Estimation of the variations in the amount of vegetation in Caño Tiburones during different hydrologic conditions

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ABSTRACT.- Presence of excessive amount of nutrients in water from different sources can cause excessive growth of vegetation in water, which can result in problems with the amount of oxygen available for aquatic animals. For this reason, it is important to study the patterns of vegetation through the year in Caño Tiburones, which can be influenced by hydrologic conditions. The objectives of this work are to: (a) Calculate the vegetation index (NDVI) in the study area during different seasons of the year, (b) Analyze the changes in the vegetation in Caño Tiburones during different hydrologic conditions and (c) Delineate the changes in the water border in Caño Tiburones for dry and wet seasons and compare them. Images were selected from the sensors Enhanced Thematic Mapper Plus and Operational Land Imager for dry and wet seasons in the period from 2001-2013; IKONOS and aerial photos were also used to achieve the objectives. The images were processed using ENVI software. GIS was also used as a tool to study the changes of vegetation in the water body during wet and dry seasons. Results show that NDVI varies temporally and spatially, with a general increase in the average NDVI for the area during wet season compared to dry season. Spatially, NDVI increases for some places but decreases in others for the same period of time. Water border increases in some places, but decreases in others for the same period of time. Those variations can be as a result of different factors, including precipitation or anthropogenic factors. Field data would be necessary to validate and understand better this system.

KEYWORDS.- Caño Tiburones, Enhanced Thematic Mapper Plus, Geographic Information System, Landsat, Normalized Difference Vegetation Index, Operational Land Imager

INTRODUCTION

Wetlands are areas where water covers the soil, or is present either at or near the surface of the soil all year for varying periods of time during the year, including the growing season. They may support both aquatic and terrestrial species. The presence of water creates conditions that favor the growth of specially adapted plants (hydrophytes) and promote the development of characteristic wetland (hydric) soils (EPA, 2012).

An important parameter that can be used to study the vegetation in wetlands or in land is the vegetation index. In situ field measurements can be related to biophysical parameters, such as the normalized difference vegetation index (NDVI), simple ratio (SR) or transformed normalized vegetation index (TNDVI) in mangroves (Baptiste and Jensen, 2006).

Different applications had been given to vegetation indices using remote sensing data. Hasmadi et al. (2010) compared different vegetation indices for mapping mangrove vegetation using data from Landsat TM. Previous studies had used ASTER data to predict mangrove biophysical variables correlating NDVI to in situ data, as the leaf-area index (LAI) (Baptiste and Jensen, 2006). Also, using IKONOS satellite data and data from

LAI-2000, it was possible to map mangrove LAI at the species level (J.M. Kovacs et al., 2005). Satyanarayana et al. (2011) assessed and obtained valuable information about the mangrove vegetation at Tumpat, Kelantan Delta using remote sensing data.

Vegetation index can also be used for monitoring of crops or study changes in vegetation in a period of time. Oguro et al. (2001) studied temporal changes of rice field using satellite data from Landsat 5 TM and Landsta 7 ETM+ and field data. The results of their study suggested that the temporal changes of vegetation indices of the rice field by satellite data are primarily correlated to the changes of the proportion ratio of rice vegetation within the rice field. Kumar (n.d) used Landsat MSS images of 1972-1973 and Landsat ETM images of 1999-2001 to study the temporal changes in mangrove cover in the Arabian Gulf countries due to the impacts of the oil industry in that region.

Using remote sensing it can be possible study the changes of vegetation and relate it to climatic events. Anyamba and Tucker (2005) related rainfall with NDVI and they could distinguish between drought and wetter periods between 1981 and 2003.

SCIENTIFIC QUESTION

The scientific question of this work is "How the vegetation patterns change in Caño Tiburones during different seasons of the year?

OBJECTIVES

The objectives of this research are: (1) Calculate the vegetation index in the study area during different season of the year, (2) Analyze the changes in vegetation in Caño Tiburones during different hydrologic conditions, and (3) Delineate the changes in water border in Caño Tiburones for dry and wet seasons and compare them.

MATERIALS AND METHODS

Site Description

The selected area of study is the Caño Tiburones. Caño Tiburones is located between Arecibo and Barceloneta municipalities in the north coast of Puerto Rico in the karst region of the island (DNER, 2012) (Figure 1). It is one of the largest estuarine wetlands of Puerto Rico (DNER, 2007). This natural reserve is very important for its ecological value, not only for it size (7000 "cuerdas" approximately), also for the hydrologic, geologic, and biologic characteristics, and it is the habitat of many wildlife species (DNER, 2007).

Figure 1. Location map of Caño Tiburones

The climate of the Caño Tiburones is warm, tropical-marine, with very small fluctuations in temperature (Zack and Class, 1984). The average annual temperature in the area is 26.9°C, and the rainiest months are May and between September and November (DNER, 2007). A relatively dry season extends from January through April (Zack and Class, 1984).

The terrains in Caño Tiburones belong to the Qs and Qsp units, which are swamp deposits of clay and silt with small amounts of sand and peat. Both units have a thickness of 3 meters and they lie over the Camuy Limestone (Tca) (DNER, 2007) (Figure 2). The topography of the Caño Tiburones is between elevations of 984 ft to the south of Arecibo and mean sea level to the coast (DNER, 2012) (Figure 3).

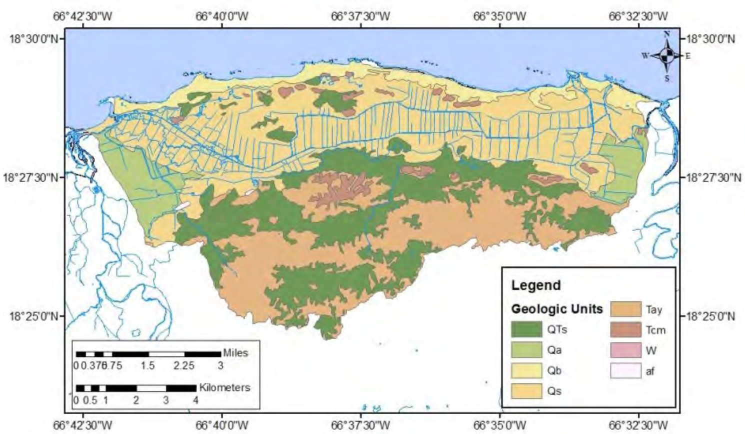


Figure 2. Geologic map of Caño Tiburones area

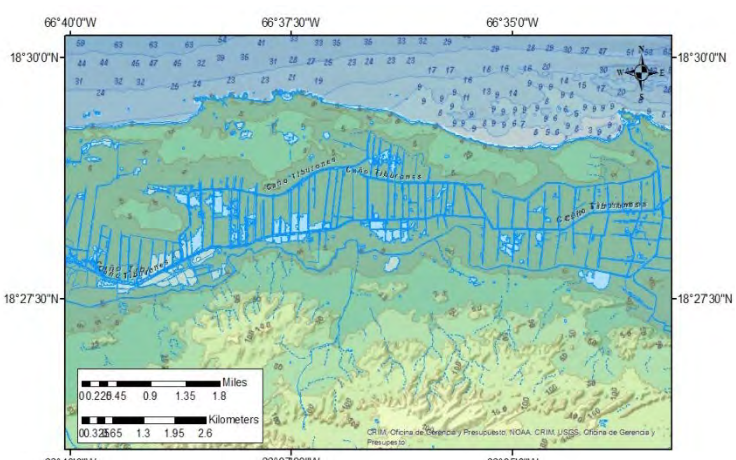


Figure 3. Topography and hydrology of the Caño Tiburones area

The hydrology of the area is compose primarily by freshwater springs to the south, saltwater springs to the north and water that comes to the wetland by runoff (DNER, 2007) (Figure 3). Groundwater flows from the limestone in the south of the area to the coast and wetlands strips. This area of wetlands was altered in the decade of 1940 using drainage channels for agricultural purposes. Excessive pumping in the area caused a decrease in the water level of the Caño Tiburones, causing a reverse hydraulic gradient and, consequently, saltwater has entered in the area. (DNER, 2012).

The flora in the Caño Tiburones is mainly aquatic, including Eneas grass *(Typha dominguensis*, which is the most common plant in the area), aquatic ferns (*Acrostichum aureum, Acrostihcum danaeifolium), grasses (Panicum acuaticum, Paspalum millegrana),* and sedges *(Cyperus odoratus,* and *Eleocharis cellulosa)* (DNER, 2007). Also, there are mangroves, lotus flowers, and water hyacinth.

Those plants have different growing characteristics. *Cyperus odoratus* has an active growing period during summer and fall, with a moderate growth rate. *Eleocharis cellulosa* has an active growing period in spring, summer, and fall, with a moderate growth rate. *Paspalum millegrana* is a perennial grass native of Puerto Rico and the Virgin Islands (USDA, 2013). Caño Tiburones natural reserve is considered an important refuge for wildlife, being the habitat of different species of birds, insects, reptiles, fishes (DNER, 2007).

Vegetation Index

Vegetation indices are dimensionless radiometric measures that indicate the abundance and activity of green vegetation. Indices as the NDVI, SR or the Soil Adjusted Vegetation Index (SAVI) are typically highly correlated with the amount of healthy green vegetation within the instantaneous field of view (IFOV) of the sensor (Baptiste and Jensen, 2006). This is due to the physiological fact that chlorophyll *a* and *b* in the palisade layer of healthy green leaves absorbs most of the incident red radiant flux while the spongy mesophyll leaf layer reflects much of the near-infrared radiant flux (Baptiste and Jensen, 2006).

The parameter used in this study is the Normalized Difference Vegetation Index (NDVI). The NDVI is a measure of the vegetative cover on the land surface over wide areas. It is an important index because seasonal and inter-annual changes in vegetation growth and activity can be monitored (Jensen, 2007). The range of NDVI is from 0 to 1, with 0 meaning no vegetation and values near to 1, dense vegetation. It is calculated from the visible and near-infrared light reflected by vegetation.

Healthy vegetation absorbs most of the visible light that hits it, and reflects a large portion of the near infrared light (Left on Figure 4). Unhealthy or sparse vegetation reflects more visible light and less near-infrared light (Right on Figure 4) (Weier and Herring, 2000).

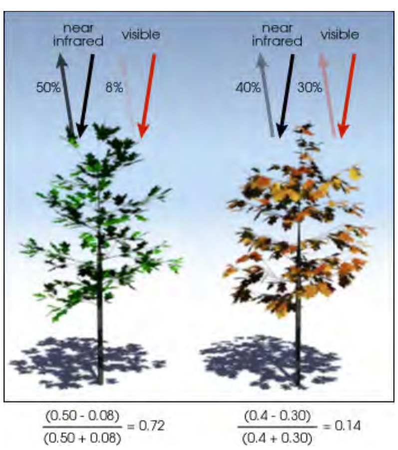


Figure 4. Example of NDVI calculation for healthy and sparse vegetation (Weier and Herring, 2000)

NDVI is calculated using:

$$NDVI = \frac{(NIR - RED)}{NIR + RED}$$

Where NIR and RED represent the reflectance of near infrared and red energies of the electromagnetic spectrum, respectively.

Satellite images and aerial photographs

The satellite images for this work were obtained from the Earth Explorer Website (USGS, 2013), and IKONOS (Gilbes, 2013). Aerial photographs were obtained from Earth Explorer Website (USGS, 2013) and provided by the professor as requested (Gilbes, 2013).

The images were selected from the satellites Landsat 7 (sensor Enhanced Thematic Mapper Plus (ETM+)) and Landsat 8 (sensor Operational Land Imager (OLI)). Satellite Landsat 7 was launched in April 15, 1999 and the main objectives of this satellite are to maintain data continuity, have a global archive of substantially cloud free, sunlit landmass imagery, and expand the use of such data for global-change research and commercial purposes (Jensen, 2007). It passes over the same place every 16 days; the sensor has a swath of 185 km and an orbit of 705 km. Landsat 7 is a sun synchronous satellite and has an inclination of 98.2° (USGS, 2013). Landsat 7 has the ETM+ sensor, which has 8 bands with characteristics shown in Table 1.

Table 1. Characteristics of ETM+ sensor (USGS, 2013)

Band	Spectral Resolution (µm)	Name	Spatial Resolution (m) at Nadir
1	0.450-0.515	Blue	30 x 30
2	0.525-0.605	Green	30 x 30
3	0.630-0.690	Red	30 x 30
4	0.750-0.900	Near Infrared	30 x 30
5	1.55-1.75	Mid Infrared	30 x 30
6	10.40-12.50	Far Infrared	60 x 60
7	2.08-2.35	Mid Infrared	30 x 30
8	0.52-0.90	Panchromatic	15 x 15

Landsat 8 satellite was launched in February 11, 2013 and it ensures the continued acquisition and availability of Landsat data. As in the case of the Landsat 7, Landsat 8 satellite passes over the same place every 16 days, and has a sun-synchronous orbit. Its orbit has 705 km and has a swath of 185 km (USGS, 2013). The sensor located in this satellite is OLI. This sensor has 9 bands with characteristics shown in

Table 2.

Table 2. Characteristics of OLI sensor (USGS, 2013)

Band	Spectral Resolution (μm)	Name	Spatial Resolution (m) at Nadir
1	0.43-0.45	Coastal/Aerosol	30 x 30
2	0.45-0.51	Blue	30 x 30
3	0.53-0.59	Green	30 x 30
4	0.64-0.67	Red	30 x 30
5	0.85-0.88	Near Infrared	30 x 30
6	1.57-1.65	SWIR-1	30 x 30
7	2.11-2.29	SWIR-1	30 x 30
8	0.50-0.68	Panchromatic	15 x 15
9	1.36-1.38	Cirrus	30 x 30

NDVI uses Red and Near Infrared Bands from the sensors. From ETM+, the bands used were band 3 and band 4, and from OLI, the bands used were band 4 and 5 (Red and NIR bands, respectively). From the IKONOS images, the bands used were band 3 and band 4 (Red and NIR bands, respectively).

The period of study of this research is from 2001 to 2013, in which images from dry and wet seasons were selected. From ETM+, the images selected correspond to the dry season (March 5, 2001, December 2, 2001, February 14, 2002, and January 6, 2003), and from OLI, the images selected correspond to the wet season (May 1, 2013, August 5, 2013, September 22, 2013, and October 24, 2013). IKONOS images were for the 2001-2002, and the aerial photographs were from 2004 to 2010.

Image processing

The images obtained from the different satellites were processed using ENVI 5.0, which is a software used for processing and analyzing geospatial imagery (Exelis, 2013). The processes followed to obtain the final results are described as follows (ENVI help):

- Layer stacking: creates a new multiband file from georeferenced images of various pixel sizes, extents, and projections.
    - ETM+ bands: bands 1-4
    - OLI bands: bands 2-5
    - IKONOS bands: 1-4
- Mosaicking: overlays two or more images that have overlapping or put together a variety of non-overlapping images and/or plots for presentation output.
    - It was apply to IKONOS image because there were three images from the area of study.
- Spatial subset: it is use to limit applying a function to a spatial subset of the image. It can be done by one of the following methods: entering samples and line values, selecting interactively from the image, entering map coordinates, using the same spatial subset that was previously used on another file, using the image shown in the meta scroll window or using the bounding box around a region of interest.
    - True color and false color images were created to compare observe the changes in the area of study in different dates.
- Dark substract: this procedure applies atmospheric scattering corrections to image data. The digital number to substract from each band can be either minimum, an average based upon a region of interest, or a specific value.
- NDVI calculation: NDVI was calculated using band math function on ENVI. This

function accesses data spatially by mapping user-defined values to bands or files.

  - The mathematical expression entered in band math function was: (float(b1)-float(b2))/(float(b1)+float(b2)), where b1=band 4 for ETM+ and IKONOS and band 5 for OLI, and b2=band 3 for ETM+ and IKONOS and band 4 for OLI.

- Build mask: creates image mask from specific data values (including the data ignore value), ranges of values, finite or infinite values, regions of interest, ENVI vector files, and annotation files.
  - For this case, the mask was created for the values between 0 and 1, which is the NDVI range of values.
- Apply mask
- Apply color to the image: using the function "Color Mapping", color tables were applied to images. Green/white linear colors were applied to the images.
- Color ramp and text: using the User Defined Annotation functions, color ramp and text were applied to the images to obtain the final images.
- Supervised Classification: this function is used to cluster pixels in a dataset into classes corresponding to user-defined training classes. Training classes are groups of pixels (Regions of Interest) or individual spectra.
  - The classes used for the supervised classification were: ocean (water), vegetation, sediments and city.
  - The method of classification used for the supervised classification was minimum distance. This classification uses the mean vectors of each region of interest and calculates the Euclidean distance from each unknown pixel to the mean vector for each class. All pixels are classified to the closest region of interest class (ENVI Tutorials).

Geographic Information System (GIS) was also used to analyze the high resolution aerial photographs. The analysis consisted in analyze the changes in vegetation in different areas for the years of 2001-2002, 2004, 2006 and 2010. Also, using the ETM+ and OLI images, the water border was delimited for March 5, 2001 and May 1, 2013 to analyze the changes between the two dates.

RESULTS AND DISCUSSION

NDVI results

Figure 5 to Figure 8 show the results of the NDVI calculations in Caño Tiburones corresponding to dry season. Comparing Figure 5 and Figure 6 it can be observed that both images are similar, but in some areas there is a change in the extension of vegetation, which is represented with bright colors in the range of 0 to 0.5. Changes between March 5, 2001 and December 2, 2001 are shown in Figure 6 with red circles.

Due to the spatial resolution of the images (30 meters) it was not possible to obtain detailed results of the NDVI for this area, especially because this is a small area. Also, it is not possible to distinguish the different types of vegetation, but it can be observed that to the south of Caño Tiburones (blue rectangle in Figure 5 and Figure 6) there is dense vegetation, due to the NDVI values larger than 0.5 as observed from the color ramp of the figure, compare to the area near the Caño Tiburones that are brighter colors, in the range between 0 and 0.5.

Both Figure 5 and Figure 6 show water (in Caño Tiburones and in the ocean) and the city with dark (black) color. This represents the mask created for values outside the range from 0 to 1. Those values represent negative values, which mean that there is no vegetation. This is because water absorbs much of the near-infrared energy that receives compare to vegetation that reflects much of the near-infrared energy received.

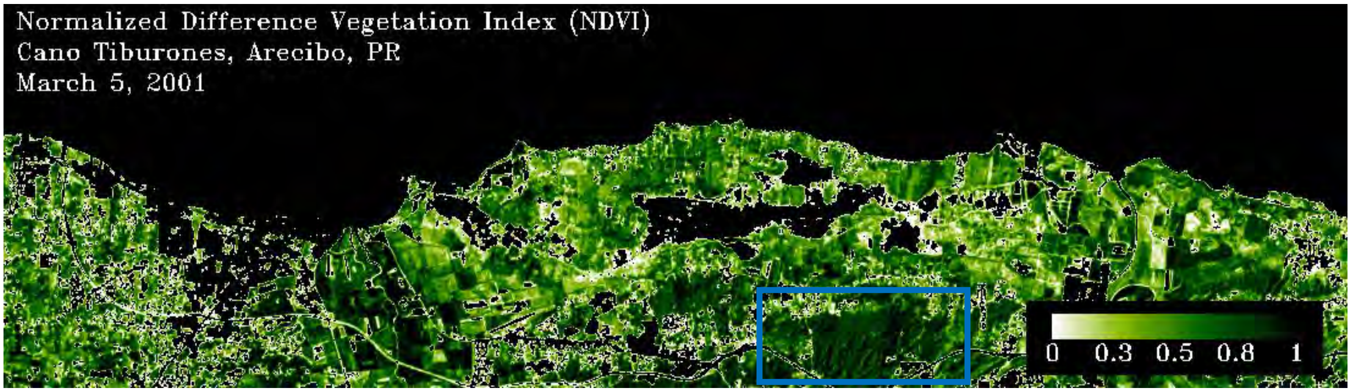


Figure 5. NDVI results-Caño Tiburones (March 5, 2001)

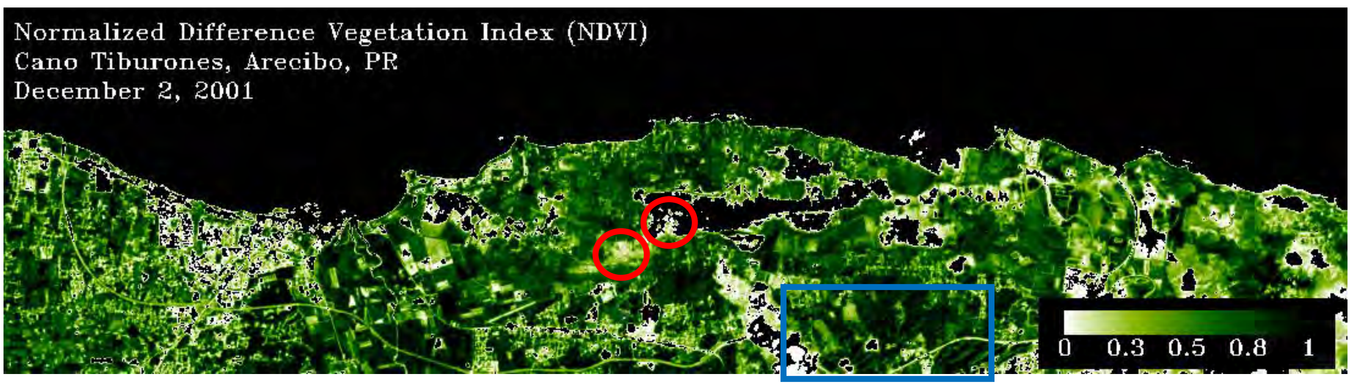


Figure 6. NDVI results-Caño Tiburones (December 2, 2001)

Comparing Figure 5, Figure 6 and Figure 7, it can be observed that there are not significant changes between the NDVI values for this area. This can means that for the period of dry season the rate of growth of the plants is slow to be detected and cannot be detected with the sensor due to the spatial resolution. Changes between December 2, 2001 and February 14, 2003 are shown in Figure 7 with a blue circle. As in Figure 5 and Figure 6, Figure 7 also shows water with black color, due to the response of water to the energy that it receives, as explained before.

Figure 7. NDVI results-Caño Tiburones (February 2002)

Comparing Figure 7 and Figure 8, it can be observed that there are not significant changes between the two images in the extension and vegetation in Caño Tiburones area. The principal change observed between the images is that for January 6, 2003, the NDVI values are less than in February 14, 2002. Those changes are shown in Figure 8 with a red rectangle. This is represented by brighter colors in Figure 8. This can mean that the amount of precipitation in the area was less in previous days to January 6, 2003, and if plants have less water in the leaves, they will reflect more red energy than it is absorbed.

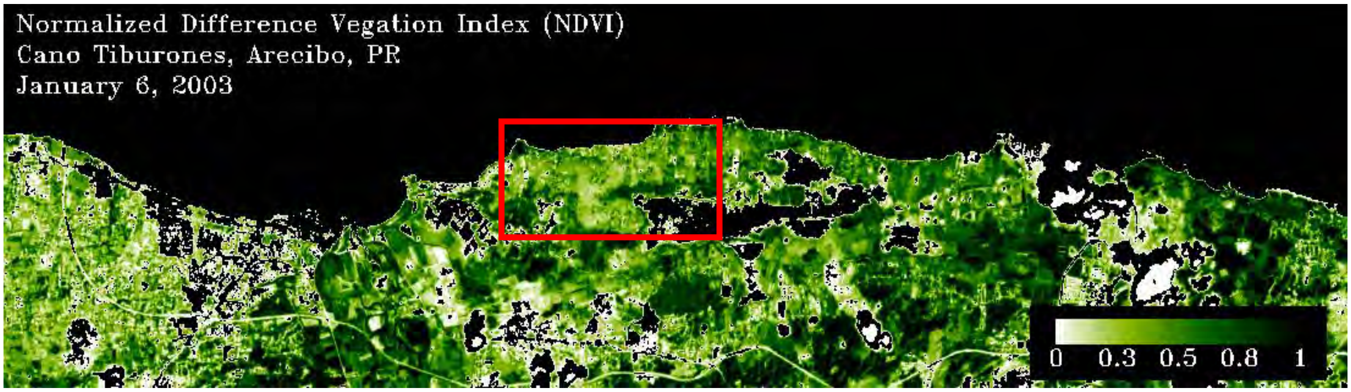


Figure 8. NDVI results-Caño Tiburones (January 6, 2003)

Figure 9 to Figure 12 show the results for the NDVI calculation corresponding to the wet season. Comparing Figure 9 and Figure 10, it can be observed that there is no significant difference between both images because both images were taken close in dates. Comparing Figure 9 and Figure 8, it can be seen that for wet season (Figure 9) NDVI values are in the range of 0.5 to 1 and in dry season (Figure 8) they are in the range from 0 to 0.5, as observed from the color ramp of both images. This indicates that for wet season, plants have more water and can growth faster and more near infrared energy is reflected.

Figure 9. NDVI results-Caño Tiburones (May 1, 2013)

Figure 10, Figure 11, and Figure 12 show the results corresponding to the NDVI calculations for August 5, 2013, September 22, 2013, and October 24, 2013, respectively. From the images, it can be observed that there are no significant changes in the results obtained, because they were taken with difference of one month between each one, and to observe any change it would be necessary that the images would be taken with less temporal resolution. Also, because of the spatial resolution of 30 meters, it is not possible to observe small changes in NDVI for small temporal resolution.

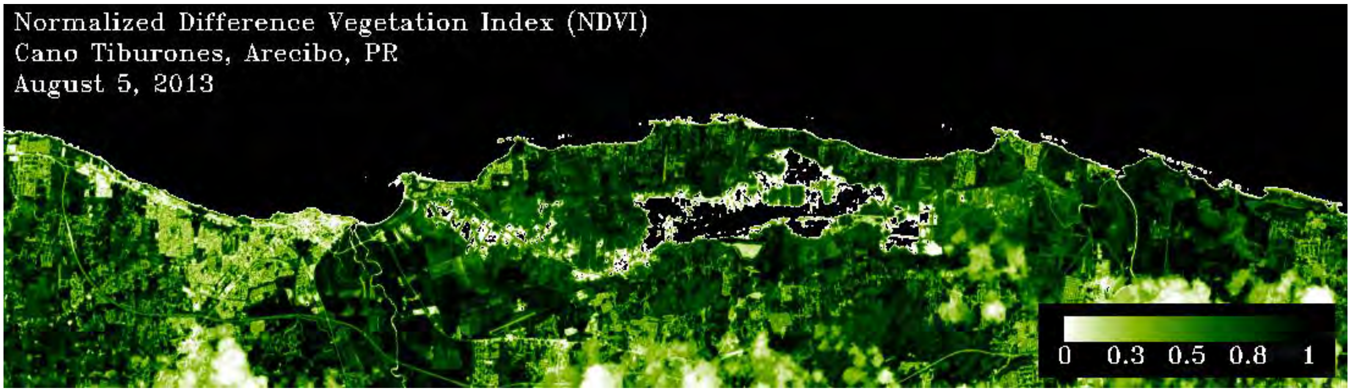


Figure 10. NDVI results-Caño Tiburones (August 5, 2013)

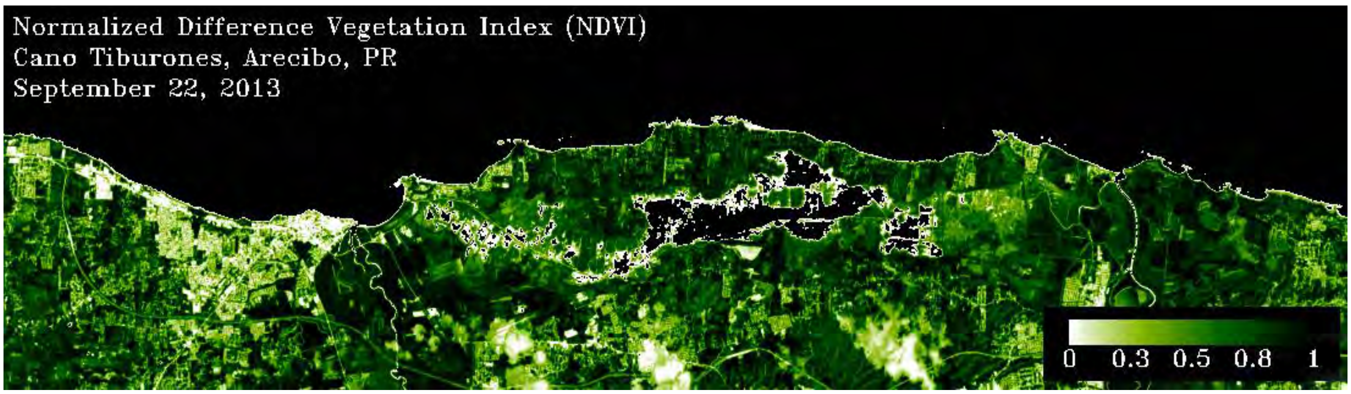


Figure 11. NDVI results-Caño Tiburones (September 22, 2013)

Figure 12. NDVI results-Caño Tiburones (October 24, 2013)

Figure 13 and Figure 14 show histograms of the NDVI values for the area of study. There were selected NDVI values in the range from 0 to 1 only, negative values were discarded. From Figure 13, it can be observed that the peaks of the graphs are in the range between 0.2 and 0.3 for March 5, 2001, and February 14, 2002, between 0.2 and 0.4 in January 6, 2003, and for December 2, 2001, the peak is the range of 0.4 to 0.5. Comparing those results to the results obtained in Figure 14, for the wet season, it can be observed that all histograms have positive skewness. All histograms are very similar, with the peaks in the range of 0.4 to 0.5.

Average NDVI values for dry season are in the range of 0.290 to 0.334, and for wet season, the range is from 0.315 to 0.334. For March 5, 2001 and February 14, 2002 the NDVI values are the same. This can indicate a pattern in dry season between different years. Maximum NDVI values are higher for wet season than for dry season, and minimum NDVI values are similar in both seasons.

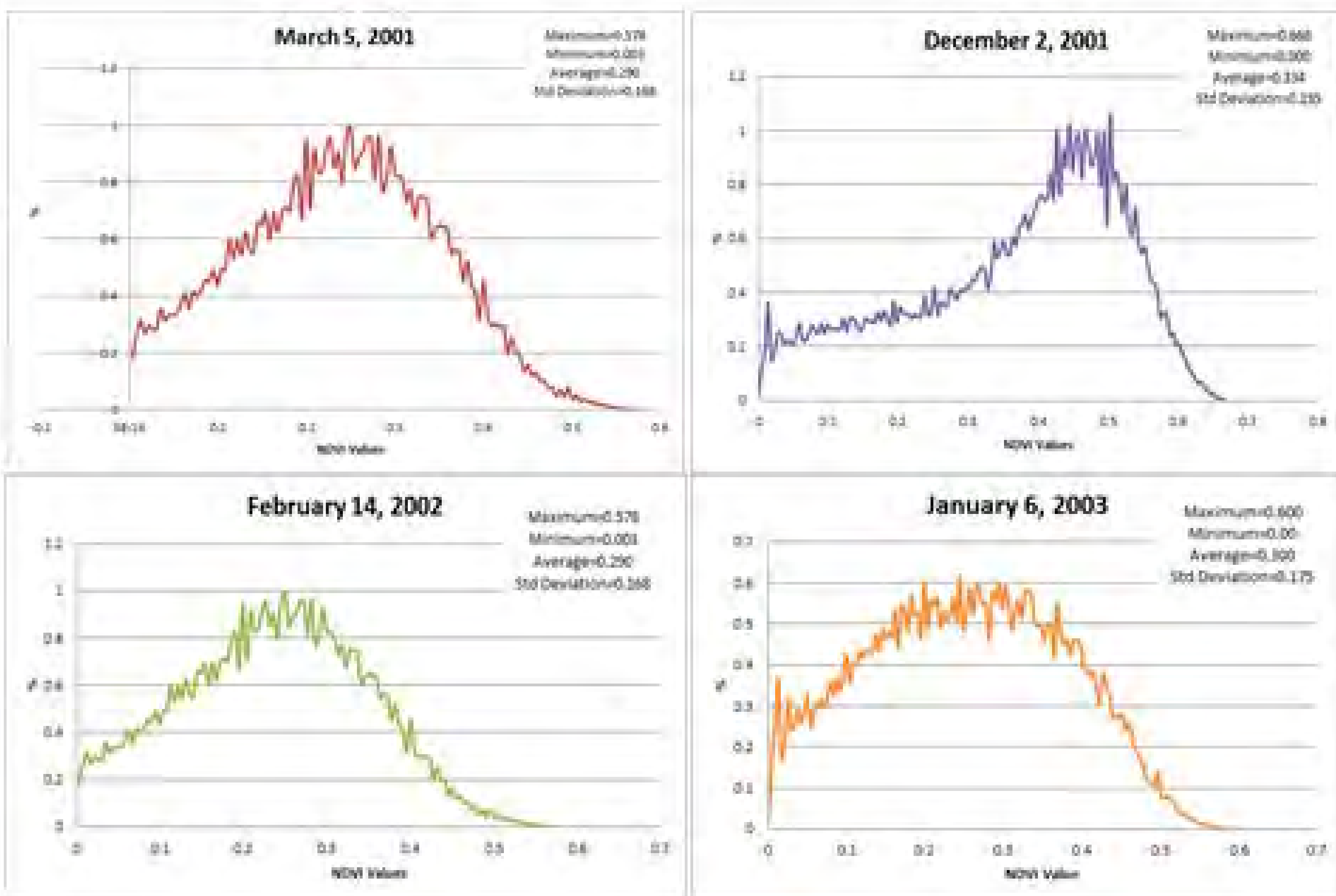


Figure 13. NDVI histograms for dry season period

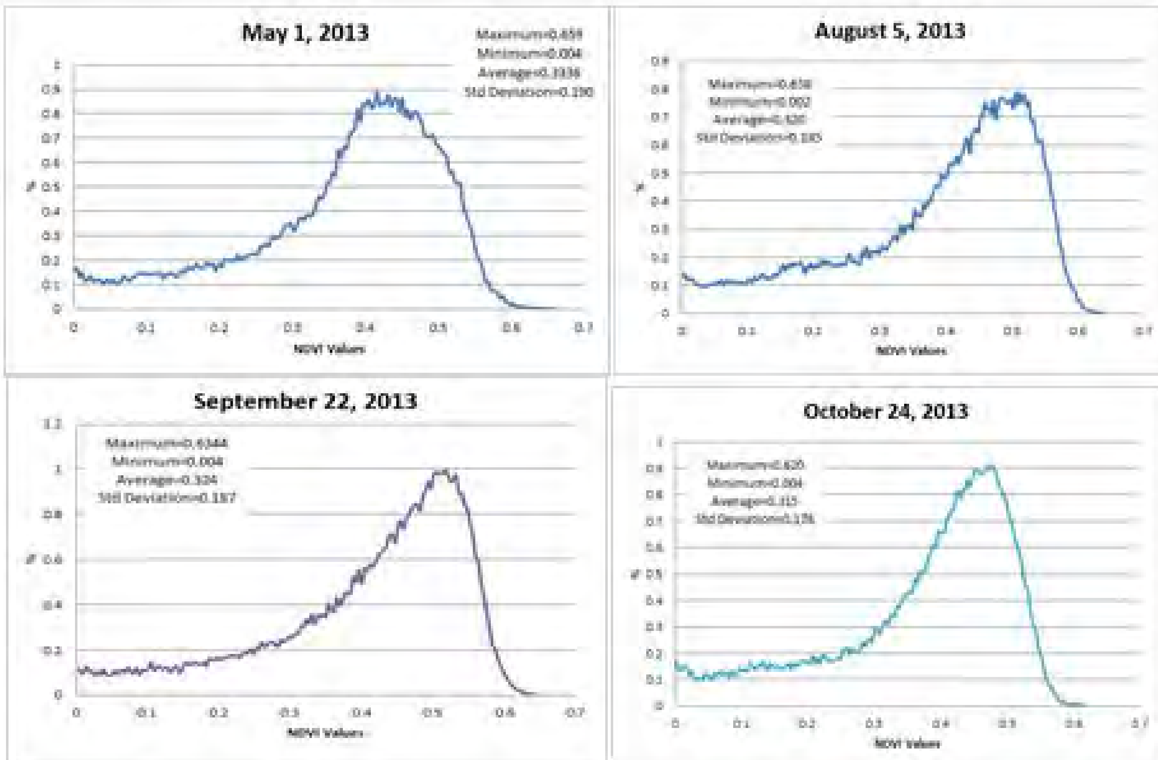


Figure 14. NDVI histograms for wet season period

Figure 15 shows a comparison between the average NDVI values for dry and wet seasons. The results show that, in general, NDVI values are higher for wet season than for dry season. This is because of the higher precipitation, plants growth more than in dry season that there is less amount of water entering in Caño Tiburones with nutrients. Some of the plants in the area of study have their active growing period during summer and fall (*Cyperus odoratus* and *Eleocharis cellulosa*), which is the wet season period. This can explain the increase in the NDVI for wet season.

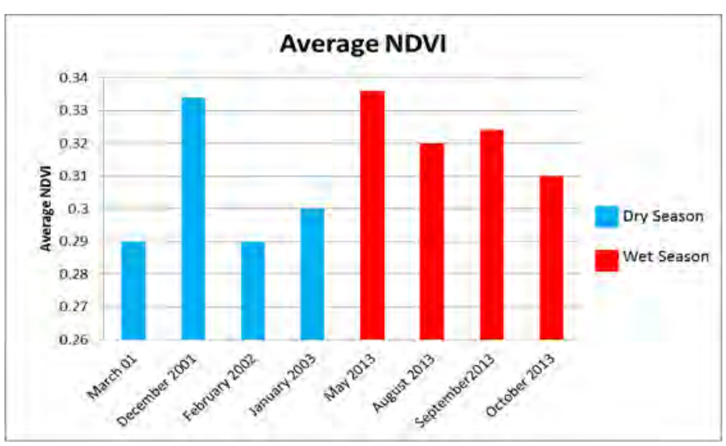


Figure 15. Comparison between average NDVI values for all dates

Using IKONOS images, it was calculated the NDVI values for 1 meter spatial resolution and for 30 meters spatial resolution to observe if there is a significant change between both spatial resolutions. Figure 16 shows the results for 1 meter spatial resolution and Figure 17 for 30 meters spatial resolution. The 1 meter spatial resolution image shows more details in the area than for the 30 meters spatial resolution, but when it is compare the statistics for both images, the difference between the 1 meter spatial resolution and 30 meters spatial resolution is 0.0019, that it is not significant (Table 3).

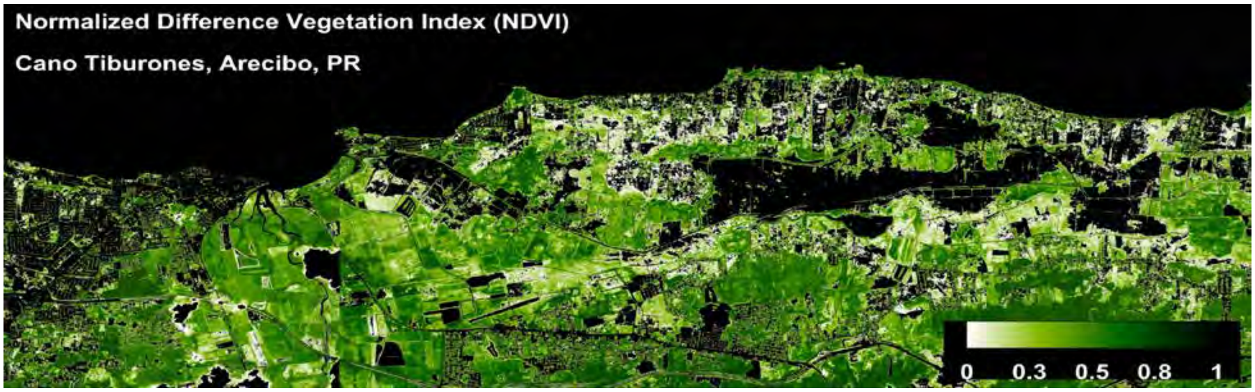


Figure 16. NDVI results-Caño Tiburones (IKONOS image-1 meter spatial resolution)

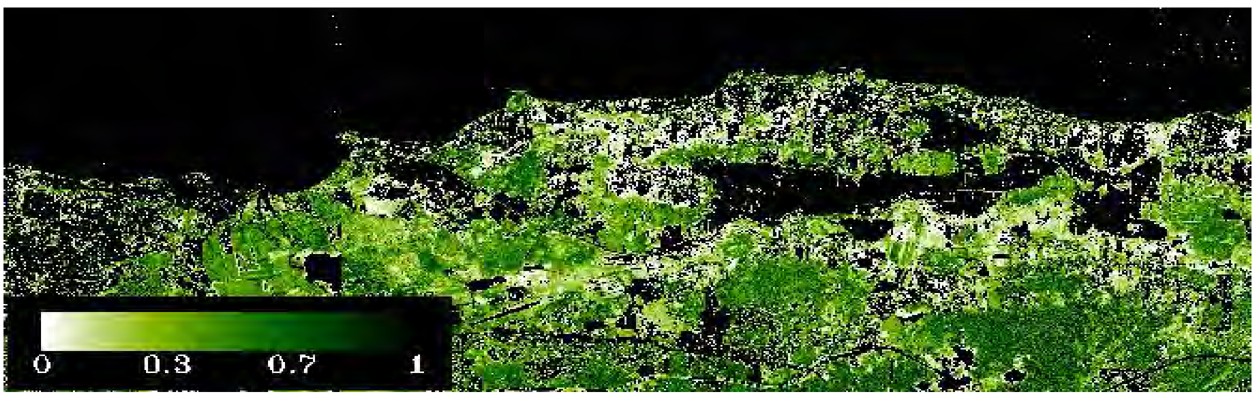


Figure 17. NDVI results-Caño Tiburones (IKONOS image-30 meters spatial resolution)

Table 3. Comparison between results of NDVI for 1 meter and 30 meters spatial resolution

	1 meter resolution	30 meter resolution
Maximum	0.9895	0.9956
Minimum	0.0039	0.0036
Average	0.2879	0.2898
Std Deviation	0.4967	0.4996

Supervised Classification

Figure 18 shows the true color, false color and supervised classification for March 5, 2001. From the images, it can be observed that in the false color image (center) vegetation can be distinguished better that for the true color image (above). This is because the false color image was created using the near-infrared band, and it works better to identify vegetation. From the supervised classification (below), it can be seen that it is very similar to the true color, except for an area in the coast that it was classified as city. This classification was done taking into consideration the number of the pixels and for this reason, it was classified as city.

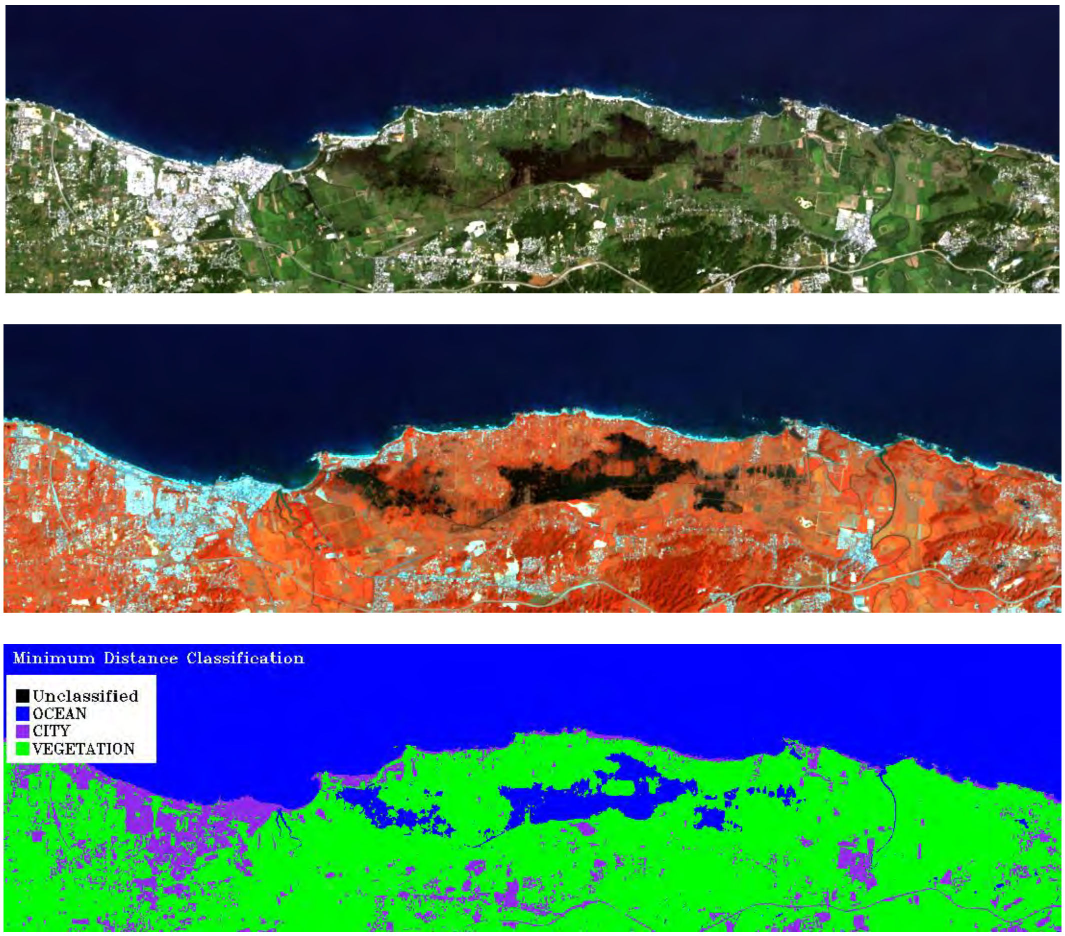


Figure 18. True color, false color andn supervised classification-March 5, 2001

Figure 19 shows the true color, false color and supervised classification for December 2, 2001. From the images, it can be observed that in the false color image (center) vegetation can be distinguished better that for the true color image (above). This is because the false color image was created using the near-infrared band, and it works better to identify vegetation. From the supervised classification (below), it can be seen that it is very similar to the true color, except for an area in the coast that it was classified as city. This classification was done taking into consideration the number of the pixels and for this reason, it was classified as city. Also, there is an area in which in the supervised classification, it was classified as city, but this area is covered by clouds and because of the method of classification, it was classified as city.

Figure 20 shows the same results for February 14, 2002, and Figure 21 for January 6, 2003. In all the images, it can be observed that clouds have an effect on the supervised classification. The true and false color images seem to be darker than the other images. Figure 22, Figure 23, Figure 24, and Figure 25 show the true color, false color and supervised classification for May 1, 2013, August 5, 2013, September 22, 2013, and October 24, 2013, respectively, in which it can be observe that there is no significant differences between the images from wet and dry seasons. This is because of the spatial resolution of 30 meters, in which it cannot detect any change with this spatial resolution. The only difference between the images is when there are sediments, or the clouds that affect the classification.

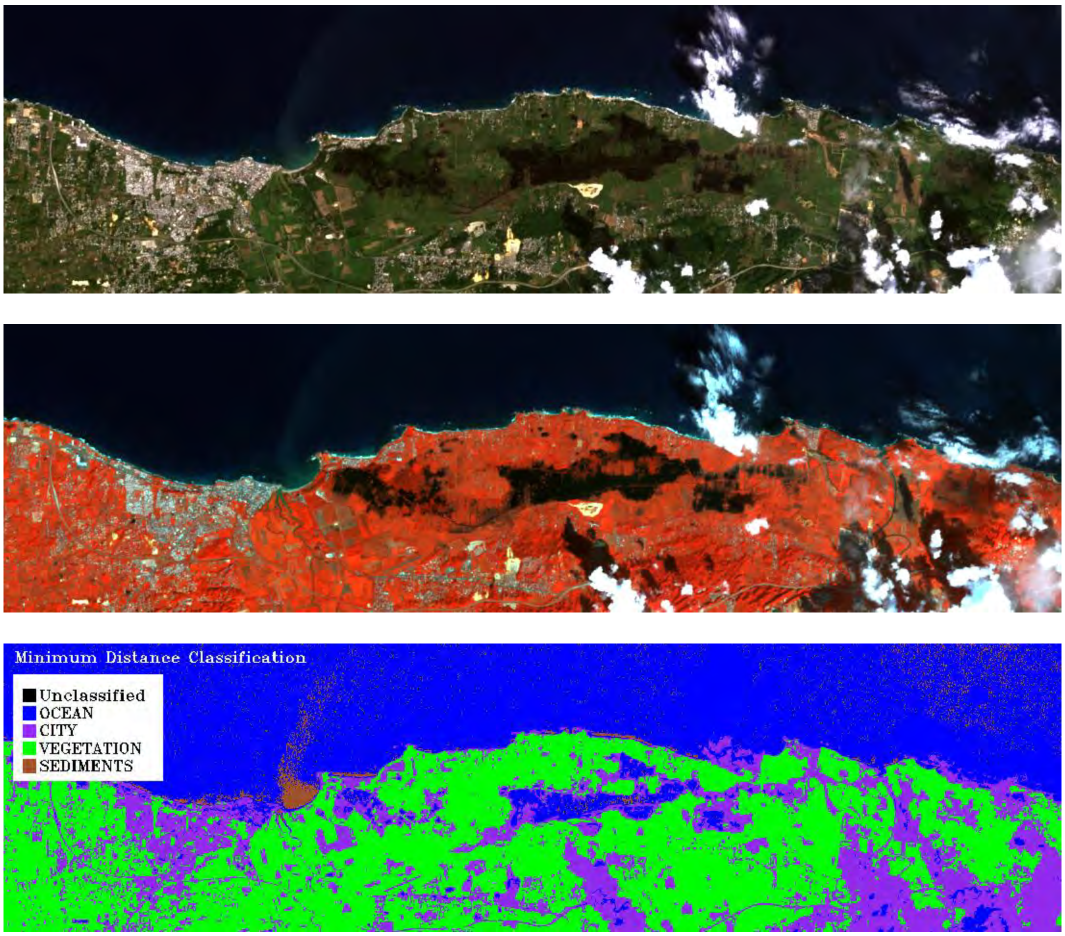


Figure 19. True color, false color, and supervised classification for December 2, 2001

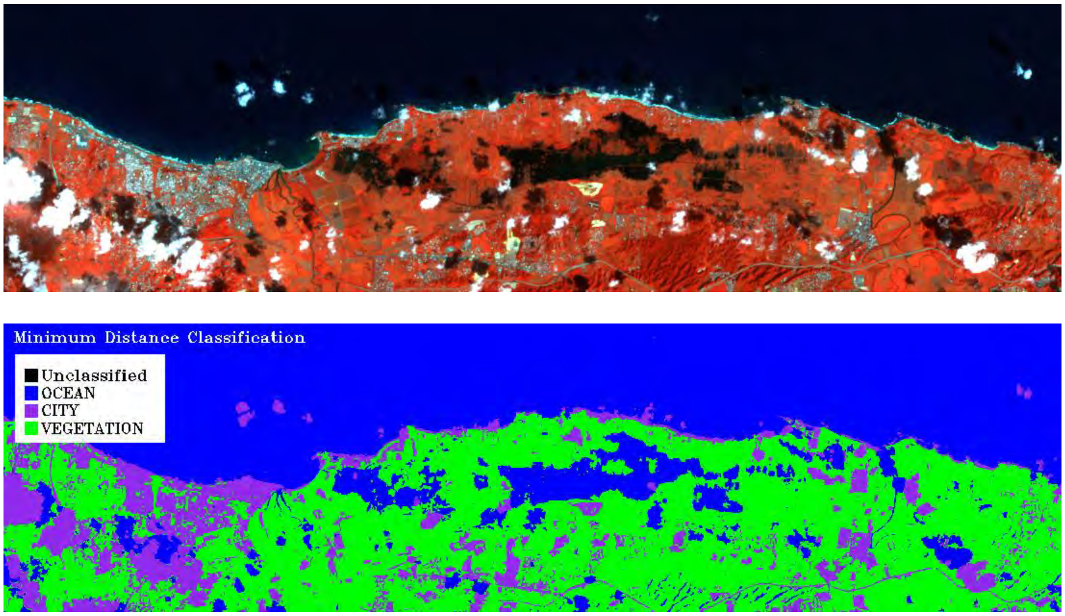


Figure 20. True color, false color, and supervised classification for February 14, 2002

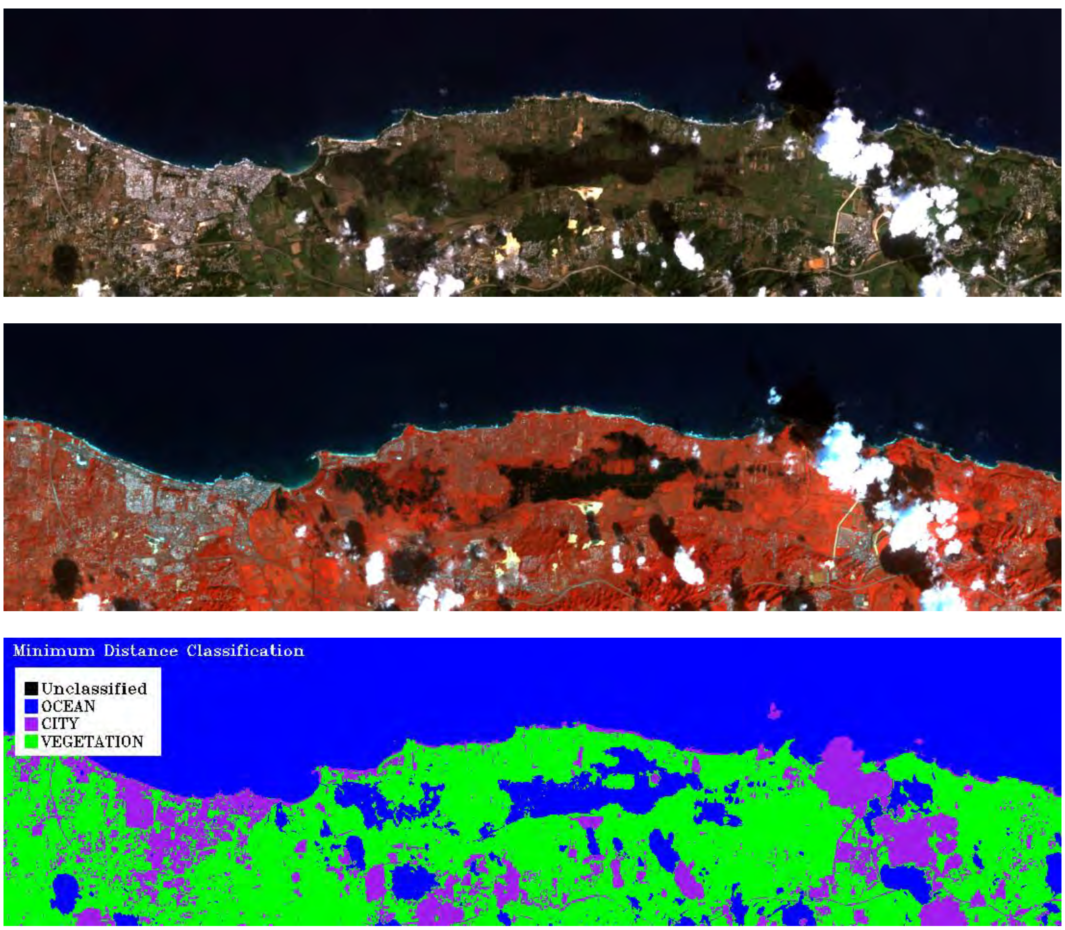


Figure 21. True color, false color, and supervised classification for January 6, 2003

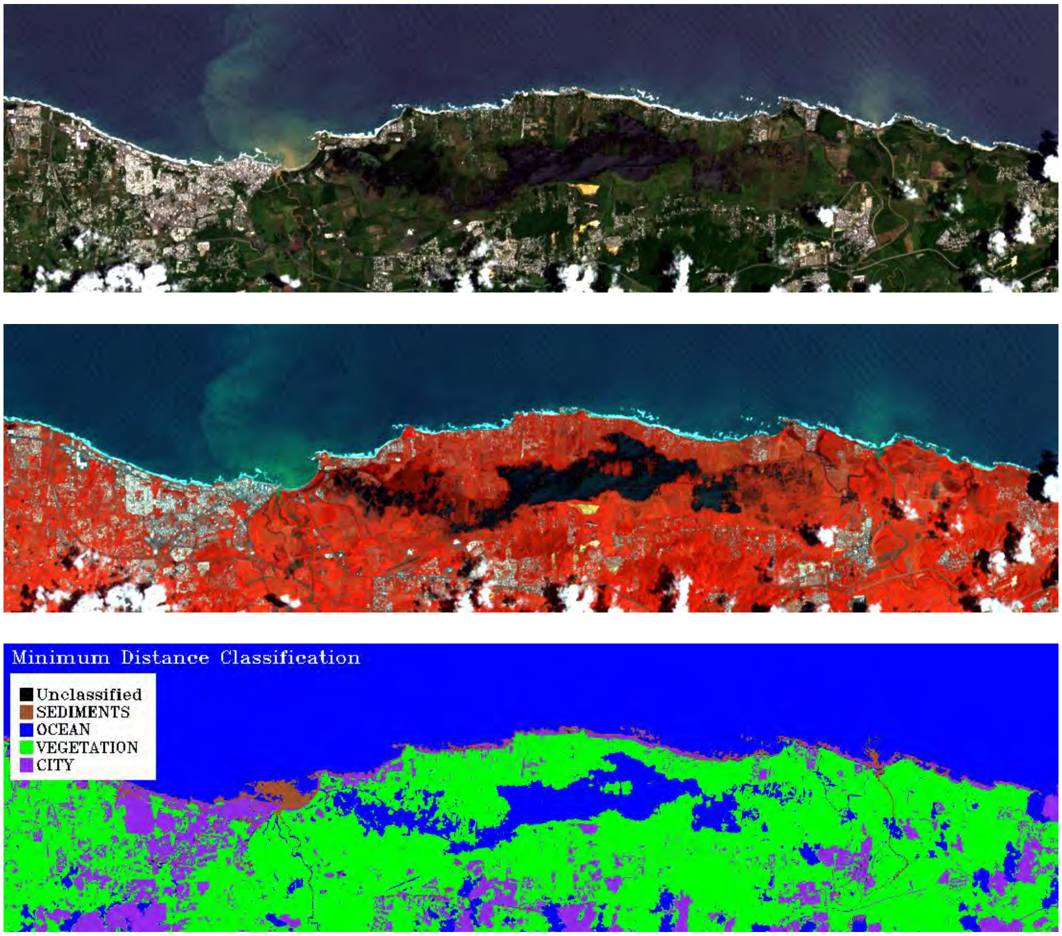
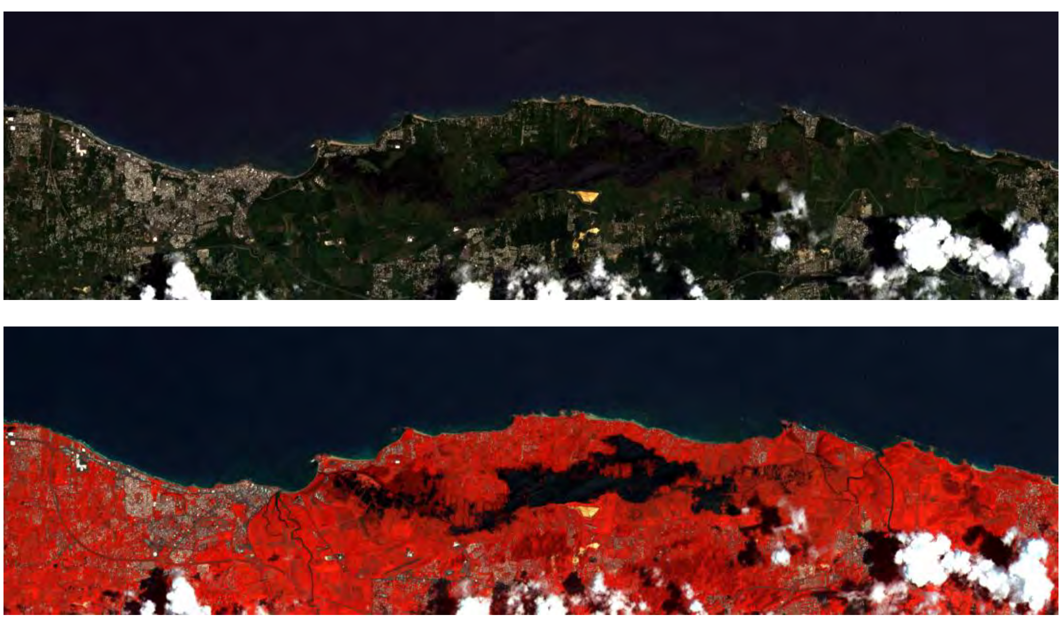


Figure 22. True color, false color and supervised classification for May 1, 2013



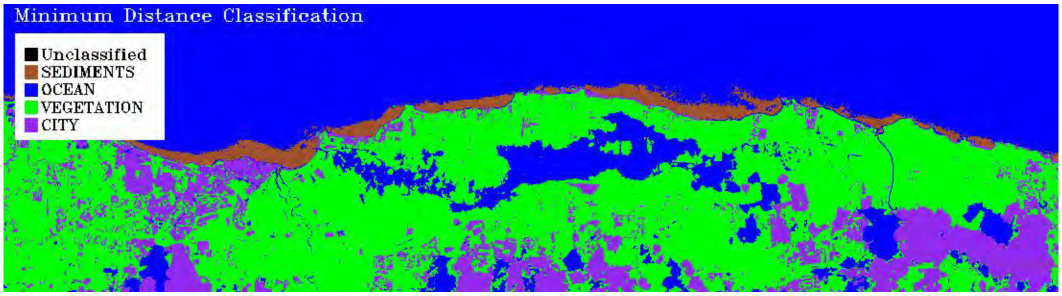


Figure 23. True color, false color and supervised classification for August 5, 2013

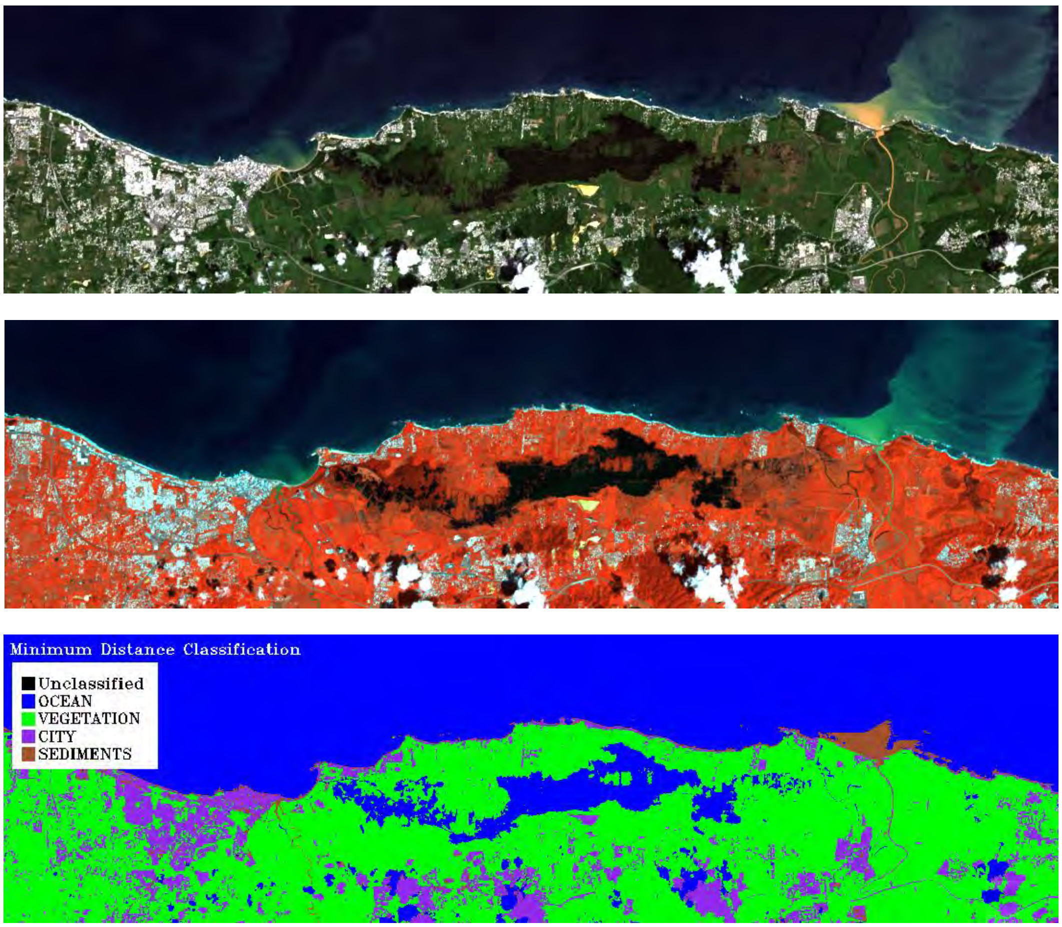


Figure 24. True color, false color and supervised classification for September 22, 2013

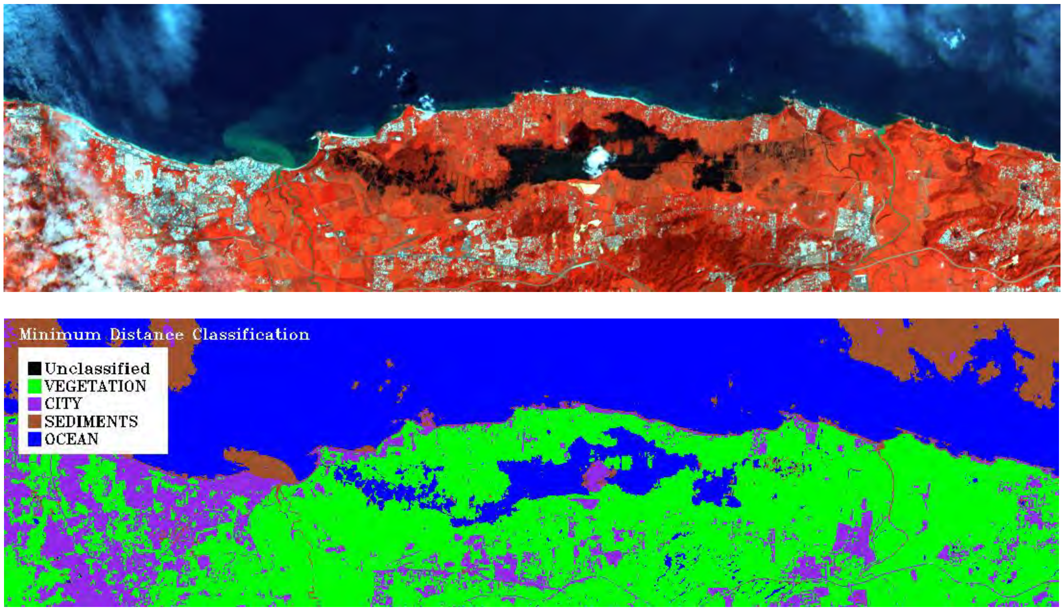


Figure 25 True color, false color and supervised classification for October 24, 2013

GIS Application

Figure 26 shows the water line for dry and wet seasons, and Figure 27 shows the comparison between both seasons. It can be seen from Figure 27 that there are areas that the water line increase in dry season, and in other areas, it increases in wet season. This can be results of the groundwater flow that can be entering in Caño Tiburones, and it can be variable from one place to other. In general, there is an increase in water line for wet season, as a result that there is more water entering in the system.

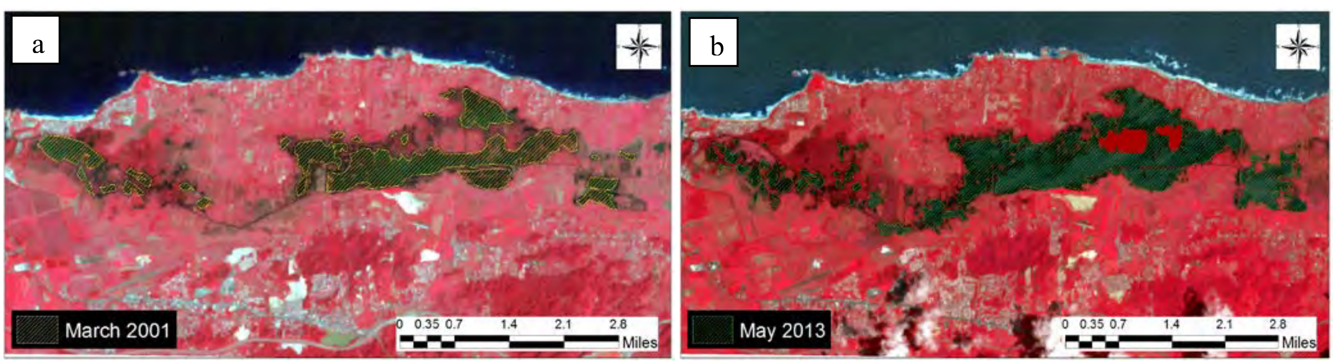


Figure 26. Extension of water in dry (a) and wet (b) seasons

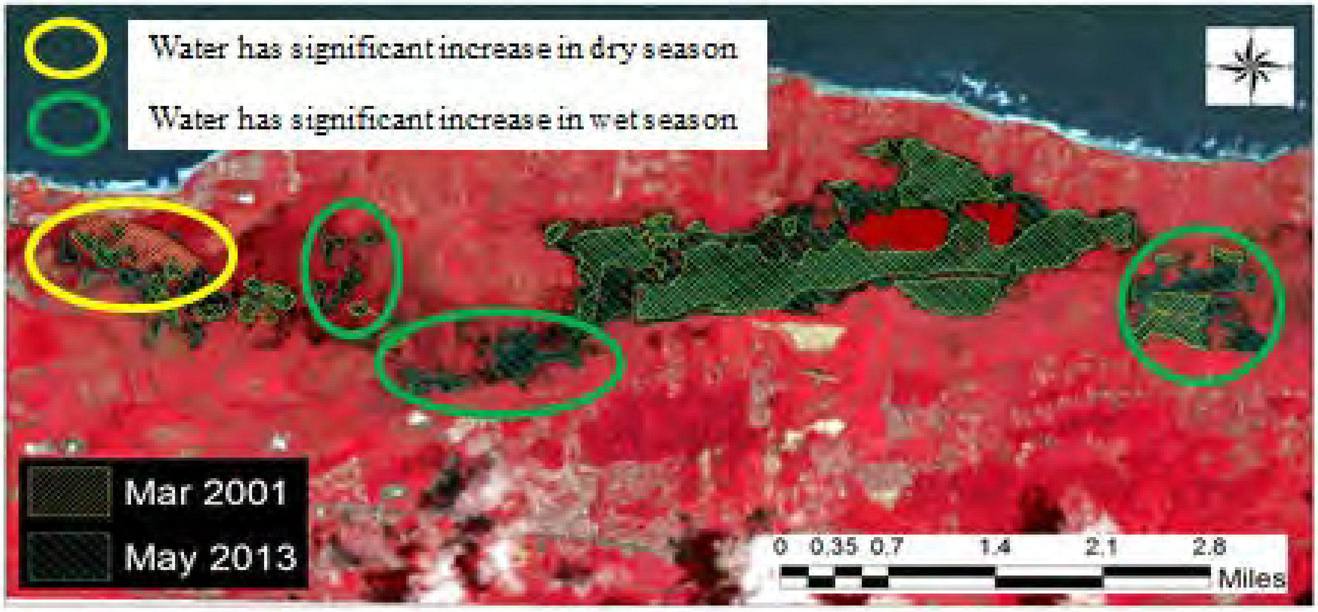


Figure 27. Comparison of water border between dry and wet seasons

Using aerial photographs it was compare the vegetation from 2001-2002 to 2010, in which it can be observe that using high resolution photographs, it can be distinguish some changes in vegetation. Comparing 2001-2002 and 2004 aerial photographs, there is a decrease in vegetation, shown by the yellow circle in Figure 28. From the same figure, for 2004 to 2006, there is an increase in vegetation shown by the red circle, as in the case from 2006 to 2010 that there is also an increase in the vegetation in the area closed by the red circle. The use of high resolution aerial photography can help to have an idea of the changes that occur in a particular area.

Figure 28. Aerial photographs of a portion of Caño Tiburones showing the difference in vegetation between 2001 and 2010

CONCLUSIONS

From this research it can be concluded that remote sensing is a useful tool to study the differences in vegetation and other characteristics of a place during different periods of time. By using satellite images and aerial photographs, researchers can obtain important information of a particular area of study. One important factor when conducting a remote sensing project is the spatial and temporal resolution of the images. Images with high spatial resolution can provide better detail of the area of study and better results.

NDVI in the study area has different spatial and temporal variations. In some places, vegetation increases during wet season, but in other places, it decreases. The variability can be a result of different factors, including precipitation or anthropogenic impact, as discharge of nutrients, changes in the channels of water bodies, and others. For the area of study, in general, there is an increase of average NDVI in wet season, which can be a result of the active growth period of some plants in the area. Water level varies between seasons, with increase in water in wet season in some areas, but in other areas, it increases in dry season.

The results of this study are needed to be validated with field data measurements, including precipitation or measure of Leaf Area Index (LAI) to establish a better correlation between NDVI and hydrologic conditions.

LIMITATIONS AND RECOMMENDATIONS

This work had many limitations. One the most common was that some images had high cloud coverage, and it was impossible to use those images for the study. Other limitation observed was the spatial resolution. If there are available image with higher spatial resolution, it would be possible to obtain more details in the NDVI or in the images, compare to 30 meters resolution. One problem found during the process of selecting the images was that Landsat 7 images has a problem of having a line in the area of study, with no data to be processed. Finally, there is a gap between dates, in which the process was done for images of 10 years of difference. It would be necessary to have images from the same year or at least two years of difference to have a better understanding of the behavior of the system in a relatively short period of time.

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