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Amaranthus pakai (Amaranthaceae), a New Critically Endangered Species from the Hawaiian Islands

Kevin Faccenda

School of Life Sciences, University of Hawai'i at Mānoa, 3190 Maile Way, St. John 101, Honolulu, Hawaii 96822, U.S.A.; Herbarium Pacificum, Bishop Museum, 1525 Bernice Street, Honolulu, Hawaii 96817, U.S.A. Author for correspondence: faccenda@hawaii.edu. https://orcid.org/0000-0002-3458-5671

Néstor David Bayón

Cátedra de Sistemática Vegetal, Facultad de Ciencias Agrarias y Forestales, Universidad Nacional de La Plata, CC 31, 1900 La Plata, Argentina. nbayon@agro.unlp.edu.ar. https://orcid.org/0000-0003-1446-129X

Katherine Waselkov

Department of Biology, California State University, Fresno, 2555 E. San Ramon Ave., Fresno, California 93740, U.S.A. kwaselkov@csufresno.edu. https://orcid.org/0000-0001-8521-3694

Robert W. Hobdy†

Abstract. *Amaranthus pakai* Faccenda & N. Bayón (Amaranthaceae), a new Hawaiian endemic species from the main islands, is described. It is most probably closely related to *A. brownii* Cristoph. & Caum, an extinct species from Nihoa Island. It also morphologically resembles *A. interruptus* R. Br. and *A. viridis* L. *Amaranthus pakai* differs from these species in its leaves with elliptical lamina, and pistillate flowers with three widely spathulate sepals, which are longer than the fruits. The first collections date back to the 19th century and suggest that this species was formerly rather widespread across the main Hawaiian Islands, but the population probably crashed during the 1800s. However, these early specimens were misidentified until recently. *Amaranthus pakai* was last seen in the wild in 2014 and, following its assessment against the IUCN criteria, is considered Critically Endangered, as only 30 to 40 plants were seen at that time.

Key words: *Amaranthus brownii*, endangered species, endemic, Pacific, *Wilsoniana*.

The genus *Amaranthus* L. has been somewhat overlooked in Hawai'i, in part due to most material of *Amaranthus* stored at the Bishop Museum (BISH) (herbarium acronyms following Thiers, 2016), Hawai'i's principal herbarium, being lost while on loan (Wagner et al., 1990). Only 10 specimens of *Amaranthus* at BISH predate the 1970s, limiting our historical understanding of this genus in Hawai'i. During a review of the introduced *Amaranthus* in the Hawaiian Islands (Faccenda & Ross, 2024), an unusual *Amaranthus* specimen was located, which triggered the present research and resulted in our description of a new species.

The species we are herein naming *Amaranthus pakai* Faccenda & N. Bayón was formerly identified as *Euxolus lineatus* (R. Br.) Moq. (now recognized as *A. interruptus* R. Br.) by collectors from the 1800s, including Hillebrand (1888). However, that name was misapplied in Hawai'i, as *A. interruptus* is a distinctly different plant with five sepals and wider leaves, found only in Australia and on the Pacific Island of Jarvis (Eliasson,

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1986; Palmer, 2009). *Amaranthus pakai* belongs to subgenus *Albersia* (Kunth) Gren. & Godr. since it is a monoecious plant, with bracts and bracteoles having a distinct midvein and wide membranaceous wings, flowers of both sexes with three sepals, and indehiscent fruits (Mosyakin & Robertson, 1996; Bayón, 2015). Judging from morphological and biogeographical evidence, the plant seems to be closely related to, and likely phylogenetically sister to, *A. brownii* Cristoph. & Caum., an extinct species that was only ever found on the Hawaiian island of Nihoa (United States Fish and Wildlife Service, 2003), and is the only other *Amaranthus* that naturally occurred in the Hawaiian Islands.

During the writing of the *Manual of Flowering Plants of Hawai'i* (Wagner et al., 1990), the specimens of *Amaranthus pakai* were not closely examined and were assumed to be *A. viridis* L. (Warren Wagner, pers. comm.). The first *A. viridis* appeared in Hawai'i in the 1830s where it was found "in ruderatis" on O'ahu (St. John, 1979; *Nuttall s.n.* PH 00028335), and Hillebrand (1888) reported this as common in gardens by the year 1871 when he left the islands.

Taxonomic Treatment

Amaranthus pakai Faccenda & N. Bayón, sp. nov. TYPE: U.S.A. Hawai'i: "Iles Sandwich," s. loc., *C. Gaudichaud 121* (holotype, P [barcode] P05251971!).

Diagnosis. *Amaranthus pakai* Faccenda & N. Bayón differs from *A. brownii* Christoph. & Caum. in its larger habit (up to 2 m, most specimens cut and not including the whole plant vs. 1 m with all specimens including whole stems or plants); larger, broader leaves with longer petioles ([3–]5–8[–12] vs. 3–5.5[–6.5] cm); proportionally shorter sepals (length:width ratio 1.4–1.9 vs. 2.5–2.7), as well as their non-overlapping geography (Table 1).

Herbs, annual, monoecious, erect; main stem single, with weaker branches, largely glabrous but with few multicellular hairs, 0.7–2 m, up to 3 cm thick at base, internodes 1.5–8 cm. Leaves herbaceous, dark green; primary leaves at each node petiolate, petiole (1–)3–5 cm, shorter than lamina; lamina narrowly elliptical to narrowly ovate, (3–)5–8(–12) × 0.6–1.8 cm, base attenuate, apex acute or obtuse with 0.5 mm mucro, margins entire, both surfaces papillose, veins raised and lighter abaxially; secondary leaves in fascicles or on short axillary branches above primary leaves, like primary leaves but up to 1–3 × 0.5 cm. Inflorescences in terminal panicles, 12–30 × 2–13 cm with racemiform branches of ca. 8 × 0.3–0.7 cm and tertiary branches of ca. 0.5 cm, with some leaves; bracts and bracteoles ovate or ovate-elliptic, acute, 0.7–1 × 0.4–0.6 mm; flowers of both sexes intermixed. Staminate flowers with 3 ovate sepals, 1.5–1.8 × 0.5–0.8 mm, their apex rounded to acute with small mucro 0.1 mm, stamens 3, anthers 0.6–0.8 mm. Pistillate flowers with 3 spathulate sepals, 0.77–1.66 × 0.52–1.36 mm with 0.1–0.5 mm mucro, midvein conspicuous; stigmas, 3, up to 0.4 mm, slender, free to base. Fruit indehiscent, broadly obovoid, 0.95–1.29 × 0.74–1.1 mm, strongly rugose, with smooth beak; seed glossy black, lenticular, ca. 1 mm diam.

Distribution and habitat. *Amaranthus pakai* is historically known from Kaua'i, O'ahu, Lāna'i, and Maui based on specimens and Hillebrand (1888). It may have occurred on other main islands historically. It is likely still present on Hawai'i Island, being last collected in 2014. No attempts have yet been made to visit the site, but future visits are planned. Little is known about its habitat. Hillebrand (1888) reports it from the edges of agricultural fields, and the Puakō population was found in grassland with scattered kiawe trees (*Neltuma pallida* (Humb. & Bonpl. ex Willd.) C. E. Hughes & G. P. Lewis) in an area that receives approximately 210 mm of rain annually.

Conservation status. Based on the eight specimens of *Amaranthus pakai* collected across most of the main Hawaiian Islands from 1825 to 1855, *A. pakai* is hypothesized to be a formerly common species, as these collectors visited Hawai'i only briefly and botanized relatively small areas compared to modern botanists. Over the past 50 years, the islands have been well botanized by both Faccenda and many other local botanists, and only one specimen of *A. pakai* has been collected in a remote area of Hawai'i Island. We also examined all 600 photographs of *Amaranthus* spp. on the citizen science website iNaturalist.org and found no observations of *A. pakai*.

Based on this evidence, we hypothesize that *Amaranthus pakai* experienced a dramatic population decline during the 1800s, disappearing from almost all the islands. The same decline played out with the extinction of *A. brownii*, presumably the sister species to *A. pakai*, on the isolated island of Nihoa in Papahānaumokuākea (the northwestern Hawaiian Islands). On Nihoa, *A. brownii* was reported as abundant in the 1920s but precipitously declined, being last seen in 1983, despite only mild disturbances and few invasive species on the island (United States Fish and Wildlife Service, 2003). A dramatic population decline after European contact is not unique to the Hawaiian *Amaranthus* species. These declines and extinctions occurred across many Hawaiian endemic vascular plant taxa, leading to more than 134 extinctions (Wood et al., 2019) and 220 further species that are reduced to 50 or fewer wild individuals (Plant Extinction Prevention Program, 2024).

Figure 1. Holotype specimen of *Amaranthus pakai* Faccenda & N. Bayón (*C. Gaudichaud 121*; P05251971).

Table 1. Morphological comparison between *Amaranthus brownii* Cristoph. & Caum, *A. pakai* Faccenda & N. Bayón, and *A. viridis* L.

	A. brownii	*A. pakai*	*A. viridis*
Plant height	0.4–1 m	0.7–2 m	0.15–0.6 m
Petiole length	3–5 mm	(1–)3–5 cm	1–9 cm
Lamina shape	linear	elliptical or narrowly ovate	ovate, ovate-elliptic, or rhombic
Lamina length	3–5.5(–6.5) cm	(3–)5–8(–12) cm	2–12 cm
Sepals of pistillate flowers	0.8–1 × 0.2–0.5 mm; spathulate	0.77–1.66 × 0.52–1.36 mm; spathulate	0.8–1.7 × 0.25 mm; oblong or narrowly spathulate
Native range	Nihoa	main Hawaiian islands	Central and South America

Given that *Amaranthus* is a genus containing many notoriously weedy species, due in part to their annual lifestyle, wind pollination, and considering that many species are adapted to disturbance (Waselkov et al., 2018), such a dramatic decline across both Hawaiian endemic species of *Amaranthus* suggests that a pathogen, rather than habitat loss or loss of mutualists, may have led to its decline. Examination of specimens of *A. pakai* with this in mind found a species of *Wilsoniana* Thines, a type of oomycete parasite, on the specimen on *Hobdy 4351*. Two species of *Wilsoniana* are known to infect *Amaranthus*: *W. amaranthi* (Schwein.) Y. J. Choi, Thines & H. D. Shinand as well as *W. bliti* (Biv.) Thines (Voglmayr & Riethmüller, 2006). It is unclear which species infected *A. pakai*. While it is not clear that this specific pathogen led to the decline of *A. pakai* or *A. brownii*, it may have played a role.

Using the IUCN Red List categories and criteria (IUCN, 2012; IUCN Standards and Petitions Committee, 2024), we find that *Amaranthus pakai* falls into the Critically Endangered (CR) category because it faces an extremely high risk of extinction in the wild. As several historical subpopulations appear to be extinct, this species is now known to occur only in a single

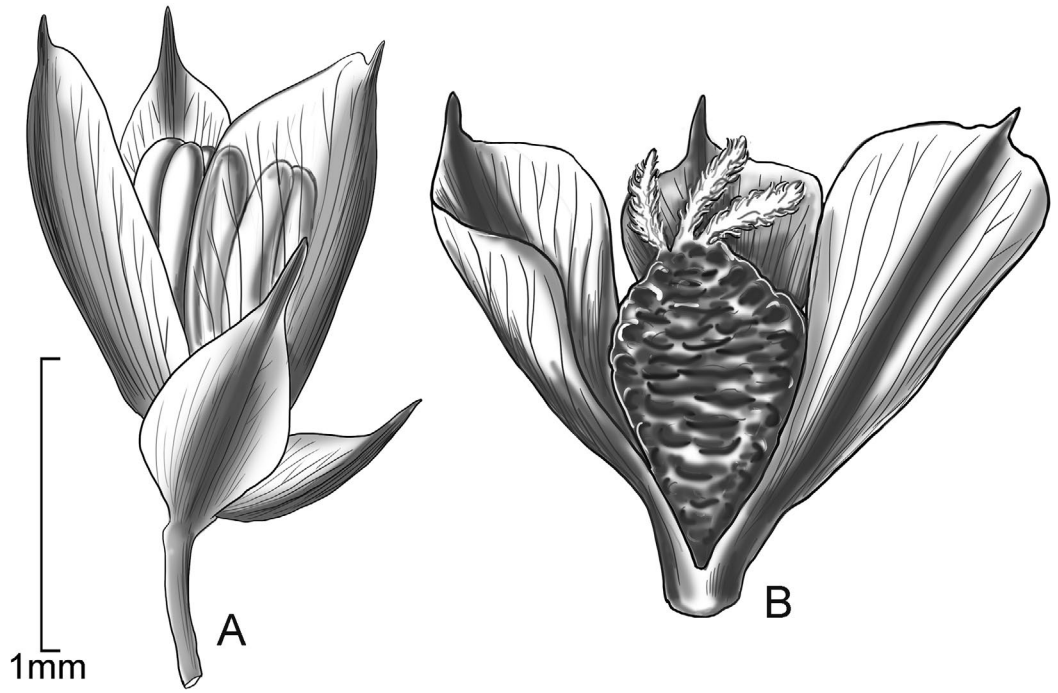

Figure 2. *Amaranthus pakai* Faccenda & N. Bayón flowers. Each sepal has only one central vein, and the lines do not correspond to veins but rather wrinkling from herbarium specimen preservation. —A. Male flower. The rightmost sepal is partially transparent to show the anthers. —B. Female flower with utricle. Drawn from U.S. Expl. Exped. 1838–1842, s. loc., *s.n.*, US00596393; illustrations by Alice R. Tangerini (Smithsonian Institution) from photomicrographs of flowers from herbarium specimens. Flower parts drawn smoothed out from more wrinkled tissue on dried herbarium specimen flowers.

subpopulation of approximately 30 to 40 plants (in 2014). This might lead us to consider applying the A criterion (population reduction) or the C criterion (small population size and decline), but we do not have data precise enough to quantify the parameters for these criteria, and the time span over which population decline has occurred is much longer than those used for criteria A (10 years) and C (three years). Considering the B criterion, the area of occupancy and, by default, extent of occurrence are both treated as being 4 km^2. The locality is not protected; habitat quality has not been assessed, and future land use plans are unknown. Even if the locality were preserved intact, the species would remain at presumptive risk from the cause of extinction of the other subpopulations, here hypothesized to be introduced disease. If the pathogen were positively identified to species and its mechanism was better understood, this would support an assessment as Critically Endangered under the B criterion (CR B1ab[v]+B2ab[v]). However, the D criterion is certainly applicable: Hobdy reported (*Hobdy 4351*) that the number of plants was small enough (fewer than 50 mature individuals) to qualify as CR D.

Etymology. Pakai is the Hawaiian name for this plant and was recorded by Gaudichaud in his journal as specifically referring to *Amaranthus* (Gaudichaud, 1826; St. John & Titcomb, 1983).

Paratypes. U.S.A. **Hawai‘i:** South Kohala, Puakō, 30–40 plants, 500 ft., 10 Apr. 2014, *R. W. Hobdy 4351* (BISH-763658); Isles Sandwich, O‘ahu, 1854–1855, *J. Remy 203* (P [bc] P05251973; P [bc] P05251972); Iles Sandwich, Lāna‘i, 1854–1855, *J. Remy 203* (P [bc] P05251969); Iles Sandwich, *C. Gaudichaud s.n.* (P [bc] P05251970); Sandwich Islands, 1838–1842, *U.S. Exploring Expedition s.n.* (US [bc] 00596393 photo); Ins. Sandwich, Woahoo [O‘ahu], May 1825, *Macrae s.n.* (HUH [bc] 02528808 photo); Sandwich Islands, Kaua‘i, *U.S. Exploring Expedition s.n.* (HUH [bc] 02528808 photo; two specimens and labels on this sheet).

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