Review of Remote Sensing Utilization for Identifying and Monitoring Change of Land Cover within Coastal Ecosystems of the Caribbean

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Abstract

The dynamic ecosystems of the Caribbean are part of one of the most critical hotspots on Earth (Meyers et al., 2000). The role of remote sensing in our technologically advanced world, places inhabitants of the Caribbean in an advantageous position to utilize this amazing resource in order to enhance and monitor their environment. Mangrove forests, coastal sand body areas and coastal water environments can be better understood and managed through satellite, aerial and ground level remote sensing. This review identifies specific aspects of remote sensing that are being used to their full advantage for conducting land cover change monitoring and analysis in the Caribbean and those capabilities that are underutilized.

Keywords: remote sensing, coastal land cover change

Introduction

Continual change is an inevitable process of the Earth and in many respects can be good or bad toward what it influences. In the last several hundred years, technological advances have allowed us to adequately and accurately monitor these changes upon the earth. The field of remote sensing has a tremendous capability to provide the needed insight of these alterations for scientists and non-experts to visually see and comprehend this significance, and subsequently discuss how humans must adapt on our way forward. Anthropogenic influences are one of the leading argued causes for the more recent climatic changes, such as increased carbon dioxide (CO_2) levels, retreating glaciers, polar ice cap melting, and rising ocean levels. Abundant low lying coastal regions of continents and thousands of islands rising barely above sea level are the most susceptible land areas to these dynamic effects. Researchers are studying many of these areas where change can already be seen such as significant alteration to flora and fauna diversity, water quality and abundance, sea and land surface temperatures, susceptibility to disease and extinction, and land erosion (Bellard *et al*., 2014; Hoggart *et al.,* 2014; James *et al.,* 2013; Saunders *et al.,* 2013; Silva, *et al.,* 2014). The convergence of where biodiversity has developed and those areas most vulnerable to a changing climate are critical ecosystems. The Caribbean Sea, its islands, and surrounding continental coastline make up one of the most notable hotspots for biodiversity in the world (Meyers *et al.,* 2000). Biodiversity, as well as water and soil quality, carbon and nutrient stocks, and net primary productivity can be significant indicators to ongoing and pending changes that affect these ecosystems (Dale & Kline, 2013). The importance of watching this area for dramatic and irreversible changes is increasing daily. The application of remote sensing is key to monitoring environments in the Caribbean and providing a clearer picture by identifying land cover change within the region.

The intent of this paper is to review the use of remote sensing in the Caribbean for studying land change along coastal ecosystems and discuss the variability in remote sensing application as applied to mangrove forests, coastal sand bodies, and coastal water environments.

Caribbean Land Use and Management Overview

Countries within the Caribbean are small in respect to many nations throughout the world. The limited size of these island landmasses and small quantity of natural resources proves to be a difficult issue to handle. The trend of urbanization due to growing population around the world is especially challenging for islands within the Caribbean. Inefficient land development over the last 50 years has caused the increasing population of Puerto Rico to contribute significantly to urban sprawl, encroaching on previously productive agriculture land and national forests (Martinuzzi *et al*., 2006). The country's total urban use covers 16% of the island and is predictably growing, although spread out, large urban clusters, found mostly on the coastal plains and in river valleys since the island's interior region poses a hindrance to development due to steep sloped mountains (Martinuzzi *et al*., 2006). Other countries in the Caribbean have not done much better at monitoring land use. Administrative problems such as inaccurate or incomplete land ownership records present problems that halt appropriate planning and management of lands (Stanfield, Barthel, & Williams, 2003). Furthermore, economic stability plays a critical part; the potential for many Caribbean nations to continue to sustain themselves financially relies heavily on tourism. However, the development of land close to pristine Caribbean beaches impacts the ecosystems that makes the beautiful island environment possible.

In recent decades, the Organisation of Eastern Caribbean States (OCES) has taken a collaborative approach toward land use and development practices, implementing the Environment & Sustainable Development Unit (ESDU) (OCES, 2014). The ESDU is charged with Biodiversity Management, Coastal and Marine Resources Management, Watershed Management, Waste Management, Environmental Planning, Sustainable Oceans Governance, Climate Change, Disaster Risk Reduction, and Public Awareness/Education (OCES, 2014). The prioritization of environmentally friendly land use practices in the region is essential to the development of appropriate land management to protect vulnerable ecosystems.

Coastal Mangrove Forest

The mangrove forest habitat is one of the most beneficial and fragile ecosystems in the world (Khan *et al*., 2012). Found throughout tropical and subtropical climates, the mangrove forest is significant to life on the islands of the Caribbean, aiding in the reduction of coastal erosion and protecting against storm surge and tidal waves (Wannasiri *et al.,* 2013). Mangrove trees grow in intertidal zones in which portions of their root system are submerged underwater; part of their intimate connection to the sea is to act as a filter cleaning pollutants out of the water (Chen *et al*., 2013). Additionally, mangrove forests have the ability to uptake a more significant amount of CO_2 from the air at a faster rate, two to four times greater than terrestrial tropical forests, due to this increased capability the sequestration is typically referred to as 'blue' carbon (Murray *et al.*, 2011).

A substantial amount of mangrove forest has been lost in the previous few decades, of which up to half in the region is contributed to shrimp aquaculture that transforms estuaries into shrimp farm ponds (Chen *et al.,* 2013). Furthermore, the mangrove forest habitat is being threatened in some areas by unsustainable logging practices (Jean-Baptise & Jensen, 2006). On Caribbean islands, the increased coastal development of luxury resorts and vacation homes that are part of the flourishing tourism industry of the islands has contributed to their destruction (Friess and Webb, 2014). It is expected that without significant protection an additional 1-2% of all mangroves will be lost globally in the next 100 years (Chen *et al.,* 2013). The need for the utilization of remote sensing in mangrove forest monitoring is enhanced by the uniqueness of this land cover; the tidal waters, soft muddy land, and a labyrinth of roots, as seen in Figure 1, makes the forest difficult to navigate for *in situ* data collection (Wannasiri *et al*., 2013).

Figure 1. Mangrove Forest terrain in Florida, which inhibits in situ data collection.

The study of mangrove forests in the Caribbean using remote sensing is relatively extensive when compared to the other ecosystems reviewed in this paper. Various imagery sensor data is conducive to research applications on mangroves, although Landsat ETM+ is the most often used (Baban *et al.,* 2009; Gibbes *et al.,* 2009), research has been conducted with Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) (Jean-Baptiste & Jensen, 2006), IKONOS, and aerial imagery (Juman

& Ramsewak, 2013). The application of vegetation indices employing the visible and near-infrared (near-IR) bands is a common analysis technique for looking at mangrove forest vegetation parameters as well as those of dry tropical forests in the area (Martinuzzi *et al*., 2008). Jean-Baptiste and Jensen (2006) were able to correlate canopy closure and leaf-area index (LAI) on the isle of Haiti at 0.851 and 0.908 respectively based on the use of normalized difference vegetation index (NDVI) and the soil adjusted vegetation index (SAVI).

In addition to examining land cover extent and mangrove forest density, remote sensing has been used to differentiate mangrove tree species. The employment of mathematical morphological tools and enhanced morphological reconstruction operators, which utilize opening by reconstruction (OBR) and closing by reconstruction (CBR), were applied to IKONOS imagery (Huang *et al*., 2009). The operators OFC (OBR followed by CBR) and CFO (CBR followed by OBR) resulted in 91% and 93% accuracy for forest mapping and 89% and 91% for species classification, respectively (Huang *et al*., 2009). The functionality of remote sensing is showcased here by facilitating the unique capability of extracting texture features that allow researchers to discern between red (*Rhizophora mangle*), black (*Avicennia germinans*), and white (*Laguncularia racemosa*) mangrove tree species (Huang *et al*., 2009).

When working in the Caribbean, the small size of most of the islands, and thus the inherent decrease in ecosystem area, can lead to data processing limitation such as that described in Baban *et al*. (2009). During the creation of a land cover map for the island of Tobago, Baban *et al*. established mangrove forest as its own class due to the unique spectral characteristics of the land cover. However the class generation was only developed after the implementation of training sites in order to perform supervised classification, compared to most other land covers that were evident in unsupervised classification. Baban *et al.* (2009) contended this is in part due to the minimal available pixels in the image, or low sample size for the mangrove area, which comprised only 4 km^2 of the island.

Remarkably the same parameters that cause error in supervised classification are actually an advantage in processing images of the land area with visual interpretation. Specifically visual analysis can be conducted over a small area relatively efficiently and coarse land covers, such as mangroves are simpler to identify (Juman & Ramsewak, 2013). This technique becomes extremely opportune when dealing with studies over time periods in which only aerial imagery is available.

Coastal Sand Bodies

The extent of sand bodies in the Caribbean is tremendous, yet little research utilizing remote sensing has been done to this point. Past research attributed siliciclastic depositional sediments to either wave-dominated or tide-dominated systems (Rankey, 2014). However geomorphic research is still ongoing to discern how carbonate sediment deposition systems differ from these two processes (Rankey, 2014). The dynamic nature of the coastal land-sea interface presents challenges that are not always easily met utilizing common data collection and analysis techniques. Additionally, research is limited because little is known in the way of what information is able to be derived from the quantitative relationship of recently deposited sand bodies such as sandbars, banks, shoals, deltas, and ridges of the Caribbean (Harris *et al.*, 2011).

Interest in the spatial patterns of these dynamic sand bodies is focused on the movement of sand in the creation of water channels between the sand bodies and the building of islands along the banks. The majority of sand bodies, such as those of the Great Bahama Bank, sit just below the water surface in crystal clear water and have a light colored sea floor. In order to map the deposits, a bathymetric digital elevation model (DEM) is created using Landsat TM/ETM+ and depth soundings, which are then correlated to the light colored pixels of the shallow seafloor (Harris *et al*., 2011). This complex environment requires thorough analysis of quantitative information, the morphology of the sand bodies are explored using DEMs and created polygons representing sandbars at depth, along with other spatial factors to create a centerline of the bank that provides information on the geometry of the sandbars (Harris *et al*., 2011).

Understanding of the sedimentary system in respect to island building and erosion is important to the Caribbean. Other research of ooid shoals in the Northern Bahamas used a boat mounted acoustic Doppler profiler (ADP) to take readings of sound waves along a profile to collect hydrodynamic trends, such as tidal velocity (Reeder & Rankey, 2008). The data was incorporated with field measurements to model flow patterns for the area (Reeder & Rankey, 2008). Additional satellite systems that are being used to perform data collection on tide- and wave-dominated sediments is Landsat and IKONOS (Rankey *et al.*, 2006).

Island shorelines comprise the largest amount of above sea level sand bodies in the Caribbean. On a daily basis, the shores are moved and morphed by wave action, wind, and weather. Shoreline change analysis and mapping with remote sensing does have significant research behind it, just not within the Caribbean (Klemas, 2011; Mann & Westphal, 2014; Mujabar & Chandrasekar, 2013). Data gaps for the region pertaining to this subject will be discussed further in the paper.

For this particular aspect of the Caribbean coastal landscape, the absolute dynamic that is trying to be captured can be the cause of limitation in what information can actually be detected.

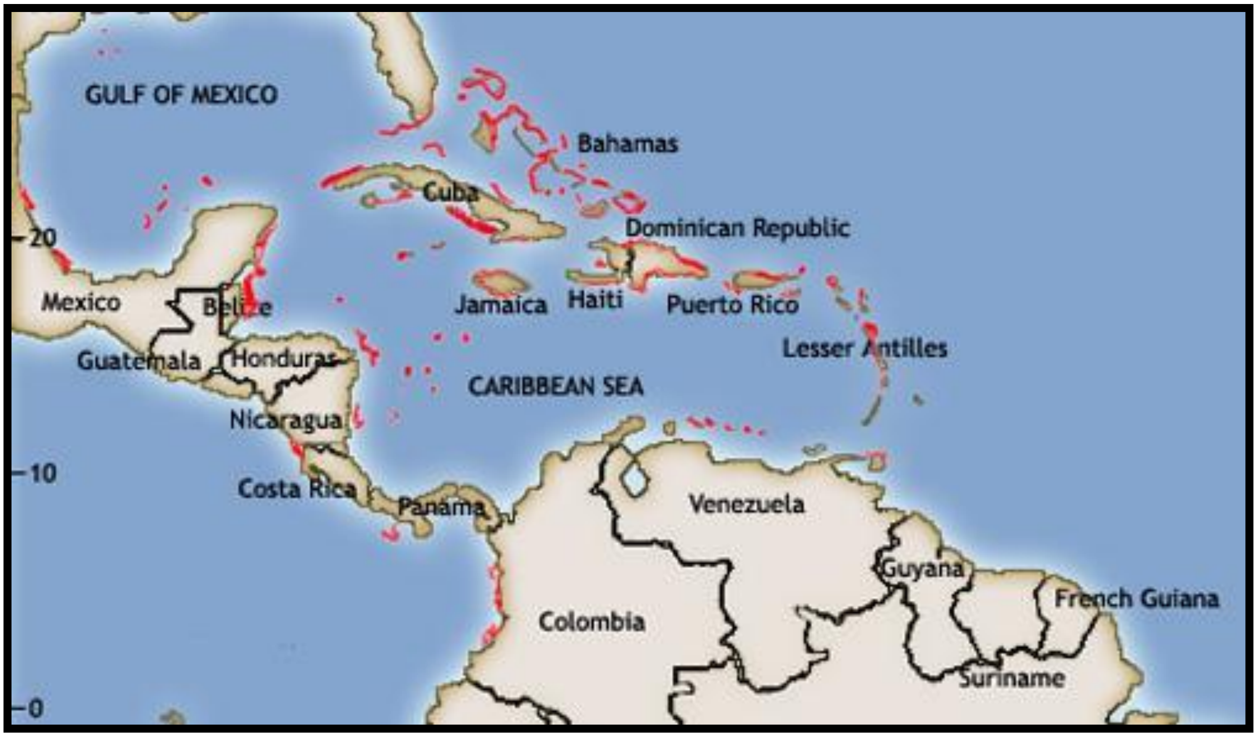

Figure 2. Map of Caribbean Coral Reefs (coral reefs identified in red).

Coastal Water Environment

Coastal waters of the Caribbean have several prominent ecosystems; mapping, detection and analysis of these aquatic areas is important to the assessment of the coastal health of the islands. One of the most widely known and widespread aquatic ecosystem of the Caribbean is the coral reef (Figure 2). The vulnerability of coral reefs from sedimentation build up, ocean acidification, extreme weather events and physical human impact, (diving, boating, etc.) is promulgating the need for more accurate analysis techniques and higher temporal remote sensing images (Relles *et al.*, 2012).

Benthic habitat mapping requires high spatial resolution to create maps that identify types of underwater communities; however coral species are not normally detectable. Both Quickbird satellite imagery and aerial photography are highly appropriate for gathering data on coral reefs. The shallow clear water locations of Caribbean corals result in quite distinct data with high resolution aerial imagery, which present more habitat classes than any satellite imagery. Satellite imaging of shallow water must be corrected for reflectance in the water column, much like atmospheric corrections are applied, to collect discernable data. Additional preprocessing that is recommended when working with imagery collected in an aquatic environment is to mask out all the terrestrial components, including those upon the water such as piers and boats. Albedo, derived from the sea bottom, is the energy most important to benthic mapping; however, water depth must be known to obtain it. Classification of Quickbird imagery using this technique off the Caribbean island of Bonaire resulted in the accurate classification of coral of only 17%-36%. However, post-processing to remove a pink sand class increased the accuracy to 41%-50% (Relles *et al.,* 2012).

Research conducted on the southwest coast of Puerto Rico and published in 2012 by Torres-Perez, Guild and Armstrong, used Combining High Performance Liquid Chromatography (HPLC), spectroscopy and derivative analysis to distinguish between two species of Caribbean corals, *Acropora cervicornis* and *Porites porites*. They were able to base their species determination on the coral's pigment. The spectral signature for the specimens was collected using a Spectroradiometer and associated fiber optic cable, the end of the collection device (cable) was held less than 1 cm from the coral during the data collection (Torres-Perez *et al.*, 2012).

Another shallow water habitat in the Caribbean is that of seagrass meadows. Remote sensing has been crucial in regional-scale mapping of seagrass which is in significant decline around the world. Little to no reliable seagrass habitat information is available, especially in the wider Caribbean region (WCR). Some comprehensive research used Landsat 7 ETM+ imagery from 2000 and 2002 to create a baseline map for seagrass habitat, which was deemed at the time as the "largest such effort worldwide" (Wabnitz *et al.,* 2008).

Collection Gaps of Remote Sensing Coastal Areas

Across the board the biggest gap in remote sensing capabilities to investigate land change in the Caribbean is the nearly non-existent use of Airborne Light Detection and Ranging (LiDAR). The ongoing degradation of mangrove forests and expected land cover change warrants more exact information for understanding the future potential of mangrove forests to sequester CO_2. According to Wannasiri *et al.* (2013) parameters such as tree height and crown diameter can help in determining area biomass and diameter at breast height (DBH), these specifics were extracted using LiDAR which provides a 3-dimensional look at the mangrove forest area. However, no use of LiDAR in research was found for the Caribbean region.

Concerns of sea level rise worldwide have brought increasing attention to the shorelines of islands and low-lying coastal lands. Therefore, a demand for knowledge on coastal evaluation information is on the rise, LiDAR has the ability to fulfill this need (Brock & Purkis, 2009). Additionally, this process progresses quickly so not only accurate but high temporal data is needed to provide suitable information to perform resource and land management planning (Mujabar & Chandrasekar, 2013). Overall, there is a lack of attention within the Caribbean to the monitoring of shoreline changes using remote sensing. Various studies have been conducted validating the use of LiDAR for beach and shoreline change. The resulting patterns of shoreline change, however, have limited analysis options such as visual interpretation and simple first-order measurements from DEMs. The process, which derived morphologic indicators from a DEM, assessed erosion susceptibility of a feature class found using prior probability through Bayes classifier (Starek *et al*., 2012). Another way to analyze shoreline position using LiDAR data is to break the beach up into uniformly eroding areas, sometimes called beach segmentation, then measure the distance from the waterline or wet/dry line to a fixed (preferably linear) feature (Klemas, 2011). Many atolls in the Pacific region have been meeting the challenge of attempting to detect long-term changes in beach width using remote sensing data. Regardless of the data limitation for these remote locations, an effort to prepare for the future is ongoing (Mann & Westphal, 2014). The islands of the Caribbean should be pursuing the same goal.

Conclusion

A multitude of remote sensing capabilities can be utilized within the Caribbean to aid in ongoing challenges to identify land cover change. The plethora of plant species, their environments, and constant alterations made by man can be detected through appropriate sensors and analysis. Initiatives such as the SERENA project that created a large area land cover map encompassing Latin America and the Caribbean is an excellent process to provide information that is urgently needed to all counties preparing for the potential changes ahead (Blanco *et al.,* 2013). As previously discussed, focus needs to be on harnessing remote sensing capabilities, such as LiDAR which has a unique ability to operate seamlessly along coastal habitats like those in the Caribbean (Collin *et al*., 2012).

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Figures

Figure 1. Mangrove Forest terrain in Florida, which inhibits in situ data collection. (Marietta College, http://www.marietta.edu/~biol/biomes/mangroves.htm

Figure 2. Map of Caribbean Coral Reefs (coral reefs identified in red). (BCCR, http://www.mousetrapmultimedia.com/virtualcoralreefdive/types.php)