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Suitability Map for Forage-Finished Beef Production Using GIS Technology: Maui County

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Introduction

The expansion of the local-grown food movement in Hawai'i has increased the demand for foods produced in our Island communities, which has directly led to improvements to farm and ranch revenues. In a ranking of the top fourteen edible commodities (HASS 2013), twelve of the crop- and livestock-sector industries saw an increase in agricultural value in the reporting period from 2010 to 2011. The value of cattle sales, for example, increased 50.1% to $46.4 million in this period.

For the beef cattle industry, the demand for grass-fed beef has increased in the Islands; however, persistent drought, loss of pasture and rangelands to development, and other competitive forces are all potential factors limiting the production of beef grown and finished on forage resources. Furthermore, it is important to note that not all pasture and rangeland areas are suitable for producing high-quality forage-finished beef.

Producing a high-quality forage-finished beef carcass is a function of genetics, forage quantity, forage quality, age of animal at slaughter, and climatic conditions that affect forage production and animal performance. A thorough understanding of how these factors interact is critical to the success of forage-finished beef production in Hawai'i. For example, genetics alone will not produce a quality carcass; the genetics must be correctly matched to the forage environment.

The quantity and quality of the forage environment is also linked to the age of animal at slaughter; consistent access to adequate quantities of high-quality forage throughout the production cycle yields a younger, higher-quality carcass at slaughter. Kim et al. (2015) found that younger slaughter age appears to be an important factor in improving the tenderness of grass-fed beef. In turn, the quantity and quality of forages varies temporally (daily, seasonally, and annually) with changes in climatic factors such as solar radiation (daily), temperature (daily, seasonally), and precipitation (seasonally, annually). Likewise, fluctuations in climatic conditions influence the production efficiency of grazing animals as they modify their behavior in order to maintain thermal balance.

It is the responsibility of the manager to implement the sustainable grazing-management practices that are essential to a successful grass-finished beef production enterprise. It is not enough to simply put stocker cattle into a pasture and expect them to grow to their full genetic potential. Implementing proper grazing-management practices maximizes the genetic potential of beef animals and protects the natural resources of the pasture (soil, forage, and water), thereby creating an economically sustainable production system. These practices will include the accurate assessment of the carrying capacity and the setting of the correct stocking rate of the pastures grazed (Thorne and Stevenson 2007), as well as the implementation of an appropriate grazing system based on a thorough evaluation of the vegetation type, landscape features (slope gradient, aspect, elevation, etc.), and management goals (Thorne et al. 2007).

The County of Maui includes the islands of Maui (772 sq mi), Moloka‘i (260 sq mi), Lana‘i (141 sq mi), and Kaho‘olawe (45 mi sq.), with a total landmass of 1,218 sq. miles (DBEDT 2014), or 779,520 acres. These islands contain a tremendous amount of ecological and biological diversity. Through geologic time, climatic impacts on the landscape have shaped the current environmental zones that are managed for grazing today. However, climate-change effects on temperature and precipitation patterns and their associated impacts on pasture ecology represent a significant challenge for land managers who must constantly adapt best management practices and planning strategies. As a foundation, ranch managers would benefit from a current inventory of pasturelands and specifically their suitability for forage-finished beef production. In Maui County grazing is a prominent agricultural enterprise on the islands of Maui, Moloka‘i, and Lana‘i. Due to the status and history of Kaho‘olawe there are no grazing operations on the island nor is there likely to be in the future. Thus, the following discussion will be focused only on Maui, Moloka‘i, and Lana‘i.

Previous Work: Pasture and Rangelands Descriptors

The foundational work by Ripperton and Hosaka (1942) defined a total of ten vegetative zones in Hawai‘i. Five main zones were determined by climatic data, and plant communities were further divided into sub-zones determined by elevation. Descriptors of the zones include plant species distribution, elevation range, rainfall, land use, natural cover, and forage species. Ripperton and Hosaka’s work identified three zones (C_2, D_2, and D_3), ranging in elevation from sea level to 4,000 ft. and in rainfall from 40 to 200 in./yr., as very good and important ranching lands. In particular, Zone C_2, ranging in elevation from 2,500 ft. to 4,000 ft. with an annual rainfall of 50 in./yr, was identified as having the finest pastures in the Territory. Dominant forages included Bermuda grass (*Cynodon dactylon*), kukaipua‘a (*Digitaria violascens*), and Spanish clover (*Desmodium uncinatum*). These vegetative zones developed over 70 years ago have lost some relevancy due to new forage introductions, climate changes, and pasture-management technology.

In a recent effort to update pasture types, May (2014) described six major naturalized range and forage types occurring in Maui County. The range and forage types were classified by predominant forages, range of annual rainfall, average annual forage production, and vegetative growth rates, with an overlay of the major land resource area designation. May identified three range and forage types as having the highest forage productivity, ranging from 8,000 to 16,000 pounds of dry matter (DM) per acre during favorable rainfall years. The rainfall in these zones, which run from sea level to the mid-elevation zones, ranges from 20 to 150 in./yr. Dominant grasses include kikuyu grass (*Pennisetum clandestinum*), pangola grass (*Digitaria decumbens*), California grass (*Brachiaria mutica*), guinea grass (*Panicum maximum*), and several temperate grass species. Legume forages include glycine (*Neonotonia wightii*), white clover (*Trifolium repens*), and greenleaf desmodium (*Desmodium intortum*). May’s and Ripperton and Hosaka’s publications provide excellent plant community descriptions, characterization of the environmental conditions, and productivity indices, but they do not provide acreage figures for each forage zone.

Objective

The objective of this publication is to utilize Geographic Information System (GIS) technology to create an updated visual representation of suitability zones for quality grass-finished beef production for the islands of Maui, Moloka‘i, and Lana‘i. The purpose of this publication is to provide a tool to empower managers to make informed decisions when considering development of a grass-finished beef production enterprise.

Map Development

Suitability zones for grass-finished beef production on known pasture and grassland areas on the islands of Maui, Moloka‘i, and Lana‘i were established using GIS layers including land-cover, rainfall, and elevation data, along with field knowledge of forage species distribution. “Pasture,” “Grassland,” and “Cultivated” cover types were derived from the National Oceanic and Atmospheric Administration’s Coastal Change Analysis Program (C-CAP) Regional Land Cover (2006), which is a raster GIS map dataset with the most recent land-cover data for the state. “Pasture” and “Grassland” are the two land-cover types most suited for either forage production or grazing, while “Cultivated” land has potential for grazing if it is abandoned or not used for the production of other agricultural goods. Only abandoned "Cultivated" lands were used in map development. "Cultivated" areas that appeared abandoned or fallow based on aerial and roadside images found on Google Earth (Google Inc. 2014) were included in mapping pasturelands suitable for grass-finished beef.

The main drivers for forage yield or quantity are moisture and temperature. Plant-available moisture is a function of the amount of rainfall received, soil moisture storage, and evaporation and plant transpiration potential (commonly combined as evapotranspiration). On the one hand, the amount of precipitation received in a given location is a function of orographic factors including elevation, aspect, and prevailing winds. Combined, these factors help explain why our windward coastal lands receive more rainfall than the leeward lands. Among these factors, elevation is the most crucial, as it controls precipitation regardless of aspect and prevailing winds. On the other hand, while evapotranspiration (ET) is complex and a complete discussion on all the factors influencing it is beyond the scope of this publication, it is most strongly affected by temperature: as temperature decreases, so does evapotranspiration. The result is that an inch of rain is more effective for plant growth at 70ºF than at 90°F because less water is lost to evapotranspiration. Temperature, in turn, is a function of elevation and declines on average by 3.5°F for every 1,000 ft. rise in elevation, an effect known as the lapse rate (Glickman 2000). Thus, elevation moderates both plant-available moisture and temperature through its influence on the amount of precipitation received and the evapotranspiration potential for a given location. Therefore, for this study the criteria selected to build the suitability zones were rainfall and elevation. Rainfall and elevation data of pasture and grassland cover types were used to distinguish between areas of high and low suitability for grass-finished beef production.

In designing the criteria for quality grass-finished beef production suitability zones, elevation was subdivided into two categories: low elevation (LO), from sea level to 2,000 ft., and high elevation (HI), between 2,000 ft and 4,500 ft. Rainfall criteria, designated as WET and DRY categories, were nested within the elevation categories. The WET category was defined as greater than 50 inches per year for low elevation and greater than 30 inches per year for high elevation, the DRY category as less than 50 inches per year for low elevation and less than 30 inches per year for high elevation. A fifth category was added to delineate the high-elevation zone greater than 4,500 ft. with rainfall greater than 30 inches per year. See Table 1.

Rainfall data were assembled from the Rainfall Atlas of Hawai‘i (2013), and digital elevation models (DEM) of the islands of Maui, Moloka‘i, and Lana‘i were obtained from the National Centers for Coastal Ocean Science (2013), a research office of the National Oceanic and Atmospheric Administration. Analyses and processing were conducted in ArcGIS 10.1, and all GIS files for the islands of Maui, Moloka‘i, and Lana‘i were projected in the following coordinate system: North American Datum (NAD) 1983 Universal Transmercator (UTM) Zone 5N.

Results and Discussion

Based on the land-cover analyses, combined with elevation and rainfall criteria, a total of 141,407 acres (18% of the total) of pasture and rangelands were identified on the islands of Maui (74,494 acres), Moloka‘i (37,236 acres), and Lana‘i (29,677 acres).

High-Quality Grass-Finished Beef Suitability Zones. Based on the combined analyses of land-cover data and selected environmental criteria of elevation and rainfall, a total of 28,564 acres of pasturelands or 20% of all potential pasture and rangelands (141,407 acres)

Table 1. Elevation and rainfall criteria used in developing the grass-finished beef suitability zones.

Elevation	Rainfall
LO, < 2,000 ft	DRY, < 50"/yr
	WET, > 50"/yr
HI, > 2,000 ft	DRY, < 30"/yr
	WET, > 30"/yr
HI, > 4,500	WET, > 30"/yr

were identified as high-quality grass-fed beef production areas across the islands of Maui (23,089 acres), Moloka‘i (5,275 acres), and Lana‘i (200 acres). The island of Maui has a larger proportion of suitable acreage (31%) for grass-finished beef than do Moloka‘i (14%) and Lana‘i (>1%).

Approximately 41.5% of the high-quality lands lie in the low-elevation-wet zone (LO/WET) and occur exclusively on Maui (9,185 acres) and Moloka‘i (2,682 acres). The high-elevation-wet zone (HI/WET), found on Maui (13,904 acres), Moloka‘i (2,593 acres), and Lana‘i (200 acres), accounted for 58.5% of the high-quality lands. Pastures in the LO/WET zone are typically dominated by one of three grass species: guinea grass (*Panicum maximum*), pangola grass (*Digitaria decumbens*), and to a lesser extent California grass (*Brachiaria mutica*). Other high-quality forage varieties in this zone include mixed pastures of signal grass (*Brachiaria decumbens*), mulato grass (*Brachiaria ruziziensis* x *B. brizantha*), and green panicgrass (*Panicum maximum* vr. *trichoglume*). Important forage legumes in the LO/WET zone include several species of *Desmodium* (*D. triflorum*, *D. intortum*, *D. uncinatum*, *D. tortuosum*, *and D. canum*), tinaroo glycine (*Neonotonia wightii*), and koa haole (*Leucaena leucocephala*). The combination of these grasses and legumes provides more-than-adequate, high-quality forage for finishing beef cattle when managed properly. Table 2 provides a complete listing of grass and legume forages that can be found in the LO/WET zone.

Table 2. Suitability zones, acreage, elevation, and rainfall, and important forage grasses and legumes for Maui, Moloka‘i, and Lana‘i Islands.

SUITABILITY ZONE	Map Code	Maui Acreage	Moloka‘i Acreage	Lana‘i Acreage	Elevation Rainfall Criteria	Important Grasses[1] **Important Legumes[2]**
Suitable for High-Quality Grass-Finished Beef	(green)	13,904	2,593	200	HI/WET 2,000 – 4,500 ft. > 30 in./yr.	Kikuyu, pangola **Clovers, vetch, trefoil**
	(orange)	9,185	2,682	0	LO/WET <2,000 ft. > 50 in./yr.	Guinea, green panic, pangola, California **Desmodium, koa haole, Tinaroo**
Other Grazing	(light blue)	10,004	0	192	HI/DRY > 2,000 ft. < 30 in./yr/	Kikuyu, orchard, rye **Clovers, vetch, trefoil, Desmodium**
	(light green)	9,035	0	0	HI/WET > 4,500 ft > 30 in./yr.	Orchard, velvet, rye, kikuyu **Clovers, vetch, trefoil**
	(yellow)	32,366	31,961	29,285	LO/DRY < 2,000 ft. < 50 in./yr.	Buffel, Rhodes, featherfinger grass **Koa haole, Desmodium, Tinaroo glycine**
TOTAL		**74,494**	**37,236**	**29,677**		

[1] Important grass forages include only those species that provide approximately 80–90% of the total nutritional value of the pasture to the grazing beef animal.
[2] Important forage legumes include those species that provide more than 10% of the nutritional value of the pasture to the grazing beef animal.

The HI/WET zone pastures occur between 2,000 and 4,500 ft. elevation and commonly include steep, sloping lands that are sensitive to grazing pressure. Therefore, they require specific grazing-management practices that protect the soil and vegetation resources. Pastures in the HI/WET zone are comprised predominately of kikuyu grass (*Pennisetum clandestinum*) or a kikuyu grass/pangola grass mix. In some pasture locations within this zone, near-monocultures of Bermuda grass (*Cynodon dactylon*) can also be found. Important legume forages within the HI/WET zone include several species of clover (*Trifolium hybridum, T. pratense, T. procumbens, T. repens, and T. subterraneum*), birdsfoot trefoil (*Lotus angustissimus*, *L. corniculatus*, *L. hispidus*, *and L. uliginosus*), common and hairy vetch (*Vicia sativa* and *V. villosa*, respectively), and bur clover and black medic (*Medicago hispida* and *M. lupulina*, respectively). Many other forage legumes can be found in the HI/WET zone (Table 2).

Other Grazing Land Zones. A total of 112,843 acres, or 79.8% of all potential pasture and rangelands, were identified as outside of the targeted climatic and environmental conditions best suited for grass-fed beef production on the islands of Maui (51,405 acres), Moloka‘i (31,961 acres), and Lana‘i (29,477 acres);

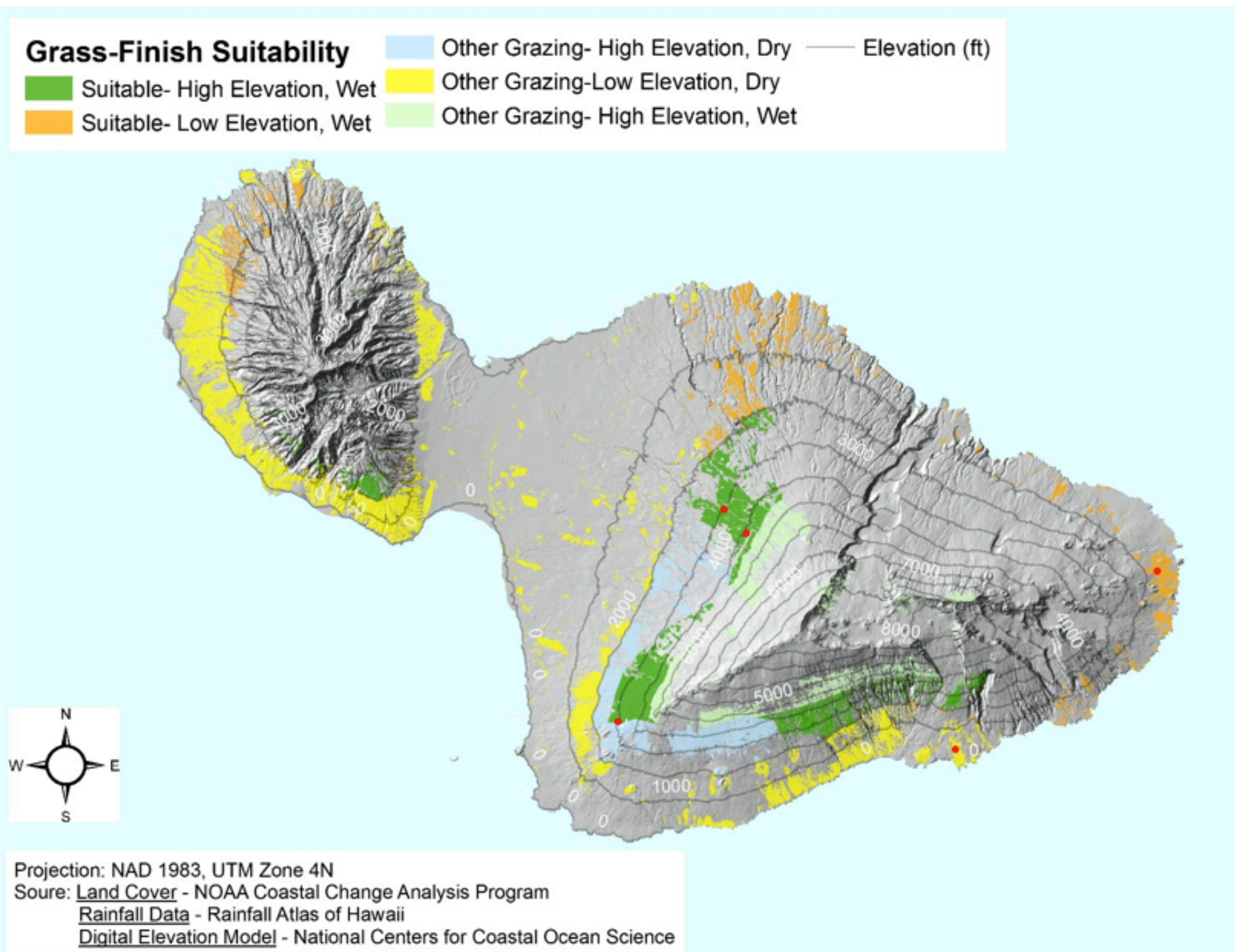

Figure 1. Grass-finished beef suitability map of the island of Maui. Refer to Table 2 for zone descriptions.

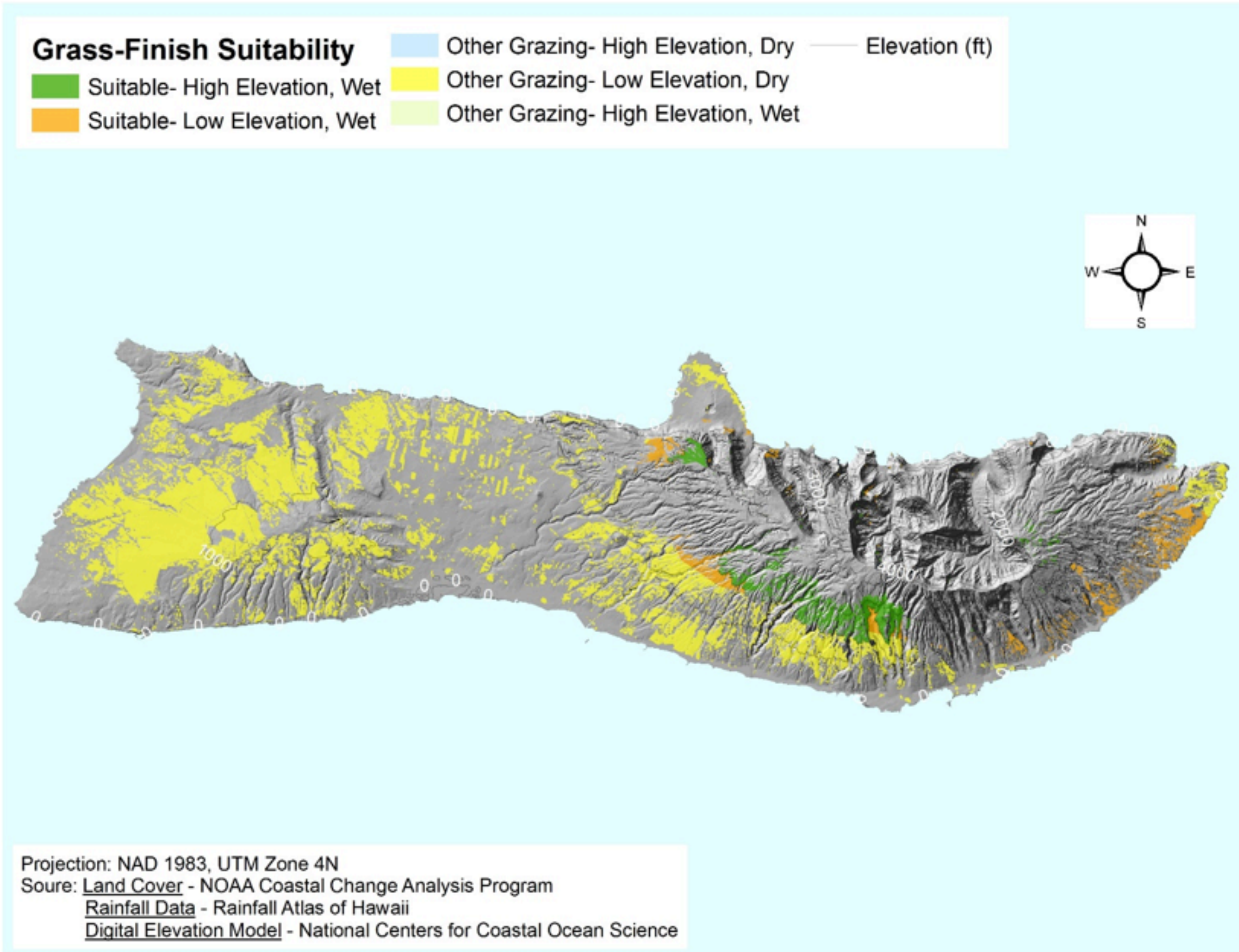

Figure 2. Grass-finished beef suitability map of the island of Moloka‘i. Refer to Table 2 for zone descriptions.

these lands would be better suited for cow–calf production. While these lands do not meet the criteria for high-quality grass-fed beef production under current conditions, with additional resources to increase forage productivity and quality some of these lands may have potential to support grass-fed beef production. These might include development of irrigation, application of fertilizers, and/or incorporation of improved varieties of *Leucaena* and other improved forages. The Other Grazing Lands category is comprised of three elevation/rainfall zones: HI/WET, HI/DRY, and LO/DRY.

The HI/WET zone accounts for 9,035 acres found exclusively on the island of Maui. It is characterized by temperate cool-season grasses, such as orchard grass (*Dactylis glomerata*), velvet grass (*Holcus lanatus*), and several rye grass species (*Lolium* sp.). Kikuyu grass is common in this zone up to about 6,000 ft. Forage production within this zone is highly seasonal, and it does not provide adequate amounts of high-quality forage throughout the production cycle of the beef animal.

The HI/DRY zone encompasses 10,004 acres on the island of Maui and 192 acres on the island of Lana‘i. This zone is a mix of kikuyu grass and temperate cool-season forage communities including orchard grass, velvet grass, and several rye grass species at the higher end of the precipitation range and at higher elevations. At the lower elevations and dryer regions of this zone

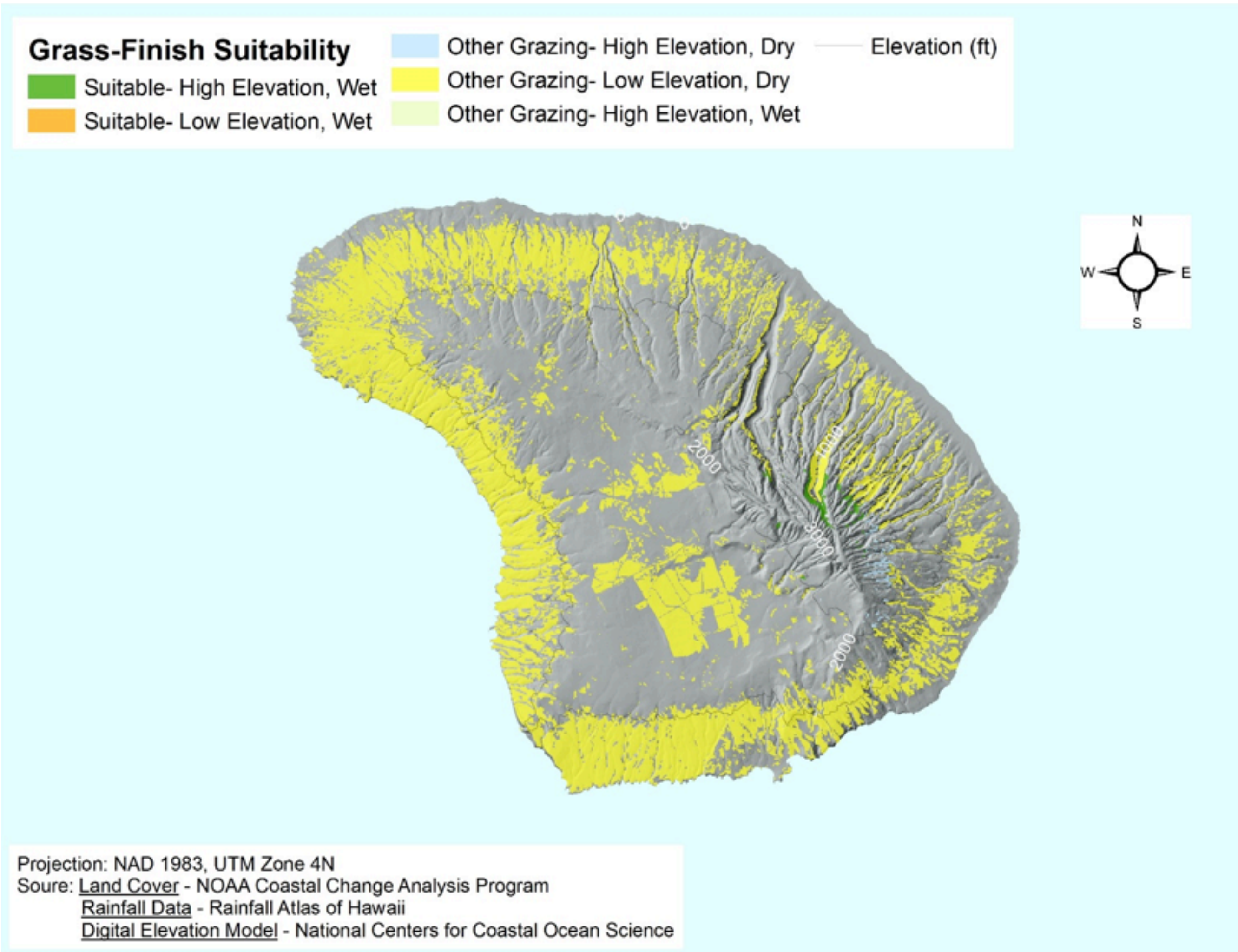

Figure 3. Grass-finished beef suitability map of the island of Lana‘i. Refer to Table 2 for zone descriptions.

the dominant kikuyu grass is often interspersed with less desirable grasses like rat-tail (*Sporobolus capensis*) and barbwire grass (*Cymbopogon refractus*). At the higher elevations of this zone the lack of rainfall and lower temperatures limit forage productivity, whereas at the lower elevations poor-quality forage (rat-tail, barbwire grass, etc.) and/or inconsistent forage quality, due to sporadic rainfall events, are the main limitations that prevent this zone from being used to produce high-quality grass-finished beef.

The LO/DRY zone accounts for 32,366 acres on the island of Maui and 29,285 acres of the island of Lana‘i. This zone is located in the arid lowland areas where buffel grass (*Cenchrus ciliaris*), featherfinger grass (*Chloris virgate*), and Rhodes grass (*Chloris gayana*) are the most dominant forage species. Other minor, less-desirable grasses that typically occur interspersed among these include several species of love grass (*Eragrostis* spp.), bristly foxtail (*Setaria veticillata*), and hairy sandbur (*Cenchrus echinatus* var. *hillebrandianus*). This dry zone does not produce enough high-quality forage over the production cycle of the beef animal to bring them to a finish within a marketable time frame.

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Note: The information from this publication can be used as a tool for ranchers, decision-makers, planners, and others interested in looking at land-use policies in Hawai‘i in relation to agricultural production. The map presented in this document is for general reference. For site-specific guidance, contact your local University of Hawai‘i-Manoa County Extension agent. An online version of the map can be found at http://gis.ctahr.hawaii.edu/.