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# Airborne lidar survey of irrigated agricultural landscapes: an application of the slope contrast method

Mark D. McCoy [a,*], Gregory P. Asner [b], Michael W. Graves [c]

[a] Department of Anthropology, University of Otago, P.O. Box 56, Dunedin 9054, New Zealand
[b] Carnegie Institution for Science, USA
[c] University of New Mexico, Department of Anthropology, USA

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ABSTRACT

Irrigated agriculture was central to the economies of many of the world's best known complex societies. New high-resolution digital elevation models (DEM) derived from remotely sensed lidar data give archaeologists the opportunity to study field systems at a scale not previously possible. Here we describe a method called slope contrast mapping that takes advantage of the dissimilarity between artificial and natural slopes to identify and map discrete features. We use this relatively simple method in our own research to identify complexes of agricultural terraces in the North Kohala district, Hawai'i Island. It has also proved useful for mapping the natural landscape, specifically the extent of flat land between valleys suited for irrigated agriculture.



## 1. Introduction

Airborne lidar (light detection and ranging) has proven its utility for remote sensing in archaeology (Bewley et al., 2005; Challis, 2006; Challis and Howard, 2006; Challis et al., 2008; Crutchley, 2006; Harmon et al., 2006; Rowlands and Sarris, 2007; Lasaponara et al., 2010; McCoy and Ladefoged, 2009; Millard et al., 2009; Parcak, 2009), especially for mapping archaeological features in forested areas (Chase et al., 2010, 2011; Crow et al., 2007; Devereux et al., 2005; Doneus et al., 2008; Gallagher and Josephs, 2008), but also natural features relevant for archaeological research (Brown, 2008; Carey et al., 2006; Challis et al., 2011). At present, "applications of lidar still face challenges, especially in defining practical processing protocols" (Campbell, 2007:p. 249).

Lidar mapping typically relies on displaying high-resolution, digital elevation models (DEM), also known as digital terrain models (DTM), using two GIS functions: hillshade and three dimensional (3D) display. The 'hillshade' operation uses grayscale shading effects that mimic natural shadows based on specified height (altitude) and direction of light source (azimuth). Alternatively, one can choose to display a lidar DEM in 3D where the shape and heights of features can quite literally stand out from the background. Recent innovations in lidar interpretation do not rely on display manipulation and instead use advanced methods of filtering data to identify anomalies (Coluzzia et al., 2011; Doneus et al., 2008; Gallagher and Josephs, 2008; Hesse, 2010), or a derived value (e.g., sky-view factor, Kokalj et al., 2011). While the specific protocols for these methods vary, advanced methods essentially use elevation data to discriminated features built above or below the expected trend in the natural ground surface.

We describe an additional application for deriving cultural features from lidar DEM called slope contrast mapping. Slope contrast mapping takes advantage of marked changes in elevation to help identify and record archaeological features. Slope is first calculated and then classified in a raster (grid) surface as flat, low, or high. This raster is then vectorized into polygons representing micro-topographical regions that can be used to easily distinguish certain types of construction forms from the natural landscape, specifically artificially flat surfaces and steep banks created by cut and fill.

Slope contrast mapping is used here to identify groups of agricultural terraces in North Kohala district of Hawai'i Island. This same GIS layer is also used to identify flat-to-low slope areas between drainages, also known as tableland, where irrigation could have been expanded. Together, the archaeological and natural features identified give us a remarkable new picture of the peak amount of land under production in the study area and, in turn, provide insight into larger economic and political changes in pre-European contact Hawaiian society.

* Corresponding author. Tel.: +64 3 479 8748; fax: +64 3 479 9095.
*E-mail address:* mark.mccoy@otago.ac.nz (M.D. McCoy).

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## 2. Background

### 2.1. The study area: windward North Kohala, Hawai'i Island

The transformation of the Hawaiian Islands from a pristine natural landscape to the massive anthropogenic patchwork of cultivated agricultural fields that marveled visitors in the late 18th century occurred over a period of no more than 1000 years beginning around A.D. 800–1000 (Kirch and McCoy, 2007). Over that time period the population of the archipelago grew from a few hundred people to a society of hundreds of thousands of people divided into polities in which a hierarchy of elites managed and collected taxes and tribute in the form of agricultural produce, or what is sometimes called surplus wealth. Kirch (1994) and others have contrasted territories that depended upon 'wet' and 'dry' environments arguing that the higher natural productivity of irrigated 'wet' agricultural systems provided less motivation for expansionist warfare when compared to non-irrigated 'dry' agricultural production systems (Fig. 1). Here, irrigated farming generally refers to the cultivation of taro (*Colocasia esculenta*) in pondfields where water is impounded in much the same way as rice paddies. Non-irrigated fields relied on rainfall alone and included a wider variety of crops including the staples sweet potatoes (*Ipomoea batatas*) and yams (*Dioscorea* spp.). For archaeologists it is critically important to determine the type and amount of agricultural lands within different Hawaiian districts as a first step to reconstructing the larger political economy, and the development of archaic states (Kirch, 2010).

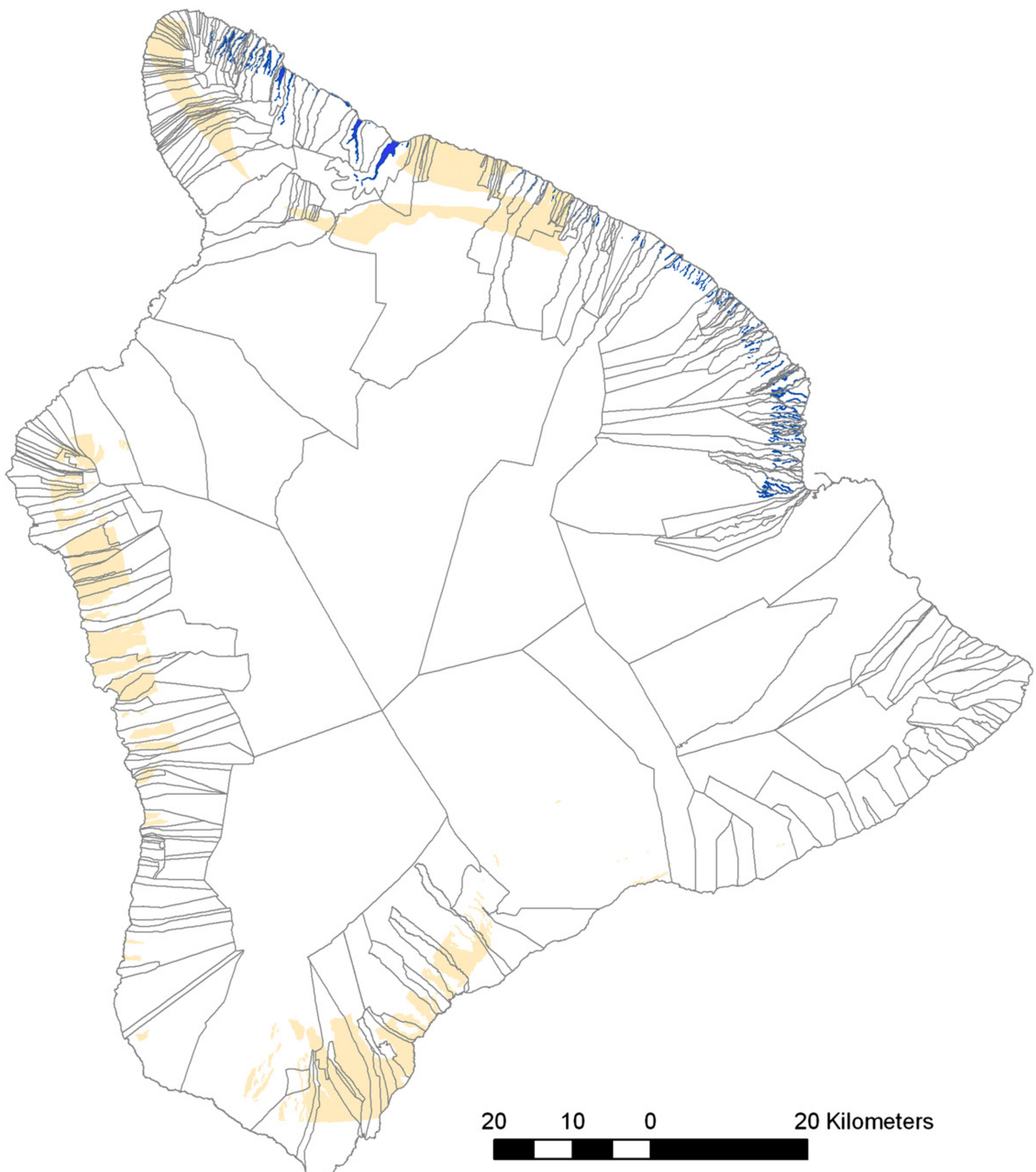


**Fig. 1.** Major Irrigated (blue) and Non-Irrigated Rain-fed Farming (yellow) Areas on Hawai'i Island (after Ladefoged et al., 2009). The North Kohala District, Hawai'i Island is located on the northernmost tip of the island. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)