

## **Anthropogenic impacts on Roatán, Honduras: Years of land-cover and land-use change**

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### **Abstract**

The Caribbean island, Roatán, Honduras, has experienced an 80-fold increase in annual tourists since the 1990s, with over 1.2 million people now visiting the island yearly. In tandem, the island's population has exploded from fewer than 13,000 people in the 1970s to over 100,000 people today. Using broadband remote sensed satellite imagery, this paper maps and measures the island's landscape change during recent decades characterized by a massive influx of tourists and rapid population growth. Results from a decision tree classifying technique applied to a Landsat 5 Thematic Mapper (TM) image from 1985 and Landsat 8 Operational Land Imager (OLI) image from 2014 suggest a vertiginous pace of urbanization; built and impervious surface has increased over 300% in the last 30 years. This rapid urbanization has serious implications for the island's marine and terrestrial ecosystems, tourism sustainability, and public health.

### **Keywords**

Land cover and land use change, Roatán, Remote sensing, Caribbean, Tourism

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## Introduction

Driven by tourists flocking to idyllic white sand beaches and unprecedented diving along the world's second largest reef and UNESCO World Heritage Site, the population of the island of Roatán, Honduras, has exploded from fewer than 13,000 people in the 1970s to over 100,000 people today (Stonich, 1995; Bay Island Voice, 2014). In tandem with the population increase, tourism has developed at an unprecedented clip: In 2011 approximately 1.2 million tourists visited the island, a 80-fold increase over the 15,000 tourists who visited in 1990 (Doiron and Weisenberger, 2013). Annual tourism now exceeds the island's population by almost 20 times. Yet how this boom in population and tourism has altered the landscape of this small Caribbean Island is not known. The objective of this paper is to use remote sensed broadband satellite imagery to map and quantify land cover and land use change (LCLUC) on Roatán from 1985 – 2014.

## Study site

Roatán is a tropical Caribbean island situated off Honduras' northern coast. The island is approximately 60km long and 5km wide, covering nearly 125 square km. It is the largest and most populated island in Honduras' *Islas de la Bahía* district and sits at the southern end of the Mesoamerican Barrier Reef System, the second largest reef in the world and a UNESCO World Heritage Site. The island contains about 800ha. of mangroves, largely on the eastern end of the island. The low-elevation mountain ridge that runs east-west of the island contains exposed rock outcrops of marble, amphibolite, and serpentine (McBirney and Bass, 1969).

## Background

Roatán presents an intriguing studio to study environment, tourism development, demographics, migration, and land change linkages. The island has contributed economic opportunity for Honduras, yet its rapid development has placed significant burden on the islands' marine and terrestrial ecosystems. In their overview of the social, economic, and environmental concerns related to tourism and development, Doiron and Weissenberger (2013) argue that there are potential negative implications for the future of tourism on Roatán. The rapid rate of island development and subsequent degradation of coral ecosystems and mangroves is far from sustainable. They contend that climate change stands to compound these already complex challenges by further threatening coral reefs and potentially increasing the likelihood of damaging extreme weather events (Doiron and Weissenberger, 2013).

Few studies have applied remote sensing to study Caribbean Islands. Mishra *et al.* (2005) is the only applied remote sensing study of Roatán. They classified high spatial resolution IKONOS imagery to map the coral ecosystem of the Sandy Bay Marine Reserve on the north shore of the western end of Roatán, distinguishing dense seagrass, mixed seagrass/sand/algae, mixed coral/sand, sand and coral classes with an overall kappa statistic of 0.774. Although no additional applied remote sensing studies exist in the scholarly literature of Roatán or other small Caribbean islands, Martinuzzi *et al.* (2005) produced compelling results in their attempt to map urban density and growth in Puerto Rico. The authors classified Landsat Enhanced Thematic Mapper (ETM+) imagery using an ISODATA method to reveal the extent of urban sprawl in Puerto Rico. Their research stands as one of the only

studies that applied remote sensing techniques to map and classify terrestrial land cover of any Caribbean island.

## Methods

### *Preprocessing*

Landsat 5 TM data from February 1, 1985 and Landsat 8 OLI from June 25, 2014 were acquired from the USGS Earth Explorer website. The entire island is cloud free for both timepoints. Bands 1-5 and 7 for the TM dataset and bands 1-8 and 9 for the OLI were compiled into ENVI, a software package developed by Exelis Visual Information Solutions, image files for both time points. Both images were cropped to an equal size centered on Roatán by using the resampling tool in ENVI. The images were co-georegistered using ground control points (GCP). The 2014 OLI image was used as a base map instead of an independent base map because no base map could be found that contained the coral/lagoon surrounding the island. Six GCPs were manually selected aiming for an RMSE of  $\sim 1$ . These GCPs were then input into ENVI's auto image-to-image registration to generate at least 20 GCPs with an RMSE  $\sim 1$ . From the auto image-image GCPs, the 1984 image was warped to the 2014 image to complete the co-registration process.

The images were not atmospherically or relatively radiometrically corrected because each image was trained and classified independently. No inter-calibration was viewed as necessary. No vegetation indices were included in this analysis. Finally, the ocean and clouds over the ocean were masked from both scenes.

### ***Classification***

Once co-registered, approximately 150 pixels were selected as regions of interest (ROI), or polygons, for each of the following classes: built/impervious, coral/lagoon, green vegetation and soil/non-photosynthetic vegetation (NPV). The ROI training data for each class was selected from relatively temporally invariant points. Key factors considered for each class included visual interpretation, spatial pattern, and spectral profile. For the built/impervious class, transect selected from Roatán's airport and the surrounding city of Coxen Hole provided the majority of the training data. Prior to the 1990s the island lacked electricity, telephones or paved roads, which made the airport the best likely target for selecting built/impervious ROIs (Roatán Education Commission, 2007) for the 1985 scene. Additional ROIs came from built areas near French Harbor along the coastline. The built/impervious training points did vary slightly between 1985 and 2014.

Green vegetation training data for both scenes was selected using similar rationale as the built/impervious classes. However, a region in the center island in the 2014 image contained slight obstruction from thin clouds. Temporally invariant vegetation ROIs in this region were included in the train data for both time points. Furthermore, ROIs were specifically included from the mangrove forest on Roatán's eastern tip. All vegetation ROIs were largely temporally invariant. Attention was paid to ensure that vegetation ROIs' spectra matched physical properties of green vegetation. They were selected for their higher scattering in the near infrared (NIR) evident at band four for TM and band five for OLI and strong liquid water absorption at the longest wavelengths (bands five and six for the TM and band7 and for OLI).

Soil/NPV proved to be the most challenging class for which to select training data. The majority of selected ROIs came from steep, undeveloped hillside on the eastern end of the island. While there was no discernable change in built environment in this area of the island between 1985 and 2014, the soil/NPV and vegetation cover shifted. This may be due to seasonal difference between the two time points. The selection of soil/NPV ROIs avoided soil/NPV from obvious anthropomorphic features (such as roads) to avoid confusion with built class specifically because the island did not have paved roads 1985. The spectral profile of soil/NPV pixels included the low reflectance around 2,000-2,300 nanometers because of the absorption features of ligno-cellulose in grasses and chlorophyll absorption in the visible red. Finally, transects from several sites surrounding the island formed coral/lagoon training data for both 1985 and 2014.

The spectral information for the training data was extracted from ENVI, input into R and ran through a decision tree for both time points. Decision tree classifying techniques have been shown to be successful methods to achieve a high degree of accuracy, yet still flexible, for land cover and land use change mapping and outperform other techniques such as maximum likelihood classifiers (Friedl and Brodley, 1997). The decision trees for both time points are physically reasonable based on the spectral properties of the classes. For example, the 1985 tree first splits at band 4, with the ocean mask and coral/lagoon having significant lower reflectance in the NIR. The split at band three demonstrates green vegetation's lower reflectance between 520-600nm, but still accommodates for some variation within soil/NPV class. The built/impervious class is clearly defined with higher values at 600nm. The 2014 decision tree follows similar logical that reflects the physical differences between the classes.

The decision trees for both 1985 and 2014 were then saved as output files and then input into ENVI. The program uses the rules developed from the R decision trees to classify the original, co-registered 1985 and 2014 scenes. The classified images did not undergo post-classification processing.

## Results and Discussion

The decision tree classifier revealed the magnitude of human impact on Roatán over the last thirty years well (fig. 1). Visually the change in built/impervious classification reveals the massive increase of the development of hotels and condos along the island's coastline, as well as the airport expansion. From 1985 – 2014 the built/impervious environment increased by 315%(table 1) while soil/NPV decreased by 57%. Vegetation remained largely unchanged.

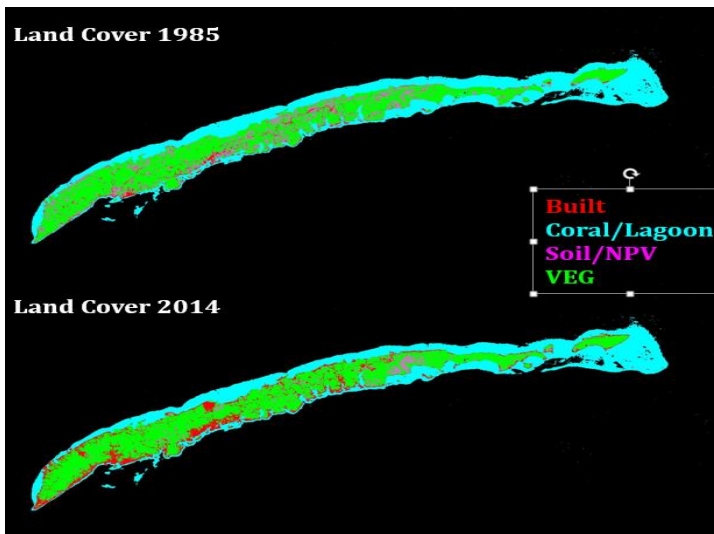


Figure 1 - Classified images for decision tree classifier for Roatán in 1985 and 2014.

Visual inspection of the classified images reveals soil/NPV and built classes on the far edges of the lagoon that are likely exposed coral or shroal which may explain why a portion of the built from 1985 transitioned to coral/lagoon class in 2014. While 315% may be an overestimation of the change in built environment, the 2014 classification corresponds well with visual validation of 2013 high spatial resolution Google Earth imagery.

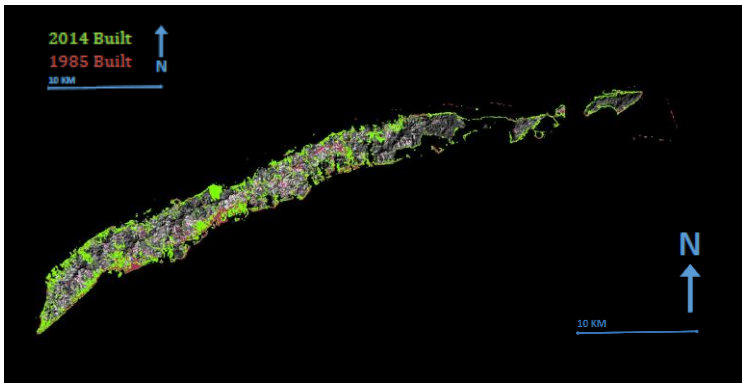


Figure 2 - Built classification results from 2014 overlaid on top of results for built classification results 1985 in Roatán.

Mapping and quantifying LCLUC for Roatán is an important first step towards exploring broader coupled human-environmental dynamics on the island, and related nearby islands. Temporal land-use and land-cover change analysis with a place-based, local focus, such as LCLUC in Roatán, combined with similar case studies can reveal more general drivers and explanations of terrestrial change around the globe (Carr, 2002; Cheong *et al.*, 2012; Lambin *et al.*, 2003). Particularly important for Roatán is measuring the magnitude and spatial pattern of the built environment, to ensure an accurate understanding of how humans have altered Roatán's environment. Such LCLUC analysis of the built environment will assist with future development



planning and the management of the island's unique environmental resources (Weng, 2012). Finally, how humans have altered Roatán's landscape has health implications for people living on the island; an increase in a built environment has been showed to be correlated with increases in vector borne diseases such as dengue fever (Rubio *et al.*, 2013).

Table 1 - Land cover and land change use in Roatán 1985 – 2014.

|              | <b><i>1985</i></b>   | <b><i>2014</i></b>   | <b><i>Total</i></b>  | <b><i>Percent</i></b> |
|--------------|----------------------|----------------------|----------------------|-----------------------|
|              | <b><i>Pixels</i></b> | <b><i>Pixels</i></b> | <b><i>Change</i></b> | <b><i>Change</i></b>  |
| Built        | 6347                 | 26356                | 20009                | 315%                  |
| Coral/Lagoon | 119784               | 114661               | -5123                | -4%                   |
| Soil/NPV     | 29116                | 12499                | -16617               | -57%                  |
| Vegetation   | 105815               | 108696               | 2881                 | 3%                    |

The change in built environment will prove useful for future planning and development of Roatán and other heavily tourist-visited tropical coastal areas. It complements research of the human impact on Roatán's marine ecosystems by highlighting that the terrestrial space of the island is finite. Indeed, in the near future there will be limited land available to develop. Sustainable tourism, by definition, implies that the benefits of tourism development are maintainable over time. This research clearly demonstrates and locates causes for concern for Roatán's sustainability.

### **Future research and conclusion**

The LCLUC analysis presented here highlights a clear case of humans drastically altering an island landscape through

rapid urbanization. Future analysis can shed light on how LCLUC impacts livelihood and health for Hondurans living on Roatán. Future research will measure the relationship between built/impervious environment and vector-borne diseases such as dengue fever, chikungunya, and malaria. Who is benefiting economically from the development of Roatán is another area to be explored in conjunction with LCLUC analysis.

Development academics, nongovernment organizations, and politicians often hail tourism as a silver bullet to improve livelihoods in low-income countries such as Honduras. Indeed, the rapid rate of tourism growth surely has benefited Roatán's and Honduras' economy. But the LCLUC change evident here shows that the growth of population, tourism, and development at its current rate will eventually lead to a completely built island. Thus Roatán may no longer be a tranquil tropical paradise, with myriad social, economic, and environmental consequences.

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