The Past and Future of Hala (Pandanus tectorius) in Hawaii

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The past and future of *hala* (*Pandanus tectorius*) in Hawai‘i

Hala or *pū hala*, known to scientists as *Pandanus tectorius*, is among the most important plants in the ecological and cultural history of Hawai‘i and the broader Pacific. Every part of this tree has uses that have been critical to the cultural heritage and survival of the peoples of this region. Once a common feature of the lowland wet forests of Hawai‘i, this treasured resource has been threatened by both natural forces and human activity. Because Hawaiian cultural heritage has been so intertwined with this natural resource, it is important to understand the ecological history of *hala*, the challenges that have impacted its survival, and the strategies being used to sustain it.

A Botanical Introduction to *Hala*

Fossil evidence and molecular clocking using DNA indicates that the Pandanaceae (the *Pandanus* family) evolved more than 70 million years ago, probably in Laurasia which consists of present day Europe and North America (Gallaher et al. unpublished data). At that time, the global climate was much warmer than it is today and Laurasia was a center of tropical plant diversity. The family has since moved southward to the present day tropics and has diversified into five genera with approxinately800 species distributed from Africa eastward to Hawai‘i. The greatest center of species diversity is located in the Western Pacific and South East Asia. Pandanaceae are not currently found in the Americas; however, the sister family to the Pandanaceae, the Cyclanthaceae, is native to South America. In Ecuador, the leaves of one species of Cyclanthaceae, *Carludovica palmata* (*toquilla* palm), are used to make the “Panama hat”, which is regarded, along with the Hawaiian *pāpale*, as the finest plaited hats in the world.

Pandanus tectorius evolved approximately 2-4 million years ago along the coast of Queensland, Australia out of a group of species that inhabit various inland watercourses such as rivers, ephemeral streams, and swamps (Gallaher et al. unpublished data). *Hala* is primarily a coastal plant and throughout much of its range is found only on beaches and coastal forests, rarely higher than a few meters above sea level. In Hawai‘i, however, *hala* forests can be found up to 610 m (2,000 ft.) in elevation often several miles away from the coast. *Pandanus tectorius*, along with a few closely related species, are the most widespread species in the family and it has spread throughout the Indo-Pacific from Africa to Hawai‘i by the action of its buoyant fruit. Ancient (> 1.2 million year old) fossils of *Pandanus* fruit found on the north shore of Kauai suggests that this plant first floated to the shores of Hawai‘i without the aid of humans (Cunningham, 1994). Over a million years later, the first Hawaiians arrived on voyaging canoes powered by the wind caught in *lauhala* (*Pandanus* leaf) sails. The first human voyagers most likely carried *hala* seeds or branches with them in order to establish groves of the plant and ensure a future supply of the valuable leaves. *Hala* is therefore considered to be both an indigenous (native) plant in

Hawaiʻi and a ʻcanoe plant' or Polynesian introduction. In addition to *hala, Freycinetia arborea,* or **ʻ***ie***ʻ***ie*, is an indigenous liana (woody vine) of the Pandanaceae which is pollinated and dispersed by birds and mammals and can be found growing on trees in wet interior forests in Hawaiʻi and in the South Pacific.

Pandanus is dioecious, which means that there are separate male and female plants. The male plants produce the *hīnano,* an inflorescence composed of hundreds of small flowers that consist only of stamen, which produce a copious quantity of pollen (*ehu hīnano*) (Figure 1). Throughout the *hīnano* are white, strongly-scented bracts (modified leaves) which are presumably designed to attract pollinators. Although the plant spends a great deal of resource on pollinator attraction, the specific pollinators of this species are unknown and experimental studies indicate that, in Hawaiʻi, the plant's pollen is primarily carried to the flowers of female plants by the wind (Cox, 1985). The female flowers of *Pandanus* resemble a smaller version of the mature fruit cluster. Like the male flowers, the female ones lack many of the typical flower parts such as sepals or petals and consist only of the reproductive parts (Figure 1). The various raised black or brown protrusions that one sees on a *Pandanus* fruit are the stigma, which receives the pollen. The pollen fertilizes the egg, which then develops into a seed. Each stigma represents a single flower, however in *P. tectorius* and other related *Pandanus* species, the tissue that surrounds each flower has fused. Often between three and eight adjacent flowers fuse to form the typical multi-seeded fruit or key (Figure 1). Since the fruit often float on the ocean for long distances and may arrive in a place where no other *Pandanus* plants are present, having many seeds in one fruit increases the chances that both a male and female can establish at the same time so that a breeding population can result. Approximately 50-80 of these fruit form a softball to basketball sized head of fruit (*ahui hala*) (Figure 1). Female *Pandanus* trees are also able to form viable seeds even if the flowers have not been pollinated. This process, called apomixis, is another strategy to promote the proliferation of plants in new areas even when only a female is able to establish. An apomictic female-only population can persist until such time that a male seed or wind-blown pollen should arrive to re-establish a breeding population (Cox, 1985).

Pandanus is unusual in that its fruit can utilize two separate dispersal mechanisms. In addition to being buoyant, the fruit of *hala* are also attractive to animals, many of which act to disperse the fruit. Crabs, tortoises, lizards, cassowary, rats, and flying foxes have all been observed feeding on the fleshy base of the fruit (Ash, 1987; Bennett, 2000; Cox, 1990; Gaulke, 2010; Lee, 1985; Wiles, Engbring, & Falanruw, 1991). These animals are typically unable to damage the seed contained within due to the hard bony endocarp (*iwi hala*) which surrounds and protects the seeds.

A *Pandanus* fruit typically germinates above ground and one to several small seedlings emerge from the fibrous end of the fruit. The stem first assumes a leaning or trailing growth form for up to 7 years until prop roots provide sufficient support to allow the sapling to grow upright. This initial growth form may permit several seedlings to survive by allowing them to grow away from one another thus reducing competition for space (Ash, 1987). At this point, the plant will assume a vertical spiral growth form with limited branching for approximately 9-12 years achieving a height of 3-5m (10-15ft). The spiral appearance of leaves along the stem during the juvenile stage is a distinctive character, from which the first part of the common name 'screwpine' is derived. The second part of this common name apparently refers to the similarities between the fruit of *Pandanus* and that of the pineapple. When grown from seed, *P. tectorius* will begin flowering after 10-25 years and the production of flowers corresponds with branching. Male trees typically produce flowers more often than females and as a consequence, male trees are more highly branched (Ash, 1987). Branching can also be induced if the growing apex of the tree is diseased or suffers physical damage, dormant buds along the stem can develop new branches and some of these may develop into plantlets complete with roots (Gallaher, personal observation). *Pandanus tectorius* can grow to a maximum height of 9 m (30 ft.) and may live to approximately 60 years (Ash, 1987). Of nine *hala* trees planted (presumably as several year old saplings) at Webster hall on the University of Hawai'i at Mānoa campus in 1961, four remain today (52+ years old), and these have the appearance of very old trees (Krajina, Rock, & St. John, 1962).

As *hala* trees age, their leaves and fruit become smaller and prop roots form just below the terminal leaf clusters. If these branches should break off, perhaps during strong winds, the entire terminal cluster of leaves and roots can form a new plant. This terminal cluster is commonly cut from mature trees and used for vegetative propagation by people throughout the Pacific. This method of propagation will ensure that the resulting tree will have similar properties as the parent tree. *Hala* can also be propagated by seed however seedlings may have a different genetic makeup and therefore different leaf or fruit qualities from the mother plant.

Lauhala experts recognize several desirable properties of the leaves that they work with and these qualities are related to both mechanical and chemical characteristics of the plant along with techniques of post-harvest processing such as flattening of the leaves. A cross-section of the leaves (Figure 2) reveals an upper and lower leaf epidermis which produces a waterproof wax and a regular pattern of fibrous vascular bundles that extend from the upper to lower epidermis. Between these bundles are nearly clear larger cells where water and leaf chemicals are stored surrounded by green cells where photosynthesis occurs. These storage cells are absent from the much thinner leaves of coconut and the *toquilla* palm. The leaves of *Pandanus* contain a wide array of natural plant chemicals including pigments and phenolic compounds including tannins (Kumar, et al., 2010; Londonkar & Kamble, 2009). Some of these chemicals accumulate in the leaves over time and act to deter the activity of insects and fungi. The tannins also contribute, along with plant pigments, to the red or brown color of the leaves while the density of fibers contributes to the durability and pliability of the leaf. Variation in these mechanical and chemical properties of *lauhala* may have a genetic basis. From out of this variation, *lauhal*a practitioners have selected favored trees with exceptional leaf-quality. Some practitioners have also observed that the habitat in which the trees grow (i.e. *pū hala* groves at the beach vs. groves in the mountains) have a marked effect on the texture and workability of the leaves indicating an environmental component to the natural variation (Gwen Kamisugi, personal communication 2012).

In Hawaiʻi, several varieties of *hala* were recognized and named (see Meilleur, Maigret, & Manshardt, 1997, p. 24). Some of the names may refer to varieties brought by Hawaiians from elsewhere in Polynesia while others may refer to unique forms that first evolved in Hawaiʻi and were recognized for some interesting physical character. It is unclear whether specific varieties were propagated and perpetuated along with other useful plants or if the names refer to forms that were observed from natural groves. The Hawaiian names for *hala* and other useful plants often used a binomial or 'two name' system. Examples include *hala* **ʻ***ula* (red *Pandanus*) or *hala melemele* (yellow *Pandanus*) referring to the color of the ripe fruit. This descriptive naming system is consistent with that used by many other traditional cultures around the world and with the system used by botanists and other biologists. Previously, it was unclear if the Hawaiian binomials were of ancient or recent origin however the variety *hala pia*, "the white *hala*", appears in an 1865 Hawaiian Dictionary entry (Andrews, 1865) and both *hala pia* and *hala* **ʻ***ula* are mentioned in chants written for King Kalākaua compiled in 1886 suggesting that these names may have been used in antiquity (Hawaiian Historical Society, 2001). Botanists recognize six forms of Hawaiian *hala*, all of which are considered to be forms of *P. tectorius* and are thus given a third name to indicate their variety (i.e. *Pandanus tectorius* var. *oahuensis).* The botanically recognized forms are distinguished primarily by the shape and size of the individual fruit.

By 1900, three additional species of *Pandanus* had been introduced to Hawaiʻi (Thrum, 1900) and a variegated *Pandanus* was commonplace by 1915 (Bryan, 1915). The introduced variegated *P. baptistii,* believed to be native to New Britain Island in Papua New Guinea, is a "thornless" species which may revert to an all-green form. This all-green form, or perhaps another variety with occasional white variegation along the leaf margins, became a favored variety used by *lauhala* practitioners known as *kilipaki* (lit. Kiribati or the Gilbert Islands) (Gwen Kamisugi, pers. comm. 2013). The thornless species is today becoming a popular plant, often replacing native "thorned" varieties in the urban landscape. These have been planted recently on the University of Hawaiʻi at Mānoa campus to replace the older Hawaiian *hala*. Several other species can be found today in botanical gardens, and private residences including the wide-leafed *P. dubius from the* western Pacific. Some *hala* weavers actively seek out and experiment with these new introductions to find leaves with desirable color, strength and texture.

Survey of the uses of *Pandanus tectorius* in Hawai‘i and throughout the Pacific

The genus *Pandanus* includes many species that are useful to people around the world. In addition to the leaves, which was and continues to be the most widely used natural fiber material in Oceania, nearly every part of the plant had important uses. The role of *hala* in several aspects of Hawaiian material culture and its role in expressive oral traditions are explored by other contributors to this monograph however a few examples from throughout Oceania are also discussed here. In addition to the ubiquitous use of leaves in plaited items, the large prop roots were a source of fibers, which could be separated by beating, and fashioned into thread or rope (Summers, 1990), the large above-ground root tips were a source of traditional medicine and the trunks of large trees, particularly male trees, are used as posts for houses and as the main structural supports for much larger structures.[1] Throughout Oceania, the highly fragrant male inflorescence is associated with sexuality and promiscuity, and the scented floral bracts along with the soft and copious quantity of pollen that is produced is considered an aphrodisiac. In many places both fruit and male flowers had important social and spiritual connotations, which continue to have important meaning today.

In some places, the fruit of several species of *Pandanus* was and continues to be an important staple food. *Pandanus conoideus* from New Guinea produces a fruit, high in beta-carotene, which is eaten raw or processed into an array of food and beverage products. *Pandanus brosimos, P. julianettii,* and *P. dubius* produce edible seeds, and *P. amaryllifolius* has aromatic leaves used in Southeast Asian cuisine (Hyndman, 1984; Teng, Shen, & Goh, 1979; Yen, 1993). Some of the earliest evidence for human habitation in the Pacific comes from 34,000-36,000 years old sites in the New Guinea highlands. Charred remains indicate that *Pandanus* was an important food source for the earliest New Guineans in areas which were otherwise resource-poor in terms of food sources (Summerhayes, et al., 2010).

The fruit of *P. tectorius* played a similar role in the human colonization of the resource-limited atolls of the central Pacific. In Kiribati and the Marshall Islands, *Pandanus* remains a staple food source providing nutrients that are a limiting factor for human populations given the relatively few plant species that can survive the poor coralline atoll soils. While the fruit of all *P. tectorius* are edible, most wild plants, including those in Hawaiʻi, have calcium oxalate crystals in their fruit tissue. This is the same

[1] The author lived for two years on Onotoa Island in the Republic of Kiribati in a large house constructed from *Pandanus* stem posts and *Pandanus* leaf thatch. The wall siding and lashing used to connect everything together was made from coconut leaves and coconut fruit fiber. Large culturally important meeting houses known as *Maneaba* are also made primarily from *Pandanus* (Maude, 1980).

compound that is found in *kalo* (*Colocasia esculenta*). The crystal is irritating or painful if the raw fruit is consumed; however, the crystal can be removed by cooking. In the central Pacific, however, many cultivated varieties of *P. tectorius* have been developed which are larger and less fibrous than wild forms and which have significantly less calcium oxalate such that they can be eaten raw[2]. These varieties are also much more nutritious relative to wild forms with up to 10 times the usual amount of beta-carotene which is an essential nutrient otherwise rare in the diets of atoll people (Englberger, et al., 2007; Englberger, Aalbersberg, Fitzgerald, Marks, & Chand, 2003). In addition to its central role as a food source, over 50 additional uses of *Pandanus* have been recorded on the atolls of the central Pacific (Thaman, 1992). The importance of *Pandanus* on Pacific atolls is also indicated by the hundreds of named cultivated varieties which can be found on these small islands.

Probably the most important use of *Pandanus*, and one which is often overlooked, is the use of *lauhala* to make *lā* or *pe'a* (canoe sails). While paddling canoes large and small were used for short distance travel, near-shore fishing, reef gathering, and recreational activities throughout the Pacific, these smaller canoes were rarely used for interisland travel. For long-distance voyages, the people of Oceania relied primarily, if not exclusively, on sailing vessels with sails made from *lauhala*. Such canoes were ubiquitous throughout both Polynesia and Micronesia. In Hawai'i the sails were made from plaited *lauhala* strips that were lashed together and to the mast with rope made from '*olonā* (*Touchardia latifolia*) (Haddon & Hornell, 1936). Micronesians and Polynesians used these vessels to sail to virtually every island and remote archipelago in the tropical Pacific possibly reaching South America (Balter, 2010; Jones, Matisoo-Smith, & Ramirez-Aliaga, 2011). In a few cases however these appear to have been one-way voyages. It appears that *hala* was not able to establish on either *Rapa nui* (Easter Island) or in *Aotearoa* (New Zealand). The lack of *lauhala* to make new sails may have resulted in the isolation of the communities on these outposts of Polynesia and may have had an important impact on the development of those societies.

The Ecology and Distribution of *Pandanus* in Hawai'i

Pandanus tectorius is often among the first plants to colonize a tropical Pacific island. For example, *P. tectorius* was already well established fourteen years after the 1883 eruption of Krakatoa "sterilized" the nearby island of Rakata and the species was recorded on Anak Krakatau in 1934, only three years after the emergence of that island (Whittaker, Bush, & Richards, 1989). Observations in

[2] On the atolls of the central Pacific, Pandanus fruit are eaten raw or processed into several products, some of which can be stored for years to be eaten in case of food shortage or taken on long-duration voyages. In Kiribati, these preserved forms are still routinely given to friends and family who are leaving the islands for a long trip abroad.

Hawaiʻi however suggests that on new lava flows *ʻōhiʻa* (*Metrosideros polymorpha*) is among the first flowering plants to establish whereas *hala* begins to establish only after at least 200 years have passed. Over time, however, *hala* tends to replace *ʻōhiʻa* near the coast, likely due to a higher tolerance of salinity (Atkinson, 1970).[3]

Pandanus tectorius has evolved specifically to the harsh conditions of the ocean and the coast. This species can survive temporary salt-water inundation and the persistent salt spray associated with coastal areas. *Hala* fruit are specially adapted to buoyancy on the ocean and the seed contained within are unaffected by prolonged saltwater exposure (Guppy, 1906; Nakanishi, 1988). In many of the coastal areas of Hawaiʻi where *hala* was once likely a dominant species, two invasive species, the Pacific almond (*Terminalia cattappa*) and ironwood (*Casuaraina equisetifolia*) now directly compete with *Pandanus* for habitat. The Pacific almond was first introduced to Hawaiʻi prior to 1923 and ironwood was introduced in the 1890's and extensively planted in the 20th century based on the notion that this species would provide protection from shoreline erosion (Kaufman & Gallaher, 2011; Wagner, Herbst, & Sohmer, 1999). *Pandanus* has now also been recommended for planting along suitable shorelines for protection from the effects of erosion, storm surge and tsunami (Nandasena, Tanaka, & Tanimoto, 2008).

Pandanus tectorius often forms dense groves with few other species present. This is in part due to the species ability to inhabit poor rocky soils and areas with moderate slope. In addition the leaves of *P. tectorius* are filled with tannins which deter decomposers and allow the leaf to decompose slowly over time. This results in the buildup of a significant leaf litter layer which may inhibit the germination of other competitor species. Hawaiians may have taken advantage of this property of *Pandanus* leaves in the implementation of the *pā hala* method of *kalo* propagation practiced in Puna, Hawaiʻi in which *kalo* was planted within intact *hala* groves and branches and leaves were then cut to cover the growing *kalo* plants. The leaves were subsequently burned to provide nutrients (Handy, Handy, & Pukui, 1972 p. 104-105).

Many species of *Pandanus* including *P. tectorius* have some ability to survive low to moderate intensity fires. A survey in Fiji following a moderate intensity fire found that *P. tectorius* less than 50cm in height were killed by fire while larger trees survived. Following fire *Pandanus* is able to reestablish and grow quickly excluding other less fire-tolerant species. People throughout the Pacific may have directly or indirectly promoted *Pandanus* by influencing natural fire regimes or by using fire to clear unwanted vegetation. In several places in the Pacific, human modification of the landscape was associated with the increase in the presence of *Pandanus*. An increase in *Pandanus* pollen following human

[3] Vegetation succession from *ʻōhiʻa* to *hala* can be observed today on old lava flows near the coast in Puna on Hawaiʻi Island.

establishment is evident at Avai‘o‘vuna Swamp in Vava‘u, Tonga (Fall, 2005) and Tukou Swamp in Rapa, French Polynesia (Prebble & Dowe, 2008). Similarly in Mangaia in the Cook Islands the expansion of *hala* as a dominant vegetation type was likely influenced by burning of other vegetation types (Kirch, 1996). At Rimatara, in the Austral Archipelago (French Polynesia), however the pollen record indicates a pre-human habitat dominated by *Pandanus* followed by a sudden increase in both charcoal and taro (*Colocasia*) pollen indicating that the area was converted from *Pandanus* forest into taro agriculture. *Pandanus* pollen and macrofossils such as leaves and fruit became more abundant at Māhā‘ulepū, Kaua‘i following Polynesian settlement indicating that the early Hawaiians either directly or indirectly promoted the spread of *hala* groves (Burney, et al., 2001).

The named *Hala* Groves of Hawai‘i

In Hawai‘i, and elsewhere throughout its range, *P. tectorius* forms extensive coastal forests. Large tracts of *hala* forest can still be found along the coast in Puna on Hawai‘i Island and this region was also once known as *Puna paia‘ala i ka hala* (Puna hedged with fragrant *Pandanus*) (Handy, et al., 1972, p. 200). Early accounts suggest that *hala* forests on the eastern coast of Hawai‘i island was once far more widespread and that *hala* forests extended many miles inland from Hilo to Kea‘au and into Puna (Wilkes, 1845). By the early 1900's however, sugar cane had replaced some of these *hala* forests (Brigham, 1906). In Hāna, Maui an extensive coastal *hala* forest, possibly once called *Kahalaoweke* (Kamakau, 1961, p. 30), can still be found although this forest is under imminent threat by an invasive scale insect (Figure 3). *Na hala o Nihoa* referred to a *hala* grove near Kalaupapa, Molokai. Large numbers of *hala* can still be found at Nihoa and in nearby areas (Bill Garnett, pers. comm. 2013). The *hala* grove known as *Na Hala o Naue*, at Hā‘ena, Kauai, is gone today. Many of the trees were killed by the April 1, 1946 tsunami with subsequent suburban development taking over areas where the forest may have re-established (Shepard, MacDonald, & Cox, 1950). A forest comprised of *hala*, along with several other species, can still be found in nearby Hanakapiai valley.

In addition to the several coastal populations of *hala* in Hawai‘i large groves are sometimes found many miles inland at elevations up to 610 m (2,000 ft.) (Wagner, et al., 1999). *Hala* can inhabit inland areas with annual rainfall greater than about 1200 mm (47 in.) and minimum temperatures above 10˚C (50˚F) (Gallaher, Unpublished Data) (Figure 3). Hala can also survive in drier areas if there is an adequate supply of near-surface ground water. One inland area known for *hala* is along the windward side of O‘ahu. From ‘Olomana and extending through the valleys and ridges of the Ko‘olau mountain to Punalu‘u or even farther north at an elevation of 120-450 m (400-1,000 ft.) is a band of intermittent *hala* forest which is likely a remnant of a much more extensive native forest. *Pandanus* was likely a large component of the pre-Hawaiian windward lowland forests, in some cases the dominant species [4]. At its southerly most point, the remnant *hala* forest extends to near the base of the Nuʻuanu Pali where the *hala* grove at Kekele, which has figured prominently in several chants and legends, was once located. The *hala* grove at Kekele has since been cleared for agricultural activities and much of it today is secondary forest dominated by alien species.

The history of the *hala* grove of Kekele represents an interesting case study of land management in Hawaiʻi. In order to accommodate human occupation following the arrival of the first Hawaiians some of the natural forest had to be removed to make way for habitation and agricultural activities, chiefly taro. In 1789, Captain Portlock described the lowlands and valleys of Kāneʻohe as being in a "great state of cultivation". Clearing by Hawaiians either through manual clearing or the use of fire may have isolated widespread *hala* forests away from their coastal origins to the back of the windward valleys and to areas protected by cultural proscriptions. The naming of *hala* groves may be one indication that such groves were protected under traditional resource management systems. Following western contact, several additional agricultural activities would significantly impact native forests in Kāneʻohe. Chief among these were cattle and other livestock such as sheep and goats, (1840- early 1900's), sugar (late 1830's-1902), coffee (late 1830's-early 1900's), rice (1860-1925), and pineapple (1890-1925) (Devaney, Kelly, Lee, & Motteler, 1982). While sugar followed by rice dominated the lowlands, cultivation of coffee and pineapple could take place on terraced hills and the backs of valleys. Cattle, goats and sheep were sometimes managed on pastures but often allowed to roam free through native forests and agricultural lands alike. Hiram Bingham referred to a "dense wood" at the base of the Nuʻuanu *pali* in 1821 (Bingham, 1849, p. 131); however, the land was leased by King Kamehameha III and Kaʻahumanu III to Boaz Mahune, Jona Piʻikoi, and others to be used as cattle pasture in 1839. Some portion of the *hala* grove was still present in November 1846 as seen by a crew member of the Danish ship the Galathea who descended the Pali through a "*Pandanus* thicket" and emerged upon a clearing owned by "Pikuiha" (possibly Jona Piʻikoi) which was occupied by numerous cattle (Bille, 1852, p. 269) . The "Great Māhele"

[4] At the high elevation Kaʻau crater, *Pandanus* pollen is recorded throughout the 28,000 year pollen record. Presumably the pollen was blown over the Koʻolau range from an extensive windward *Pandanus* forests. *Pandanus* appears only as a trace however in the 3,000 year record of pollen from the coastal Kawainui marsh indicating that the windward *Pandanus* forests of Oʻahu may not have extended completely to the coasts in the drier areas such as in South Kāneʻohe, Kailua, or Waimānalo but was somewhat confined to inland wetter areas (Athens & Ward, 1991; Athens & Ward, 1993; Hotchkiss & Juvik, 1999).

of 1848 which instituted private land ownership was followed by foreign land ownership in 1850. The lands of Kekele, now divided, changed hands several times and were the subject of an 1857 Hawaiʻi Supreme Court case where it was established that cattle had been run over the land (Davis, 1866). A visitor to Hawaiʻi in 1853 observed that the plains below the Nuʻuanu pali had been cleared stating, "Hundreds of cattle may be seen feeding on the rich pasture with which these plains are covered" (Bates, 1854, p. 104). A similar observation was published in a Hawaiian newspaper in 1866: "Kekele is the land just below Nuʻuanu, so fragrant with the *hala* blossoms and fruit used for leis. It was a rich land a while ago but now there are not many plants because animals (cattle, horses, etc.) are permitted there." (Sterling & Summers, 1978).

Today commercial sugar, coffee, rice and cattle are gone from Kāneʻohe. Interestingly, taro cultivation is back as a growing niche industry and *hala* is being replanted in riparian (riverbank) restoration and erosion control programs however much of the land has been developed for urban and suburban use. Lands that were once dominated by *hala* in windward Oʻahu including Kekele are now primarily covered by houses, golf courses, or invasive species that moved in after the abandonment of agriculture. The remnant groves of *Pandanus* that remains in the backs of valleys and along the lower foothills of the Koʻolau Mountain is all that remains of the once widespread forest.

Modern Threats to Hawaiian *Hala*

The *Pandanus* scale insect, *Thysanococcus pandani,* was accidentally introduced to Hāna, Maui, likely on material imported to one of the botanical gardens in the area. Prior to this, the scale was only known to live on *P. tectorius* in Java and Singapore which is believed to be the native range of the insect. The scale was first observed in Hawaiʻi in November 1995 at the National Tropical Botanical Garden in Hāna and by October 1996, it occupied a half mile strip along the coast. The scale reached Keʻanae by November 2002 and was found on the offshore islets of Keopuka, Moku Huki, and Puʻu Kū in 2005 (Starr, Starr, & Wood, 2006). The scale has presently spread to virtually all areas of Maui. The scale insect covers the leaves and fruit of *Pandanus* and feeds on sugars in the plant weakening or sometimes killing adult plants (Stickney, 1934) (Figure 4). Young plants are quickly killed and in any case the leaves of *hala* trees infested with the scale are rendered useless to *hala* weavers. Although this scale is a wingless insect, it likely spreads by blowing through the air from plant to plant and may also be dispersed unknowingly by people who transport infested leaves or fruit.

Between 2003 and 2006, *Pandanus* scale was intercepted on five occasions by agricultural inspectors in Los Angeles County. All of these were found on tropical flower shipments originating from Maui (County of Los Angeles, 2004; Gevork Arakelian, Senior Biologist, Los Angeles County, pers.

comm. 2013). Due to funding and or staff limitations, the State of Hawaiʻi is not able to provide inspection services for interisland shipments and there are currently no restrictions on the import of infected *Pandanus* material from Maui to Oʻahu. In addition, there are currently no known effective measures to combat or control the scale (Darcy Oishi, State Dept. of Agriculture, pers. comm. 2013).

The Hawaiʻi Department of Agriculture has recently begun to search for a bio-control for the *hala* scale. The first step of this process will be a search within the native range of the scale for a natural enemy such as a parasitic wasp or predator ladybug which exclusively parasitizes or feeds upon *Thysanococcus*. Once a predator or predators are found, testing will be done in the native range before regulatory approval is sought to conduct subsequent testing and finally conduct controlled release of the bio-control in Hawaiʻi. Any candidate bio-control must be effective in controlling the scale insect and must not negatively impact any native or commercially important organisms in Hawaiʻi. Funding has recently been obtained by the Hawaiʻi State Department of agriculture to begin to address the *hala* scale problem and the timeline for these efforts is 4-6 years following the identification of suitable bio-control candidates (Darcy Oishi, pers. comm.).

Conclusions

Pandanus has had a profound effect on the people of Oceania. It has enabled them to move beyond the reef and become an ocean-voyaging people allowing them to explore the vastness of the Pacific. Over the past two hundred years, deforestation, reduction of habitat and more recently the effect of the introduced scale has resulted in a significant reduction of natural *hala* forests. In Hawaiʻi hanging values, resource needs, and cultural systems have removed any protections on historical named groves and favorite trees. Today adequate supplies of *lauhala* that meet the stringent quality thresholds applied by weavers are lacking and *Pandanus leaves* for use in weaving are being imported from other countries including Tahiti and the Philippines. Faced with these threats, *lauhala* practitioners have taken on the role of resource managers. *Hala* weaving groups actively manage trees and at least one group has begun to establish new groves. The *kumu* (teachers) of these groups are educating a new generation of weavers, not only in the painstaking skill of plaiting *lauhala*, but also in the process of propagating and tending *hala* trees. They are learning how to recognize the natural diversity within the resource and select the trees and leaves that will produce the highest quality results. As more individuals become aware of the growing threats to sustaining this resource so important to Hawaiian culture, it is hoped that even more solutions will be found to protect, nurture, and restore *hala* to levels needed to insure sustainability of the resource and the cultural features it supports.

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Figure 1.Parts of the *pū hala (P. tectorius).* A small grove of planted trees (top); Infructescence and male inflorescence (middle); A single *hala* fruit split lengthwise showing the upper floatation tissue, central hard tissue enclosing the several seeds, and the lower sweet tissue (bottom left); and the distinctive prop roots of this species (bottom right).

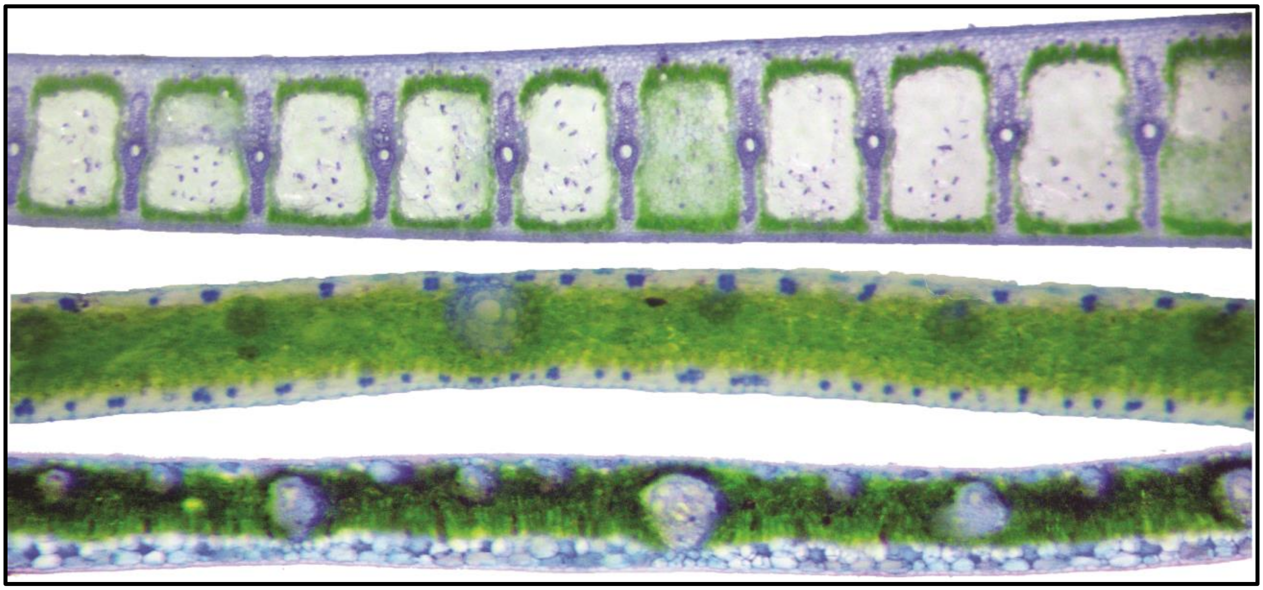

Figure 2 Leaf cross-sections of *hala* (top), the Panama hat plant (middle) and coconut (bottom). Fibers have been stained dark (purple/blue) with toluidine blue. This comparison illustrates the unique structural features of *hala* particularly the regular arrangement of vascular bundles and storage cells.

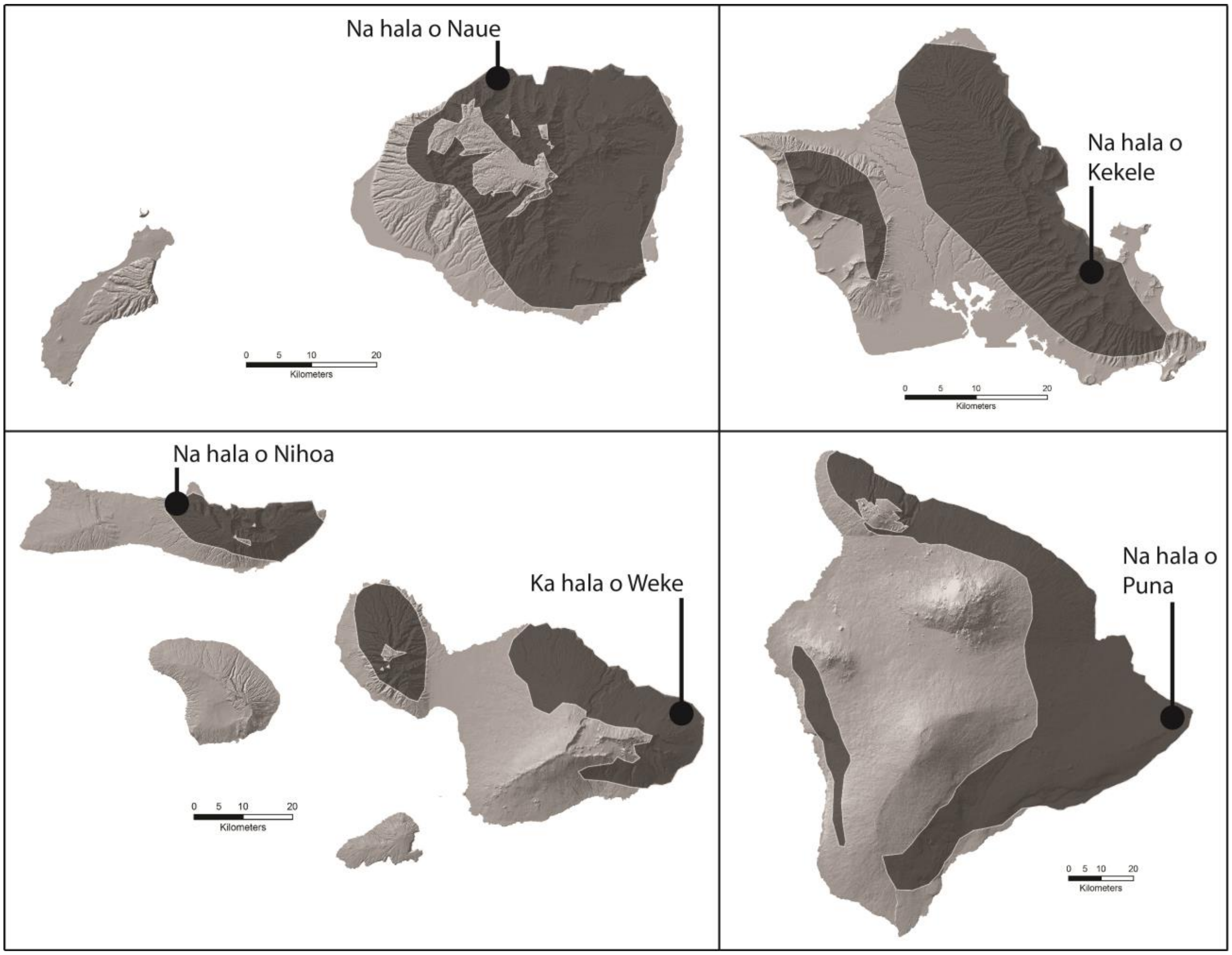

Figure 3. Potential distribution of *hala* in Hawai'i (darkened areas) and some of the named *hala* groves. The potential distribution is based on the rainfall and temperature tolerances of *P. tectorius* based on data from throughout its natural range. This corresponds to areas in Hawai'i with a mean annual rainfall greater than 1200 mm (47 inches) and a minimum temperature greater than 10˚C (50˚F) (Thomson, Englberger, Guarino, & Elevitch, 2006). Geospatial climate data from the Rainfall Atlas of Hawai'i (Giambelluca, et al., 2012) and the Prism Climate Group (Daly & Halbleib, 2006).

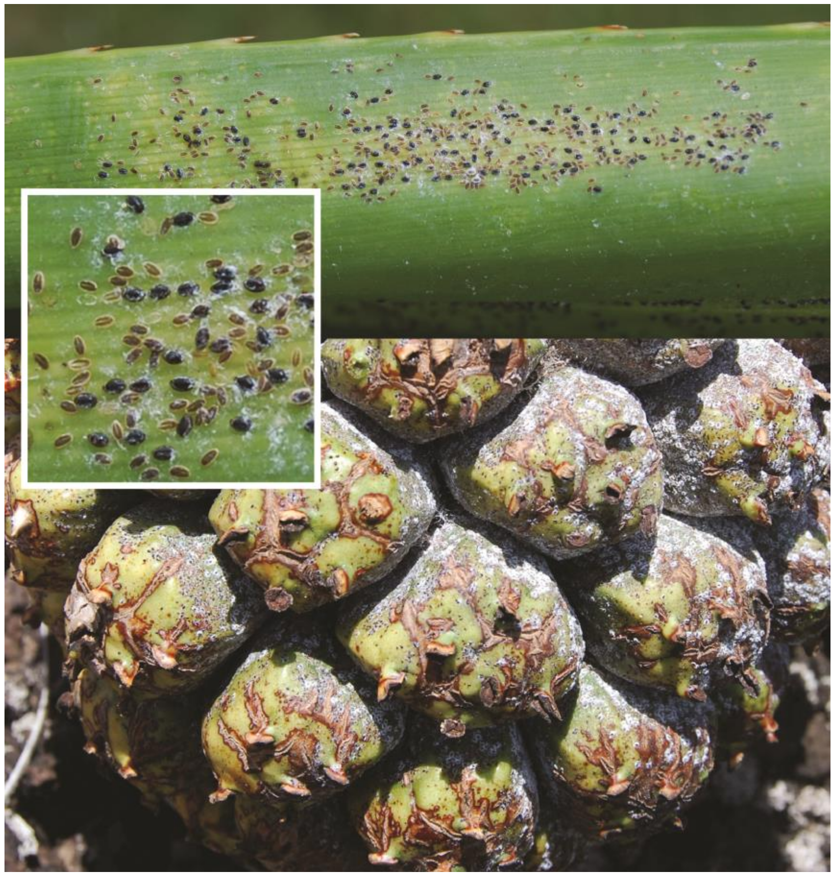

Figure 4. The *Pandanus* scale *Thysanococcus pandani* on leaves and fruit of *hala* at Hana Maui.