Study of the Effects of Land Use and Land Cover in Laguna Grande Bioluminescent Bay

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Abstract

One of the most valuable ecosystems in Puerto Rico is the Laguna Grande in Las Croabas Fajardo, Puerto Rico. The bay is considered bioluminescent due to the high concentration of microorganisms, called dinoflagellates. Besides being a valuable ecosystem, the bay is the destination of many tourist who visit the island every year to enjoy its beauty. Last year, specifically on November 18, 2013 the bioluminescent of the bay greatly declined. Many hypotheses were mentioned by scientists and the people that live around the bay about a possible explanation for the phenomenon. For this project, five satellites images, one from TM, another one from ETM+, and three from OLI, were selected in order to find a possible explanation for this event. The images were captured on dates previous, during, and after the event. For the analysis of the images a Neural Net supervised classification was performed for each one, in order to determine any land use or land cover effect that could affect the bioluminescent of the bay. Finally the results suggest that no land use or land cover changes occur that could cause the lack of bioluminescent on the bay. On the other hand a strong present of suspended sediments over the ocean's water along with a strong tide event can be a possible reason for the lack of bioluminescent in the bay.

Keywords: land use, land cover, supervised classifications, Laguna Grande, bioluminescent bay.

I. Introduction

One of the most valuable ecosystems in Puerto Rico is the Laguna Grande in Las Croabas, Fajardo, Puerto Rico (Figure 1). Laguna Grande has a perimeter of approximately 2.19 km and an area of 0.27 km^2. The bay is considered bioluminescent because of its high concentration of microorganisms, called dinoflagellates.

Besides being a valuable natural resource, the bay is the destination of many tourists who visit the island every year to enjoy its beauty.

Dinoflagellates are the primary source of flow-agitated bioluminescence in Laguna Grande. As stated in the scientific article "Population fluctuations of Pyrodinium bahamense and Ceratium furca (Dinophyceae) in Laguna Grande, Puerto

Rico, and environmental" the two most abundant dinoflagellate species in Puerto Rico bioluminescent bays and lagoons are the Pyrodinium bahamense (figure 3) and the Ceratium furca, but the last one is not bioluminescent. The Pyrodinium bahamens are single celled microorganisms and common members of the plankton, which are marine plants, animals or bacteria that live near or on the water's surface. These bioluminescent dinoflagellates range in size from 30µm to 1 mm and are found in waters with high percent of salinity and warmers than 20^{0}C. Sometimes they are found in high concentrations, what occasioned an amazing phenomenon, called red tides. The high concentration of dinoflagellates discolors the water during red tides; this phenomenon does not occur often and when happens it does not last forever, but in some places, like in Laguna Grande the brilliant bioluminescence persists throughout the year.

On November 18, 2013 a situation captured the attention of the scientific community, and both local and international media; the bioluminescence of Laguna Grande dramatically declined during the tourist season, when people flooded the area to partake in the bio-bay attractions. When the phenomenon was reported, the event had been happening for approximately 8 days. As a result, a lot of hypothesis about a possible explanation for this event were mentioned, not just by scientists but also by residents of the area. Some of the popular ones are: the effects of a near construction in the area that could be contaminating the bay with the asphalts that was being used and finally by natural reasons.

Figure 1. The red square shows the location of the Laguna Grande in Las Croabas, Fajardo Puerto Rico (Image from Google Earth).

Figure 2. Picture of the Laguna Grande in Las Croabas, Fajardo Puerto Rico (Image from http://images.travelpod.com/tripwow/photos/ta-0099-f2b6-37ea/-laguna-grande-our-bioluminescent-bay-fajardo-puerto-rico+1152_12781268092-tpfil02aw-25619.jpg)

Figure 3. Pyrodinium Bahamense is one of the most abundance dinoflagellate in Laguna Grande Bioluminescent Bay. (Image from http://elyunque.com/Vieques/pyrodinium.jpg)

This study is intended to find a possible explanation for the lack of bioluminescence in the Laguna Grande during November 18, 2013. For the purpose of this study, remote sensing images captured by three different sensors were analyzed before, during, and after Laguna Grande was reported to have gone dark in November 18, 2013. The images were pre-processed and analyzed using the ENVI (Exelis Visual Information Solutions) Image Analysis Software. After that, supervised classifications were applied to the images in order to find a possible explanation for the lack of bioluminescence in the bay.

II. Objective

Evaluate the area around the bay, in order to determine if there is any direct cause that produced the lack of bioluminescence.

III. Methodology

By accessing earthexplorer.usgs.gov, level 1 images in GeoTIFF format from the northeast coast of Puerto Rico that contained Laguna Grande were downloaded with a cloud coverage of less than 40%. The images were produced by three sensors: Operational Land Imager (OLI), Enhanced Thematic Mapper Plus (ETM+) and Thematic Mapper (TM) (Table 1).

A total of five dates were chosen to acquire the images from the sensors: November 18, 1984 (TM); March 27, 2000 (ETM+); May 26, 2013 (OLI); November 18, 2013 (OLI); and January 5, 2014 (OLI).

	TM	**ETM+**	**OLI/TIRS**
Number of bands	7	8	9
Radiometric Resolution	8 bits	8 bits	12 bits
Spatial Resolution	30 m Thermal: 120 m	30 m Pan: 15m Thermal: 120m	30 m Pan: 15 m Thermal: 100 m
Temporal Resolution	16 days	16 days	16 days
Spectral Range	0.45-12.5 µm	0.45-12.5 µm	0.43-12.51 µm

Table 1. Description of Thematic Mapper, Enhanced Thematic Mapper Plus and Operational Land Imager sensors.

The GeoTIFF files were processed using ENVI software. After opening the file, a layer stacking was performed, to accommodate all of the bands into one file, followed by a dark subtract atmospheric correction with spatial resizing that contained the desired area (Laguna Grande).

Regions of interest (ROI) files were created for each image in order to perform supervised classifications. The regions of interest chosen were: City, Vegetation, Water, Clouds, Suspended Sediments and Cloud Shadow. The supervised classifications performed were: Minimum Distance, Maximum Likelihood, and Neural Net. Unsupervised classifications were also performed using IsoData and K-means, however these were not used for the analysis but to compare their results with the supervised classification results.

IV. Results

1. Neural Net Classifications

The Supervised Classification that produced the best overall results was the Neural Net Classification. For each one of the five images, it captured with impressive accuracy the ROIs that were designed.

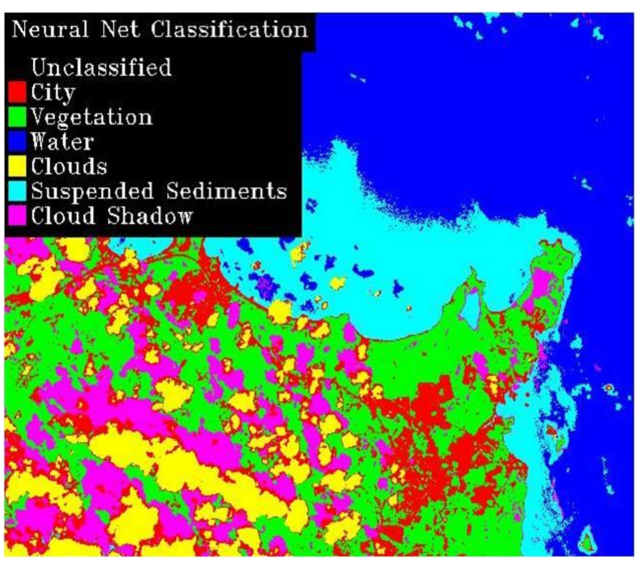

Figure 4. Neural Net Classification for the TM Image.

Figure 4 shows the Classification performed for the TM image. Clouds and their shadows are mainly in the center and of the image. The towns of Rio Grande (north) and Fajardo (east) are well defined as city areas. If looked closely, two areas are of special attention in this image. The first one is the Laguna Grande, which was classified as "Cloud Shadow" when Neural Net was run. However, no cloud is detected directly above or in its immediate surroundings. One possible reason for this is that the pixels forming the Laguna Grande are quite dark and their color is similar to a cloud shadow, making the software mistaking it for a cloud shadow, instead of depicting it as water.

The second area that is of our attention is the light blue color close to the coast, which is a broad area of Suspended Sediments. These sediments can come from nearby rivers or transported to the area by waves.

The second image studied was the ETM+ Classification, which can be seen on Figure 5. Here, city areas are overestimated, as cloud shadows are depicted as cities.

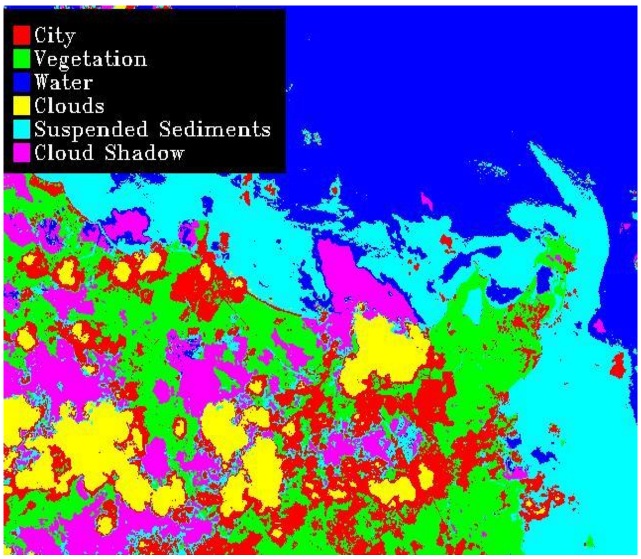

Figure 5. Neural Net Classification for the ETM+ Image.

The sediment concentration has diminished especially north of Puerto Rico in comparison with the 1984 image, however it is still present in the area, and there is slightly more concentration east of Fajardo. Also, in this image, the Laguna Grande is presented as water, an improvement from the TM Neural Net Classification.

More recent images of the Laguna Grande were analyzed, and Figure 6 shows one of them, taken by the OLI sensor on May 2013, about six months before the main event. City and cloud areas are very precise, but one classification stands out: there are no suspended sediments anywhere. The water is completely clean.

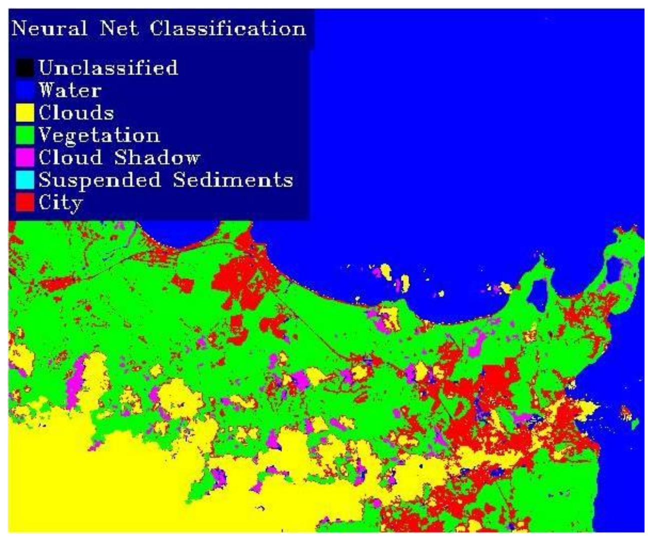

Figure 6. Neural Net Classification for the OLI Image (May 2013).

Furthermore, this is the only image that shows both Laguna Grande and Laguna Aguas Prietas (the small lagoon west of Laguna Grande), as water. Under normal conditions, Laguna Aguas Prietas has a high concentration of sediments in it.

Figure 7 shows the Neural Net Classification obtained for the image taken on November 18, 2013. Coincidentally, this is the day on which the news about Laguna Grande going dark was first reported.

At first glance, a sharp difference between the previous image (May 2013) and this one is noted: the amount of suspended sediments suspended along the coast has increased dramatically.

This image makes contrast with the other one, as in just six months; the amount of sediments went up from zero to nearly covering all of the immediate water around Laguna Grande. This sediment could easily have accumulated on the lagoon, and be the primarily cause of why it went dark on November 2013.

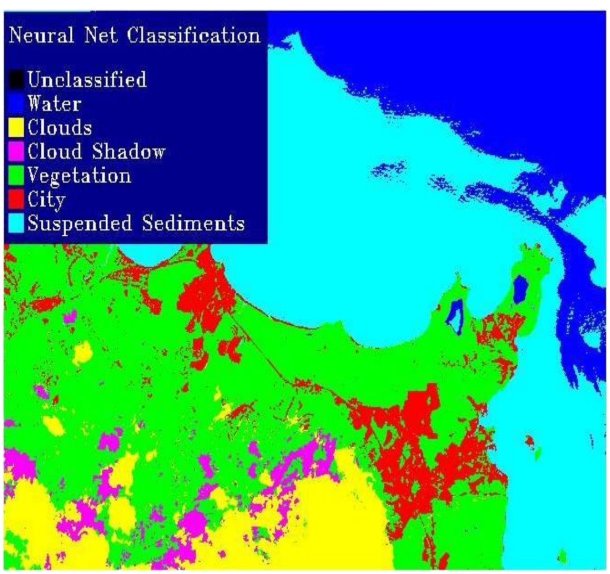

Figure 7. Neural Net Classification for the OLI Image (November 2013).

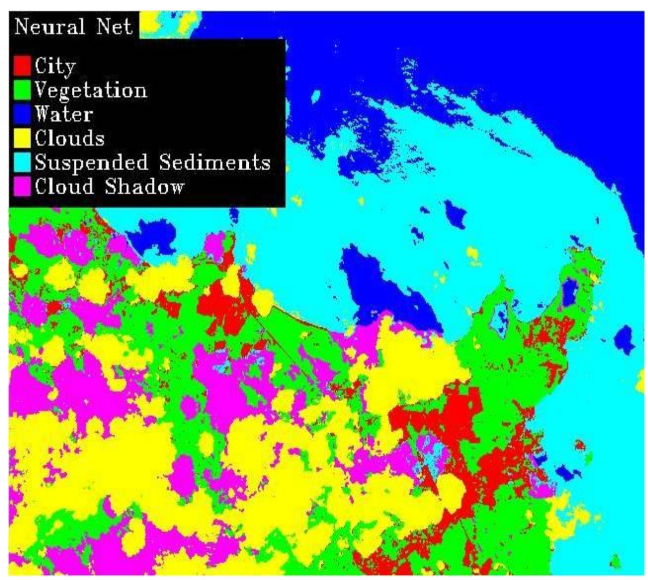

Figure 8. Neural Net Classification for the OLI Image (January 2014).

Figure 8 shows the area around Laguna Grande on January 2014. Sediment accumulation has somewhat decreased, but it is still of special concern, because of its presence near the lagoon.

2. Statistics

After the Neural Net Classification was performed, the Statistics for each image were calculated. These serve to see how much of each ROI has every image, and to observe if there was any change throughout the years. Table 2 shows the Statistics, in per cent for each image.

	Regions of Interest	**18 Nov 1984**	**27 Mar 2000**	**26 May 2013**	**18 Nov 2013**	**5 Jan 2014**
1	City	10.76	12.97	4.97	5.78	4.93
2	Vegetation	17.63	15.54	15.21	28.87	15.25
3	Water	30.92	31.81	18.9	15.95	18.6
4	Clouds	7.38	6.94	16.83	7.37	17.91
5	Suspended Sediments	24.98	23.33	33.4	39.51	34.4
6	Cloud Shadow	8.32	9.42	8.45	2.52	8.91

Table 2. Summary of the Statistics calculated for each Neural Net Classification.

3. Bathymetry and Sediment Origin

As shown in Figure 9, there are two main rivers that input sediments into the Fajardo coast, these are the Río Juan Martín, located on the northern coastline, and the Río Fajardo, located on the eastern coastline.

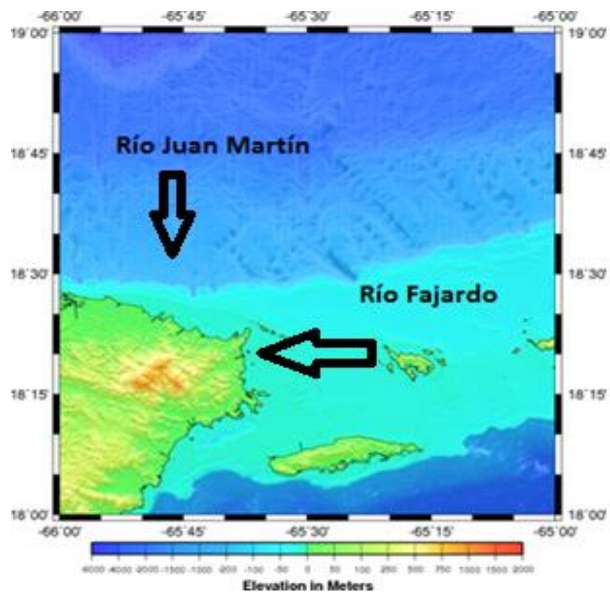

Figure 9. Bathymetric map of the northeast coast of Puerto Rico, area where Laguna Grande is located (Image from http://www .ngdc.noaa.gov/mgg/coastal/grddas09/html/gna19066.h tm).

Figure 10 shows these rivers, and in addition other water bodies in the Fajardo area.

Figure 10. Map with identified rivers and stream that can potentially affect the suspended sediment intake of Laguna Grande (Image from Google Earth).

Appendix 1 shows a topographic and bathymetric contour map of the studied area. Where the suspended sediments appeared most prominent, the water depth seem to range from 0 to 50 m however the area from 0 to 30 m is less. Taking this into account, anything deeper than 20 meters (which is the majority of the area) absorbs all of the visible and NIR wavelengths. This means that the signal came only from the color of the water and not from the reflection of the bottom, meaning, from the presence of the suspended sediments.

V. Conclusions

There is no significant evidence of land cover changes around Laguna Grande from 1984 to 2014. This is visually evident by the comparison of classified images however it could not be confirmed by the statistical analysis because of its lack of reliability brought on by the diverse cloud and shadow abundance that altered the other distribution of values.

A strong presence of suspended sediments in the ocean was recognized in the Neural Net supervised classification during the event of November 18, 2013. This correlated with a reported high tide event (seen in Appendix 2) that occurred a week before the 18th. Therefore, we suggest that the high tide event caused the spreading of sediments which affected the bioluminescence of Laguna Grande.

For our purposes, the Neural Net classification was by far the best classification; this because maximum likelihood overestimated classifications like City and Cloud Shadows, and marked the lagoons as suspended sediments. Minimum distance, on the other hand, underestimated clouds and city portions. Neural net, however, was precise in determining each classification.

VI. Recommendations

In order to perform a better supervised classification, a feature extraction method should be created. As a result, the classification would be created on the basis of what the analyst is looking for. Also, it would be ideal to create a specific supervised classification for the area of interest such as; for example, the classification performed on the study "Monitoring urban land cover and vegetation change by multi-temporal sensing information" by Peijun et al. 2010.

In addition, a selection of clearer images, meaning fewer clouds, would help to more precisely determine statistical data.

VII. References

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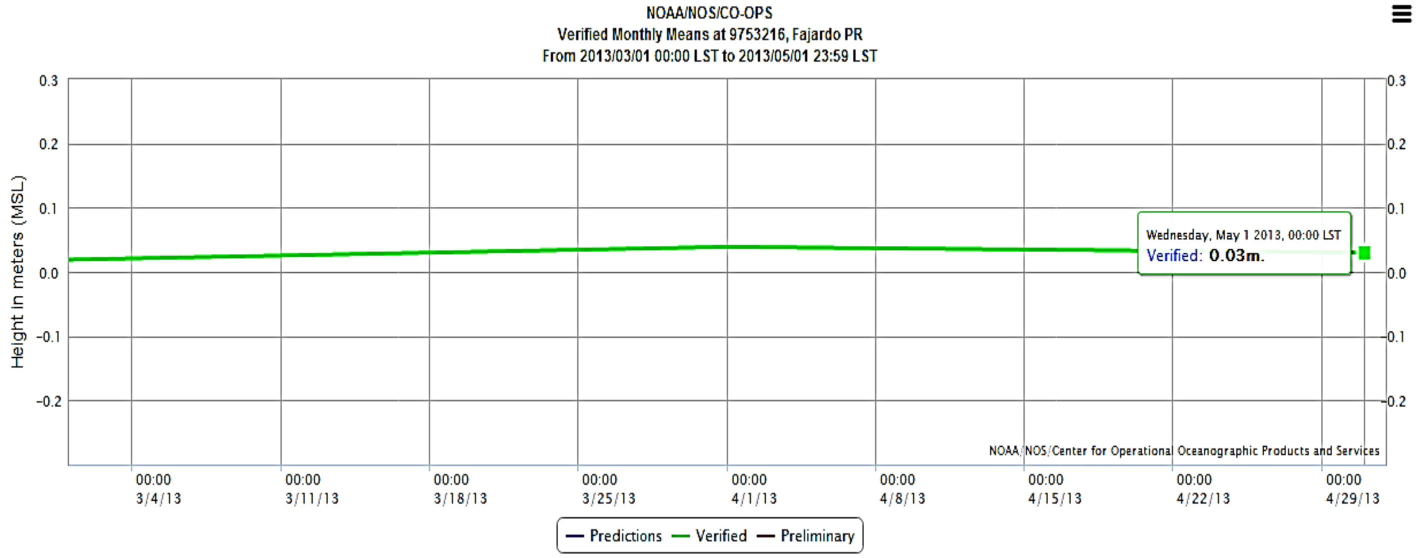
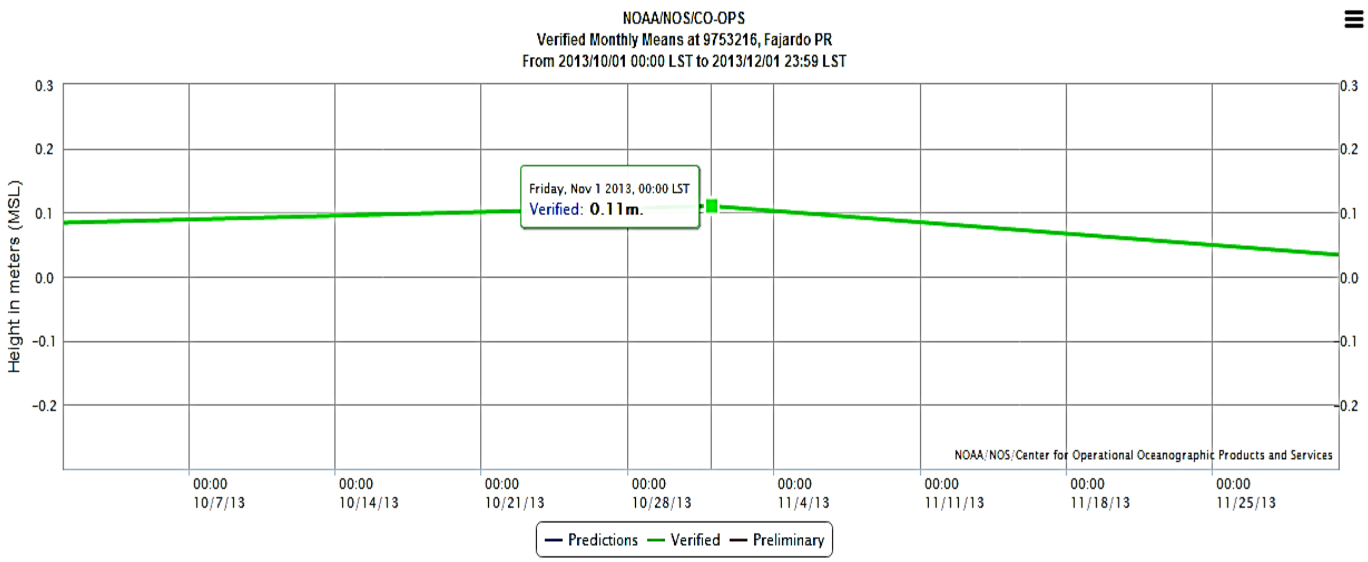
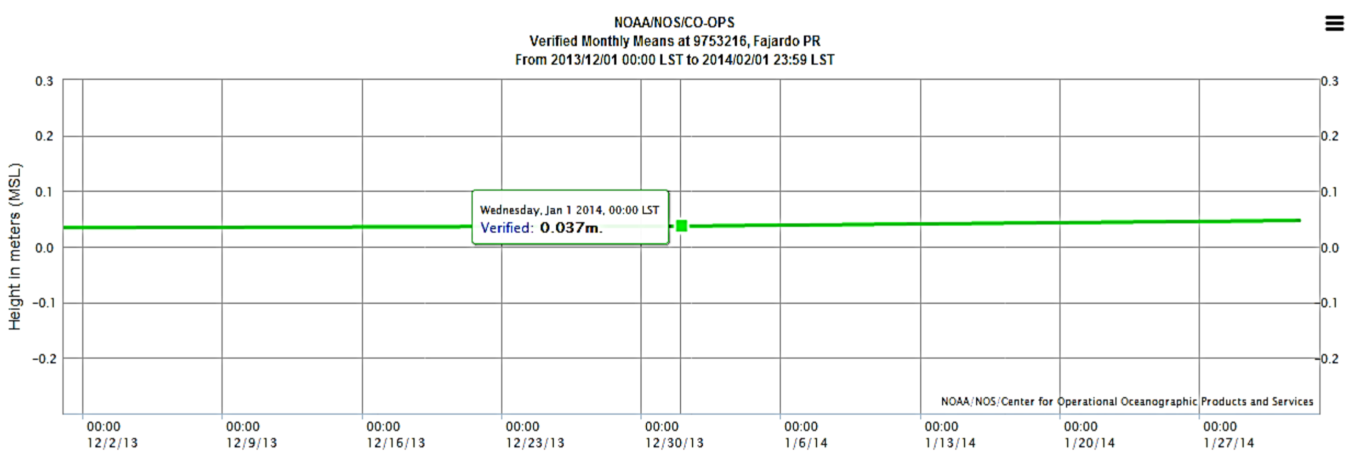
Appendix 1. Composite topographic and bathymetric contour map of Fajardo and Cayo Icacos.







Appendix 2. Graphs of Mean Sea Level measured by NOAA at the Fajardo Station. May 2013 is shown at the top, November 2013 at the middle, and January 2014 shown at the bottom. Graphs provided by NOAA Tides & Currents website (tidesandcurrents.noaa.gov).