

Alien Ferns in Hawai'i¹

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ABSTRACT: Human activity has led to the naturalization of 30 species of pteridophytes in the Hawaiian flora. The first record of naturalized ferns in Hawai'i is in collections made in 1887. By 1950, 21 species had become established. Many of these species have spread into the native forests and are now found on all the main Islands. Since then, nine additional alien species of ferns and fern allies have been found growing in the wild. The naturalized ferns represent fewer than 16% of the pteridophyte species in Hawai'i. Although some of these species do not appear to be serious problems in the local ecosystem, others are known to be having a pronounced impact. Some naturalized ferns are displacing native species; others are hybridizing with native ferns; and still others are invading native forests, crowding out the local vegetation, and posing a serious threat to the Hawaiian ecosystem. Continued disturbance of the native habitat and introduction of new alien plants contribute to successful invasion of alien plants into the Hawaiian Islands. More than 260 species of alien pteridophytes are in cultivation on the Islands, mostly in botanical gardens and arboretums. These provide a reservoir of species for new additions to the local flora. Programs need to be established to restrict the invasion of alien species into the Hawaiian ecosystem.

THIRTY ALIEN PTERIDOPHYTE species are currently naturalized in the Hawaiian Islands, where they grow, reproduce, and spread in the native vegetation. William Hillebrand's *Flora of the Hawaiian Islands* did not list a single non-native fern (Hillebrand 1888). The first known records of the naturalization of non-native pteridophytes were found in collections made in 1887 on O'ahu by W. E. Safford. In 1950, Warren Herb Wagner, Jr., published a comprehensive study of the ferns naturalized in Hawai'i and listed 21 species that had become established. He pointed out that by 1888 ferns had been thoroughly collected in Hawai'i, and it seemed improbable that any of the naturalized species in that study were growing wild in the Islands at the time of Hillebrand's work. The immigration of additional pteridophyte species into Hawai'i has continued steadily since Wagner's report. This paper examines changes that

have occurred since 1950, giving ecological notes and distribution for all known naturalized ferns and fern allies in the Hawaiian Islands. Throughout this paper all references to Wagner and/or to 1950 records, unless otherwise indicated, are based on records in *Ferns Naturalized in Hawaii* (Wagner 1950).

The current status of naturalized ferns and fern allies in Hawai'i is shown in Table 1. In the table the species are arranged by the date of their first collection in Hawai'i as determined by the earliest available herbarium collections or, in some cases, written observations or anecdotal information as indicated in the text. The occurrence of each species on each of the islands of Hawai'i is based primarily on known collections. It is likely that many of the ferns are established on the less thoroughly collected islands, such as Molo'ka'i, and that continued collections will help fill in these records.

Alien Species in Hawai'i

Adiantum raddianum Presl [syn. *A. cuneatum* Langsdorff & Fischer], Delta Maidenhair,

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TABLE 1

NATURALIZED FERNS AND FERN ALLIES IN HAWAII ARRANGED BY YEAR OF THEIR FIRST COLLECTION

SPECIES	YEAR	KAUAI	O'AHU	MOLOKA'I	MAUI	HAWAII
<i>Pteris vittata</i> L.	1887	✓	✓		✓	✓
<i>Thelypteris dentata</i> (Forsskål) E. St. John	1887	✓	✓	✓	✓	✓
<i>Pityrogramma austroamericana</i> Domin	1903	✓	✓	✓	✓	✓
<i>Adiantum raddianum</i> Presl	1907	✓	✓	✓	✓	✓
<i>Macrothelypteris torresiana</i> (Gaudichaud) Ching	1908	✓	✓	✓	✓	✓
<i>Pityrogramma calomelanos</i> (L.) Link	1908	✓	✓	✓	✓	✓
<i>Phlebodium aureum</i> (L.) J. Smith	1909	✓	✓		✓	✓
<i>Diplazium esculentum</i> (Retzius) Swartz	1910	✓	✓		✓	✓
<i>Blechnum occidentale</i> L.	1917	✓	✓	✓	✓	✓
<i>Ceratopteris thalictroides</i> (L.) Brongniart	1919	✓	✓		✓	✓
<i>Phymatosorus grossus</i> (Langsdorff & Fischer) Brownlie	1919	✓	✓	✓	✓	✓
<i>Adiantum hispidulum</i> Swartz	1923	✓	✓	✓	✓	✓
<i>Nephrolepis multiflora</i> (Roxburgh) Jarrett ex Morton	1923	✓	✓	✓	✓	✓
<i>Thelypteris parasitica</i> (L.) Fosberg	1926	✓	✓	✓	✓	✓
<i>Cyrtomium falcatum</i> (L. f.) Presl	1928		✓	✓	✓	✓
<i>Cheilanthes viridis</i> (Forsskål) Swartz	1928	✓	✓		✓	
<i>Lygodium japonicum</i> (Thunberg) Swartz	1936					✓
<i>Nephrolepis falcata</i> (Cavanilles) C. Christensen cv. <i>Furcans</i>	1936	✓	✓	✓	✓	✓
<i>Azolla filiculoides</i> Lamarck	1937	✓	✓	✓	✓	✓
<i>Deparia petersenii</i> (Kunze) M. Kato	1938	✓	✓	✓	✓	✓
<i>Selaginella kraussiana</i> (Kunze) A. Braun	1938		✓		✓	✓
<i>Angiopteris evecta</i> (G. Forster) Hoffmann	1950		✓		✓	✓
<i>Lindsaea ensifolia</i> Swartz var. <i>ensifolia</i>	1969	✓	✓		✓	✓
<i>Cyathea cooperi</i> (W. J. Hooker ex F. Mueller) Domin	1970	✓	✓		✓	✓
<i>Tectaria incisa</i> Cavanilles	1972	✓	✓			✓
<i>Adiantum</i> 'Edwinii'	1981				✓	
<i>Nephrolepis hirsutula</i> (G. Forster) Presl cv. <i>Superba</i>	1983	✓			✓	
<i>Adiantum tenerum</i> Swartz	1987				✓	
<i>Selaginella stellata</i> Spring	1990					✓
<i>Platyserium bifurcatum</i> (Cavanilles) C. Christensen ssp. <i>bifurcatum</i>	1991		✓		✓	✓

✓, Species recorded on the island.

is now the most common species of *Adiantum* in the Islands, where it grows on moist and shaded rocks, slopes, and river and roadside banks. Wagner cited collection by Abbé Faurie from Keālia, Kauai, made in January 1910, as the first wild-collected record. He also quoted from a 1949 letter by H. L. Lyon, who wrote that he had first seen *A. raddianum* in the wild in 1907 and that by 1949 it had become widespread. A form with small, narrow segments and brown indusia grows on the slopes of Haleakalā from 900 to 2400 m (*Hobby* 3482 & 3484, BISH). This alien species continues to spread, whereas the indigenous *A. capillus-veneris* L. is now uncommon and is apparently being replaced by *A. raddianum*.

Adiantum hispidulum Swartz, Rough Maid-

enhair, reported by Wagner only from O'ahu, Maui, and Hawaii, is now established on all of the Islands. D. LeRoy Topping first collected this species in the wild in Pauoa Valley, Honolulu, O'ahu, in 1923, where it was growing among rocks, lantana, and guava bushes (*Topping* 2634, BISH). This species, easily recognized by the pedately divided blades, is native to Asia, Africa, India, Australia, and the Pacific. Now widely naturalized in Hawaii, it grows in dry, sunny, and rocky slopes and woods.

Adiantum tenerum Swartz, Brittle Maidenhair, was found to be established on Maui by Tim Flynn in 1987. It is common in a grove of *Terminalia* located behind the Hāna community building at Ka'uiki on the east

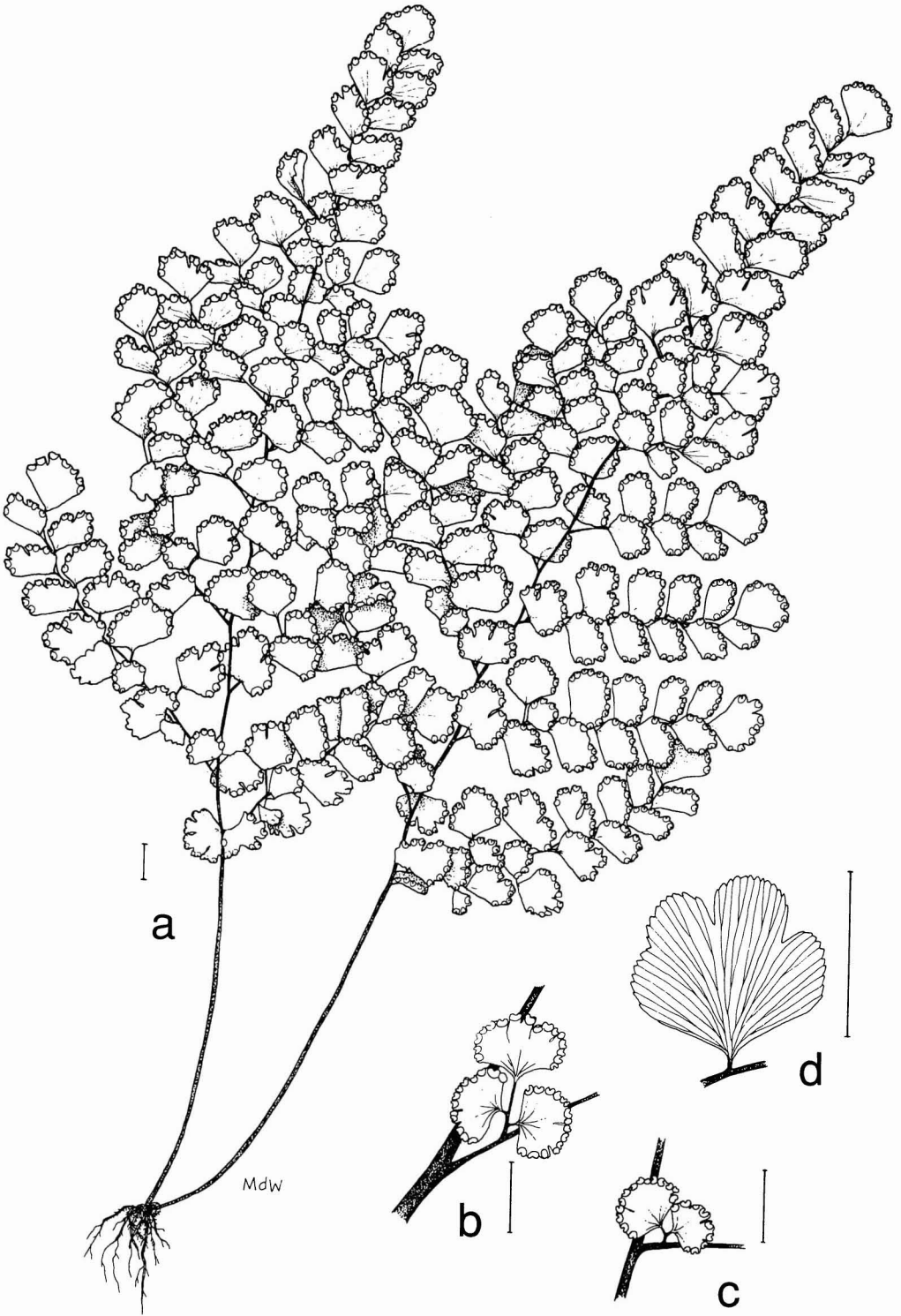


FIGURE 1. *Adiantum* 'Edwinii': a, habit; b and c, basal acroscopic pinnule of lower pinna; d, segment detail. Scale = 1.0 cm.

side of Hāna Bay (*Flynn 2418 & 2513*, PTBG). A popular species in cultivation from the New World, *A. tenerum* differs from the other twice-or-more-pinnate species of *Adiantum* in the Hawaiian flora by the presence of a small enlarged disk at the base of each segment. The dark color of the stalk does not extend into the base of the segment.

Still another escaped *Adiantum* was found by Robert Hobdy growing in two localities on Maui and one on Lānaʻi (Figure 1). This fern, which often covers entire cliff faces and rock slopes, has 2–3-pinnate, gracefully pendent, lanceolate to ovate-lanceolate fronds up to 1 m long and 60 cm wide. The segments, which in large specimens measure 3 by 3 cm, are obovate to rhomboid or flabellate, and the veins in the segments end in the sinuses at the margins. The pinnae bear a short-stalked, basal, acroscopic pinnule that overlaps the rachis and, in the basal pinnae, is usually two-branched. In large fronds several of the basal pinnules of the lower pinnae are pinnately divided, some with as many as five segments. This *Adiantum* has some characteristics in common with *A. concinnum* Humboldt & Bonpland ex Willdenow, but is considerably larger. This plant has been known in cultivation under the name of *Adiantum* 'Edwinii' (Hoshizaki 1970, Goudey 1985), and it may be a hybrid or a cultivar of *A. concinnum*. It was first collected on Maui above Waikapū in 1981 (*Hobdy 996*) and in 1986 was found growing on Maui on a cliff along ʻĪao Valley Road, where it is abundant (*Hobdy 2681*, BISH). In 1992 Hobdy found another colony of this fern on Lānaʻi (*Hobdy 3516*, MICH).

Angiopteris evecta (G. Forster) Hoffmann, Mule's Foot Fern, has the distinction of being the only naturalized fern for which we have precise introduction information. It was brought to Hawaiʻi in 1927 by H. L. Lyon and planted in upper Mānoa Valley, Oʻahu, in what is now the Lyon Arboretum of the University of Hawaiʻi. This fern has huge leaves that can reach more than 7 m in length and shade out large areas. Its spread within the Lyon Arboretum and into the nearby forested ridges and valleys was described by E. Funk (1987), who anticipated its con-

tinued spread (Funk 1987). It became a pest in the arboretum and poses a similar threat in other areas where it grows. The plant that Funk reported as having been seen along the Hāna Highway, East Maui, was no longer in evidence in 1994 and may have been destroyed (R. Hobdy, pers. comm.). In 1994 Art Medeiros found *A. evecta* spreading into the lowland wet forest above Hāna, Maui, where it probably escaped from cultivation in the tropical nursery Helani Gardens (R. Hobdy, pers. comm.). It is now sparsely naturalized on Maui from Keʻanae to Hāna (A. Medeiros, pers. comm.). In 1992 *Angiopteris* was collected on Hawaiʻi growing in the Waiākea Forest Reserve (*Imoto & Bergfeld 03/31/92*, HVNP). Several large plants are in cultivation on the Hāmākua Coast, Hawaiʻi, on the grounds of the Hawaiʻi Tropical Botanical Garden. This wet coastal area seems particularly favorable for serving as a springboard for the naturalization of many alien plants, and the escape of *Angiopteris evecta* should be anticipated and guarded against.

The species of *Azolla* are difficult to tell apart because the plants are small and the characters used to separate them are difficult to see, requiring the use of a light microscope to see epidermal hairs and a scanning electron microscope for examination of megaspores. Moreover, most of the plants collected are sterile and lack the megaspores needed for identification. The genus is important in the cultivation of rice because all species can fix atmospheric nitrogen, thus resulting in greater crop yields. Several species have been brought into Hawaiʻi for horticultural and experimental purposes (Lumpkin 1993).

Azolla filiculoides Lamarck was deliberately brought into the Islands as part of a mosquito abatement program in rice fields, but it was not until around 1934 that it became fully naturalized in taro patches and irrigation ditches on Oʻahu (Fosberg 1943). In 1950 Wagner reported that he had collections of it from both Oʻahu and Maui. It is now well established in flooded areas on all the islands except Hawaiʻi, where it most likely also occurs, although I have seen no collections. *Azolla filiculoides* can be found

floating in flooded areas such as taro patches, rice paddies, ditches, and ponds. It can form large mats that can prevent weed growth and thereby reduce mosquito breeding.

Azolla caroliniana Willdenow has recently been identified as being established in Hawai'i, but confirmation of its identity is needed.

Blechnum occidentale L., Hammock Fern, a garden escape from tropical America, has continued its spread throughout Hawaiian forests since Wagner reported it in 1950. It is now a common weedy fern along trail sides, stream banks, forested slopes, and gulches on all islands, often growing in solid stands. In 1917 C. N. Forbes collected *B. occidentale* in the Honokōhau Drainage Basin on Maui, remarking in his notes that the genus was new to the Islands. Soon afterward it was collected on O'ahu and Kaua'i. Degener (1946a) pointed out that "this fern is spreading rapidly along dry, partly shaded embankments." Warren H. Wagner (1950) remarked that in the middle and late 1940s it was "common in suitable places everywhere" on all of the islands except Hawai'i. This aggressive, fast-growing fern is now widely naturalized in Hawai'i, often in large populations, effectively preventing the germination and growth of native species where it occurs. Smith (1985) listed *B. occidentale* as a candidate for monitoring because of its potential for becoming a serious pest. There has been no improvement of the situation since.

Ceratopteris thalictroides (L.) Brongniart, Swamp Fern, is reported to have been common in taro patches on Kaua'i and O'ahu in 1907, although the first collection of it was not made until 1919 (*Forbes 2530.O*, BISH) (Lloyd 1973). It became widespread on O'ahu and Kaua'i, but by 1973, because of intensive weeding and reduction in the number of taro patches, its distribution had become more limited. It has never been reported from any of the other islands even though taro is cultivated on them. Lloyd, in a study of the sexual and vegetative reproduction of *C. thalictroides* in Hawai'i, expected that it soon would be eliminated from the Hawaiian flora (Lloyd 1973). Recent reports indicate that it is still extant in taro fields in Hanalei and

Hanapēpē on the island of Kaua'i (Flynn, pers. comm.).

Cheilanthes viridis (Forsskål) Swartz [syn. *Pellaea viridis* (Forsskål) Prantl (the "viridis" group of species is poorly understood and needs to be studied and revised)], Green Cliff Brake, was first collected in the wild in 1928 and was known to be well established in several localities on O'ahu in 1950 (Wagner 1950). It is now also reported from Kaua'i, where it was found growing in Waimea Canyon in 1987 (*Flynn & Weller 2082*, PTBG) and in Lāwa'i Valley in 1995 (*Flynn 5719*, PTBG). On Maui a plant was seen growing in a dry gulch above Lahaina in the early 1980s (Hobdy, pers. comm.), and a collection was made of it in Halepōhaku Ridge, West Maui in 1991 (*Hobdy & Medeiros 3269*, BISH). This southern African fern is common in cultivation, from which it probably escaped; it does not appear to be an aggressive colonizer.

Cyathea cooperi (W. J. Hooker ex F. Mueller) Domin [syn. *Sphaeropteris cooperi* (W. J. Hooker ex F. Muell.) Tryon], Australian Tree Fern, is among the most recent immigrant alien ferns and is also one of the most troublesome. *Cyathea cooperi* is the most commonly available tree fern in local nurseries, is a fast grower, and, unfortunately, readily escapes from cultivation. Two articles were published in 1992 that sounded the alarm about the threat posed to the Hawaiian biota by the aggressive *C. cooperi*. Loope et al. (1992) listed it as among "the worst alien plant invaders of Haleakalā." A detailed study on the distribution, growth pattern, and impact of *C. cooperi* on the Hawaiian rain forests, particularly in Kīpahulu Valley, Maui, was published by Medeiros et al. (1992). That study led to the recommendation that this species be formally declared a "Noxious Weed" by the state and that its distribution in the horticultural trade be halted. It was described as an invasive, disruptive species capable of radically modifying its habitat. It was reported to be escaping from cultivation from the Lyon Arboretum, Mānoa Valley, O'ahu, as early as the 1950s. It is now known to be naturalized on Kaua'i, O'ahu, and Maui. On Kaua'i, in the Kōke'e area, four or five Australian Tree

Ferns were planted in the 1970s and most likely served as the source of hundreds of plants now found growing in the *koa/‘ōhi‘a* forest throughout the region. Each mature plant produces large quantities of spores that are readily dispersed across long distances. It is clear that *C. cooperi* is an aggressive and invasive plant that seriously alters its habitat. Efforts to control it are currently limited to Haleakalā National Park, while its spread continues elsewhere. New invasions are to be expected, especially as its cultivation increases.

Cyrtomium falcatum (L. f.) Presl, Holly Fern, from eastern Asia, is a popular fern in cultivation and has been known from the wild in Hawai‘i since it was first collected in 1928 on the cliffs and gulches above Kalau-papa, Moloka‘i (Degener 1946b). It has been found naturalized on each of the major islands except Kaua‘i. Hobdy (pers. comm.) informed me that it shows a marked preference for damp windward sea cliffs and is now fairly common on such sites on Maui and Moloka‘i; elsewhere it is rare and widely scattered. *Cyrtomium falcatum* has escaped from cultivation in widely scattered warmer areas of the United States, New Zealand, Australia, and South America. It is apparently an apogamous species, reproducing without sexual reproduction.

Deparia petersenii (Kunze) M. Kato (incorrectly known as *Athyrium japonicum* or *Diplazium japonicum*) was known in 1950 only from the Kohala Mountains on Hawai‘i. Now it has invaded all the islands. It has spread rapidly and widely along trails, roadsides, stream banks, and secondary forest floors and has extended its range along the edges of the native forest and into the forest floor itself. *Deparia petersenii*, native to the tropical and subtropical regions of eastern Asia, was first collected in Hawai‘i in 1938 (Skottsberg 3179, BISH). It is an aggressive, fast-growing weed that often volunteers in gardens and is sometimes cultivated. It has also naturalized in the southeastern United States, southeastern Brazil, and the Azores.

In 1950 *Diplazium esculentum* (Retzius) Swartz [syn. *Athyrium esculentum* (Retzius) Copeland], Edible Fern, had a very limited

distribution in Hawai‘i. Wagner reported having seen it on Maui. The first collection of it was made in 1910 on Kaua‘i (Faurie 154) as reported by Copeland (1914). This species is from southeastern Asia and the Pacific and is the most commonly eaten of all ferns. Its caudex often reaches a height of 1.5 m. It is currently found on all of the larger islands except Moloka‘i; its absence on the latter may simply reflect the failure of collectors to take a specimen of this weedy fern. *Diplazium esculentum* grows in large stands in wet areas, such as along stream banks; for instance, it occurs abundantly in valleys along the Hāmākua Coast of Hawai‘i and in wet areas of Pu‘u ‘Ōhi‘a and Mānoa Valley, O‘ahu.

Lindsaea ensifolia Swartz var. *ensifolia* was first found growing in the wild around steam vents near Puhimau Crater along Chain-of-Craters Road, Volcanoes National Park, Hawaii, in 1969 (Wagner 1971). Originally, because of the unusual habitat in which it was found, it was thought to be native. Since its appearance, *L. ensifolia* has been found well established in widely scattered areas on Kaua‘i (Hume 325, BISH), O‘ahu (Wilson 1706, BISH), Maui (Hobdy 1746, BISH), and Hawai‘i (Takeuchi 3584, BISH). Current characteristics of its growth and distribution in the Islands indicate that *L. ensifolia* var. *ensifolia* is, in fact, a recent immigrant. On Kaua‘i, Tim Flynn (pers. comm.) informed me that it is persisting and spreading around recently abandoned homesites and may not yet have escaped from cultivation.

A large population of *L. ensifolia* is growing in an abandoned orchard on the northeastern side of Kāhili Mountain Park, Kōloa District, Kaua‘i, together with the indigenous *Odontosoria chinensis* (L.) J. Smith. There several individual plants of a hybrid between the two species, which has been described as \times *Lindsaeosoria flynnii* W. H. Wagner (Wagner 1993), can be found. This is one of several hybrids between native and naturalized species found on the Islands.

Lygodium japonicum (Thunberg) Swartz, Climbing Fern, can still be found scrambling on grasses and shrubs on the banks at the southern end of Pepe‘ekeo Scenic Drive

north of Hilo (*Wilson 2437*, BISH). It is native to eastern Asia and is common in cultivation, from which it occasionally escapes. It was first collected in Hawai'i in 1936 and was described as being semiestablished around an old garden (Fosberg 1943). *Lygodium japonicum* has persisted north of Hilo but does not seem to have spread substantially or to have been particularly damaging. By contrast, in some places in the southeastern United States, this species grows over other vegetation and smothers it, resulting in its death.

Macrothelypteris torresiana (Gaudichaud) Ching [syn. *Lastrea torresiana* (Gaudichaud) Moore; *Dryopteris uliginosa* (Kunze) C. Christensen], Wood Fern, a widespread invader from the Old World, has been collected on all the islands except Moloka'i, where it may simply have been overlooked. Native to the tropical and subtropical regions of Asia and Africa, this invasive species has extended its range throughout the Pacific and has colonized the New World from the southeastern United States to northern Argentina and the Caribbean. Wagner reported that it was first noted as naturalized in Hawai'i in 1892. The earliest specimens I have seen from Hawai'i were collected in 1915 (*Forbes 606.H*, BISH), although Maxon (1923) cited a collection from O'ahu in 1908. Wagner anticipated that this species would spread throughout the island forests because it was already well established in scattered areas, a prediction that certainly has been borne out.

There has been much confusion about the identity of *Nephrolepis* species in Hawai'i and which ones are native. Two species are now understood to be indigenous: *N. exaltata* (L.) Schott and *N. cordifolia* (L.) Presl. The most conspicuous and abundant naturalized species is *N. multiflora* (Roxburgh) Jarrett ex Morton, reported incorrectly as *N. hirsutula* or *N. exaltata*. *Nephrolepis multiflora* is an aggressive, fast-growing plant. Native to India and tropical Asia, it can be found on all the islands in almost solid stands along roadsides, trail sides, and barren, disturbed soil, such as in fields and orchards. It is a pioneer colonizer of lava flows, often as the only plant and in great quantities. *Nephro-*

lepis multiflora is also popular in garden plantings in the ground and in containers. It can be distinguished from the other wild species of the genus most easily by the presence of a line of short, erect hairs along the upper (adaxial) surface of the costa. The uniqueness of the species was pointed out by Morton (1974). The earliest collection of this species was made by D. LeRoy Topping in July 1923 (*Topping 2705*, BISH). Wagner reported that by 1950 it was only "very localized in the islands" on Kaua'i, O'ahu, and Hawai'i. In Puerto Rico, Proctor called it the most common fern on the island, even though it probably was introduced only after 1940 (Proctor 1989). It is no less aggressive in Hawai'i.

Nephrolepis falcata (Cavanilles) C. Christensen cv. *Furcans* (as *N. biserrata* var. *furcans* Hortorum), Fishtail Fern, *hi'ui'a*, is a common fern in cultivation and is easily recognized by the arching fronds and pinnae with tips forked one to three times. Proctor (1961) wrote that this cultivar was first introduced into European cultivation from Australia. It was first collected in the wild by F. R. Fosberg on Moloka'i at the mouth of the Wailau Valley in 1936 (*Fosberg 13453*, BISH), where it was growing around old homesites and spreading up the valley. It is now established in the flora on all of the islands in scattered localities, where it is usually locally common.

In May 1983 Robert Hobdy found *Nephrolepis hirsutula* (G. Forster) Presl cv. *Superba* growing along the roadside in lower Nāhiku by the Makapipi Stream bridge in East Maui (*Hobdy 1766*, BISH). It was growing among plants of the more common *N. multiflora*. Three years later, in March 1986, Tim Flynn and Lynwood Hume found another naturalized population of this cultivar in the Halele'a Forest Reserve, Hanalei Valley, Kaua'i, where they described it as common on the banks of a small tributary stream of the Hanalei River (*Flynn 1612*, PTBG). This robust cultivar has erect fronds covered with hairy-margined scales and pinnae with irregularly undulate or laciniate-lobed margins. This fern was known in cultivation, and specimens of it were collected in Honolulu gardens in 1940 (*Neal April 2, 1940*, BISH) and

again in 1944 (*Neal 1246*, BISH). Proctor (1977) reported this fern to be common in cultivation in the Lesser Antilles, where it sometimes persisted or spread from abandoned plantings. This is similar to its pattern in Hawai'i, where it does not appear to be an aggressive invader.

It is interesting that the presence of *N. hirsutula* itself has not been documented in Hawai'i. It is known from Australia and Asia to the Pacific Islands and is very common in Fiji and throughout central Polynesia, and would seem a likely candidate for immigration to the Hawaiian Islands. Reports of its presence in Hawai'i have been based mostly on misidentification of *N. multiflora*, which, although similar in appearance, can be distinguished by the presence of a row of short, erect hairs on the adaxial surface of the pinna midrib and also by the appressed or only slightly spreading white to light tan, lanceolate to linear-lanceolate rachis scales with long, hairy margins, the hairs often densely interwoven to form a woolly, matlike covering. *Nephrolepis hirsutula* has narrow, linear-lanceolate, often hairlike brownish, hairy-margined scales on the adaxial surface of the midrib and rusty brown, at times darker in the center, dense rachis scales that have spreading hairy margins, but do not form a woolly covering.

Phlebodium aureum (L.) J. Smith, a commonly cultivated New World escapee, is now recorded from all the high islands except Moloka'i. It may well also be established on that island, but I have seen no collections of it. It was first collected in 1910 on Kaua'i (*Forbes 308*, BISH), and in 1950 Wagner reported it to be growing frequently in the wild on O'ahu and Kaua'i. *Phlebodium aureum* is an epiphyte in forests and near habitations; a particularly large population is found in the trees and on some of the buildings along Banyan Drive, Hilo, Hawai'i.

Phymatosorus grossus (Langsdorff & Fischer) Brownlie, *Maile-Scented Fern*, *laua'e*, is probably the most commonly encountered fern in the Hawaiian Islands. It is found in street plantings and in home and public gardens, where it is used as a border plant, ground cover, or individual planting, and

often as a container plant. It has escaped from cultivation and is found on all main islands growing as a ground cover in the lower forests. This plant has long been known as *Phymatosorus scolopendria* or *Microsorium scolopendria*, but Brownlie (1977) pointed out that *P. scolopendria* (Burm.) Pichi-Sermolli has fronds with only one to four pairs of lobes and grows as an epiphyte, whereas *Phymatosorus grossus* has larger fronds with up to 10 pairs of lobes and is mostly terrestrial. *Phymatosorus grossus* is found growing in the wild from Australia and New Caledonia to Fiji and eastward throughout the South Pacific, where it is the most common species of this genus. The earliest collection in Hawai'i was made in Kipahulu, Maui, by C. N. Forbes (*Forbes 1778.M*, BISH) in December 1919. In a handwritten note on that herbarium sheet Forbes noted: "Thoroughly naturalized between Hana and Kaupo in many places." Wagner reviewed reports of the presence and advent of the species in Hawai'i and noted that reports and collections of this species as naturalized from various localities increased substantially beginning in 1922. It seems to have appeared in the late 1910s and spread rapidly throughout the Islands.

It is of interest that this alien fern should have been given a Hawaiian name and said to have been used in pre-European culture in perfuming tapa and in the making of *leis* (Krauss 1993). It is most likely that Hawaiians in the twentieth century have used *P. grossus* to replace the rare, fragrant, endemic *Microsorium spectrum* (Kaulfuss) Copeland, which may have been used originally to provide a pleasant scent to tapa (Fosberg 1942, Abbott 1992).

The two species of *Pityrogramma* found in Hawai'i are introductions from the Americas and have in the past been considered to be varieties of a single species, *P. calomelanos* (e.g., by Tryon & Tryon [1982]). Recently, the two have been recognized as distinct species, which, when growing together, frequently hybridize to produce sterile offspring. Early reports, which treated these two as a single species, failed to note the color of the coating on the underside of the frond. In such

cases it is not possible to know which of the two is being referred to; without documenting specimens the reports may refer to either species. Wagner (1993) published a key that detailed the differences between the two species, as well as their hybrid.

Pityrogramma austroamericana Domin [syn. *Pityrogramma calomelanos* (L.) Link var. *aureoflava* (W. H. Hooker) Weatherby ex F. M. Bailey], Goldfern, native to tropical America, was first wild-collected on Kaua'i in 1903 (*Brodie Sept. 13, 1903*, BISH). This very popular cultivated fern was naturalized on all of the main islands by 1950, where it prefers to grow on bare roadside banks and trail sides, and in open, disturbed areas. The fronds of the mature goldfern are spreading, not erect, and mostly bipinnate. In horticulture, this fern is widely incorrectly known as *P. hybrida*.

Pityrogramma calomelanos (L.) Link, Silverfern, also from tropical America, probably made its appearance in the Hawaiian landscape at about the same time as the goldfern. Like the goldfern, this species was very popular in cultivation. The earliest wild collection that I have seen was made in 1908 on O'ahu, in Punalu'u Valley (*Rock 13*, BISH). The silverfern grows in areas similar to those inhabited by the goldfern, but tends to favor shadier conditions. It has fronds that are erect or arching and frequently three-pinnate. It is found less frequently than the goldfern and seems to have become even less common in recent years.

Wherever the goldfern and silverfern are found growing together, hybrid intermediate plants are frequently found. These vigorous hybrids, recently named *Pityrogramma* × *mckenneyi* W. H. Wagner (1993), produce sterile spores but reproduce vegetatively by root proliferations.

Platyserium bifurcatum (Cavanilles) C. Christensen ssp. *bifurcatum*, Common Stag-horn Fern, is naturalized on O'ahu, Maui, and Hawai'i in the vicinity of populated areas where it has escaped from cultivation in gardens. It was first collected in 1991 from large trees near the headquarters of 'Ulu-palakua Ranch, East Maui, by R. Hobdy, who counted more than 100 plants grow-

ing as epiphytes (*Hobdy 3380*, BISH). Other populations of this popular cultivated fern are known in high, difficult-to-reach tree branches in residences along Tantalus Drive, Makiki Heights, Honolulu, O'ahu; trees in gardens along the Pali Highway, Nu'uuanu Valley, O'ahu; and large trees growing along Banyan Drive, Hilo, Hawai'i. The fertile fronds bear large areas of sporangia on the lower surfaces of their lobe tips; great quantities of spores are released, which are carried to nearby trees, giving rise to new plants. The known populations of naturalized plants are localized, and their continued spread bears watching.

Platyserium superbum DeJoncheere & Hennipman has not been included in this list of naturalized species, but in 1992 Barbara Joe Hoshizaki (pers. comm.) found that young plants of this fern were volunteering on tree branches near cultivated plants growing in Nu'uuanu Valley, O'ahu. It will no doubt find this valley a very favorable area for continued spread.

The appearance of *Pteris vittata* L., Chinese Brake, is documented by a collection of W. E. Safford from O'ahu in 1887 (BISH 09092). Reported in 1950 as occurring on three of the islands (O'ahu, Maui, and Hawai'i), there seem to be no specimens of it from Moloka'i, although it probably has been overlooked, ignored, or dismissed by collectors there. On Kaua'i it was first collected in 1986 in Waimea Canyon (*Flynn et al. 1485*, PTBG), and in 1993 it was found growing in Nu'alolo Aina (*Wood & Perlman 2382*, PTBG). *Pteris vittata* is native to Africa, Asia, and Australia and is now widely naturalized in scattered warm regions of the Americas. It is widely cultivated and readily escapes, and its spread is anticipated in areas where it does not yet occur. In Hawai'i it grows in open and abandoned areas, along roadsides, on old walls and buildings, and in fields and gardens.

The record of the naturalization of *Selaginella kraussiana* (Kunze) A. Braun, Spreading Clubmoss, in Hawai'i dates to 1938, when G. E. Olson collected it in the lawns of the Kīlauea residences in Hawaii Volcanoes National Park. *Selaginella kraussiana* is an

African species with prostrate, mat-forming, much-branched stems that root along their length. It is undeniably the most common *Selaginella* in cultivation, from which it frequently escapes. It can now be found well established in the Kīlauea area of Hawai'i, where it grows in lawns, at edges of fields, and along trails and roadsides in wet areas. Since Wagner's report in 1950, *S. kraussiana* has been found on O'ahu (*Herat* 271, BISH) and was recently collected along the Hāna Highway on Maui (*Hobdy* 3448, BISH).

A more recently discovered naturalized species is *S. stellata* Spring (*S. galliottii* Spring), which, in 1990, was found growing in solid stands along the trail sides and in the understory at 'Akaka Falls State Park along the Hāmākua Coast of Hawai'i (*Wilson* 1855, BISH), which is forested by mostly alien species. The species is native to southern Mexico and Central America. There is no clue as to how it arrived in the Islands, and I have found no record that it is cultivated in Hawai'i. The plants have frondlike, gracefully arching branches that bear numerous ascending strobili 1–2 cm long. The stems are jointed along their length, and only the basal 1/3 of the main stem bears rhizophores (Figure 2). The stems fragment readily at the joints, disarticulating to produce fragments that may function in vegetative propagation. *Selaginella stellata* occurs in large numbers in this state park.

Tectaria incisa Cavanilles was first wild-collected in 1985 in Waimanu Valley, Hawai'i (*Hobdy* 2430, BISH), and on Hā'u-pu Mountain, Kōloa District, Kaua'i (*Lau* 1307.2, BISH). It was collected in 1989 at the Lyon Arboretum, Mānoa Valley, O'ahu, where it was being cultivated and spreading on the grounds; it had been brought in from Waipi'o Valley, Hawai'i, in 1977 (*Wilson* 1692, BISH). *Tectaria incisa* is native from southern Mexico to northern Argentina and in the West Indies, and has escaped from cultivation in southern Florida. The pinnate fronds occasionally produce buds or plantlets at the base of the pinnae that facilitate its spread. Plants bearing axillary buds are at times referred to as forma *vivipara* (Jenman) Morton. This appears to be an aggressive in-

vader in Hawai'i, and its spread should be carefully monitored.

Thelypteris dentata (Forsskål) E. St. John has the distinction of being one of the very first alien species to have naturalized in Hawai'i. W. E. Safford, botanist and lieutenant in the U.S. Navy, made a collection of it on O'ahu in 1887, and in 1897 Heller reported it to be common on that island (see Wagner 1950). It is now indeed common on all of the main islands, particularly in disturbed areas, most noticeably along roadsides and trails. It can also be found growing in large stands as a ground cover in disturbed forested areas. This species has become one of the most commonly encountered ferns along Hawaiian trails.

Thelypteris parasitica (L.) Fosberg evidently did not reach the Islands until a couple of decades later; it was first collected in 1926. It is now widely found throughout the Islands, often in association with *T. dentata*, and is now much more common than *T. dentata*. Wherever the two species occur together, they commonly form hybrids. This hybrid was described by Wagner (1993) as *Thelypteris* × *incesta* W. H. Wagner, and at the same time he published a key to help in distinguishing the three taxa.

Thelypteris dentata also hybridizes with the Hawaiian endemic *Thelypteris cyatheoides* (Kaulfuss) Fosberg. The hybrid is triploid and forms large, widely scattered clones. It has been named *Thelypteris* × *palmeri* W. H. Wagner (1993); although it resembles *T. dentata*, it is larger and has pinnae with more lobes that are less deeply incised. It should be sought wherever the two species coexist.

Other Species

Acrostichum aureum L. is the only alien fern that was once established in Hawai'i but is no longer found in the wild. Wagner reported on plants that were introduced in 1926 from the Philippines that were growing at Kamehameha School Farm, Haha'ione Valley, Maunaloa (now Hawai'i Kai), O'ahu, during 1933–1938. Field notes by Thomas R. L. McGuire, Board of Agriculture of the

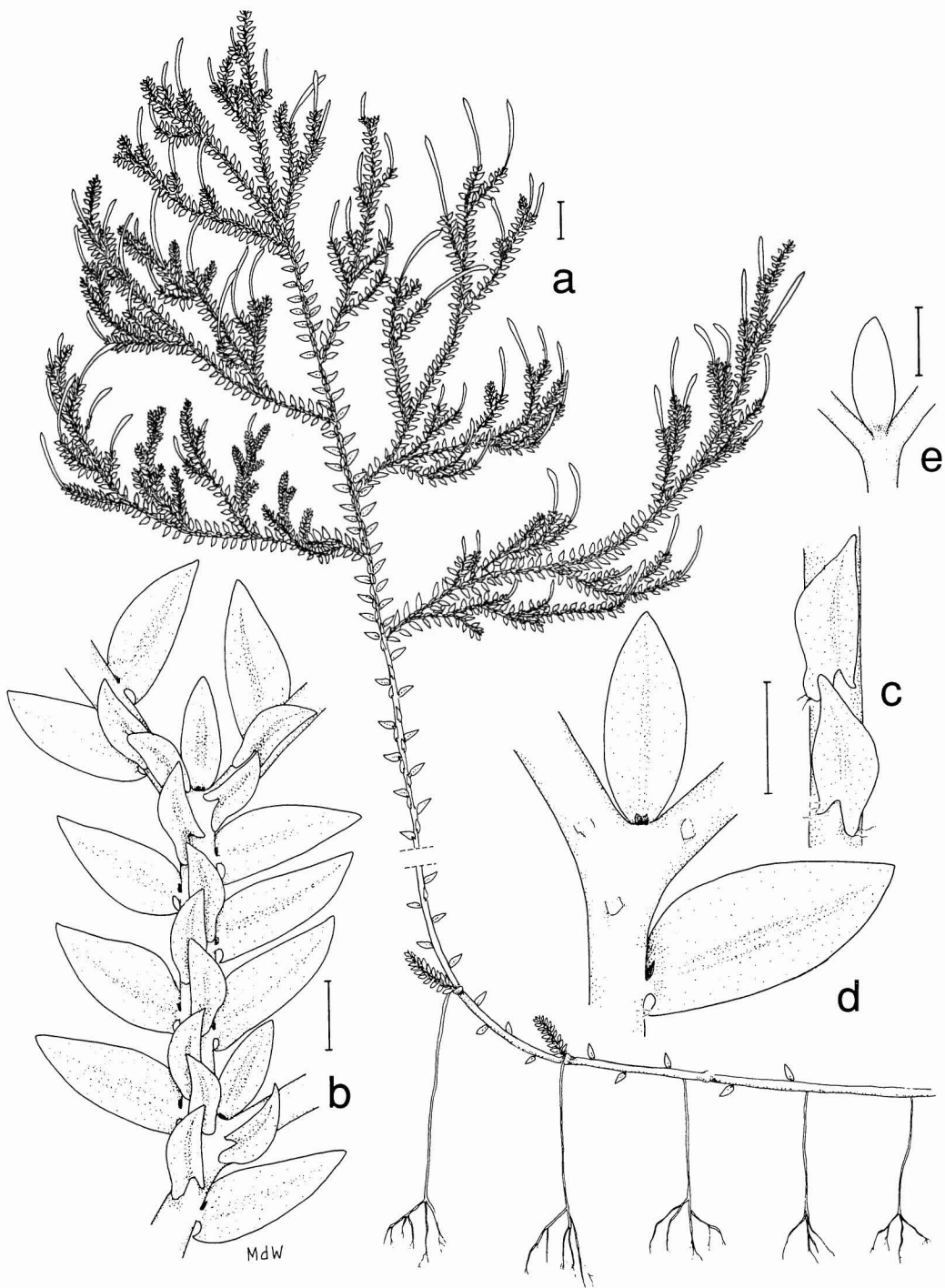


FIGURE 2. *Selaginella stellata*: a, habit; b, upper surface of branch; c, median leaves; d, axillary leaf, adaxial view, and lateral leaf; e, axillary leaf, abaxial view. Scale = 1.0 cm for a; 1.0 mm for b–e.

Division of Forestry, made available to me by Derral R. Herbst and dated 18 July 1927 record in the marsh back of Kuapā fishpond: "Two ferns, *Acrostichum aureum*, planted same date [7 August 1926] are growing very slowly." This population persisted and spread slowly in the area, but the last remaining plants were destroyed in the 1980s during landscaping of the community club of Hawai'i Kai (Herbst, pers. comm.). No other populations of this species have been reported out of cultivation.

DISCUSSION

Considerable attention has been paid to the advent of alien plants to Hawai'i and to their establishment and spread in the Islands. W. L. Wagner et al. (1990) listed 861 species of naturalized angiosperms in Hawai'i, representing 47% of flowering plants treated in their manual. Among important publications dealing with the immigration and establishment of alien plants in Hawai'i are a study by Smith (1985) of the impact of alien plants on the native Hawaiian biota; a paper by Loope and Mueller-Dombois (1989) examining the characteristics of islands subjected to biological invasions, paying particular attention to Hawai'i; and, most recently, a volume that includes 44 papers on alien invasions (Stone et al. 1992). Studies have shown that the factors allowing for the successful establishment of large numbers of alien plants in the Hawaiian Islands are the widespread disturbance of native habitat by humans, introduced animals, or natural causes; human activities, either deliberate or unintentional, that introduce large numbers of plant species; and the ideal growing conditions found in the Islands.

With very few exceptions, the recent attention paid to the problems presented by the naturalization of alien plants has not included pteridophytes. The Hawaiian fern flora is estimated to include about 170 native and 30 naturalized species (Wagner 1995). The naturalized ferns represent fewer than 16% of all the pteridophytes, a figure substantially lower than that for the flowering

plants. Since 1950, nine new immigrant ferns and fern allies have been found naturalized in Hawai'i. The invasion by alien pteridophytes has been gradual but steady, averaging about three new species per decade. Twenty-five of the 30 naturalized species are frequently cultivated; only two of them are not known to be cultivated in the Hawaiian Islands (*Lindsaea ensifolia* and *Selaginella stellata*). Undoubtedly, Hawaiian gardens have provided the principal port of entry for the introduction of alien pteridophytes. Botanical gardens have, on more than one occasion, served as a source for naturalized ferns. A recent inventory of the cultivated ferns and fern allies in Hawai'i listed more than 260 species of alien cultivated pteridophytes, most of them in botanical gardens and arboreta (C. Imada, pers. comm.). These plants are well situated to supply additional alien species to the local flora.

It would be advantageous to be able to predict which alien species would escape from cultivation and spread in the Hawaiian flora; this would allow us to guard against these species and attempt to exclude them. However, data on growth behavior of ferns in other regions provide only limited information about their probable growth patterns in Hawai'i.

Recent floristic studies of two Pacific islands allow for comparisons with Hawai'i. Brownlie (1977) included only two naturalized fern species, *Ceratopteris thalictroides* (L.) Brongniart and *Salvinia auriculata* Aublet, in his Fiji fern flora. In New Zealand, however, Brownsey and Smith-Dodsworth (1989) found 22 naturalized pteridophyte species, and three additional species have been found since then (P. J. Brownsey, pers. comm.). Only four species now naturalized in New Zealand are also established aliens in Hawai'i: *Adiantum raddianum*, *Cyrtomium falcatum*, *Cheilanthes viridis*, and *Selaginella kraussiana*. *Adiantum hispidulum*, naturalized in Hawai'i, is indigenous to New Zealand. *Azolla filiculoides* is listed by Brownsey as indigenous to New Zealand, but he points out that these plants are frequently referred to as *A. rubra* R. Brown or *A. filiculoides* var. *rubra* (R. Brown) Strasburger, which is

different from the plants found in Hawai'i. Two ferns indigenous to Hawai'i, *Adiantum capillus-veneris* L. and *Pteris cretica* L., have become naturalized in New Zealand.

Of the species naturalized in New Zealand and also in Hawai'i, only *Adiantum raddianum* has spread widely in the Hawaiian Islands and is crowding out the indigenous *A. capillus-veneris*. In contrast, in New Zealand, *A. raddianum* is naturalized only in a few places around Auckland, Taranaki, and Wellington (Brownsey 1981, 1988). The aggressive growth of *Nephrolepis multiflora* in Hawai'i might have been anticipated, but its early introduction and escape, and because of the uncertainty about its identity and even whether it was indigenous or introduced, apparently did not arouse concern. The impact of *Angiopteris evecta* and *Cyathea cooperi* on the Hawaiian native flora could not have been entirely anticipated; they are not serious problems elsewhere. *Salvinia molesta* D. S. Mitchell, a well-known pest of waterways, is in cultivation in Hawai'i; perhaps its escape into the Hawaiian ecosystem should be expected.

Because of the isolation of the Hawaiian ecosystem and the absence of many selective pressures during its evolutionary development, this ecosystem is particularly susceptible to invasion; its fragility is well documented (see Loope and Mueller-Dombois 1989). Notwithstanding the difficulties in predicting the behavior of alien ferns when introduced into Hawai'i, when a challenge to the ecosystem is demonstrated, control and eradication efforts should be mounted. Often, however, these are initiated too late and inadequately to eliminate the threat. The cultivation of serious pest ferns, such as *Angiopteris evecta* and *Cyathea cooperi*, in nurseries, botanical gardens, and home gardens, particularly in areas near native forests, invites their continued spread into the native ecosystem. Control programs must involve cooperative efforts not only of local, state, and federal agencies, but also of the general public. Considering the historical record in the prevention and control of the introduction and spread of the far more threatening seed plants, it is difficult to anticipate better re-

sults in limiting pteridophyte invasions, but an effort must be made.

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