Loss of Coastlines After Natural Disasters and the Importance of Coral Reefs: Ponce and Rincon as Sample Areas

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Abstract

Aim To identify the changes in coastal areas and document if hurricanes and earthquakes have had an effect on the loss of coral reefs or coastline. Utilizing Ponce and Rincon as sample areas to mapping coastline and transformation of coral reef through years 2010, 2017 and 2020.

Location Puerto Rico; Ponce and Rincon.

Methods Coastlines and coral reefs were mapped through ENVI, using the Region of Interest (ROI) tool. While Coastlines were solely lined using the ROI's as vector overlay the coral reefs were identified using the Maximum Likelihood method of classification.

Results It was identified that the coastline changed partially from 2010 to 2020, most noticeable in Ponce. Coral reefs seemed to be more abundant on Rincon in 2020 than 2010.

Main Conclusions The Rincon coastline seems to have recovered from the hurricanes while the Ponce coastline continues receding. The corals in Ponce declined recently while in Rincon they seem to be more abundant than before.

Keywords

Coral reefs, Coastline, Ponce, Rincon, ENVI, Coastal changes, Landsat7 ETM+, Landsat 8 OLI, Maximum Likelihood.

Introduction

Hurricanes and earthquakes are some of the natural events that affect coral reefs, in recent years Puerto Rico (PR) has suffered various devastating natural events, investigating how it has affected its coastal area can help understand the effects. Taking Ponce and Rincon as the sample areas to study these phenomena allows us to identify small and big changes that could be common around the island. These two locations were chosen because Rincon was known for tourism surrounding snorkeling and scuba diving, and Ponce suffered earthquakes that damaged La Guancha.

Corals have an important role not only in commerce, in both areas, but also serve as the natural protection to the coastline and serve as a home to the aquatic ecosystems in the shore. Corals also provide on average 65% of our oxygen, making them one of the most important ecosystems, followed by rainforests. (NOAA, 2021)

The sensors used included Landsat ETM+, which has a total of eight bands and spatial resolution ranging from 15 to 60 meters; and Landsat 8 OLI, which has a total of nine bands and spatial resolution of 30 meters. Which were decided following peer reviewed scientific papers as: “Mapping of Coral Reefs with Multispectral Satellites: A Review of Recent Papers” (Hedley et. al. 2016), “Remote sensing of coral reefs and their physical environment” (Nguyen et. al. 2021),” Mysterious Coral Reef Halos Can Be Seen from Space” (Morton, M. 2019), and “Remote Sensing of Coral Reefs for Monitoring and Management: A Review” (Goodman, J. et. al.)

The investigations taken into account for the comparison in the investigation included “The state of the beaches in Puerto Rico Post-Maria” (Barreto, 2022) and “Status of Puerto

Rico's Coral Reefs in the Aftermath of Hurricanes Irma and Maria - DRNA" (Bradley, 2022).

This investigation aims to identify how the coastline looks after natural disasters and to understand how the coral reefs are being affected with the changes in the coastline. It has been observed that the coastline has changed dramatically in recent years, the investigation seeks to identify if the changes have been constantly negative or if the coastline has been able to recover. As Well as documenting how, these changes affect coral reefs or if there is no evident correlation between the two.

Objectives

The objectives include documenting the changes in the coastline and coral reef abundance. Even though the loss of coastal areas in Puerto Rico has been noticed, there are a few projects discussing and documenting the changes to bring more attention to the importance of these ecosystems. The first objective is based on remote sensing while the second objective is more of an ethical and ecological factor to make people conscious of the impact and the rapid rate at which our coast is changing.

For this investigation it's important to compare the results to other works because of the many discrepancies the methods can cause.

Materials and Methods

Images from Landsat 7 ETM+ and Landsat 8 OLI sensors were gathered through Earth explorer, collecting images from 2010, 2017 and 2020. These images were acquired with EarthExplorer and processed through ENVI using the ROI and Maximum Likelihood Tools. This allowed the identification of distinct differences between the designated areas and the changes that occurred through the years visually.

Another resource used during the development was the Allen Coral Atlas for comparison and visual guide to know how the coral distribution should look. While CostaVisPR helped do the same with the coastline changes.

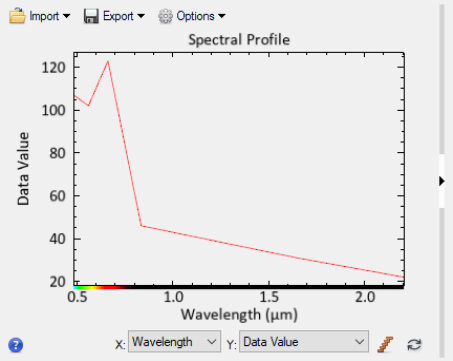
It was difficult to find projects on the Puerto Rico coastline but a recently published project by UPRRP “The state of the beaches in Puerto Rico Post-Maria” (Barreto, 2022) undergraduate students was used to compare results.

After processing the images, the percentages of distribution of the coral and halo classes were gathered to quantify the abundance of coral reefs that the Maximum Likelihood showed in each image.

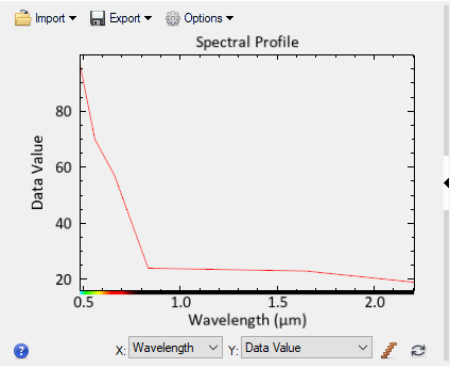
Procedure

The images were categorized by years, and each underwent atmospheric correction through dark subtraction and resizing. For Ponce the resizing was 500 x 1000 and for Rincon 500 x 500. The only image that required mosaics was Ponce 2010.

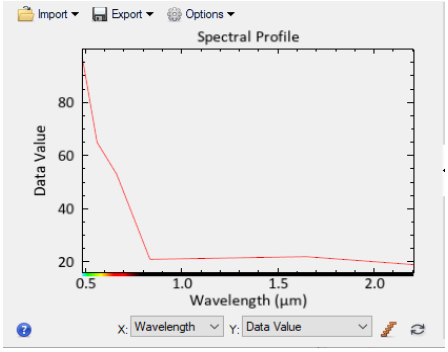
For the coral reefs the distribution of classes was determined by analyzing the picture visually and noticing the most prominent features. In Ponce the distribution was direct, separating land, water, coral halos, and coral reefs. For the Rincon area the distribution had to be broaden, since all pictures showed the sediment of the nearby rivers being deposited into the coast. To be able to cause the minimum confusion to the program three classes were identified. The classes included high/most sediment, medium sediment, and low/least sediment. ENVI allowed us to observe an average of the wavelengths that these slightly different classes show.



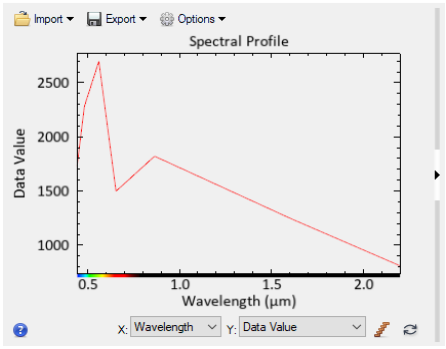
Graph I: High/most sediment spectral profile



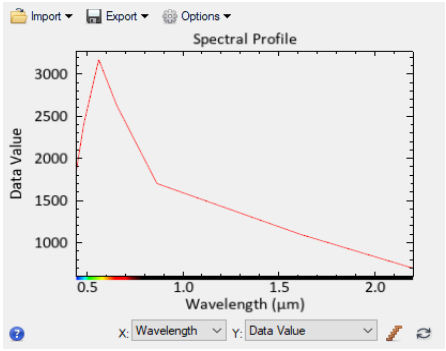
Graph II: Medium sediment spectral profile



Graph III: Low/least sediment spectral profile



Graph VI: Coral reef halos spectral profile



Graph V: Coral reefs spectral profile

Coastlines were determined using enhancement and making the image grayscale to have a better perception of the coast in each of the images. After the ROI of the coastline was finished, they were all opened on the same image showing the changes through the years.

Results

Coral reefs

Ponce

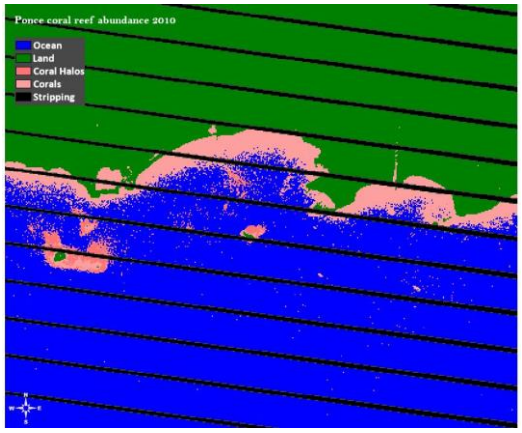


Image I: Landsat 7 ETM+ (2010), Maximum Likelihood coral reefs identification Ponce area

Class Summary	Pixel Count	Percent
Unclassified	15428	9.404335
Ocean	75566	46.062224
Land	57137	34.828591
Coral Halos	1666	1.015532
Corals	9638	5.874966
Masked Pixels	4617	2.814352

Table I: Landsat 7 ETM+ (2010), Percentage of classes Ponce area

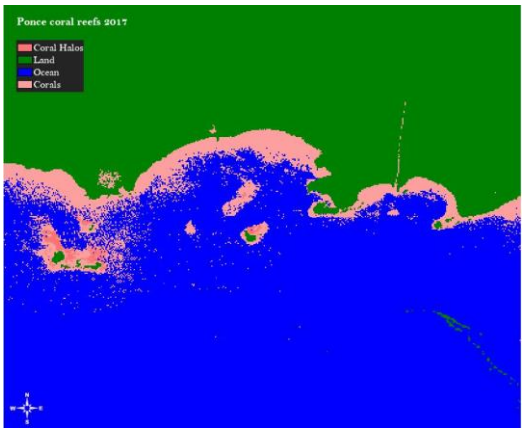


Image II: Landsat 8 OLI (2017), Maximum Likelihood coral reefs identification Ponce area

Class Summary	Pixel Count	Percent
Unclassified	0	0.000000
Coral Halos	644	0.392558
Land	65604	39.989759
Ocean	86637	52.810694
Corals	11166	6.806378
Masked Pixels	1	0.000610

Table II: Landsat 8 OLI (2017), Percentage of classes Ponce area

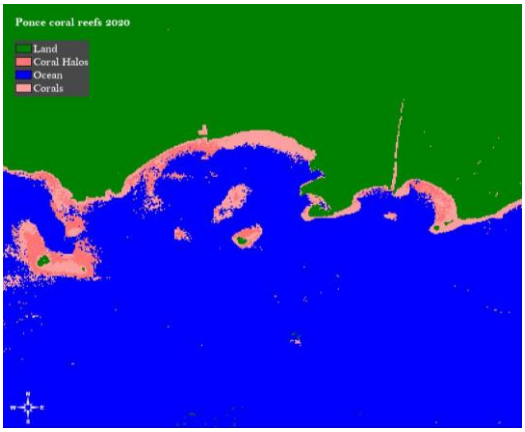
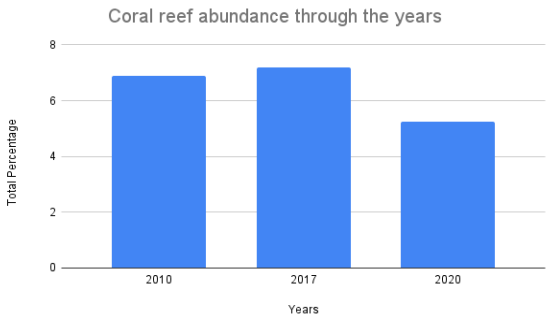


Image III: Landsat 8 OLI (2020), Percentage of classes Ponce area

Class Summary	Pixel Count	Percent
Unclassified	0	0.000000
Land	65196	39.741058
Coral Halos	2901	1.768342
Ocean	90234	55.003292
Corals	5720	3.486699
Masked Pixels	1	0.000610

Table III: Landsat 8 OLI (2020), Maximum Likelihood coral reefs identification Ponce area



Graph I: Coral reef abundance through the years in Ponce coast

For Ponce it was found that the abundance of corals seems to be receding through the years. As shown on Table I in 2010 and 2017 the average was around 7% of coral reefs while in 2020 it shows to be around 5%. Considering that the image of 2010 ss from ETM+ and that the images from 2017 and 2020 are from OLI, it could be assumed that the change in the sensor was not a variable that affected greatly the differences of percentages. The results of the Maximum Likelihood can be affected by multiple reasons, and these could be the reason 2020 is drastically different from 2017.

Rincon

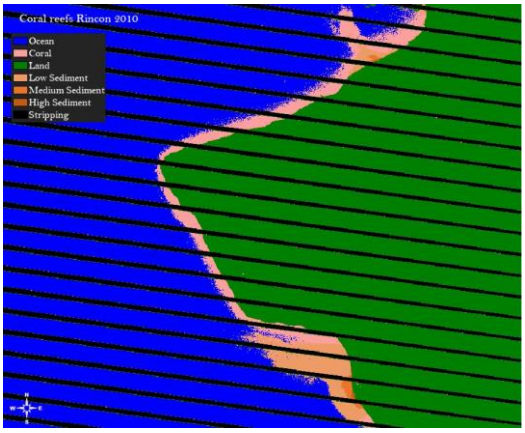


Image IV: Landsat 7 ETM+ (2010), Maximum Likelihood coral reefs identification Rincon area

Class Summary	Pixel Count	Percent
Unclassified	102115	19.679281
Ocean	191085	36.825298
Coral	13575	2.616131
Land	200397	38.619878
Low Sediment	8323	1.603982
Medium Sediment	1484	0.285992
High Sediment	87	0.016766
Masked Pixels	1830	0.352672

Table IV: Landsat 7 ETM+ (2010), Percentage of classes Rincon area

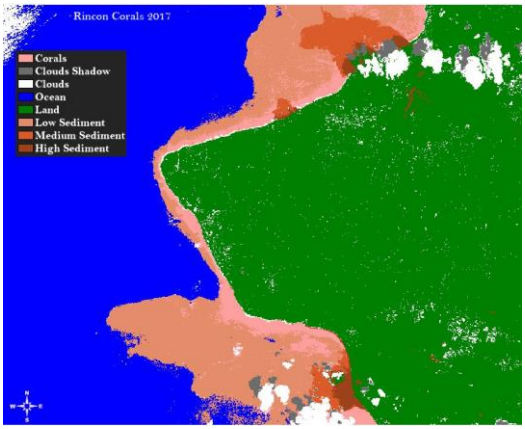


Image V: Landsat 8 OLI (2017), Maximum

Likelihood coral reefs identification Rincon area

Class Summary	Pixel Count	Percent
Unclassified	0	0.000000
Corals	15110	2.911952
Clouds Shadow	4079	0.786092
Clouds	18487	3.562756
Ocean	190646	36.740696
Land	222201	42.821876
Low Sediment	55706	10.735485
Medium Sediment	8965	1.727707
High Sediment	3701	0.713245
Masked Pixels	1	0.000193

Table V: Landsat 8 OLI (2017), Percentage of classes Rincon area

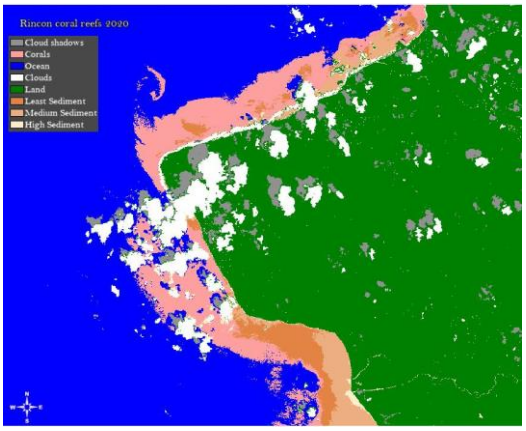
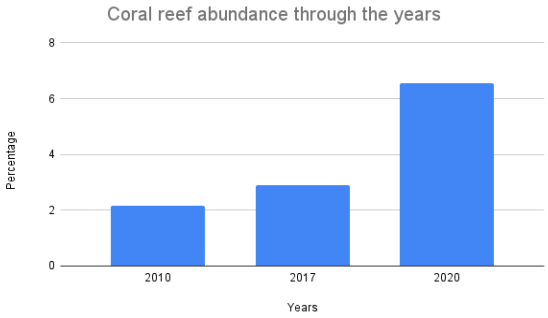


Image VI: Landsat 8 OLI (2020), Maximum Likelihood coral reefs identification Rincon area

Class Summary	Pixel Count	Percent
Unclassified	0	0.000000
Cloud shadows	14368	2.768956
Corals	33983	6.549097
Ocean	210098	40.489424
Clouds	26687	5.143034
Land	211202	40.702183
Least Sediment	9492	1.829268
Medium Sediment	10036	1.934106
High Sediment	3029	0.583739
Masked Pixels	1	0.000193

Table VI: Landsat 8 OLI (2020), Percentage of classes Rincon area



Graph II: Coral reef abundance through the years in Rincon coast

In Rincon it was found that 2020, once again, seemed drastically different from 2010 and 2017. In this case the percentage of abundance was higher and confirmed that it is due to the program overestimating and classifying the areas differently than anticipated.

Coastline

Ponce

Image VII: Landsat 8 OLI (2020), ROI of the coastline Ponce area in a decade

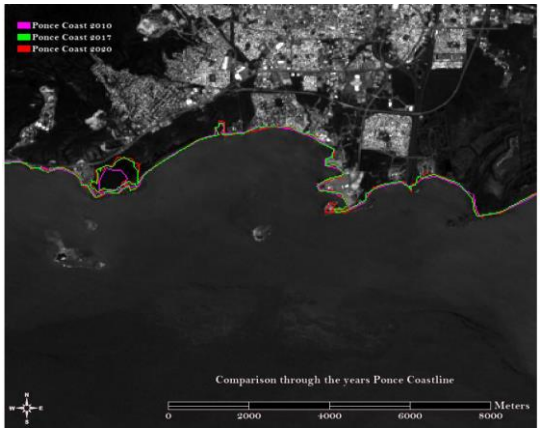
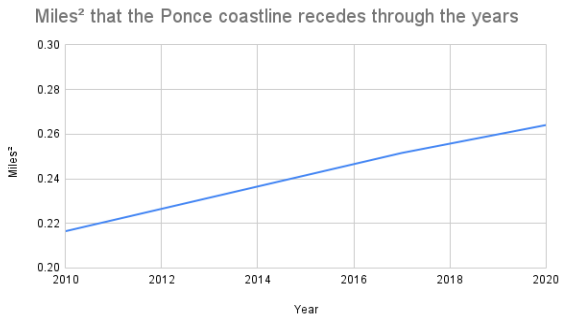
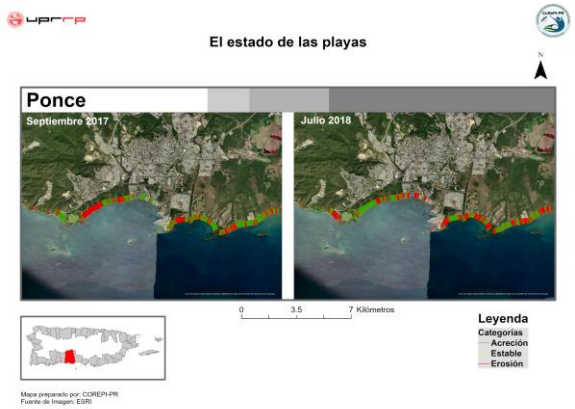


Image VIII: Landsat 8 OLI (2020), ROI of the coastline Ponce area through the years



Graph III: Ponce Coastline recedes through the years

On a lesser relative part, the Ponce Coastline could be quantified for its constant receding through the years. This data is accurate with the data found on other investigations such as the one conducted by Barreto.



Analysis of the Ponce coastline from" The state of the beaches in Puerto Rico Post-Maria" (Barreto-Orta 2022)

Rincon

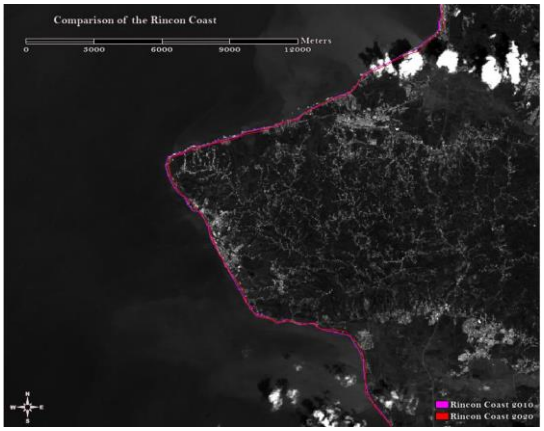


Image IX: Landsat 8 OLI (2020), ROI of the coastline Rincon in a decade

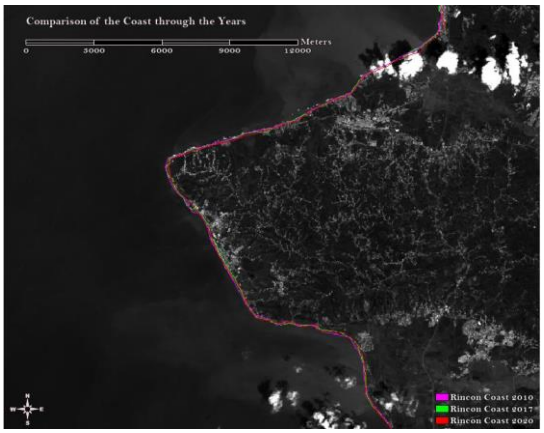
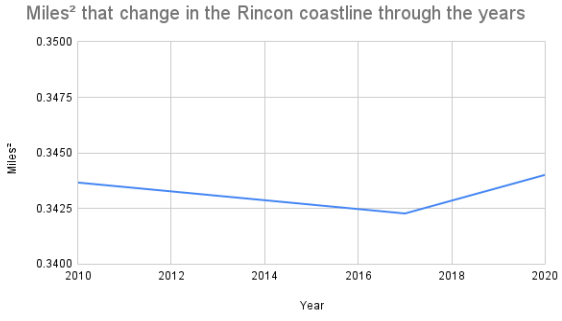
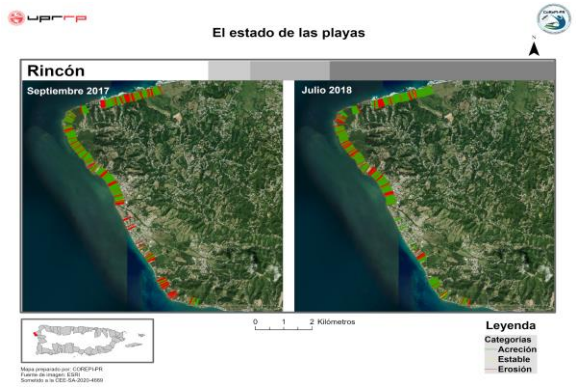


Image X: Landsat 8 OLI (2020), ROI of the coastline Rincon area through the years



Graph IV: Rincon Coastline through the years

The Rincon Coastline seemed to be more stable, and the receding started in 2017.



Analysis of the Rincon coastline from" The state of the beaches in Puerto Rico Post-Maria" (Barreto-Orta 2022)

Discussion

It was found that the classification of images is difficult even if one of the most precise methods of supervised classification is used. This can be due to multiple reasons ranging from the different types of sensors, the atmospheric correction, the disparity of classes and the program limitations and selection of ROI. The results could be influenced by one or multiple of these factors.

Since coral reefs are underwater there are many factors that should have been taken into consideration and others that could not be taken into consideration because of the limited resources during the project. The lack of secondary investigation in Puerto Rico and the difficulties encountered with images make it difficult to get precise conclusions.

The coastlines are more coherent and quantifiable, allowed to observe and compare how the coastline did recede in Ponce 2017 and continued to do so into 2020. This can be heavily attributed to hurricanes of that year since the decline on the coastline is evident and the results on Rincon show changes in the coastline in that year as well.

If both data sets from coral reefs and coastlines are compared it can be observed that coral reefs and coastlines do seem to have a relationship but not exactly as it was hypothesized. If the percentages of corals were correct the graphs would show that as the coastline recedes in Ponce the coral reefs become more abundant. While showing that in Rincon the more the coastline recedes the less coral reefs there are. The second one seems to be more accurate, but the ROI and the Maximum Likelihood on Rincon represented a problem for classification.

For future investigation it is recommended to have access to a sensor with better spatial resolution. To have images of the area sensors like IKONOS or hyperspectral sensors Hyperion. It is also important to have access to a better atmospheric correction. To make an investigation like this more accurate and quantifiable it would require having measurements of the changes of sea level throughout the years and barometric data. Overall, to have more data to compare the abundance of corals and its relationship to coastlines

References

"Allen Coral Atlas." 2022. *Allencoralatlas.Org*. Accessed May 20.

https://allencoralatlas.org/atlas/#11.54/17.9791/-66.6259.

Barreto-Orta, Maritza. 2022. “El Estado de Las Playas de Puerto Rico Post-María (Grupo 4).” *Esri*. https://storymaps.arcgis.com/stories/cfb881871c384069ab59621e58492f1c.

Bradley, Dorothy. 2022. “Status of Puerto Rico’s Coral Reefs in the Aftermath of Hurricanes Irma and Maria - DRNA.” *Readkong.Com*. Accessed May 20. https://www.readkong.com/page/status-of-puerto-rico-s-coral-reefs-in-the-aftermath-of-6452377.

Chao, Julie. 2018. “Berkeley Lab Researchers Use Remote Sensing Techniques to Assess Hurricane Impact on Trees.” *Earth and Environmental Sciences Area*. https://eesa.lbl.gov/berkeley-lab-researchers-use-remote-sensing-techniques-assess-tree-mortality-puerto-rico-hurricanes/.

“Coral Reef Project: Puerto Rico.” 2022. *Usgs.Gov*. Accessed May 20. https://www.usgs.gov/centers/pcmsc/science/coral-reef-project-puerto-rico.

“Coral Reefs.” 2022. *Coastalwiki.Org*. Accessed May 20. http://www.coastalwiki.org/wiki/Coral_reefs

“CostaVisPR: Vista Aérea de La Transformación Costera de Puerto Rico.” 2022. *Costavispr.Org*. Accessed May 20. https://www.costavispr.org.

De abril de, 27. 2022. “El Estado de Las Playas de Puerto Rico Post-María (Grupo 4).” *Esri*. https://storymaps.arcgis.com/stories/cfb881871c384069ab59621e58492f1c.

“Exploring Reefs from Space.” 2015. https://earthobservatory.nasa.gov/images/86163/exploring-reefs-from-space.

Goodman, James A., Samuel J. Purkis, and Stuart R. Phinn, eds. 2013. *Coral Reef Remote Sensing*. Dordrecht: Springer Netherlands.

Hedley, John, Chris Roelfsema, Iliana Chollett, Alastair Harborne, Scott Heron, Scarla Weeks, William Skirving, et al. 2016. “Remote Sensing of Coral Reefs for Monitoring and Management: A Review.” *Remote Sensing* 8 (2): 118. doi:10.3390/rs8020118.

Knudby, Anders, Simon J. Pittman, Joseph Maina, and Gwilym Rowlands. 2014. “Remote Sensing and Modeling of Coral Reef Resilience.” In *Remote Sensing and Modeling*, 103–134. Cham: Springer International Publishing.

“Landsat 7 (L7) Data Users Handbook.” 2019. *Amazonaws.Com*. https://d9-wret.s3.us-west-2.amazonaws.com/assets/palladium/production/s3fs-public/atoms/files/LSDS-1927_L7_Data_Users_Handbook-v2.pdf.

Morton, Mary. 2019. “Mysterious Coral Reef Halos Can Be Seen from Space.” *Eos* 100. doi:10.1029/2019eo122611.

Morton, Mary. 2022. “Mysterious Coral Reef Halos Can Be Seen from Space.” *Researchgate.Net*. Accessed May 20. https://www.researchgate.net/publication/332894948_Mysterious_Coral_Reef_Halos_Can_Be_Seen_from_Space.

Mumby, Peter J., William Skirving, Alan E. Strong, John T. Hardy, Ellsworth F. LeDrew, Eric J. Hochberg, Rick P. Stumpf, and Laura T. David. 2004. “Remote Sensing of Coral Reefs and Their Physical Environment.” *Marine Pollution Bulletin* 48 (3–4): 219–228.

doi:10.1016/j.marpolbul.2003.10.031.

“Natural and Cultural Resources Recovery Support Function.” 2022. *Fema.Gov*. Accessed May 20. https://www.fema.gov/press-release/20210318/natural-and-cultural-resources-recovery-support-function.

Nguyen, Teo, Benoît Liquet, Kerrie Mengersen, and Damien Sous. 2021. “Mapping of Coral Reefs with Multispectral Satellites: A Review of Recent Papers.” *Remote Sensing* 13 (21): 4470. doi:10.3390/rs13214470.

NOAA. 2022. “How Much Oxygen Comes from the Ocean?” Accessed May 20. https://oceanservice.noaa.gov/facts/ocean-oxygen.html.

“Publications: Armstrong and Singh 2006.” 2022. *Mesophotic.Org*. Accessed May 20. http://www.mesophotic.org/publications/131

Sanders, Laura. 2021. “Satellites Are Being Used to Help Save the World’s Coral Reefs.” *Euronews*. https://www.euronews.com/green/2021/01/14/space-satellites-hold-the-secret-to-saving-the-world-s-coral-reefs.

“The Plan to Map Every Coral Reef on Earth – from Space.” 2021. *UNEP*. https://www.unep.org/news-and-stories/story/plan-map-every-coral-reef-earth-space.

USGS-U.S. Geological Survey. 2022. “EarthExplorer.” *USGS - U.S. Geological Survey*. Accessed May 20. https://earthexplorer.usgs.gov.

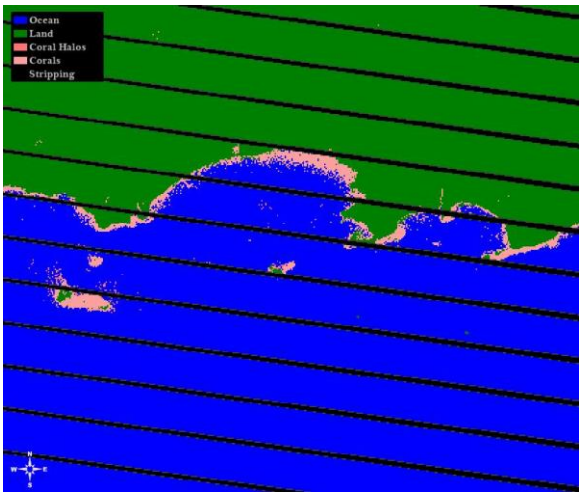
“Using Satellite Images, Scientists Create Comprehensive Global Coral Reef Atlas Online.” 2021. *Tech2*. https://www.firstpost.com/tech/science/using-satellite-images-scientists-create-comprehensive-global-coral-reef-atlas-online-9949261.html.

2022a. *Dmu.Dk*. Accessed May 20. https://www.dmu.dk/RESCOMAN/Project/Backgrounds/challenges.htm.

2022b. *Researchgate.Net*. Accessed May 20. https://www.researchgate.net/figure/Map-showing-the-major-cities-on-the-coastal-area-in-Lebanon-Source-Destination-360_fig1_308720859.

Appendix

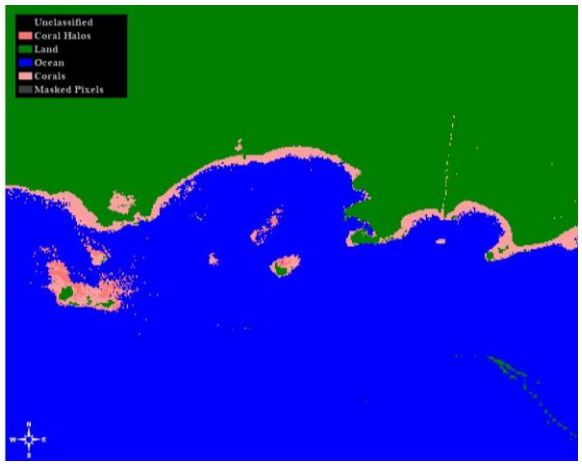
Ponce



Landsat 7 ETM+ (2010), Maximum Likelihood coral reefs identification Ponce area training

Class Summary	Pixel Count	Percent
Unclassified	15428	9.404335
Ocean	83065	50.633336
Land	57699	35.171165
Coral Halos	161	0.098140
Corals	3082	1.878673
Masked Pixels	4617	2.814352

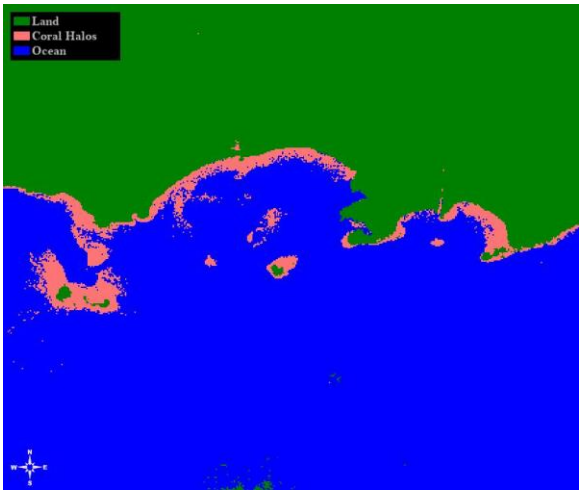
Landsat 7 ETM+ (2010), Percentage of classes Ponce area training



Landsat 8 OLI (2017), Maximum Likelihood coral reefs identification Ponce area training

Class Summary	Pixel Count	Percent
Unclassified	0	0.000000
Coral Halos	834	0.508375
Land	65374	39.849560
Ocean	93353	56.904518
Corals	4490	2.736937
Masked Pixels	1	0.000610

Landsat 8 OLI (2017), Percentage of classes Ponce area training

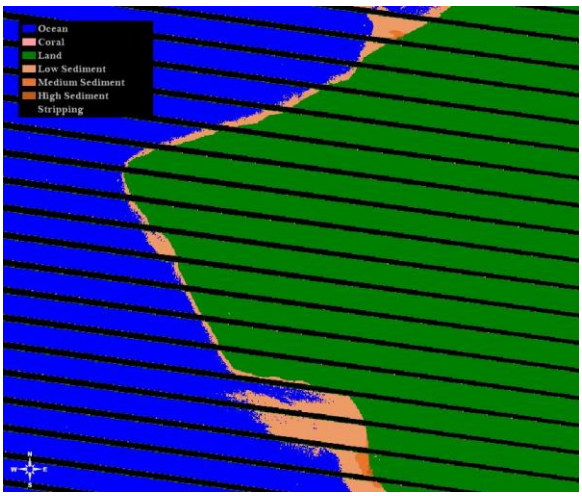


Landsat 8 OLI (2020), Maximum Likelihood coral reefs identification Ponce area training

Class Summary	Pixel Count	Percent
Unclassified	0	0.000000
Land	65974	40.215298
Coral Halos	5956	3.630556
Ocean	92121	56.153537
Masked Pixels	1	0.000610

Landsat 8 OLI (2020), Percentage of classes Ponce area

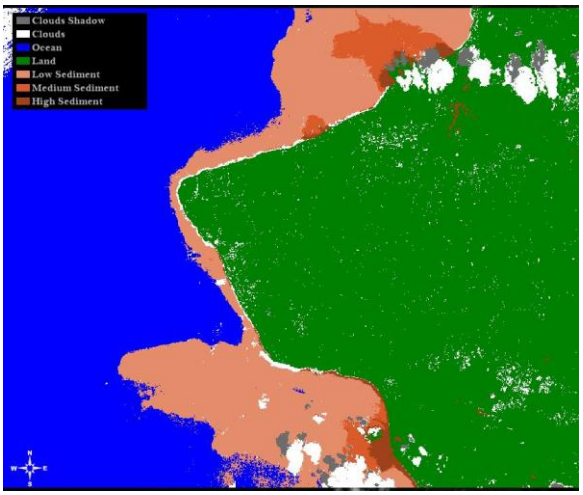
Rincon



Landsat 7 ETM+ (2010), Maximum Likelihood coral reefs identification Rincon area

Class Summary	Pixel Count	Percent
Unclassified	0	0.000000
Corals	15110	2.911952
Clouds Shadow	4079	0.786092
Clouds	18487	3.562756
Ocean	190646	36.740696
Land	222201	42.821876
Low Sediment	55706	10.735485
Medium Sediment	8965	1.727707
High Sediment	3701	0.713245
Masked Pixels	1	0.000193

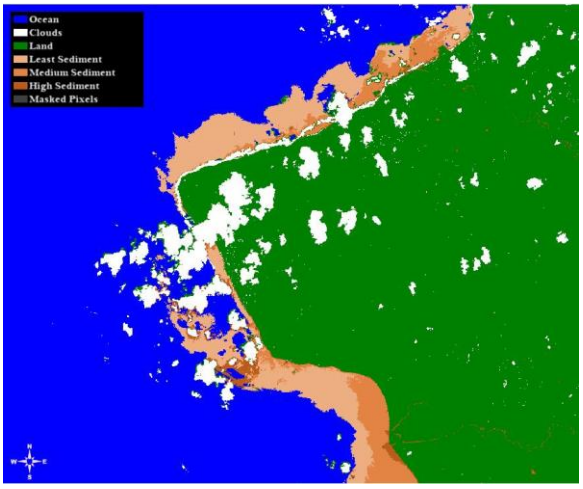
Landsat 7 ETM+ (2010), Percentage of classes Rincon area



Landsat 8 OLI (2017), Maximum Likelihood coral reefs identification Rincon area training

Class Summary	Pixel Count	Percent
Unclassified	102115	19.679281
Ocean	191085	36.825298
Coral	13575	2.616131
Land	200397	38.619878
Low Sediment	8323	1.603982
Medium Sediment	1484	0.285992
High Sediment	87	0.016766
Masked Pixels	1830	0.352672

Landsat 8 OLI (2017), Percentage of classes Rincon area training



Landsat 8 OLI (2020), Maximum Likelihood coral reefs identification Rincon area training

Class Summary	Pixel Count	Percent
Unclassified	0	0.000000
Ocean	225866	43.528183
Clouds	27010	5.205282
Land	223853	43.140244
Least Sediment	26571	5.120679
Medium Sediment	11140	2.146866
High Sediment	4455	0.858554
Masked Pixels	1	0.000193

Landsat 8 OLI (2020), Percentage of classes Rincon area training

Allen Coral Atlas Ponce Coral reefs abundance

Allen Coral Atlas Rincon Coral reefs abundance