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Suitability Map for Forage-Finished Beef Production Using GIS Technology: Hawaiʻi Island

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Introduction

The expansion of the local-grown food movement in Hawaiʻi has increased the demand for foods produced in our Island communities, with direct 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, 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 Hawaiʻi. For example, genetics alone will not produce a quality carcass; the genetics must be correctly matched to the forage environment.

The age of animal at slaughter is also linked to the quantity and quality of the forage environment; consistent access to adequate quantities of high-quality forage throughout the production cycle yields a younger, higher-quality carcass at slaughter. In turn, the quantity and quality of forages varies temporally (daily, seasonally, and annually) with changes in climatic factors such as solar radiation (daily), temperatures (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.

The island of Hawaiʻi encompasses 4,028 square miles of ecological and biological diversity. Through geologic time, climatic impacts on the landscape have shaped the current environmental zones that are managed 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 implementation of 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.

Previous Work: Pasture and Rangelands Descriptors

The foundational work by Ripperton and Hosaka (1942) defined a total of ten vegetative zones in Hawaiʻi. Five main zones were determined by climatic data and plant communities and were further divided

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into sub-zones determined by elevation. Descriptors of the zones include plant species distribution, elevation range, rainfall, land use, natural cover, and forage species. Riperton 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 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 naturalized major range and forage types on the island of Hawai‘i. 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 per acre on a dry matter basis 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*). These previous 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 the Geographic Information System (GIS) technology to create an updated visual representation of suitability zones for quality grass-finished beef production.

Map Development

Suitability zones for grass-finished beef production on known pasture and grassland areas on Hawai‘i island were established using GIS layers including land-cover, rainfall, and elevation data, along with field knowledge of forage species distribution. “Pasture” and “Grassland” 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. These two land-cover types are the most suited for either forage production or grazing.

The main drivers of 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 of all the factors influencing it is beyond the scope of this publication, temperature has the greatest control over ET, and as temperature decreases, so does evapotranspiration. The result is that an inch of rain is more effective for plant growth at 70°F 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, what is known as the laps 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 grass-finish suitability.

In designing the criteria for quality grass-finishing 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 Hawai‘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 island of Hawai‘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 570,662 acres of pasture and rangelands were identified on Hawai‘i Island. This is slightly less than the acreage reported by Melrose and Delparte (2012) where a total of 638,466 pasture and rangeland acres were identified based on a land-cover lay and a tax map key quantification approach, and only slightly more than their reported 533,127 acres based on pasture-use designation when landowners reported to the County of Hawai‘i real property tax records.

High-Quality Grass-Finishing Suitability Zones. Based on the combined analyses of land-cover data and selected environmental criteria of elevation and rainfall, a total of 210,368 acres of pasturelands, or 36.9% of all potential pasture and rangelands, were identified as high-quality grass-fed beef production areas on the Island of Hawai‘i.

Table 1. Elevation and rainfall criteria used in developing grass-finishing 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

Approximately 58.1% of the high-quality lands lie in the low-elevation wet zone (LO/WET) and 41.9% of the lands are in the high-elevation wet zone (HI/WET). 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 listing of the major grass and legume forages that can be found in the LO/WET zone.

The HI/WET zone pastures are predominately dominated by Kikuyugrass (*Pennisetum clandestinum*) or a Kikuyugrass/Pangola grass mix. 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 hipida* and *M. lupulina*, respectively).

Other Grazing Land Zones. A total of 360,294 acres or 63.1% of all potential pasture and rangelands were identified as outside of the targeted climatic and environmental conditions best suited for grass-fed beef production; 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. This 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.

The HI/WET zone accounts for 69,194 acres and is characterized by temperate cool-season grasses, such as orchard grass (*Dactylis glomerata*), velvetgrass (*Holcus lanatus*), and several rye grass species (*Lolium* sp.). Kikuyugrass is common in this zone up to about 6,000 ft. Forage production within this zone is highly seasonal and does not provide adequate amounts of high-quality forage throughout the production cycle of the finishing beef animal.

The HI/DRY zone encompasses 164,756 acres and is a mix of kikuyugrass and temperate cool-season forage communities including orchard grass, velvetgrass, and several rye grass species at the higher end of the precipitation range and at higher elevations and fountain grass (*Pennisetum setaceum*) in the lower elevations and dryer regions of this zone. Lack of rainfall and lower temperatures at the higher elevations limits forage productivity in this region, whereas at the lower elevations poor-quality forage (fountain grass) is the

Table 2. Suitability zones, including acreage, elevation, and rainfall, and important forage grasses and *legumes*.

Suitability Zone	Map Code	Acreage	Elevation, Rainfall Criteria	Important Grasses[1] *Important Legumes*[2]
Suitable for High-Quality Grass-Finished Beef		122,207	HI WET 2,000 – 4,500 ft. > 30 in./yr.	Kikuyu, Pangola ***Clovers, Vetch, Trefoil***
		88,161	LO WET < 2,000 ft. > 50 in./yr.	Guinea, Green panic, Pangola, California ***Desmodium, Koa haole, Tinaroo***
Suitable for Other Grazing		164,756	HI DRY > 2,000 ft. < 30 in./yr/	Kikuyu, Orchard, Rye, Fountain ***Clovers, Vetch, Trefoil, Desmodium***
		69,194	HI WET > 4,500 ft > 30 in./yr.	Orchard, Velvet, Rye, Kikuyu ***Clovers, Vetch, Trefoil***
		126,344	LO DRY < 2,000 ft. < 50 in./yr.	Fountain, Buffel ***Koa haole, Desmodium, Tinaroo, Glycine***
TOTAL		**570,662**		

[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.

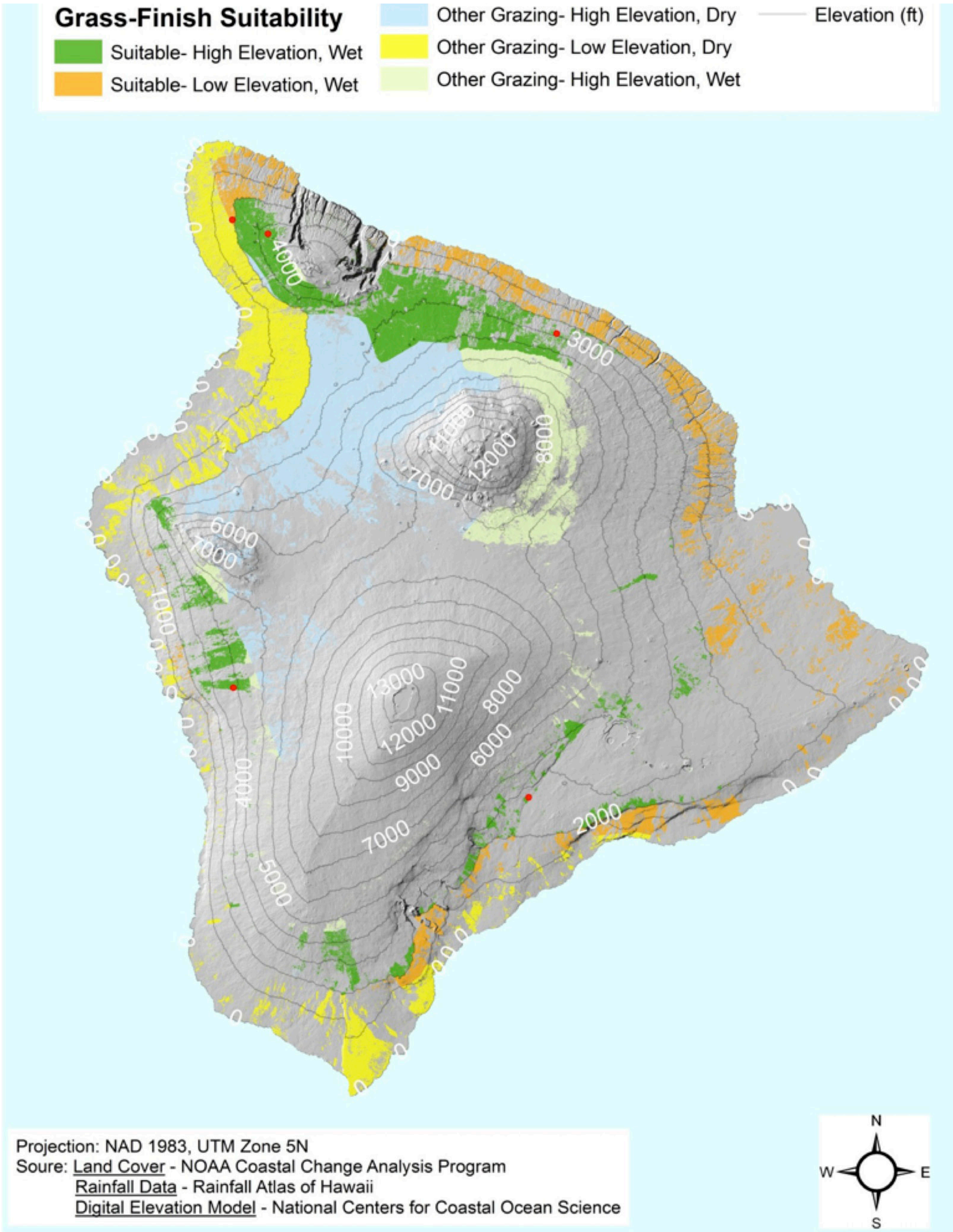

Figure 1. Grass-finishing suitability map of the Island of Hawai'i. Refer to Table 2 for zone descriptions.

limitation. In either case, forage quantity and quality are not consistent enough to produce high-quality grass-finished beef.

The LO/DRY zone accounts for 126,344 acres and is located in the arid lowland areas where fountain grass and buffel grass (*Cenchrus ciliaris*) are the most dominant forage species. 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. An online version of the map can be found at http://gis.ctahr.hawaii.edu/