Ecological site VX157X01X003
Rocky Volcanic Ash Savanna Kiawe/buffelgrass (Prosopis pallida/Pennisetum ciliare)

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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): 157X–Arid and Semiarid Low Mountain Slopes

This MLRA occurs in the State of Hawaii on the islands of Hawaii and Maui. It consists primarily of moderately dissected, gently sloping to steep, leeward mountain slopes. Elevation ranges from sea level to about 6000 feet (0 to 1830 meters). Underlying geology is largely basaltic aa, which is covered by volcanic ash. Climate is dry tropical. Average annual precipitation typically ranges from 10 to 35 inches (255 to 890 millimeters), rising to 45 inches (1145 millimeters) on higher slopes, and mostly occurs from October through May. Much of the rainfall occurs in kona storms during winter. Average annual temperatures range from 55 to 76 degrees F (13 to 24 degrees C), with very little seasonal variation. Soils are mostly Andisols, Mollisols, and Aridisols with isohyperthermic or isothermic soil temperature regimes and ustic or aridic soil moisture regimes. Native vegetation is rare and consists of species characteristic of dry habitats, such as ilima, wiliwili, and aiea. Naturalized grasses such as buffelgrass and kikuyugrass and trees such as kiawe are common.

Classification relationships

This ecological site occurs within Major Land Resource Area (MLRA) 157 - Arid and Semiarid Low Mountain Slopes.

Ecological site concept

This ecological site is largely naturalized grassland on the lower western and southern slopes of Haleakala on the island of Maui and the lower western slope of Kohala and

Mauna Kea on the island of Hawaii, the rain shadows of these mountains. Most of the area is owned by the State of Hawaii and Division of Hawaiian Homelands, but parts are on private ranches and other private holdings. On Maui, examples of this ecological site can be seen from Route 37 Piilani Highway and the part of Route 31 that goes through Kihei and Wailea. On Hawaii, examples can be seen along the northern end of Route 19, including at Spencer Beach State Park, and along Route 270, including at Mahukona Beach Park.

The central concept of the Rocky Volcanic Ash Savanna is of well drained, deep and very deep Andisols, moderately deep or deep Aridisols, and shallow Mollisols formed in deposits of volcanic ash deposited over aa lava flows. This Ecological Site occurs on lava flows that are within a range of 50,000 up to 900,000 years old with a few exceptions. Annual air temperatures and rainfall are associated with very warm (isohyperthermic), seasonally dry (aridic or aridic/ustic intergrade) soil conditions. High rock contents (stony, very stony, extremely stony) and/or coarse textures in the soils reduce their plant available water holding capacity in usually coarse-textured surface horizons but, by reducing soil content per unit volume, allow water to infiltrate deep into the soil for storage in finer-textured subsurface horizons. Elevations range from sea level (0 meters) to about 2000 feet (615 meters).

Associated sites

VX157X01X008	**Rocky Isothermic Naturalized Grassland Koa haole/guineagrass - buffelgrass/glycine (Leucaena leucocephala/Urochloa maxima - Cenchrus ciliaris/Neonotonia wightii)** The Rocky Isothermic Naturalized Grassland occurs only on the island of Maui. It forms part of the upper-elevation boundary of the Rocky Volcanic Ash Savanna on Maui. It has a cooler soil temperature regime (isothermic), moister soil moisture regime (mostly ustic versus torric), greater average annual rainfall (15 to 40 versus 7 to 20 inches), occupies higher elevations (1000 to 2600 versus 0 to 2200 feet), supports native dry forest rather than savanna and shrubland, and has a different dominant forage grass species (guineagrass versus buffelgrass) compared to the Rocky Volcanic Ash Savanna. Due to the moister conditions, soils in the Rocky Isothermic Naturalized Grassland are more weathered (Mollisols, Andisols, and a Histosol) than the Aridisols and Andisols in the Rocky Volcanic Ash Savanna.
VX160X01X503	**Isothermic Forest** The Isothermic Forest occurs only on the island of Hawaii. It adjoins the eastern, upper-elevation border of the Rocky Volcanic Ash Savanna. It has a cooler soil temperature regime (isothermic versus isohyperthermic), moister soil moisture regime (mostly ustic versus torric), greater average annual rainfall (20 to 40 versus 7 to 20 inches), supports native dry forest rther than savanna and shrubland, and has a different dominant forage grass species (kikuyugrass versus buffelgrass) compared to the Rocky Volcanic Ash Savanna. Both sites have soils that formed in volcanic ash.

VX157X01X004	**Alluvial Woodland (Kiawe/Prosopis pallida)** The Alluvial Woodland occurs only on the island of Hawaii. It is situated at the coast from 0 to 50 feet elevation, where it has received alluvium from higher areas via drainageways within the surrounding Rocky Volcanic Ash Savanna. It receives lower average annual rainfall (7 to 10 versus 7 to 20 inches) than the Rocky Volcanic Ash Savanna and receives occasional, very brief flooding. Most importantly, it has a deep water table accessible to the roots of kiawe trees, resulting in a kiawe woodland rather than a tree/grass savanna.
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 forms the northeastern boundary of the Rocky Volcanic Ash Savanna on the island of Hawaii where average annual rainfall increases rapidly to the northeast due to atmospheric moisture curving around the northern end of Kohala Volcano. It has the same soil temperature regime (isohyperthermic although a few degrees F cooler), moister soil moisture regime (mostly ustic versus torric), greater average annual rainfall (20 to 60 versus 7 to 20 inches), supports native dry forest rather than savanna and shrubland, and has a different dominant forage grass species (guineagrass versus buffelgrass) compared to the Rocky Volcanic Ash Savanna. Due to the moister conditions and, in places, greater geologic age, soils in the Isohyperthermic Ustic Naturalized Grassland are more weathered (mostly Mollisols, Oxisols, and Ultisols) than the Aridisols and Andisols in the Rocky Volcanic Ash Savanna.
VX161A01X001	**Isohyperthermic Desert** The Isohyperthermic Desert occurs only on the island of Hawaii on flows emanating from Mauna Loa rather the Kohala or Mauna Kea flows of the Rocky Volcanic Ash Savanna. It adjoins the southern border of the Rocky Volcanic Ash Savanna on Hawaii. These two ecological sites share soil temperature regimes (although the Isohyperthermic Desert has higher soil temperatures) and soil moisture regimes and have very similar rainfall, and elevations. Both have soils primarily formed in volcanic ash, but soils in the Isohyperthermic Desert range from shallow to moderately deep compared to moderately deep to very deep in the Rocky Volcanic Ash Savanna. Plant species are similar in both sites, although the Isohyperthermic Desert currently has shared dominance of buffelgrass and crimson fountaingrass. This is likely due to the origination point and rate of spread of fountaingrass rather than any other factors.

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 part of the Rocky Volcanic Ash Savanna on Maui. These two ecological sites share soil temperature and moisture regimes and have very similar rainfall, elevations, and vegetation. Due to moderately to much older substrates, soils in the Rocky Isohyperthermic Torric Naturalized Grassland are mostly Mollisols rather than the Andisols or Aridisols occuring in the Rocky Volcanic Ash Savanna.

Similar sites

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 7 to 20 inches), lower elevation range (0 to 1000 versus 0 to 2000 feet), and supports native grassland and shrubland rather than savanna and shrubland. The two site share the same dominant forage grass species (buffelgrass), but the Torric Naturalized Grassland has very little kiawe, unlike the Rocky Volcanic Ash Savanna. 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.
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 2000 feet), and supports similar vegetation compared to the Rocky Volcanic Ash Savanna The ecological sites share buffelgrass as a potential dominant forage grass species. The soils in the Isohyperthermic Torric Naturalized Grassland are mostly formed in alluvium and are older and more weathered, although some soils are Andisols as in the Rocky Volcanic Ash Savanna.
VX163X01X001	**Shrink-Swell Clay** The Naturalized Grassland 15 to 30 Inch Precipitation Zone is on the islands of Oahu and Kauai. It has the same soil temperature regime (isohyperthermic), same soil moisture regime (mostly torric), greater average annual rainfall (15 to 35 versus 7 to 20 inches), lower elevation range (0 to 400 versus 0 to 2000 feet), and supports similar vegetation compared to the Rocky Volcanic Ash Savanna. The ecological sites share buffelgrass as a potential dominant forage grass species. The soils in the Naturalized Grassland 15 to 30 Inch Precipitation Zone are older and more weathered (mostly Mollisols and Aridisols) than the Andisols in the Rocky Volcanic Ash Savanna.

VX158X01X002	**Isohyperthermic Torric Naturalized Grassland Kiawe/buffelgrass (Prosopis pallida/Pennisetum ciliare)** The Isohyperthermic Torric Naturalized Grassland is on the islands of Maui, Molokai, Lanai, and Kauai. It has the same soil temperature regime (isohyperthermic), soil moisture regime (torric), greater average annual rainfall (10 to 40 versus 7 to 20 inches), particularly on Kauai, similar elevation range, and supports similar plant species compared to the Rocky Volcanic Ash Savanna. The ecological sites share buffelgrass as a potential dominant forage grass species. The soils in the Isohyperthermic Torric Naturalized Grassland are older and more weathered (mostly Mollisols and Oxisols) than the Andisols in the Rocky Volcanic Ash Savanna.
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, and different Soil Orders (mostly Mollisols versus Andisols), and supports similar vegetation compared to the Rocky Volcanic Ash Savanna. The ecological sites share buffelgrass as a potential dominant forage grass species.

Table 1. Dominant plant species

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

Legacy ID

R157XY003HI

Physiographic features

This ecological site occurs on volcanic ash deposited over lava flows on mountain slopes, interfluves and coastal plains of shield volcanoes. Lava flows are mostly aa (loose, cobbly), although there are smaller areas of pahoehoe and alluvium.

Table 2. Representative physiographic features

Landforms	(1) Shield volcano > Mountain slope (2) Interfluve (3) Coastal plain (4)
Runoff class	Very low to medium

Flooding frequency	None
Ponding frequency	None
Elevation	0–610 m
Slope	1–25%
Ponding depth	0 cm
Water table depth	152 cm
Aspect	W, S, SW

Climatic features

(Unless otherwise cited, the information in this section is derived from Western Regional Climate Center, cited 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).

The islands lie within the trade wind zone. Significant amounts of moisture are picked up from the ocean by trade winds up to an altitude of more than about 6000 feet (1850 meters). As the trade winds from the northeast are forced up the mountains of the islands their moisture condenses, creating rain on the windward slopes; the leeward sides of the island receive less of this moisture, depending on the height of the mountains.

Hawaiian indigenous understanding recognized two seasons: Kau or Kauwela (dry season) when the sun was directly overhead, days are long and warm and tradewinds are stronger and more consistent; Kau started on the first new moon in May when the Pleiades set at sunrise (Handy, 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 1991, Sanderson, 1993). These seasons are mostly consistent with modern observations today. These phenomena of pressure systems and seasonal differences interact with the islands’ topography which together creates the various climate zones and patterns observed in the islands. One such general pattern can be seen in the differences in rainfall amounts between winter and summer; in low elevation dry areas the differences are greater whereas wetter areas exhibit less seasonal variation in rainfall.

Summary for this ecological site
Average annual precipitation in this ecological site ranges from 7 to 20 inches (175 to 500

millimeters). Most of the precipitation occurs from October through April. Average annual temperatures range from 73 to 76 degrees F (23 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 islands 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; frequent cloudiness higher on the mountain slopes usually does not shade this area due to the angle of the sun.

Soils in the Mahukona series (map units 411 and 412) receive higher average annual rainfall (20 to 35 inches or 125 to 700 millimeters) than other soils in this ecological site due to their location at the extreme north tip of Kohala, where the prevailing winds bring more moisture around the peninsula.

Table 3. Representative climatic features

Frost-free period (characteristic range)	365 days
Freeze-free period (characteristic range)	365 days
Precipitation total (characteristic range)	305-381 mm
Frost-free period (actual range)	365 days
Freeze-free period (actual range)	365 days
Precipitation total (actual range)	279-406 mm
Frost-free period (average)	365 days
Freeze-free period (average)	365 days
Precipitation total (average)	330 mm

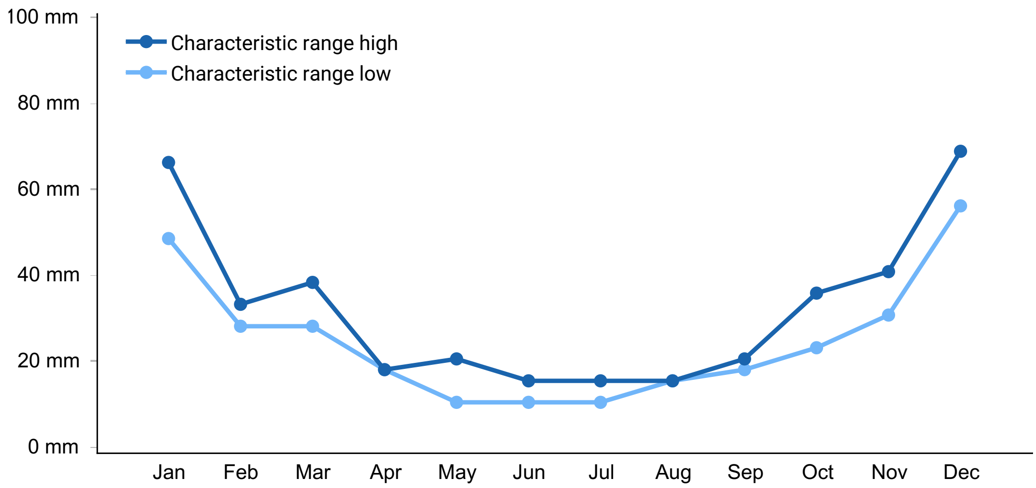

Figure 1. Monthly precipitation range

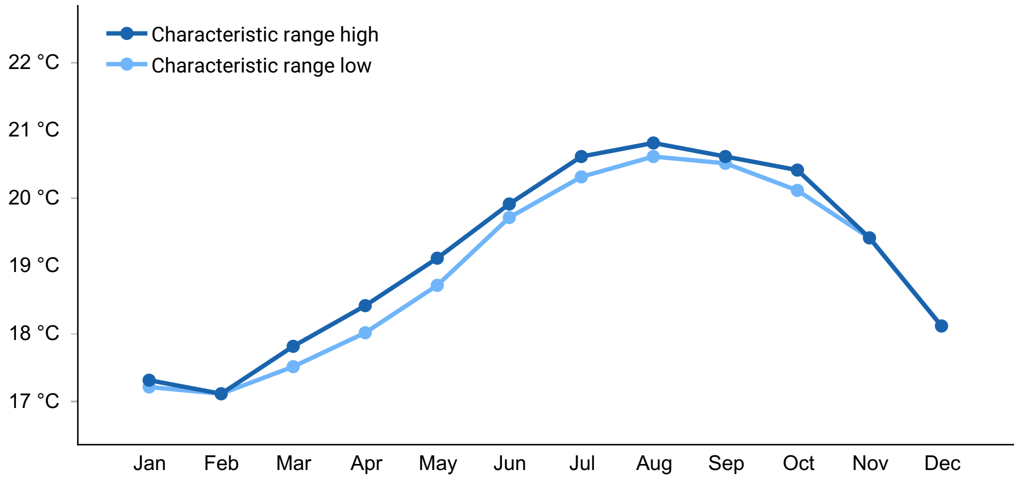

Figure 2. Monthly minimum temperature range

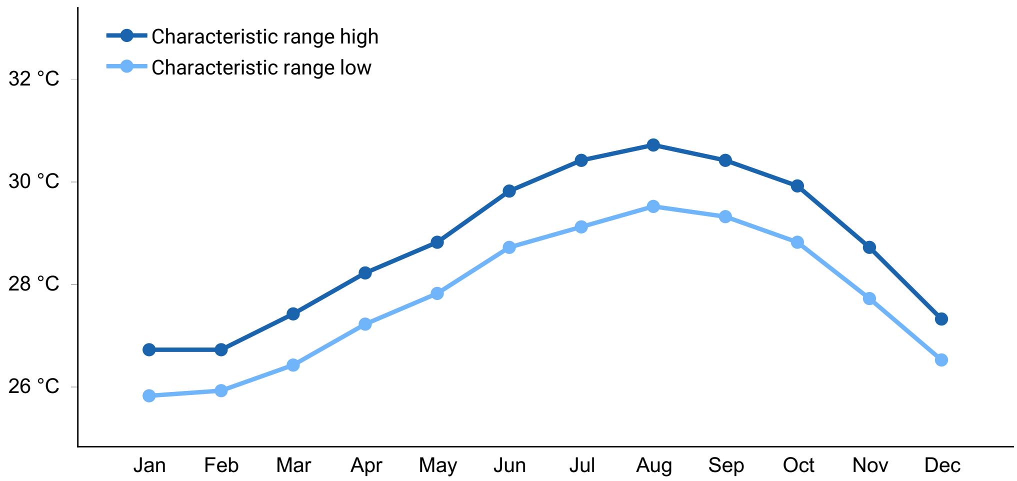

Figure 3. Monthly maximum temperature range

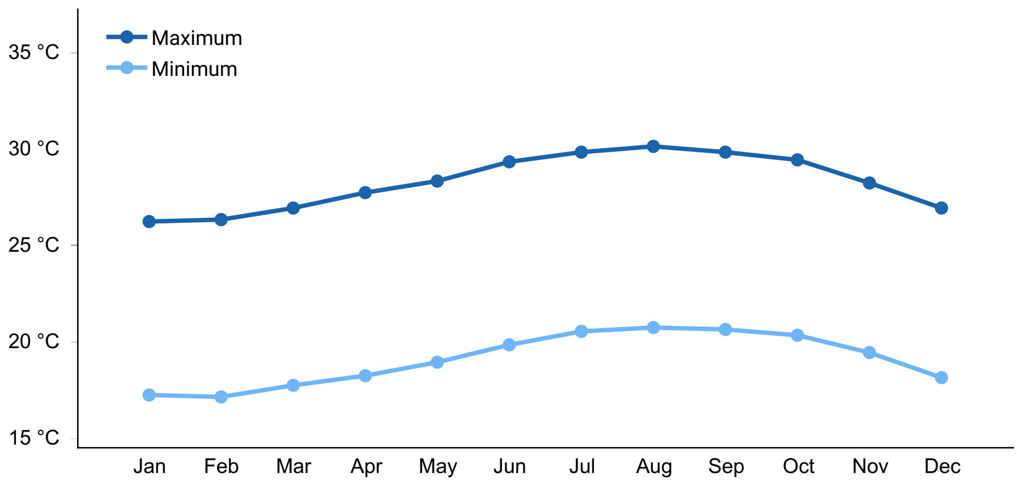

Figure 4. Monthly average minimum and maximum temperature

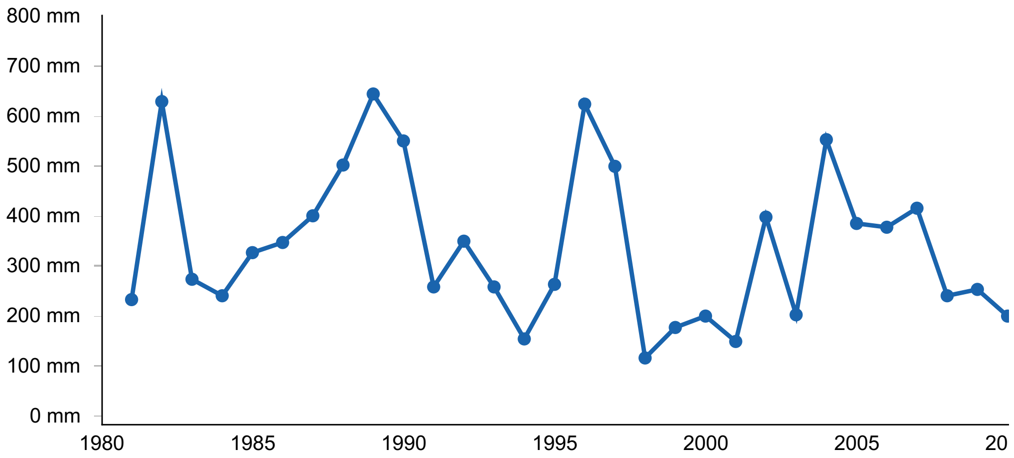

Figure 5. Annual precipitation pattern

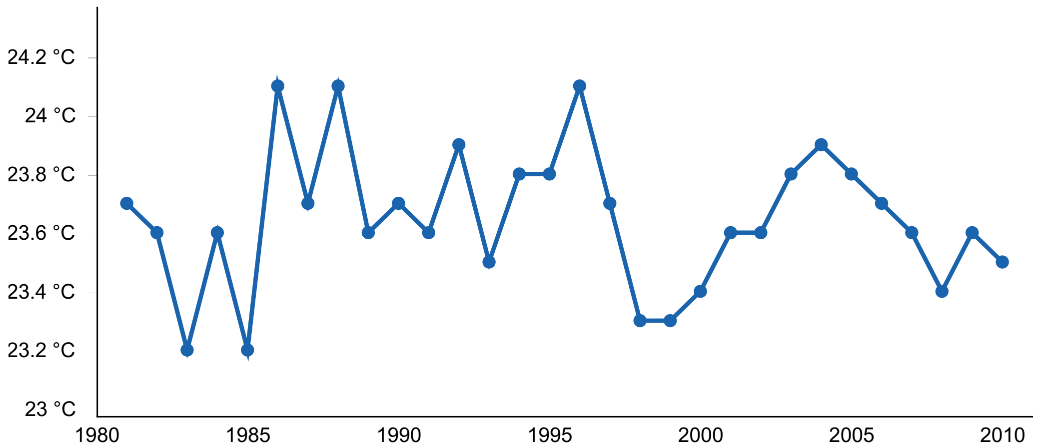

Figure 6. Annual average temperature pattern

Climate stations used

- (1) MAKENA GOLF CRS 249.1 [USC00515842], Kihei, HI
- (2) PUUKOHOLA HEIAU 98.1 [USC00518422], Kamuela, HI

Influencing water features

Mostly ephemeral streams flow through small gulches during periods of heavy rainfall. These gulches are associated with the areas of alluvial soils occurring in this ecological site. The narrow zones through which water typically flows are often associated with higher kiawe density than surrounding areas. Broader alluvial zones sometimes have higher kiawe density throughout, but typically in these broader zones the higher kiawe density occurs only in the narrow areas in streambeds and down at the shoreline.

Soil features

Most of the soils in this ecological site formed from volcanic ash deposited over and in the interstices of basaltic aa lava. Soils in the Kawaihae series formed from volcanic ash deposited over pahoehoe. Although pahoehoe is thought of as having a solid surface, many pahoehoe flows cracked and/or were lifted from beneath, creating rock fragments like those found in aa. The lava rock fragments found in these soils range in size from gravel (up to 3 inches, or 2 mm to 76 mm) to stones (10 to 25 inches, or 250 mm to 600 mm), but are primarily cobbles (76 mm to 250 mm, or 3 to 10 inches) and gravel. Below the layer of rock fragments is massive lava called "bluerock." Interstices between stones are filled with fine soil material near the surface. The deepest horizon typically consists of rocks with empty voids between them.

Soils in the Puako and Lalamilo series formed in alluvial volcanic ash deposited by ephemeral or permanent streams in small gulches; these soils make up a small part of the ecological site.

Soil temperature regimes are isohypothermic (very warm). Soil moisture regimes are torric (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, in Keawakapu and Mahukona soils, moister than torric, being intergrades between ustic and aridic (aridic is similar to torric). Basically, all the soils are similar as to soil moisture regime. All but the two alluvial soils are either stony, very stony, extremely stony, very cobbly, or extremely cobbly. This reduces the amount of soil material per unit of volume, which reduces overall water holding capacity of the soil. However, given the moderate to very rapid permeability of all the soils, it enables water to percolate to deeper horizons, which have finer textures and good water holding capacity in all the soils in this ecological site. This provides deep water storage for plants with tap roots, of which kiawe is the commonest example. Kiawe as a phreatophyte, thrives where it can access groundwater or deep soil moisture. Its taproot often reaches a depth of 20-25 m (Gallagher, 2010). Kiawe is also implicated as a potential cause of changes in local hydrology and mineral cycling due to it's efficient water harvesting capability and nitrogen fixation (Dudley, 2014). All the soils are well drained. Surface soil pH of most of the soils ranges from 5.8 to 7.4; extreme pH in subsurface soils within 30 inches (75 centimeters) of the surface range from 6.8 to 8.6.

The volcanic ash soils of the Hawaiian Islands are derived mostly from basaltic ash that varies relatively little in chemical composition (Hazlett and Hyndman 1996; Vitousek 2004)). Most of these volcanic ash soils are classified today as Andisols, which have these general management characteristics: ion exchange capacity that varies with pH, but mostly retaining anions such as nitrate; high phosphorus adsorption, which restricts phosphorus availability to plants; excellent physical properties (low bulk density, good friability, weak stickiness, stable soil aggregates) for cultivation, seedling emergence, and plant root growth; resistance to compaction and an ability to recover from compaction following repeated cycles of wetting and drying; and high capacity to hold water, relative to apparent texture, that is available to plants. These characteristics are due to the properties of the parent material, the clay-size noncrystalline materials formed by weathering, and the soil organic matter accumulated during soil formation (Shoji et al. 1993).

MAKENA, OANAPUKA, WAIKUI, HAPUNA, LALAMILO, and PUAKO soils are classified as Torrands, or Andisols with a torric soil moisture regime. They are deep or very deep

(40 to more than 60 inches or 100 to more than 150 centimeters) soils. They originally formed in volcanic ash and are old and weathered enough to exhibit characteristics of Andisols but not to have developed further into other soil orders.

Makena soils are stony and have no root-restricting layers.

Oanapuka soils are distinguished in this group by having vitric properties. This means they contain a large percentage of volcanic glass or coarser cinders and pumice that has not yet been weathered out of the soil. These soils have lower water holding capacity than other Andisols. However, they have other properties that are favorable to plant growth: They have lower phosphorus retention than other Andisols, so this nutrient is more available to plants; the basaltic glass weathers, releasing fresh plant nutrients; they have low bulk density, which is favorable to root penetration; and, although the mineral particles in these soils have variable charge, they develop cation exchange at pH around and above 6 (Oanapuka pH is 6.0 in the top 2 inches (5 centimeters), then ranges from 6.5 to 7.4 in the deep (to about 43 inches or 107 centimeters) layer that contains common to many roots. All other things being equal, Oanapuka soils are likely to have higher vegetation production than other soils in this ecological site.

Waikui and Hapuna soils are distinguished in this group by having mollic properties in their surface horizons. Please see the description of Keawakapu soils below for an explanation of mollic properties. These soils are all extremely cobbly. Hapuna soils are strongly cemented by calcium carbonate and silica in the horizon from about 12 to 17 inches (30 to 42 centimeters) deep; this horizon partly impedes root penetration below this depth.

Lalamilo and Puako soils formed in volcanic ash that was transported by water to form narrow alluvial deposits in gulches. They both have fine sandy loam texture with relatively low water holding capacity, but both receive intermittent runoff. Puako soils have a surface horizon with mollic properties (see discussion under Keawakapu soils below), and they are occasionally flooded for brief periods. Lalamilo soils are very strongly cemented by calcium carbonate and silica at depths of about 63 to 65 inches (160 to 165 centimeters), which is too deep to materially affect plant growth in this environment.

Soils of the KEAWAKAPU series are classified as Aridic Haplustolls. They originally formed in volcanic ash deposited in aa but are old and weathered enough to have developed beyond Andisols to the Mollisols soil order. They are shallow (10 to 20 inches, or 25 to 50 centimeters) soils but can be as deep as 30 inches (75 centimeters) in some locations. They have an ustic soil moisture regime but are even drier, intergrading to an aridic soil moisture regime. Many of the soils in very warm, dry parts of the Hawaiian Islands are Mollisols or have mollic properties. Some of their unique 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, high (greater than 50 percent) base saturation, and a dominance of crystalline clay minerals of moderate or high cation-exchange capacity. Although Mollisols usually form under grass in seasonally dry climates, they can form under a forest ecosystem.

KAWAIHAE soils are classified as Aridisols, which have an aridic soil moisture regime, which is 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. Soils in this series are very cobbly, and there are high sodium contents occurring from about 16 inches (41 centimeters) depth to the pahoehoe lava at about 33 inches (84 centimeters). These sodic horizons are associated with prismatic structure, and the sodium contents may impede root density below about 24 inches (61 centimeters).

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 in which this ecological site is partly located, 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/or contain plant and animal species of interest to conservationists. They are either 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.

LAVA FLOWS, AA (rLW) are lava flows that are too young to have accumulated much soil (either organic or mineral) in the interstices between aa rocks. They support lichens and a few grasses, herbs, shrubs, and scrubby trees. The amount of vegetation they support is variable, but they are sparsely vegetated compared to surrounding soils in this ecological site.

VERY STONY LAND (rVS) on Maui occurs mostly in parent materials of aa lava with volcanic ash. Fifty to ninety 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.

Table 4. Representative soil features

Parent material	(1) Volcanic ash–basalt
Surface texture	(1) Very stony, extremely stony silt loam (2) Very cobbly, extremely cobbly silt loam (3) Extremely stony silt loam
Drainage class	Well drained to somewhat excessively drained

Permeability class	Moderately rapid to rapid
Depth to restrictive layer	91–160 cm
Soil depth	91–160 cm
Surface fragment cover <=3"	20–40%
Surface fragment cover >3"	3–15%
Available water capacity (0-101.6cm)	5.84–17.53 cm
Electrical conductivity (0-76.2cm)	0–2 mmhos/cm
Sodium adsorption ratio (0-76.2cm)	0
Soil reaction (1:1 water) (0-76.2cm)	5.8–7.7
Subsurface fragment volume <=3" (0-76.2cm)	0–45%
Subsurface fragment volume >3" (0-76.2cm)	10–45%

Table 5. Representative soil features (actual values)

Drainage class	Not specified
Permeability class	Not specified
Depth to restrictive layer	Not specified
Soil depth	Not specified
Surface fragment cover <=3"	Not specified
Surface fragment cover >3"	Not specified
Available water capacity (0-101.6cm)	Not specified
Electrical conductivity (0-76.2cm)	Not specified
Sodium adsorption ratio (0-76.2cm)	76
Soil reaction (1:1 water) (0-76.2cm)	8.6
Subsurface fragment volume <=3" (0-76.2cm)	Not specified
Subsurface fragment volume >3" (0-76.2cm)	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. Heavy rainfall can cause soil erosion and strong flows in gulches. Major storm events have also been known to trigger significant mud slides and flooding events. (Stearns 1942). Large earthquakes, such as the quake in 1938 may also cause geomorphically significant change to landscapes, although these are rare and impossible to predict. (Stearns 1942).

Wildfires prior to human settlement was probably infrequent. Lightning usually occurs in the wetter months and mostly at high elevations and moist windward slopes, and lava flows are intermittent and localized (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.

The first humans are believed to have migrated to Hawaii between 1000 and 1260 AD (Allen, 2014, Wilmhurst, 2011). Subsequent migrations and population growth 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). Lincoln et al (2018) notes that “at the inlet just south of the Kohala peninsula, two intensive hybrid systems that intermittently irrigated dryland areas existed.”

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 overgrazing 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. Much of the original forest of this ecological site has been cleared and planted with introduced grasses for livestock grazing, and the remaining native plant communities have been highly disturbed.

The original native vegetation was dry forest, savanna, and shrubland. Common species, based on the current environment and remnant occurrences, may have included alahee (*Psydrax odorata*), ohe makai (Polyscias sandwicensis syn. *Reynoldsia sandwicensis*), wiliwili (*Erythrina sandwicensis*), naio (*Myoporum sandwicense*), ‘ilie’e (Plumbago zeylaniza), ‘a’ali’i (*Dodonaea viscosa*), ilima (*Sida fallax*), ekoko (Euphorbia celastroides), ‘aheahea or ‘aweoweo (*Chenopodium oahuense*), huehue (*Cocculus orbiculatus*), and native grasses.

Since the loss of the native dry savannas, most of this ecological site has been utilized by livestock. Originally, the animals were feral or semi-feral. Today, the area is fenced and managed primarily for cattle. Where goat populations are high, vegetation damage can be intense, resulting in areas of bare soil and erosion, which if allowed to persist, may not stabilize on its own. The additional presence of deer on Maui exacerbates this problem, producing bare soils or areas dominated by toxic or otherwise unpalatable forbs and sparse grasses.

State and transition model

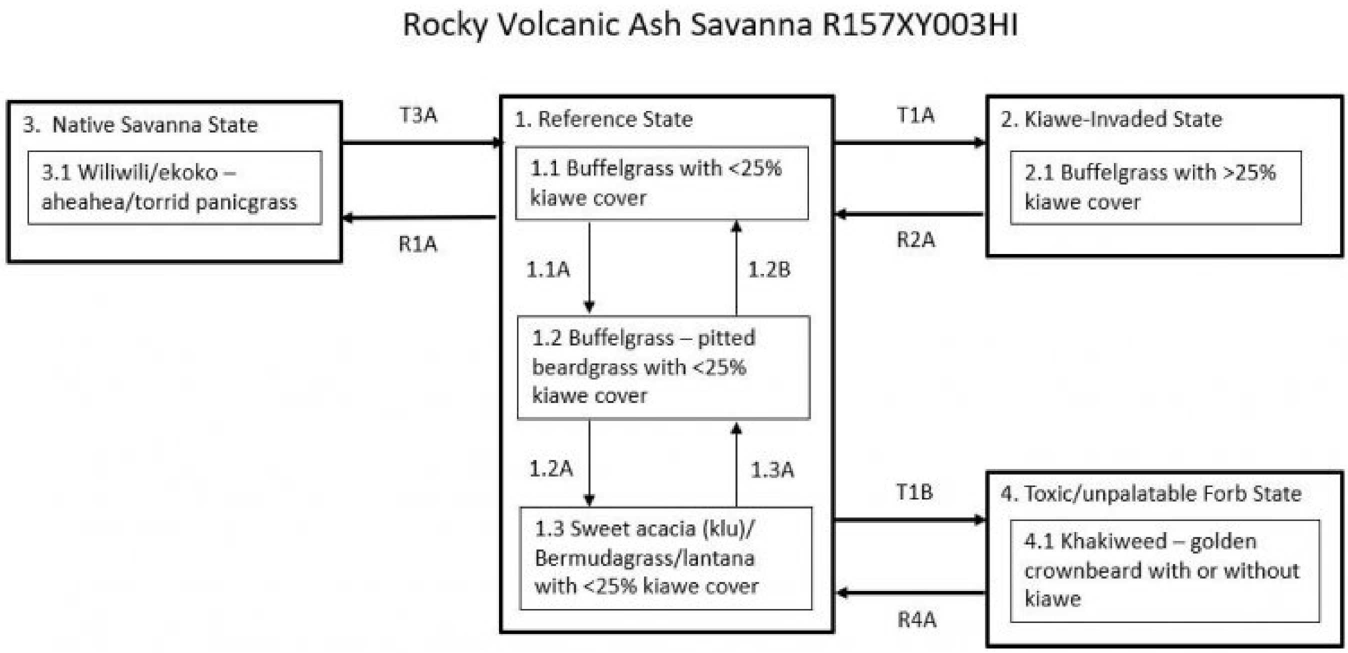

Figure 7. R157XY003 State and Transition Model (Rocky Volcanic Ash Savanna)

State 1
Reference State

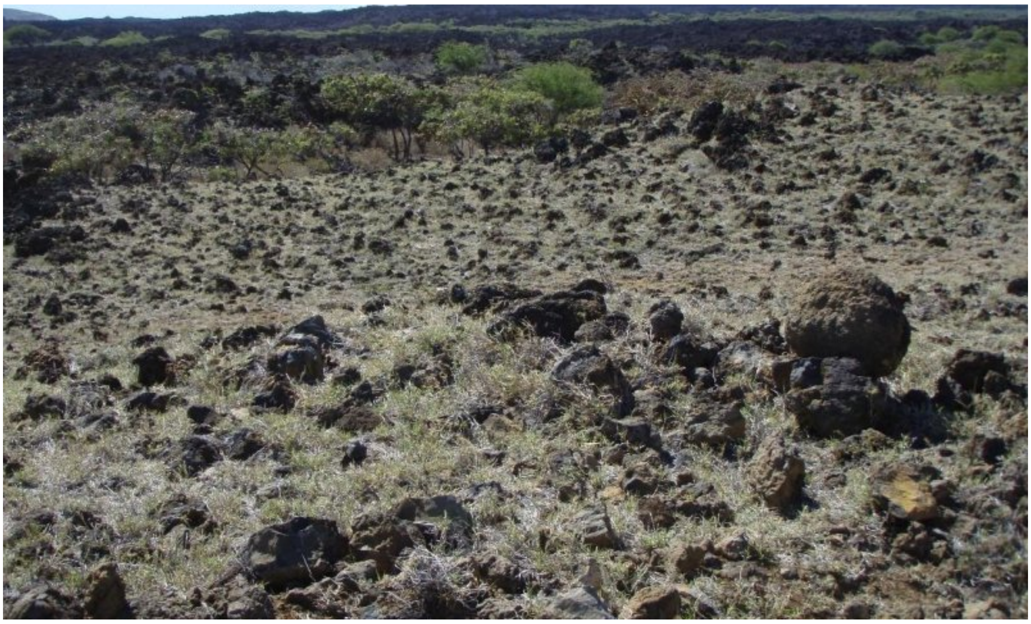

Figure 8. Reference State 1.1. Buffelgrass (in dry conditions). Map Unit OED, Oanapuka extremely stony silt loam, 7 to 25% slopes. Elevation 100 feet, annual rainfall ~ 15 inches. An 'a'a lava flow, Map Unit rLW visible in distance. David Clausnitzer, 7/22/08.

Figure 9. Reference State 1.1. Buffelgrass height and vigor absent grazing by domestic and feral ungulates. Keawakapu extremely stony silty clay loam, 3 to 25 percent Map Unit. Elevation 660 feet. Annual rainfall ~15 inches. John Proctor, 2/04/21.

Figure 10. Reference State 1.1. Buffelgrass (after recent rains) with remnant native wiliwili trees. Map Unit OED, Oanapuka extremely stony silt loam, 7 to 25% slopes. Elevation ~ 1000 feet, annual rainfall about 20 inches. David Clausnitzer, 7/22/08.

This state consists of three community phases dominated by introduced grasses with less than 25 percent canopy cover of introduced trees. The transition from one plant community within the state to another is often related to the dynamics of fire, grazing, and brush management. State 1 transitions to State 2 (Kiawe-Invaded) with lack of brush management practices or absence of wildfire. State 1 transitions to State 4 (Toxic/Unpalatable Forb) with extreme overgrazing and browsing by goats and/or deer.

Characteristics and indicators. The dominant grass species is buffelgrass (*Pennisetum ciliare*). Kiawe (*Prosopis pallida*) is the most abundant naturalized tree species. Because kiawe is a phreatophyte, access to soil moisture or groundwater can considerably affect this plant's abundance.

Resilience management. With lack of brush control or absence of fire, this state will transition to State 2 Kiawe-Invaded, in which production and cover of buffelgrass and other forages is reduced by shade and possibly competition from kiawe. Accumulation of fine (grass) fuels under light or no grazing pressure increases the likelihood of fire. This can produce an open grassland with little tree overstory wherein more frequent fire is perpetuated by rapid revegetation of highly fire-resilient, non-native grass species. Non-native savannas in Hawaii that are not grazed present fire protection challenges to embedded or adjoining developed areas and increase the rate of erosion and sediment transport to the ocean. With longer-term overgrazing and browsing by goats and, on Maui, deer, nearly all forages are removed, leading to a transition to State 4 Toxic/unpalatable Forb State. 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, depending on location, include bluestems (Bothriochloa spp.), Natal redtop or rose Natal grass (*Melinis repens*), swollen fingergrass (*Chloris barbata*), feather fingergrass (*Chloris virgata*) 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*), low-vigor buffelgrass, and weedy annual forbs become more abundant, as well as lesser amounts of pricklypear cactus or Barbary fig (*Opuntia ficus-indica*, mostly in gulches). 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 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
- buffelgrass (*Pennisetum ciliare*), grass

Community 1.1
Buffelgrass with <25% kiawe cover

Buffelgrass (*Pennisetum ciliare*) is the dominant forage species present. Kiawe (*Prosopis pallida*) and koa haole (*Leucaena leucocephala*) may be present. Kiawe is a potentially tall tree, up to 30 feet; its pods have forage value. If present at canopy cover greater than 25 percent, it can reduce production of grasses and forbs. Koa haole is a small tree that is browsed by livestock. Under continuous or excessively-heavy grazing, this phase will change to phase 1.2 Buffelgrass-pitted beardgrass with <25% kiawe cover. Buffelgrass (*Pennisetum ciliare*) comprises most of the productivity of this community phase. Other grass species that may be present are a variety of guineagrass (*Urochloa maxima*) known as panicgrass - especially in pockets of increased moisture, native piligrass (*Heteropogon contortus*) and hardstem lovegrass (*Eragrostis atropioides*). Other species that may be present include desmanthus (*Desmanthus virgatus*), a leguminous shrub, uhaloa (*Waltheria indica*) and 'akia (Wikstromia spp). In properly-managed areas, herbaceous plant basal cover is only interrupted by surface cobbles and stones, therefore this community has very little bare-ground patches.

Resilience management. Most of the naturalized plants in this community evolved in other ecosystems where the presence of herbivores and/or wildfire is a natural force. Kiawe extracts nutrients and water from the soil at greater depths and earlier in the growing season than the naturalized grasses do. Conversely, the kiawe overstory canopy tends to promote a microclimate favorable to growth of the buffelgrass and green panicgrass. Prescribed grazing, brush management, suppression of wildfires, and an extended fire return interval (10-15 years) are key components in maintaining this community phase. Where goat populations are high, vegetation damage can be intense, resulting in areas of bare soil and erosion, which if allowed to persist, may not stabilize on its own. The additional presence of deer on Maui exacerbates this problem, producing bare soil or areas dominated by toxic or otherwise unpalatable forbs and sparse grasses. This community phase is good for livestock grazing, but shrub cover may interfere with livestock handling and gathering operations. On the Big Island total annual average air-dry herbage production ranges from 700 to 3000 pounds per acre. Average production for initial stocking rate recommendations is 1100 to 1300 pounds per acre per year, not including the utilization of a 25% harvest efficiency and take-half/leave-half adjustment. Initial recommended stocking rate is expected to vary from 0.35 AUM/acre/year to 0.46 AUM/acre/year. The presence of kiawe allows wildlife like axis deer to utilize this habitat, but can detract from its value as rangeland for domestic livestock. Prevalence of feral goat populations utilizing forage intended for livestock can also be a severe problem.

Dominant plant species

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

Community 1.2
Buffelgrass - pitted beardgrass with <25% kiawe cover

This community phase consists of lower-value grass species that become abundant upon continuous heavy grazing of buffelgrass. Further overgrazing exacerbates this process, causing a community change to State 4.1. An overstory of kiawe (*Prosopis pallida*) may be present at up to 25 percent canopy cover. Pitted beardgrass (*Bothriochloa pertusa*), broomsedge beardgrass (*Andropogon virginicus*) and swollen fingergrass (*Chloris barbata*) have both increased in cover and production. Buffelgrass (Cenchrus ciliaris) 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. This plant community occurs under continuous grazing pressures that have been experienced consistently in the recent short-term past. It is the precursor community phase to Phase 3.1.1 (Sweet acacia (klu) / Bermudagrass/lantana), but has not been subjected to poor grazing management for as long. This community provides less forage amounts (and forage quality) than State 1, Phase 1 or State 4, Phase 1 communities.

Dominant plant species

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

Dominant resource concerns

- Sheet and rill erosion
- Wind erosion
- Organic matter depletion
- Plant productivity and health

Community 1.3
Sweet acacia (klu) / Bermudagrass/lantana with <25% kiawe cover

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. Litter is reduced and bare ground is increasing and becoming common, so soil erosion by wind and water can be excessive. An overstory of kiawe (*Prosopis pallida*) may be present at up to 25 percent canopy cover. 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.

Resilience management. This community phase occurs with long-term continuous grazing pressure. Recognition of this community enables the landowner/manager to implement key management decisions before a significant economic/ecological threshold into State 4 is crossed. This community provides significantly less forage amounts for grazing animals that other community phases within this State.

Dominant plant species

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

Dominant resource concerns

- Sheet and rill erosion
- Wind erosion
- Organic matter depletion
- Plant productivity and health

Pathway 1.1A
Community 1.1 to 1.2

Phase 1.1 can change to phase 1.2 with continuous grazing. Buffelgrass cover and vigor are reduced by continuous grazing, causing it to decrease and be partially replaced by pitted beardgrass and other short grasses. The application of prescribed grazing and a planned grazing system allowing for sufficient plant rest of forage species are expected to cause this community to remain intact. Systematic defoliation by ungulates limits the growth (above and below ground) and reproduction of perennial grasses. The near continuous cover and vigor typical of buffelgrass in the Reference State 1. Phase 1.1 is reduced. This results in the creation of pockets of bare ground and the reduction of organic litter accumulation to the soil surface. Access to water is the greatest limiting factor to plant survival in this site. Water infiltration is reduced in areas of bare ground and/or reduced buffelgrass cover. Solar radiation penetration to the soil surface increases in areas of bare ground and/or reduced buffelgrass cover. These changes create a competitive advantage which favors the establishment and spread of pitted beardgrass (a less palatable perennial short grass). Buffelgrass becomes partially replaced by pitted beardgrass. With continued systematic herbivory, pitted beardgrass will become the dominant grass cover.

Context dependence. Where goat populations are high, vegetation damage can be intense, resulting in areas of bare soil and erosion, which if allowed to persist, may not stabilize on its own. The additional presence of deer on Maui exacerbates this problem, producing bare soil or areas dominated by toxic or otherwise unpalatable forbs and sparse grasses.

Conservation practices

Prescribed Grazing
Planned Grazing System

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. Apply brush management and weed control as necessary. Continued rest from systematic defoliation by ungulates results in improved growth (above and below ground) and reproduction of perennial grasses. The cover and vigor of buffelgrass is increasing and their propagules are dispersing. Buffelgrass begins to replace pitted beardgrass as the dominant perennial grass cover. Litter accumulation is increasing, and bare ground is becoming infrequent on the landscape. Access to water is the greatest limiting factor to plant survival in this site. With decreased bare ground and increased buffelgrass cover, water infiltration increases markedly. Solar radiation penetration to the soil surface begins to decrease as perennial short grasses are replaced by the taller buffelgrass. Soil erosion by wind and water is stabilized. These changes create a competitive advantage which favors the reestablishment and spread of buffelgrass. Buffelgrass has replaced pitted beardgrass as the dominant grass cover. Unpalatable shrubs (Lantana and Klu), forbs, and subshrubs have decreased.

Context dependence. Adequate spring and summer rain events help accelerate vegetative growth, reproduction, and reestablishment of buffelgrass.

Conservation practices

Brush Management
Prescribed Grazing
Planned Grazing System
Invasive Species Pest Management

Pathway 1.2A
Community 1.2 to 1.3

Phase 1.2 changes to phase 1.3 with long-term and/or heavy continuous grazing. Species composition changes to dominance by short grasses, weedy forbs, and shrubs. Bare ground increases markedly. With implementation of prescribed grazing and a planned grazing system, this shift is not expected to occur. It is likely that brush management and weed control will be needed. Long-term systematic defoliation by ungulates continues to limit the growth (above and below ground), reproduction of perennial grasses. The cover and vigor of buffelgrass-pitted beardgrass is greatly reduced. Mortality of these grass species are increasing, resulting in new niches for other species to colonize. Litter accumulation is greatly reduced, and bare ground is increasing and becoming common. Access to water is the greatest limiting factor to plant survival in this site. With increased bare ground and reduced perennial grass cover, water infiltration decreases markedly. Solar radiation penetration to the soil surface increases in areas of bare ground and/or reduced buffelgrass-pitted beardgrass cover. Soil erosion by wind and water are increasing. These changes create a competitive advantage which favors the establishment and further spread of bermudagrass as well as invasive shrub species. Phase 1.3 consists mostly of grass species that are highly tolerant of continued systematic herbivory, particularly Bermudagrass, along with increased amounts of unpalatable shrubs, forbs, and subshrubs. The Klu/Bermudagrass/Lantana community phase is a precursor to a shift to State 4.1. With implementation of Prescribed Grazing and a planned grazing system, these shifts are not expected to occur.

Context dependence. Where goat populations are high, vegetation damage can be intense, resulting in areas of bare soil and erosion, which if allowed to persist, may not stabilize on its own. The additional presence of deer on Maui exacerbates this problem, producing bare soil or areas dominated by toxic or otherwise unpalatable forbs and sparse grasses.

Conservation practices

Brush Management
Planned Grazing System
Prescribed Grazing
Invasive Species Pest Management

Pathway 1.3A
Community 1.3 to 1.2

Phase 1.3 can change to phase 1.2 by application of a prescribed grazing program that allows buffelgrass to reassume dominance. Intensive weed and brush control may be necessary. Measures to control wind and water erosion may also be needed. Adequate rest from long-term systematic defoliation by ungulates results in improved growth (above and below ground) and reproduction of perennial grasses. The cover and vigor of buffelgrass and pitted beardgrass are increasing and their propagules are dispersing. Pitted beardgrass may still be the dominant perennial grass cover. Buffelgrass and pitted beardgrass recolonize new niches which have resulted from weed control and brush control efforts. Litter accumulation is increasing, and bare ground is becoming less common. Access to water is the greatest limiting factor to plant survival in this site. With decreased bare ground and increased perennial grass cover water infiltration increases. Solar radiation penetration to the soil surface begins to decrease. Soil erosion by wind and water is stabilizing. These changes create a competitive advantage which favors the reestablishment and spread of buffelgrass and pitted beard grass, which can also limit the additional spread of invasive shrub species. Buffelgrass and pitted beardgrass have replaced bermudagrass as the dominant grass covers.

Context dependence. Adequate spring and summer rain events help accelerate vegetative growth, reproduction, and reestablishment of buffelgrass and pitted beardgrass.

Conservation practices

Brush Management
Prescribed Grazing
Planned Grazing System
Invasive Species Pest Management
Grazing Management Plan - Applied

State 2
Kiawe-Invaded State

Figure 11. State 2.1. Kiawe-Invaded (heavily grazed) State. Buffelgrass with estimated 60 % Kiawe canopy cover. Keawakapu extremely stony silty clay loam, 3 to 25 % slopes Map Unit. Elevation 680 feet. Annual rainfall about 15 inches. John Proctor, 2/04/21.

State 2 Kiawe Invaded is characterized by dense kiawe canopy covers over 25%. Scattered grasses and forbs may be in the understory. This state consists of one community phase.

Characteristics and indicators. It occurs when brush management has not been practiced or if wildfire has not occurred for a long time, allowing kiawe to increase in density and stature to a level at which understory production is significantly reduced.

Resilience management. To cross a threshold back to State 1, a fire return interval <15 years is needed, and likely additional brush management strategies to avoid proliferation of invasive shrubs (lantana, klu, koa-haole, etc). Prescribed grazing strategies allowing for sufficient rest of herbaceous forages will be needed as well. Conversion from State 2 back to any community in State 1 will require extensive labor, time and money.

Dominant plant species

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

Dominant resource concerns

- Organic matter depletion
- Naturally available moisture use
- Plant productivity and health
- Wildfire hazard from biomass accumulation

State 3
Native Savanna State

Figure 12. State 3.1. Facsimile of Native Savanna. Kiawe killed and fencing established to protect existing and introduced native trees, shrubs and forbs including Naio, 'a'ali'i, and Alahee. Oanapuka extremely stony silt loam, 7 to 25% slopes. Elevation 80'.

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.

Dominant plant species

- wili wili (*Erythrina sandwicensis*), tree
- 'ohe makai (*Reynoldsia sandwicensis*), tree
- yellow ‘ilima (*Sida fallax*), shrub

Community 3.1
Wili wili - ohe makai/ilima

The hypothetical appearance of this community phase is an open canopy of low to medium height (15-25 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. Among the common tree species would be wili wili (*Erythrina sandwicensis*), ohe makai (Polyscias sandwicensis), koaia (*Acacia koa*ia), lama (*Diospyros sandwicensis*), kului (*Nototrichium sandwicense*), hao (*Rauvolfia sandwicensis*), and alahee (Psydrax odoratum). Some common shrubs would be maiapilo or native caper (*Capparis sandwichiana*), aheahea (*Chenopodium oahuense*), akoko (Euphorbia spp.), mao or Hawaiian cotton (*Gossypium tomentosum*), iliahi (*Santalum ellipticum*), and ilima (*Sida fallax*). Some common vines would be huehue (*Cocculus orbiculatus*), dodder (Cuscuta campestris), pauohiiaka (Jacquemontia sandwicensis), and koali awa (*Ipomoea indica*). Forbs, grasses, and grasslike species would be present.

Resilience management. To protect and maintain this community the site must be fenced to exclude all domestic and feral ungulates. A firebreak must be established and maintained around the fence line by grazing or mowing. A long-term Integrated Pest Management program must be established and maintained that includes early detection and rapid response of invasive plant species or pathogens which may threaten this plant community.

Dominant plant species

- wili wili (*Erythrina sandwicensis*), tree
- 'ohe makai (*Reynoldsia sandwicensis*), tree
- yellow ‘ilima (*Sida fallax*), shrub

State 4
Toxic/Unpalatable Forb State

Figure 13. State 4.1. Toxic/unpalatable Forb. Onapuka extremely stony silt loam, 7 to 25 percent slopes Map Unit. Near sea level at La Perouse Bay, south of Wailea, Maui. Annual rainfall about 20 inches. March 2021. John Proctor

Figure 14. State 4.1. Toxic/unpalatable Forb. Onapuka extremely stony silt loam, 7 to 25 percent slopes Map Unit. Near sea level at La Perouse Bay, south of Wailea, Maui. Annual rainfall about 20 inches. March 2021. John Proctor

State 4 Toxic/Unpalatable Forb consists of one community phase vegetated mostly with toxic or otherwise highly unpalatable plants; kiawe may be present in varying amounts. It is caused and maintained primarily by constant heavy browsing and grazing by feral goats and/or deer.

Characteristics and indicators. Where there is no kiawe canopy (Big Island), the site goes to bare ground and starts to erode. Where there is kiawe to create a shaded microclimate, toxic forbs have replaced all acceptable forages. Many of these forbs behave more like annuals and will die during prolonged dry conditions. These sites are very prone to serious soil erosion.

Resilience management. Management and significant reduction in the numbers of the feral animals in the area is necessary. This may involve fencing, trapping, and other herd reduction methods. The soil seed bank will probably bring back a variety of plant species in a favorable weather year but seeding of desired forages or native plants is recommended, along with continuous weed and brush control as necessary. Sites that are severely eroded may require additional management inputs and conservation practices.

Dominant plant species

- kiawe (*Prosopis pallida*), tree
- pitted beardgrass (*Bothriochloa pertusa*), grass
- golden crownbeard (*Verbesina encelioides*), other herbaceous
- scarlet spiderling (*Boerhavia coccinea*), other herbaceous
- keeled wormseed (*Dysphania carinata*), other herbaceous
- Santa Maria feverfew (*Parthenium hysterophorus*), other herbaceous
- khakiweed (*Alternanthera pungens*), other herbaceous
- septicweed (*Senna occidentalis*), other herbaceous

Dominant resource concerns

- Sheet and rill erosion
- Wind erosion
- Organic matter depletion
- Surface water depletion
- Plant productivity and health
- Plant structure and composition
- Feed and forage imbalance

Community 4.1
Golden crownbeard-Chenopodium

Some of the most common forbs in this community phase are golden crownbeard (*Verbesina encelioides*), scarlet spiderling (*Boerhavia coccinea*), keeled wormseed (*Dysphania carinata* syn. Chenopodium carinatum), Santa Maria feverfew (*Parthenium hysterophorus*), coffee senna or septicweed (*Senna occidentalis*) and khakiweed (*Alternanthera pungens*). Undesirable grass species such as pitted beardgrass (*Bothriochloa pertusa*) may be sparsely present. Bare ground patches are large and frequently connected.

Resilience management. Management and significant reduction in the numbers of the feral animals in the area is necessary. This may involve fencing, trapping, and other herd reduction methods. The soil seed bank will probably bring back a variety of plant species in a favorable weather year but seeding of desired forages or native plants is recommended, along with continuous weed and brush control as necessary. Sites that are severely eroded may require additional management inputs and conservation practices.

Dominant plant species

- kiawe (*Prosopis pallida*), tree
- pitted beardgrass (*Bothriochloa pertusa*), grass
- golden crownbeard (*Verbesina encelioides*), other herbaceous
- scarlet spiderling (*Boerhavia coccinea*), other herbaceous
- dysphania (*Dysphania*), other herbaceous
- Santa Maria feverfew (*Parthenium hysterophorus*), other herbaceous
- septicweed (*Senna occidentalis*), other herbaceous

Transition T1A
State 1 to 2

Reference State

Kiawe-Invaded State

State 1 Reference transitions to State 2 Kiawe Invaded in the absence of disturbance such as fire or brush management. Kiawe seedlings are usually found associated with animal droppings and are intolerant of shade. The continuous Buffelgrass cover typical of State 1 (Reference), Phase 1.1 can limit kiawe establishment. The dominance of perennial short grasses and increasing bare ground typified in State 1, Phase 1.2 and Phase 1.3 can provide kiawe seedlings an advantage to establish. Seedling survival depends primarily on sufficient rainfall during 4 to 6 weeks after germination. As recruitment and dispersal progress, kiawe begins to out compete perennial grasses for water, soil nutrients, and light. Access to water is the greatest limiting factor to plant survival in this site. As a phreatophyte kiawe thrives where it has access to both soil moisture and ground water. It develops an overstory canopy cover that reduces solar radiation penetration to the soil surface. Kiawe is also implicated as a potential cause of changes in local hydrology and mineral cycling due to it’s efficient water harvesting capability and nitrogen fixation (Dudley, 2014).

Constraints to recovery. Conversion from State 2 back to any community in State 1 will require extensive labor, time, and money. Controlling Kiawe by mechanical means can cause soil disturbance impacts. Kiawe and weedy species from the seed bank may flourish after Kiawe trees are removed. This is exacerbated in areas where the soils are disturbed.

Conservation practices

Brush Management
Firebreak
Land Clearing
Prescribed Grazing
Fuel Break
Grazing Management Plan

Restoration pathway R1A
State 1 to 3

Reference State

Native Savanna State

State 1 Reference transitions and is maintained to State 3 Native Savanna with significant management inputs. The site must be fenced to exclude all domestic and feral ungulates. A firebreak must be established 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. Supplemental irrigation may be necessary in the early stages of restoration. Expected Effects: Increased Litter Accumulation, Increased Nutrient Availability, Increased Water Infiltration, Reduced Solar radiation, Increased Soil Moisture, Genetic Conservation, Enhanced Wildlife Habitat including Improved Pollinator Forage and Nesting.

Context dependence. Conversion from any community in State 1 Reference to State 3 Native Savanna will require extensive and sustained labor, time, and money.

Conservation practices

Fence
Irrigation System, Microirrigation
Integrated Pest Management (IPM)
Tree/Shrub Establishment
Restoration and Management of Rare and Declining Habitats
Native Plant Community Restoration and Management
Fuel Break
Pathogen Management
Conservation Plan Implementation
Monitoring and Evaluation
Establish pollinator and/or beneficial insect habitat

Transition T1B
State 1 to 4

Reference State

Toxic/Unpalatable Forb State

State 1 Reference transitions and is maintained to State 4 Toxic/Unpalatable Forb primarily by constant heavy browsing and grazing by feral goats and on Maui, deer, such that nearly all perennial grass and forb (forages) are removed. Large patches of mortality within the grass and forb functional groups are becoming common on the landscape. In areas where ground cover has persisted, the cover and vigor of perennial grass and forbs have become greatly reduced. Litter accumulation is greatly reduced to non-existent, and bare ground patches are large and frequently connected. This results in the creation of large barren areas suitable for toxic forbs to colonize. Access to water is the greatest limiting factor to plant survival in this site. Water infiltration is greatly reduced in areas of bare ground and/or reduced perennial grass cover. Solar radiation penetration to the soil surface increases significantly in areas of bare ground and/or reduced perennial grass cover. These changes create a competitive advantage which favors the establishment and further spread of toxic/unpalatable forbs as well as invasive shrub species.

Constraints to recovery. Many of these forbs behave more like annuals and will die during prolonged dry conditions. As such, these sites are very prone to serious soil erosion by water and wind as indicated by: water flow paths, pedestalled plants with roots exposed, and/or in extreme situations, the mineral horizons become exposed.

Conservation practices

Brush Management
Fence
Land Reclamation, Landslide Treatment
Prescribed Grazing
Integrated Pest Management (IPM)
Planned Grazing System
Prescribed Grazing
Invasive Plant Species Control
Biological suppression and other non-chemical techniques to manage herbaceous weeds invasive species

Restoration pathway R2A
State 2 to 1

Kiawe-Invaded State

Reference State

State 2 Kiawe Invaded transitions to State 1 Reference when kiawe are cleared by fire, herbicidal application, or mechanical means. While wildfire will kill kiawe, prescribed burning is typically not done in Hawaii due to the level of risk to relict native ecosystems and enjoined or embedded development. Once cleared, additional brush management strategies to avoid introduction of invasive shrubs (lantana, klu, koa-haole, etc) will be required and prescribed grazing strategies allowing for sufficient rest of perennial grasses and forbs will be needed. Fire: The effects of fire impacts on plant populations and habitat quality depend on fire severity (high, medium low), habitat type burned, species biology, timing of burning (wet or dry), plant phenology (stage of plant development when burned) and site conditions (e.g., topography, moisture (Brown et al 2000). Fire will kill Kiawe and will also reduce its postfire recruitment through direct mortality of the seeds on or near the surface (Gallaher and Merlin 2010, Smith and Tunison 1992). However, vigorous regeneration from the seed bank can occur in areas of high ground disturbance. Invasive, fire-prone grasses such as buffelgrass encourage wildfire because they ignite and spread wildfire quickly (HWMO 2019). Non-native savannas in Hawaii that are not grazed create hazardous fuels which result in wildfire frequency and increased increased rates of erosion and sediment transport to the ocean. These alien grasses usually recover to pre-burn levels and often intensify after fire. Fire thus promotes conditions that increase fire frequency and size by increasing the continuity and/or fuel loadings of alien grasses (Smith and Tunison 1992). Many native species, for example, wiliwili and lama, remaining in this ecological are not adapted to fire. For this reason, relictual native woodlands are now threatened by fine fuel loading from alien grasses. Mechanical Control: Some mechanical techniques that have been employed successfully include blade plowing, chain pulling, bulldozing, and stick raking (Gallaher and Merlin 2010). These methods can create high levels of ground disturbance and soil compaction. Herbicidal Control. Basal bark and cutstump application of have been employed in Hawaii (Pers Obs 2021). Although this method works well for isolated individuals, it is both cost- and time-prohibitive for large areas with dense stands. Once cleared, perennial grasses and forbs reassume dominance where they have regained access to soil moisture, nutrients and light.

Context dependence. Conversion from State 2 back to any community in State 1 will require extensive labor, time, and money.

Conservation practices

Brush Management
Land Clearing
Prescribed Grazing
Integrated Pest Management (IPM)
Invasive Plant Species Control
Grazing Management Plan

Transition T3A
State 3 to 1

Native Savanna State

Reference State

State 3 Native Savanna transitions to State 1 Reference when it is cleared by fire, long-term ungulate disturbance, or mechanical means. While wildfire will clear most native vegetation, prescribed burning is typically not done in Hawaii due to the level of risk to enjoined or embedded relict native ecosystems and development. Desired perennial grass and forbs (typically naturalized forage species) are then re-established. These disturbances initiate change by affecting the composition, structure, and pattern of vegetation on the landscape (Brown et al 2000 re fire). They affect plants directly, by injury and mortality, and indirectly, by changing resource availability including light, nutrients, pollinators, and mutually beneficial microorganisms such as mycorrhizae, translating into vegetation changes (clearing) at the plant, population, and community level. Fire Effects: Fires of all intensities, timing, and causes are harmful to most native ecosystems in Hawai`i (Smith and Tunison 1992). Alien species, particularly grasses such as buffelgrass, recover rapidly and fill in the spaces left by native plants, which recover more slowly, if at all. In Hawaii, fires establish a destructive cycle by increasing fuel loadings of flammable alien grasses, which in turn increase fire frequency and fire size. Subsequent burns further inhibit the reestablishment of native trees species. Some native species easily killed by fire include wiliwili, lama, and akia (Smith and Tunison 1992). Native species tolerant (aerial portions of all native plant species are readily killed by fire, but some resprout or recover from seed) to a very low frequency of fire, recover to some degree after burns, but typically to populations far less than those found in pre-burn conditions because they typically must compete with fire-stimulated alien grasses. Naio (*Myoporum sandwicense*) resprouts after fire as long as the fire is not too intense. Regrowth is slow and the original canopy cover takes over five years to regenerate. The seeds of `a`ali`i (*Dodonaea viscosa*) germinate readily after fire, but it is not known if they are fire-stimulated. `A`ali`i may reach higher densities after fire than before. Most native bunchgrasses recover rapidly after burning. Pili grass resprouts readily with a significant increase in cover following low-intensity fire. Effects of Continued, Long-Term Systematic Herbivory With continued, long-term systematic herbivory and browsing by goats and, on Maui, deer, nearly all native grass and forbs (forages) and regenerating shrub and tree seedlings are removed allowing buffelgrass to resume dominance.

Constraints to recovery. Prescribed burning is not, on the whole, an effective management tool in Hawai`i, although it may have potential limited management and research value (Smith and Tunison 1992). Moreover, the intensification of fire-prone alien grasses following fire assures the increased incidence of fire, thereby establishing a self-perpetuating alien grass/fire cycle. The effects of fire argue strongly that all agencies responsible for the management of fire in natural areas in Hawai`i should aggressively suppress all fires, whether caused by lava flows, lightning, or humans.

Conservation practices

Brush Management
Prescribed Grazing
Range Planting
Integrated Pest Management (IPM)
Prescribed Grazing
Invasive Plant Species Control
Grazing Management Plan - Written

Restoration pathway R4A
State 4 to 1

Toxic/Unpalatable Forb State

Reference State

State 4 Toxic/Unpalatable Forb transitions to State 1 Reference with significant management inputs. Management and significant reduction in the numbers of the feral animals in the area is necessary. This may involve fencing, trapping, and other herd reduction methods. The soil seed bank will probably bring back a variety of plant species in a favorable weather year but seeding of desired forages or native plants is recommended, along with continuous weed and brush control as necessary. Sites that are severely eroded may require additional management inputs and conservation practices. Expected Effects: Rest from Continued Disturbance, Soil Stabilization, Reduced Soil Erosion (wind and water), Recruitment and Dispersal of Perennial Grasses, Increased Perennial Grass Cover, Reduced Toxic Forb, Decreased Solar Radiation to Soil Surface, Soil Stabilization, and Increased Water Infiltration.

Context dependence. Adequate spring and summer rain events help accelerate vegetative growth, reproduction, and reestablishment of perennial grasses including buffelgrass and pitted beardgrass.

Conservation practices

Brush Management
Fence
Land Reclamation, Landslide Treatment
Range Planting

Planned Grazing System
Prescribed Grazing
Invasive Plant Species Control

Additional community tables

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.

CaCO3 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.

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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:**