Ecological site VX158X01X002 Isohyperthermic Torric Naturalized Grassland Kiawe/buffelgrass (Prosopis pallida/Pennisetum ciliare)

Last updated: 4/17/2025
Accessed: 03/26/2026

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): 158X–Semiarid and Subhumid Low Mountain Slopes

This MLRA occurs in the State of Hawaii on the islands of Hawaii, Maui, Lanai, Molokai, Oahu, and Kauai. It consists primarily of nearly level to moderately steep slopes that are dissected in places by gulches. It occurs on leeward, drier sides of the older volcanoes within the Hawaiian Islands. Elevation ranges from sea level to 1600 feet (0 to 490 meters). Geology is largely highly weathered volcanic ash overlying basic igneous rocks. Alluvium derived from basic igneous rocks occurs in some areas. Average annual precipitation typically ranges from 10 to 30 inches (255 to 760 millimeters), rising to over 60 inches (1525 millimeters) in some areas, and mostly occurs from November through March. Much of the rainfall occurs in kona storms during winter. Average annual temperatures range from 69 to 76 degrees F (21 to 24 degrees C), with very little seasonal variation. Soils are mostly Oxisols, Mollisols, and Aridisols with isohyperthermic soil temperature regime and ustic or aridic (torric) soil moisture regimes. Native vegetation is rare and consists of species characteristic of dry habitats, such as wiliwili, ohe makai, ilima and uhaloa. Naturalized grasses, such as buffelgrass and guineagrass, and trees, such as koa haole and kiawe, are common.

Classification relationships

This ecological site occurs within Major Land Resource Area (MLRA) 158 - Arid and Semiarid Low Mountain Slopes.

Ecological site concept

This ecological site is largely naturalized grassland at low elevations on the leeward slopes of Maui, Molokai, Lanai, Oahu, and Kauai. Much of the area is, or has been, in intensive agriculture or has been developed. Principal landowners are large private land companies, ranches, the State of Hawaii, and Division of Hawaiian Homelands. It is easily accessed along Routes 37 and 30/380 in central Maui, Route 30 near Lahaina in west Maui, south and west of Lanai City along Route 440 on Lanai, Routes 460 and 480 around Hoolehua on Molokai, Routes 99 and 750 north of Waipahu on Oahu, and along Route 50 between Kalaheo and Waimea on Kauai.

The central concept of the Isohyperthermic Torric Naturalized Grassland is of well drained, moderately deep to very deep soils, most of which are Mollisols (mineral soils with high organic matter content and base saturation) formed in alluvium or residuum from basic igneous rock. 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 (0 meters) to about 1500 feet (460 meters), up to about 2400 feet (740 meters) in extreme locations. Because very little of the original native vegetation remains, the reference state of this ecological site consists of naturalized grassland vegetation. The dominant grass species is buffelgrass (*Pennisetum ciliare*), although green panicgrass (*Urochloa maxima*) occurs in some areas. Common naturalized trees are kiawe (*Prosopis pallida*) and koa haole (*Leucaena leucocephala*).

Associated sites

VX163X01X001	**Shrink-Swell Clay** The Clayey Alluvial Plain is on the islands of Oahu, Kauai, Molokai, and Lanai. It occurs typically on flat alluvial coastal plains below gentle slopes on which occur the Isohyperthermic Torric Naturalized Grassland. It has the same soil temperature regime (isohyperthermic), same soil moisture regime (mostly torric), similar average annual rainfall, lower elevation range (0 to 400 versus 0 to 1800 feet), and supports similar vegetation compared to the Isohyperthermic Torric Naturalized Grassland. The ecological sites share buffelgrass as a potential dominant forage grass species. Soils in the Clayey Alluvial Plain are mostly Vertisols, and all have clayey textures in the surface horizon.
VX165X01X001	**Isothermic Ustic Naturalized Grassland** The Naturalized Grassland 30 to 60 Inch Precipitation Zone borders the upper elevation boundary of the Isohyperthermic Torric Naturalized Grassland. It has a cooler soil temperature regime (isothermic), moister soil moisture regime (ustic), greater average annual rainfall (30 to 60 versus 10 to 30 inches), higher elevation range (500 to 2500 feet versus 0 to 1800 feet), and a different dominant forage grass species (guineagrass versus buffelgrass) compared to the Isothermic Naturalized Grassland. Most of the soils are Ultisols and Oxisols rather than the Mollisols that are most common in the Isohyperthermic Torric Naturalized Grassland.

VX158X01X004	**Rocky Isohyperthermic Torric Naturalized Grassland Kiawe/uhaloa/buffelgrass (Prosopis pallida/Waltheria indica/Pennisetum ciliare)** The Rocky Isohyperthermic Torric Naturalized Grassland occurs on Maui, Molokai, and Kauai. It adjoins and interfingers with the Isohyperthermic Torric Naturalized Grassland on those islands. These two ecological sites share soil temperature and moisture regimes and have similar rainfall, elevations, and plant species. The differrence between them is the high rock contents of the soils or, in a few cases, root-limiting layers or coarse textures in the soils of the Rocky Isohyperthermic Torric Naturalized Grassland; these factors limit vegetation productivity.
VX158X01X401	**Isohyperthermic Ustic Naturalized Grassland Koa haole/guineagrass/glycine (Leucaena leucocephala/Urochloa maxima/Neonotonia wightii)** The Isohyperthermic Ustic Naturalized Grassland occurs on the islands of Hawaii, Maui, Molokai, Lanai, Oahu, and Kauai. It adjoins some higher elevation and/or windward borders of the Isohyperthermic Torric Naturalized Grassland. It has the same soil temperature regime although a few degrees cooler, moister soil moisture regime (mostly ustic versus torric), greater average annual rainfall (20 to 60 versus 10 to 30 inches), supports native dry forest rather than savanna and shrubland, and has a different dominant forage grass species (guineagrass versus buffelgrass) compared to the Isohyperthermic Torric Naturalized Grassland.

Similar sites

VX166X01X001	**Isohyperthermic Torric Naturalized Grassland** The Isothermic Torric Naturalized Grassland is on the islands of Oahu, Molokai, and Lanai. It has the same soil temperature regime (isohyperthermic), same soil moisture regime (torric), similar average annual rainfall, lower elevation range (0 to 400 feet versus 0 to 1800 feet), and supports similar vegetation compared to the Rocky Volcanic Ash Savanna The ecological sites share buffelgrass as a potential dominant forage grass species.
VX158X01X004	**Rocky Isohyperthermic Torric Naturalized Grassland Kiawe/uhaloa/buffelgrass (Prosopis pallida/Waltheria indica/Pennisetum ciliare)** The Rocky Isohyperthermic Torric Naturalized Grassland is on the islands of Maui, Molokai, and Kauai. It has the same soil temperature regime (isohyperthermic), the same soil moisture regime (mostly torric), similar average annual rainfall, similar array of Soil Orders, and supports similar plant species compared to the Isohyperthermic Torric Naturalized Grassland. The ecological sites share buffelgrass as a potential dominant forage grass species. However, soil moisture storage in the Rocky Isohyperthermic Torric Naturalized Grassland is limited, primarily by high volumes of stones and cobbles in the soil profile, but also by other soil moisture limiting factors such as vitric mineralogy, shallow depths, and kaolinitic minerals forming

VX157X01X001	**Torric Naturalized Grassland** The Torric Naturalized Grassland occurs only on the island of Hawaii. It has the same soil temperature regime (isohyperthermic), soil moisture regime (torric), greater average annual rainfall (15 to 30 versus 10 to 30 inches), lower elevation range (0 to 1000 versus 0 to 18000 feet), and supports native grassland and shrubland rather than savanna and shrubland compared with the Isohyperthermic Torric Naturalized Grassland. The two sites share the same dominant forage grass species (buffelgrass), but the Torric Naturalized Grassland has very little kiawe, unlike the Isohyperthermic Torric Naturalized Grassland. This is likely due to the extreme windiness of the Torric Naturalized Grassland and the lack of finer-textured subsurface horizons to store water for deep-rooted kiawe that depend on that moisture source in order to compete.

Table 1. Dominant plant species

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

Legacy ID

R158XY002HI

Physiographic features

This ecological site primarily occurs on sloping mountainsides of shield volcanoes. Flooding typically does not occur in this ecological site. However, low elevation areas of Pulehu soils, which occur on alluvial fans, stream terraces, and in basins, may be subject to flooding.

Table 2. Representative physiographic features

Landforms	(1) Shield volcano > Alluvial fan
Runoff class	Very low to high
Flooding frequency	None
Ponding frequency	None
Elevation	0–457 m
Slope	0–35%
Water table depth	152 cm
Aspect	W, N, S, SW

Climatic features

Summary for this ecological site

Average annual precipitation in this ecological site ranges from 10 to 30 inches (250 to 750 mm). Extremes of average annual precipitation may range as high as 40 inches (1000 mm) or even higher on Kauai. In these extreme high rainfall areas, the ecological site probably grades into another ecological site. Most of the precipitation occurs from October through April. Average annual temperatures range from 72 to 75 degrees F (22 to 24 degrees C). 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. Conditions are generally clear; except at the highest extremes of this ecological site, frequent cloudiness higher on the mountain slopes usually does not shade this area due to the angle of the sun.

The Hoolehua plains on the windward side of west Molokai and the slopes on the north side of Lanai are subject to severe wind erosion by trade winds funneled between the highlands of east and west Molokai or through the channel between Molokai and Lanai. The central valley of Maui is windy due to trade winds passing around the northwest corner of Haleakala.

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).

Two seasons can be defined during the year: a winter season from October through April and a summer season from May through September. Summer has warmer temperatures, steadier and stronger trade winds, few widespread rainstorms, and generally lower average monthly rainfall than winter. The Kona Coast of Hawaii (the “Big Island”) is the only area where summer rainfall exceeds winter rainfall. Differences in rainfall amounts between winter and summer are most marked in low elevation dry areas; wetter areas exhibit less seasonal variation in rainfall.

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 (1850 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. The zones of highest rainfall on the windward flanks of the highest mountains (more than 10,000 feet or 3075 meters), which include Mauna Kea, Mauna Loa, and Haleakala, occur at elevations of 2,000 to 4,000 feet (615 to 1230 meters). A temperature inversion that fluctuates between about 5,000 and 7,000 feet (1540 to 2150 meters) on these three highest mountains creates a boundary between lower moist air and higher dry air. Above the inversion, rainfall is scant, skies are usually clear, humidity is low, and temperatures can drop below freezing. On West Maui, Kauai, Molokai, Oahu, and Lanai, 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.

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 1948) 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).

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.

Table 3. Representative climatic features

Frost-free period (characteristic range)	365 days
Freeze-free period (characteristic range)	365 days
Precipitation total (characteristic range)	254-762 mm
Frost-free period (actual range)	
Freeze-free period (actual range)	
Precipitation total (actual range)	254-1,016 mm

Influencing water features

Some ephemeral streams that have formed gulches in this ecological site. These can flow during and after heavy rainstorms.

Soil features

The soils in this ecological site are mineral soils that formed in alluvium or residuum derived from basic igneous rock. They have isohyperthermic (very warm) soil temperature regimes. Most of the soils have torric soil moisture regimes (in normal years, dry for more than half of the growing season and moist for less than 90 consecutive days during the growing season) or are drier (torric or aridic) intergrades of ustic (in normal years, dry for more than 90 cumulative days but less than 180 days). Haleiwa, Mokuleia, Niu, Pakala, and Pulehu soils are classified as having an ustic moisture regime. All of the soils are well drained. Most are moderately deep (20 to 40 inches or 50 to 100 centimeters) to very deep (>60 inches or 150 centimeters). Mokuleia clay loam (map unit Mt) and a phase of Molokai series, Molokai silty clay loam, shallow variant, 15 to 25 percent slopes, severely eroded (map unit MvD3), are shallow, having depths ranging from 12 to 20 inches (30 to 50 centimeters).

Surface horizons have pH ranging from 5.8 to 7.7 except for Pakala clay loam at 5.0; extreme pH in subsurface horizons within 30 inches (75 centimeters) of the surface range from 5.8 to 7.7. The Five Islands Soil Survey shows surface horizons of some soil series as having unusually low pH; these series include Molokai (pH 4.4), Uwala (pH 4.8), and Waikapu (pH 5.1). The pHs of these three soil series were measured in fields cultivated for pineapple, which was common when the survey was performed (late 1960s to early 1970s); pHs of other soils that were measured under sugarcane or pasture do not exhibit such intense acidity. This phenomenon has been studied in locations around the world and is due to factors involved in pineapple cultivation. The Five Islands survey writes for Molokai soils that "…soil is slightly acid to neutral except that areas used for pineapple are commonly very strongly acid or extremely acid in the surface layer." It is possible that surface pH has reverted to normal in the decades since pineapple cultivation ended. If planning to establish crops, forage, or trees on these soils or in areas that had been cultivated for pineapple, a pH test is advisable.

EWA, HALEIWA, MAKAWELI, MOKULEIA, PAMOA, PULEHU, WAHIKULI, and WAIAKOA soils are classified as Mollisols. Many of the soils in very warm (mostly isohyperthermic, but sometimes isothermic), dry (torric, aridic, or ustic with aridic intergrade) areas of Hawaii are Mollisols or have mollic properties. Their key properties are a combination of a relatively thick, dark surface horizon (mollic epipedon) that does not become hard when dry, a dominance of calcium among the extractable cations, and a dominance of crystalline clay minerals of moderate or high cation-exchange capacity. These properties are conducive to plant growth. Although Mollisols usually form under grass in seasonally dry climates, they can form under a forest ecosystem. The original native vegetation was likely dry forest or savanna.

Pulehu soils are on alluvial fans, stream terraces, and in basins; low areas are subject to flooding. We have no data on flooding frequency or duration.

MOLOKAI, NIU, PAKALA, UWALA, and WAIKAPU soils are classified as Oxisols or have oxic properties. Oxisols are more highly weathered than other soils; they have a deep, subsurface oxic horizon dominated by clay-size particles of iron and aluminum hydrous oxides. Plant nutrients have been largely leached out of the soil. At low pH, phosphorus is adsorbed onto the oxides, making it largely unavailable to plants, and the ability to retain cation nutrients such as calcium, magnesium, and potassium against leaching is low. With the exception of more acidic Pakala and Uwala soils, these Oxisols have subsurface soils with near neutral, neutral, or basic pH, which would counteract the more extreme problems of phosphorus fixation and low nutrient cation retention. Most of the soluble silica, which is an important element for grass tissue stability, has been leached out of the soil. Cementation of clay-sized minerals by iron oxides create a stable, well drained, workable soil, but the cemented, sand-like ("pseudosand") particles often create droughty conditions as well. Maintenance of soil organic matter will help to counteract this characteristic.

Molokai soils have an umbric (thick, dark, high in organic matter, low base saturation) surface horizon that is like a low fertility mollic horizon (see above). They are classified as Eutrotorrox. "Eutro-" indicates higher (>35%) base saturation than typical Oxisols.

Uwala and Waikapu soils have an umbric surface horizon but do not have the "eutro-" characteristic of Molokai soils. They also may have very low pH surface horizons. However, Waikapu soils have neutral or higher pH in the subsoil starting at 12 inches (30 centimeters) depth, which would partly counteract problems with phosphorus fixation and low cation retention.

Niu soils do not have an umbric surface horizon, but they have higher-than-typical base saturation as indicated by the "eutr-" characteristic.

Pakala soils have naturally low pH, so phosphorus availability and cation holding capacity are low. These soils occur on bottomlands and alluvial fans and infrequently are flooded by stream overflow.

KEAHUA soils are classified as Aridisols, which are soils with a light-colored surface horizon that has low organic matter content. They are moist for only short periods during the year. The soil moisture regime is an intergrade between aridic and ustic, so is not as dry as most other Aridisols. Like the Oxisols discussed above, it may be droughty due to cementation of clay particles into sand-size aggregates that limit available water-holding capacity.

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 Five Islands Soil Survey upon which this ecological site is based, Miscellaneous Areas are extensive, and most and 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/or 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.

CINDER LAND (rCL) occurs in parent materials of a mix of cinders, pumice, and volcanic ash on cinder cones. It supports a scattering of plants but is sparsely vegetated compared to surrounding soils in this ecological site.

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 similar to 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.

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*), klu (*Vachellia farnesiana*), pili grass (*Heteropogon contortus*), uhaloa (*Waltheria indica*), and koa haole (*Leucaena leucocephala*).

ROCK OUTCROP (rRO) has exposed bedrock covering more than ninety percent of the surface. Small areas of lithified coral sand occur on Kauai, Oahu, Lanai, and Molokai. Gulches on Kauai support sparse vegetation on steep sides and denser vegetation in gulch bottoms. Gulch sides on Maui, Molokai, and Lanai are sparsely vegetated; bottoms can be sparse or moderately vegetated.

ROUGH BROKEN LAND (rRR) occurs on very steep sides of gulches and mountainsides. Soil amounts and characteristics are variable; beneath the soil is soft weathered rock. Most occurrences in the vicinity of this ecological site appear to support substantial vegetation cover. Common plant species are common guava (*Psidium guajava*), Natal redtop (*Melinis repens*), bermudagrass (*Cynodon dactylon*), koa haole (*Leucaena leucocephala*), and molassesgrass (*Melinis minutiflora*). Active soil erosion is common.

ROUGH BROKEN AND STONY LAND (rRS) occurs on Maui in very steep, stony gulches. Some soil is present in variable amounts. It generally supports shrubs, small trees, and grass with a significant amount of bare ground.

RUBBLE LAND (rRU) occurs only on Kauai at bases of very steep slopes; ninety percent of the surface is covered by stones or boulders. It usually is well vegetated by koa haole (*Leucaena leucocephala*).

STONY ALLUVIAL LAND (rSM) consists of stones, boulders, and soil deposited by streams along bottoms of gulches and on alluvial fans. Much of it appears to be well vegetated, especially in gulch bottoms, although the driest gulch bottoms are sparsely vegetated. Common species are kiawe (*Prosopis pallida*), sweet acacia or klu (*Acacia farnesiana*), ilima (*Sida cordifolia*), pili (*Heteropogon contortus*), and lantana (*Lantana camara*).

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 similar to Ewa series and clay similar to Lualualei series. It is well vegetated by kiawe (*Prosopis pallida*), lantana (*Lantana camara*), koa haole (*Leucaena leucocephala*), bermudagrass (*Cynodon dactylon*), and annual plants.

STONY STEEP LAND (rSY) occurs only on Oahu. It consists of masses of boulders and stones covering fifty to ninety of the surface in valleys and on sideslopes of drainageways. Slopes are 40 to 70 percent. It is well vegetated by kiawe, koa haole, and grasses.

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 similar to that found on soil series.

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 similar to 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, ilima, pili, fingergrass (*Chloris barbata*).

Table 4. Representative soil features

Parent material	(1) Alluvium–igneous rock (2) Residuum–igneous rock
Surface texture	(1) Stony, cobbly silty clay loam (2) Stony, cobbly silty clay loamStony, cobbly clay loam (3) Stony, cobbly silty clay loamStony, cobbly clay loamStony sandy loam (4) Cobbly silty clay
Drainage class	Well drained

Permeability class	Moderate to moderately rapid
Soil depth	81–183 cm
Surface fragment cover <=3"	Not specified
Surface fragment cover >3"	0–2%
Available water capacity (0-101.6cm)	10.92–14.73 cm
Soil reaction (1:1 water) (0-50.8cm)	5.8–7.7
Subsurface fragment volume <=3" (Depth not specified)	Not specified
Subsurface fragment volume >3" (Depth not specified)	Not specified

Table 5. Representative soil features (actual values)

Drainage class	Not specified
Permeability class	Not specified
Soil depth	30–183 cm
Surface fragment cover <=3"	Not specified
Surface fragment cover >3"	Not specified
Available water capacity (0-101.6cm)	Not specified
Soil reaction (1:1 water) (0-50.8cm)	5–7.7
Subsurface fragment volume <=3" (Depth not specified)	Not specified
Subsurface fragment volume >3" (Depth not specified)	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. It is possible that strong storms may sometimes cause minor windthrow of trees. Wildfires started by lightning rarely may affect this ecological site.

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.

The first humans are believed to have migrated to Hawaii between 1000 and 1260 AD (Allen, 2014, Wilmhurst, 2011). Subsequent migrations and population growth gradually increased so that by 1600 AD at least 80% of all the lands in Hawaii below about 1500 feet (roughly 500 meters) in elevation had been extensively altered by humans (Kirch 1982); some pollen core data suggest that up to 100% 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).

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).

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).

The original native vegetation was dry savanna or shrubland. Common native species, based on the current environment and remnant occurrences would have included alahee (*Psydrax odorata*), ohe makai (Polyscias sandwicensis), wiliwili (*Erythrina sandwicensis*), naio (*Myoporum sandwicense*), koaia (*Acacia koa*ia), aalii (*Dodonaea viscosa*), ilima (*Sida fallax*), Uhaloa (*Waltheria indica*), (*Cocculus orbiculatus*), and native grasses.

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. Much of the original dry savanna of this ecological site was cleared for intensive, irrigated production of sugarcane and pineapple. Few areas with native plant communities remain. Naturalized grasses, such as buffelgrass and guineagrass, and trees, such as koa haole and kiawe, are common.

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. However, there is a recent emphasis to transform approximately 41,000 acres of Maui’s vacant former sugarcane land into a center of sustainable and diversified agriculture to improve food security and nutrition in Hawai’i while supporting local employment.

State and transition model

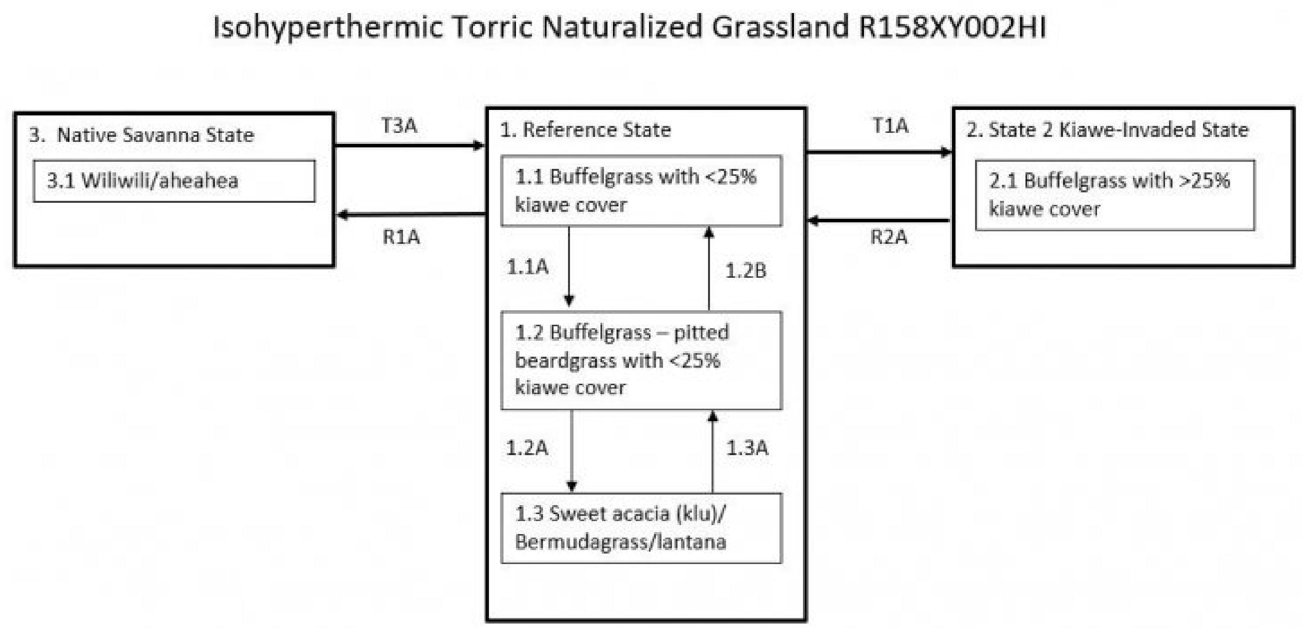

Figure 1. STM for Isohyperthermic Torric Naturalized Grassland (R158XY002)

State 1
Reference

Figure 2. State 1. Reference. Guinneagrass with Lantana. Pasture health departing with season long grazing and axis deer pressure. Elevation ~ 400 feet. Annual precipitation ~ 24 inches. Molokai silty clay loam, 3-7% slopes. John Proctor. Feb 24th. 2021

This state consists of three community phases dominated by introduced grasses and less than 25 percent canopy cover of introduced trees.

Resilience management. In the absence of disturbance such as fire or brush control, this state will transition to State 2 Kiawe-Invaded, in which production and cover of buffelgrass and other forages is reduced. Accumulation of fine fuels under light or no grazing pressure increases the likelihood of wildfire. 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
Buffelgrass with <25% kiawe cover (Pennisetum ciliare/Prosopis pallida)

Buffelgrass is the dominant forage species present. Kiawe (*Prosopis pallida*) and koa haole (*Leucaena leucocephala*) may be 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 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 Buffelgrass-pitted beardgrass with <25% kiawe cover.

Resilience management. With continuous heavy grazing, particularly by cattle, buffelgrass will decrease. Koa haole and bush indigo (*Indigofera suffruticosa*) also will decrease under heavy grazing pressure. Increasers include jaraguagrass or thatchinggrass (*Hyparrhenia rufa*), barbwiregrass (*Cymbopogon refractus*), molassesgrass (*Melinis minutiflora*), Natal redtop or rose Natal grass (*Melinis repens*), bluestems (Bothriochloa spp.), and lesser amounts of buffelgrass and weedy forbs. With severe deterioration, shrubby species such as lantana (*Lantana camara*) and apple of

Sodom (Solanum linnaeaum) increase. Shortgrasses such as Bermudagrass (*Cynodon dactylon*), kikuyugrass, low-vigor buffelgrass, and weedy annual forbs become more abundant, as well as lesser amounts of pricklypear cactus or Barbary fig (*Opuntia ficus-indica*). Pricklypear cactus abundance has been limited by an introduced biocontrol insect. Native aalii (*Dodonaea viscosa*) can increase with exclusion of livestock grazing or lack of wildfire. The forage potential of the site is reduced by the increased canopy cover of this native shrub. Canopy cover of kiawe (*Prosopis pallida*) is less than 25 percent. Some other grass species that may be present are green panicgrass (a variety of guineagrass, *Urochloa maxima*) and native piligrass (*Heteropogon contortus*), and hardstem lovegrass (*Eragrostis atropioides*).

Dominant plant species

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

Community 1.2
Buffelgrass – pitted beardgrass with <25% kiawe cover (Pennisetum ciliare – Bothriochloa pertusa/Prosopis pallida)

This community phase consists of lower-value grass species that become abundant upon continuous heavy herbivory of buffelgrass. Kiawe (*Prosopis pallida*) canopy cover is less than 25 percent. Pitted beardgrass (*Bothriochloa pertusa*) and swollen fingergrass (*Chloris barbata*) have both increased in cover and production. Buffelgrass (Cenchrus ciliaris) abundance is much reduced. Koa haole is much reduced compared with phase 1.1. Unpalatable species such as uhaloa (*Waltheria indica*), Japanese tea (*Chamaecrista nictitans*), Australian saltbush (*Atriplex semibaccata*), and golden crownbeard (*Verbesina encelioides*) have increased.

Resilience management. Further overgrazing exacerbates this process, causing a community change to phase 1.3.

Dominant plant species

- kiawe (*Prosopis pallida*), tree
- buffelgrass (*Pennisetum ciliare*), grass
- pitted beardgrass (*Bothriochloa pertusa*), grass

Community 1.3
Sweet acacia (klu)/Bermudagrass/lantana (Acacia farnesiana/Cynodon dactylon/Lantana camara)

This community phase consists mostly of grass species that are highly tolerant of grazing, particularly Bermudagrass, along with increased amounts of unpalatable shrubs, forbs, and subshrubs. Koa haole is gone or is browsed down to stumps. Bare ground is extensive, so soil erosion by wind and water can be excessive. Kiawe (*Prosopis pallida*) canopy cover is less than 25 percent. The most abundant grass species is Bermudagrass (*Cynodon dactylon*). Sweet acacia or klu (*Acacia farnesiana*) and lantana (*Lantana camara*) are common, unpalatable shrubs. Some native aalii (*Dodonaea viscosa*), ilima (*Sida cordifolia*), and uhaloa (*Waltheria indica*) typically are present.

Dominant plant species

- sweet acacia (*Acacia farnesiana*), shrub
- lantana (*Lantana camara*), shrub
- Bermudagrass (*Cynodon dactylon*), grass

Dominant resource concerns

- Sheet and rill erosion
- Wind erosion
- Plant productivity and health

Pathway P1.1A
Community 1.1 to 1.2

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

Pathway P1.2B
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. Invasive plant species control and brush management may be necessary if taller weedy forbs and/or shrubs are abundant.

Conservation practices

Prescribed Grazing
Planned Grazing System

Pathway P1.2A
Community 1.2 to 1.3

This community phase changes to phase 1.3 with long-term and/or heavy continuous herbivory. Species composition changes to dominance by shortgrasses, weedy forbs, and shrubs. Bare ground increases markedly.

Pathway P1.3A
Community 1.3 to 1.2

Community phase 1.3 can change to phase 1.2 by application of a prescribed grazing program that allows buffelgrass to reassume dominance. Invasive plant species control and brush management will be needed where taller weedy forbs and/or shrubs are abundant.

Conservation practices

Brush Management
Prescribed Grazing
Planned Grazing System
Invasive Species Pest Management

State 2
Kiawe-Invaded, >25% Cover

Figure 3. State 2. Kiawe Invaded. Guinneagrass converting to sourgrass from severe drought and grazing pressure from axis deer. Waikapu silty clay loam, 3 to 7 % slopes. Elevation ~ 300 feet. Annual precipitation ~ 15 inches. John Proctor. Feb 01, 2021.

This state consists of one community phase. It occurs in the absence of disturbance such as fire or brush control allowing kiawe to increase in density and stature to a level at which understory production is significantly reduced.

Community 2.1
Buffelgrass with >25% kiawe cover (Pennisetum ciliare/Prosopis pallida)

The kiawe canopy cover is 25 percent or higher. The understory consists of remnant buffelgrass 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, and there may be shallow, seasonal stream channels cut into the soil.

Dominant plant species

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

State 3
Native Savanna

Figure 4. State 3. Native Savanna. This photo of of native wili wili seeds provides a representation of the restored native savanna state. John Proctor. Feb. 2021.

This state consists of one community phase. Intact examples of this community no longer exist. This description is compiled from field observations of remnant vegetation, isolated plants on disturbed sites, a similar ecological site on the Island of Hawaii, and historical accounts.

Community 3.1

Wiliwili/aheahea Erythrina sandwicensis/Chenopodium oahuense

The hypothetical appearance of this 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. Among these are ohe makai (Polyscias sandwicensis, formerly *Reynoldsia sandwicensis*), wiliwili (*Erythrina sandwicensis*), lama (*Diospyros sandwicensis*), hao (*Rauvolfia sandwicensis*), and koaia (*Acacia koa*ia). Forest Understory Composition 3.1 Among the common native shrubs would be koola ula (*Abutilon menziesii*), aheahea (*Chenopodium oahuense*), aalii (*Dodonaea viscosa*), and ohai (*Sesbania tomentosa*). Common forbs would be pua kala (*Argemone glauca*) and nehe (Lipochaeta spp.). Some common grass species would be hardstem lovegrass (*Eragrostis atropioides*), kawelu (*Eragrostis variabilis*), pili (*Heteropogon contortus*), and kakonakona (*Panicum fauriei*, *P. konaense*, *P. pellitum*, *P. torridum*, and *P. xerophilum*). Common vines would be awikiwiki (*Canavalia hawaiiensis* and *C. pubescens*), dodder (Cuscuta campestris), pauohiiaka (Jacquemontia sandwicensis), and kupala (*Sicyos pachycarpus*).

Resilience management. A transition from State 3 Native Savanna to State 1 Reference may be avoided by building a fence or controlling animals such that all domestic and feral ungulates are excluded from the site. A firebreak must be created and maintained around the fence line by grazing or mowing. Apply invasive plant species control as needed.

Dominant plant species

- wili wili (*Erythrina sandwicensis*), tree
- alaweo (*Chenopodium oahuense*), shrub

Dominant resource concerns

- Terrestrial habitat for wildlife and invertebrates

Transition T1A
State 1 to 2

Reference

Kiawe-Invaded, >25% Cover

State 1 Reference transitions to State 2 Kiawe-Invaded in the absence of disturbance such as brush management practices or fire.

Restoration pathway R1A
State 1 to 3

Reference

Native Savanna

State 1 can be restored to a facsimile of State 3 Native Savanna. The site must be fenced or animals controlled such that all domestic and feral ungulates are excluded from the site. A firebreak must be created and maintained around the fence line by grazing or mowing. Buffelgrass and other non-native vegetation must be killed, followed by plantings of native trees, shrubs, and vines. Apply additional invasive plant species control as needed. Supplemental irrigation may be necessary in the early stages of restoration.

Conservation practices

Fence
Firebreak
Native Plant Community Restoration and Management
Invasive Plant Species Control
Invasive Species Pest Management

Restoration pathway R2A
State 2 to 1

Kiawe-Invaded, >25% Cover

Reference

State 2 Kiawe-Invaded can be restored to State 1 Reference by applying land clearing and brush management. Apply invasive plant species control as needed. Fire will kill kiawe; prescribed burning is typically not done in Hawaii due to the level of risk.

Conservation practices

Brush Management
Land Clearing
Invasive Plant Species Control

Transition T3A
State 3 to 1

Native Savanna

Reference

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

Conservation practices

Brush Management
Land Clearing
Range Planting

Additional community tables

Inventory data references

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.

Aquisalids: These are salty soils in wet areas. Although wet, the dissolved salts make the soils physiologically dry (the chemical activity, or effective concentration, of water is low). Aquisalids typically support plant species that are adapted to these conditions.

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.

Ash field: a land area covered by a thick or distinctive deposit of volcanic ash that can be traced to a specific source and has well defined boundaries. The term “ash flow” is erroneously used in the Physiographic section of this ESD due to a flaw in the national database.

Ashy: A “soil texture modifier” for volcanic ash soils having a water content at the crop wilting point of less than 30 percent; a soil that holds relatively less water than “medial” and “hydrous” soils.

Available water capacity: The amount of soil water available to plants to the depth of the first root-restricting layer.

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

Blue rock: The dense, hard, massive lava that forms the inner core of an aa lava flow.

Bulk density: the weight of dry soil per unit of volume. Lower bulk density indicates a greater amount of pore space that can hold water and air in a soil.

$CaCO_3$ 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.

Isomesic soil temperature regime: A regime in which mean annual soil temperature is 47 degrees F (8 degrees C) or higher but lower than 59 degrees F (15 degrees C) and mean summer and mean winter soil temperatures differ by less than 11 degrees F (6 degrees C) at a specified depth.

Isothermic soil temperature regime: A regime in which mean annual soil temperature is 59 degrees F (15 degrees C) or higher but lower than 72 degrees F (22 degrees C) and mean summer and mean winter soil temperatures differ by less than 11 degrees F (6 degrees C) at a specified depth.

Kipuka: An area of land surrounded by younger (more recent) lava. Soils and plant communities within a kipuka are older than, and often quite different from, those on the surrounding surfaces.

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.

Makai: a Hawaiian word meaning “toward the sea.”

Mauka: a Hawaiian word meaning “toward the mountain” or “inland.”

Medial: A “soil texture modifier” for volcanic ash soils having a water content at the crop wilting point of 30 to 100 percent; a soil that holds an amount of water intermediate to “hydrous” or “ashy” soils.

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.

Oxisols: Soils characteristic of humid, tropical or subtropical regions that formed on land surfaces that have been stable for a long time. In Hawaii, they typically occur on islands or parts of islands that have been volcanically inactive for a long time. Oxisols are highly weathered, consist largely of quartz, kaolin clays, and aluminum oxides, and have low ion exchange capacity and loamy or clayey texture.

Pahoehoe lava: A type of basaltic lava with a smooth, billowy, or rope-like surface and vesicular interior.

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.

Phosphorus adsorption: The ability of soil materials to tightly retain phosphorous ions, which are a plant nutrient. Some volcanic ash soils retain phosphorus so strongly that it is partly unavailable to plants.

Psamments: Sandy soils that have low water-holding capacity, are susceptible to wind erosion, and typically have ground water deeper than 20 inches (50 centimeters).

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 1500 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.

Spodosols: Soils with a spodic B horizon that has an accumulation of black or reddish amorphous materials that have a high pH-dependent ion exchange capacity, coarse texture, and few base cations. Above the spodic horizon there often is a light-colored albic horizon that was the source of the amorphous materials in the spodic horizon.

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.

Udic soil moisture regime: A regime in which the soil is not dry in any part for as long as 90 cumulative days in normal years, and so provides ample moisture for plants. In Hawaii it is associated with forests in which hapuu (tree ferns) are usually moderately to highly abundant.

Ultisols: Soils that have been intensively leached and weathered. They have a B horizon that has accumulated clay that has translocated there from higher horizons. They have moderate to low cation exchange capacity and low base saturation. The highest base saturation normally is in the few centimeters directly beneath the surface due to cycling of bases by plants.

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.

Other References

Abrahamson I. 2013. Fire regimes in Hawaiian plant communities. In: Fire Effects Information System, US Dept. of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. Available"
www.fs.fed.us/database/feis/fire_regimes/Hawaii/all.html

Allen, M.S., 2014. Marquesan colonization chronologies and post-colonization interaction: implications for Hawaiian origins and the ‘Marquesan Homeland’ hypothesis. Journal of Pacific Archaeology, 5(2), pp.1-17.

Armstrong RW. 1973. Atlas of Hawaii. University of Hawaii Press, Honolulu.

Athens JS. Ch. 12 Hawaiian Native Lowland Vegetation in Prehistory in Historical Ecology in the Pacific Islands – Prehistoric Environmental and Landscape Change. Kirch, PV and TL Hunt, eds. 1997. Yale U. Press, New Haven.

Burney DA, HF James, LP Burney, SL Olson, W Kikuchi, WL Wagner, M Burney, D McCloskey, D Kikuchi, FV Grady, R Gage II, and R Nishek. 2001. Fossil evidence for a diverse biota from Kauai and tis transformation since human arrival. Ecological Monographs 71:615-641.

Christensen CC. 1983. Report 17: Analysis of land snails. In: Archaeological investigations of the Mudlane-Waimea-Kawaihae Road Corridor, Island of Hawaii: An Interdisciplinary Study of an Environmental Transect. Clark JT. and Kirch PV, eds. Dept. of Anthropology, Bernice Pauahi Bishop Museum, Report 83-1, Honolulu, HI.

Clark JT. 1983. Report 3: The Waimea-Kawaihae Region: Historical Background. In: Archaeological investigations of the Mudlane-Waimea-Kawaihae Road Corridor, Island of Hawaii: An Interdisciplinary Study of an Environmental Transect. Clark JT and Kirch PV, eds. Dept. of Anthropology, Bernice Pauahi Bishop Museum, Report 83-1, Honolulu, HI.

Clark JT. 1983. Report 7: Archaeological investigations in Section 4. In: Archaeological investigations of the Mudlane-Waimea-Kawaihae Road Corridor, Island of Hawaii: An

Interdisciplinary Study of an Environmental Transect. Clark JT and Kirch PV, eds. Dept. of Anthropology, Bernice Pauahi Bishop Museum, Report 83-1, Honolulu, HI.

Clark JT. 1983. Report 8: Archaeological investigations of agricultural sites in the Waimea area. In: Archaeological investigations of the Mudlane-Waimea-Kawaihae Road Corridor, Island of Hawaii: An Interdisciplinary Study of an Environmental Transect. Clark JT and Kirch PV, eds. Dept. of Anthropology, Bernice Pauahi Bishop Museum, Report 83-1, Honolulu, HI.

Craighill ES and EG Handy. 1991. Native Planters in Old Hawaii – Their Life, Lore, and Environment. Bernice P. Bishop Museum Bulletin 233, Bishop Museum Press, Honolulu, HI

Cuddihy LW and CP Stone. 1990. Alteration of Native Hawaiian Vegetation: Effects of Humans, Their Activities and Introductions. Honolulu: University of Hawaii Cooperative National Park Resources Study Unit.

Deenik J and AT McClellan. 2007. Soils of Hawaii. Soil and Crop Management, Sept. 2007, SCM-20. Cooperative Extension Service, College of Tropical Agriculture and Human Resources. University of Hawaii at Manoa. Available online at: https://www.ctahr.hawaii.edu/oc/freepubs/pdf/SCM-20.pdf

Dixon JB and Schulze DG, eds. 2002. Soil Mineralogy with Environmental Applications. Volume 7. Soil Science Society of America. Available online at: https://acsess.onlinelibrary.wiley.com/doi/book/10.2136/sssabookser7

Giambelluca TW and TA Schroeder. 1998. Climate. In: Atlas of Hawaii, 3rd edition. SP Juvik, JO Juvik, and RR Paradise, eds. pp. 49-59. Honolulu: University of Hawaii Press.

Gil CR. 2016-2017. Ananas comosus. Colegio Bolivar Agricultural Science. Available online at: https://www.colegiobolivar.edu.co/garden/wp-content/uploads/2017/06/Crosas-Ananas-comosus-2017.pdf

Hazlett RW and DW Hyndman. 1996. Roadside Geology of Hawaii. Mountain Press Publishing Company, Missoula MT.

Henke LA. 1929. A Survey of Livestock in Hawaii. Research Publication No. 5. University of Hawaii, Honolulu.

Horrocks M. 2009. Sweet potato (Ipomoea batatas) and banana (Musa sp.) microfossils in deposits from the Kona Field System, Island of Hawaii. Journal of Archaeological Science, May 2009.

Imada, C. 2012. Hawaiian Native and Naturalized Vascular Plants Checklist (December 2012 update). Bishop Museum Technical Report 60. Bishop Museum Press, Honolulu.

Jacobi JD. 1989. Vegetation Maps of the Upland Plant Communities on the Islands of Hawaii, Maui, Molokai, and Lanai. Technical Report 68. Cooperative National Park Resources Studies Unit, University of Hawaii at Manoa and National Park Service.

Juvik JO and D Nullet. 1993. Relationships between rainfall, cloud-water interception, and canopy throughfall in a Hawaiian montane forest. IN: Tropical Montane Cloud Forests. Proc. Int. Sym., San Juan, PR. Hamilton LS, JO Juvik, and FN Scatena, eds. East-West Center.

Kirch PV. 1982. The impact of the prehistoric Polynesians in the Hawaiian ecosystem. Pacific Science 36(1):1-14.

Kirch PV. 1983. Introduction. In: Archaeological investigations of the Mudlane-Waimea-Kawaihae Road Corridor, Island of Hawaii: An Interdisciplinary Study of an Environmental Transect. Clark JT and Kirch PV, eds. Dept. of Anthropology, Bernice Pauahi Bishop Museum, Report 83-1, Honolulu, HI.

Kirch PV. 1985. Feathered Gods and Fishhooks: An Introduction to Hawaiian Archaeology and Prehistory. Honolulu: University of Hawaii Press.

Kirch PV. 2000. On the Road of the Winds: An Archaeological History of the Pacific Islands Before European Contact. Berkeley: University of California Press.

Kirch, P.V., 2011. When did the Polynesians settle Hawaii? A review of 150 years of scholarly inquiry and a tentative answer. Hawaiian Archaeology, 12(2011), pp.3-26.

Leopold LB. 1949. The interaction of trade wind and sea breeze, Hawaii. Journal of Meteorology 6: 312-320.

Little EL Jr. and RG Skolmen. 1989. Common Forest Trees of Hawaii (Native and Introduced). US Department of Agriculture-US Forest Service Agriculture Handbook No. 679. (out of print). Available at www.fs.fed.us/psw/publications/documents/misc/ah679.pdf

Maly K and O Maly. 2004. He Moolelo Aina: A Cultural Study of the Puu O Umi Natural Area Reserve and Kohala-Hamakua Mountain Lands, Districts of Kohala and Hamakua, Island of Hawaii. Kumu Pono Associates, Hilo HI.

McEldowney H. 1983. Report 16: A description of major vegetation patterns in the Waimea-Kawaihae region during the early historic period. In: Archaeological investigations of the Mudlane-Waimea-Kawaihae Road Corridor, Island of Hawaii: An Interdisciplinary Study of an Environmental Transect. Clark JT and Kirch PV, eds. Dept. of Anthropology, Bernice Pauahi Bishop Museum, Report 83-1, Honolulu, HI.

Mubyana T. 1997/98. Effects of continuous sugarcane and pineapple cropping on organic matter and soil microbial biomass. Journal of African Research and Development 27&28:258-269.

Mueller-Dombois D and FR Fosberg. 1998. Vegetation of the Tropical Pacific Islands. Springer-Verlag New York, Inc.

Palmer DD. 2003. Hawaii’s Ferns and Fern Allies. University of Hawaii Press, Honolulu.

Pratt HD. 1998. A Pocket Guide to Hawaii’s Trees and Shrubs. Mutual Publishing, Honolulu.

Reppun F, Silva JHS, Wong K, and Deenik JL. 2017. A Soil Phosphorus Primer for Hawaiian Soils. Soil and Crop Management, August 2017, SCM-33. College of Tropical Agriculture and Human Resources, University of Hawaii at Manoa. Available online at: https://www.ctahr.hawaii.edu/oc/freepubs/pdf/SCM-33.pdf

Ripperton JC and EY Hosaka. 1942. Vegetation zones of Hawaii. Hawaii Agricultural Experiment Station Bulletin 89:1-60.

Rock JF. The Indigenous Trees of the Hawaiian Islands. 1st edition 1913, reprinted 1974, Charles E. Tuttle Company, Rutland, VT and Tokyo, Japan.

Schroeder TA. 1981. Characteristics of local winds in northwest Hawaii. Journal of Applied Meteorology 20: 874-881.

Shoji SD, M Nanzyo, and R Dahlgren. 1993. Volcanic Ash Soils: Genesis, Properties and Utilization. Elsevier, New York.

Silva JA and R Uchida, eds. 2000. Plant Nutrient Management in Hawaii’s Soils, Approaches for Tropical and Subtropical Agriculture. College of Tropical Agriculture and Human Resources, University of Hawaii at Manoa. Available online at: https://www.ctahr.hawaii.edu/oc/freepubs/pdf/pnm0.pdf

Sohmer SH and R Gustafson. 2000. Plants and Flowers of Hawaii. University of Hawaii Press, Honolulu.

Soil Survey Staff. 2014. Soil Taxonomy, Twelfth Edition. USDA – NRCS.

Steadman DW. 1995. Prehistoric extinctions of Pacific island birds: biodiversity meets zooarchaeology. Science 267:1123-1131.

USDA-NRCS-PIA T&E Species GIS files. Not publicly available.

USDA-NRCS. 2011. Soil Survey Laboratory Information Manual. Soil Survey Investigations Report No. 45, Version 2.0. National Soil Survey Center, Lincoln, Nebraska.

USDA-NRCS. 2006. Major Land Resource Regions. USDA Agriculture Handbook 296. http://soils.usda.gov/MLRAExplorer

USDA-NRCS. Island of Hawaii Soil Surveys 801 and 701. Available online at https://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm

USDA-SCS. 1972. Soil Survey of Islands of Kauai, Oahu, Maui, Molokai, and Lanai, State of Hawaii. Foote DE, Hill EL, Nakamura S, and F Stephens, in cooperation with The University of Hawaii Agricultural Experiment Station.

USDI-USGS. 2006. A GAP Analysis of Hawaii. Final Report and Data.

Vitousek P. 2004. Nutrient Cycling and Limitation: Hawaii as a Model Ecosystem. Princeton University Press, Princeton and Oxford.

Wagner WL, DR Herbst, and SH Sohmer. 1999. Manual of the Flowering Plants of Hawaii, Revised Edition. Bishop Museum Press, Honolulu.

Welch DJ 1983. Report 5: Archaeological investigations in Section 2. In: Archaeological investigations of the Mudlane-Waimea-Kawaihae Road Corridor, Island of Hawaii: An Interdisciplinary Study of an Environmental Transect. Clark JT and Kirch PV, eds. Dept. of Anthropology, Bernice Pauahi Bishop Museum, Report 83-1, Honolulu, HI.

Western Regional Climate Center, cited 2020. Climate of Hawaii. Available: https://wrcc.dri.edu/Climate/narrative_hi.php

Whistler WA. 1995. Wayside Plants of the Islands: A Guide to the Lowland Flora of the Pacific Islands. Isle Botanica, Honolulu.

Wilmshurst, J.M., Hunt, T.L., Lipo, C.P. & Anderson, A.J. 2011. High-precision radiocarbon dating shows recent and rapid initial human colonization of East Polynesia. Proceedings of the National Academy of Sciences, USA, 108:1815–1820.

Other references

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.

Aquisalids: These are salty soils in wet areas. Although wet, the dissolved salts make the soils physiologically dry (the chemical activity, or effective concentration, of water is low). Aquisalids typically support plant species that are adapted to these conditions.

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.

Ash field: a land area covered by a thick or distinctive deposit of volcanic ash that can be traced to a specific source and has well defined boundaries. The term “ash flow” is erroneously used in the Physiographic section of this ESD due to a flaw in the national database.

Ashy: A “soil texture modifier” for volcanic ash soils having a water content at the crop wilting point of less than 30 percent; a soil that holds relatively less water than “medial” and “hydrous” soils.

Available water capacity: The amount of soil water available to plants to the depth of the first root-restricting layer.

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

Blue rock: The dense, hard, massive lava that forms the inner core of an aa lava flow.

Bulk density: the weight of dry soil per unit of volume. Lower bulk density indicates a greater amount of pore space that can hold water and air in a soil.

$CaCO_3$ 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.

Isomesic soil temperature regime: A regime in which mean annual soil temperature is 47 degrees F (8 degrees C) or higher but lower than 59 degrees F (15 degrees C) and mean summer and mean winter soil temperatures differ by less than 11 degrees F (6 degrees C) at a specified depth.

Isothermic soil temperature regime: A regime in which mean annual soil temperature is 59 degrees F (15 degrees C) or higher but lower than 72 degrees F (22 degrees C) and mean summer and mean winter soil temperatures differ by less than 11 degrees F (6 degrees C) at a specified depth.

Kipuka: An area of land surrounded by younger (more recent) lava. Soils and plant communities within a kipuka are older than, and often quite different from, those on the surrounding surfaces.

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.

Makai: a Hawaiian word meaning “toward the sea.”

Mauka: a Hawaiian word meaning “toward the mountain” or “inland.”

Medial: A “soil texture modifier” for volcanic ash soils having a water content at the crop wilting point of 30 to 100 percent; a soil that holds an amount of water intermediate to “hydrous” or “ashy” soils.

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.

Oxisols: Soils characteristic of humid, tropical or subtropical regions that formed on land surfaces that have been stable for a long time. In Hawaii, they typically occur on islands or parts of islands that have been volcanically inactive for a long time. Oxisols are highly weathered, consist largely of quartz, kaolin clays, and aluminum oxides, and have low ion exchange capacity and loamy or clayey texture.

Pahoehoe lava: A type of basaltic lava with a smooth, billowy, or rope-like surface and vesicular interior.

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.

Phosphorus adsorption: The ability of soil materials to tightly retain phosphorous ions, which are a plant nutrient. Some volcanic ash soils retain phosphorus so strongly that it is partly unavailable to plants.

Psamments: Sandy soils that have low water-holding capacity, are susceptible to wind erosion, and typically have ground water deeper than 20 inches (50 centimeters).

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 1500 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.

Spodosols: Soils with a spodic B horizon that has an accumulation of black or reddish amorphous materials that have a high pH-dependent ion exchange capacity, coarse texture, and few base cations. Above the spodic horizon there often is a light-colored albic horizon that was the source of the amorphous materials in the spodic horizon.

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.

Udic soil moisture regime: A regime in which the soil is not dry in any part for as long as 90 cumulative days in normal years, and so provides ample moisture for plants. In Hawaii it is associated with forests in which hapuu (tree ferns) are usually moderately to highly abundant.

Ultisols: Soils that have been intensively leached and weathered. They have a B horizon that has accumulated clay that has translocated there from higher horizons. They have moderate to low cation exchange capacity and low base saturation. The highest base saturation normally is in the few centimeters directly beneath the surface due to cycling of bases by plants.

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.

Other References

Abrahamson I. 2013. Fire regimes in Hawaiian plant communities. In: Fire Effects Information System, US Dept. of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. Available"
www.fs.fed.us/database/feis/fire_regimes/Hawaii/all.html

Armstrong RW. 1973. Atlas of Hawaii. University of Hawaii Press, Honolulu.

Athens JS. Ch. 12 Hawaiian Native Lowland Vegetation in Prehistory in Historical Ecology in the Pacific Islands – Prehistoric Environmental and Landscape Change. Kirch, PV and TL Hunt, eds. 1997. Yale U. Press, New Haven.

Burney DA, HF James, LP Burney, SL Olson, W Kikuchi, WL Wagner, M Burney, D McCloskey, D Kikuchi, FV Grady, R Gage II, and R Nishek. 2001. Fossil evidence for a diverse biota from Kauai and tis transformation since human arrival. Ecological Monographs 71:615-641.

Christensen CC. 1983. Report 17: Analysis of land snails. In: Archaeological investigations of the Mudlane-Waimea-Kawaihae Road Corridor, Island of Hawaii: An Interdisciplinary Study of an Environmental Transect. Clark JT. and Kirch PV, eds. Dept. of Anthropology, Bernice Pauahi Bishop Museum, Report 83-1, Honolulu, HI.

Clark JT. 1983. Report 3: The Waimea-Kawaihae Region: Historical Background. In: Archaeological investigations of the Mudlane-Waimea-Kawaihae Road Corridor, Island of Hawaii: An Interdisciplinary Study of an Environmental Transect. Clark JT and Kirch PV, eds. Dept. of Anthropology, Bernice Pauahi Bishop Museum, Report 83-1, Honolulu, HI.

Clark JT. 1983. Report 7: Archaeological investigations in Section 4. In: Archaeological investigations of the Mudlane-Waimea-Kawaihae Road Corridor, Island of Hawaii: An Interdisciplinary Study of an Environmental Transect. Clark JT and Kirch PV, eds. Dept. of Anthropology, Bernice Pauahi Bishop Museum, Report 83-1, Honolulu, HI.

Clark JT. 1983. Report 8: Archaeological investigations of agricultural sites in the Waimea area. In: Archaeological investigations of the Mudlane-Waimea-Kawaihae Road Corridor, Island of Hawaii: An Interdisciplinary Study of an Environmental Transect. Clark JT and Kirch PV, eds. Dept. of Anthropology, Bernice Pauahi Bishop Museum, Report 83-1, Honolulu, HI.

Craighill ES and EG Handy. 1991. Native Planters in Old Hawaii – Their Life, Lore, and Environment. Bernice P. Bishop Museum Bulletin 233, Bishop Museum Press, Honolulu, HI

Cuddihy LW and CP Stone. 1990. Alteration of Native Hawaiian Vegetation: Effects of Humans, Their Activities and Introductions. Honolulu: University of Hawaii Cooperative National Park Resources Study Unit.

Deenik J and AT McClellan. 2007. Soils of Hawaii. Soil and Crop Management, Sept. 2007, SCM-20. Cooperative Extension Service, College of Tropical Agriculture and Human Resources. University of Hawaii at Manoa. Available online at: https://www.ctahr.hawaii.edu/oc/freepubs/pdf/SCM-20.pdf

Dixon JB and Schulze DG, eds. 2002. Soil Mineralogy with Environmental Applications. Volume 7. Soil Science Society of America. Available online at: https://acsess.onlinelibrary.wiley.com/doi/book/10.2136/sssabookser7

Giambelluca TW and TA Schroeder. 1998. Climate. In: Atlas of Hawaii, 3rd edition. SP Juvik, JO Juvik, and RR Paradise, eds. pp. 49-59. Honolulu: University of Hawaii Press.

Gil CR. 2016-2017. Ananas comosus. Colegio Bolivar Agricultural Science. Available online at: https://www.colegiobolivar.edu.co/garden/wp-content/uploads/2017/06/Crosas-Ananas-comosus-2017.pdf

Hazlett RW and DW Hyndman. 1996. Roadside Geology of Hawaii. Mountain Press Publishing Company, Missoula MT.

Henke LA. 1929. A Survey of Livestock in Hawaii. Research Publication No. 5. University of Hawaii, Honolulu.

Horrocks M. 2009. Sweet potato (Ipomoea batatas) and banana (Musa sp.) microfossils in deposits from the Kona Field System, Island of Hawaii. Journal of Archaeological Science, May 2009.

Imada, C. 2012. Hawaiian Native and Naturalized Vascular Plants Checklist (December 2012 update). Bishop Museum Technical Report 60. Bishop Museum Press, Honolulu.

Jacobi JD. 1989. Vegetation Maps of the Upland Plant Communities on the Islands of Hawaii, Maui, Molokai, and Lanai. Technical Report 68. Cooperative National Park Resources Studies Unit, University of Hawaii at Manoa and National Park Service.

Juvik JO and D Nullet. 1993. Relationships between rainfall, cloud-water interception, and canopy throughfall in a Hawaiian montane forest. IN: Tropical Montane Cloud Forests. Proc. Int. Sym., San Juan, PR. Hamilton LS, JO Juvik, and FN Scatena, eds. East-West Center.

Kirch PV. 1982. The impact of the prehistoric Polynesians in the Hawaiian ecosystem. Pacific Science 36(1):1-14.

Kirch PV. 1983. Introduction. In: Archaeological investigations of the Mudlane-Waimea-Kawaihae Road Corridor, Island of Hawaii: An Interdisciplinary Study of an Environmental Transect. Clark JT and Kirch PV, eds. Dept. of Anthropology, Bernice Pauahi Bishop Museum, Report 83-1, Honolulu, HI.

Kirch PV. 1985. Feathered Gods and Fishhooks: An Introduction to Hawaiian Archaeology and Prehistory. Honolulu: University of Hawaii Press.

Kirch PV. 2000. On the Road of the Winds: An Archaeological History of the Pacific Islands Before European Contact. Berkeley: University of California Press.

Leopold LB. 1949. The interaction of trade wind and sea breeze, Hawaii. Journal of Meteorology 6: 312-320.

Little EL Jr. and RG Skolmen. 1989. Common Forest Trees of Hawaii (Native and Introduced). US Department of Agriculture-US Forest Service Agriculture Handbook No. 679. (out of print). Available at www.fs.fed.us/psw/publications/documents/misc/ah679.pdf

Maly K and O Maly. 2004. He Moolelo Aina: A Cultural Study of the Puu O Umi Natural Area Reserve and Kohala-Hamakua Mountain Lands, Districts of Kohala and Hamakua, Island of Hawaii. Kumu Pono Associates, Hilo HI.

McEldowney H. 1983. Report 16: A description of major vegetation patterns in the Waimea-Kawaihae region during the early historic period. In: Archaeological investigations of the Mudlane-Waimea-Kawaihae Road Corridor, Island of Hawaii: An Interdisciplinary Study of an Environmental Transect. Clark JT and Kirch PV, eds. Dept. of Anthropology, Bernice Pauahi Bishop Museum, Report 83-1, Honolulu, HI.

Mubyana T. 1997/98. Effects of continuous sugarcane and pineapple cropping on organic matter and soil microbial biomass. Journal of African Research and Development 27&28:258-269.

Mueller-Dombois D and FR Fosberg. 1998. Vegetation of the Tropical Pacific Islands. Springer-Verlag New York, Inc.

Palmer DD. 2003. Hawaii's Ferns and Fern Allies. University of Hawaii Press, Honolulu.

Pratt HD. 1998. A Pocket Guide to Hawaii's Trees and Shrubs. Mutual Publishing, Honolulu.

Reppun F, Silva JHS, Wong K, and Deenik JL. 2017. A Soil Phosphorus Primer for Hawaiian Soils. Soil and Crop Management, August 2017, SCM-33. College of Tropical Agriculture and Human Resources, University of Hawaii at Manoa. Available online at: https://www.ctahr.hawaii.edu/oc/freepubs/pdf/SCM-33.pdf

Ripperton JC and EY Hosaka. 1942. Vegetation zones of Hawaii. Hawaii Agricultural Experiment Station Bulletin 89:1-60.

Rock JF. The Indigenous Trees of the Hawaiian Islands. 1st edition 1913, reprinted 1974, Charles E. Tuttle Company, Rutland, VT and Tokyo, Japan.

Schroeder TA. 1981. Characteristics of local winds in northwest Hawaii. Journal of Applied Meteorology 20: 874-881.

Shoji SD, M Nanzyo, and R Dahlgren. 1993. Volcanic Ash Soils: Genesis, Properties and Utilization. Elsevier, New York.

Silva JA and R Uchida, eds. 2000. Plant Nutrient Management in Hawaii's Soils, Approaches for Tropical and Subtropical Agriculture. College of Tropical Agriculture and Human Resources, University of Hawaii at Manoa. Available online at: https://www.ctahr.hawaii.edu/oc/freepubs/pdf/pnm0.pdf

Sohmer SH and R Gustafson. 2000. Plants and Flowers of Hawaii. University of Hawaii Press, Honolulu.

Soil Survey Staff. 2014. Soil Taxonomy, Twelfth Edition. USDA – NRCS.

Steadman DW. 1995. Prehistoric extinctions of Pacific island birds: biodiversity meets zooarchaeology. Science 267:1123-1131.

USDA-NRCS-PIA T&E Species GIS files. Not publicly available.

USDA-NRCS. 2011. Soil Survey Laboratory Information Manual. Soil Survey Investigations Report No. 45, Version 2.0. National Soil Survey Center, Lincoln, Nebraska.

USDA-NRCS. 2006. Major Land Resource Regions. USDA Agriculture Handbook 296. http://soils.usda.gov/MLRAExplorer

USDA-NRCS. Island of Hawaii Soil Surveys 801 and 701. Available online at https://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm

USDA-SCS. 1972. Soil Survey of Islands of Kauai, Oahu, Maui, Molokai, and Lanai, State of Hawaii. Foote DE, Hill EL, Nakamura S, and F Stephens, in cooperation with The University of Hawaii Agricultural Experiment Station.

USDI-USGS. 2006. A GAP Analysis of Hawaii. Final Report and Data.

Vitousek P. 2004. Nutrient Cycling and Limitation: Hawaii as a Model Ecosystem. Princeton University Press, Princeton and Oxford.

Wagner WL, DR Herbst, and SH Sohmer. 1999. Manual of the Flowering Plants of Hawaii, Revised Edition. Bishop Museum Press, Honolulu.

Welch DJ 1983. Report 5: Archaeological investigations in Section 2. In: Archaeological investigations of the Mudlane-Waimea-Kawaihae Road Corridor, Island of Hawaii: An Interdisciplinary Study of an Environmental Transect. Clark JT and Kirch PV, eds. Dept. of Anthropology, Bernice Pauahi Bishop Museum, Report 83-1, Honolulu, HI.

Western Regional Climate Center, cited 2020. Climate of Hawaii. Available: https://wrcc.dri.edu/Climate/narrative_hi.php

Whistler WA. 1995. Wayside Plants of the Islands: A Guide to the Lowland Flora of the Pacific Islands. Isle Botanica, Honolulu.

Contributors

David Clausnitzer
John Proctor
Carolyn Wong
Mathew Cocking
Amy Koch
Mike Kolman
Kendra Moseley
Michael Constantinides

Jennifer Higashino

Acknowledgments

Assistance, advice, review, and/or insights:

Elena Dosamantes, NRCS
David Duvauchelle, NRCS
David Kormomorowski, NRCS
John Colon, NRCS
Richard Ogoshi, NRCS
Lexus Kalawe, SWCD
Dohna Bicoy, NRCS
Randy Bartlett, Puu Kukui Watershed Preserve
Alison Cohan, The Nature Conservancy
Michael Constantinides, NRCS-PIA
Gordon Cran, Kapapala Ranch
Diana Crow, Ulupalakua Ranch
Lance DeSilva, Hawaii DLNR
Kerri Fay, Waikamoi Preserve, The Nature Conservancy
Alex Franco, Kaupo Ranch
Ranae Ganske-Cerizo, NRCS
Carl Hashimoto, NRCS
Jennifer Higashino, USFWS and NRCS
Bob Hobdy, consultant
Wallace Jennings, NRCS
Mel Johansen, The Nature Conservancy
Jordan Jokiel, Haleakala Ranch
Mike Kolman, NRCS
David Leonard, volunteer
Penny Levin
Reese Libby, GIS - NRCS
Hannah Lutgen, Maui SWCD
Joseph May, NRCS
Scott Meidel, Haleakala Ranch
Anna Palomino, Hoolawa Farms Inc.
Jon Price, USGS
Tamara Sherrill, USFWS, Maui Nui Botanical Garden
Amber Starr, Hana Ranch
Kahana Stone, NRCS
Mark Vaught, Water Resources, Alexander & Baldwin
Jacqueline Vega, NRCS
Rich von Wellsheim, Whispering Bamboos, Kipahulu

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	03/26/2026
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:**