

# REMOTE SENSING AND GIS-BASED ANALYSES OF PREHISTORIC AGRICULTURAL PRODUCTION AND HABITATION IN THE SIGATOKA VALLEY, FIJI

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## ABSTRACT

In *The Sigatoka Valley-Pathway Into Prehistory* (Parry 1987), geographer John Parry displays a detailed aerial photograph analysis of settlement patterns within the context of Fijian prehistory. He concluded that the environment played a decisive role in the nature and distribution of prehistoric human settlement. The research presented in this study offers a re-analysis of Parry's work using remotely sensed data, hydrological modeling, and a geographic information system (GIS). Specifically, an image from SPOT satellite and over 200 aerial photographs were manually and digitally analyzed for the visible presence of archaeological features, as well as regional vegetation patterns that may have historic origins. The results compliment Parry's work to a high degree, and also more directly measure the environmental variables that fostered settlement and competition in the Sigatoka. Additionally, this study indicates the locales which would have had the potential to foster the growth of long-term occupations and fortifications, and assesses the degree to which harvest risk could have played a role in the climate of competition, warfare, and migration.

## INTRODUCTION

The Sigatoka valley is located within the southwestern corner of the main island of Viti Levu, Fiji. It skirts the boundary between the windward and leeward side of the island, serving as the drainage for 1700 km<sup>2</sup> of mountains and valleys. The topography is quite rugged throughout, and in the highlands most peaks reach elevations between 400 and 1200 meters above sea level. Despite the general dryness of the area, this region is the 'salad bowl' of Fiji. Its fame for agricultural production is also historic, as evinced by the multitudes of human settlements, and the *in situ* preservation of traditional gardens and the cultivation of root crops. The Sigatoka is also famous for the site of a long history of warfare and migration. In his 1987 study of the geography and prehistoric settlements of the Sigatoka valley, Parry remarked upon the numerous fortifications that dotted the landscape, and also the varied cultural and linguistic origins of the inhabitants. He concluded that the ecological conditions of the region-- with small pockets of productive land spread unevenly throughout the valley, gave rise to competition, conflict, and the fission of prehistoric groups.

The research described in this report was conducted in order to test Parry's conclusions concerning the prehistory of the valley. In addition, this research aimed to significantly broaden the study area and incorporate more fine-scaled geographical data, including remotely sensed satellite images and aerial photos, and hydrological data. Also, this research would incorporate new analytic technology, including geographic information systems (GIS), and terrain analysis software.

## METHODS

### *Remote Sensing Survey*

Two forms of remote sensing were used survey the Sigatoka valley for the presence of prehistoric habitation sites and agricultural features. The first was a multispectral SPOT image that covered 3/4 of the valley drainage. Several analyses were performed on this image, including cluster analyses, edge and texture analyses, and vegetation index analyses. The results were used to identify areas that were well-watered and exhibited vibrant plant growth. This image also served as a layer within the GIS database. Second, 200 large scale (1:16,000) black and white aerial photos were analyzed for the presence of archaeological sites. This analysis expanded Parry's original survey area by nearly 600 km<sup>2</sup>, and allowed for the identification of the remains of prehistoric villages, agricultural features, and defensive constructions, including the more remote drainages in the upper reaches of the Sigatoka. All of the photos were stereo-pairs, and a 4x stereoscope was used to emphasize (and thus more easily identify) elevation in constructed features such as house-foundations (*yavu*) and terraced embankments.

Recording the features involved placing mylar overlays over each photo, and marking the observed archaeological features with ink. The location and morphology of these features were later plotted into a GIS

database and incorporated into a digital elevation model (DEM) created to represent the topography of the valley. The effects of the inherent distortion in the photos was compensated for by correlating features in the photos with corrected (distortion-free) features on topographic maps; e.g., nearby streams, ridges, or roads. Through the course of aerial-photo analysis 473 habitation sites were identified, as well as 236 sets of agricultural terraces and 61 instances of ponded-field agriculture. The grand total, that of 770 features, represents the most extensive remotely-sensed survey in the Sigatoka valley to date.

#### *GIS Analyses*

Following the creation of the GIS database, a series of analyses were performed to determine the geographical properties of each site locale including potential natural defenses (steepness of the surrounding topography), and the immediate (1 km radius) access to resources. The productive potential of these resources was also analyzed by determining the co-occurrence of variables related to agricultural production, including the distribution of soils and vegetation as indicated by maps and the SPOT satellite image, lands at less than 20 degrees slope (required for dry-land cultivation), and the potential for irrigation of wetland taro in the terraced features. The analysis of these data had the potential to reveal more than broad generalizations concerning the nature of settlement, conflict, and migration in Sigatoka prehistory, and also pinpoint areas that may have been more prone to environmental stress and reduced productivity.

Hydrological modeling offered several methods for determining flow rates within drainages. The designation of stream orders was used to calculate rates of stream-flow within the various branches of a tributary. The premise of the stream-order formula is that order number is directly proportional to the size of the contributing watershed, to channel dimensions, and to stream discharge at that place in the system. In this manner, two drainage networks that differ greatly in linear scale can be compared with respect to the use of order number (Strahler 1964: 4:43). Applying the method required mapping the channel network of the Sigatoka, including all intermittent and permanent streams, as well as the smallest fingertip tributaries. The initial tributaries were designated order 1. When two first order streams conjoined, they produced a second order stream. All the tributaries of the Sigatoka were ordered in this manner, and then compared to stream-flow data for the valley (Davies 1992), which was then used to determine the rates of stream-flow at the locations where irrigated agricultural features were located. In addition to determining the rates of stream-flow for each stream in the Sigatoka, the flow data were compared to the area of the terraces they fed in order to determine if the rates of flow would provide adequate amounts of irrigation water (140-373 m<sup>3</sup>/hectare/day) for year-round high yield hydrophytic (wetland taro) agriculture. If indeed the rates of stream flow were adequate to produce high yields, then the flow was deemed sufficient. If the stream rates fell between 79 and 140 m<sup>3</sup> of water/hectare/day, then the flow was deemed to be "possibly sufficient".

Determining the association of these features with habitation sites was accomplished using a simple measure of proximity. The point score of agricultural features that fell within 1 km of a habitation site were tallied, and used to produce a total productive potential score for each habitation site. Overlap between sites and terraces occurred in many cases, as the features often occur close together. However, as the chronology of sites is completely unknown, the issue of resource sharing between sites that may or may not have been contemporaneous cannot be addressed at this time. In addition to the productive potential of the irrigated terraces, the percentage of land within 1 km of each site that lies between 0 and 20 degrees slope was recorded. As swidden agriculture often leaves no visible remains, and also the use of modern cultivation has effectively obliterated any trace of ponded-field agriculture along the valley bottom, the measurement of flat land was used as a proxy measure for the potential cultivation of dry taros, yams, and non-irrigated crops. Coincidentally, the occurrence of sandy, well drained soils (those favored by yams) mapped onto the flat alluvial terraces that lie between 0 and 20 degrees slope.

## RESULTS

The results of these analyses spatially indicate the areas that would have been the most desirable in terms of the cultivation of wetland and dryland crops. In addition, the combined productivity of the lands surrounding each settlement indicate the spatial (and likely temporal) distribution of three modes of habitation in the Sigatoka valley-- that of defense, production, and defended production.

#### *The Productive Potential of the Sigatoka Valley*

Fifty-four percent of the sites in the sample would have had no access to irrigated terrace cultivation. Most of the populations in the lower and middle parts of the valley could not have relied upon hydrophytic crops for subsistence-- water sources were largely unavailable, and the porous nature of the soils would have made cultivation difficult. However, the upper reaches of the Sigatoka with its silty soils and abundant water resources would have been well suited to such production. Most of the settlements of the region would have undoubtedly been reliant upon the taro harvest.

In contrast, the most remote (and often most precariously located) habitations would not have had immediate access to level sandy deposits that would have nourished yams and other dry crops. However, 80% of the settlements would have been able to produce low to moderate amounts of crops in their immediate vicinity. Nearly all of these sites are located within the lower elevations of the valley, especially around the wide meanders of the middle and lower valley.

These results indicate that there was the potential for competition over particular locales in the valley, especially after times of environmental disturbances. Summer droughts had the potential to ruin the taro crop and also deplete the amount of soil moisture needed to germinate the yams planted in the fall. Heavy winter rains and floods, as well as spring time cyclones, also have the potential to destroy the yam harvest, and cause significant damage to earthen terrace constructions. Depending upon the timing and magnitude of these events, the data presented above indicate that few areas in the Sigatoka could have offered the assurance of high productivity under any circumstances-- for most areas, there was a definitive risk of harvest failure.

Figure 1 indicates habitations in the Sigatoka that would have been the most reliable, in terms of high-moderate yields of both dryland and hydrophytic crops. Most of these sites are large and well-fortified, and were also noted in historic accounts from the contact period as the strongholds of various populations (Gordon 1879, Boyd 1877, in Clunie 1984). It is very likely that these sites were the focus of many conquests and raids, as they would have maintained a stable resource base during times of environmental disturbance. Migrating groups uprooted by harvest failure or marauding neighbors would have focused their attention on these locales. Therefore it is very likely that future ground-level investigations of these settlements will yield long chronologies, and also evidence for multiple occupations.

#### *Habitation Strategies in the Sigatoka*

When the total productive potentials for all the resources surrounding the habitation sites are combined and compared with the variable levels of natural and constructed defense, the result is a graphic depiction of production and warfare in the Sigatoka valley. This variability manifests in three strategies for habitations-- that of a defensive strategy, a production strategy, and a defended production strategy.

The most predominant, including 58% of the sites in the valley (278 sites), is a defensive strategy that privileges the position of a defensive location and constructions over access to the most agriculturally productive areas. This strategy is typified by the construction of small sites (less than 3 hectares) along ridgelines and mountain tops, some of which are further defended with constructed ditches and scarps. The second most common subsistence strategy in the Sigatoka is that of a defensive production strategy. Thirty percent (142) of the sites in the sample indicate this strategy through their location in flat, agriculturally productive terrain that does not provide any natural means of defense. However, these sites are defended with constructed defenses, predominantly with the ring-ditch and the defensive scarp. Lastly, 11% (53) of the sites in the Sigatoka are indicative of a production strategy. These sites are located on flat terrain that provides no natural defenses, predominantly the level alluvial terraces of the valley bottom. These sites also lack any visible fortifications.

#### *Summary*

In sum, as Parry indicated the settlement pattern of the valley is one of defense and gardening. The majority of the habitations were small, usually less than 3 hectares in area probably containing populations around 70-100 people (Parry 1987:125). Nearly all of the habitations were defended, either by natural or constructed means, and those that are associated with high or moderate levels of production prioritized defense in site location and/or construction. In addition, very large defended settlements situated in areas of only moderate-low productivity were constructed. These sites may represent, as Parry hypothesized, the aggregation of populations and the formation of political hegemonies that maintained control over a large sections of the valley.

The populations of the Sigatoka also constructed refuges, usually along the rugged mountain ridges, to be used in retreats or times of disturbance. These sites are often large but not well connected to resources. Thus, it is likely that these refuges were maintained by several related groups to be used in times of need, and were supplied from more productive garden plots in the lowlands.

## DISCUSSION

The results of this study compliment Parry's original work in a variety of ways, and also provide some new insights that may direct future research in the area. First, Parry concluded that prehistoric competition in the valley was focused on the acquisition of well-defended habitation sites with immediate access to dense and predictable resources. The social and linguistic diversity of the region was due to a cycle of migration, conquest, and eventual isolation, which was perpetuated by a war-like atmosphere. The research presented above upholds this claim, and also provides a more detailed analysis of the co-occurrence of fortifications and resources. However, unlike Parry

these data also indicate potential risks for agriculturalists living in different parts of the valley. This has indications for the role of environment in settlement patterning and also the potential for social unrest following poor harvests of either dryland or wetland crops. Undoubtedly, future research into climate change and the effects of ENSO in the Southwestern Pacific will shed light onto the cycle of weather disturbances and climatic fluctuations, and the repercussions these phenomena may have had on prehistoric agriculture in the valley.

### CONCLUSION

The results of these analyses fare well in comparison to Parry's original conclusions for the prehistory of the Sigatoka valley. More importantly, this research highlights the ways in which space-borne and air-borne remote sensing can be used for archaeological research. Developing nations which lack the internal infrastructure and funding to perform ground-level survey research will undoubtedly benefit from the use of this technology to locate and plot archaeological sites. In addition, the analytic potential of remotely sensed data can aid a great deal in analyzing landscapes and pinpointing resources that played important roles in prehistoric developments. With the spatial analysis of the Sigatoka valley in place, future research into the antiquity of social groups and competition in the Sigatoka will be reliant upon the acquisition of temporal data; namely the creation of relative and absolute chronologies for the habitation sites. Future ground-level research at locales identified by this study will include excavation that will undoubtedly provide these data.

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Figure 1

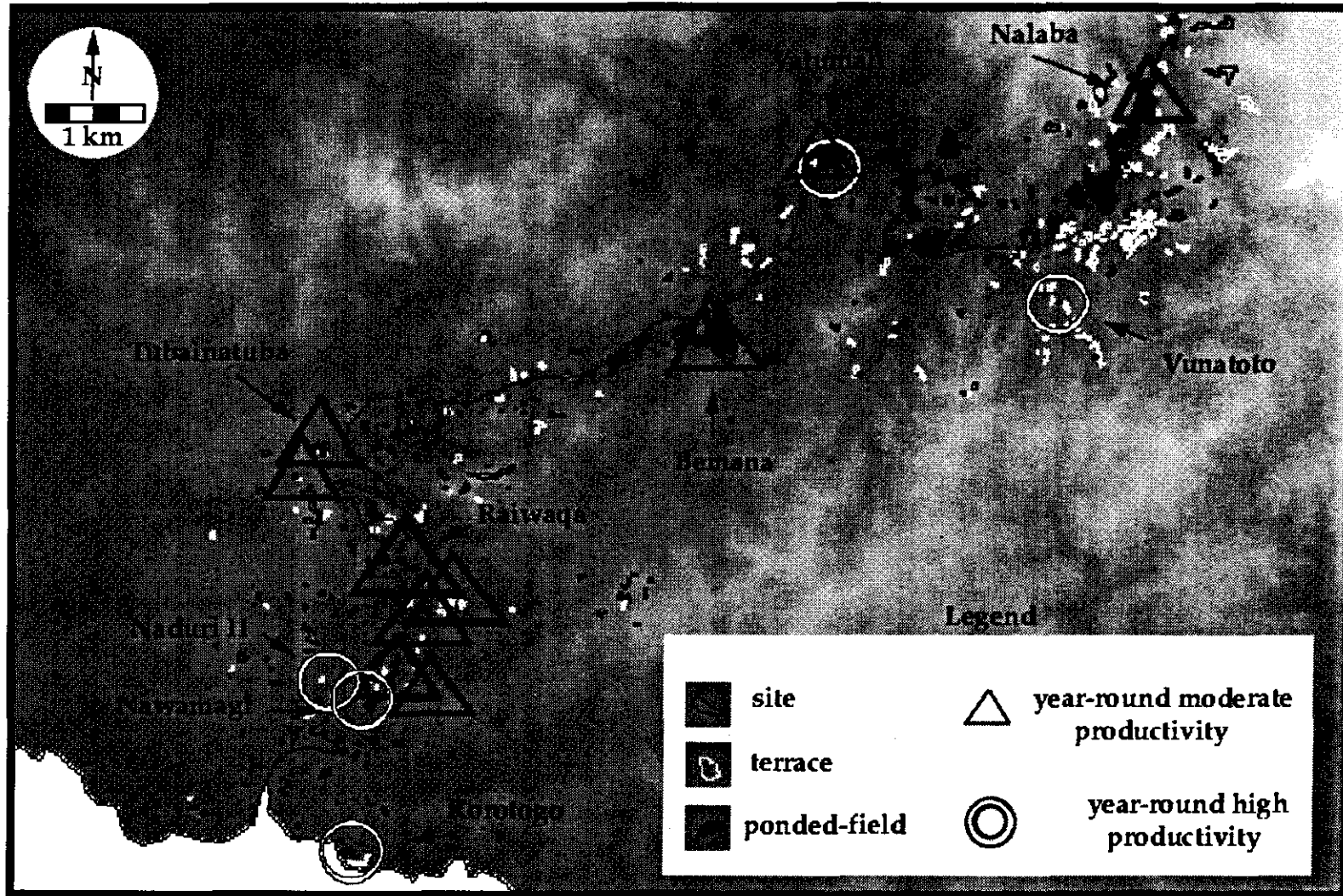


Figure 1: GIS generated image of the Sigatoka Valley. Icons indicate habitation sites with moderate-high production potential.