USDA Natural Resources
Conservation Service

Ecological site VX163X01X001
Shrink-Swell Clay

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General information

Provisional. A provisional ecological site description has undergone quality control and quality assurance review. It contains a working state and transition model and enough information to identify the ecological site.

MLRA notes

Major Land Resource Area (MLRA): 163X–Alluvial Fans and Coastal Plains

This MLRA is in the State of Hawaii on the islands of Maui, Lanai, Molokai, Oahu, and Kauai. Elevation ranges from sea level to 800 feet (0 to 244 meters) with elevation extremes up to 1,600 feet (488 meters). The terrain is nearly level and gently sloping coastal plains and adjacent alluvial fans. Beneath the unconsolidated sediments are basalt, coral limestone, calcareous sand deposits, volcanic ash, coral sand, and fill. Average annual precipitation ranges from 10 to 40 inches (254 to 1,016 millimeters) with precipitation extremes up to 122 inches (3,099 millimeters) in select places on Oahu and Kauai (Giambelluca et al., 2013). Most of the rainfall occurs from November through March during kona storms that come in from the leeward side of the islands. Average annual temperatures range from 68 to 82 degrees F (20 to 28 degrees C) with little seasonal variation (Giambelluca et al., 2014). Dominant soils are Mollisols, Aridisols, Entisols, and Vertisols with an isohyperthermic soil temperature regime and aquic or aridic (torric) to ustic soil moisture regimes. Vegetation consists of forbs, grasses, and shrubs with some trees. Almost all the plant species typically encountered are introduced species that have become naturalized in Hawaii (USDA-NRCS, 2006).

Classification relationships

This ecological site occurs within Major Land Resource Area (MLRA) 163 - Alluvial Fans and Coastal Plains.

The Aha Moku System, which dates back to the 9th century and has been passed down through oral tradition and generational wisdom, effectively sustains Hawaii's natural ecosystems and environment (DLNR, 2024). This site-specific and resource-based approach balances land and ocean resources essential for fostering healthy, thriving communities. Grounded in Native Hawaiian generational knowledge, the Aha Moku System emphasizes community consultation to prioritize the health and welfare of Hawaii’s natural and cultural resources. It is rooted in the concept of 'ahupua'a, the traditional system of land and ocean management in Hawaii. For collaboration, this ecological framework encompasses the following mokus:

Oahu Moku Acres: Wai’anae (7,982), Kona (5,468), Ewa (5,420), Ko’olaupoko (1,677), Ko’olauloa (881), and Waialua (677).

Kauai Moku Acres: Kona (2,490), Ko’olau (99), and Napali (42).

Molokai Moku Aces: Kona (1,497).

Lanai Moku Acres: Lahaina (67).

Ecological site concept

This ecological site is largely cropland or naturalized grassland at low elevations on the leeward slopes of Molokai, Lanai, Oahu, and Kauai. Much of the area is in cropland, grazing land, or has been developed (USDI-USGS, 2006). Principal landowners are the United States Government, the State of Hawaii, and private land companies and ranches. It can be accessed along Kaunakakai Road on the southwestern coast of Molokai, on the eastern coast of Lanai along the local road near Lopa, near Route 93 near Waianae on Oahu, and along Route 50 Kekaha on Kauai.

The central concept of the Shrink-Swell Clay Ecological Site is of clayey soils formed in alluvium, volcanic tuff, or residuum from basic igneous rock. The soils are in the Soil Order of Vertisols. Annual air temperatures and rainfall are associated with very warm (isohyperthermic), seasonally dry (aridic/torric or aridic/ustic intergrade) soil conditions. Elevations range from sea level to 800 feet (0 to 244 meters) with elevation extremes up to 1,600 feet (488 meters) (USDA-SCS, 1972). Because very little of the original native vegetation remains, the reference state of this ecological site consists of naturalized grassland vegetation. The dominant introduced grass species is buffelgrass (*Pennisetum ciliare*). Common naturalized trees are kiawe (*Prosopis pallida*) and white leadtree or haole (*Leucaena leucocephala*).

The original native vegetation was probably dry savanna or shrubland with grasses. Common native species, based largely on conjecture until field work can be done, may have been 'ohe makai (*Reynoldsia sandwicensis*), wili wili (*Erythrina sandwicensis*), lama (*Diospyros sandwicensis*), naio (*Myoporum sandwicense*), Florida hopbush or aalii (*Dodonaea viscosa*), yellow ‘ilima (*Sida fallax*), oval-leaf clustervine or pauohiiaka (*Jacquemontia ovalifolia* ssp. sandwicensis), queen coralbead or huehue (*Cocculus orbiculatus*), and native grasses (Rock, 1913; Wagner et al., 1999).

Associated sites

VX158X01X002	**Isohyperthermic Torric Naturalized Grassland Kiawe/buffelgrass (Prosopis pallida/Pennisetum ciliare)** The Isohyperthermic Torric Naturalized Grassland Ecological Site has a similar climate to this ecological site, but its soils are very different. It does not have shrink-swell clays (Vertisols) and generally has less water-holding capacity. The plant species of these ecological sites are similar.
VX158X01X401	**Isohyperthermic Ustic Naturalized Grassland Koa haole/guineagrass/glycine (Leucaena leucocephala/Urochloa maxima/Neonotonia wightii)** The Isohyperthermic Ustic Naturalized Grassland Ecological Site has a moister and slightly cooler climate than this ecological site and its soils are very different. It does not have shrink-swell clays (Vertisols). The plant species of Shrink-Swell Clay are similar to those found in the lowest elevations of the Isohyperthermic Ustic Naturalized Grassland.
VX163X01X004	**South and West Aspect Isohyperthermic Naturalized Grassland** The South and West Aspect Isohyperthermic Naturalized Grassland Ecological Site has a similar climate and aspect to this ecological site. It does not have shrink-swell clays (Vertisols) and generally less water-holding capacity. The plant species of these ecological sites are similar.

Table 1. Dominant plant species

Tree	(1) *Prosopis pallida* (2) *Leucaena leucocephala*
Shrub	Not specified
Herbaceous	(1) *Pennisetum ciliare*

Legacy ID

R163XY001HI

Physiographic features

This ecological site primarily occurs on coastal plain landscapes on level to slightly sloping alluvial fans and alluvial flats (USDA-SCS, 1972).

Table 2. Representative physiographic features

Landforms	(1) Coastal plain > Alluvial fan (2) Coastal plain > Alluvial flat
Runoff class	Low to high
Flooding frequency	None to rare

Ponding frequency	None to rare
Elevation	0–800 ft
Slope	0–12%
Water table depth	72 in
Aspect	SE, S, SW

Table 3. Representative physiographic features (actual ranges)

Runoff class	Very low to very high
Flooding frequency	Not specified
Ponding frequency	Not specified
Elevation	0–1,600 ft
Slope	0–35%
Water table depth	42–72 in

Climatic features

Summary for this ecological site

Rainfall statistics were determined from University of Hawaii's Rainfall Atlas Raster Data (Giambelluca et al., 2013). Most of the precipitation falls from October through April. Representative (20th and 80th percentiles) values for annual average precipitation range from 23 to 43 inches (584 to 1,092 millimeters) while actual (10th and 90th percentiles) values for annual average precipitation range from 22 to 52 inches (559 to 1,321 millimeters). Extreme values range from 14 to 122 inches (356 to 3,099 millimeters). The mean annual precipitation is 33 inches (838 millimeters) and the median annual average precipitation is 28 inches (711 millimeters).

Temperature statistics were determined from University of Hawaii's Surface Temperature Raster Data (Giambelluca et al., 2014). Representative (20th and 80th percentiles) values for annual temperatures range from 75 to 81 degrees F (24 to 27 degrees C) while actual (10th and 90th percentiles) values for annual temperatures range from 73 to 81 degrees F (23 to 27 degrees C). Extreme values range from 70 to 82 degrees F (21 to 28 degrees C). The mean annual temperature is 77 degrees F (25 degrees C) and the median annual temperature is 75 degrees F (24 degrees C).

The data presented in the climate normals tables below are from the Western Region Climate Center (Western Regional Climate Center, 2020). The available climate station data are most representative of the low and moderate precipitation areas of this ecological site. I used these data because they provide a reasonable approximation of the University of Hawaii data presented above.

Conditions typically are very dry. Rainfall occurs as occasional light trade wind showers that drift over from the windward side of the island and as heavier rainfall during major winter storms. Major storms are important for soil moisture recharge, and the number of major storms is highly variable. Drought can result from a winter with few or no storms. Due to the latitude, daylength varies little during the year, resulting in only about a 50 percent variation in solar energy input between June maximum to December minimum. This variation is somewhat less than that found in the continental United States (USDA-SCS, 1972; Western Regional Climate Center, 2020).

General principles

Air temperature in the Hawaiian Islands is buffered by the surrounding ocean so that the range in temperature through the year is narrow. This creates “iso" - soil temperature regimes in which mean summer and winter temperatures differ by less than 6 degrees C (11 degrees F) (USDA-SCS, 1972; Western Regional Climate Center, 2020).

Hawaiian indigenous understanding recognized two seasons: Kau or Kauwela (dry season), and Ho`oilo (wet season). During Kau, the sun is directly overhead, days are long and warm, and the trade winds are stronger and more consistent; Kau started on the first new moon in May when the Pleiades set at sunrise (Handy et al., 1991). During Ho’oilo (wet season) the sun is declined toward the south, days are shorter, temperatures cooler and winds more variable and generally started with the first new moon in November. Ho’oilo is also the season when extensive low-pressure systems often approach the islands from the west, producing heavy rainstorms that primarily affect the leeward sides, but can envelope the entire island. (Malo, 1903; Handy et al., 1991; Sanderson, 1993). Differences in rainfall amounts between winter and summer are most marked in low elevation dry areas; wetter areas exhibit less seasonal variation in rainfall (USDA-SCS, 1972; Western Regional Climate Center, 2020).

The islands lie within the trade wind zone. Moisture is picked up from the ocean by trade winds to an altitude of about 6,000 feet (1,850 meters). As the trade winds from the northeast are forced up the islands’ mountains their moisture condenses, creating rain on the windward slopes; the leeward sides of the island receive little of this moisture.

On Kauai, Molokai, Lanai, and Oahu where the mountains are all lower than 6,000 feet (1850 meters), the highest rainfall amounts occur along or near the summits. The moist trade winds usually flow across these lower mountains and around the higher mountains. Lanai is sheltered from the trade winds by the much larger island of Maui, putting it in a rain shadow during trade wind weather; rainfall on Lanai is uncharacteristically low for Hawaii (USDA-SCS, 1972; Western Regional Climate Center, 2020).

Besides the trade winds discussed above, other rainfall sources on the Hawaiian Islands include: a) Widespread winter storms that usually approach the islands from the west, producing heavy rainstorms that primarily affect the leeward sides but can envelope much larger areas; b) "Naulu storms" (Leopold, 1949) caused by local convergence of sea breezes and trade winds to produce summertime cumulus clouds, resulting in infrequent, short-duration, high-intensity rainfall and afternoon shade over leeward dry areas; and c) Fog drip, particularly important to areas with relatively low rainfall, that adds a significant amount of water to areas where clouds intersect mountains (Juvik and Nullet, 1993; Western Regional Climate Center, 2020).

The heaviest rains are brought by winter storms. The greatest amounts of storm rainfall do not always occur in areas with the highest average rainfall, and a storm may bring half of the mean annual rainfall to a dry area in one day (USDA-SCS, 1972; Western Regional Climate Center, 2020).

Table 4. Representative climatic features

Frost-free period (characteristic range)	365 days
Freeze-free period (characteristic range)	365 days
Precipitation total (characteristic range)	23-43 in
Frost-free period (actual range)	365 days
Freeze-free period (actual range)	365 days
Precipitation total (actual range)	22-52 in
Frost-free period (average)	365 days
Freeze-free period (average)	365 days
Precipitation total (average)	33 in

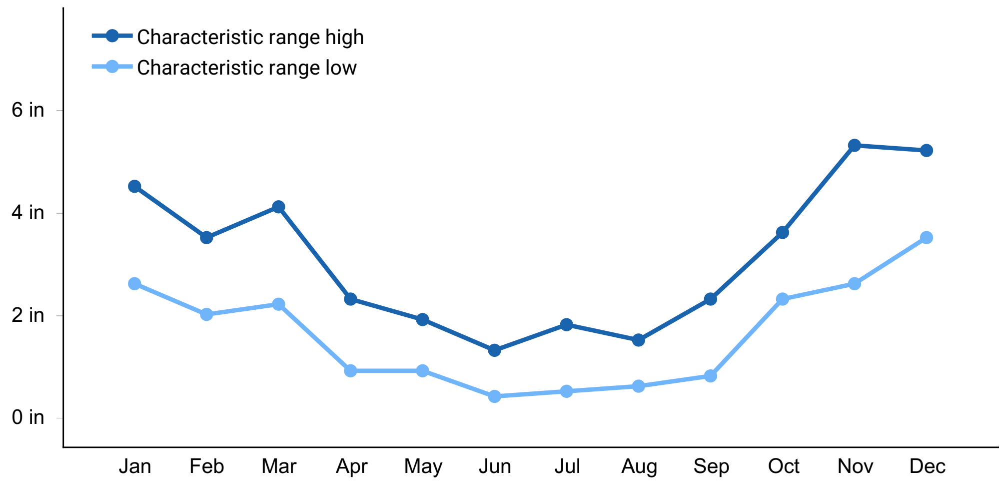

Figure 1. Monthly precipitation range

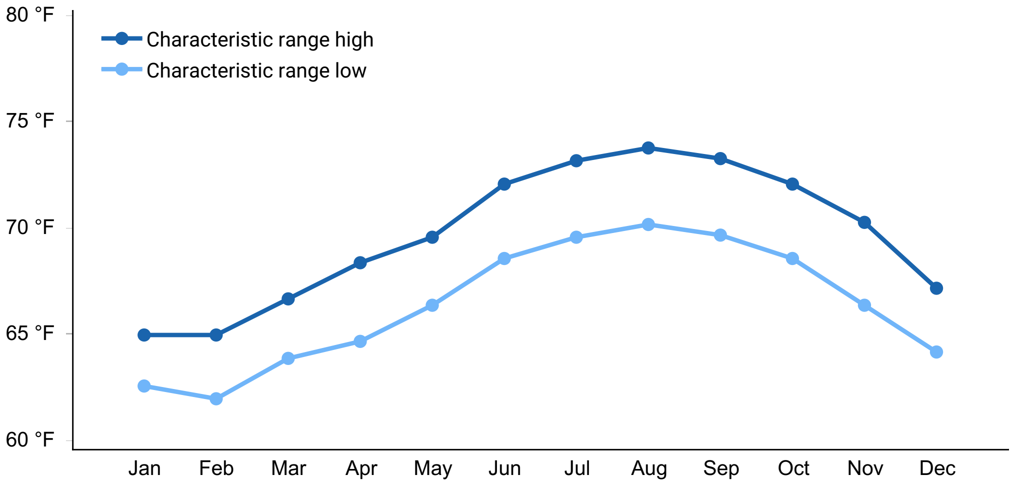

Figure 2. Monthly minimum temperature range

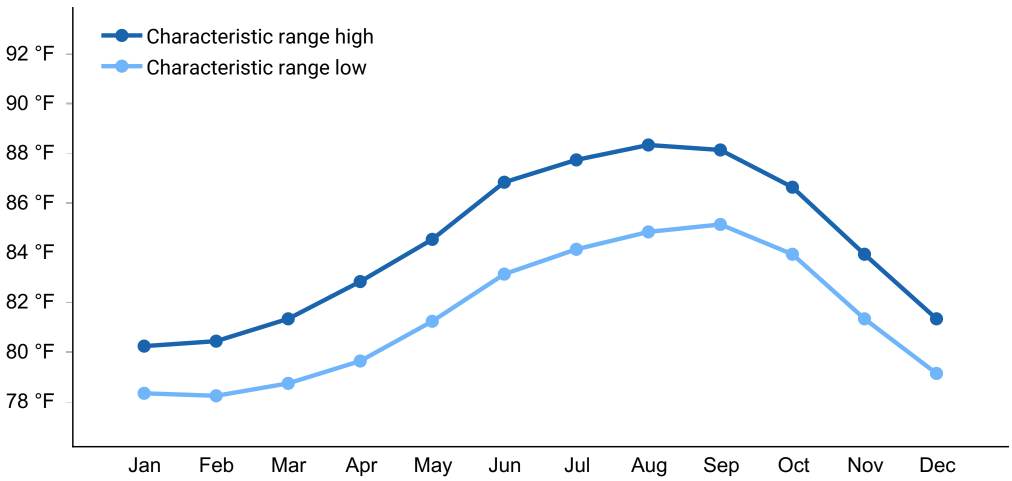

Figure 3. Monthly maximum temperature range

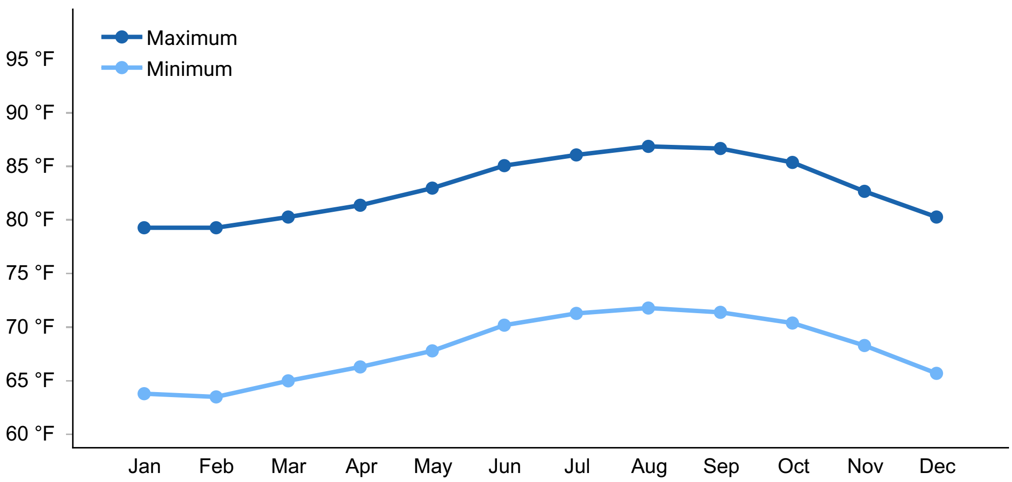

Figure 4. Monthly average minimum and maximum temperature

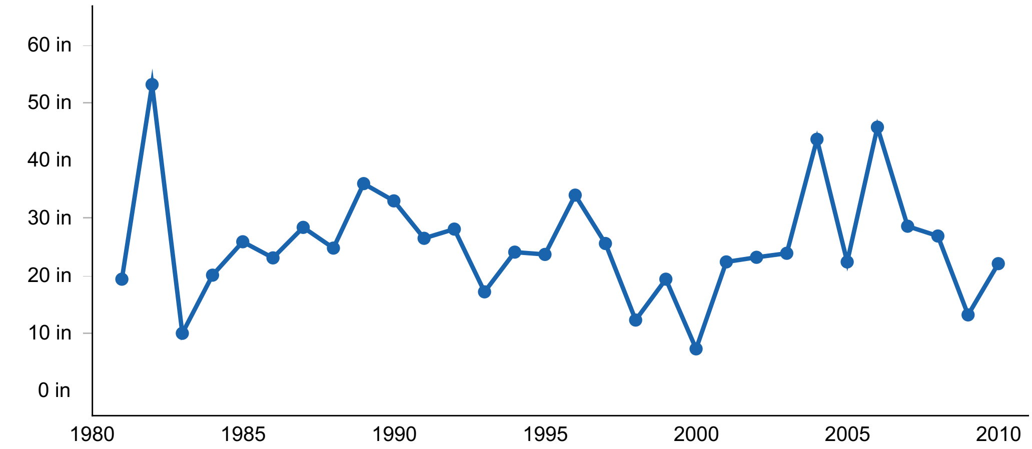

Figure 5. Annual precipitation pattern

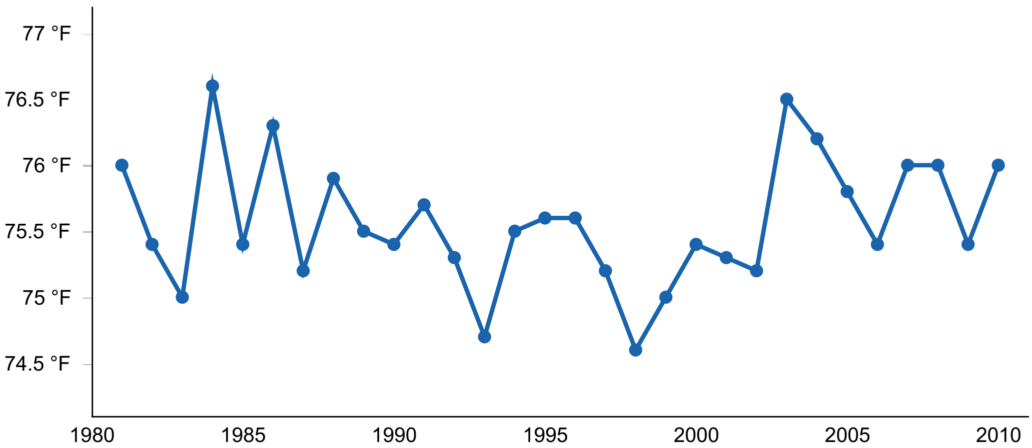

Figure 6. Annual average temperature pattern

Climate stations used

- (1) WAIMEA 947 [USC00519629], Kekaha, HI
- (2) BARKING SANDS [USW00022501], Kekaha, HI
- (3) WAIKIKI 717.2 [USC00519397], Honolulu, HI
- (4) EWA KALAELOA AP [USW00022551], Kapolei, HI
- (5) HONOLULU INTL AP [USW00022521], Honolulu, HI
- (6) WAIMANALO EXP F 795.1 [USC00519523], Waimanalo, HI
- (7) MAKAWELI 965 [USC00515864], Hanapepe, HI
- (8) PUU MANAWAHUA 725.6 [USC00518500], Kapolei, HI
- (9) WAIMEA VALLEY 892.2 [USC00519603], Haleiwa, HI
- (10) KII-KAHUKU 911 [USC00514500], Kahuku, HI

Influencing water features

Many areas are dissected by intermittent streams (USFWS, 2023).

Number of National Wetland Inventory (NWI) features overlapping ecological this site: riverine (209), freshwater forested/shrub wetland (123), freshwater emergent wetland

(120), freshwater pond (86), estuarine and marine deepwater (18), and lake (2). (USFWS, 2023).

Number of National Hydrologic Dataset (NHD) features overlapping this ecological site: lake/pond (56), reservoir (13), foreshore (5), sea/ocean (2), steam/river (1), and swamp/marsh (1). (USGS, 2019).

Soil features

The soil components associated with this ecological site are Honouliuli, Kaena, Kapuhikani, Lualualei, Makalapa, and Nonopahu.

They are mineral soils that formed primarily in alluvium or on marine terraces. They have isohyperthermic (very warm) soil temperature regimes. Most of the soils have a torric or aridic soil moisture regime (in normal years, dry for more than half of the growing season and moist for less than 90 consecutive days during the growing season), except for Kaena which is aquic. Soil drainage values range from well drained to poorly drained. Soil depths range from moderately deep (Makalapa) to deep or very deep. Surface horizons from 0 to 10 inches (0 to 254 millimeters) have pH values ranging from 7.0 to 7.6 while pH values from 10 to 20 inches (254 to 762 millimeters) range from 6.5 to 7.9. All the soils are clayey, either throughout or in their upper horizons, and are in landscape positions that retain base cations derived from parent materials and inflows of water from surrounding areas (USDA-SCS, 1972).

All the soils are classified in the soil order Vertisols. Soils in this order have a high content of clay, pronounced changes in volume with changes in moisture, and deep cracks that open when soils are dry and close when soils become wet. They tend to be fertile and to store and retain high amounts of water. On a global basis, their natural vegetation in semiarid climates is usually open savanna, shrubland, or grassland (Shoji et al., 1993; Virmani et al., 1982).

Kapuhikani soils are extremely stony within the soil profile and shallow to moderately deep (20 to 27 inches or 40 to 68 centimeters). They are classified as calcitorrert and support a calcium carbonate equivalent up to 10 which higher than any of the other soils. They support sparse vegetation with much bare ground (USDA-SCS, 1972).

Kaena soils are aquic and somewhat poorly to poorly drained. However, they support the same natural vegetation as all the other soils and are used for growing crops; there is no mention of artificial irrigation in the Soil Survey. Roots are abundant to a depth of 37 inches (92 centimeters) and are present to 54 inches (135 centimeters). The upper 10 inches (25 centimeters) of soil have some “mottles” but not a gleyed matrix. Deeper horizons have a gleyed matrix with fine “mottles” suggesting seasonal drainage and oxidation in localized sites throughout the soil profile; the descriptions of hydromorphic features do not allow for further assumptions than these. There is no mention of “self-mulching” or cracking depth for Kaena soils. Given the available soil description, climate, and dominant vegetation, it is apparent that soil conditions produce vegetation and management that fit within the concept of this ecological site (USDA-SCS, 1972).

Adjoining the soils described above are areas mapped as Miscellaneous Areas. By definition, they have little or no soil and support little or no vegetation. In the Soil Survey of Islands of Kauai, Oahu, Maui, Molokai, and Lanai, State of Hawaii upon which this ecological site is based, Miscellaneous Areas are extensive, and most were mapped by low-intensity reconnaissance methods that provide less-detailed information than that presented for soil series and their phases. In many cases, however, Miscellaneous Areas in Maui, Molokai, Lanai, Oahu, and Kauai are moderately- to well-vegetated and may contain plant and animal species of interest to conservationists. They are either extremely difficult to access or were not considered important enough at the time of this survey to warrant full expenditure of resources. They are described in the following paragraphs (USDA-SCS, 1972).

Coral Outcrop (CR) occurs on Oahu and Lanai. It consists of coral or cemented calcareous sand. Eighty to 90 percent is coral outcrop and 10 to 20 percent is a thin layer of friable, red soil material in cracks, crevices, and depressions. The soil material is like Mamala series. Much of this Miscellaneous Area is covered by urban development. Otherwise, it supports patches of grasses and kiawe (*Prosopis pallida*). Some areas on Oahu support dense stands of kiawe. It is not known if this is natural or due to crushing of stone or movement of fine materials by heavy equipment (USDA-SCS, 1972).

Rock Land (Rrk) occurs on parent materials of basalt or andesite. Rock cover on the surface ranges from 25 to 90 percent; soils are very shallow (less than 10 inches or 25 centimeters). Near this ecological site it occurs mostly in gulches created by ephemeral streams. Vegetation is generally sparse, but in some spots, vegetation is dense due to localized accumulations of soil and extra moisture from seasonal stream flows. Common plant species are kiawe (*Prosopis pallida*), sweet acacia or klu (*Vachellia farnesiana*), tanglehead or pili grass (*Heteropogon contortus*), uhaloa (*Waltheria indica*), and white leadtree or koa haole (*Leucaena leucocephala*) (USDA-SCS, 1972).

Stony Land (Rst) occurs only in the Waianae Mountains of Oahu. It consists of a mass of boulders and stones covering fifteen to ninety percent of the surface in valleys and on sideslopes of drainageways. Slopes are 5 to 40 percent. Soils occurring among the boulders and stones consists of silty clay loam like Ewa series and clay similar to Lualualei series. It is well vegetated by kiawe (*Prosopis pallida*), lantana (*Lantana camara*), white leadtree or koa haole (*Leucaena leucocephala*), Bermudagrass (*Cynodon dactylon*), and annual plants (USDA-SCS, 1972).

Very Stony Land (Rvs) occurs mostly in parent materials of aa lava with volcanic ash. Fifty to 90 percent of the surface is covered with stones and boulders. Some occurrences of Very Stony Land adjoining this ecological site support vegetation as dense as, or denser than, some soil series. The array of plant species is probably like that found on the predominant soil series in the area (USDA-SCS, 1972).

Very Stony Land, Eroded (Rvt2) occurs only on Molokai and Lanai. Fifty to 75 percent of the surface is covered with stones and boulders. It is common in shallow gullies and a few deep gullies. Soil material is like Holomua, Molokai, Pamoa, and Waikapu series. Slopes are 3 to 40 percent. It contains more soil material than Very Stony Land (Rvs) and appears to support more vegetation than Very Stony Land. Soils are clayey and shallower than 24 inches (60 centimeters) but is deeper in low areas where soil can accumulate. It is mostly vegetated but has some bare spots and areas; common species are kiawe (*Prosopis pallida*), yellow ‘ilima (*Sida fallax*), tanglehead or pili grass (*Heteropogon contortus*), and swollen fingergrass (*Chloris barbata*) (USDA-SCS, 1972).

Table 5. Representative soil features

Parent material	(1) Alluvium–igneous rock (2) Colluvium–igneous rock (3) Residuum–basalt (4) Tuff
Surface texture	(1) Clay (2) Stony clay (3) Very stony clay (4) Extremely stony clay
Family particle size	(1) Very-fine (2) Fine
Drainage class	Poorly drained to well drained
Permeability class	Very slow
Depth to restrictive layer	38–72 in
Soil depth	38–72 in
Surface fragment cover <=3"	0–6%
Surface fragment cover >3"	0–35%
Available water capacity (0-40in)	4–6 in
Calcium carbonate equivalent (0-40in)	0%
Electrical conductivity (0-40in)	0 mmhos/cm
Sodium adsorption ratio (0-40in)	0
Soil reaction (1:1 water) (0-10in)	7–7.6
Subsurface fragment volume <=3" (0-40in)	3–10%

Subsurface fragment volume >3" (0-40in)	2–35%

Table 6. Representative soil features (actual values)

Drainage class	Not specified
Permeability class	Not specified
Depth to restrictive layer	27–72 in
Soil depth	27–72 in
Surface fragment cover <=3"	Not specified
Surface fragment cover >3"	Not specified
Available water capacity (0-40in)	4–16 in
Calcium carbonate equivalent (0-40in)	0–10%
Electrical conductivity (0-40in)	Not specified
Sodium adsorption ratio (0-40in)	Not specified
Soil reaction (1:1 water) (0-10in)	Not specified
Subsurface fragment volume <=3" (0-40in)	Not specified
Subsurface fragment volume >3" (0-40in)	Not specified

Ecological dynamics

The information in this ecological site description (ESD), including the state-and-transition model (STM), was developed using archaeological and historical data, professional experience, and scientific studies. The information is representative of a complex set of plant communities. Not all scenarios or plants are included. Key indicator plants, animals, and ecological processes are described to inform land management decisions.

Natural Disturbances

There have been no lava flows or heavy volcanic ash flows on this ecological site that are recent enough to have affected the current vegetation and soils (USDA-SCS, 1972). It is possible that strong storms may sometimes cause minor windthrow of trees. Wildfires started by lightning rarely affect this ecological site (Abrahamson, 2013).

Human Disturbances

Human-related disturbances have been more important than natural disturbances in this ecological site since the arrival of Polynesians and, later, Europeans. This is reflected in the state-and-transition model diagram.

Humans arrived in the Hawaiian Islands 1,200 to 1,500 years ago. Their population gradually increased so that by 1,600 AD at least 80 percent of all the lands in Hawaii below about 1,500 feet (roughly 500 meters) in elevation had been extensively altered by humans (Kirch, 1982); some pollen core data suggest that up to 100 percent of lowlands may have been altered (Athens, 1997). By the time of European contact late in the 18th century, the Polynesians had developed high population densities and placed large areas under intensive agriculture (Cuddihy and Stone, 1990). However, much of this ecological site was probably too dry for agriculture, except possibly burning to favor the growth of tanglehead or pili grass (*Heteropogon contortus*) used for thatching.

Prehistoric native lowland forest disturbance can be attributed to clearing for agriculture by hand or by fire, introduction of new plants, animals, possibly plant diseases, and wood harvesting. The introduced Pacific rat would have eaten bird eggs, invertebrates, and the seeds of native plants (Athens, 1997).

Approximately 64 percent (20,163 acres) of this 31, 660-acre ecological site overlaps with the Lincoln et al., (2023) modeled colluvial agroecological systems; Of which, 37 percent (11, 665 acres) are modeled as Intensive Colluvial systems, and 27 percent (8,498 acres) are modeled as Marginal Colluvial systems.

The Intensive Colluvial systems were implemented on fertile colluvial deposits on gentle and moderate slopes and would include crops such as, coco yam or kalo (*Colocasia esculenta*), giant taro or ape (*Alocasia macrorrhizos*), water yam or uhi (*Dioscorea alata*), banana or maia (*Musa balbisiana*), breadfruit or ulu (*Artocarpus altilis*), batflower or pia (*Tacca leontopetaloides*), tiplant, ti, or ki (*Cordyline fruticosa*), olona (*Touchardia latifolia*), paper mulberry or wauke (*Broussonetia papyrifera*) and Indian walnut or kukui (*Aleurites moluccanus*) (Lincoln et al., 2023).

The Marginal Colluvial systems were implemented on steeper and more arid ground where additional cultivation efforts were not worth the investments of time and infrastructure. The Marginal Colluvial systems would include, Portia tree or milo (*Thespesia populnea*), kou (*Cordia subcordata*), and Alexandrian laurel or kamani (*Calophyllum inophyllum*), with opportunistic plantings of drought-tolerant crops such as sweetpotato or uala (*Ipomoea batatas*) and bottle gourd or ipu (*Lagenaria siceraria*) (Lincoln et al., 2023).

After the arrival of Europeans, documentary evidence attests to accelerated and extensive deforestation, erosion, siltation, and changes in local weather patterns (Kirch, 1983) due to more intensive land use, modern tools, and introduction of more plant, animal, and microbe species. Introduced kiawe trees (*Prosopis pallida*) are widespread in this ecological site.

The Polynesians introduced dogs, Pacific rats, and small pigs to the islands. After European discovery, cattle, sheep, horses, goats, and larger European pigs were introduced in the final decades of the 18th century. These animals ranged free on the islands, becoming very numerous and destructive by the early decades of the 19th century. Additionally, packs of feral dogs had become established, as confirmed by reports of their depredations on sheep. By 1851, records reported severe overstocking of pastures, lack of fences, and large numbers of feral livestock (Henke, 1929).

Through the 20th and into the 21st centuries, increases in human populations with attendant land development, as well as accelerated introduction of non-native mammals (including deer), birds, reptiles, amphibians, invertebrates, plants, and microorganisms, have brought about dramatic changes to wild ecosystems in Hawaii. Some of the original dry forest of this ecological site was cleared for intensive agriculture. Few areas with native plant communities remain. Since the loss of the native dry forests and abandonment of modern agriculture, most of this ecological site has been utilized by livestock or developed for urban uses.

State and transition model

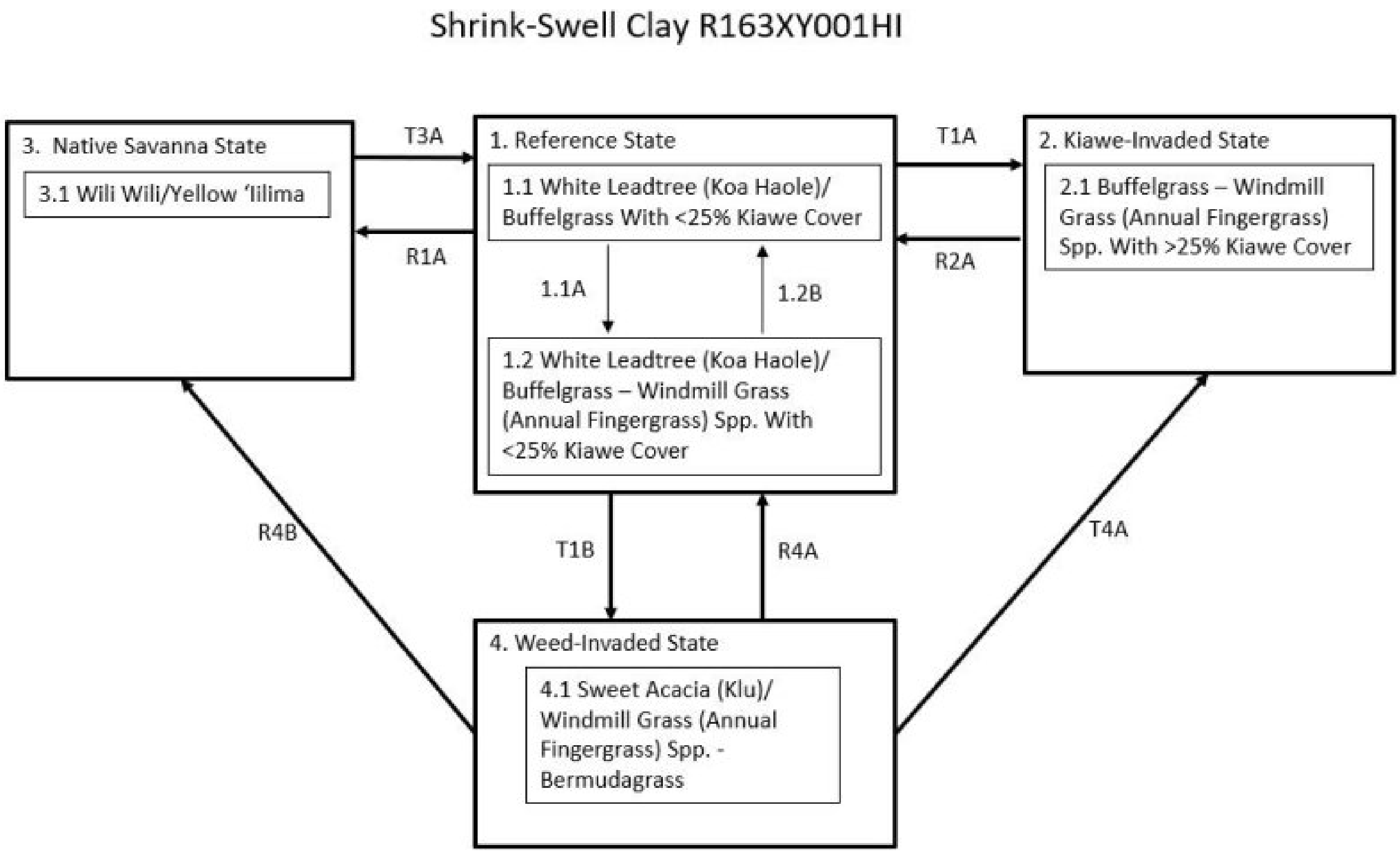

Figure 7. State-and-Transition Model diagram. for R163XY001HI (Shrink-Swell Clay)

State 1

Reference State

The Reference State (1) consists of two community phases dominated by introduced grasses and less than 25 percent canopy cover of introduced trees. With lack of brush control or absence of wildfire, this state will transition to Kiawe-Invaded State (2), in which production and cover of buffelgrass (*Pennisetum ciliare*), white leadtree or koa haole (*Leucaena leucocephala*), and other forages is reduced. Accumulation of fine fuels under light or no grazing pressure increases the risk of fire. This can produce an open grassland with little tree overstory but presents a fire threat to developed areas nearby and likelihood of eroded soil entering the nearby ocean.

Community 1.1
White Leadtree (Koa Haole)/Buffelgrass With <25% Kiawe Cover

Buffelgrass (*Pennisetum ciliare*) is the dominant forage species present. Kiawe (*Prosopis pallida*) and white leadtree or koa haole (*Leucaena leucocephala*) typically are present. Kiawe is a potentially tall tree; its pods have some forage value. If present at canopy cover greater than 25 percent, it can reduce production of grasses, white leadtree or koa haole, and forbs. Koa haole is a small, leguminous tree that is browsed by livestock. Under continuous or heavy grazing, this phase will change to phase 1.2 White Leadtree (Koa Haole)/Buffelgrass - Windmill Grass (Annual Fingergrass) Species With Less Than 25 Percent Kawe Cover. With continuous heavy grazing, particularly by cattle, buffelgrass will decrease. Koa haole and anil de pasto or bush indigo (*Indigofera suffruticosa*) also will decrease under heavy grazing pressure. Increasers include barbwire grass (*Cymbopogon refractus*), beardgrass (Bothriochloa spp.), windmill grass or annual fingergrasses (Chloris spp.), klu (*Vachellia farnesiana*), and weedy forbs. Possible annual fingergrass species are swollen fingergrass (*C. barbata*), radiate fingergrass (*C. radiata*), and feather fingergrass (*C. virgata*). With severe deterioration, shrubby species such as lantana (*Lantana camara*) and American black nightshade or apple of Sodom (*Solanum americanum*) increase. Shortgrasses such as Bermudagrass (*Cynodon dactylon*) and weedy annual forbs become more abundant. Native species such as the Florida hopbush or aalii (*Dodonaea viscosa*) can increase with exclusion of livestock grazing or lack of fire. The forage potential of the site is reduced by the increased canopy cover of this native shrub.

Dominant plant species

- kiawe (*Prosopis pallida*), tree
- white leadtree (*Leucaena leucocephala*), tree
- buffelgrass (*Pennisetum ciliare*), grass

Community 1.2
White Leadtree (Koa Haole)/Buffelgrass – Windmill Grass (Annual Fingergrass) Spp. With <25% Kiawe Cover

This community phase consists of reduced abundance buffelgrass along with lower-value grass species that increase upon continuous heavy grazing of buffelgrass (*Pennisetum ciliare*). Further overgrazing exacerbates this process, causing a transition to the Weed-Invaded State (4). Kiawe (*Prosopis pallida*) canopy cover is less than 25 percent. Pitted beardgrass (*Bothriochloa pertusa*) and windmill grass or annual fingergrass species (Chloris spp.) have increased in cover and production. Buffelgrass abundance is reduced. Koa haole is much reduced compared with phase 1.1. Unpalatable species such as uhaloa (*Waltheria indica*), sensitive partridge pea or Japanese tea (*Chamaecrista nictitans*), Australian saltbush (*Atriplex semibaccata*), and golden crownbeard (*Verbesina encelioides*) have increased.

Dominant plant species

- kiawe (*Prosopis pallida*), tree
- white leadtree (*Leucaena leucocephala*), tree
- buffelgrass (*Pennisetum ciliare*), grass
- windmill grass (*Chloris*), grass

Pathway 1.1A
Community 1.1 to 1.2

Buffelgrass and koa haole cover and vigor are reduced by continuous grazing, causing it to decrease and be partially replaced by less desirable forages.

Pathway 1.2B
Community 1.2 to 1.1

Phase 1.2 can change to phase 1.1 by application of a prescribed grazing program that allows buffelgrass to reassume dominance and heavily browsed white leadtree (koa haole) trees to regrow. Weed control may be necessary if taller weedy forbs or shrubs or both are abundant.

State 2
Kiawe-Invaded, >25% Cover

The Kiawe-Invaded State (2) consists of one community phase. It occurs when brush management has not been practiced or if fire has not occurred for a long time, allowing kiawe (*Prosopis pallida*) to increase in density and stature to a level at which understory production is significantly reduced.

Community 2.1
Buffelgrass – Windmill Grass (Annual Fingergrass) Spp. With >25% Kiawe Cover

The kiawe (*Prosopis pallida*) canopy cover is 25 percent or higher. The understory consists of remnant buffelgrass (*Pennisetum ciliare*), windmill grass or annual fingergrass

(Chloris Spp.) and other grasses. This plant community is poor for livestock grazing due to reduced forage amounts beneath the dense tree canopy. Bare ground has increased.

Dominant plant species

- kiawe (*Prosopis pallida*), tree
- buffelgrass (*Pennisetum ciliare*), grass
- windmill grass (*Chloris*), grass

State 3
Native Savanna State

The Native Savanna State (3) consists of one community phase. Intact examples of this community no longer exist. This historical description is compiled from field observations of remnant vegetation, isolated plants on disturbed sites, and similar ecological sites.

Community 3.1
Wili Wili/Yellow 'lima

This historical community phase is an open canopy of low to medium height (15 to 25 feet; 4.5 to 8 meters) trees, a shrub understory, and a ground layer of vines, herbs, and grasses. The species present would be typical of other low elevation dry Hawaiian sites. Common tree species are those that are found in Hawaiian dry forests, with an emphasis on species that are adapted for the lower elevations and warmest, driest end of the spectrum (Rock, 1913; Wagner et al., 1999). Among these are ohe makai (*Reynoldsia sandwicensis*), wili wili (*Erythrina sandwicensis*), lama (*Diospyros sandwicensis*), and naio (*Myoporum sandwicense*). Among the common native shrubs would be mao or Hawai'ian cotton (*Gossypium tomentosum*), alaweo or aheahea (*Chenopodium oahuense*), Florida hopbush or aalii (*Dodonaea viscosa*), yellow 'ilima (*Sida fallax*), and Oahu riverhemp or ohai (*Sesbania tomentosa*). Common forbs would be smooth pricklypoppy or pua kala (*Argemone glauca*) and nehe (Lipochaeta spp.). Some common grass species would be hardstem lovegrass (*Eragrostis atropioides*), kawelu (*Eragrostis variabilis*), tanglehead or pili (*Heteropogon contortus*), Faurie’s panicgrass (*Panicum fauriei*), Kona panicgrass (*P. konaense*), Maui panicgrass (*P. pellitum*), torrid panicgrass (*P. torridum*), and kakonakona (*P. xerophilum*). Common vines would be kauna'oa or dodder (*Cuscuta sandwichiana*), queen coralbead or huehue (*Cocculus orbiculatus*), oval-leaf clustervine or pauohiiaka (*Jacquemontia ovalifolia* ssp. sandwicensis), paha or kupala (*Sicyos pachycarpus*), and pricklyfruit bur cucumber (*S. hispidus*) (Rock, 1913; Wagner et al., 1999).

Dominant plant species

- wili wili (*Erythrina sandwicensis*), tree
- yellow ‘ilima (*Sida fallax*), other herbaceous

State 4

Weed-Invaded

The Weed-Invaded State (4) consists mostly of grass species that are highly tolerant of grazing along with increased amounts of unpalatable shrubs, forbs, and subshrubs. White leadtree or koa haole (*Leucaena leucocephala*) is gone or is browsed down to stumps. Bare ground is extensive, so soil erosion by wind and water can be excessive.

Community 4.1
Sweet Acacia (Klu)/Windmill Grass (Annual Fingergrass) Spp. - Bermudagrass

Kiawe (*Prosopis pallida*) canopy cover is less than 25 percent. The most abundant grass species are annual fingergrasses species (Chloris spp.) and Bermudagrass (*Cynodon dactylon*). Sweet acacia or klu (*Vachellia farnesiana*) and lantana (*Lantana camara*) are common, unpalatable shrubs. Some native species including Florida hopbush or aalii (*Dodonaea viscosa*), yellow 'ilima (*Sida fallax*), and uhaloa (*Waltheria indica*) typically are present.

Dominant plant species

- sweet acacia (*Vachellia farnesiana*), tree
- windmill grass (*Chloris*), grass
- Bermudagrass (*Cynodon dactylon*), grass

Transition T1A
State 1 to 2

Reference State (1) transitions to Kiawe-Invaded State (2) with lack of disturbance (brush management practices or absence of fire).

Restoration pathway R1A
State 1 to 3

Reference State (1) can be restored to a facsimile of Native Savanna State (3). The site must be fenced to exclude all domestic and feral ungulates. Perimeter protection from fire must be created and maintained around the fence line. Non-native vegetation must be removed, followed by plantings of native trees, shrubs, and vines. Supplemental irrigation may be necessary in the early stages of restoration.

Transition T1B
State 1 to 4

Reference State (1) transitions to Weed-Invaded State (4) with long-term and heavy continuous grazing. Species composition changes to dominance by shortgrasses, weedy forbs, and shrubs. Bare ground increases markedly.

Restoration pathway R2A
State 2 to 1

Kiawe-Invaded State (2) can be restored to Reference State (1) by applying brush management. Fire will kill kiawe, but there may not be enough understory fuels to carry an intense fire.

Transition T3A
State 3 to 1

Native Forest State (3) transitions to Reference State (1) when cleared by fire, long-term ungulate disturbance, or mechanical means. Desired forage species are then established.

Restoration pathway R4A
State 4 to 1

Weed Invaded State (4) can be restored to Reference State (1) by application of a prescribed grazing program that allows buffelgrass to reassume dominance. Weed control and brush management are likely to be necessary.

Transition T4A
State 4 to 2

Weed Invaded State (4) transitions to Kiawe-Invaded State (2) with lack of brush management practices or absence of fire along with a nearby source of kiawe seeds.

Restoration pathway R4B
State 4 to 3

Weed Invaded State (4) can be restored to a facsimile of Native Savanna State (3). The site must be fenced to exclude all domestic and feral ungulates. Perimeter protection from fire must be created and maintained around the fence line. Non-native vegetation must be removed, followed by plantings of native trees, shrubs, and vines. Supplemental irrigation may be necessary in the early stages of restoration.

Additional community tables

Other references

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DEFINITIONS

These definitions have been greatly simplified for brevity and do not cover every aspect of each topic.

Aa lava: A type of basaltic lava having a rough, jagged, clinkery surface and a vesicular interior.

Alluvial: Materials or processes associated with transportation and/or deposition by running water.

Aquic soil moisture regime: A regime in which the soil is free of dissolved oxygen because it is saturated by water. This regime typically exists in bogs or swamps.

Aridic soil moisture regime: A regime in which defined parts of the soil are, in normal years, dry for more than half of the growing season and moist for less than 90 consecutive days during the growing season. In Hawaii it is associated with hot, dry areas with plants such as kiawe, wiliwili, and buffelgrass. The terms aridic and torric are basically the same.

Basal area or basal cover: The cross sectional area of the stem or stems of a plant or of all plants in a stand.

$CaCO_3$ equivalent: The amount of free lime in a soil. Free lime exists as solid material and typically occurs in regions with a dry climate.

Canopy cover: The percentage of ground covered by the vertical projection downward of the outermost perimeter of the spread of plant foliage. Small openings within the canopy are included.

Community pathway: A description of the causes of shifts between community phases. A community pathway is reversible and is attributable to succession, natural disturbances, short-term climatic variation, and facilitating practices, such as grazing management.

Community phase: A unique assemblage of plants and associated dynamic soil properties within a state.

Dominant species: Plant species or species groups that exert considerable influence upon a community due to size, abundance, or cover.

Drainage class: The frequency, duration, and depth of a water table in a soil. There are seven drainage classes, ranging from "excessively drained" (soils with very rare or very deep water tables) to "well drained" (soils that provide ample water for plant growth but are not so wet as to inhibit root growth) to "very poorly drained" (soils with a water table at or near the surface during much of the growing season that inhibits growth of most plants).

Electrical conductivity (EC): A measure of the salinity of a soil. The standard unit is deciSiemens per meter (dS/m), which is numerically equivalent to millimhos per centimeter (mmhos/cm). An EC greater than about 4 dS/m indicates a salinity level that is unfavorable to growth of most plants.

Friability: A soil consistency term pertaining to the ease of crumbling of soils.

Gleyed: A condition of soil from which iron has been reduced (in the redox chemistry sense) and removed during soil formation or that saturation with stagnant water has preserved a reduced state. If iron has been removed, the soil is the color of uncoated sand and silt particles. If iron is present in a reduced state, the soil is the color of reduced iron (typically bluish-gray). Redox concentrations (spots of oxidized iron, formerly called mottles are often present.

Hydrous: A “soil texture modifier” for volcanic ash soils having a water content at the crop wilting point of 100 percent or more; a soil that holds more water than “medial” or “ashy” soils.

Ion exchange capacity: The ability of soil materials such as clay or organic matter to retain ions (which may be plant nutrients) and to release those ions for uptake by roots.

Isohyperthermic soil temperature regime: A regime in which mean annual soil temperature is 72 degrees F (22 degrees C) or higher and mean summer and mean winter soil temperatures differ by less than 11 degrees F (6 degrees C) at a specified depth.

Major Land Resource Area (MLRA): A geographic area defined by NRCS that is characterized by a particular pattern of soils, climate, water resources, and land uses. The island of Hawaii contains nine MLRAs, some of which also occur on other islands in the state.

Mollisols: Soils with relatively thick, dark surface horizons, high cation-exchange capacity, high calcium content, that do not become hard or very hard when dry. Mollisols are conducive to plant growth. They characteristically form under grass in climates that are seasonally dry, but can form under forests.

Naturalized plant community: A community dominated by adapted, introduced species. It is a relatively stable community resulting from secondary succession after disturbance. Most grasslands in Hawaii are in this category.

Parent material: Unconsolidated and chemically weathered material from which a soil is developed.

Perudic soil moisture regime: A very wet regime found where precipitation exceeds evapotranspiration in all months of normal years. On the island of Hawaii, this regime is found on top of Kohala and on parts of the windward side of Mauna Kea.

pH: The numerical expression of the relative acidity or alkalinity of a soil sample. A pH of 7 is neutral; a pH below 7 is acidic and a pH above 7 is basic.

Reference community phase: The phase exhibiting the characteristics of the reference state and containing the full complement of plant species that historically occupied the site. It is the community phase used to classify an ecological site.

Reference state: A state that describes the ecological potential and natural or historical range of variability of an ecological site.

Residuum: Unconsolidated mineral material that has chemically and physically weathered from rock and has not moved from its place of origin.

Restoration pathway: A term describing the environmental conditions and practices that are required to recover a state that has undergone a transition.

Sodium adsorption ratio (SAR): A measure of the amount of dissolved sodium relative to calcium and magnesium in the soil water. SAR values higher than 13 create soil conditions unfavorable to most plants.

Soil moisture regime: A term referring to the presence or absence either of ground water or of water held at a tension of less than 1,500 kPa (the crop wilting point) in the soil or in specific horizons during periods of the year.

Soil temperature regime: A defined class based on mean annual soil temperature and on differences between summer and winter temperatures at a specified depth.

Soil reaction: Numerical expression in pH units of the relative acidity or alkalinity or a soil.

State: One or more community phases and their soil properties that interact with the abiotic and biotic environment to produce persistent functional and structural attributes associated with a characteristic range of variability.

State-and-transition model: A method used to display information about relationships between vegetation, soil, animals, hydrology, disturbances, and management actions on an ecological site.

Torric soil moisture regime: See Aridic soil moisture regime.

Transition: A term describing the biotic or abiotic variables or events that contribute to loss of state resilience and result in shifts between states.

Ustic soil moisture regime: A regime in which moisture is limited but present at a time when conditions are suitable for plant growth. In Hawaii it usually is associated with dry forests and subalpine shrublands.

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Rangeland health reference sheet

Interpreting Indicators of Rangeland Health is a qualitative assessment protocol used to determine ecosystem condition based on benchmark characteristics described in the Reference Sheet. A suite of 17 (or more) indicators are typically considered in an assessment. The ecological site(s) representative of an assessment location must be known prior to applying the protocol and must be verified based on soils and climate. Current plant community cannot be used to identify the ecological site.

Author(s)/participant(s)	
Contact for lead author	
Date	05/21/2025
Approved by	Kendra Moseley
Approval date	
Composition (Indicators 10 and 12) based on	Annual Production

Indicators

1. **Number and extent of rills:**

2. **Presence of water flow patterns:**

3. **Number and height of erosional pedestals or terracettes:**

4. **Bare ground from Ecological Site Description or other studies (rock, litter, lichen, moss, plant canopy are not bare ground):**

5. **Number of gullies and erosion associated with gullies:**

6. **Extent of wind scoured, blowouts and/or depositional areas:**

7. **Amount of litter movement (describe size and distance expected to travel):**

8. **Soil surface (top few mm) resistance to erosion (stability values are averages - most sites will show a range of values):**

9. **Soil surface structure and SOM content (include type of structure and A-horizon color and thickness):**

10. **Effect of community phase composition (relative proportion of different functional groups) and spatial distribution on infiltration and runoff:**

11. **Presence and thickness of compaction layer (usually none; describe soil profile features which may be mistaken for compaction on this site):**

12. **Functional/Structural Groups (list in order of descending dominance by above-ground annual-production or live foliar cover using symbols: >>, >, = to indicate much greater than, greater than, and equal to):**

    Dominant:

    Sub-dominant:

    Other:

    Additional:

13. **Amount of plant mortality and decadence (include which functional groups are expected to show mortality or decadence):**

14. **Average percent litter cover (%) and depth (in):**

15. **Expected annual annual-production (this is TOTAL above-ground annual-production, not just forage annual-production):**

16. **Potential invasive (including noxious) species (native and non-native). List species which BOTH characterize degraded states and have the potential to become a dominant or co-dominant species on the ecological site if their future establishment and growth is not actively controlled by management interventions. Species that become dominant for only one to several years (e.g., short-term response to drought or wildfire) are not invasive plants. Note that unlike other indicators, we are describing what is NOT expected in the reference state for the ecological site:**

17. **Perennial plant reproductive capability:**