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A short review of leucaena as an invasive species in Hawaii

Una breve reseña de leucaena como especie invasora en Hawái

TRAVIS IDOL

Dept. of Natural Resources and Environmental Management, University of Hawaii-Manoa, Honolulu, USA. manoa.hawaii.edu

Abstract

Leucaena leucocephala subsp. *leucocephala* was introduced to Hawaii after European settlement and spread widely for cattle fodder and fuelwood. As in many other tropical locations where it has been introduced, it has naturalized and spread in disturbed and drier habitats. While it is common in disturbed areas, it is much less common in intact native dry forests. It is resilient to wildfire and mammalian grazing, which conversely threaten the integrity of remnant native dryland forest. The successional trajectory of areas dominated by leucaena has not been well studied in Hawaii, but it is probable that other non-native rather than native species will replace it. As a result of its widespread distribution, especially on steep slopes, priority for its eradication or control is low. Current biocontrol options are limited in effectiveness. Control of leucaena can and should be given greater priority to protect native dryland forests and inhibit spread of seeds. Restoration of dryland habitats requires intensive, sustained efforts, usually involving volunteers. Combining cultural and/or use values in restoration projects holds promise for stimulating and sustaining community involvement.

Keywords: Forest disturbance, forest succession, shrub legumes, species introduction.

Resumen

Leucaena leucocephala subsp. *leucocephala* se introdujo en Hawái después del asentamiento europeo y se extendió ampliamente para uso como forraje y leña. Como en muchos otros lugares tropicales donde se ha introducido, se ha naturalizado y extendido hacia hábitats perturbados y más secos. Si bien es común su presencia en áreas perturbadas, es mucho menos común en bosques nativos intactos. Es resistente a los incendios forestales y al ramoneo de mamíferos, que, a la inversa, amenazan la integridad del bosque nativo remanente de tierras secas. El proceso sucesional de áreas dominadas por leucaena no se ha estudiado bien en Hawái, pero es probable que otras especies no nativas, en lugar de nativas, la reemplacen. Como resultado de su amplia distribución, especialmente en pendientes pronunciadas, su erradicación o control se considera de baja prioridad. La efectividad de opciones actuales de control biológico es limitada. El control de la leucaena puede y debe recibir mayor prioridad para proteger los bosques nativos de tierras secas e inhibir la dispersión de semillas. La restauración de los hábitats de las tierras secas requiere esfuerzos intensivos y sostenidos, generalmente con la participación de voluntarios. La combinación de valores culturales y/o de uso en proyectos de restauración es una estrategia promisoria para estimular y mantener la participación de la comunidad.

Palabras clave: Introducción de especies, leguminosa arbustiva, perturbación forestal, sucesión forestal.

Hawaii as a model system for studying invasive species

The Hawaiian archipelago is globally the most isolated group of islands from any continental land mass; hence, it has one of the highest proportions of endemic species of any terrestrial location. Despite these isolated and unique characteristics, diversity of soil types and land forms and the wide range in elevation (sea level to >3,000 m) and mean annual precipitation (<250 to 10,000 mm) within and across the islands make it a near-ideal natural laboratory for

Correspondence: T. Idol, Department of Natural Resources and Environmental Management, University of Hawaii-Manoa, 1910 East West Road, Honolulu, HI 96822, USA. Email: idol@hawaii.edu

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studying patterns of biological and ecological function and adaptation across environmental gradients (Vitousek 2004). Unfortunately, these characteristics also make it extremely vulnerable to the naturalization and spread of introduced plant and animal species.

As in most places in the world colonized by humans, Hawaii has a wealth of introduced plant species adapted to chronic human-associated disturbances, such as land clearing, wildfires, soil disturbance, agriculture and grazing, plus the built environment. Of these one of the most common woody species is *Leucaena leucocephala* subsp. *leucocephala*, known locally by its Hawaiian epithet 'koa haole' (in English 'foreign koa'), given the superficial similarity of seedlings to the native species, *Acacia koa*. As elsewhere in the tropics, leucaena was deliberately introduced to Hawaii, where it was distributed widely as animal fodder and fuelwood. It subsequently became naturalized and spread into disturbed habitats, especially drier forest and scrub habitats. The history and study of its introduction and spread, current geographic distribution, successional status and possible replacement with other species in Hawaii provide a spatial and temporal microcosm to understand and guide the study of other pioneer woody invasive species in the tropics.

Introduction and spread

As in most places in the world, the exact date of first introduction of leucaena to Hawaii is disputed. In his book of Hawaiian plants, *Flora Hawaiiensis*, botanist Otto Degener claims that it was first introduced in 1864 and was widespread 20 years later (Degener 1946). Cuddihy and Stone (1990) cite reports as early as 1837 of deliberate spreading of seed for cattle grazing and fuelwood. Regardless of the exact date of introduction, by the early 1930s, agricultural researchers and extension specialists reported on and recommended the use of leucaena for pastures to improve forage quality (Henke 1929; Ripperton et al. 1933) and to stop erosion of gullies (Zschokke 1931). Zschokke (1931) acknowledged concerns about wind and water dispersal of leucaena seeds down slopes into agricultural fields, where it was considered a major weed. Despite these concerns, he recommended establishment of leucaena on dry hillslopes to replace cactus (no scientific name given but likely prickly pear cactus, *Opuntia ficus-indica*) and lantana (*Lantana camara*) as part of a conversion to pasture for grazing by beef cattle. He reported that large areas on the islands of Kauai and Hawaii had been seeded with leucaena.

Geographic extent and conditions favoring invasion

It is clear from these few reports that the widespread distribution of leucaena in Hawaii today is a combination of deliberate introduction and spread on multiple islands, coupled with naturalization via wind and water dispersal of seeds mostly into disturbed habitats. Leucaena is found primarily at lower elevations (<300 m) and drier habitats in the Hawaiian Islands (Little and Skolmen 2003), especially those that have been subject to chronic disturbance by humans and grazing or browsing mammals. Based on statewide forest inventory estimates, there are approximately 61 million leucaena trees in Hawaii, with stem diameter ranging in size from 2.5 to 22 cm and totaling over 200,000 t of dry matter (USFS 2018). This ranks as the third-most numerous tree in Hawaii but is not in the top 10 in terms of total volume or biomass. It is common or dominant on 10% of the total land area of the state (USGS 2015).

Ecologist Frank Egler described leucaena as common in 3 distinct moisture-elevation zones in Hawaii, sharing dominance with different species in each zone (Egler 1947). All 3 zones experience xeric precipitation regimes, where mean annual precipitation is less than potential evapo-transporation, and the majority of rainfall occurs in the cooler autumn and winter seasons. Egler, partly relying on reports from early European explorers, also hypothesized that Polynesian settlers had cleared coastal lowlands extensively and converted them to agriculture, even in dry areas. These conditions would favor the naturalization of a species like leucaena, which is adapted to disturbed sites. It would also encourage deliberate spreading of seeds of leucaena and other useful plants onto sparsely vegetated areas or those covered in 'weeds', i.e. species that were not considered useful, in order to improve them.

Grazing and browsing mammals, including livestock and wild game animals, were introduced soon after European 'discovery' of the islands. Captain James Cook led the first European ship to reach the Hawaiian Islands in 1788. In 1793, Captain George Vancouver gave a few cattle to the chief of the Island of Hawaii as a gift. Harvest of the cattle was forbidden to allow the population to grow, so herd numbers increased quickly and cattle roamed freely on Hawaii and the other islands where they were introduced. Other domestic livestock, such as goats and sheep, and even game animals, like the Eurasian wild pig (*Sus scrofa*), Axis deer (*Axis axis*) and mouflon sheep (*Ovis orientalis*), were introduced to various islands throughout the archipelago. With their lower rainfall and thus productivity, dryland areas suffered most from the population growth of introduced mammals.

The eventual introduction of fencing and active livestock management reduced the damage these animals caused, but also removed the only significant biological control over leucaena and other disturbance-adapted species. While low-lying areas suitable for agriculture soon were sown to pineapple and sugarcane plantations, leucaena and other non-native species spread onto and dominated the dry hillsides. As mentioned by Zschokke (1931), leucaena was regarded as a 'boon' for livestock grazing on these hills but as a 'weed' for the down-slope farmers, who struggled to control it in their agricultural fields. As Hawaii's human population has expanded and the state has become more of a tourist destination, livestock grazing has slowly declined, leaving leucaena completely uncontrolled on hillsides, dry stream beds and abandoned agricultural land. As in many other populated areas of the tropics, leucaena is a common 'roadside weed' and is found more generally along open edges of fields, fence lines, empty urban and suburban lots, riparian forests and similar disturbed but open habitats.

Unlike most native dryland plant species, leucaena benefits from periodic wildfires. Its ability to resprout vigorously from the stump allows it to recover quickly after fire. Its recalcitrant seeds can withstand fast-moving fires common in dry scrub or grassland habitats. In Puerto Rico, Wolfe (2012) observed that leucaena saplings in dryland areas grew better than native saplings in competition with introduced grasses and were less affected by grass-fueled wildfires. Despite its reputation as a verdant tropical paradise, 40% of Hawaii's land surface is classified as either grassland, shrubland or dry forest (USGS 2015). Wildfires in Hawaii annually burn as much area proportionally as any other US state, including those of the western US (Trauernicht et al. 2015). Although these are generally smaller fires, they are concentrated in dry scrub and forest land, the very habitats that favor leucaena dominance. Since most of these fires are a result of human activity, they reinforce the association of leucaena with human-disturbed areas. Native Hawaiian species evolved in the absence of frequent wildfires, as would be caused by lightning strikes. No woody species have evolved the thick bark necessary to survive moderate-intensity fires, and only a few have seeds that are stimulated to germinate in response to wildfire.

Successional replacement

Since leucaena is associated with disturbed, open habitats, it is considered an early-successional pioneer species in forest development. Egler (1942) hypothesized that leucaena and other common non-native species in Hawaii's lowlands would eventually be replaced by native species. Part of his reasoning was that Hawaii's ecosystems are protected from major disturbances such as hurricanes or fires resulting from lightning strikes and, prior to human contact, were free of grazing or browsing mammals. While the islands were created by volcanic uplift, only Hawaii Island has active volcanoes at present. Therefore, Hawaii should have a diversity of late-successional native species. In the Caribbean island of Martinique, Egler (1942) observed leucaena in similar dry lowland environments; however, it was much less dominant than in other environments and it appeared that it was being replaced by native species. Thus, given adequate protection from human-associated disturbances, including grazing mammals, native Hawaiian species should eventually replace non-native pioneers like leucaena.

A related hypothesis proposed by Hatheway (1952) was that native Hawaiian dryland forest should be resistant to invasion by non-native species in the absence of major disturbances. He surveyed a native dryland forest within a protected reserve on Oahu that already included non-native woody species. He hypothesized that over time the native species should be able to maintain their dominance and even expand into the surrounding forest dominated by non-native species within the reserve. Resurveys of this area in 1970 and again in 2016 showed a slow decline in native species dominance and a subsequent increase in non-native species (J. Hibit pers. comm.). There also was no evidence of spread of native species into the surrounding forest dominated by non-natives.

While present in each of the surveys, leucaena was not one of the dominant species. Its abundance declined over time, but surviving trees grew larger, suggesting little, if any, successful reproduction was occurring. This agrees with observations by this author that leucaena can persist in the understory of dry to mesic forests but does not produce seed or grow into the overstory in the absence of large openings in the forest canopy. More generally, it suggests that other non-native rather than native species are likely to replace leucaena in Hawaii's dryland forests. Where wildfires and mammalian grazing persist, these successional changes are likely to be inhibited or reset, and leucaena will continue to be a dominant species in these ecosystems.

Priorities and options for control

Leucaena leucocephala is listed as one of the "100 Worst Invaders" globally (ISSG 2010), and is classified as a highly invasive species in Hawaii (HPWRA 2018). Olckers (2011) classified it as a 'conflict species' because of the tension between its value for human use and its propensity to naturalize and spread in dry and disturbed

habitats. In Hawaii, its abundance throughout the islands causes authorities to give it a low priority for eradication or control. Newly introduced species, those with limited spatial distribution or those that invade and disrupt native ecosystems or threaten native species are higher priorities for control (HISC 2018).

Manual or mechanical eradication of leucaena is challenging. Its resilience to repeated and frequent grazing means that livestock or wild game animals can at most control its vegetative growth and production of seeds. Indeed, one reason Zschokke (1931) recommended it for control of gully erosion was the well-founded belief that, once established, it could survive and function under regular grazing pressure. Leucaena is resistant to many common herbicides but is sensitive to others, in particular triclopyr and picloram (Jim and Santo 1990; Cook et al. 2005). Recommendations are generally for basal bark or cut stump application of a herbicide mix or repeated applications of glyphosate to resprouting shoots.

Natural or assisted biocontrol of leucaena has been studied in Australia (Raghu et al. 2005) and South Africa (Olckers 2011). The leaf-sucking leucaena psyllid (*Heteropsylla cubana*) is now widespread globally and can cause slow growth or dieback of growing shoot tips. However, its effects tend to be seasonal and are usually not sufficient to kill established trees or prevent seed production during at least part of the year. A seed-boring bruchid beetle, *Acanthoscelides macrophthalmus*, is relatively specific to leucaena and is common in many areas of leucaena infestation. It was introduced to South Africa, evaluated for host specificity and eventually released in 1999 (Olckers 2011). It established well in the area of release, but appears incapable of achieving consistent and adequate seed predation to prevent spread of leucaena. The fact that leucaena coexists with both *H. cubana* and *A. macrophthalmus* throughout much of its range and is still considered an invasive species suggests these options are unlikely to be effective in most places. Both natural observations and management recommendations emphasize that grazing and browsing are more effective measures to control growth and seeding of leucaena.

Given the scale of leucaena coverage in Hawaii and the intensity of control measures required, eradication and replacement or restoration of native vegetation will have to be highly prioritized. Hillsides dominated by leucaena will be a low priority. Clearing fire breaks, riparian zones and the edges of remaining native dry forest habitat should be given higher priority to reduce wildfire risks, inhibit its movement into native forests after disturbance and provide a buffer along waterways to reduce seed dispersal. The leucaena Code of Practice (The Leucaena Network 2018) provides practical guidelines to reduce seed production and the likelihood of spread off farms and pastures that mirror these general recommendations.

Finally, dryland forest restoration is inherently more difficult than in mesic areas because of the low rainfall and thus relatively slow growth of naturally colonizing or planted native species. Wildfire risks are also higher, especially when surrounded by invasive grasses and shrubs that are adapted to fire. In Hawaii, efforts have focused on protection of remaining native forest combined with small-scale restoration of high-priority areas. Such efforts can be successful in reducing non-native species cover, establishing healthy populations of native species and encouraging natural recruitment of native seedlings. This usually requires years of effort by professionals and coordinated volunteers, and it is usually confined to just a few hectares in areas that are reasonably accessible (e.g. Medeiros et al. 2014). However, given that leucaena is associated with human-disturbed habitats, there are many areas in drier parts of the state close to both remnant native forest and residential neighborhoods that could be sites for community-based restoration. Successful examples of such projects often include important cultural aspects, such as perpetuating cultural history or practices (HFI 2016) or reviving traditional agricultural and land management systems as part of a larger watershed restoration and management strategy (Ka'ala Farms 2018).

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(Note of the editors: All hyperlinks were verified 08 August 2019.)

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