# Vegetation of an Alpine Bog on East Maui, Hawaii[1]

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ABSTRACT: Ten species of vascular plants, two bryophytes, and one lichen comprised the flora of a bog located on the northeast outer slopes of Haleakala Crater at 7,440 ft elevation. The vegetation was dominated by *Carex montis-eeka* and *Deschampsia australis*, along with lesser amounts of *Oreobolus furcatus* and the dwarf *Vaccinium pahalae*. Despite its higher location, the area shares similarities with other Hawaiian bogs, except that it possesses a very simple flora. *Lobelia* and/or *Argyroxiphium* spp. may have once existed in the bog but could have been eliminated by past heavy grazing. The bog occupies a large saucer-shaped depression filled with acid peat. It is considered to have developed by the process of hydrarch plant succession rather than the usual site deterioration and plant retrogression.

THE NORTHEAST OUTER SLOPES of Haleakala Crater on East Maui, Hawaii, starting at Kalapawili Ridge at 8,000 ft (2,438 m) and descending to about 7,300 ft (2,225 m) elevation, are dominated by a mountain pili or Hawaiian hairgrass (*Deschampsia australis* (Nees) Hillebr. forma *haleakalensis* Skottsb.) grassland. The grassland is classified as alpine since it occurs above the upper limits of forest which generally has a well-defined treeline between 7,000 ft (2,134 m) and 7,300 ft (2,225 m) elevation, possesses a flora, physiognomy, and climate that are typically alpine, and because the term "alpine" has been used for such areas by previous Hawaiian investigators (Skottsberg, 1931; Hartt and Neal, 1940; Fosberg, 1959; Mueller-Dombois, 1967). This paper presents the floral, vegetational, and physical features of a treeless bog located in the northeast sector of the grassland at 7,440 ft (2,268 m) elevation. Three small montane bogs that occur at lower elevations are also described.

## METHODS

Plant specimens collected from the bogs have been distributed from the California State College, Los Angeles Herbarium to the Bernice P. Bishop Museum, Smithsonian Institution, National Herbarium, and Rancho Santa Ana Botanic Garden.

The alpine bog vegetation was sampled for percent frequency of occurrence using 60 quadrats, each 25 cm by 25 cm or one-sixteenth $m^2$ in size. The samples were randomly distributed within the bog to provide maximum coverage. Percent cover was obtained from two 50-ft line-intercepts, each placed centrally along a predetermined compass line in one-half of the bog. Plant intercepts were read to the nearest 0.1 ft, except for those of the mosses, lichens, *Panicum* sp., and *Carex svenonis* which were too small and mixed to be readily separated. Various species' heights were measured, as were the diameters of *Oreobolus furcatus* hummocks or cushions.

Peat depths were measured at five equally spaced locations across the bog, a central soil profile was dug, soil pH was measured, and a number of open-water pockets were measured.

## RESULTS

### *Floristic Composition*

A total of 14 taxa of 13 species in nine families was encountered in the alpine bog which includes 10 species of vascular plants, two bryophytes, and one lichen (Table 1). The most important families with regards to diversity were the Cyperaceae, represented by two genera —*Carex* with three species and *Oreobolus* with

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TABLE 1

PRESENCE LIST OF ALPINE BOG SPECIES FROM EAST MAUI, HAWAII ARRANGED BY FAMILIES

LICHENS
Cladoniaceae
*Cladonia* sp.
MOSSES
Dicranaceae
*Campylopus skottsbergii* Brotherus
Grimmiaceae
*Racomitrium lanuginosum* (Hedwig) Bridel. var. *sandvicense* Reichardt
FLOWERING PLANTS
Cyperaceae (Sedge Family)
*Carex alligata* W. Boott var. *alligata*
*Carex montis-eeka* Hillebr.
*Carex svenonis* Skottsb.
*Oreobolus furcatus* Mann var. *furcatus*
*Oreobolus furcatus* Mann var. *gaimardioides* Skottsb.
Poaceae (Grass Family)
*Deschampsia australis* (Nees) Hillebr. forma *haleakalensis* Skottsb.
*Panicum* sp.
Asteraceae
*Hypochaeris radicata* L.
Epacridaceae (Epacris Family)
*Styphelia tameiameiae* (Cham. & Schlecht.) F. V. Muell. var. *tameiameiae*
Ericaceae (Heath Family)
*Vaccinium pahalae* Skottsb.
Plantaginaceae (Plantain Family)
*Plantago pachyphylla* A. Gray var. *mauiensis* A. Gray

two varieties of one species—and the Poaceae with one species each in *Deschampsia* and *Panicum*. The other seven families were represented by one species each.

The flora contained only one exotic species, the perennial *Hypochaeris radicata*. All the other species are endemic to the Hawaiian Islands. *Oreobolus furcatus* var. *gaimardioides* and *Vaccinium pahalae* appear to be restricted on East Maui to this bog site. All other taxa are known to occur either in the adjacent heath scrub or in bogs in the montane rain forest.

The bog contained four taxa known only from East Maui; a new species of *Panicum*, varieties or forms of *Plantago pachyphylla*, *Deschampsia australis*, and a potential new form of *Vaccinium pahalae*. *Carex montis-eeka*, *Oreobolus furcatus* var. *gaimardioides*, the new *Panicum*, and *Vaccinium pahalae* were unknown or only recently known (Warner, 1967) from East Maui.

Two taxa have distinctive characteristics and appear worthy of nomenclatural recognition. The *Panicum* is similar to *P. imbricatum* Hillebr. of West Maui and is one of two taxa St. John is describing as a new species based on the collections of C. N. Forbes from other bogs of East Maui (H. St. John, personal communication). The diminutive *Vaccinium* has leaves similar to those of *Vaccinium pahalae* of the island of Hawaii, but the corollas are distinctive—campanulate, short and molted red-green, rather than urceolate and solidly dark red. Studies may eventually lead to the recognition of this taxon as a new variety or form based on floral differences.

*Vegetational Composition*

The bog was dominated by a mixed stand of *Carex montis-eeka* and *Deschampsia australis* which grew to an average height of 8 inches (20 cm) out of and between cushions of *Oreobolus furcatus* (Table 2). The uniform dense stands of grey-green sedge and grass gave the bog the appearance of a drab meadow (Figs. 1*a*, *b*; 2*a*). The dwarf and single-stemmed form of *Vaccinium pahalae* (Fig. 2*b*) was widely scattered throughout the bog, resulting in a high percent frequency of occurrence (78.3 percent). It, however, accounted for only a minor part of the total cover (0.5 percent) because of

TABLE 2

PERCENT FREQUENCY OF OCCURENCE OF ALPINE SPECIES FOUND IN A BOG ON EAST MAUI, HAWAII

| SPECIES | PERCENT FREQUENCY | PERCENT COVER |
|---|---|---|
| *Deschampsia australis* | 93.3 | 10.1 |
| *Carex montis-eeka* | 86.5 | 60.6 |
| *Vaccinium pahalae* | 78.3 | 0.5 |
| *Oreobolus furcatus* | 73.3 | 35.0 |
| *Carex svenonis* | 50.0 | |
| *Racomitrium lanuginosum* | 45.0 | |
| *Campylopus skottsbergii* | 31.7 | 6.6 |
| *Panicum* sp. | 13.3 | |
| *Cladonia* sp. | 11.7 | |
| *Hypochaeris radicata* | 11.7 | 0.1 |
| *Styphelia tameiameiae* | 1.7 | |
| Bare Ground | | 0.6 |

NOTE: Study based on 60 quadrats, each 25 cm by 25 cm. Percent cover based on two 50-ft line-intercepts.

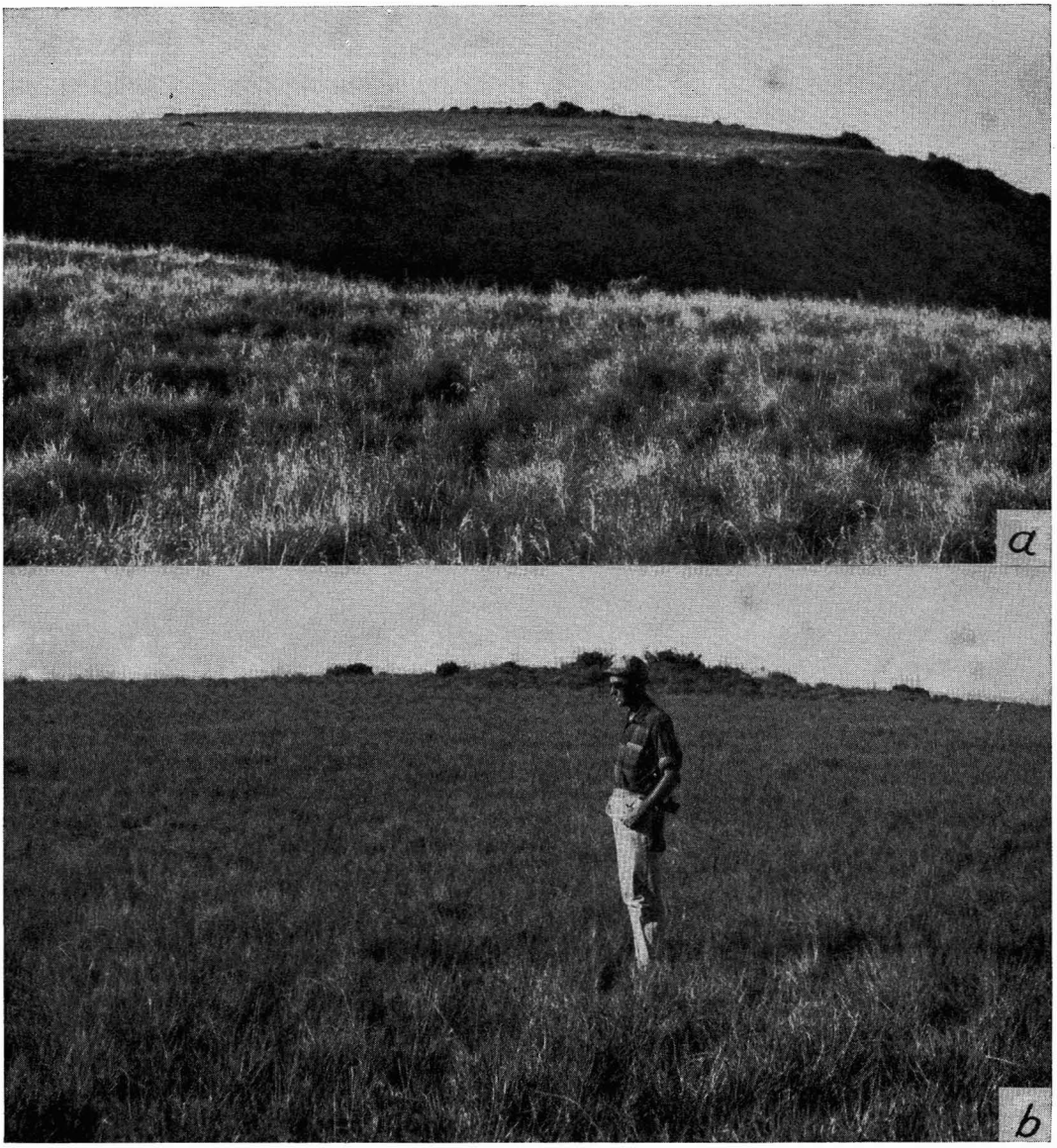


FIG. 1. *a,* The flat-surfaced alpine bog in the background occupies a saucer-shaped depression with a shrub-studded rim. The bog occurs at 7,440 ft elevation and is surrounded by *Deschampsia australis* tussock grassland; *b,* the soggy alpine bog is covered by a mixed stand of *Carex montis-eeka* and *Deschampsia australis.*

its small size which seldom exceeded 2 inches (5 cm) in height. Numerous dead *Vaccinium* plants, with their dried foliage still intact, were observed but not sampled. The only other woody species present was *Styphelia tameiameiae,* represented by a few stunted shrubs up to 2 ft (0.6 m) in height that were most common around the bog periphery. This species commonly attained heights of 3 to 5 ft (0.9 to 1.5 m) or more outside the bog. The *Deschampsia* grass also differed, forming a thin sod of short stems and leaves (Fig. 1*b*), whereas in the adjacent grassland it formed bunches or tussocks that commonly reached several feet in height, particularly in wet areas.

Other species with relatively high percent

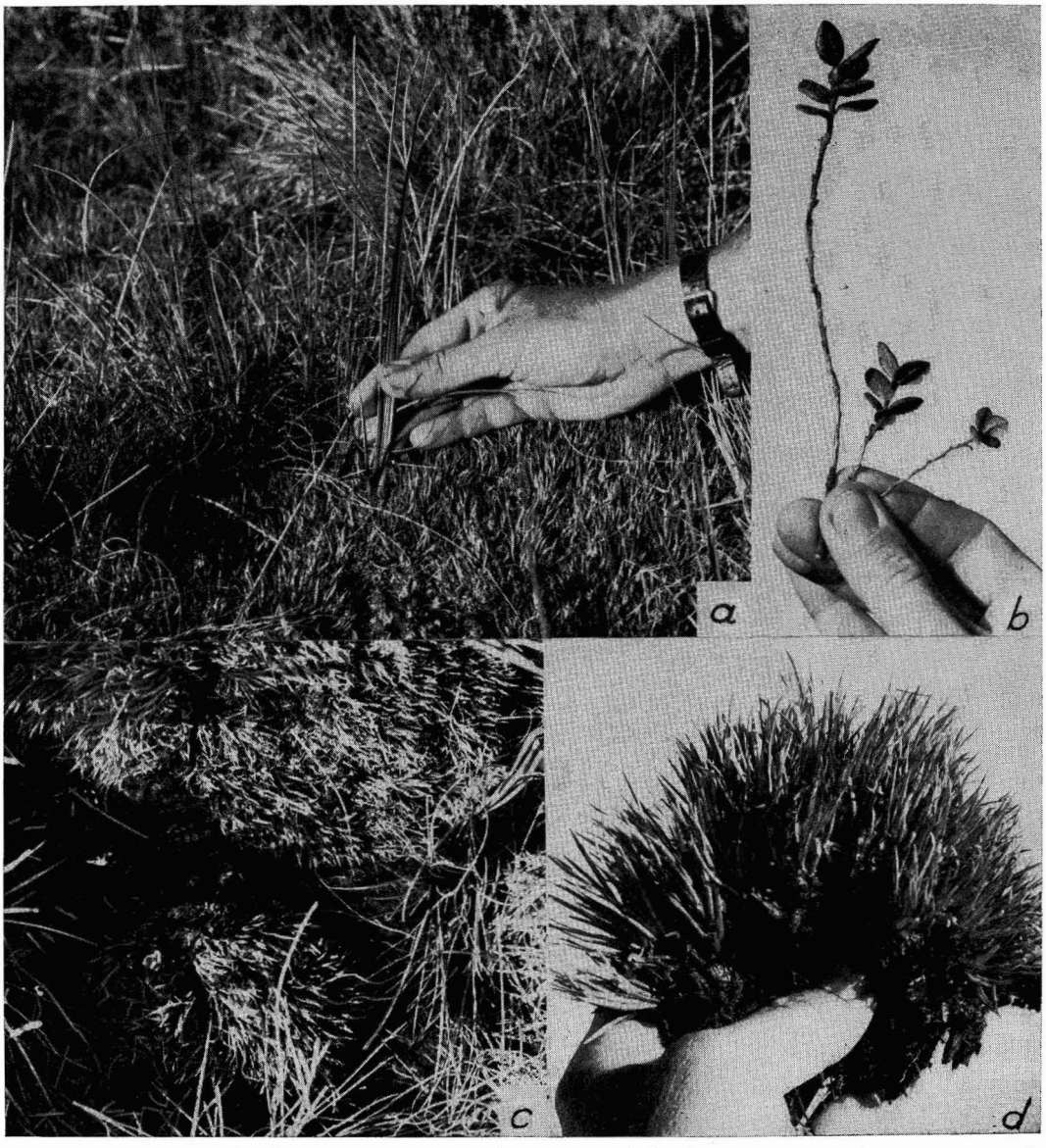


FIG. 2. *a, Carex montis-eeka* (in hand) growing from an *Oreobolus furcatus* cushion; *b,* the dwarf, woody *Vaccinium pahalae* occurs throughout the bog. Three typical plants are shown; *c, d,* turfy cushions of *Oreobolus furcatus* are characteristic of many Hawaiian bogs. These raised hummocks provide sites in the wet and acid bogs for sedges, grasses, mosses, and lichens.

frequencies of occurrence were *Carex svenonis* (50 percent), and the mosses *Racomitrium lanuginosum* (45 percent), and *Campylopus skottsbergii* (31.7 percent) (Table 2), but because of narrow leaves or small sizes, accounted for only a minor portion of the plant cover (Table 2).

The bog surface had a spongy and billowy texture produced by the raised cushions of *Oreobolus furcatus* (Figs. 2*a, c, d*). The crests of these cushions were preferred sites for *Cladonia* sp. growth, and the bases and edges sustained concentrations of *Racomitrium lanuginosum* and *Campylopus skottsbergii.* Mea-

sured *Oreobolus* cushions averaged 17.0 inches (43 cm) in diameter, ranging from 10 to 26 inches (25 to 66 cm), and averaged 4.4 inches (11 cm) in height, ranging from 2 to 8 inches (5 to 20 cm) above ground.

*Physical Features*

The bog surface was flat and level (Fig. 1*a*, *b*) and underlain with reddish-brown sedge-grass peats that were extremely soft. Peat depths, ranging from 46 inches (1.2 m) near the edge to 60 inches (1.5 m) in the center, indicated that the peat had accumulated in a large saucer-shaped depression (Fig. 1), apparently formed by volcanic action and/or erosion and then perhaps rendered impervious by clay accumulation (Wentworth, Wells, and Allen, 1939). The filled depression was circular in shape with a diameter of approximately 80 yards (73 m), and was situated at the base of a series of sloping and descending benches that supported *Deschampsia* tussock grassland. As a result, the bog received considerable runoff from the relatively impervious soils and the watershed of the surrounding grasslands, intensifying the already heavy rainfall which might possibly be as much as 250 inches (635 cm) or more annually (MacCaughey, 1916). Selling (1948) thought that most Hawaiian bogs receive about 200 inches (500 cm) of precipitation annually. The bog not only served as a catch basin for water, but also for organic matter and soil washed and eroded from the grasslands. During rainy periods which generally occur the year around, although the summer months may be sometimes somewhat drier, the peat became saturated and water stood on the level surface before seeping away or flooding over the bog rim to lower elevations. Overflow drainage appeared to take place principally along the eastern margin where the water flowed into an adjacent gulch. A number of open-water pockets occurred on the northcentral bog surface, perhaps indicating the lowest part of the bog. These small hollows accounted for most of the bare ground listed in Table 2. Additional pockets flanked the eastern bog edge. These openings were devoid of vascular plants and ranged from 10 by 10 inches (25 by 25 cm) to 24 by 36 inches (61 by 91 cm) in size and from 4 to 14 inches (10 to 36 cm) in depth. These depressions normally held water, but occasionally dried out during rainless periods. The swampy condition in these pockets apparently inhibited the growth of vascular plants, but blackish-green mats of algae combined with dead roots and leaves of the surrounding vegetation lined the dark liquid-muck bottoms. Plants identified from collected mat material include an abundance of the blue-green alga *Hapalosiphon* sp., with lesser amounts of desmids *Micrasterias truncata, Tetmemorus* sp., and *Staurastrum* sp., and the bluegreen *Chroococcus* sp. The edges of the depressions were often encircled with the same mosses that occurred around the edges of the *Oreobolus* cushions.

The peat soils were wet and cold, with undecomposed plant material present. The soil was smeary to the touch and water could be squeezed from it. The upper soil layers were reddish-brown and semisolid with a 5.0 to 5.5 pH, and the lower layers were yellow-brown and semiliquid with a 4.5 pH as measured with a Hellig-Truog soil tester.

Little is known about the climate of the upper northeast outer slopes of Haleakala Crater. A few comments can be made based on observations made during visits to the area. The upper slopes appeared to be strongly affected by the northeast trade winds which tended to blow steadily and sometimes forcefully. The trade winds usually produced a heavy cloud cover over the rainforest below. This tended to move upslope and reach ground level in the upper forest, forest edge, and grassland. Air moisture, even when it is not raining or cloudy, was often at or near saturation. The grassland was swept by rapidly moving ground-level clouds or windblown mists, light rains, or downpours under a low cloud cover. Heavy dews or sometimes hoarfrosts occurred during clear nights. The soils were usually wet, muddy, or flooded, or carried streams of runoff. Nighttime frosts occurred during all seasons. Snow occasionally occurred in the winter months but did not persist. When clear weather prevailed, which appeared to be the exception, the area received intense insolation, but temperatures during the June 1969 study period seldom exceeded 70° F. Diurnal temperature fluctuations

of up to 40° F were measured. Daytime temperatures differed up to 30° F between clear and cloudy skies.

*Montane Bogs*

Three additional bogs were found within the montane rain forest between lakes Wai Anapanapa and Wai Eleele (Maciolek, 1969). The uppermost area consisted of several small pockets of bog within a swampy 1-acre *Deschampsia* tussock grassland located on a saddle adjacent to and just above Wai Anapanapa at about 6,800 ft (2,073 m) elevation. The sides of the grassland opening sloped to the center and then drained into the lake at the upper end, and sloped toward the opposite direction along the middle and lower portions, dropping off into a steep fern and forest-covered gulch.

Two other bogs occurred along narrow portions of a pali or cliff separating Kipahulu Valley from the northeast slopes and the Hana drainage. These saddles were separated from each other by forested *puus* or hills. The bogs were closer to Wai Anapanapa than Wai Eleele and occurred just above 6,700 ft (2,042 m) elevation. These open pockets were abruptly surrounded by a mature ohia lehua (*Metrosideros collina* ssp. *polymorpha*) forest and had generally flat surfaces that sloped to the northeast. Some of the common plants in these wet, watery, and spongy-soft sites were *Deschampsia australis, Carex alligata* var. *alligata, Carex montis-eeka, Carex svenonis*, and *Dryopteris glabra* as well as some species previously mentioned in the alpine bog (Table 3).

Bog conditions and typical plants, including *Carex macloviana* var. *subfusca, Carex nealae, Luzula compestris* var. *hawaiiensis*, and *Rubus hawaiiensis* were also found along the immediate shores of Wai Anapanapa. A sedge mat surrounded part of Wai Eleele extending out over its dark waters for at least 5 ft (1.5 m). Another small bog was observed below Wai Eleele, under 6,700 ft (2,042 m) elevation, in the bottom of an inverted cone or steep-sided basin or sink, similar to the sink containing Wai Anapanapa. This lower bog hole apparently received water from Wai Eleele when it overflowed, and was surrounded by dense tangles of *Broussaisia arguta* and *Rubus hawaiiensis*.

TABLE 3

PLANTS OCCURING IN THREE MONTANE BOGS WITHIN *Metrosideros-Cheirodendron* FORESTS BETWEEN 6,800 AND 6,700 FEET ELEVATION ON EAST MAUI, HAWAII

| |
|---|
| Aspidiaceae |
| *Dryopteris glabra* (Brack.) Kuntze |
| Cyperaceae |
| *Carex alligata* W. Boott var. *alligata* |
| *Carex alligata* W. Boott var. *degeneri* Krauss |
| *Carex macloviana* D'urv. var. *subfusca* (W. Boott) Kunkenth. |
| *Carex montis-eeka* Hillebr. |
| *Carex nealae* Krauss |
| *Carex svenonis* Skottsb. |
| Juncaceae |
| *Luzula campestris* (L.) DC. var. *hawaiiensis* (Buch.) Degener & Fosberg |
| Poaceae |
| *Deschampsia australis* (Nees) Hillebr. forma *haleakalensis* Skottsb. |
| *Holcus lanatus* L. |
| *Panicum* spp. (2) |
| Ericaceae |
| *Vaccinium berberidifolium* (A. Gray) Skottsb. |
| Epacridaceae |
| *Styphelia tameiameiae* (Cham. & Schlecht.) F. V. Muell. var. *tameiameiae* |

These montane bogs may have also been visited by C. N. Forbes (1920) and by H. St. John (personal communication).

## DISCUSSION

Bogs or montane mires have been reported for Kauai, Oahu, Molokai, West Maui, and Hawaii (Hillebrand, 1888; Rock, 1913; MacCaughey, 1916; Campbell, 1920; Fosberg, 1936; Fosberg and Hosaka, 1938; Skottsberg, 1940; Selling, 1942, 1948). But they have not been studied on East Maui, except that Pickering in 1876 (in Selling, 1948) collected *Oreobolus* there and MacCaughey (1916) mentioned "Wai-a-napa-napa" on Maui as an important bog region. Forbes (1920), Gregory (1920), O. Degener, H. St. John (personal communications), A. L. Mitchell, and De Wreede (Lamoureux, 1967) collected within either the upper forest, Haleakala Crater, or Kaupo and Koolau gaps, but it is doubtful if the alpine bog was visited.

The bog is unique since it represents the highest elevational bog, 7,440 ft (2,268 m),

described in Hawaii, the previous high being Puu Kukui Bog on West Maui at 5,788 ft (1,764 m) elevation, followed by the Kaala Bogs in the Kohala Mountains, Hawaii at 5,505 ft (1,679 m), and Waialeale Bog on Kauai at 5,280 ft (1,609 m) elevation (Rock, 1913; Selling, 1948). The study area exceeds all other described Hawaiian bogs by at least 1,500 ft (457 m) elevation, and is the only one occurring above treeline in an alpine area.

Despite its high elevation and alpine status, the vegetation shares similarities with other Hawaiian bogs. The universal characteristic of Hawaiian bogs is the dwarf nature of the herbaceous and woody vegetation. Present vegetation heights are similar to those reported by Selling (1948) and Fosberg (1961). Herbaceous dwarfness may often be more than the result of environmental-physiological reactions, and may actually represent genetic and species differences. Other general characteristics of Hawaiian bogs are the turfy and hummocky growth, the flat-surfaced or level sites, and the extreme wetness of the soils and local climates. A few species might be common to all Hawaiian bogs (Rock, 1913), some are restricted to one area, and some species have invaded bogs from the surrounding forest (Fosberg and Hosaka, 1938; Fosberg, 1961). *Oreobolus furcatus* (Fig. 2*d*) is common to most Hawaiian bogs, along with dwarf species or forms of *Panicum* and *Deschampsia* (Skottsberg, 1944; Selling, 1948; Fosberg, 1961). Selling (1948) stated that *Oreobolus* is the principal peat-forming plant, giving the peat a reddish brown color; it probably accounted for the similarly colored substrate in this study. *Racomitrium lanuginosum* also has a wide Hawaiian distribution (Selling, 1948; Fosberg, 1961). *Carex montiseeka* is common on Kauai, Molokai, and Maui (Krauss, 1950), and may reach optimum growth in extremely wet bogs. Other bogs are dominated by *Rhynchospora lavarum* (Fosberg, 1961), a species not encountered in the present study. *Carex svenonis* is common to wet regions and bogs above 5,000 ft (1,524 m) elevation on Maui and Hawaii (Krauss, 1950). *Vaccinium pahalae* is known from Hawaii, Molokai, and Oahu bogs (Fosberg and Hosaka, 1938).

Using the limited published data, it appears that most of the species found in the alpine bog are also found in West Maui bogs (Rock, 1913; Selling, 1948). This degree of similarity was expected because Puu Kukui Bog on West Maui is the closest in distance and elevation. The present area, however, is depauperate in comparison to West Maui bogs, lacking the diversity and number of endemics present there and in other bogs (Selling, 1948). The simple flora, with only 10 common native species (Table 2), the homogeneous nature of the vegetation, and the absence of unusual Hawaiian plants such as *Acaena exigua, Drosera longifolia, Lobelia* spp., and *Argyroxiphium* spp. sets it apart from other Hawaiian bogs. This lack of diversity may be partly explained by the alpine location. The usual wet forest invaders have been excluded and the surrounding grassland possesses few species for invasion. *Lobelia* and/or *Argyroxiphium* spp. may have once existed but could have been eliminated by feral goats (Yocom, 1967) and pigs, and especially by the large numbers of cattle that once grazed the area (O. Degener, E. Grassi, T. Silva, Kaupo Ranch, personal communications). Present signs of herbivore damage were not found. Greenswords (*Argyroxiphium virescens* Hbd.) once existed on the northeast outer slopes of Haleakala Crater (Forbes, 1920; O. Degener, R. Harris, personal communications). We collected *Argyroxiphium grayanum* (Hillebr.) Degener (no. 3566) in a boggy opening above Wai Eleele which possessed growing conditions similar to those of the bog. *Cyanea horrida* (Rock) Degener & Hosaka (no. 3541), and *Lobelia grayana* E. Wimm. (no. 3547) still exist in the protection of the forest and might have also existed in the alpine bog prior to heavy grazing.

Hillebrand (1888), Rock (1913), MacCaughey (1916), Campbell (1920), Fosberg and Hosaka (1938), Robyns and Lamb (1939), Skottsberg (1940), Selling (1942, 1948), and Fosberg (1961) speculated as to reasons for the existence of Hawaiian bogs. Fosberg (1961) summarized these observations and generalizations, proposing that Hawaiian bogs generally owe their existence to locally wet and cold climatic conditions, as well as special topographic and soil features. He stated that certain

level or gently sloping forested areas, usually at upper elevations, receive heavy rainfall, and develop clay or hard pans (Wentworth, Wells, and Allen, 1939) which impede drainage. The results are swamping, increased acidity, and poor aeration. The soils become waterlogged, the trees drown, and the forest becomes decadent, deteriorating through a series of vegetational stages to a sedge bog formation.

Explanations or descriptions of bogs reverting back to forest have not been found. It seems likely that if environmental, topographic, edaphic, and vegetational changes bring about the existence of bogs, the process might be occasionally reversed, or be cyclic in nature (Cowles, 1911, 1928). Heavy downpours producing slumping, scalping, massive erosion, or landslides may help to eliminate some bogs, particularly over long periods of time.

Some Hawaiian bogs might have come into existence by another process other than plant retrogression and site deterioration. The alpine bog appears to have enough geomorphological similarities with surrounding bodies of water to indicate that the bog has progressed from open water to a terrestial site by the process of hydrarch succession aided by erosion. A shallow open-water pond of similar size and structure exists where the base of Kalapawili pali meets the head of Kipahulu Valley. In addition, Lake Wai Anapanapa is a shallow closed-basin pond, ranging from 2 to 6 ft (0.6 to 1.8 m) in depth (Maciolek, 1969). Its algae-choked waters are perhaps indicative of advanced eutrophication and its shallow nature and muck-filled bottom suggest senescence. The deep crater just below Lake Wai Eleele appears to have been converted to a terrestrial bog, but was once a lake or pond like Wai Anapanapa. Bog plants were found on all these lake margins. The deepest lake, Wai Eleele, possesses a sedge mat similar to those formed in temperate and boreal bogs. In fact, the lakes appear to share characteristics with postglacial bog lakes of the mainland (Reid, 1961), including acidic conditions, soft waters (Maciolek, 1969), sedge mats, peat accumulations, suspected high iron contents, cool temperatures, and stained or dark-colored waters. The Hawaiian word *'ele'ele* means "black" in English. Hard pans are common in Hawaiian bogs (Selling, 1948) and have been used to account for their formation (Fosberg, 1961); they may form by podzolization, a process usually associated with northern and boreal areas. An obvious inference from these similarities is that hydrach plant succession has played a role in the formation of this and perhaps other Hawaiian bogs. Once established, these bogs continue to build by way of peat accumulations, which Rock (1913) claimed reached 10 to 15 ft (3 to 4.6 m) in depth and which Selling (1948) found to reach a maximum depth of 10.5 ft (3.2 m). The continuously accumulating peat may help these bogs to persist, but might occasionally be retrogressively affected by fire as documented by Selling's (1948) comment that Lehua Maka Noe Bog on Kauai had a very shallow peat because it had been recently burned.

This alpine bog might provide paleobotanic information on Hawaii's past climate, tephrochronology, and Late Quarternary chronology, in addition to that presented by Selling (1948).

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