To Restore the Watersheds: Early Twentieth-Century Tree Planting in Hawai'i

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The forest reserves of Hawai'i were established in the early 1900s in response to concerns about supplies of freshwater in the islands and the degraded condition of the native forests protecting the watersheds. Tree-planting was a coordinated effort involving both Harold Lyon and the Hawaiian Sugar Planters' Association and Territorial Forestry under the direction of R. S. Hosmer. The early foresters planted many types of trees on an experimental basis, but concluded that native species were of limited utility and turned largely to introduced species for large-scale reforestation efforts. The number of trees planted rose to many millions by the 1930s, when Depression-era labor was available for planting. Lyon envisioned the plantations as a buffer zone that would be established between the remaining native forests and the lower-elevation agricultural lands to protect the native forests and perform the functions (maintaining input of water to aquifers) that native forest no longer could. This large-scale attempt to engineer nature was probably the largest environmental project ever carried out in the islands. Forestry introductions have been a significant contributor to Hawaii's alien-species crisis, with many of these tree species now problem invasives. *Key Words: alien species, Hawaiian Islands, tree plantations, watershed.*

Prominent features of the landscape in many areas of the Hawaiian Islands are plantations of exotic trees that were established primarily in the 1920s and 1930s. Clearly evident on the slopes and ridges above Honolulu, for instance, are columnar *Araucaria* along the ridgelines and patches of *Casuarina* and eucalypts on the ridges and hill slopes. All are introductions dating from this period. This article provides a brief history of the early tree-planting era in Hawai'i, including the reasons planting was undertaken, the species planted, the current status of the plantations, and some of the consequences of this extensive exercise in experimental plantation forestry, which was probably the largest environmental project ever carried out in the islands. Particularly significant when considering the current state of the native biota are the way native forest species were viewed by foresters and the types and diversity of introduced tree species that were planted.

Widespread disturbance of Hawaii's native ecosystems began with the first arrival of humans (Kirch 1982; Athens and Ward 1993; Burney et al. 2001) and has continued. The Hawaiians organized their land-use practices around ahupua'a, land divisions equivalent to watersheds that extended from mountain to sea and included offshore resources. They also recognized a well-defined sequence of elevational zones defined by vegetation type and agricultural potential (Ekern 1993, 90). The lowlands, dry-forest uplands, and lower part of the wet-montane-forest zone were used for agriculture. The upper-elevation montane rainforests, viewed as the realm of the gods (wao), were entered mainly for traditional collecting and hunting practices. After European contact, a variety of factors, including the trade in sandalwood, began to put pressure on the forests (Cuddihy and Stone 1990, 37; see Table 1). Although the royalty was very much associated with extraction of sandalwood during the early 1800s, later monarchs took a variety of measures in support of forest conservation (Cox 1992, 170, 182).[1]

Degradation of the forests was most evident on O'ahu, where disturbance was high owing to the large area at low elevation and the historical locus of this island as the center of human population going back to the Polynesian era. Forest decline reached a maximum by the late 1800s/early twentieth century owing to burning of the forests to locate the fragrant sandalwood (*Santalum* spp.) trees, demand for firewood, commercial logging operations, conversion to agricultural and pastureland, the effects of grazing and browsing ungulates (including cattle, goats, and pigs), and increased fire frequency (Cuddihy and Stone 1990, 41). By this time, native forest was found mainly above ~400 m (1,400 ft). Degraded grass scrubland with isolated introduced and native trees covered much of the midelevation slopes, with woodlands of introduced kiawe (*Prosopis* spp.) dominating in lower, flatter areas (Egler 1947, 421).[2]

Forests and the Water Problem

The sugar planters who were developing an agricultural industry in Hawai'i and planning the future of the islands

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Table 1. Chronology of Events in Hawaiian Forestry

1815–1826	Height of the sandalwood trade
1846	Kamehameha declares forests and timber government property
1856–1891	Kalakaua takes action in support of forest conservation and tree planting
1903	Territorial government establishes Division of Forestry; R. S. Hosmer hired as superintendent and begins tree nursery
1907–1920	Joseph Rock contracted by Territorial Forestry to collect plants in Hawai'i and abroad
1914	Forest reserves, numbering twenty-seven, total 683,000 acres; Hosmer succeeded as Territorial Forester by C. S. Judd
1918	Hawaiian Sugar Planters' Association (HSPA) establishes Department of Botany and Forestry, headed by H. L. Lyon, and acquires Foster Garden in Honolulu as tree nursery
1919–1924	HSPA acquires tracts of land in Mānoa and Pauoa valleys on O'ahu for use as arboreta and trial gardens
1919–1932	2.3 million trees planted on forest reserves through combined efforts of HSPA and Territorial Forestry
1930	Forest reserves total 1 million acres (one-quarter of land area)
1934–1940	Civilian Conservation Corps plants 12.5 million trees on forest reserves

in the late 1800s[3] were concerned about the state of the forests and convened a standing committee of the sugar planters' association to deal with forestry issues and affairs. Discussions in the pages of *The Planters' Monthly* reflect the scientific debate then current concerning the relationship between forests and climate and whether deforestation could be responsible for droughts, floods, and the collapse of civilizations. One report describes the sad state of St. Helena, where forests and soils had been lost and residents had been reduced to importing firewood (Planters' Labor and Supply Co. 1882, 135).[4] Another questions whether the droughts of 1881 and 1882 in Hawai'i had been caused by forest loss (Planters' Labor and Supply Co. 1883, 242).

After the overthrow of the queen in 1893 and annexation of the islands by the United States in 1903, the new territorial government, dominated by sugar interests, gave high priority to forest issues. The Board of Commissioners of Agriculture and Forestry began publication of the *Hawaiian Forester and Agriculturalist* and established a Division of Forestry. The first foresters in the islands had been employed privately by individual plantation owners, but in 1904, R. S. Hosmer, a graduate of Harvard and the forestry program at Yale who had worked with Gifford Pinchot, became the superintendent of forestry at the recommendation of federal foresters. Hosmer (1910, 85) equated forests and water in the most practical terms: "There is no sentiment about forestry in Hawaii. It is purely a business proposition—a matter of dollars and cents." If the high-elevation forests were lost, rain would run off to the sea, "escaping its duty for irrigation" and "endangering property along its course" (Board of Commissioners of Agriculture and Forestry 1903/04, 41). Of particular concern was the situation on O'ahu, where the deforested slopes behind Honolulu extended into the main recharge area for the island's aquifer and water was needed for the population of Honolulu as well as for agriculture.

The link between tree-planting and the sugar planters can be seen particularly clearly in the career of Harold Lyon, who arrived in Hawai'i in 1907 as a plant pathologist in the employ of the Hawaiian Sugar Planters' Association (HSPA). Diseases of sugar cane occupied Lyon's efforts for several years, but his purview gradually broadened to include a variety of problems relating to Hawaiian agriculture, including deforestation. Lyon was a strong voice for forests. In an early report, he discussed the water situation on O'ahu, the insufficient supplies of water available for agriculture, and the role of the forested high-elevation areas of the windward Koolaus in recharging the island's aquifer (Lyon 1923). He described the water budget and the action of forested watersheds in slowing the rate of runoff and increasing infiltration and flow of water to groundwater. It was evident to Lyon and others that deforestation was increasing runoff—water that was essentially lost to agriculture, since the topography of the islands, with their many short streams, makes impoundment, and in many cases diversion, impractical. As evidence for the water-conserving role of vegetation, Lyon noted the drying out of many streams that had previously been more continuously flowing, an observation that by this time had been made repeatedly. Lyon emphasized that the problem was not just increased demand for water but also the conditions determining supply—"The candle is burning at both ends and we only fan the flames"—and argued that resources should be committed to reforest the watersheds with "healthy, water-conserving forest" (Lyon 1923, 292). Neglect of the islands' forests would be "suicidal," for "everything fails with the failure of our water supply" (Lyon 1923, 293).

The argument for forests was made differently at different times. In a later statement entitled "Facts of

Great Importance," Lyon described the role of mountains in bringing about rainfall through orographic effects, but then added that the islands' (montane) rainforests act to augment orographic rainfall by extracting water from the air, saying that "a forest-covered mountain range of 2,000 ft on O'ahu [serves to] pull down as much water as a barren range of 3,000 ft" (Lyon 1947, 1). Here he alluded to the capture of fog drip by trees in foggy areas and within the montane cloud belt, a phenomenon known in Hawai'i and other areas (Ekern 1964; Juvik and Ekern 1978; Bruijnzeel 2000, 304). On the island of Lāna'i, for instance, which lies in the rain shadow of Maui and receives little rainfall, a visitor can easily observe the constant drip of water underneath the tall Araucarias widely planted there.

An important consideration as plans for reforestation were being drawn up were the views of Lyon and others concerning the state of native forests and the potential of native species in reforestation. Early in Lyon's tenure in Hawai'i, H. P. Baldwin, a sugar planter on Maui, asked him to travel there to see a tract of *Metrosideros polymorpha* ('ōh'ia lehua) forest that was dying from unknown causes. Lyon concluded that retreat of the forest boundary was exposing the forest interior and leading to forest decline (Lyon 1904, 151). He also thought that introduced plants, including grasses and ferns, were competing with native trees and adversely affecting tree regeneration, in addition to drying out the forest and increasing its susceptibility to fire. After a few more years of study, he was able to enlarge upon the forest problem. Arrival of the ancestors of the native plants soon after the islands were formed meant that native species were better adapted to new and well-drained soils than to the older soils that had developed over time (Lyon 1919, 289). As evidence, he cited the ability of native species to colonize new volcanic substrates and their more tenuous hold in other areas, where "the slightest disturbance causes them to die" (Lyon 1919, 291).[5]

To Lyon, forest decline was irrevocable and irreversible: "The native trees are quite unable to tolerate interference from man and stock or to repel aggression of introduced plants. They quickly succumb before the forces turned against them. They possess no ability to regenerate. They regain no lost ground" (Lyon 1923, 289). Consequently, he felt that reforestation would have to rely on exotic tree species and envisioned plantations of introduced trees as a buffer zone (his "barrier forests") between the remaining native forests and the lower-elevation agricultural lands, to protect native forests and perform the functions that native forest no longer could. The challenge was to create forests replete with shrubs, ferns, and mosses, an aim quite different from that of traditional monoculture forestry. The putting together of these plant associations was an experimental undertaking of significant proportions. The steps mandated were clear. First, collect material from all over the world. Then grow these plants, determine their characteristics, eliminate those with "habits and propensities" making them "undesirable denizens of our forests," and identify those capable of growing over a range of elevations (sea level to 1,800–2,000 m) and climate (250–1,000 cm of rain) and also of naturalizing (Lyon 1919, 293). Finally, "bring those trees together on our watersheds, pit them against each other, and they will work out their own salvation by eventually resolving themselves into a balanced society, which will give us the complete forest cover on our watersheds that we now desire to create" (Lyon 1919, 295).

Early Efforts

The main work of Territorial Forestry during its first ten years (1904–1914) was establishment of the forest reserves at middle to high elevations. These included mostly government lands but also some private tracts. Hosmer pursued the goals of fencing the reserves and removing free-ranging stock animals, including goats, sheep, horses, cattle, and pigs. The acquisition and fencing of the upper elevations of the islands must have acted as a further disruption of the ahupua'a system, truncating at their upper reaches those ahupua'a still functioning as such through the dislocations and decline of the Hawaiian population during the 1800s. Hosmer also established tree nurseries and began a range of extension-related work, supplying trees to land owners and the public, sponsoring Arbor Day events, and so on. These activities were undertaken as resources permitted, but many of the objectives of the Forestry Division, such as construction of fences and removal of animals, were met through efforts of private landowners (Board of Commissioners of Agriculture and Forestry 1903/04, 1906, 1907, 1908, 1909/10).

In many ways, forestry practices in Hawai'i were codified during this time. Hosmer, upholding earlier suggestions, distinguished between protection forests, those on the wet windward slopes, the most important product of which was water, and commercial forests, the most important product of which was wood (Board of Commissioners of Agriculture and Forestry 1907, 52). Commercial forests, having no springs or surface streams, were considered nonessential with regard to water. The only large area of commercial forest was on the leeward side of the Big Island of Hawai'i, where harvesting of 'ōhi'a lehua to use as ties for plantation railroads and koa (*Acacia koa*) for timber was beginning.

Hosmer was also active in experimenting with new plant species, a line of enquiry he felt the territory ought to "take hold of and push vigorously" (Board of Commissioners of Agriculture and Forestry 1913/14, 52). The botanist Joseph Rock was contracted to collect plants. He began by making a herbarium collection of Hawaiian plants and collecting seeds for propagation. Rock later traveled extensively abroad, collecting plants that showed promise for Hawai'i.[6] He was a strong advocate, as well as a beneficiary, of funding for basic research (the Forestry Division subsidized several of his taxonomic studies), and a tireless traveler and collector. Rock also recognized the threat to native forests and enjoined the planters' community to protect these forests and not imagine that they could be replaced by forests of introduced trees (Rock 1919, 173). The full-page photographs accompanying his article on forest preservation in Hawai'i are clearly designed to show off the Hawaiian forests to best advantage. While perhaps not as impressive as the giant trees he photographed in the nature reserves of Asia, 'ōhi'a lehua with skirts of scandent 'ie 'ie (*Freycinetia arborea*) and a subcanopy of tree ferns are undoubtedly picturesque.

Also gaining attention during this time was the idea of establishing forests on the upper slopes (1,800–3,000 m) of Mauna Kea (Big Island) and Haleakala (Maui), above the tree line for native tree species (Board of Commissioners of Agriculture and Forestry 1908, 25). The federal government provided assistance for several early experimental plantings of exotic conifers (none is native to the islands) at high-elevation sites. Of the eighty-six species planted, nineteen were partially successful (Kraebel 1922, 151).

In 1914, Hosmer resigned to be chair of the Department of Forestry at Cornell. When Charles Judd took over as Territorial Forester—second in a series of Yale foresters to hold the post—twenty-seven forest reserves included ~280,000 ha, efforts had been made to protect these forests, and fees from timber concessions and leases of water rights were beginning to bring in needed resources (Board of Commissioners on Agriculture and Forestry 1913/14, 36). Judd was able to hire foresters, putting one on each of the main islands. Regulations on forest use, published in Chinese, Japanese, Hawaiian, Portuguese, and English, were similar to those in the mainland United States, although some, such as prohibition of cattle from watershed areas, were more specific to Hawai'i (Board of Commissioners of Agriculture and Forestry 1915/16, 24, 28–31).

According to Lyon, lack of resources and personnel in the territorial forestry office led the HSPA to establish its own Department of Agriculture and Forestry in 1918 (Lyon 1929, 55). Although Lyon, who headed the department, stressed that it acted in a support and advisory capacity only, there was clearly a high degree of cooperation and coordination between the HSPA and Territorial Forestry from the early days, when the HSPA paid half of the salary of government entomologists, through later tree-planting efforts, which were carried out jointly for more than thirty years.

The HSPA acquired plant material, developed propagation techniques, researched characteristics of tree species, and supplied seedlings to territorial foresters. Lyon arranged to lease a tract of land near downtown Honolulu to use as a tree nursery. A few years later, further lands were leased: Haukulu and 'Āihualama in Mānoa Valley, with plantable land at 400–1,000 ft, and Ka'ākaukukui in adjoining Pauoa Valley, with plantable land at 1,500–2,000 ft (Lyon 1929, 60). Lyon's plans to distribute seedlings to all the islands ran into a problem when transport of soil between islands was prohibited because of disease. In response, he developed a method of shipping seedlings packed in moss that he came to consider superior to shipping in soil (Lyon 1929, 64).

Choice of Tree Species

Many native plants were tried out on an experimental basis, but few were extensively used for reforestation. The nurserymen could germinate the seeds, but seed sources were limited and seedlings grew slowly, were subject to disease, and did poorly when set out—were "outcompeted," according to Judd.[7] The most important dominant of the Hawaiian forests, 'ōhi'a lehua, could be established only with "the same tender care that must be used in raising an incubator baby." Other species had "obscure" reproductive habits (Judd 1927a, 48). The foresters had the best luck with koa and, to a lesser extent, sandalwood, but often planted exotic representatives of these genera along with the native taxa.

Most successful were some common elements of the pantropical introduced flora—trees such as *Eucalyptus*, *Casuarina*, and *Grevillea* species. Although these trees grew well, they were not considered ideal, at least by Lyon. He (1929, 76) preferred trees and shrubs that would organize themselves into "forest societies" that would have a shrub and herb layer and thus be analogous to native forest and mimic the latter's water-absorbing capacity. He also recognized as undesirable water-demanding trees, such as many of the eucalypts. Since he wanted the plantations to remain on the landscape, the utility or value of their timber was not an issue; in fact, Lyon preferred trees that were worthless in this regard.

And, because he felt native forest was in permanent decline, he was particularly interested in species that would become naturalized and spread upward as native forest retreated.

The figs, or banyans (genus *Ficus*), topped Lyon's list of desirable tree species (1929, 83). To Lyon, there was a fig for every situation. By 1927, he had experimented with eighty species in this genus, which has no native representatives in Hawai'i. He even hoped that the figs would provide a "complete solution" for many of the forestry problems (Lyon 1929, 83). Their habit of germinating in the crown of another tree or in a stump or log and then sending down roots to the soil surface meant that seedlings would not have to compete with ferns and introduced grasses to become established. Mynah birds could disperse the seeds, and other fig-eating birds could be introduced. Absence of the wasp pollinators specific to individual fig species was not an obstacle, since the necessary fig wasps could also be imported (four species were established during 1909–1938, and there were attempts at importing several others).[8] Another plus was that the seeds could be sown from the air, as had been done on several occasions with the assistance of the U.S. Army Air Service by 1927. Lyon (1929, 90) also mentioned that 224 pounds of seeds collected from one fruiting individual of *Ficus macrophylla* would yield more than six million seedlings, enough to reforest all the islands' watersheds.

A remarkable characteristic of Hawai'i forestry through much of its history is the large number of species used in experimental plantings. Many people key to the forestry efforts, including Hosmer, Rock, Judd, and Lyon, were strongly interested in new plants for Hawai'i. One reason may have been the large range of conditions present in the islands and the need to try out a wide variety of trees. But there is no question that the allure of tropical diversity and the ease with which plants could be grown in Hawai'i were hard to resist. Lyon traveled world-wide collecting plants and seeds and also solicited for seeds from abroad. By 1927, he had grown 900 new species of trees and shrubs and considered more than 180 promising (Lyon 1929, 76). Lyon continued to make introductions through the 1940s: he is thought to have introduced into the islands close to 10,000 plant species (including herbaceous taxa) by the end of his life (Bryan 1980, 23). He and Rock appear to have been in competition in this regard and are known to have argued as to who had been the first to introduce a particular palm species (Bryan 1980, 24).

The list of plantings on the forest reserves through 1960 runs from *Abelia* to *Zizyphus* and includes more than 1,000 species of trees, shrubs, herbs, grasses, and ferns (Skolmen 1980). Most of these (more than 800) are trees. There are many tropical species: 36 species of *Ficus*; Australian taxa (*Eucalpytus, Melaleuca, Grevillea, Casuarina*) including 89 species of *Eucalyptus*; and native forest plants, 78 species in all. Among the higher-latitude taxa are a variety of North American tree species and gymnosperms including 46 species of *Pinus*. Lastly, there are trees with special attributes: those with precious timber like species of *Swietenia* and *Toona*; *Hydnocarpus anthelminticus*, a source of chaulmoogra oil, used in the treatment of leprosy; *Cinchona* spp., planted during World War II as a source for quinine; spice plants like as allspice (*Pimenta dioica*) and cinnamon (*Cinnamomum zeylandicum*); ornamentals; and various tropical and temperate nut and fruit trees. Some of the plantings represented new introductions into the islands, others reintroductions, yet others further dissem-inations of already established species.

In the end, the species planted most frequently were those that were easy to establish, grew rapidly, and produced abundant seeds, not necessarily those that would allow development of an understory or have optimal hydrologic characteristics. Eucalypts like *E. robusta*, for example, are water-demanding and capable of lowering water tables in some areas, yet this species was the most widely planted (more than two million trees; Skolmen 1980, 200). Its ability "to grow in almost any situation, to withstand the wind, to grow fast and produce good fuel and timber and to sprout from the stump," combined with the ease with which its seeds could be germinated, put this species in "the highest rank of popularity" (Board of Commissioners of Agriculture and Forestry 1915/16, 44). Species of *Eucalyptus* and other Australian taxa dominate the tallies (Table 2), totals for several of the eucalypts, *Grevillea*, and *Casuarina* nearing or exceeding one to two million. Leguminous species, including native *Acacia koa*, were also planted in large numbers, as were some gymnosperms. Tropical ash (*Fraxinus uhdei*) was the sixth most commonly planted species. Figures for *Eucalyptus robusta* and *Melaleuca quinquenervia* are probably lower in Table 2 than in actuality, since these two species were often overplanted when the original plantings failed. Nor do the totals reflect trees established as a result of aerial seeding (Skolmen 1980, iii).

The lists of reserve plantings also provide an idea of the types of trees planted more widely in the islands, since Territorial Forestry was also supplying trees for woodlots, watersheds, and windbreaks, as well as ornamental plants and fruit trees, to plantation owners, ranchers, farmers, and homeowners. R. G. Skolmen (1980, iii) estimates that trees planted outside the reserves approximated the reserve plantings in total numbers.

Table 2. Most Commonly Planted Tree Species, 1908–1960

Myrtaceae	
Eucalyptus robusta	2,321,000
Melaleuca leucodendron (quinquenervia)	1,733,000
Eucalyptus saligna	437,000
Eucalyptus camaldulensis	429,000
Tristania conferta	396,000
Eucalyptus sideroxylon	151,000
Eucalyptus paniculata	138,000
Eucalyptus citriodora	127,000
Eucalyptus pilularis	121,000
Eucalyptus microcorys	102,000
Proteaceae	
Grevillea robusta	2,242,000
Leguminosae	
Acacia koa	1,137,000
Acacia confusa	295,000
Albizia montana	145,000
Albizia moluccana (falcata)	138,000
Haematoxylon campechianum	108,000
Casuarinaceae	
Casuarina glauca	998,000
Gymnosperms	
Cryptomeria japonica	499,000
Cupressus macrocarpa	216,000
Pinus pinaster	173,000
Sequoia sempervirens	130,000
Pinus radiata	121,000
Oleaceae	
Fraxinus uhdei	460,000
Meliaceae	
Toona ciliata var. *australis*	190,000

Source: Nelson (1965, 16).

Tree Planting through the 1930s

As a result of the partnership between HSPA and Territorial Forestry, large numbers of seedlings began to be available for planting in the 1920s. On the map of O'ahu, where early efforts were concentrated, a ring of barrier forests began to be discernible around the Ko'olau reserves on the eastern half of the island (Figure 1). Numbers of trees planted rose throughout the decade, as did diversity of species represented (Figure 2A, B). There were also experiments in sowing seeds from the air—more than 1,500 pounds during 1929–1930 (Board of Commissioners of Agriculture and Forestry 1929/30, 47).

Animal control measures continued. Some animals were herded from the forests, but the numbers killed reached into the tens of thousands each year (Figure 2C). Goats were shot, trapped, and poisoned. Boy Scouts participating in a goat drive shot 7,000 animals on the Big Island (Board of Commissioners of Agriculture and Forestry 1921/22, 24). On Maui, a bounty of U.S.$.51 a head was levied (Board of Commissioners of Agriculture and Forestry 1925/26, 20). A sharpshooter in South Kona shot 3,811 goats and 295 pigs, wearing out the barrels of two rifles (Board of Commissioners of Agriculture and Forestry 1929/30, 37).

The pig problem proved the least tractable. By 1930, it was clear to a forester on O'ahu that pigs were as serious a threat to the forests as cattle or goats had ever been. These animals, he concluded, would never be eliminated by "casual hunters," who pursued them "merely for sport or the meat which they supply" and only drove them farther into the forests (McEldowney 1930, 273).[9]

Foresters worried about introduced weeds, such as Hilo grass (*Paspalum conjugatum*, invasive in rangeland and forest), found the list of undesirable plants growing during the 1920s and solicited the help of ranchers and other landowners in eradicating them (Board of Commissioners 1919/20, 28). The uluhe fern (*Dicranopteris linearis*) was counted as undesirable because of its tendency to form fire-promoting thickets and its invasive character.[10] Judd considered it introduced, although it is native, and gave eradication high priority. He supervised eradication experiments and dispatched one of his staff to Africa to collect seeds of a species of a tree (the legume *Virgilia capensis*) used there to control the fern. When attack from above (seeding of trees by air) was not successful, he attacked from below—by planting a species of bamboo (*Schizostachyum glaucifolium*) that he considered native but is likely a Polynesian introduction (Judd 1927b, 55). Lyon concurred in thinking the fern a threat and suggested that vines such as *Pothos aureus* could be used for a smothering effect (Lyon 1927, 310). One alien plant that foresters wanted to protect, however, was kiawe. These trees, first planted in 1832, covered thousands of acres of the dry lowlands, where they produced shade, wood, honey, and seedpods for forage (Board of Commissioners of Agriculture and Forestry 1919/20, 35).

The Great Depression began to be felt strongly in Hawai'i in 1933. Anticipating a drastic cut in appropriations from the legislature, Judd traveled to Washington, DC, to plea that Hawai'i receive its share of relief funding (Board of Commissioners of Agriculture and Forestry 1933/34, 24). Late in 1933, after most of the paid staff in forestry had been laid off, over 500 men began emergency conservation work in the forest reserves. In 1935, the number rose to 1,200 (Board of Commissioners of Agriculture and Forestry 1935/36, 17). These men laid trails, built fences, shot animals, and planted trees. Eleven tons of the seeds of koa haole (*Leucaena leucocephala*, a forage legume) that they collected were broadcast by Army bombers over the dry lowlands (Board of Commissioners of Agriculture and Forestry 1933/34, 22). The number of trees planted rose by a factor of ten, then a

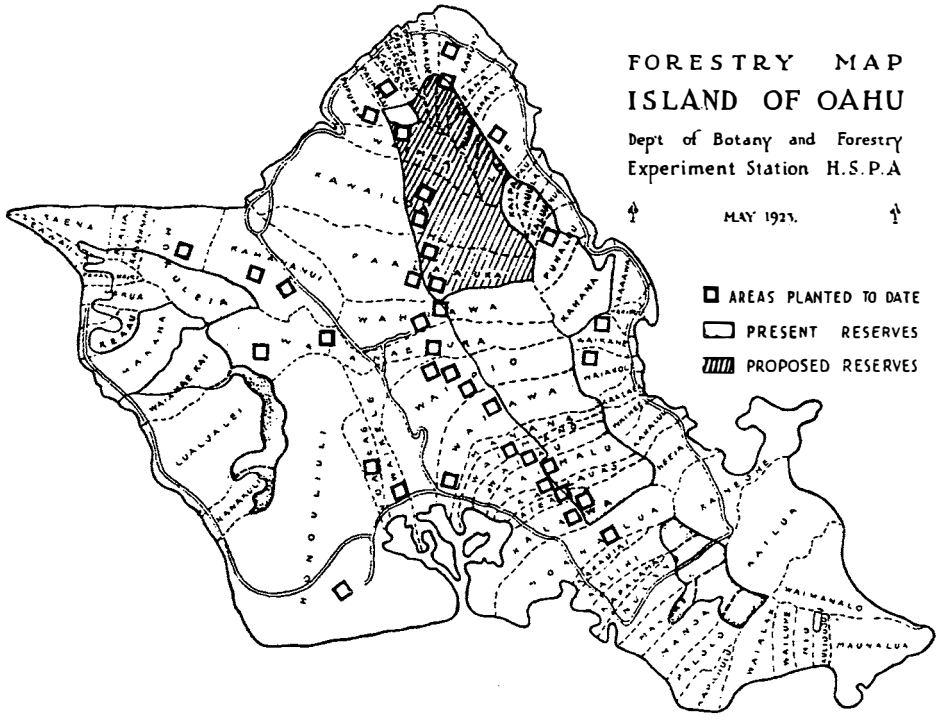

Figure 1. Map showing forest reserves established and projected by 1923, together with early plantings of barrier forests. *Source*: Lyon (1923, 295).

factor of thirty to forty. So many animals were eradicated that populations appeared to be under control in many areas. By 1940, the Civilian Conservation Corps had planted 12.5 million trees and eradicated over 100,000 animals, accomplishing thirty to forty years of work in eight years, according to official reports (Board of Commissioners of Agriculture and Forestry 1941/42, 33,41).

The War Years and After

World War II changed everything in Hawai'i. After Pearl Harbor, the islands were at the center of the war effort, with direct consequences for forestry. The Civilian Conservation Corps disbanded; troops training for jungle warfare roamed the forests; the military commandeered or confiscated the guns used to hunt animals; live ordnance became a hazard in many areas; and plantation trees were cut to meet the need for timber. The foresters adjusted, resorting to aerial seeding in burned-over or perilous territory and encouraging military men to go goat-hunting for recreation.[11]

After the war, plantings rose, but to only a small fraction of Depression-era figures. Costs were high, and efforts were restricted to denuded areas most in need of cover and places where mechanized planting techniques could be used (Board of Commissioners of Agriculture and Forestry 1949/50, 60). Aerial seeding was used in locations still containing live ordnance. One new initiative, undertaken in recognition of the threatened status of many native species, was establishing arboreta of native trees on all the islands (Board of Commissioners of Agriculture and Forestry 1949/50, 63). By the late 1950s, territorial entomologists, increasingly concerned with biological control of problem plants, had introduced biological control agents for *Lantana camara* (invasive in a variety of habitats), gorse (*Ulex europaeus*, a pasture weed), firebush (*Myrica faya*, invasive in native forest), sourbush (*Pluchea symphytifolia*, a dryland plant), *Melastoma candidum* (invasive on the Big Island), and Christmas berry (*Schinus terebinthefolius*, a weedy tree invasive in disturbed habitats).[12]

The number of animals killed, which had declined through the war years from Depression-era highs, again rose, increasing to the point that foresters often stopped issuing hunting permits for fear that population declines would be too steep. They closed seasons for wild sheep on Mauna Kea and pigs and goats on Kauai and instituted bag limits in other cases (Board of Commissioners of Agriculture and Forestry 1947/48, 61; 1957/58, 124). Notably, the language of the biennial reports changed

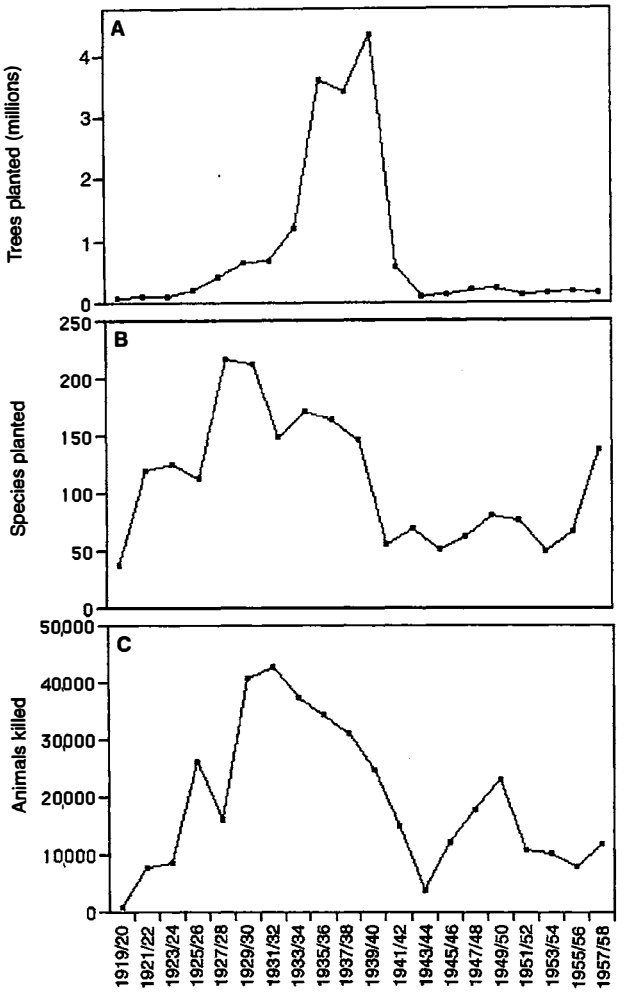

Figure 2. Activities of Territorial Forestry on the forest reserves, 1919–1958: (A) number of trees planted; (B) number of species planted; (C) number of animals eradicated. Data come from the biennial reports of the Board of Commissions on Agriculture and Forestry, Territory of Hawaii (in C, 1933/34 omitted).

through the 1950s, as references to eradication of destructive wild animals gave way to talk of "harvesting" of animal populations. Protection of the forests had expanded to include protection of animal populations and the idea that sound forest management could encompass recreational uses, including hunting of nonnative animals. It was the era of multiple use, a goal the territorial government pursued by establishing parks and recreational areas in the forest reserves and rezoning forest lands.

An article appearing in a Territorial Forestry publication in 1948 took up the old question of forests and water (Lennox 1948).[13] The writer concluded that the effect of forests in augmenting precipitation had not been demonstrated conclusively and pointed to the need for more information about the effect of cover on the hydrologic cycle, suggesting that more definitive answers could be obtained by studying paired watersheds supporting different types of vegetation. The Forestry Division carried out two such studies, one a comparison of fern versus forest cover and the other a comparison of grasses versus forests. Results of the first study—which involved a series of manipulations, including burning and experimental tree-planting—showed higher stream-flow in the fern-covered watershed, although federal foresters who analyzed the data did not consider the findings definitive (Anderson, Duffy, and Yamamoto 1966).[14]

With many of the tree plantations reaching maturity during the 1950s, Territorial Forestry faced the problem of determining the commercial potential of timber from harvestable trees—that is, those considered nonessential with regard to watersheds. Lester Bryan, who was in charge of Big Island forestry, supervised a study of the milling, checking, and warping characteristics of thirty-six plantation species and traveled to Australia and New Zealand to obtain information about milling and logging techniques (Board of Commissioners of Agriculture and Forestry 1951/52, 106). The one species planted in sufficient quantities to be used in commercial forestry, *Eucalyptus robusta*, had wood of limited utility (Board of Commissioners of Agriculture and Forestry 1951/52, 112). Another widely planted species, tropical ash, was more promising, with wood that could be used in furniture-making. Further tree-planting, it was hoped, would take more account of future use. The foresters also looked to the federal government, which became partners with the territory in the Cooperative Forestry Research Center (later the Center for Pacific Islands Forestry), established in 1957. It fell to federal foresters to compile the planting records and begin a more thorough assessment of the growth characteristics and timber potential of the plantation species (Nelson and Schubert 1976; Skolmen 1980).

Current Status of the Plantations and Conclusions

Lyon and others planned that the plantations would remain on the landscape. Many still do, although a complete assessment is difficult because of inadequate planting records (Nelson and Schubert 1976, 2). Quite a few of the plantation trees have naturalized as was hoped. On O'ahu, Araucarias are spreading down slope along the ridgelines, *Casuarina* is coming in on slopes and along the coast, and bamboo creeps from its original plots at higher elevations and along watercourses. Of Lyon's figs, only *Ficus microcarpa* has taken hold, occurring at low frequency at low elevations and along streams. Many

less commonly planted taxa are also now naturalized—*Cinnamomum*, for example, which is invasive in several of the valleys behind Honolulu.

Maturing along with the plantation trees is our understanding of the dimensions of the alien-species problem in Hawai'i (Vitousek, Loope, and Stone 1987; Stone, Smith, and Tunison 1992; Cox 1999; Staples and Crowe 2001). The native biota is largely endemic and includes many rare and endangered taxa that are vulnerable to disturbance, habitat loss, and adverse effects associated with introduced species. Coupled with this is the staggering number of alien species, not yet exceeding the number of natives—at least for plants—but getting close (Warshauer 1998, 146). Appendix 1 lists the introduced woody plants that are currently problem invasives. Of the 95 taxa considered to be among the worst threats to native biota (Smith 2001), *more than half appear on the plantings lists for the tree plantations*.

There were those who had reservations about the introduction of so many plant species. The botanist Otto Degener mentions his longstanding disagreements with Lyon over this issue in a volume commemorating Lyon's life (Hartt 1980, 39). The flora that Degener published with his wife provides documentation of some of these criticisms. The description of *Grevillea robusta* notes that in one month during 1933, "100,000 of these weedy trees were set out in our forest reserves," where "the simple expedient of removing feral herbivores would have allowed the more preferable native vegetation to return to its former glory" (Degener and Degener 1960). In their view, forestry appropriations should have been matched with funds for eradication of plants proved "harmful or a nuisance." That the uluhe fern was a problem requiring attention they considered a bugbear:

> It retards the growth of seedling trees, but that it is a danger to our forests is far-fetched—they have coped [with it] from time immemorial. When landslides . . . occur, the earliest pioneer to cover the naked, red scar is the uluhe. Should this fern be exterminated and replaced by various flowering plants palatable to a veritable menagerie of feral pigs, goats, deer, mouflon, antelope and what not roaming about due to unwise introductions, erosion will become rampant. Our green islands will follow goat-wrecked Kahoolawe and the sorry land-remnants west of Kaui to a dusty end. (Degener and Degener 1959)[15]

If objections from Degener or others had any effect, however, it is hard to discern. The people involved in the forestry efforts were, to all appearances, confident of their ability to engineer nature: tree plantations would enhance the water supply and protect native forests; desirable plants could be introduced, together with their animal pollinators and seed dispersers; undesirable organisms could be suppressed; and the best science could be brought to bear should any problems arise. They appear to have had little concern for the unfolding lesson in unintended consequences that is a part of their legacy.

Appendix 1: Alien Woody Plants Considered among the Greatest Threats to Native Hawaiian Biota, Together with Dates of First Plantings by Territorial Forestry

Acacia confusa (Formosan koa, Fabaceae)	1925
Acacia farnesiana (klu, Fabace)	–
Acacia mearnsii (black wattle, Fabaceae)	–
Acacia melanoxylon (Australian blackwood, Fabaceae)	1919
Ailanthus altissima (tree of heaven, Simaroubaceae)	1924
Angiopteris evecta (Madagascar tree fern, Marattiaceae)	1959
Ardisia elliptica (shoebutton ardisia, Myrsinaceae)	1926
Bruguiera gymnorrhiza (oriental mangrove, Rhizophoraceae)	1930
Buddleia madagascariensis (butterfly bush, Buddleiaceae)	–
Caesalpinia decapetala (cats claw, Fabaceae)	–
Castilloa elastica (Panama rubber tree, Moraceae)	1930
Casuarina equisetifolia (common ironwood, Casuarinaceae)	1924
Casuarina glauca (longleaf ironwood, Casuarinaceae)	1919
Cecropia obtusifolia (trumpet tree, Cecropiaceae)	1927
Cestrum nocturnum (night cestrum, Solanaceae)	1926
Chrysophyllum oliviforme (satin leaf, Sapotaceae)	–
Cinchona pubescens (quinine tree, Rubiaceae)	1928
Cinnamomum burmannii (padang cassia, Lauraceae)	–
Citharexylum caudatum (juniper berry, Verbenaceae)	–
Citharexylum spinosum (fiddlewood, Verbenaceae)	1930
Clerodendrum laponicum (glorybower, Verbenaceae)	1926
Clidemia hirta (Koster's curse, Melastomataceae)	–
Cordia glabra (broad-leaved cordia, Boraginaceae)	1926
Corynocarpus laevigatus (New Zealand laurel, Corynocarpaceae)	1925
Elaeagnus umbellata (oleaster, Elaeagnaceae)	–
Eriobotrya japonica (loquat, Rosaceae)	1925
Eucalyptus globulus (blue gum, Myrtaceae)	1910
Ficus microcarpa (Chinese banyon, Moraceae)	1921
Flindersia brayleyana (Queensland maple, Rutaceae)	1935
Fraxinus uhdei (tropical ash, Oleaceae)	1924
Furcraea foetida (Mauritius hemp, Agavaceae)	–
Grevillea banksii (kahili flower, Proteaceae)	–
Grevillea robusta (silky oak, Proteaceae)	1910
Haematoxylum campechianum (logwood, Fabaceae)	1918
Heliocarpus popayanensis (white moho, Tiliaceae)	1924
Jasminum fluminense (Oleaceae)	–
Lantana camara (lantana, Verbenaceae)	–
Leptospermum ericoides (tree manuba, Myrtaceae)	–
Leptospermum scoparium (New Zealand tea, Myrtaceae)	1930
Leucaena leucocephala (koa haole, Fabaceae)	?
Lonicera japonica (Japanese honeysuckle, Caprifoliaceae)	?
Lophostemon confertus (brush box, Myrtaceae)	1923
Melaleuca quinquenervia (paper bark, Myrtaceae)	1924
Melastoma candidum (Indian rhododendron, Melastomataceae)	–
Melia azedarach (Chinaberry, Meliaceae)	–

Melochia umbellata (melochia, Sterculiaceae)	1925
Merremia tuberosa (wood rose, Convolvulaceae)	–
Miconia calvescens (miconia, Melastomataceae)	–
Mimosa invisa (Fabaceae)	–
Montanoa hibiscifolia (tree daisy, Asteraceae)	–
Myrica faya (firetree, Myricaceae)	–
Olea europaea ssp. *africana* (olive, Oleaceae)	1951
Oxyspora paniculata (oxyspora, Melastomataceae)	–
Paraserianthes falcataria (Moluccca albizia, Fabaceae)	1925
Passiflora edulis (passion fruit, Passifloraceae)	1938
Passiflora laurifolia (yellow granadilla, Passifloraceae)	–
Passiflora ligularis (sweet granadilla, Passifloraceae)	–
Passiflora mollissima (banana poka, Passifloraceae)	–
Phormium tenax (New Zealand flax, Agavaceae)	1922
Pinus caribaea (slash pine, Pinaceae)	1910
Pinus patula (Mexican weeping pine, Pinaceae)	1933
Pinus pinaster (cluster pine, Pinaceae)	1931
Pithecellobium dulce (opiuma, Fabaceae)	1952
Pluchea indica (Indian fleabane, Asteraceae)	–
Pluchea symphytifolia (sourbush, Asteraceae)	–
Prosopis pallida (kiawe, Fabaceae)	–
Psidium cattleianum (strawberry guava, Myrtaceae)	1934
Psidium guajava (guava, Myrtaceae)	1926
Pyracantha angustifolia (firethorn, Rosaceae)	–?
Rhizophora mangle (red mangrove, Rhizophoraceae)	–
Rhodomyrtus tomentosa (rose myrtle, Myrtaceae)	–
Ricinus communis (castor bean, Euphorbiaceae)	1928
Rubus argutus (prickly Florida blackberry, Rosaceae)	–
Rubus ellipticus (yellow Himalyan raspberry, Rosaceae)	–
Rubus glaucus (raspberry, Rosaceae)	–
Rubus niveus (hill or Mysore raspberry, Rosaceae)	–
Rubus sieboldii (Rosaceae)	–
Samanea saman (monkeypod, Fabaceae)	1919
Schefflera actinophylla (umbrella tree, Araliaceae)	?
Schinus terebinthifolius (Christmasberry, Anacardiaceae)	1928
Spathodea campanulata (African tulip tree, Bignoniaceae)	1921
Sphaeropteris cooperi (Australian tree fern, Cyatheaceae)	–
Swietenia mahagoni (mahogany, Meliaceae)	1918
Syzygium cumini (Java plum, Myrtaceae)	1923
Syzygium jambos (rose apple, Myrtaceae)	1926
Terminalia catappa (tropical almond, Combretaceae)	1924
Terminalia myriocarpa (jhalna, Combretaceae)	1921
Thunbergia grandiflora (Bengal trumpet, Acanthaceae)	–
Tibouchina herbacea (glorybush, Melastomataceae)	–
Tibouchina urvilleana (lasiandra, Melastomataceae)	1936
Tithonia diversifolia (tree marigold, Asteraceae)	–
Toona ciliata (Australian red cedar, Meliaceae)	1920
Trema orientalis (charcoal tree, Ulmaceae)	1925
Ulex europaeus (gorse, Fabaceae)	–
Wisteria sinensis (Chinese wisteria, Fabaceae)	–

Note: Dashes indicate not planted by forestry. *Sources:* Species list–Smith (2001); information about planting dates—Nelson (1965).

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Notes

1. Thomas Cox (1992) notes that conservation efforts dating from the period of royal rule are left out of many later accounts and questions various other aspects of the narratives dealing with territorial forestry written by principals in those efforts.
2. The midelevation slopes are now largely wooded, but the vegetation of the drier, low-elevation areas is much as F. E. Egler (1947) describes it.
3. Sumner LaCroix and Chris Grandy (1997) detail the political and economic factors leading to overthrow of the monarchy and the emergence of a sugar economy.
4. The Planters' Labor and Supply Co. later became the Hawaiian Sugar Planters' Association; *The Planters' Monthly* continued as *The Hawaiian Planters' Record.*
5. Lyon's views on native vegetation can certainly be disputed.
6. Rock was employed by Territorial Forestry from 1907/08 through 1911/12 and became Honorary Consulting Botanist after joining the faculty of the College of Hawai'i, continuing to collect for Territorial Forestry through 1919/20 (see Board of Commissioners of Agriculture and Forestry 1907 through 1919/20).
7. Judd (1929, 38) discusses the difficulties in propagating native species.
8. For the status of fig-wasp introductions, see Wagner, Herbst, and Sohmer (1999, 924).
9. Pigs remain the bane of Hawaii's forests. Difficulties in eliminating them have both a practical and social dimension.
10. Various forestry reports discuss problems with the fern (Board of Commissioners of Agriculture and Forestry 1925/26, 25; 1927/28, 29; 1931/32, 29).
11. For information on the war years, see Board of Commissioners of Agriculture and Forestry (1941/42, 33, 35, 38; 1943/44, 17, 40, 41, 42).
12. Information about plants from Smith 2001; nomenclature according to Wagner et al. 1999.
13. Colin G. Lennox was president of the Board of Agriculture and Forestry at this time.
14. Perhaps a clearer example of the hydrological effects of the plantings is the lowered water table in areas such as the valley bottom of Nu'uanu on O'ahu, where there are extensive stands of *Eucalyptus*. Additional issues include the effect of the plantations on native forest regeneration (Harrington and Ewel 1997; Woodcock, Perry, and Giambelluca 1999), nutrient-cycling (Mack, D'Antonio, and Lev 2001), and native bird populations.
15. Kaho'olawe, a small island in the rain shadow of Maui, was heavily affected by goats and used as a bombing target and is now public land. Ni'ihau, lying off the coast of Kaua'i and also dry and low-lying, is privately owned.

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