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Evaluation of forest cover estimates for Haiti using supervised classification of Landsat data

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ABSTRACT

This study uses 2010–2011 Landsat Thematic Mapper (TM) imagery to estimate total forested area in Haiti. The thematic map was generated using radiometric normalization of digital numbers by a modified normalization method utilizing pseudo-invariant polygons (PIPs), followed by supervised classification of the mosaicked image using the Food and Agriculture Organization (FAO) of the United Nations Land Cover Classification System. Classification results were compared to other sources of land-cover data produced for similar years, with an emphasis on the statistics presented by the FAO. Three global land cover datasets (GLC2000, Globcover, 2009, and MODIS MCD12Q1), and a national-scale dataset (a land cover analysis by Haitian National Centre for Geospatial Information (CNIGS)) were reclassified and compared. According to our classification, approximately 32.3% of Haiti's total land area was tree covered in 2010–2011. This result was confirmed using an error-adjusted area estimator, which predicted a tree covered area of 32.4%. Standardization to the FAO's forest cover class definition reduces the amount of tree cover of our supervised classification to 29.4%. This result was greater than the reported FAO value of 4% and the value for the recoded GLC2000 dataset of 7.0%, but is comparable to values for three other recoded datasets: MCD12Q1 (21.1%), Globcover (2009) (26.9%), and CNIGS (19.5%). We propose that at coarse resolutions, the segmented and patchy nature of Haiti's forests resulted in a systematic underestimation of the extent of forest cover. It appears the best explanation for the significant difference between our results, FAO statistics, and compared datasets is the accuracy of the data sources and the resolution of the imagery used for land cover analyses. Analysis of recoded global datasets and results from this study suggest a strong linear relationship ($R^2 = 0.996$ for tree cover) between spatial resolution and land cover estimates.

1. Introduction

Since its founding in 1804, growth in Haiti's population, and the proportion of people living in urban settings, has led to an increase in demand for fuel wood and charcoal. As of 1999, the Haitian Ministry of Environment estimated that 85% of the Haitian population depends on biomass energy for domestic purposes with 3.3 million m^3 of fuel wood used in Haiti per year (CFET, 1997). Conversion of native forests for resource utilization has led to deforestation, soil loss, water quality degradation, and economic/political instability (Stevenson, 1989; Wampler, 2011; Wampler and Sisson, 2011).

Deforestation and tropical forest degradation in Haiti is arguably the most publicized in the world, but in many ways is the least examined (Versluis and Rogan, 2010). Remote sensing analyses of land-use and land-cover change have been done for locations in Central and South America (Broich, 2009; Clark, 2012; Clark et al., 2010; De Souza Soler and Verburg, 2010; Díaz-Gallegos et al., 2010; Guild et al., 2004; Ichii et al., 2003; Marsik et al., 2011; Mendoza, 2011; Morton et al., 2005; Renó et al., 2011; Sanchez-Azofeifa, 2001; Schulz, 2010), but relatively few focus on the Caribbean Island nations (Aide et al., 2012; Alvarez-Berríos et al., 2013; Clark, 2012; Evelyn and Camirand, 2003; Hernandez-Leal et al., 2006; Martinuzzi, 2007; Sanchez-Azofeifa, 2001); and even fewer are specific to Haiti (Grace et al., 2012; Versluis and Rogan, 2010; Wilson et al., 2001).

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Table 1
Peer-reviewed articles that cite forest cover statistics in Haiti and their citation sources. Note that these are not independent land-cover analyses, but studies that cite a forest cover statistic for Haiti. All but two of the studies examined cite a United Nations body for the source of their statistic.

Peer-reviewed publications	Amount of forest cover reported	Source of data or citation
Bannister (2003)	Under 2% in 1994	UNDP (1996)
Dolisca et al. (2007)	3%	FAO (1988)
Erikson (2004)	<1%	The Miami Herald
Foxx (2012)	<2%	None given
Hedges (2006)	4%	FAO (2005)
Higuera-Gundy et al. (1999)	5%	None given
Hosonuma et al. (2012)	1–25%[a]	FAO (2010)
Huber et al. (2010)	<1%	Paryski et al. (1989)
Koyuncu and Yilmaz (2009)	10%	None given
Mainka and McNeely (2011)	1%	None given
Pellek (1990)	3%	None given
Rudel et al. (2005)	3.2%	FAO (2000)
Williams (2011)	<1%	None given
Wright (2005)	Supports less than 10% of potential closed-canopy forest	None given

[a] Hosonuma et al. (2012) classified forest cover between 1 and 25% into a single category called "phase 3". The actual number reported by the FAO for Haiti was not provided.

Recent disasters such as flooding in 2004, hurricanes in 2008, and the earthquake in 2010 have focused world attention on this region, the topic of deforestation in Haiti, and its related environmental consequences. The percentage of remaining forest cover is often central to reports by media and government organizations. However, the statistics of forest cover in Haiti cited by recent scientific publications vary widely, and most are not attributed to peer-reviewed sources (Table 1).

The lack of easily accessed, peer-reviewed data sources may contribute to the conflicting statistics regarding forest cover and deforestation in Haiti. After a thorough literature review and search for web-based data, only two recent analyses that provide national level forest statistics for Haiti were found: (1) the Food and Agriculture Organization of the United Nations (FAO) Global Forest Resource Assessment (FRA) 2010 (based on data provided by Haitian officials, not remote sensing-based data) (FAO, 2010b); and (2) a March 2013 land-cover/land-change study of the Greater Antilles region (Alvarez-Berríos et al., 2013). A national level land-use dataset produced by the Haitian National Centre for Geospatial Information (CNIGS) was also noted, however forest statistics were not extracted from Geographic Information System (GIS) data or tabulated (CNIGS, 2008).

Three freely available datasets that provide global level land-use data were also found. However, calculation of national level statistics requires a number of GIS operations such as re-projection, mosaicking, sub-setting, and recoding. These are as follows: (1) NASA's Moderate Resolution Imaging Spectroradiometer (MODIS) derived global land-cover dataset at 500 m resolution (MCD12Q1, 2010); (2) the GLC2000 land-cover dataset at 1 km resolution (GLC2000, 2003); and (3) the Globcover (2009) dataset at 300 m resolution (Bontemps et al., 2011; Globcover, 2009) (Table 2).

Increased interest in Haitian forest cover and deforestation, coupled with the lack of easily accessible, and reliable, statistics has demonstrated the need for high resolution remote sensing analysis of the region. The FAO has been called by some "the main actor in assessing the world's forest" (Mather, 2005). This paper uses published remote sensing techniques and recent Landsat imagery to determine the extent of tropical forest cover in Haiti. The methods used to generate land-cover statistics presented by this study were tailored to be compatible with FAO land-cover definitions. Using a generalized FAO land cover classification system (LCCS), a supervised classification of recent (2010–2011) 30-m resolution Landsat 5 TM imagery was accomplished using ERDAS IMAGINE 2011 (Intergraph Corporation; Madison, Alabama) and ArcGIS 10 (ESRI; Redlands, California). Similar supervised classification methods have been widely used to extract land-cover features (Oyana et al., 2009; Sirikulchayanon et al., 2008; Sun, 2004; Sun et al., 2003). Classification results were compared to three global land cover datasets (GLC2000, Globcover, 2009, and MODIS MCD12Q1), and a national-scale dataset (CNIGS) produced for similar years, with an emphasis on the statistics presented by the FAO.

Table 2
Data products used for land cover statistics comparison.

Study	Year	Satellite	Sensor/product	Bands used	Resolution	Overall accuracy	Agencies	Classification scheme
GLC2000	2000	SPOT-4	Vegetation	B (437–480 nm), R (615–700 nm), NIR (722–892 nm), SWIR (1600–1692 nm)	1 km	68.60%	United States Geological Survey (USGS)[b]	NCVS-FGDC
MCD12Q1	2010	Terra/Aqua	MODIS/MCD12Q1	Bi-directional Reflectance Distribution Function (NBAR), Land Surface Temperature (LST)	500 m	74.80%[a]	University of Boston[c]	UMD Land Cover Type 2
Globcover (2009)	2009	Envisat	MERIS-FR	All	300 m	58.00%	European Space Agency (ESA)[d]	UN-LCCS
CNIGS	1998	SPOT-5	Unknown	Unknown	Unknown	Unknown	Haitian National Centre For Geospatial Information (CNIGS)[e]	Unknown
This Study	2010	Landsat 5	TM	B (520–600 nm), R (630–690 nm) NIR (760–900 nm)	30 m	78.00%[f]	N/A	UN-LCCS FAO et al. (2009)

[a] Calculated using 2005 image composites.
[b] http://bioval.jrc.ec.europa.eu/products/glc2000/products.php.
[c] https://lpdaac.usgs.gov/get_data/data_pool.
[d] http://due.esrin.esa.int/globcover/.
[e] http://haitidata.org/data/geonode:hti_biota_landcover_spot_cnigs_041998_polygon.
[f] Overall accuracy improves to 83% using an error-adjusted estimate (see Section 4.2)