+	

Total Weeds Present	23	38	54	27	50	25	17	12	10	0

principally for watershed management. Where cropping has been abandoned, the area is dominated by broomsedge, cats-claw, Christmasberry, Formosan koa, fountaingrass, guava, Indian fleabane, Java plum, klu, koa haole, Koster's curse, lantana, and sourbush.

There are some notable exceptions to this general description of Zone B. Along the coastline in areas subjected to salt-water spray, there is a specialized ecosystem dominated by Fimbristylis. This community is still predominantly native because most weeds cannot tolerate the salt-water stress. Where cattle graze, the small shrubs have disappeared due to trampling and overgrazing. Many of these stress-resistant native species also occur elsewhere. Above 300 m on old unweathered lava flows or where there are many boulders, pockets of native dry forest have survived, e.g. Auwahi, Maui. Unfortunately, these woodlands frequently have a heavy ground cover of alien grasses, e.g. kikuyugrass, as well as heavy infestations of lantana. Survival of such woodlands is tenuous because kikuyugrass inhibits seed germination (Sanchez and Davis 1969) and cattle graze anything that grows.

In areas between sea level and 1,300 m where the annual rainfall ranges from 1,000-1,500 mm (Zone C) and where there is sufficient soil, sugar cane, pineapple, and more recently macadamia nut, plantations are found below approximately 650 m. Above this elevation most of the native forests have been converted to grassland. Some forest plantations have also been established in this zone. Below 1,300 m large areas have been infested and are now dominated by common guava from sea level to 400 m and strawberry guava from 300-1,300 m. Below 400 m the worst weeds are bamboo, broomsedge, Christmasberry, fiddlewood, glorybush, common guava, Indian rhododendron, Java plum, kahili ginger, koa haole, Koster's curse, roseapple, rosemyrtle, sourbush, white ginger, and yellow ginger. Above 400 m, Christmasberry, fiddlewood, Java plum, roseapple and sourbush drop out and fayatree moves in. Although much of the land in Zone C would be suitable for cattle grazing, it is overwhelmed by guava unless pastures are heavily grazed or the guava poisoned. Very few species can survive the competitive exclusion, principally by shading, although allelopathy is also suspected. Pockets of native vegetation still survive, but if feral pigs are not excluded from these areas they will soon be converted into guava woodlands (Diong 1983).

In areas between sea level and 2,300 m where the annual rainfall exceeds 1,500 mm (Zone D), the land below 1,350 m has been greatly altered by agriculture. Sugar cane is grown below 500 m although some plantations reach above 650 m. The gullies at these lower elevations are forested by a tropical weed flora (i.e., African tulip tree, ardisia, bush beardgrass, broomsedge, gingers, glorybush, Hilo grass, Indian rhododendron, Koster's curse, palmgrass, and roseapple) in which few native species survive. Between approximately 650 and 2,500 m, much of the land has been designated forest reserve for watershed protection. These forested areas are also maintained as hunting preserves, particularly for feral pigs. Areas not in reserve status have been converted to montane parklands by cattle ranching. Below 1,200 m strawberry guava is frequently dominant, forming monotypic stands. Between 1,000 and 1,650 m alien species are creating significant problems, e.g. banana poka, broomsedge, gingers, gorse, and velvetgrass. However, there are large tracts of 'ohi'a forest, generally in wetter areas, that have not been invaded by alien species other than a few relatively unimportant herbaceous plants.

Between 1,650 and 2,200 m there are numerous mires which have been undisturbed until quite recently. On Kaua'i, few weeds have moved into the disturbed sites although _Juncus planifolius_ R. Br. has invaded the summit area of Wai'ale'ale (J. Canfield and R.L. Stemmermann, pers. comm.). On Haleakala, where feral pigs have destroyed the _Oreobolus furcatus_ tussock community in some mires, hairy cats-ear and velvetgrass have become established, although they are partially displaced by the _Oreobolus_ once disturbance ceases. The resistance of Hawaiian mires to alien plant invasion is unclear, but the environmentally suboptimal conditions of these areas for plant growth (Crawford 1983) may reduce the competitive advantage of the weeds.

In the inversion layer zone between 2,000 and 2,300 m, where the annual rainfall is less than 1,250 mm, the native koa forests have been converted to cattle ranches and few intact segments remain. Most of the grasses in these parklands are aliens, principally kikuyugrass, although a few native grasses remain. However, along with the introduction of favored pasture grasses, e.g. sweet vernal grass, a number of less desirable grasses (e.g., orchard grass and velvetgrass) became established and spread to other areas. The dense growth and allelopathic secretions of grasses prevent the successful germination of koa and other native seeds. In some instances, koa sucker growth is inhibited. However, even when suckers grow they are soon eaten back by cattle and goats.

Above 2,300 m (Zone E), depending on the elevation that the inversion level reaches, the annual rainfall is less than 1,250 mm. This is one of the least impacted areas and alien species are not common except on deep ash or where the forest has been opened by feral goats and sheep. Giant mullein, hairy cats-ear, sheep sorrel (Rumex acetosella L.), orchardgrass, and velvetgrass are the most common weeds in this environment. Above 2,650 m the climatic conditions are so severe that there is little vegetation (Hedberg 1951). Any plant that does emerge is promptly eaten by feral herbivores. These high elevation environments are generally protected from alien plant introductions because most of the ports of entry are in the tropical lowlands. Temperate species would have difficulty getting established at lower elevations. However, recently, 2 temperate weeds were introduced at Haleakala National Park (but fortunately immediately eradicated), indicating the danger of temperate weed introductions to Hawai'i's high elevation ecosystems during construction of roads and facilities. It is hoped that similar monitoring and precautions will be taken during the construction of the new telescopes and support facilities atop Mauna Kea.

IMPACT OF WEEDS ON HAWAIIAN ECOSYSTEMS

Weeds can have a number of very different effects on associated plants. Physical displacement of other species, either directly or indirectly, is the most frequent mode of action. They can also deprive associated plants of water or nutrients, particularly nitrogen, not so much the result of greater efficiency of uptake (Mahmoud and Grime 1976) but by absorbing their "fair share" of a generally limited resource. Allelopathy from root secretions (Martin and Rademacher 1960) or aerial portions (Sanchez and Davis 1969; Gogue, Hurst, and Bancroft 1974) is often a direct competitive action. Weeds also act as primary or alternate hosts for pests and diseases. All these impacts can undoubtedly be found in the activity of alien species on native ecological processes in Hawai'i. However, the most common impact is displacement when weeds colonize disturbed sites (e.g. pig diggings, burnt areas) and occupy them before the slower growing native species can reestablish. Other adverse effects not commonly associated with weed activity are discussed below.

Formation of Monotypic Stands

The replacement of a relatively diverse native ecosystem by monotypic stands of alien species is a serious disruption of the ecosystem. In Hawai'i, the loss of diversity in even small areas can have a devastating effect on the survival of species, many of which are already endangered, almost extinct, or confined to very small areas. For example, Cyanea superba, a candidate endangered species, is now restricted to 2 areas of less than 0.1 ha each in the Mokule'ia Forest Reserve on O'ahu. Most of its former habitats are now occupied by strawberry guava. Where it survives it is threatened by the overgrowth of weeds, fire, and feral animals. The highly restricted distributions of many endemic species are not understood but are probably related to loss of dispersability characteristic of many island species (Carlquist 1965). Native primary consumers rarely adapt to aliens, and in the majority of instances they are excluded from the alien ecosystems.

Strawberry guava was introduced in 1825 (St. John 1973) and soon established in the wild (Judd 1936). On most islands, nearly monotypic stands of this species infest hundreds of hectares of mesic and well-drained rain forest areas between 200 and 1,300 m. Vast areas of mature 'ohi'a and koa forests have a dense understory of strawberry guava. Native species regenerate rarely; some straggly specimens of native plants, e.g. Alyxia olivaeformis, Osmanthus sandwicensis, Psychotria mariniana, are able to survive under the guava. However, the prognosis for native ecosystem reestablishment in guava thickets is poor for 3 reasons. First, the shade is so deep that no seeds germinate, or if they do they die for lack of sufficient light. In old strawberry guava stands in mesic areas, there is no ground cover. In rain forest areas, Oplismenis hirtellus and Christella dentata dominate the ground cover. Second, the fruit is relished by feral pigs, which move into these thickets during the fruiting season (Diong 1983) and thoroughly disturb the ground. Seeds, unharmed by passage through the gut, are dispersed in pig feces, generally to another disturbed site where they have a competitive edge. Third, there is growing evidence of allelopathic activity in the fallen leaves.

The creation of monotypic stands of alien species may in fact be followed by a more disastrous event. As the weed exploits and exhausts the particular resource that it is able to use, it may outgrow itself. Or, as the natural processes of aging and diseases take their toll, the population may crash, resulting in accelerated erosion or further weed invasions, but rarely in the reestablishment of even a semblance of the original native ecosystem. These population crashes are not uncommon events elsewhere (Salisbury 1964) but as yet have not been recorded in Hawai'i. Such crashes rarely provide sufficient time for the orderly reestablishment of a diversified ecosystem.

Changing Fire Characteristics

Although Vogl (1969) proposed that fire is a frequent natural formative agent in Hawaiian ecology, Mueller-Dombois (1981) found in one area of Hawai'i Volcanoes National Park that carbon-dated charcoal deposits and other evidence suggested a very low frequency. Human activity and the introduction of weeds, particularly grasses, has changed that. Since 1910 most fires in the Park have been started by man (Smith, Parman, and Wampler 1980). Much of the area in the Park supports a scattered scrub forest separated by patches of very sparsely vegetated lava. Fires, ignited by infrequent lava flows, were not uncommon. However, these fires were small in area because of the natural firebreaks in the vegetation mosaic.

In the early 1970's the situation changed. The National Park Service began a major resource management program to rid the park of feral goats (Baker and Reeser 1972). A few years before, both bush beardgrass and broomsedge had invaded the area. After most goats were removed, the grasses were no longer grazed and consequently colonized the many ash-filled cracks in lava flows, creating a continuous ground cover between islands of native scrub forest. The flowering stalks of these species are persistent after death, creating excellent fuel. These grasses are fire-stimulated, rapidly resprouting from basal sprouts after burning.

The total area burned by fires in lowland ecosystems is now 2 orders of magnitude larger than before the invasion of these grasses, even though an aggressive program of fire suppression by Park staff has significantly diminished the sizes of individual fires. Rapid regeneration of grass overshadows the reestablishment of most native species whose cover and abundance are drastically reduced for many years after the fire. As if to add insult to injury, the grasses also secrete a very persistent allelopathic agent (Rice 1972). The native _Styphelia tameiameiae_ (Cham.) F. Muell., a common shrub in this ecosystem, is not fire-tolerant and will be excluded from burnt areas until it is reintroduced.

Changing Soil-Water Regimes

Many weeds introduced into oceanic islands come from temperate areas of Europe and America. Their phenology is occasionally not in synchrony with local climatic conditions, which results in significant changes in the edaphic ecology of the area.

Broomsedge is a bunchgrass that became established in the Hawaiian Islands about 50 years ago. It quickly invaded open sites with a deep soil or ash deposit where the annual rainfall was above 100 mm. Originally from the southeastern United States, it has retained the phenological pattern of its native area (Sorensen 1980). However, as Mueller-Dombois (1973) pointed out, the dormant period for broomsedge coincides with the wettest months in the islands, so that water is retained in the soil instead of being depleted through evapotranspiration. Surface runoff results in increased rates of erosion, with slumping on steeper slopes. Under native evergreen rain forest canopies, water is transpired away rapidly and the remainder percolates through the soil. Erosion and slumping are rare.

Changing Nutrient Status

Volcanically active areas do not have mature soils. Instead they have either lava or ash substrata characterized by low levels of nitrates. Plants which grow in such areas are adapted to survive under these conditions. However, species that can fix nitrogen will have faster growth rates than natives. Eleven of the 86 alien plants listed in table 1 fix nitrogen. Nitrogen-fixers will also enrich the soil as their litter decomposes. The outcome is an enriched soil in which other plants may grow, potentially replacing the original occupants of the area.

Fayatree is capable of fixing nitrogen in root nodules containing the actinomycete Frankia (Mian, Bond, and Rodrigues-Barrueco 1976; Miguel and Rodriguez-Barrueco 1974). The invasion of Myrica is relatively recent so that no floristic changes have been noted to date. Bradshaw et al. (1964), Rorison (1968), Mahmoud and Grime (1976), Higgs and James (1969), and Whelan and Edward (1975) have all shown that species native to poor soils are no more efficient at absorbing mineral nutrients than those native to good soils. Mahmoud and Grime (1976) further demonstrated the exclusion of plants native to poor soils, when grown on good soil with the plants adapted to good soils. The converse was not true. In the case of Myrica faya there is the distinct possibility that by enriching the soil it will enhance its own survival, perhaps to the exclusion of the native species. A monotypic infestation is already present in Hamakua, Hawai'i, which perhaps exemplifies this phenomenon; however, the history is insufficiently known.

Mutually Beneficial Interaction between Alien Plants and Animals

The absence of terrestrial mammals in the Hawaiian fauna has resulted in the lack of defense mechanisms against such animals. The introduction of mammals, especially ungulates, produced a new selective pressure on the native flora. Coupled with simultaneous introduction of alien plants, many of which are components of early secondary succession in their native habitat, Hawaiian ecosystems were faced with serious threats to their integrity.

Animals which dig up subterranean foods as part of their normal foraging activity are frequently important disseminators of plant propagules and play a role in nutrient cycling. In their native habitats, such disturbance is followed by a successional series of vegetation ultimately leading to some sort of climax community. In Hawai'i a natural successional series of this nature does not exist. Disturbance here has a significant deleterious impact on the native ecosystem, destroying ground cover, damaging roots, and opening up the understory. Most native species cannot tolerate this disturbance; however, many aliens are dependent on it for their establishment. When the alien species is an important food resource for a feral animal, a mutually beneficial interaction will develop between the 2 species. The relationship between feral pigs and such plants as strawberry guava, banana poka, and hairy cats-ear illustrate this point. Pigs are attracted to the abundant fruit of strawberry guava and banana poka. As pigs forage for other foods they disturb the ground, providing a seedbed for the guava and poka. Seeds are defecated up to 48 hours after consumption. They germinate and grow rapidly, occupying the site before the native plants establish. In the case of cats-ear, pigs destroy the weeds by digging up and consuming the roots. However, the digging provides an ideal seedbed for the establishment of the numerous, wind-dispersed seeds of this species. Why native species do not germinate or grow as rapidly as aliens is not yet known but can be related to their role in succession and the type of seedbed to which they are adapted. In both examples, original infestations are intensified or expanded, providing even more food resources for pigs.

IMPACTS OF WEEDS ON OTHER TROPICAL AND SUBTROPICAL ISLANDS

With a few exceptions--i.e., African Banks, Amirante (Feare 1979); Caroline Atoll (Clapp and Silbey 1971); Gough Island (Wace 1966); Henderson Island (Melville 1979); Raine Island (Stoddart, Gibbs, and Hopley 1981); and Wilingili Atoll, Maldives (Spicer and Newbery 1979)--alien species have become weeds and serious pests on every island that man has visited. Island ecosystems have been invaded to a considerable extent, but generally only after disturbance by direct human influence, e.g., fire, plantations, and introduced herbivores. For brevity's sake, I will review the literature on tropical and subtropical areas only. There is an extensive literature on temperate and subantarctic islands which is beyond the scope of this paper.

Atlantic Ocean and Caribbean Sea

The effects of alien organisms have been studied on only a few islands, but enough information is provided in floristic accounts and notes on many other *islands to allow a reasonable analysis of the status of* weeds on most islands. Although the prehistoric flora of St. Helena is poorly known, one-third of the known endemic flora is extinct and no vestiges of former ecosystems remain. New Zealand flax is the most serious pest. Ascension Island was relatively barren on its discovery and apparently a dismal place (Duffey 1964; Melville 1979). Over a thousand species have been introduced to vegetate the island. Many of them are familiar weeds on tropical islands, but only Melinis minutiflora (locally known as greasy grass) forms extensive ground cover above 500 m. Barbados has been severely disturbed by sugar cane cropping, but there is a sizeable remnant of the seasonal forest (Watts 1970). Mahogany has invaded most communities and abandoned fields. Anisomeris fasciculata K. Schum., Cordia glabra L., and Haematoxylon campechianum L. are also common. In the outer Leeward Islands of the West Indies, alien species have invaded all ecosystems (Harris 1962, 1965; Loveless 1960). Haematoxylon campechianum and koa haole are perhaps the most prevalent weeds along with kiawe and several thorny Acacia spp., common guava, Guineagrass, and Bermudagrass (Cynodon dactylon (L.) Pers.). Although "the position of aliens ... is formidable," Harris concluded that once human interference stops, the native species will replace the currently dominant aliens. The Cayman Islands have been significantly disturbed by agriculture, and 2 species, false kamani and Colubrina asiatica (L.) Brongn., are both invading inshore areas of the islands (Sauer 1982). In the Tortuga Keys, common ironwood has formed a dense woodland on Loggerhead Key, but the remaining 10 keys have not been affected by the alien species (Stoddart and Fosberg 1981b). Except for the 2 mid-Atlantic islands, most other islands appear to be able to revert to near-native plant formations once human interference ceases.

Indian Ocean

The native vegetation of the following islands has been almost totally destroyed by human activity: Diego Garcia (Stoddart 1971), the coral islands north of Madagascar, except Aldabra (Stoddart 1967), and Rodriguez Island (Melville 1979). In addition, however, the situation on Madagascar is among the worst examples of human mediated destruction of native ecosystems in the world (Humbert 1927). Rauh (1979) stated that "in less than 200 years the green island of Madagascar has been transformed into a red sand island simply by the activity of Man!" Aldabra (Stoddart and Wright 1967), Reunion (Melville 1979), and the Seychelles (Stoddart and Fosberg 1981a) have been occupied or exploited for sugar cane or copra for some time, but substantial segments of native ecosystems are still present. Mauritius has been severely disturbed by sugar plantations, but a number of reserves were set up in 1944. However, their continued existence is threatened by Ligustrum walkeri Decne, strawberry guava, Rubus spp. and Ardisia spp.

Pacific Ocean

Most of the central Pacific atolls have been severely disturbed by man (Egler 1942; Fosberg 1953; Lee 1974). The atolls are such specialized habitats that alien species, although maintaining themselves, do not become disruptive elements of the ecosystem. On the high islands the picture is very different. Their diversity of habitats and isolation have resulted in the evolution of new species and unique associations of species. Unfortunately, due to "haphazard exploitation and development" the "sorry state of the Hawaiian islands, many of the Galapagos, [and] Juan Fernandez ... will be repeated" (Wace 1966). The recent forest cropping in Fiji is yet another example of destructive expoitation (Melville 1979). The disturbance creates avenues for the invasion of alien species which, once established, can dominate that area and invade other habitats. The weed pests in Hawai'i have been discussed already. Clidemia hirta is a serious weed in Fijian forests (Wester and Wood 1977) although it is under partial biocontrol (Simmonds 1933). Klu, lantana, Mimosa invisa, common guava, and Urena lobata have all been declared noxious (Mune and Parham 1967). In the Galapagos, Cinchona succirubra Pav. ex Klotz., common guava, and Digitaria decumbens Stent are all serious pests (van der Werff 1979). Miconia magnifica is invading the forests of Tahiti, overwhelming the native ecosystems (Whistler, in press). In Samoa, Castilloa elastica, Koster's curse, Funtumia elastica, Mikania micrantha and Passiflora laurifolia are serious forest weeds (Whistler, in press). Lantana, koa haole, and common guava are also present but do not form extensive dense stands. Yet, in Tonga they are the 3 worst weeds in the forests (G. Buelow, pers. comm.). In the Northern Marianas, koa haole is almost ubiquitous because of aerial seeding after World War II (C.S. Hodges, pers. comm.).

WHAT NEEDS TO BE DONE

Three separate programs are needed to manage the alien pest problem in Hawai'i:

1. Prevent further introductions.
2. Stop the disturbance of ecosystems.
3. Develop strategies to allow native species to reestablish themselves.

Prevent Further Introductions

The prevention of further importations of alien species is imperative if we are to manage our native habitats effectively. The money spent on controlling pests would be much better spent on productive enterprises. Resources will still be needed to educate people not to import biological material indiscriminately, as well as to intercept deliberate attempts to smuggle material into the State. An immediate political step would be to require that all future government-sponsored landscaping use native species or plants that are known not to naturalize in Hawai'i.

A total prohibition on importations is not necessary. However, an outright ban on certain plant groups is imperative, e.g. all melastomes. Fifteen species in this group have already been introduced, 3 of which are serious weeds (Plucknett and Stone 1961). Further importation of Rubus, grasses, passion fruit, and members of the Myrtaceae should be banned also, as should species known to be problems in other tropical islands. These include the following species (from lists cited in this paper): Anisomeris fasciculata, Funtumia elastica, Ligustrum walkeri, Mikania micrantha, Operculina ventricosa, and Passiflora rubra. Species known to be part of primary or secondary succession in tropical or subtropical areas should be evaluated before they are permitted entry. The evaluations should be conducted by a group of botanists familiar with weeds in tropical and temperate areas. They should be constituted as a State Commission similar to the Animal Advisory Commission. They should have the authority to ban outright any importation. Their recommendations should be addressed to the Boards of Agriculture and Land and Natural Resources, who would have the right to veto any recommendation permitting entry but not overrule a negative decision of the Commission. Applications for permission to import should follow a format similar to an environmental impact statement.

Without the cooperation of the general public, there is little likelihood that any preventive program will work. Public education is a Federal and State responsibility. The best place to conduct the education of tourists and visitors is on the plane prior to arrival in the Islands. A 5-minute "commercial" explaining the problem and the importance of preventing plant and animal introductions would be much more effective than the printed form currently handed out in an almost cavalier fashion by the airlines. "Honesty" boxes should be provided in the baggage claim area where people can discard material prior to leaving the airport. Confiscation of material should be minimized except from people who are bringing potentially hazardous material to the Islands. Quarantine of imported material is important to minimize the introduction of associated pests and diseases. A more visible and concerned presence by the State's agriculture inspectors at ports of disembarkation is also necessary. Periodic inspection of baggage similar to the procedure on departure for mainlands would help keep people honest. The constant disclaimer by the State that it does not have sufficient funds to support such a program is a tacit acknowledgement that it does not consider alien plant introductions to be a major problem. Failure to enforce current regulations has resulted in the importation of Miconia magnifica and its consequent establishment in Hilo, which may turn out to be a very serious problem.

Two recent brochures, "Beware of the Noxious Weed" and "Are You a Carrier?", published by Foster Botanic Garden, Honolulu, are a valuable first step toward educating the general public on weed problems in Hawai'i. Much more needs to be done.

Stop Disturbance of Ecosystems

Many biologists have stressed the relationship between disturbance of ecosystems and alien establishment (e.g., Harper 1965; Stone, this volume). Two separate actions are necessary to reduce disturbance. The first is to change the State Constitution so that preservation of the State's natural resources is really mandated of the land managers. The second is to develop feral ungulate management programs to the point that the native forests are no longer significantly disturbed by these animals.

The State's Constitution is somewhat ambiguous regarding its natural resources. On the one hand, it talks about preservation and on the other, about the benefit of the public. The latter is currently interpreted as permitting exploitation. Some steps have been taken in the right direction. The State's Natural Area Reserve System, although originally an enlightened program, has become emasculated by politics and lack of finances and manpower. The number of areas formally designated is low. But even after areas are designated, no management is conducted because there are no funds allocated for that purpose. The resources of these areas are poorly known and research is discouraged by a cumbersome, time-consuming bureaucracy. Yet disturbances continue, sometimes on a large scale, resulting in the further degradation of ecosystems and the continued spread of alien species. Cooperation among the various government agencies with responsibilities in this area could also result in more effective management of pests. The recent signing of a memorandum of agreement between various State and Federal agencies regarding forest pest control is encouraging. However, the contributions of each of the agencies will be largely influenced by the internal budgets of each.

We have to accept the fact that feral ungulates are here to stay. However, it is possible to keep them out of areas not now infested, e.g. Oloku'i, Moloka'i; much of the Alaka'i Swamp, Kaua'i; Pu'u Kukui, 'Eke Crater, and Lihau Peak, West Maui; and to exclude them from important areas, e.g. national parks, State Natural Area Reserves, and the critical habitats of endangered and threatened species. The practice of maintaining sustained yields of animals by regulating the number of animals taken in forest reserves and other conservation areas should cease. This approach aggravates the alien plant problem by ensuring some level of perpetual disturbance in the forests.

Develop Strategies to Encourage Native Species Reestablishment

Two programs are needed. The first is the formulation and implementation of research on the biology of the most troublesome weeds. The second is the development of an integrated pest management system.

The most basic research questions concern location and effects of alien species. If sufficient historical information on infestations is available, and there generally is a wealth of anecdotal information, the dynamics of the invasion can be described. The most susceptible habitats can be identified and measures adopted to contain or prevent outbreaks in areas where management is possible. By evaluating the biology of the alien, it is sometimes possible to identify critical points in the life cycle when it is susceptible to control. Herbicides have significantly different impacts at different stages of a plant's growth and development. Likewise, not all biological control agents are effective in all habitats. For example, lantana has been contained in some areas by biological control agents but remains uncontrolled in others (Gardner and Davis 1982). The most important functions of research are to evaluate the role of weeds in island ecosystems, their impact on individual native species, their dependency upon disturbance for success, and management strategies.

Weed management needs much greater evaluation today than in the past. The indiscriminate use of herbicides is very dangerous, not only to human health but also to the well-being of the native ecosystems in which they are used. Agricultural weed control strategies are generally developed to eliminate all species other than the crop. In natural ecosystems we generally try to eliminate one species only and preserve the rest. In addition, we are ignorant of the longevity or secondary effects of herbicides in tropical areas because most chemicals are evaluated in temperate ecosystems. Also, weeds can develop resistance to herbicides

(Hanson 1956, 1962). This problem becomes more acute the longer the herbicide program is conducted. The temptation to use higher dosages, a very common practice in agriculture, must be assiduously avoided. Physical damage to the ecosystem almost always occurs during the application of the herbicide. However, a particular advantage of herbicide use is that the soil is left undisturbed, and in many instances the dead plant tissues form a ground cover that will impede the growth of seedlings.

Mechanical control is very expensive because it requires manpower. Another negative factor is the accompanying damage to the ecosystem in the process of weeding. The disturbance of the soil under the plant generally stimulates weed seeds to germinate.

Natural areas are not amenable to some techniques of weed control, e.g. changing cultural practices. However, the extent of the infestation or the sensitivity of the protected area may preclude any disturbance. In these instances, biological control is a potentially powerful weapon, but it is not a panacea (Howarth 1983; Mellanby 1974) and sometimes operates only in very restricted ranges. It is very expensive initially and the agents are not confined within any political boundaries.

Biological control is not the final solution to alien species problems in Hawai'i, yet some successes make it extremely attractive because it seems to be the natural solution to a problem. Although most species have other organisms that parasitize or feed on them, the successful introduction of these organisms is a formidable problem. Many may not be suitable for importation for the following reasons.

1. They may not be species specific. In general, this would automatically exclude a species, but there are instances where whole genera may be the target of a control program, e.g. Melastoma. However, as Harris (1973) and Pimentel (1963) point out, it may be better to look for biocontrol agents on closely related species because those specific to the target organism may be in a symbiotic balance.

2. They may themselves be parasitized by insects or fungi already present. It would not be appropriate to introduce a control agent that itself may be controlled to a level at which it is no longer effective.

3. The target species is related to sugar cane, pineapple or some other important agricultural crop. The possibility that a species introduced to control the relative may slip over to one of these important

agricultural crops would be enough to prohibit entry.

The situation could also be reversed where the relative may act as a reservoir for a pest of the crop. However, this approach has been carried too far in Hawai'i, where the sugar cane industry has resisted all efforts to import biological control agents against any grass. On the other hand, it is surprising that the pineapple industry has not objected to the continuing, almost uncontrolled, importation of bromeliads.

4. The ecological requirements of the agent may be found only in part of the target species range in the Islands, if at all.

5. The species may be controlled only by a number of organisms which affect different stages of the plant's life history. The problem is that as more species are introduced, the likelihood of secondary impacts increases. It is impossible to screen the potential agent against all native species. In fact, most agents are only evaluated against commercially important species and sometimes related or important native species.

6. The alien may not be controlled by herbivores or parasites but by succession in its native habitat. Many pests of tropical island ecosystems appear to be of this nature. They would not be amenable to biological control and would have to be controlled by other means.

7. Parasites of control agents may have been introduced earlier in relation to another problem. The early importation of general parasites of Lepidoptera may prevent the use of heliconiid butterflies as control agents of Passiflora in Hawai'i.

These last points are often misunderstood by many casual exponents of biological control. The problem is further complicated by the fact that problematic alien species generally infest their "fundamental" niche (Hutchinson 1957), having escaped many of the constraints which confined them to the "realized" niche of their native environment. Thus, a suitable biological control agent will probably only be effective in a segment of the insular range of the alien.

Biological control is a science wrapped up in a restrictive bureaucracy, but with good reason. At times the rules appear overly stifling, but they are necessary to prevent abuse and to adequately demonstrate the safety of the proposal. It is tragic that such rules are not applied to the importation of alien plants in the first place. That biological control is not a panacea is further emphasized by its expense and the time necessary to verify that an agent is not only suitable but reasonably certain not to have undesirable side effects. It is, therefore, initiated only after all else fails.

Thus, there is no easy answer to controlling alien plants in insular environments. Each species has to be managed on its own and generally by a number of different approaches. It is the successful integration of these different approaches that is the challenge to the research scientist and the manager. Solutions are not to be quickly found in most cases, but probably control is possible for most plants.

CONCLUSIONS

Introduced plants can be quite innocuous. For example, it is highly unlikely that such horticultural favorites as plumeria (Plumeria acuminata Ait.) or pua kenikeni (Fagraea berteriana Gray) will ever pose a threat to native ecosystems. On the other hand, a number of alien species, e.g. Koster's curse and strawberry guava, are very serious threats. My candidates for the 10 most serious weeds in Hawai'i, in order of priority, are: strawberry guava, Koster's curse, banana poka, fountaingrass, fayatree, kikuyugrass, Christmasberry, blackberry, molassesgrass, and bushbeardgrass.

It is generally believed that under natural conditions island ecosystems are stable, invasion-resistant assemblages of species whose combined resource exploitation is in balance with productivity (MacArthur 1972). Without other alien influences, island biogeographers and ecologists would predict that very few alien introductions would become established in native communities (Cockayne 1928; Allan 1936; Anderson 1952). However, island ecosystems are disturbed to varying degrees by man, fire, feral ungulates, introduced birds, and a vast array of alien invertebrates. In Hawai'i, a significant number of native species has become extinct due to alien influences. Thus the underlying ecological processes on which native communities are structured have changed, probably irreversibly, in most cases.

One problem facing managers of native ecosystems is the determination of the significance of negative impacts of alien plants in native ecological processes. If a weed does not affect, or only marginally affects, ecosystems, e.g., Euphorbia hirta L., then it can be tolerated. As the system recovers, such species will be contained. Species at the other end of the scale, e.g., strawberry guava, need immediate attention. The mechanism of entry and establishment of an alien in the ecosystem is very important. If a weed is dependent on disturbance, then control can focus on preventing such occurrences, where possible. However, if the weed is invasive, then management must attempt to reduce or eliminate the species. Probably no species is beyond control as long as time and money are available. However, political and practical considerations may preclude such optimism. Such considerations include whether: the target species is socially useful in some context; it is too closely related to a commercial crop species; its impact in a remote ecosystem is too unfamiliar to attract the necessary funding; or the control program interferes with the activities of a special interest group, such as hunters.

This paper identifies 86 alien plants which are serious weeds in Hawaiian ecosystems. All but one, Hypochoeris radicata, displace native species when growing in the same habitat. Twenty-six (30%) have, or are suspected of having, allelopathic activity against native species. Twelve (14%), principally grasses, are fire-enhanced species which invade the fire-disturbed area much faster than the natives. In so doing, they increase the fuel level in the ecosystem and carry fires over larger areas than before and generally at higher intensities. On the other hand, another 10 (12%) species are known to inhibit fires.

Just over half of the significant aliens, 45 (52%), are phanaerophytes, 18 (21%) chamaephytes, 10 (12%) hemicryotophytes, 6 (7%) lianes, 5 (6%) are geophytes, and 2 (2%) therophytes. The preponderance of trees, particularly evergreen species, is of considerable concern because they become an integral part of the canopy. Here they have a much greater disruptive influence on ecological processes. The large number of vines, all of them photophilic canopy species, is particularly important in Hawai'i where this growth form is poorly represented in the flora and, until recently, not a significant feature in the ecosystem. Thus, instead of being a natural part of succession as in other tropical areas, they destroy the forest structure by shading or breaking native tree branches.

Seventy-five percent of the weed species are well-adapted for dispersal in the Islands. Thirty (35%) are dispersed by predominantly alien, frugivorous birds, 29 (34%) by wind, and 9 (10%) on clothing or animal hides. One species is dispersed by water. However, it is somewhat surprising that 23 (27%) are dispersed only by man in the Islands. Once established, their infestation intensifies with some local dispersal by physical means.

Forty-five (52%) species are confined to the highly altered lowland (below 800 m) ecosystems, 10

(12%) range from sea level to mid-elevations (between 800-1,700 m), 18 (21%) are principally confined to mid-elevations, 3 (3%) to both mid- and higher elevations (up to 2,700 m), and 10 (12%) are confined to the higher elevations. The preponderance of pests in the lowlands is expected due to the extent and variety of disturbance there, as well as the increased opportunity for introduction.

Most of the weeds presented in this listing invade native communities only after some type of disturbance, generally the consequence of man but occasionally natural, e.g., landslides, hurricanes, and treefalls. However, approximately half of the species listed (particularly those dispersed by wind or birds) can invade native ecosystems but generally remain minor components until some disturbance occurs. Twenty-three species have the ability to invade and take over native ecosystems without any apparent disturbance. These are: African tuliptree, Ardisia, banana poka, blackberry, bush beardgrass, Christmasberry, fiddlewood, fountaingrass, glorybush, huehue-haole, Indian fleabane, Indian rhododendron, juniperberry, kahili ginger, Koster's curse, lantana, melochia, miconia, raspberry, roseapple, rosemyrtle, strawberry guava, and yellow Himalayan raspberry.

Egler (1942) suggested that weeds, such as koa haole, would ameliorate ravaged native ecosystems, allowing native species to reestablish themselves. Unfortunately, the time frame about which he was talking is so long that many natives would already be extirpated before conditions were favorable. Very few native species are able to maintain themselves in heavy infestations of arborescent weeds. Those that do are generally so weakened that seed production is severely diminished or absent. However, the critical weakness is that the native species cannot compete against the aliens in the germinant and early seedling stages. The outcome is that the seedbank of native species is exhausted, effectively excluding the species from that area; reinvasion would be the only means of reestablishment. Since weeds normally occupy all the available space in the habitat, the prognosis for the native species is dismal. Overall, it is almost hopeless because succession, if it occurs at all, is generally by alien species. One weed is replaced by another; in the case of koa haole, Christmasberry and Java plum are frequent invaders of the habitat. The native species are therefore still excluded.

With the exception of St. Helena and Madagascar, the Hawaiian Islands contain the most ravaged island ecosystems in the world. The introduction of more than 4,600 different plants can only have a devastating effect on the survival of the 1,700+ native species.

It is fortunate that less than 100 aliens have become pests. However, that number will increase continuously if restrictions are not imposed. It is because of such considerations that it is imperative that the importation of alien plants be stopped and the continued disturbance of native ecosystems prevented.

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LITERATURE CITED

Achhireddy, N.R., and M. Singh. In press. Allelopathic effects of lantana (*Lantana camara*) on milkweed vine (*Morrenia odorata*). *Weed Sci.* 32.

Allan, H.H. 1936. Indigene versus alien in the New Zealand plant world. *Ecology* 17:187-193.

Amerson, A.B., Jr. 1971. *The natural history of French Frigate Shoals, Northwestern Hawaiian Islands.* Atoll Res. Bull. 150.

Amerson, A.B., Jr., R.B. Clapp, and W.O. Wirts II. 1974. *The natural history of Pearl and Hermes Reef, Northwestern Hawaiian Islands.* Atoll Res. Bull. 174.

Anderson, E. 1952. *Plants, man and life*. Berkeley, Calif.: Univ. Calif. Pr.

Baker, J.K., and D.W. Reeser. 1972. *Goat management problems in Hawaii Volcanoes National Park: a history, analysis, and management plan*. Natl. Park Serv. Nat. Resour. Rep. 2.

Bradshaw, A.D., M.J. Chadwick, D. Jowett, and R.W. Snaydon. 1964. Experimental investigations into the mineral nutrition of several grass species: IV. Nitrogen level. *J. Ecol.* 52:665-676.

Carlquist, S. 1965. *Island life. A natural history of the islands of the world*. New York: Nat. Hist. Pr.

Chou, C.H., and C.C. Young. 1975. Phytotoxic substances in twelve subtropical grasses. *J. Chem. Ecol.* 1: 183-193.

Clapp, R.B., and F.C. Silbey. 1971. *Notes on the vascular flora and terrestrial vertebrates of Caroline Atoll, Southern Line Islands.* Atoll Res. Bull. 145.

Clapp, R.B., and W.O. Wirtz, II. 1975. *The natural history of Lisianski Island, Northwestern Hawaiian Islands.* Atoll Res. Bull. 186.

Clapp, R.B., E. Kridler, and R.R. Fleet. 1977. *The natural history of Nihoa Island, Northwestern Hawaiian Islands.* Atoll Res. Bull. 207.

Cockayne, L. 1928. *The vegetation of New Zealand.* Weinheim, New Zealand: H.R. Engelmann.

Crawford, R.M.M. 1983. Root survival in flooded soils. In Ecosystems of the world. 4A. Mires, swamps, bog, fen and moor: general studies, ed. A.J.P. Gore, 257-283. Amsterdam: Elsevier Sci. Pub. Co.

Diong, C.H. 1983. Population ecology and management of the feral pig (*Sus scrofa* L.) in Kipahulu Valley, Haleakala National Park, Maui, Hawaii. Ph.D. Diss., Univ. Hawaii, Honolulu.

Duffey, E. 1964. The terrestrial ecology of Ascension Island. J. Appl. Ecol. 1:219-251.

Egler, F.E. 1942. Indigene versus alien in the development of arid Hawaiian vegetation. Ecology 23:14-23.

Ely, C.A., and R.B. Clapp. 1973. The natural history of Laysan Island, Northwestern Hawaiian Islands. Atoll Res. Bull. 171.

Feare, C.J. 1979. Ecological observations on African Banks, Amirantes. Atoll Res. Bull. 227.

Fosberg, F.R. 1948. Derivation of the flora of the Hawaiian Islands. In Insects of Hawaii, ed. E.C. Zimmerman, Vol. 1, Introduction, 107-119. Honolulu: Univ. Hawaii Pr.

Fosberg, F.R. 1953. Vegetation of Central Pacific atolls, a brief summary. Atoll Res. Bull. 23.

Gardner, D.E. 1984. Kikuyu grass rust caused by *Phakopsora apoda* in Hawaii. Plant Dis. 68:826.

Gardner, D.E., and C.J. Davis. 1982. The prospects for biological control of nonnative plants in Hawaiian national parks. Univ. Hawaii Coop. Natl. Park Resour. Stud. Unit Tech. Rep. 48. Honolulu: Univ. Hawaii.

Gardner, D.E., and V.A.D. Kageler. 1983. Glyphosate in the control of kikuyugrass, and its effects on associated native and nonnative plants in Hawaiian national parks. Univ. Hawaii Coop. Natl. Park Resour. Stud. Unit Tech. Rep. 49. Honolulu: Univ. Hawaii.

Gerrish, G. and D. Mueller-Dombois. 1980. Behavior of native and non-native plants in two tropical rain forests on Oahu, Hawaiian Islands. Phytocoenologia 8:237-295.

Gogue, G.J., C.J. Hurst, and L. Bancroft. 1974. Growth inhibition by Schinus terebinthifolius. Am. Soc. Hort. Sci. 9:45.

Hanson, N.S. 1956. Dalapon for control of grasses on Hawaiian sugar cane lands. Down to Earth 12:2-5.

Hanson, N.S. 1962. Weed control practices and research for sugar cane in Hawaii. Weeds 10:192-200.

Harper, J.L. 1965. Establishment, aggression, and cohabitation in weedy species. In The genetics of colonizing species , ed. H.G. Baker and G.L. Stebbins, 243-265. New York: Academic Pr.

Harris, D.R. 1962. Invasion of oceanic islands by alien plants. Inst. Brit. Geogr. Trans. 31:67-82.

Harris, D.R. 1965. Plants, animals and man in the outer Leeward Islands. Univ. Calif. Pub. Geogr. 18.

Harris, P. 1973. The selection of effective agents for the biological control of weeds. Proc. 3rd Internatl. Symp. Biol. Contr. Weeds, 75-85. Montpelier, France.

Haselwood, E.L., and G.G. Motter. 1983. Handbook of Hawaiian weeds. 2nd ed. Honolulu: Univ. Hawaii Pr.

Hedburg, O. 1951. Vegetation belts of the East-African Mountains. Svensk Bot. Tidsk. 45:140-202.

Higgs, D.E.B., and D.B. James. 1969. Comparative studies on the biology of upland grasses: I. Rate of dry matter production and its control in four grass species. J. Ecol. 57:553-563.

Hosaka, E.Y. 1958. Kikuyugrass in Hawaii. Univ. Hawaii Agric. Ext. Serv. Circ. 389.

Hosaka, E.Y., and A. Thistle. 1954. Noxious plants of the Hawaiian ranges. Univ. Hawaii Coop. Ext. Serv. Bull. 62.

Howarth, F.G. 1983. Classical biocontrol: panacea or Pandora's box. Proc. Hawaii. Entomol. Soc. 24 (2&3):239-244.

Humbert, G. 1927. La destruction d'une flore insulaire par le feu. Acad. Malagache Mem. V.

Hutchinson, Q.E. 1957. Concluding remarks. Cold Spring Harbor 22nd Symp. Quant. Biol., 415-427.

Jacobi, J.D. 1981. Vegetation changes in a subalpine grassland in Hawaii following disturbance by feral pigs. Univ. Hawaii Coop. Natl. Park Resour. Stud. Unit Tech. Rep. 41. Honolulu: Univ. Hawaii.

Judd, C.S. 1936. Seed dispersal in Hawaii. Mid. Pac. Mag. 49:111-118.

Kirch, P.V. 1982. The impact of the prehistoric Polynesians on the Hawaiian ecosystem. Pac. Sci. 36:1-14.

Krajina, V.J. 1963. Biogeoclimatic zones of the Hawaiian Islands. Hawaii. Bot. Soc. Newsl. 2: 93-98.

Lamoureux, C.H. 1963. The flora and vegetation of Laysan Island. Atoll Res. Bull. 97.

La Rosa, A.M. 1983. The biology and ecology of Passiflora mollissima in Hawaii. M.S. Thesis, Univ. Hawaii, Honolulu.

Lee, M.A.B. 1974. Distribution of native and invader plant species on the island of Guam. Biotropica 6:158-164.

Loveless, A.R. 1960. The vegetation of Antigua, West Indies. J. Ecol. 48:495-527.

MacArthur, R.H. 1972. Geographical ecology: patterns in the distribution of species. New York: Harper and Row.

Mahmoud, A., and J.P. Grime. 1976. An analysis of competitive ability in three perennial grasses. New Phytol. 77:431-435.

Markin, G.P. 1984. Biological control of the noxious weed gorse Ulex europaeus L.: a status report. Proc. 5th Hawaii Volcanoes Natl. Park Nat. Sci. Conf., 77. Honolulu: Univ. Hawaii.

Martin, P., and B. Rademacher. 1960. Studies on the mutual influences of weeds and crops. In The biology of weeds, ed. J.L. Harper, 143-152. Oxford, England: Blackwell Sci. Pub.

Mellanby, K. 1974. The future of biological control in Britain: a conservationist's view. In Biology in pest and disease control, ed. D. Price-Jones and M.E. Solomon, 349-353. Oxford, England: Blackwell Sci. Pub.

Melville, R. 1979. Endangered island floras. In Plants and Islands, ed. D. Bramwell, 361-378. London: Academic Pr.

Mian, S., G. Bond, and C. Rodrigues-Barrueco. 1976. Effective and ineffective root nodules in Myrica faya. Proc. Royal Soc. Lond., Ser. B, 194:285-293.

Miguel, C., and C. Rodrigues-Barrueco. 1974. Acetylene-reducing activity of detached root nodules of Myrica faya Ait. Plant and Soil 41:521-526.

Mueller-Dombois, D. 1973. A non-adapted vegetation interferes with water removal in a tropical rain forest area in Hawaii. Trop. Ecol. 14:1-18.

Mueller-Dombois, D. 1981. Understanding Hawaiian forest ecosystems: the key to biological conservation. In Island ecosystems: biological organization in selected Hawaiian communities, ed. D. Mueller-Dombois, K.W. Bridges, and H.L. Carson, 502-520. Stroudsburg, Penn.: Hutchinson Ross Pub. Co.

Mune, T.L., and J.W. Parham. 1967. The declared noxious weeds of Fiji and their control. Fiji Dep. Agric. Bull. 48.

Nakahara, L.M., and P.Y. Lai. 1984. New state record ... Psyllids. Hawaii Pest Rep. 4:2-9.

Neal, M.C. 1965. In gardens of Hawaii. B.P. Bishop Mus. Spec. Pub. 50.

Norton, G.A., and G.R. Conway. 1977. The economic and social context of pest disease and weed problems. In Origins of pest, parasite, disease and weed problems, ed. J.M. Cherrett and G.R. Sapar, 205-226. Oxford, England: Blackwell Sci. Pub.

Pimentel, D. 1963. Introducing parasites and predators to control native plants. Can. Entomol. 95: 785-792.

Plucknett, D.L., and B.C. Stone. 1961. The principal weedy Melastomaceae in Hawaii. Pac. Sci. 15: 301-303.

Rauh, W. 1979. Problems of biological conservation in Madagascar. In Plants and islands, ed. D. Bramwell, 405-422. London: Academic Pr.

Rice, E.L. 1972. Allelopathic effects of Andropogon virginicus and its persistence in old fields. Am. J. Bot. 59:752-755.

Ripperton, J.C., and E.Y. Hosaka. 1942. Vegetation zones of Hawaii. Hawaii Agric. Exp. Stn. Bull. 89.

Rorison, I.H. 1968. The response to phosphorus of some ecologically distinct plant species: I. Growth rates and phosphorus absorption. New Phytol. 67: 913-923.

St. John, H. 1973. List and summary of the flowering plants in the Hawaiian Islands. Pac. Trop. Bot. Gard. Mem. 1.

St. John, H. 1978. The first collection of Hawaiian plants by David Nelson in 1779. Hawaiian plant studies 55. Pac. Sci. 32:315-324.

Salisbury, E. 1964. Weeds and aliens. 2nd ed. London: Collins.

Sanchez, J., and F. Davis. 1969. Growth inhibitors in kikuyu (Pennisetum clandestinum) as factors of its competitive ability. [Abstract] I Semm. Soc. Colomb. de Contr. des Malezas y Fisiol. Vegetal (COMALES), 23-24, 58-59.

Sauer, J.D. 1982. Cayman Island seashore vegetation: a study in comparative biogeography. Univ. Calif. Pub. Geogr., Vol. 25.

Simmonds, H.W. 1933. The biological control of the weed Clidemia hirta D. Don. in Fiji. Entomol. Res. Bull. 24:345-348.

Simpson, B.B., ed. 1977. Mesquite: its biology in two desert scrub ecosystems. U.S. Internatl. Biol. Prog. Synth. Ser. 4. Stroudsburg, Penn.: Dowden, Hutchinson and Ross.

Smith, C.W., T. Parman and K. Wampler. 1980. Impact of fire in a tropical submontane seasonal forest. In Proc. 2nd Conf. Sci. Res. Natl. Parks. Vol. 10, Fire Ecology, 313-324. San Francisco, Calif.: Natl. Park Serv.

Sorensen, J.C. 1980. Phenology of Andropogon virginicus in Hawaii. M.S. Thesis, Univ. Hawaii, Honolulu.

Spicer, R.A., and D. Mc. Newbery. 1979. The terrestrial vegetation of an Indian Ocean coral island: Wilingili, Addu Atoll, Maldive Islands. 1. Transect analysis of the vegetation. Atoll Res. Bull. 231.

Stoddart, D.R. 1967. Summary of the ecology of coral islands north of Madagascar (excluding Aldabra). In Ecology of Aldabra Atoll, Indian Ocean, ed. D.R. Stoddart, 53-62. Atoll Res. Bull. 118.

Stoddart, D.R. 1971. Land Vegetation of Diego Garcia. In Geography and ecology of Diego Garcia Atoll, Chagos Archipelago., ed. D.R. Stoddart and J.D. Taylor, 127-142. Atoll Res. Bull. 149.

Stoddart, D.R., and F.R. Fosberg. 1981a. Bird and Dennis Islands, Seychelles. Atoll Res. Bull. 252.

Stoddart, D.R., and F.R. Fosberg. 1981. Topographic and floristic change, Dry Tortugas, Florida 1904-1977. Atoll Res. Bull. 253.

Stoddart, D.R., and C.A. Wright. 1967. Geography and ecology of Aldabra Atoll. In Ecology of Aldabra Atoll, Indian Ocean., ed. D.R. Stoddart, 11-52. Atoll Res. Bull. 118.

Stoddart, D.R., P.E. Gibbs, and D. Hopley. 1981. Natural history of Raine Island, Great Barrier Reef. Atoll Res. Bull. 254.

Stone, C.P. Alien animals in Hawaii's native ecosystems: toward controlling the adverse effects of introduced vertebrates. [This volume]

van der Werff, H. 1979. Conservation and vegetation of the Galapagos Islands. In Plants and Islands, ed. D. Bramwell, 391-404. London: Academic Pr.

Vogl, R.J. 1969. The role of fire in the evolution of the Hawaiian flora and vegetation. Proc. Ann. Tall Timbers Fire Ecol. Conf., April 1969, 5-60. Tallahassee.

Wace, N.M. 1966. The last of the virgin islands. Discovery 27:36-42.

Warshauer, F.R., J.D. Jacobi, A.M. La Rosa, J.M. Scott, and C.W. Smith. 1983. The distribution, impact and potential management of the introduced vine Passiflora mollissima (Passifloraceae) in Hawaii. Univ. Hawaii Coop. Natl. Park Resour. Stud. Unit Tech. Rep. 48. Honolulu: Univ. Hawaii.

Watt, T.A. 1978. The biology of Holcus lanatus L. (Yorkshire fog) and its significance in grassland. Herbage Abstracts 48:195-204.

Watts, D. 1970. Persistence and Change in the vegetation of oceanic islands. Can. Geogr. 14: 91-109.

Wester, L.L., and H.B. Wood. 1977. Koster's curse (Clidemia hirta), a weed pest in Hawaiian forests. Environ. Conserv. 4:35-41.

Whelan, B.R., and D.G. Edwards. 1975. Uptake of potassium by Setaria anceps and Macroptilium atropurpureum from the same standard solution culture. Austral. J. Agric. Res. 26:819-829.

Whistler, W.A. In press. Weed handbook for Western Polynesia. Eschborn, W. Germany: Geselischafr fur Techniche Zussamznarbeit.

Woodward, P.W. 1972. The natural history of Kure Atoll, Northwestern Hawaiian Islands. Atoll Res. Bull. 164.