Utilizing Amerindian Hunters' Descriptions to Guide the Production of a Vegetation Map

Anthony Ravindra Cummings, School of Economic, Political and Policy Studies, University of Texas at Dallas, Richardson, TX, USA

Jane M. Read, Department of Geography, Syracuse University, Syracuse, NY, USA

Jose M. V. Fragoso, Biology Department, Stanford University, Stanford, CA, USA

ABSTRACT

Describing vegetation types is critical for managing natural resources and assessing ecosystem risk. Vegetation maps are historically produced by "Western experts," often ignoring local-level groups critical to resource management. Indigenous hunters, as resource managers, have strong connections to their landscapes and their descriptions of vegetation within their homelands can be useful in the map-making process. This project examined the usefulness of vegetation descriptions from Rupununi, Southern Guyana Indigenous hunters in the map-making process and how their descriptions were influenced by biophysical environmental attributes. A Landsat TM and ASTER DEM merged imagery of the Rupununi was classified using Indigenous hunters' vegetation descriptions to train the classification and assess accuracy. Based on the hunters' vegetation descriptions an eleven-class map was produced that covered the main vegetation types they described. Whereas "expert" maps rely on organized forest inventory data, Indigenous hunters' vegetation classifications were influenced by their interactions with the biophysical environment. The final map shows that Indigenous hunters may be important partners in the map-making process and play key roles in tropical forest management decision-making processes.

Keywords: *Amerindians, Guyana, Indigenous Hunters, Process Cartography, Rupununi, Vegetation Map*

1. INTRODUCTION

Describing vegetation types associated with the distribution of natural resources is critical at a number of levels, including wider ecosystem management and the sustainable management of individual classes of natural resources. In the realm of ecological risk assessment, "vegetation type" has particular significance and is accepted as synonymous to "ecosystem types", "ecological communities", "habitats", and "biotopes" (Keith et al., 2013). Therefore describing vegetation types is critical in ecosystem risk assessment studies (Keith et al., 2013) allowing for the definition of ecosystem characteristics, including native biota, abiotic characteristics,

DOI: 10.4018/ijagr.2015010107

spatial distribution and characteristic processes and interactions in gauging whether an ecosystem is threatened. Further, dissecting vegetation types to reveal forest types and other forms of flora is instrumental in understanding the potential geographical range of a species (e.g. Franklin, 2009; Pearson, 2007). In the sustainable management of multiple-use plant species, for instance, Peters (1996) suggested that defining forest types within which species are distributed and their associated abundance is vital. But often, interpreting the exact meaning of a forest type can be problematic across scientific disciplines (de Granville, 1988; Prance, 1979), let alone between Western experts and local-level experts such as Indigenous peoples. Interpreting the meaning of forest types is critical, especially in tropical settings where successful natural resource management, from wildlife to tree species, is accepted as the task of a wide group of resource managers, including scientists and Indigenous peoples (Chapin, Lamb, & Threlkeld, 2005; Stocks, 2005). This implies that the current dominant model of defining the vital parameters of management, such as forest types, through scientists or state-driven processes in a top-down approach (e.g., Fanshawe, 1952; ter Steege, 2001) may exclude the critical component of local people in the management process. Efforts to include Indigenous ideas in the map-making process, including defining vegetation types, will invariably enhance their role in sustainable resource management efforts. In an era where maps depicting forest types are derived from Geographic Information Systems (GIS) and remotely sensed data, such maps must be relevant to all users (Simms, 2010) particularly as they are increasingly used in resource management decision-making processes. GIS and remote sensing technologies provide opportunities for map users at all levels to be involved in the map-making process. This project examined the role of Indigenous hunters in describing vegetation for creating a map of the Rupununi region, Southern Guyana.

Recent efforts by the scholarly community to include local or Indigenous knowledge in scientific research (e.g., Luzar et al., 2011) have included the map-making process. In mapmaking, like scientific research, the challenge has been defending the legitimacy of local or Indigenous knowledge as a viable source of data. Local knowledge, by definition, is informed by culture as opposed to state "expert" or scientific knowledge which is informed by positivist science (Robbins, 2003). In response to the challenge over local knowledge's legitimacy, scholars, including Agrawal (1995), Robbins (2003) and Ross, Sherman, Snodgrass, Delcore, and Sherman, (2011) compared local and scientific knowledge and concluded that local knowledge has a legitimate place in scientific research. Ross et al., (2011), for example, provided a comprehensive overview of the differences and similarities between Indigenous knowledge and scientific knowledge, suggesting that both types of knowledge are influenced by social, cultural and political forces, yet Indigenous knowledge is often viewed as less legitimate. Nevertheless they argued that traditional knowledge has a significant place in natural resource management decision making processes. As a result, and especially in the map-making process, there are increasing efforts to include Indigenous and non-Indigenous conventions in the same maps (e.g., Pearce & Louis, 2008).

Local knowledge has been incorporated into GIS research in three primary ways (Robbins, 2003). Firstly, through the wave of counter-mapping efforts of the 1990s (Peluso, 1995; Robbins, 2003; Rundstrom, 2009), local knowledge and categories are used to challenge existing spatial management documents (Robbins, 2003). Peluso (1995) argued that official maps and documents in Indonesian Borneo removed traditional rights to forests. As a consequence, the only means Indigenous peoples had for asserting rights to such forests were through new maps utilizing local knowledge and emphasizing local land uses in the production process. Similar models portraying the landscape from the perspective of Indigenous peoples have been adopted in post-Apartheid South Africa (Weiner, Warner, Harris, & Levin, 1995), and Amazonia where resource users, including miners, have been included to manage environmental problems (Spiegel, Ribeiro, Sousa, & Veiga, 2012). Secondly, and the widest incorporation of local knowledge in map-making, has been through the provision of supplemental information for integrated formal planning (Robbins, 2003). This approach draws on ideas of participatory GIS (McCall & Minang, 2005) popularized in the 1980s and 1990s (Cinderby, 1999; Elwood, 2006; Harris, Weiner, Warner, & Levin, 1995; Herlihy, 2003; Koti, 2010) and allows local knowledge to boost scientific information to produce hybrid and broad views of resource management issues (Omotayo & Musa, 1999). Examples of this approach include Robbins (2003) utilizing herders' knowledge to compile a vegetation map of Rajasthan, India, for comparison with an official forest map. Likewise, Indigenous peoples themselves have utilized GIS and remote sensing technology to map their territories in order to pursue land ownership claims (Hellier, Newton, & Gaona, 1999; Pearce & Louis, 2008; Rees, Williams, & Vitebsky, 2003; Simms, 2010; Smith, Benavides, & Pariona, 2003; Tobias, 2000) and to plan for sustainable management of their lands (Cummings, 2006; Hellier et al., 1999). Further, Robbins (2003) and Turner and Hiernaux (2002) referred to examples in Latin America and Africa where Indigenous peoples and their allies successfully completed ecological assessments and land cover classifications.

The third approach to traditional knowledge incorporation into GIS was proposed by Robbins (2003), and suggests that local knowledge, like that of Western experts, can be submitted as a hypothesis for falsification. In trying to reconcile local knowledge, cultural knowledge and scientific knowledge, this approach suggests that local knowledge is science by other means. Through this approach, Indigenous knowledge is viewed as a form of science, but one that is different from positivist science. The approach claims that local science asserts Indigenous categorizations and understandings of physical processes which reflect more or less accurate apprehensions of real material systems (Robbins, 2003). By incorporating and evaluating local knowledge, analysts consider themselves closer to an accurate picture of the overall system. As a result, the void, largely of communication, that exists between landscape interpretations of local people and Western experts can be filled (Al-Kodmany, 2001). But, as Robbins (2003) noted, this approach also has limitations in that like other areas of scientific endeavor, it is invariably influenced by social, cultural, and political forces that guide the need for consensus and negotiation common in laboratories and scientific knowledge production. However, this approach has the potential to allow for reduced tensions between official views of landscapes and those of Indigenous peoples, especially in settings where the potential for resource use conflict exists, such as in multiple-use forestry. With the foregoing in mind, this project addressed two overarching questions. Firstly, can Amerindian hunters' vegetation descriptions serve to inform a landscape scale map for understanding the distribution of multiple-use species? Secondly, what biophysical environmental attributes influence vegetation classes as described by Amerindian hunters?

1.1. Goals

This project, based in Guyana, South America, had two main objectives. First, to complete a vegetation classification using Landsat TM and ASTER DEM data of the Rupununi, Southern Guyana, based on vegetation descriptions obtained from Amerindian hunters of the landscape to guide the process. This objective drew on the third approach for the inclusion of local knowledge in GIS (Robbins, 2003), where vegetation descriptions (vegetation classification) from Amerindian hunters were used to produce an alternative to Western expert vegetation maps. An alternative map was critical, as the most widely utilized vegetation maps in Guyana were produced by Western experts[1] (e.g., Fanshawe, 1952; Huber, Gharbarran, & Funk, 1995; ter Steege, 2001) and these dominate the resource management landscape. The latter two maps built on the work of Fanshawe (van Andel, 2001), and relied heavily on organized forest inventory data, and satellite imagery in the map-making process. In the case of the maps produced by Fanshawe (1952) field plots were developed to classify vegetation, which were subsequently mapped.

Vegetation classification is accomplished either qualitatively or quantitatively (Keeler-Wolf, 2007). The qualitative approach of vegetation classification is based on intuitive life-form approach such as comparing woodlands versus forests, and scrub versus grasslands. The quantitative approach is much more involved and sets certain rules based on usually the percentage of cover or other biomass measure of either species or life forms present in a stand of vegetation. The vegetation mapping process attempts to graphically display the location of the different vegetation types and emphasize their spatial relationships (Keeler-Wolf, 2007). In the case of the Western expert maps of Guyana's vegetation, they emphasized the scientific worldview of the map producers (Chapin & Threlkeld, 2001; Monmonier, 1991; Rundstrom, 1991; 1995) limiting their utility for all managers, including Indigenous peoples who are affected by their portrayal of reality. This project recognized Indigenous peoples' ability to describe their landscape, and hypothesizes that such descriptions can be used in the map-making process.

Ideally, a map of this nature will trigger discussions in Guyana and the wider Neotropics where changes in the resource management landscape will involve Indigenous peoples and their lands, especially through initiatives like Guyana's Low Carbon Development Strategy (LCDS) (LCDS, 2009). Guyana's LCDS aims to protect forests (State, and Amerindian-owned if Amerindian communities opt in), under the umbrella framework of the United Nations' Reduced Emission from Deforestation and Degradation (REDD+) program (un-redd.org), and will require monitoring forest change utilizing vegetation maps. The interpretation of map classes and how these change over time will be critical in REDD+ monitoring, reporting and verification (MRV) activities. Deciding on map classes that incorporate the way Indigenous peoples perceive forests may become important as more Indigenous communities participate in MRV initiatives (see Corbera & Schroeder, 2010; Skutsch, McCall, Karky, Zahabu, & Peters-Guarin, 2009). Differences in opinion as to the place of traditional knowledge and indeed the role and involvement of Indigenous people in the map-making process could lead to challenges over the value of ecosystem services that tropical forests provide. A map developed with Indigenous people actively involved in the map-making process therefore, especially where remotely-sensed data from satellites are classified, may be useful in this regard.

The second objective, closely related to the first, assessed how attributes of the biophysical environment relate to the Amerindian hunters description of vegetation. Scholars, including Rundstrom (1991) and Harley (1989) suggested that Indigenous peoples' view of the landscape is part of a larger *process cartography;* that is, Indigenous peoples' view of their landscape offers more than a static snapshot in time. This project hypothesized that Indigenous hunters are similarly inclined, and that their descriptions of vegetation will portray their human-environment interactions, with barriers to their movement in the landscape for hunting, gathering and traditional activities being emphasized (Read et al., 2010). Hunters' descriptions of vegetation will therefore reflect the biophysical environmental attributes around them, in a sense presenting an informal inventory of forest and other landscape characteristics, as opposed to formal inventories utilized by Western experts. Biophysical environmental attributes - elevation, tree density, basal area and moisture – were compared across vegetation classes to assess how these may have influenced hunters' vegetation descriptions.

2. METHODS

2.1. Background to the Rupununi Case Study

This research was completed in the Rupununi in Southern Guyana. Features of the biophysical environment and logistic factors control hunting patterns both over space and time. Species abundances and the real and perceived amount of effort required to bring home a kill influence a hunter's decision on where to hunt in the wider Neotropics and the Rupununi (Read et al., 2010). These ideas of "sense of place" (Read et al., 2010) may similarly impact how a hunter describes the landscape. Therefore, biophysical environmental attributes such as elevation, moisture, size (basal area) and height of trees, and the number of trees in any given area (density) may influence how an Indigenous hunter describes and uses vegetation. The underlying notion of this project was that whereas a botanist or biologist relies on formal forest inventory data for making decisions on vegetation types, hunters make similar judgments, but these are made relative to accessibility and ease of movement within their landscape for hunting, gathering, and other traditional activities; that is, resource use. The hunters' descriptions can therefore be incorporated with non-Indigenous methods (Pearce & Louis, 2008) to guide the production of maps that may be useful to Indigenous peoples and the scientific community alike. Many examples exist of Indigenous peoples mapping their landscape in the Guyana context, but these have been limited in scale and scope. Forte (2000) reproduced hand-drawn maps used by communities surrounding the recently gazetted Kanuku Mountains Protected Areas (KMPA) to plan the delivery of health services, understand spatial distribution of wells, and plan for the future delivery of utilities. More formally, the communities of the North Rupununi collaborated with the Iwokrama International Center for Rainforest Conservation and Development (IIC) to map hunting and fishing grounds and farming areas (Iwokrama, 2002). In Guyana's North West District (NWD) the Carib, Warrau and Arawak peoples mapped the distribution of the multiple-use tree species – *Carapa guianensis* – along the Waini River (Cummings, 2006), while the Wapishiana people of the South Rupununi mapped their territory and natural resources to aid in resource management decision-making processes (Stabroeknews, 2012).

The communities of the North Rupununi represented a superb opportunity for demonstrating that Indigenous peoples can actively participate in research initiatives regarded as positivist science. These communities have long expressed a desire to sustainably manage their natural resources within the context of their changing homelands, and have welcomed initiatives that will provide them with skills to this end. As such, the larger National Science Foundation (NSF) funded project of which this project was a part, "BE/CNH: Biodiversity Dynamics and Land-Use Changes in the Amazon: Multi-Scale Interactions Between Ecological Systems and Resource-Use Decisions by Indigenous Peoples", or Project Fauna, represented an opportunity for the communities to understand in greater detail their natural resource base, including wildlife density and resource use patterns, to plan for the sustainable management of these resources.

A key to Project Fauna's success was building strong relationships with the communities across the Rupununi. The project's goals were explained to Amerindian communities through community meetings, to the larger fora of Amerindian community leadership (the North Rupununi District Development Board, for instance), and to the Ministry of Amerindian Affairs. Project Fauna met with the Makushi and Wapishiana peoples across the Rupununi, and communities were invited to participate in the project. Most communities were interested in participating as they saw that they could learn methods to monitor their natural resources themselves, including gaining a better understanding of their wildlife populations that are critical to their diets. Communities that decided to participate in the project were asked to select a minimum of two persons, of which one must be an experienced hunter, to collect data in their respective villages. Project Fauna trained the selected participants in data collection protocols for biophysical, socioeconomic and spiritual variables, among other skills such as using global position systems. The project worked for at least two years and frequently longer in each community. In addition to gathering data about their communities and environment, a major output of the project was an atlas created for each community showing the data gathered, to be used by the communities for their own purposes. Copies of other outputs, such as fruit and animal guides, published reports, and academic papers were, and continue to be, shared with the communities. Moreover, each community has at their disposal personnel trained to monitor their own natural resources and tools with which they can engage national level stakeholders.

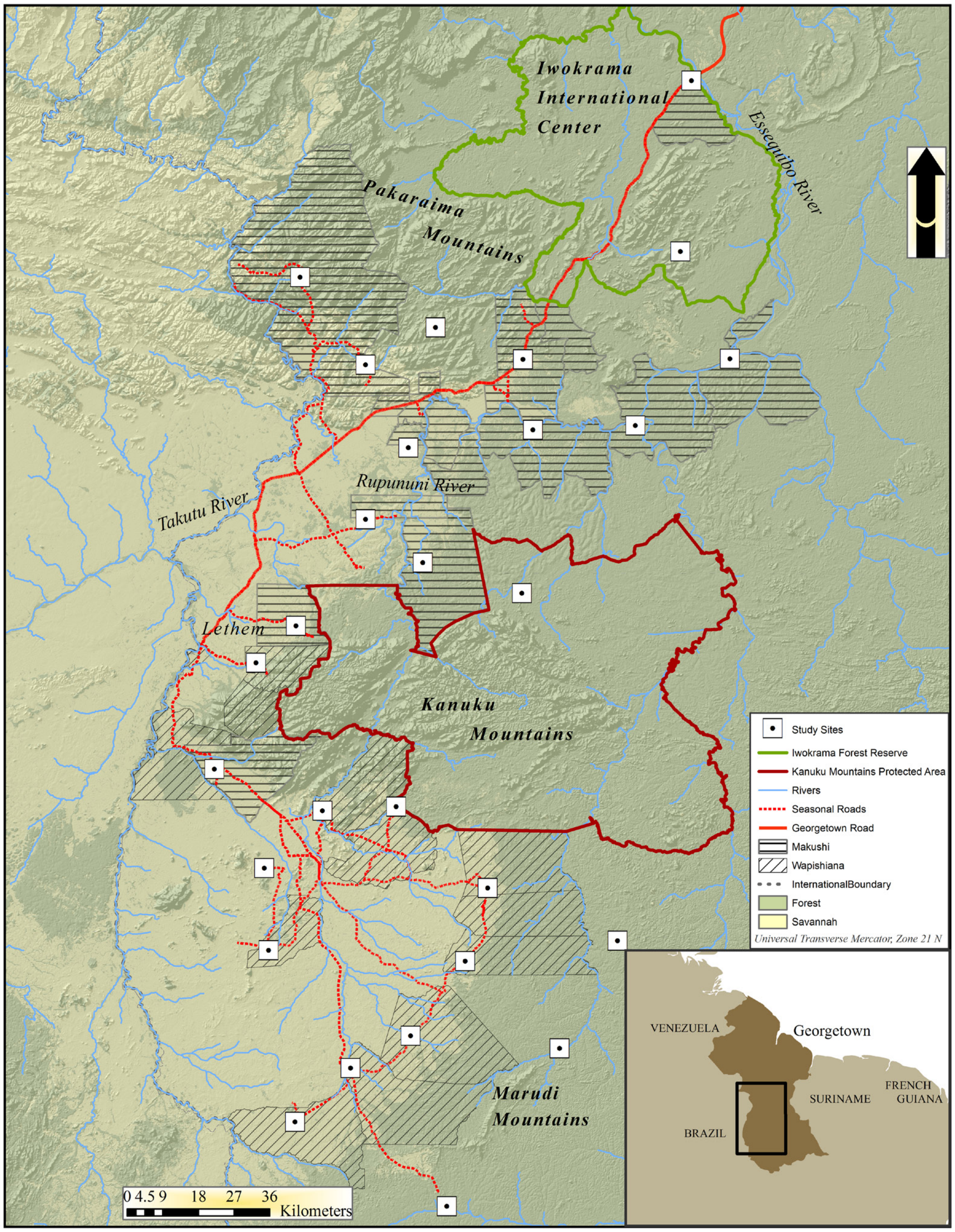
2.2. Study Area

This study was completed in the tropical moist forest and savannah biome (Read et al., 2010) of the Rupununi, Southern Guyana (Figure 1). The area of interest spanned approximately 48,000 km^2 and has elevation ranging from 30 m to approximately 1,100 m (Read et al., 2010). The area is the primary homelands of the Cariban-speaking Makushi and Arawakan-speaking Wapishiana Amerindian groups (Colchester, 1999) (Figure 1), but members of other Amerindian groups also make the study area their home. Archaeological evidence (Plew, 2004) suggests that Amerindians have lived in the Rupununi for more than 10,000 years and as of today the majority still rely heavily on subsistence practices, including swidden agriculture, fishing and hunting (Communities of the North Rupununi, 2006; David et al., 2006; Forte, 1996; Read et al., 2010). The study area hosts twenty-six (26) legally-titled Amerindian communities, two (2) protected areas - the IIC and KMPA (Figure 1), and a Conservation Concession. Legal title to lands gives Amerindians control over all above surface resources, including their forests. Access to communities by non-Amerindians is determined by community leadership (see Amerindian Act, 2006). For much of its recent history air transport represented the primary means through which communication between the study area and coastal Guyana occurred. But recent road developments promises to bring unprecedented external contact and a new layer of anthropogenic change. Broadly, the vegetation of the Rupununi includes savannahs, forests, bush islands, rocks with their associated vegetation, wet savannah and ponds, oxbow lakes, rivers, and creeks with their associated vegetation (Jansen-Jacobs & ter Steege, 2000). Previous efforts including Clarke, Funk, and Hollowell (2001), Eden (1964, 1973), Fanshawe (1952), Huber et al., (1995), and ter Steege (2001) have described various aspects of the area's vegetation.

2.3. Obtaining Vegetation Descriptions

Twenty eight (28) randomly located study sites were selected - twenty-three (23) Amerindian communities and five (5) controls - within the study area (see Luzar et al., (2011) and Read et al., (2010) for details on study site selection and distribution). At each study site, eight (8) randomly located 4-kilometer long transects were installed; four each in two zones – 0 to 6 km and 6 to 12 km – respectively, from a study site's center. At each site, a two-person team (referred to as hunters hereafter) consisting of an experienced hunter and a recorder, nominated by their villages or a village close to a control site, alternatively observed for wildlife and signs of wildlife (e.g., feces, hair, carcasses, or body parts, digging, burrows, eaten fruit or seeds, browsed plants, Fragoso et al., 2013) on transects at two-week intervals (Luzar et al., 2011; Read et al., 2010). The term hunter is used in this paper because these Indigenous men brought specific skills in detecting wildlife and working in the forests to the research. This term also separates their skills from those of other project participants. The hunters were native to their respective villages and the Rupununi, and were working in familiar settings. Hunters varied in their experience and background, with some having previously participated in research initiatives and monitoring projects, while others had not (Luzar et al., 2011). Data collected by the hunters included descriptions of vegetation

Figure 1. Study area with the homelands of the dominant Amerindian groups, study sites and protected areas highlighted on a background of a generalized vegetation map created from Landsat imagery



within which wildlife or signs of wildlife were observed. The process produced an initial list

Table 1. Details on remotely sensed data utilized in this study

Data	Acquisition date/ release date	World References System (WRS) boundaries	Pixel size (m)	Number of bands used
Landsat 5	1st October, 2005	Path: 231; row: 57	30	6
	1st October, 2005	Path: 231; row: 58	30	6
	2nd September, 2006	Path: 231; row: 59	30	6
ASTER GDEM	17th October, 2011	Study area	30	n/a

of vegetation descriptions for various portions of transects that were stored in a database. The initial list of vegetation descriptions was filtered, producing a common list of vegetation types across study sites. The filtered list was given to hunters to serve as a guide for describing all transects - savannah and forested - at their study sites. Hunters recorded the distance along transects (in meters) occupied by a certain vegetation type and noted when changes in vegetation occurred along transects to the closest meter mark. In addition, vegetation descriptions were collected by a tree inventory team sampling for trees and palms at fourteen forested study sites between July and December 2008. The tree inventory team included hunters as tree spotters, and were accompanied by local hunters as they described vegetation on transects. Vegetation was described between July 2008 and April 2009 by more than twenty-eight two person teams. As the Landsat imagery (see Table 1) used in this study were obtained in September and October, vegetation descriptions collected between July and December, 2008 were primarily used allowing for the impacts in seasonal changes and vegetation phenological variability to be minimized. Hunters' vegetation descriptions were mapped in a GIS environment and examined for vegetation classification themes (Keeler-Wolf, 2007) to develop a hierarchical classification scheme for the vegetation map. Because the data were gathered by more than 50 different people, there were many variations in the way that vegetation was described, and these were summarized into broader classes while staying as true as possible to the class described by the hunters based on both the wording of the vegetation descriptions as well as through discussions with hunters familiar with the entire area.

2.4. Remotely Sensed Data

Three Landsat 5 scenes were downloaded from the United States Geological Survey (USGS) Earth Resources Observation and Science (EROS) Center (Table 1). The USGS archives were searched extensively to acquire imagery closer to the time of hunter vegetation descriptions, but due to heavy cloud cover, the decommissioning of Landsat 5 and failure of the scan line corrector (SLC) in Landsat 7 this was not possible. ASTER Global Digital Elevation Model (GDEM)[2] scenes covering the study area were also acquired. Both the Landsat TM and ASTER GDEM data were acquired at 30 m pixel resolution.

2.5. Image Pre-Processing

Bands 1-5 and 7 of the three Landsat TM scenes were georeferenced, converted to top of atmosphere reflectance (Chavez, 1996), stacked, mosaicked and merged with the ASTER GDEM. The decision was made to merge the Landsat Imagery and ASTER GDEM as conversations with hunters, observations of hunters in the field, and visual inspection of hunters' vegetation descriptions suggested that elevation was influential in their decision making processes for describing vegetation. Clouds, cloud shadows and forest and other shadows were masked out of the data using an

Table 2. The distribution of hunters' vegetation descriptions and the percentage of the overall sample used for classification training and accuracy assessment

Vegetation Class	Length of transects (km) described	Training Data (Percentage)	Reference Data (Percentage)
Seasonally Flooded Mixed High and Low Forest	129.1	7.0	7.5
Lowland High Forest	129.8	6.9	7.7
Lowland Mixed High and Low Forest	122.2	6.4	7.3
Upland Low Forest	43.1	2.3	2.5
Upland High Forest	69.9	3.6	4.2
Mountain Mixed High and Low Forest	48.8	2.0	3.4
Seasonally Flooded and Swampy Savannah	82.4	4.2	5.0
Savannah with Bare Soil	232.7	12.8	13.3
Upland Savannah	22	1.1	1.3
Mountain Savannah	9.8	0.5	0.6
Rivers, creeks, and other water bodies	1.7	0.1	0.1
	891.5	47.0	53.0

unsupervised clustering technique (Helmer, Ramos, del Mar Lopez, Quiñones, & Diaz, 2002). Prior to merging, negative values in the ASTER GDEM, a common problem associated with these data, were removed.

2.6. Image Classification

The hunters' vegetation descriptions were separated into two random samples of approximately 50% each (Table 2) of the landscape to train the image classification (Johannsen & Daughtry, 2009) and assess map accuracy (Congalton & Green, 1999; Stehman & Foody, 2009). The data were separated using a stratified random sample by vegetation classes and study sites. The training sample was used to guide an unsupervised classification (Lillesand, Kiefer, & Chipman, 2004) separating the merged Land imagery and ASTER GDEM into 50 unbiased spectral classes without human input. Hunters' vegetation descriptions were overlaid on the unsupervised classification to determine which spectral classes best corresponded to vegetation descriptions.

2.7. Accuracy Assessment

Three methods were used to assess the accuracy of the classified product. First, two hunters who described vegetation and had extensive knowledge of the study area gave informal impressions of the final vegetation map. Hunters were shown the map, asked whether they agreed with the classification, and whether glaring errors existed based on their knowledge. The second approach used the sub-sample of vegetation description data to generate 80 random reference points for each vegetation class. The vegetation referenced by each point was compared with the classified image (Congalton & Green, 1996; Stehman, 1997). The resulting error matrix showed how reference data compared to the classified image and highlighted confused classes. The third approach compared the vegetation description of transect segments held for accuracy assessment and that were used as reference for the 80 random points with the classified image to assess whether any portion of the transect was incorrectly classified and if so, which class(es) were confused. An error matrix, highlighting the percentage of transects correctly classified, was completed for this approach with overall accuracy computed as the percentage of transects correctly classified per class.

2.8. Vegetation Description and Biophysical Environmental Attributes

To assess the influence of the biophysical environmental attributes on hunters' descriptions of vegetation, 30 random points, located on transects and at least 50 m apart to minimize spatial redundancy, were generated for each vegetation class. The variation of these attributes by vegetation classes was assessed and compared. Five biophysical environmental variables were assessed:

1. **Elevation:** Derived from the ASTER GDEM
2. **Moisture Content:** The normalized difference water index (NDWI) was utilized as proxy for moisture. Two versions of NDWI are described in the literature (Ji, Zhang, & Wylie, 2009). The first, developed by Gao (1996), utilizes the normalized difference between the Near Infrared (NIR) and Short Wave Infrared (SWIR) bands of Landsat. The second, developed by McFeeters (1996), is the normalized difference of the green and NIR bands. Gao's NDWI was chosen since it is most widely used in the literature for understanding forest moisture. NDWI values range from 0 (minimum) to 1 (maximum).
3. **Vegetation Vigor:** The normalized difference vegetation index (NDVI) (Huete & Jackson, 1987) measures vegetation vigor and is impacted by forest density and structure. The NDVI values range from 0 (least vigorous) to 1 (most vigorous).
4. **Tree Size (Basal Area):** The mean diameter-at-breast-height (dbh) was computed for trees sampled at fourteen (14) forested study sites within a 500 m2 (50mx10m) transect segment. The mean dbh was mapped as a raster layer to aid in extracting a dbh value for each of the randomly generated points.
5. **Tree Density (Number of Trees):** A simple count of trees per 500 m2 was mapped in a GIS as a raster layer to aid in extracting a tree density value for each of the randomly generated points.

3. RESULTS

3.1. Vegetation Descriptions

Hunter vegetation descriptions were obtained for 223 of 224 transects or the equivalent of 891 kilometers of the study area (Table 2). The overall sample contained more than 150 unique descriptions. Vegetation descriptions contained details on land-use, occurrence of recent fires, hydrology (rivers, creeks, swamps, flooding events), dominant vegetation type (forest or savannah), current or recent farms, approximate age of old farms, and an indication of elevation of the area being described. The descriptions contained themes relating to vegetation characteristics, and biophysical environmental attributes. Vegetation characteristics descriptions included: bush island, farms, old farms, high bush, low bush, ite palm swamp, muri shrub, rock low bush, and savannah. It should be noted that in the Rupununi and Guyana context, "bush" suggests forest, while savannah suggests herbaceous vegetation. Inferences could also be made on the vegetation characteristics, tree density (number of trees), tree size (dbh) and tree height, based on the descriptions. For instance, both high bush and low bush refer to forested areas, but high bush suggested an area with a higher density of larger (dbh) and invariably taller trees, while low bush indicated an area of lower density and smaller trees. Bush islands are areas of forest within savannah. Ite palm swamp are seasonally or permanently flooded areas, primarily in savannah, dominated by *Mauritia spp*. palms, while "muri shrub" is forest of lower tree densities, shorter trees and smaller sizes (dbh) generally located in the savannah-forest transition. Modification of the term "bush" signaled transitions between forest types and indeed savannah types as is common in tropical settings (e.g. Powell et al., 2004). For example, "bushy savannah" implied an area with a heavy herbaceous undergrowth, but with significant coverage of trees and/or shrubs. Generally, bushy savannah indicated a higher density of Kaiambe (*Curatella americana*) trees which are generally associated with the Rupununi savannahs. The absence of the "bushy" descriptor for savannah by the same logic, suggested the absence or lower density of trees within herbaceous vegetation.

The physical environmental themes reflected two main features: hydrology and elevation. Hydrological themes included: "flooded", "swamp (y)", "river" and "creek", while elevation themes included: "mountain", "hilly", "upland" and "lowland". Physical environmental themes generally modified vegetation characteristic themes. For instance, hunters may have described vegetation as Flooded Low Bush or Mountain High Bush, combining the two descriptors to provide both a vegetation and physical environment depiction. There were however, as expected with the number of hunters describing vegetation, uncertainties and ambiguities in the data, as is common in GIS data sets (Longley, Goodchild, Maguire, & Rhind, 2001). For example, one hunter's description may have been, "Flooded Low Bush", while another, presumably describing similar vegetation, may describe it as, "Low Bush Flooded". As hunters worked independently at their own study sites, these differences were not surprising. Obvious differences in descriptions were "standardized" where possible and the descriptions were used to develop a hierarchical classification scheme similar to those developed by Anderson, Hardy, Roach, and Witmer (1976); Robbins (2003) and Simms (2010) using the most common and dominant vegetation and biophysical environmental characteristics.

3.2. Vegetation Classes

The final vegetation classes portrayed in the map represent a compromise between hunters' vegetation descriptions and fitting these to the scale of the remote sensing data. While vegetation descriptions were very detailed, many were not discernable using the remote sensing data. To get around this issue vegetation descriptions were merged. The most dominant and common themes of vegetation and biophysical environmental attributes in the hunters' description were combined and led to eleven (11) major vegetation classes (Figure 2 and Table 3), based on the broader forest and savannah vegetation types. Although this may appear to be moving away from the Indigenous people's descriptions of vegetation the map classes still provide insights into key features of hunters' vegetation descriptions including seasonality and elevation as these may influence hunters' movements within the landscape. Compromises were also made with the terms used for describing classes, with the most prominent being the term *bush* being substituted with *forest* to allow for more universal clarity as in some parts of the world bush may refer to savannah-like vegetation. Six (6) classes described forests, four (4) described savannahs and one (1) described water bodies and hydrological features. The forest classes, "Seasonally Flooded Mixed High and Low Forest"; "Lowland High Forest"; "Lowland Mixed High and Low Forest"; "Upland Low Forest"; "Upland High Forest" and; "Mountain Mixed High and Low Forest", represent mainly the hydrological features associated with the study area and also a progression from lower to higher elevations. Likewise, savannah classes, "Seasonally Flooded and Swampy Savannah"; "Savannah with Bare Soil"; "Upland Savannah" and; "Mountain Savannah", reflected frequency and duration of flooding and progression along an elevation gradient within which herbaceous communities were located. The names of the classes were derived directly from the hunters' vegetation descriptions or were influenced by the themes reflected in their descriptions. The biophysical environmental and vegetation attributes (tree density and size) associated with these classes varied (Table 4), but elevation and tree density were the main factors separating classes. These coarse-scale vegetation classes

Figure 2. Vegetation map of the Rupununi derived from the classification of landsat data using descriptions from Makushi and Wapishiana Amerindian hunters

allowed for the ambiguity and uncertainty contained in the hunters' descriptions to be minimized, while still reflecting details on the Rupununi landscape from the hunters' perspective. Vegetation descriptions allowed for the study area to be separated into various transitions within the broad savannah and forest classes.

The vegetation classes varied in their abundance in the landscape. For instance, the Seasonally Flooded Mixed High and Low Forest and Lowland High Forest classes dominated the forested landscape, while the Savannah

Table 3. Vegetation types derived from amerindian hunters' vegetation descriptions

Vegetation Class	Description
Forest Classes:	
Seasonally Flooded Mixed High and Low Forest (SFM)	Vegetation that are seasonally flooded (low bush and high bush) and a high proportion of muri shrub. Most of the current farms, old farms and logging areas are associated with this class.
Lowland High Forest (LHF)	Forests at slightly higher elevation that the Seasonally Flooded Mixed High and Low Forest. Dominated by larger trees, this class also experiences some flooding, but are located away from rivers and creeks. Also includes farming areas.
Lowland Mixed High and Low Forest (LMF)	The zone of forests between the Lowland High Forests and Upland High Forest areas.
Upland High Forest (UHF)	Forests away from the flood zones in the North Rupununi. In the South Rupununi however, the forests in this class, are the areas within which swidden agriculture occurs.
Upland Low Forest (ULF)	Smaller trees and shrubs at a slightly lower elevation than forests in the Upland High Forest area.
Mountain Mixed High and Low Forest (MMF)	Forests found at the highest elevation in the Rupununi, mainly on the Pakaraima and Kanuku Mountain ranges. This class is dominated by taller trees, but smaller trees and some shrubs are also present.
Savannah Classes:	
Seasonally Flooded and Swampy Savannah (SFS)	Dominated by herbaceous vegetation that is flooded during rainy seasons. Trees and shrubs may be present, but at lower density than forests. This class is associated with the banks of rivers, creeks and Ite Swamps, especially in the South Rupununi. The Georgetown to Lethem road is included in this class.
Savannah with Bare Soil (SBS)	Dominated by herbaceous vegetation and uncovered ground (including rocks) that are not as frequently flooded.
Upland Savannah (ULS)	Isolated patches of herbaceous vegetation at higher elevations. These areas appear to be the transition between Upland Forest and Mountain Forest especially in the Pakaraima mountains area. In the South Rupununi current farming areas were observed to be spectrally similar to these areas.
Mountain Savannah (MTS)	Different from the Upland Savannah class by being located at higher elevations.
Other Classes:	
Rivers, creeks, and other water bodies (RVP)	Rivers, creeks, ponds and lakes and their associated vegetation.
Clouds, Cloud Shadows and Forest Shadows	Areas in the image that were covered by clouds, cloud shadows and forest shadows.

Table 4. Biophysical environmental attributes measured and the mean value for each attribute for the ten vegetation classes

Vegetation Class	Elevation (m)	Density (trees/500m²)	Tree Sizes (DBH/500m²)	NDVI	NDWI
SFM	109	Highest	Larger	0.9	0.7
LHF	130	Highest	Largest	0.9	0.7
LMH	180	Higher	Largest	0.8	0.7
ULF	346	High	Large	0.9	0.7
UHF	365	Higher	Larger	0.9	0.7
MMF	714	Highest	Largest	0.9	0.7
SFS	113	n/a	n/a	0.5	0.5
SBS	149	n/a	n/a	0.4	0.4
ULS	271	n/a	n/a	0.5	0.3
MTS	301	n/a	n/a	0.6	0.5

with Bare Soil class dominated the savannah landscape (Figure 2). The Upland Low Forest and Upland Savannah classes were rare. It should be noted that these coarse-scale classes are not absolute; that is, descriptions do not suggest that these are the only regions associated with a particular vegetation characteristic or biophysical environment attribute. Rather, the classes represent the best fit to the imagery given hunters' vegetation descriptions. As an illustration, the class Lowland High Forest refers to forested vegetation at higher elevations (Table 4) when compared to the Seasonally Flooded Mixed High and Low Forest adjacent to this class. The classification does not suggest the absence of flooding within the Lowland High Forest area, rather, based on the descriptions from hunters these areas appear to flood less frequently and for shorter periods. Areas in the class Seasonally Flooded Mixed High and Low Forest areas on the other hand may experience extended flooding during the rainy seasons.

Further, the upland and mountain forest classes describe vegetation at progressively higher elevations. Upland Low Forest is different from Upland High Forest in three ways: smaller trees (dbh); lower tree density and lower elevation (Table 4). Similarly, the Mountain Mixed High and Low Forest class, implies forests on "mountain" (mainly the Kanuku and Pakaraima Mountains; see Figure 2) elevations. Discriminating between the mountain low bush (smaller trees) and mountain high bush (larger trees) was not possible, but the analysis (Table 4) showed this class located at elevation above the Upland classes with slightly larger trees (dbh) and higher tree density.

Hunters' descriptions also reflected the different perspective of hunters working across the study area. Based on elevation, the North Rupununi was more diverse than the South, including forest and savannah at lower flooded regions to forest and savannah in mountains. The South Rupununi on the other hand, had a higher overall elevation than the North, but was less diverse in terms of elevation, and the number of vegetation classes. It appears as though these differences influenced hunters' descriptions of vegetation. In the South Rupununi, for example, hunters working in villages in higher elevations described their vegetation with the "mountain" prefix, e.g. Mountain High Bush. Even though this description reflected their local reality and scale, at the larger Rupununi study area scale, similar vegetation was classified differently and were not spectrally similar to that occurring in the cloud forests of the Kanuku and Pakaraima Mountains as described by Jansen-Jacobs and ter Steege (2000). In such cases, the hunters' description was a better fit to the Upland classes, where the Upland prefix referred to vegetation in the transition between lowland and mountainous areas. In this sense the Upland Low Forest and Upland High Forest classes provide insights into elevation, but also into tree sizes (dbh) and density (number of trees) present in these areas. The terms flooded, upland and mountain are similarly applicable to the savannah vegetation classes, where a strong link to elevation (Table 4) was also evident. By the same logic, the Seasonally Flooded Savannahs were located at lower elevations and Mountain Savannahs at higher elevations. As the name suggests, the pond and water body class included rivers, creeks, oxbow lakes and permanent swamps of the Rupununi and their associated vegetation similar to those described by Jansen-Jacobs and ter Steege (2000).

Higher moisture content (Gao's NDWI) was associated with vegetation types that experienced flooding, for example Seasonally Flooded Mixed High and Low Forest (Table 3). The NDWI values appear to reflect drainage and runoff from the forested mountainous areas, with lower values at higher elevations. But against this trend seen in forests, the Mountain Savannah class had slightly higher moisture than the Seasonally Flooded and Swampy Savannah, perhaps reflecting faster evaporation rates in the open savannah environments at lower elevations and higher rainfall rates as these savannahs are adjacent to the cloud forests (Jensen-Jacobs and ter Steege, 2001) of Pakaraima Mountains. As expected, the forested vegetation classes had very little differences in NDVI values (Table 4) with Lowland High Forest the most vigorous and Lowland Mixed High and Low Forest the least vigorous. Savannah classes had similar NDVI values, with Mountain Savannah the most vigorous.

3.3. Accuracy Assessment

As per standard practice in remote sensing the accuracy of the final map was assessed using three methods (please refer to Accuracy Assessment in the Methods section). The two hunters who assessed map accuracy noted that the map seemed to represent their perception of the landscape well. Since the hunters were from the North Rupununi, however, and the hunters from the Central and Southern Rupununi study sites could not view the map it was difficult to conclude based on these two hunters how well the final map represented all hunters' perceptions of their landscape. However, given that the two North Rupununi hunters have extensive knowledge of the Rupununi landscape, and have frequented the Central and South Rupununi villages, the map appears to be a good model of the study area's vegetation.

The conventional hard accuracy assessment with the rule of thumb of 80 reference points per class (Congalton & Green, 1999) yielded an overall accuracy of 64.1% (Table 5) which is considered low in the literature, with 85% being the goal (Anderson et al., 1976). However, lower accuracy assessment results are not unusual (Powell et al., 2004). The overall accuracy aside, many of the classes varied in producers' and users' accuracy measurements. Four forested classes – Seasonally Flooded Mixed High and Low Forest; Lowland High Forest; Lowland Mixed High and Low Forest; and Mountain Mixed High and Low Forest, had user's accuracy above 70%. This means that the map shows these forest classes correctly more than 70% of the time on the ground. Upland High Forest had a user's accuracy below 48.5%. Similarly, the Upland Low Forest users' accuracy was 58.33%. With the exception of Seasonally Flooded Mixed High and Low Forest (33%) and Upland Low Forest (43.75%; Table 5) all the forested classes had Producer's accuracy above 50%, meaning that of the actual area in the landscape defined as these classes, more than 50% were correctly classified. The number of confused classes (Table 5) reflects the difficulty in discriminating between the vegetation classes, both forested and savannah.

The third accuracy assessment approach gave better overall accuracy of 68% (Table 6). However, the error matrix showed that transect segments, when compared with the

Table 5. Error matrix for the hard vegetation classification

Classified Data	SFM	RVP	SFS	LHF	SBS	LMH	ULS	UHF	ULF	MTS	MMF	Producers Accuracy	Users Accuracy
SFM	**57**	0	1	11	1	2	0	0	0	0	0	33	80
RVP	0	**35**	3	0	0	0	0	0	0	0	0	29	92
SFS	6	45	**52**	3	13	5	4	0	2	1	0	59	40
LHF	14	0	0	**62**	2	5	0	2	0	0	0	90	73
SBS	0	0	17	0	**57**	3	0	0	2	0	0	79	72
LMF	0	0	1	3	2	**52**	1	8	7	0	0	80	70
ULS	0	0	2	0	1	1	**46**	1	0	35	3	12	52
UHF	2	0	1	0	0	8	16	**49**	20	2	3	66	49
ULF	0	0	0	0	1	0	6	6	**35**	2	10	26	58
MTS	0	0	1	0	1	0	4	1	0	**40**	3	44	80
MMF	0	0	0	1	0	0	3	6	14	0	**61**	88	72
Column Total	80	80	80	80	80	80	80	80	80	80	80	**Overall Accuracy: 64.3%**	

vegetation map (Figure 2) had various portions mis-classified. Using this approach, only the Seasonally Flooded and Swampy Savannah and Mountain Savannah classes had less than 50% (44.57 and 27.26) percent of transects misclassified. It should be noted here that Upland Low Forest (80%) class had a significant improvement in accuracy when compared to the second approach. Interestingly though, there were very few transect segments that were completely misclassified, suggesting that seasonal changes may have been the main reason for the lower accuracies reported for the second approach. Similar classes were confused in the second and third approaches (Tables 5 and 6).

4. DISCUSSION

The descriptions of vegetation provided by Amerindian hunters proved useful in completing a vegetation map of the Rupununi, Southern Guyana. The final map (Figures 2 and 3) represents a synergy between hunters' description of vegetation and the ability to map these using remotely sensed data. Hunters' vegetation descriptions were essentially a vegetation classification (Keeler-Wolf, 2007) with rich details on the qualitative descriptions of vegetation forms that could not be included in the final map. For instance, descriptions such as Muri Shrub and bushy savannah could not be detected spectrally and hence are not reflected on the final map. In cases like these, descriptions were incorporated into one of the larger classes like Seasonally Flooded Mixed High and Low Forest and Seasonally Flooded and Swampy Savannah for these two descriptions, respectively. Similarly, the Ite (*Mauritia spp.*) swamp areas could not be discriminated from Seasonally Flooded and Swampy Savannah areas. But hunters' identification of these vegetation types and the subtle differences between them demonstrated their attention to detail in their landscape, evidently identifying transition zones typical of tropical forests that are difficult to map (Powell et al., 2004). The difficulties in mapping these classes may be due to limitations in the remotely sensed data and seasonal difference associated with data collection periods.

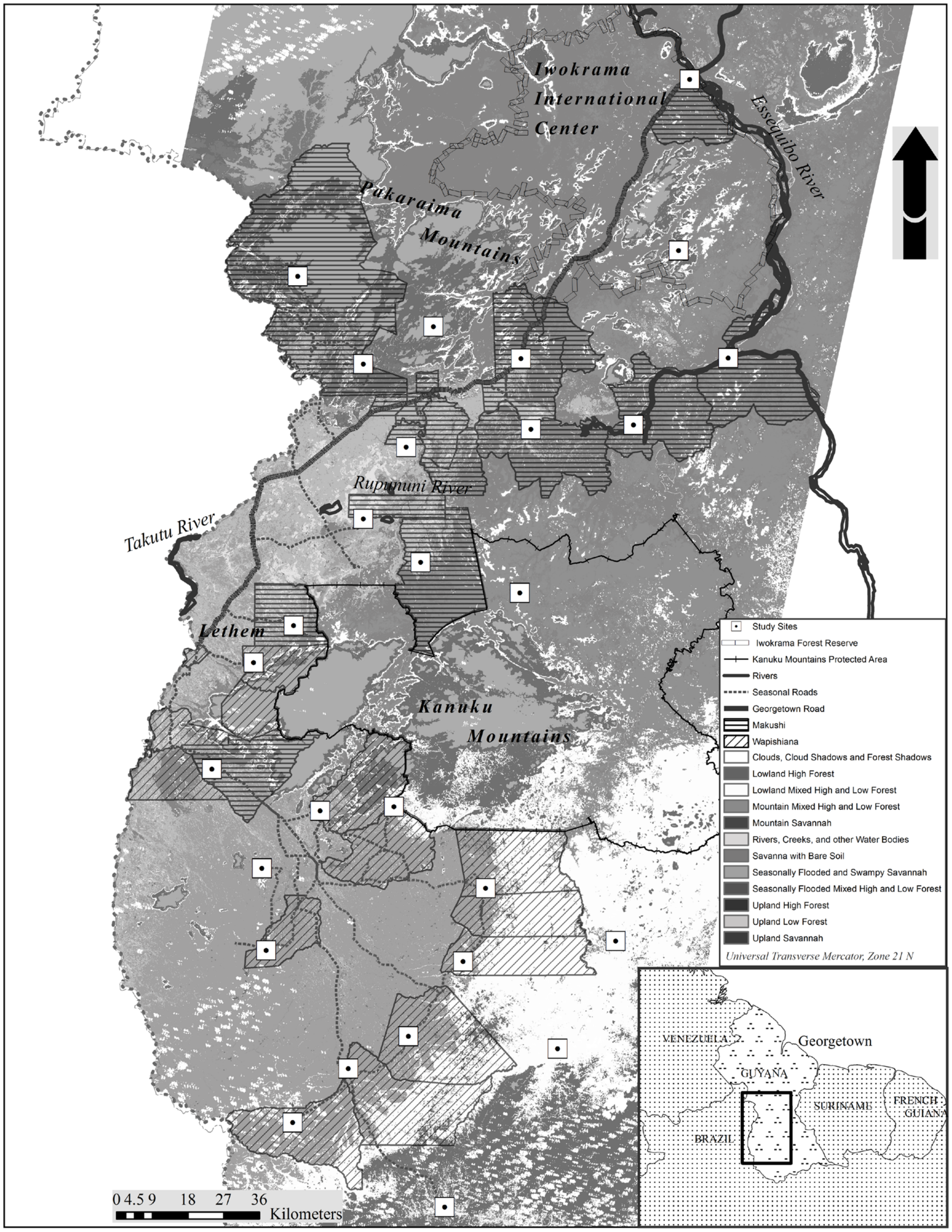
Table 6. Error Matrix showing the percentages (length) of transects correctly classified on the final map (the values in each row are scaled by the reference data total)

	Classified Data												
Reference Data	**No Data**	**SFM**	**RVP**	**SFS**	**LHF**	**SBS**	**LMF**	**ULS**	**UHF**	**ULF**	**MTS**	**MMF**	**Producers Accuracy**
SFM	1.36	**69.67**	0.88	7.30	14.95	0.24	3.91	0	0.94	0	0	0	69.67%
RVP	0	0	**79.80**	10.73	1.66	7.81	0	0	0	0	0	0	79.80%
SFS	0.38	3.14	16.47	**44.57**	0.90	32.52	0.28	1.57	0	0	0.18	0	44.57%
LHF	0.33	15.20	0	0.33	**77.26**	0.67	5.39	0	0.81	0	0	0	77.26%
SBS	4.79	0.07	0.48	1.12	0.98	**85.13**	4.36	2.81	0	0	0.26	0	85.13%
LMF	1.60	1.80	0	0	10.39	3.31	**69.58**	0.02	12.99	0.31	0	0	69.58
ULS	0	0	0	1.62	0	6.44	0.80	**74.26**	11.21	5.39	0.25	0	74.26%
UHF	1.51	0	0	0	1.15	0	16.90	0	**78.25**	2.20	0	0	78.25%
ULS	0	0	0	0	0	0	0	0	20	**80**	0	0	80.0%
MTS	0.99	0	0	0.31	0.85	23.53	6.85	19.73	12.41	0	**27.26**	8.08	27.26%
MMF	1.50	0	0	0	1.56	1.17	3.25	3.13	27.73	0.53	0.39	**60.72** **Overall Accuracy=68%**	60.72%

From the imagery perspective, the classification process allows for similar spectral regions to be grouped into classes (Campbell, 2002; Lillesand et al., 2008) and in theory each object on the earth surface has a unique and characteristic way in which it interacts with electromagnetic radiation (Mather, 1999). These characteristic interactions are what allow for the discrimination of one object from another. In practice this theory works well for discriminating objects with marked differences in physical properties such as vegetation and water (Campbell, 2002), but less so for similar objects such as vegetation types (Cochrane, 2000); as all vegetation has similar spectral responses.

Changes in the Rupununi landscape between 2005-2006 (when imagery were obtained) and 2008 (when vegetation was described) were limited (personal observation) but seasonal changes undoubtedly impacted vegetation descriptions. Despite formal records of weather conditions being absent for the study area, it is likely that weather patterns were different between the time of imagery acquisition and vegetation descriptions. Vegetation descriptions occurred over a growing season, beginning at the end of the rainy season (July- August) towards the beginning of the short rainy season and ideally for vegetation classification image acquisition and training data collection should occur at the same time (Jensen, 2007). Therefore, despite the value of terms such as high bush, low bush, savannah and the related adjectives such as mountain, flooded, burnt, lowland, swampy, and upland, the map was limited in terms of the level of detail it could portray. But, the hunters' descriptions provided insights into the condition of vegetation as well as a marked methodological departure from Western expert produced maps with "lay people" providing data for classification training and assessment. Hunters' connection to their landscape and the *process cartography* idea alluded to by Harley (1989) and Rundstrom (1991) were reflected in their descriptions. This work suggests that including Indigenous

Figure 3. The vegetation map of the Rupununi produced using descriptions from Makushi and Wapishiana Amerindian hunters relative to Amerindian homelands and the wider Rupununi landscape



peoples in scientific research could be critical in resource management initiatives, and in particular the map-making process.

The fact that only eleven broad vegetation classes were mapped must also be viewed in light of the challenges associated with mapping a tropical forest where multiple data sources existed. The initial list of vegetation descriptions could have been reinforced through a mechanism for hunters to share notes on vegetation descriptions at their respective study sites and that is an area that future studies could address. Further, the vegetation descriptions were compiled from twenty-eight study sites with potentially different local scale peculiarities in vegetation and topography, but also collected by no less than twenty-eight different sets of hunters. The chances for ambiguities and uncertainties (Longley et al., 2001) in the data set were high, and indeed evident. The final map classes therefore reflect a compromise between hunters' vegetation descriptions and a chance to allow these classes to receive universal acceptance in map-making in Guyana and the Neotropics where map classes may have implications for Indigenous peoples such as in REDD+ MRV activities. This analysis has shown that hunters' vegetation descriptions were useful, and that hunters, and by extension Indigenous peoples and their local-level expertise as noted by others such as Ross et al. (2011), offers a viable alternative for inclusion in natural resource management initiatives, especially those initiated in a top-down manner.

Even though the vegetation descriptions were not developed from forest inventories and empirical measures of biophysical environmental attributes, they reflected both of these qualities that are critical to understanding vegetation classification and spatial distribution (Keeler-Wolf, 2007). Hunters' vegetation descriptions reflected the barriers to their movements within their landscape, in particular elevation (Table 4), and the impact these have on their mobility for hunting and gathering (Read et al., 2010). These biophysical factors are important for resource management as well, as they may indicate areas where resources may be vulnerable to exploitation. Further, from a resource management perspective, the vegetation descriptions from hunters also indicated where swidden agriculture and gathering occurs, and these areas appear to be similar in physical environmental characteristics as other Neotropical settings (Huber & Zent, 1995) and may be useful for gauging future resource management conflicts.

The conventional accuracy of the vegetation classification was below those recommended in the literature (Anderson et al., 1976; Congalton & Green, 1999), but accuracies at this level are not uncommon in tropical forest settings (Powell et al., 2004). This must also be taken in perspective, in that one may be hard pressed to obtain reports on accuracies on the Western expert maps (Fanshawe, 1952; Huber et al., 1995; ter Steege, 2001) produced for Guyana, including the study area. Nevertheless, future studies, and especially those seeking to incorporate Indigenous peoples in the map-making process should consider softer approaches to accuracy assessment, including the multiple resolution method (Pontius & Cheuk, 2010) and fuzzy set approaches (Lewis & Brown, 2004; Gopal & Woodcock, 2004). Softer classification approaches may allow for uncertainties in training data collection to be included as factors in accuracy assessment.

In the final analysis, the map appeared to have satisfactorily captured the variability present in the study area based on the views of hunters' vegetation descriptions. The final map was a clear departure from Western expert maps where much more emphasis is placed on vegetation forms and dominant plant species. Our map made reference to seasonality and elevation and reflects how these factors may impact hunters movement within their landscape. As far as we know, no previous effort has set out to use Indigenous peoples' descriptions of vegetation to classify remotely sensed data, even though other Westerners have used Indigenous knowledge to create GIS maps. This is a clear departure from the literature, and especially in the era where the value of vegetation, in particular those of tropical areas with high carbon storage potential, is being elevated, the use of Indigenous peoples' classification of vegetation provides the opportunity for reconciling traditional knowledge and views of their landscape with the Western (positivist) science view. In this regard, Indigenous people and the states within which they live may arrive at consensus positions to ensure they are rewarded for the stewardship of their forests.

5. CONCLUSION

Indigenous hunters' descriptions of vegetation provided a different perspective from those of western scientists such as Fanshawe (1952), Huber et al. (1995) and ter Steege (2001). This study confirmed views of other scholars, suggesting that Indigenous hunters can be able collaborators in scientific research (e.g. Luzar et al., 2011). The norm in vegetation cover analysis is for Western experts to classify vegetation (Keeler-Wolf, 2007), and then complete a classification and accuracy assessment (e.g. Stehman, 1997). Other approaches utilize Indigenous people and local groups in every step of the map-making process (Cinderby, 1999; Herlihy, 2003; Harris et al., 1995). We posit that a hybrid approach is possible and viable in settings where the role of Indigenous peoples in resource management is critical. Indigenous peoples have strong relationships to their environment and maps produced by "official" sources could threaten these associations and their influence in management. Where Indigenous peoples want to rely on maps to understand how changes in their landscape may affect their livelihoods, such differences in opinion over the composition of map classes (Pearce & Louis, 2008) could be important in shaping how they understand data presented to them. The map produced in this work (Figure 2) provides an alternative to the traditional Western view, similar to those produced by Robbins (2003) and Simms (2010), and represents a marked departure from the Western expert driven map-making process where views of state experts or scientists are imposed on the landscape (Chapin & Threlkeld, 2001). We hope the map will be judged for more than accuracy—though granted that is critical—but also for fostering the conversation on map-making in Guyana, and the wider Neotropics, with the intention of having Indigenous peoples more actively included in resource management decision-making processes. This paper demonstrates that Indigenous peoples have a role to play in areas once dominated by Western experts, thereby presenting national and local level resource managers with options for understanding landscapes to be used in addressing critical questions on land-cover change and changes in landscape configurations. Such a map may be used at multiple levels, from the management of individual classes of resources such as multiple-use plant species relative to Amerindian lands and their surrounding landscapes (see Figure 3), to broader assessments of risks to ecosystems, in an era dominated by REDD+ and other such initiatives.

ACKNOWLEDGMENT

This paper represents hours of dedicated work and service from the hunters at the various study sites. We acknowledge and thank: Adrian Thompson, Archie Johnson, Dennis Miguel, Oswald Bellaramie, Eustace Martin, Alvin Winter, Derrick Winter, Campbell James, Benedict Joseph, Thaddeus Joseph, Ozias James, Orville Milton, Keary Duncan, John Duncan, John Loyola, Handley Thomas, Ram Henry, Alphaeus Thomas, Brucelee Henry, Selverio Edwards, Persaud Moses, Gilbert Domingo, Urbie Francis, Fonso Francis, Jessie Domingo, Hilarion Ernest, Richardson Isaacs, Rodney Charlie, Eugene Charlie, Randolph Brown, Davis Brown, Cameron Anton, John Benjamin, Clive Ewell, Kevin Edwards, Terrence Benjami, Cyril Jonas, Hitler Benedict, Joe Fredericks, Andrew Mandook, Mr. Martin, Bernard Manaka, Mirichi Manaka, Aaron Martin, Billy Martin, Eli Martin, James Pablo, Alphonso Francis, Nedward Francis, Marcellus, Leslie, Felix, Nicholas Mandook, Allan Patrick, Ewell Paul, Gomar Honorio, Wycliffe Alvin, Anthony Alvin, Stanley LaCruz, Raymond Antone, Cornelius Francis, Adrian Johnson, Gregory Thomas, Franklin Lally, Kib Mark

Rufino, Vibert George, Edgar Caitan, Johnny, Michael Jacobs, William Pereira, Philip Lally, Reginald Pedro, Rickford Law, Aaron Pereira, Carl St. Hill, Carlson St. Hill, Cornelius St. Hill, Donald Andries, Jackson Joel, Alexis Nagarine, Danford Moses, Marcus Moses, Martin St. Hill, Desmond St. Hill, Basil Douglas. We are grateful to the people of the Rupununi, in particular the leadership of the North Rupununi District Development Board (NRDDB), Bina Hill Institute and the South Central Peoples Development Association (SCPDA). At Project Fauna the late Dr. Kye Phipps was instrumental in clarifying vegetation descriptions while the other members of the team, including Dr. Han Overman, Dr. Jeff Luzar and Ms. Ketlen Williams, supported data collection and editing. The Guyana Environmental Protection Agency (EPA) in conjunction with the Ministry of Amerindian Affairs granted permission for this research. The Guyana Lands and Surveys Commission kindly provided base maps and maps of Amerindian communities. Funding for this project was made possible by the US National Science Foundation BE/CNH Grant 0837531.

REFERENCES

Agrawal, A. (1995). Dismantling the divide between Indigenous and scientific knowledge. *Development and Change*, *26*(3), 413–439. doi:10.1111/j.1467-7660.1995.tb00560.x

Al-Kodmany, K. (2001). Bridging the gap between technical and local knowledge: Tools for promoting community-based planning and design. *Journal of Architectural and Planning Research*, *18*(2), 110–130.

Amerindian Act of 2006, 29:01 Laws of Guyana, 37.

Anderson, J. R., Hardy, E. E., Roach, J. T., & Witmer, R. E. (1976). A land use land cover classification system for use with remote sensor data. Washington, DC: United States Geological Survey.

Campbell, J. B. (2002). *Introduction to remote sensing* (3rd ed.). New York: Taylor and Francis.

Chapin, M., Lamb, Z., & Threlkeld, B. (2005). Mapping indigenous lands. *Annual Review of Anthropology*, *34*(1), 619–638. doi:10.1146/annurev.anthro.34.081804.120429

Chapin, M., & Threlkeld, B. (2001). *Indigenous landscapes: A study in ethnocartography*. Arlington, VA: Center for the Support of Native Lands.

Chavez, P. S. (1996). Image-based atmospheric corrections – Revisited and improved. *Photogrammetric Engineering and Remote Sensing*, *62*(9), 1025–1036.

Cinderby, S. (1999). Geographic information systems (GIS) for participation: The future of environmental GIS? *International Journal of Environment and Pollution*, *11*(3), 304–315. doi:10.1504/IJEP.1999.002263

Clarke, H. D., Funk, V. A., & Hollowell, T. (2001). *Plant diversity of the Iwokrama Forest*. Guyana: Botanical Research Institute of Texas.

Cochrane, M. A. (2000). Using vegetation reflectance variability for species level classification of hyperspectral data. *International Journal of Remote Sensing*, *21*(10), 2075–2087. doi:10.1080/01431160050021303

Colchester, M. (1999). *Guyana: Fragile frontier*. World Rainforest Movement.

Communities of the North Rupununi. (2006). *By-Laws for the Management of Natural Resources by the Communities of the North Rupununi. Final Report from Government of Guyana/United Nations Development Programme Sub Project, Promoting Community Participation in the Management of Natural Resources and Environment*. Georgetown, Guyana: Ministry of Amerindian Affairs.

Congalton, R. G., & Green, K. (1999). *Assessing the accuracy of remotely sensed data: principles and practices*. CRC Press.

Corbera, E., & Schroeder, H. (2011). Governing and implementing REDD+. *Environmental Science & Policy*, *14*(2), 89–99. doi:10.1016/j.envsci.2010.11.002

Cummings, A. (2006). *Sustainable utilization of crabwood (Carapa guianensis) as a non-timber forest product in the proposed Shell Beach Protected Area through the development of a community-based management system project. Final Report from International Union for the Conservation of Nature (IUCN)*. Georgetown, Guyana: Tropical Rainforest Programme and Guyana Marine Turtle Conservation Society Project.

David, B., Isaacs, P., Johnny, A., Johnson, L., Pugsley, M., Ramacindo, C., … Winter, Y. (2006). Wa Wiizi – Wa Kaduzu: Customary use of biological resources and related traditional practices within Wapichan territory in Guyana. Forest Peoples Programme.

de Granville, J. (1988). Phytogeographical characteristics of the Guianan forests. *Taxon*, *37*(3), 578–594. doi:10.2307/1221101

Eden, M. J. (1964). *The savanna ecosystem of northern Rupununi, British Guiana*. McGill University.

Eden, M. J. (1973). The savanna environment, Guyana, 1. Some aspects of weathering and landforms. 11. Savanna vegetation in the northern Rupununi. McGill University.

Elwood, S. (2006). Critical issues in participatory GIS: Deconstructions, reconstructions, and new research directions. *Transactions in GIS*, *10*(5), 693–708. doi:10.1111/j.1467-9671.2006.01023.x

Fanshawe, D. B. (1952). *The vegetation of British Guyana. A preliminary review*. Oxford, UK: Imperial Forestry Institute.

Forte, G. (2000). Socio-economic surveys of the Amerindian Communities Adjacent to the Proposed Kanuku Mountains Protected Areas. Report prepared for Conservation International (Guyana), Georgetown, Guyana.

Forte, J. (1996). *Makusipe Komanto Iseru: Sustaining Makushi way of life*. Guyana: North Rupununi District Development Board.

Fragoso, J. M. V., Silvius, K., Kurten, E., Luzar, J., Overman, H., Levi, T., … Oliveira, L. (2013). *The not-so-empty forest: Conventional survey methods underestimate Amazonian vertebrate species abundance and bias policy decisions*. Unpublished manuscript.

Franklin, J. (2009). *Mapping species distributions: spatial inference and prediction*. Cambridge, UK: Cambridge University Press. doi:10.1017/CBO9780511810602

Gao, B. C. (1996). NDWI- A normalized difference water index for remote sensing of vegetation liquid water from space. *Remote Sensing of Environment*, *58*(3), 257–266. doi:10.1016/S0034-4257(96)00067-3

Gopal, S., & Woodcock, C. (1994). Theory and methods for accuracy assessment of thematic maps using fuzzy sets. *Photogrammetric Engineering and Remote Sensing*, *60*, 181–188.

Harley, J. B. (1989). Deconstructing the map. *Cartographica*, *269*(2), 1–20. doi:10.3138/E635-7827-1757-9T53

Harris, T., Weiner, D., Warner, T., & Levin, R. (1995). Pursuing social goals through participatory GIS: Redressing South Africa's historical political ecology. In J. Pickles (Ed.), *Ground truth* (pp. 196–222). New York: The Guilford Press.

Hellier, A., Newton, A. C., & Gaona, S. O. (1999). Use of indigenous knowledge for rapidly assessing trends in biodiversity: A case study from Chiapas, Mexico. *Biodiversity and Conservation*, *8*(7), 869–889. doi:10.1023/A:1008862005556

Helmer, E. H., Ramos, O., del Mar Lopez, T., Quiñones, M., & Diaz, W. (2002). Mapping forest type and land cover of Puerto Rico, a component of the Caribbean biodiversity hotspot. *Caribbean Journal of Science*, *38*, 165–183.

Herlihy, P. H. (2003). Participatory research mapping of indigenous lands in Darien, Panama. *Human Organization*, *62*(4), 315–331.

Huber, O., Gharbarran, O. G., & Funk, V. (1995). Vegetation map of Guyana. Georgetown, Guyana: Centre for the Study of Biological Diversity. Retrieved from http://botany.si.edu/bdg/vegmap.html

Huber, O., & Zent, S. (1995). Indigenous people and vegetation in the Venezuelan Guayana: Some ecological considerations. *Scientia Guaianae*, *5*, 37–64.

Huete, A. R., & Jackson, R. D. (1987). Suitability of Spectral Indices for Evaluating Vegetation Characteristics of Arid Rangelands. *Remote Sensing of Environment*, *23*(2), 213–232. doi:10.1016/0034-4257(87)90038-1

Iwokrama. (2002). *Community Resource Mapping Project*. Georgetown, Guyana: Social Sciences Unit, Iwokrama International Center for Rainforest Conservation and Development.

Jansen-Jacobs, A., & ter Steege, H. (2000). Southwest Guyana: A complex mosaic of savannahs and forests. In H. ter Steege (Ed.), *Plant diversity of Guyana* (pp. 147–158). Tropenbos Guyana Programme.

Jensen, J. R. (2007). *Remote sensing of the environment: An earth resource perspective*. Prentice Hall.

Ji, L., Zhang, L., & Wylie, B. (2009). Analysis of dynamic thresholds for the normalized difference water index. *Photogrammetric Engineering and Remote Sensing*, *75*(11), 307–1317. doi:10.14358/PERS.75.11.1307

Johannsen, C. J., & Daughtry, C. S. T. (2009). Surface reference data collection. In T. A. Warner, M. D. Nellis, & G. M. Foody (Eds.), *The Sage handbook of remote sensing* (pp. 244–256). Los Angeles, cA: Sage. doi:10.4135/9780857021052.n17

Keeler-Wolf, T. (2007). The history of vegetation classification and mapping in California. In M. Barbour, T. Keeler-Wolf, & A. A. Schoenherr (Eds.), *Terrestrial vegetation of California* (pp. 1–42). Berkeley, CA: University of California Press; doi:10.1525/california/9780520249554.003.0001

Keith, D. A., Rodríguez, J. P., Rodríguez-Clark, K. M., Nicholson, E., Aapala, K., & Alonso, A. et al. (2013). Scienti.fic foundations for an IUCN red list of ecosystems. *PLoS ONE*, *8*(5), e62111. doi:10.1371/journal.pone.0062111 PMID:23667454

Koti, F. T. (2010). Confronting sociospatial exclusion on the fringe of Africa's cities using participatory GIS: Lessons from Athi River Town, Kenya. *Africa Today*, *56*(3), 62–82. doi:10.2979/AFT.2010.56.3.62

LCDS. (2009). *Amerindian Land Status 2009*. Retrieved from www.lcds.gov.gy

Lewis, H. G., & Brown, M. (2004). A generalized confusion matrix for assessing area estimates from remotely sensed data. *International Journal of Remote Sensing*, *22*(16), 3223–3235. doi:10.1080/01431160152558332

Lillesand, T., Kiefer, R., & Chipman, J. (2008). *Remote sensing and image interpretation* (6th ed.). New York: John Wiley and Sons.

Longley, P., Goodchild, M. F., Maguire, D. J., & Rhind, D. W. (2001). *Geographical information systems and science*. Chichester, UK: John Wiley and Sons.

Luzar, J. B., Silvius, K. M., Overman, H., Giery, S. T., Read, J. M., & Fragoso, J. M. V. (2011). Large-scale environmental monitoring by indigenous peoples. *Bioscience*, *61*(10), 771–781. doi:10.1525/bio.2011.61.10.7

Mather, P. M. (1999). *Computer processing of remotely-sensed images: An introduction* (2nd ed.). Chichester, UK: John Wiley and Sons.

McCall, M. K., & Minang, P. A. (2005). Assessing participatory GIS for community-based natural resource management: Claiming community forests in Cameroon. *The Geographical Journal*, *171*(4), 340–356. doi:10.1111/j.1475-4959.2005.00173.x

McFeeters, S. K. (1996). The use of normalized difference water index (NDWI) in the delineation of open water features. *International Journal of Remote Sensing*, *17*(7), 1425–1432. doi:10.1080/01431169608948714

Monmonier, M. (1991). *How to lie with maps*. Chicago: The University of Chicago Press.

Omotayo, A., & Musa, M. W. (1999). The role of Indigenous land classification and management practices in sustaining land use systems in the semi-arid zone of Nigeria. *Journal of Sustainable Agriculture*, *14*(1), 49–58. doi:10.1300/J064v14n01_05

Pearce, M. W., & Louis, R. P. (2008). Mapping indigenous depth of place. *American Indian Culture and Research Journal*, *32*(3), 107–126.

Pearson, R. G. (2007). *Species' distribution modeling for conservation educators and practitioners*. American Museum of Natural History. Retrieved from http://ncep.amnh.org

Peluso, N. (1995). Whose woods are these? Counter-mapping forest territories in Kalimantan, Indonesia. *Antipode*, *27*(4), 383–388. doi:10.1111/j.1467-8330.1995.tb00286.x

Peters, C. M. (1996). III: Introduction to the ecology of tropical forest resources. In C. M. Peters (Ed.), *The ecology and management of non-timber forest resources* (pp. 5–97). World Bank. doi:10.1596/0-8213-3619-3

Plew, M. G. (2004). The archaeology of Iwokrama and the North Rupununi. *Proceedings. Academy of Natural Sciences of Philadelphia*, *154*(1), 7–28. doi:10.1635/0097-3157(2004)154[0007:TAOIAT]2.0.CO;2

Pontius, R. G., & Cheuk, M. L. (2010). A generalized cross tabulation matrix to compare soft classified maps at multiple resolutions. *International Journal of Information Science*, *20*(1), 130.

Powell, R. L., Matzke, N., de Souza, C. Jr, Clark, M., Numata, I., Hess, L. L., & Roberts, D. A. (2004). Sources of error in accuracy assessment of thematic land-cover maps in the Brazilian Amazon. *Remote Sensing of Environment*, *90*(2), 221–234. doi:10.1016/j.rse.2003.12.007

Prance, G. T. (1979). Notes on the vegetation of Amazonia III: The terminology of Amazonian forest types subject to inundation. *Brittonia*, *31*(1), 26–38. doi:10.2307/2806669

Read, J. M., Fragoso, J. M. V., Silvius, K. M., Luzar, J., Overman, H., & Cummings, A. (2010). Space, place, and hunting patterns among indigenous peoples of the Guyanese Rupununi region. *Journal of Latin American Geography*, *9*(3), 213–243. doi:10.1353/lag.2010.0030

Rees, W. G., Williams, M., & Vitebsky, P. (2003). Mapping land cover change in a reindeer herding area of the Russian Arctic using Landsat TM and ETM+ imagery and Indigenous knowledge. *Remote Sensing of Environment*, *85*(4), 441–452. doi:10.1016/S0034-4257(03)00037-3

Robbins, P. (2003). Beyond ground truth: GIS and the environmental knowledge of herders, professional foresters, and other traditional communities. *Human Ecology*, *31*(2), 233–253. doi:10.1023/A:1023932829887

Ross, A., Sherman, P. K., Snodgrass, J. G., Delcore, H. D., & Sherman, R. (2011). *Indigenous peoples and the collaborative stewardship of nature: Knowledge binds and institutional conflicts*. Walnut Creek: LeftCoast Press.

Rundstrom, R. (1991). Mapping, postmodernism, indigenous people and the changing direction of North American cartography. *Cartographica*, *28*(2), 1–12. doi:10.3138/5J46-51T2-7M42-316G

Rundstrom, R. (1995). GIS, indigenous peoples, and epistemological diversity. *Cartography and Geographic Information Systems*, *22*(1), 45–57. doi:10.1559/152304095782540564

Rundstrom, R. (2009). Counter-mapping. In R. Kitchin & N. Thrift (Eds.), *International encyclopedia of human geography* (pp. 314–318). Oxford, UK: Elsevier; doi:10.1016/B978-008044910-4.00017-1

Simms, E. L. (2010). Representation in remote sensing classifications of Aboriginal landscape descriptions. *The Canadian Geographer*, *54*(4), 492–505. doi:10.1111/j.1541-0064.2010.00317.x

Skutsch, M., McCall, M. K., Karky, B., Zahabu, E., & Peters-Guarin, G. (2009). *Case studies on measuring and assessing forest degradation: Community measurement of carbon stock change for REDD* (Working Paper 156). FAO Forest Resources Assessment.

Smith, R. C., Benavides, M., Pariona, M., & Tuesta, E. (2003). Mapping the past and the future: Geomatics and indigenous territories in the Peruvian Amazon. *Human Organization*, *62*(4), 357–368.

Spiegel, A. J., Ribeiro, C. A. A. S., Sousa, R., & Veiga, M. M. (2012). Mapping spaces of environmental dispute: GIS, mining, and surveillance in the Amazon. *Annals of the Association of American Geographers*, *102*(92), 320–349. doi:10.1080/00045608.2011.641861

Stabroeknews. (2012). *Wapichan digital maps to decrease land grabs, preserve culture*. Retrieved from http://www.stabroeknews.com/2012/news/stories/02/09/wapichan-digital-maps-to-decrease-landgrabs-preserve-culture/

Stehman, S. V. (1997). Selecting and interpreting measures of thematic classification accuracy. *Remote Sensing of Environment*, *62*(1), 77–89. doi:10.1016/S0034-4257(97)00083-7

Stehman, S. V., & Foody, G. M. (2009). Accuracy assessment. In T. A. Warner, M. D. Nellis, & G. M. Foody (Eds.), *The Sage handbook of remote sensing* (pp. 297–311). Los Angeles, CA: Sage; doi:10.4135/9780857021052.n21

Stocks, A. (2005). Too much for too few: Problems of indigenous land rights in Latin America. *Annual Review of Anthropology*, *34*(1), 85–104. doi:10.1146/annurev.anthro.33.070203.143844

ter Steege, H. (2001). Vegetation of Guyana: Guyana integrated natural resources information system. Georgetown, Guyana: Guyana Forestry Commission. Retrieved from http://www.forestry.gov.gy/vegmap.htm

Tobias, T. N. (2000). *Chief Kerry's Moose: A guidebook to land use and occupancy mapping, research design and data collection*. Canada: Union of British Columbia Chiefs and Ecotrust Canada.

Turner, M. D., & Hiernaux, P. (2002). The use of herders' accounts to map livestock activities across agropastoral landscapes in semi-arid Africa. *Landscape Ecology*, *17*(5), 367–385. doi:10.1023/A:1021238208019

van Andel, T. (2001). Floristic composition and diversity of mixed primary and secondary forests in northwest Guyana. *Biodiversity and Conservation*, *10*(10), 645–1682. doi:10.1023/A:1012069717077

Weiner, D., Warner, T. A., Harris, T., & Levin, R. M. (1995). Apartheid representations in a digital landscape: GIS, remote sensing and local knowledge in Kiepersol, South Africa. *Cartography and Geographic Information Systems*, *22*(1), 30–44. doi:10.1559/152304095782540537

ENDNOTES

[1] Details on the Huber et al., 1995 and ter Steege, 2001 vegetation maps are available at: http://botany.si.edu/bdg/vegmap.html

and: http://www.forestry.gov.gy/vegmap.htm respectively.

2 Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Global Digital Elevation Model (GDEM) was developed jointly by the Ministry of Economy, Trade, and Industry (METI) of Japan and the United States National Aeronautics and Space Administration (NASA).

Anthony R. Cummings, Assistant Professor within the School of Economic, Political and Policy Science at the University of Texas at Dallas specializes in human-environment interactions, geographic information systems and remote sensing, and natural resource management. His work is primarily concerned with understanding how changes in land use and land cover in Guyana and surrounding countries impacts indigenous peoples and the sustainability of their livelihoods. He has worked with groups of indigenous peoples in northern and southern Guyana to develop natural resource management plans that caters to the changes unfolding within their homelands. He has also worked on issues of transboundary freshwater management in Amazonia. He teaches courses in physical geography, global environmental change, and remote sensing.

Jane M. Read, Associate Professor in the Department of Geography at Syracuse University, specializes in geographic information systems, remote sensing, land use and land cover, and human-environment interactions. Much of her research has focused in the neotropics, including Costa Rica, Brazil, and Guyana, although she has also studied historical land changes in the Adirondacks of New York State, USA. She has published on applications of GIS and remote sensing to land-use and land-cover changes, selective logging operations, and indigenous hunting patterns. She was Co-PI on the NSF-funded project, of which this research was a part. She is currently examining the spatial history of land use around Onondaga Lake, New York, USA. She teaches courses in global environmental change, tropical environments, GIS, and remote sensing.

Jose M.V. Fragoso is a tropical ecologist at Stanford University. Joe has decades of experience working on issues relevant to indigenous peoples and their livelihoods, primarily studying the lowland tapir and peccary species. He was the PI on the NSF funded project that led to the production of this paper. He is currently continuing research in Guyana and Brazil on issues relevant to indigenous peoples and their livelihoods.