Remote sensing techniques: A study of the Puerto Rico mangrove zones before and after the events of hurricane maria to assess vegetation loss in and mitigation in the area.

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Abstract: Puerto Rico throughout history has been affected by heavy storm events that have caused some of the most important natural ecosystems to lose one of its prime vegetation resources, the mangrove. During hurricanes, the rotational speed of the force of wind causes loss in vegetation and in coastal areas for which the damage may be direct or indirect. By using remote sensing techniques and processing images in the ENVI software, large mangrove areas can be studied. The images in this study correspond to the PlanetLabs planetscope sensor that allows the acquisition of high-resolution images with a minimal eight bands and a maximum of fourteen bands. Theses sensor images that were acquired correspond to the dates before and after the events of Hurricane Maria. By applying an algorithm for the "Normalize Difference Vegetation Index" (NDVI) and the "short wave normalize difference vegetation index (SNDVI) for finding the change to the mangrove areas biomass. These analyzes resulted in varying values for both dates, these values allow for the calculation of an FVC- Fractional vegetation coverage, which estimates the relation of the biomass coverage in a predetermine zone. Based on these results, many of the mangrove zones suffered heavy losses in biomass as well as increased in ground exposure due to the reduction in vegetation. These values are conclusive in term of the concentration of vegetation in the areas were the mangrove zones were selected, there are still other factor that need to be considered to supply a complete assessments of the effects of theses ecosystem in relation to a storm event. In this cased the addition of other methods such as a field assessment, a more in-depth day to day study and lastly the application of other algorithm that may prove useful in determine the soil suspension factors based on the loss of vegetation in the area. Additional research may prove useful if applying the EVI algorithm to limit certain atmospheric errors when conduction image processing.

Key words: Vegetation, ENVI, SNDVI, NDVI, Planetscope, FVC.

INTRODUCTION

Mangrove zones prove to be some of the most efficient and productive ecosystems on earth, they are regions specific to areas of tropical and subtropical zones. Through the last years the mangrove species have been affected by both anthropogenic and natural forces, these forces have altered the mangroves species in coastal zones. Other effects on mangrove regions are in areas of development for which the affecting force is anthropogenic in nature. This ecosystem through the years has become one of the most key factors in terms of nursing grounds for many species of fauna as well as many other functions. The integrity of this ecosystem has changed through the years at an alarming rate because of development and extreme weather events, changes in sea level (Valle et al. 2019).

By using remote sensing techniques, it can have numerous advantages in question of mangrove monitoring in terms of the synoptic aspect and repeated coverage, and historical data. Therefore, remote sensing can correspond to field investigation implementation in regions of vast swamplands, marshlands, and other mangrove forest. The use of remote sensor imagery can be widely used for monitoring mangroves forest due to the spatial coverage and temporal coverage.

Mangrove system migration may allow for the protection of the coastal communities from section of coastal hazards as well known as the coastal ecology hazard mitigation. However, to decide proper mitigation factor in zones of mangroves the determination of magnitudes of the events need to be decided, the energy absorption of the magnitude requires systems of high concentration of mangrove density. For which studies of bathymetry and spectral characteristics of the incident wave and their arrival times.

MATERIALS AND METHODS

Study area

Preliminary study areas correspond to the coastal sections of Puerto Rico and were chosen based on the approximate effect area of Hurricane Maria. The selection of the mangrove zones is related to the hurricane pathing as well as the zone distance from the hurricane path figure 1. The mangrove zones in this study are the following: Campamento Piñónes (18 26’ 48” N -65 58’ 07” W), Paseo lineal de Isabela (18 30’ 35”N -67 03’ 33”W), Punta Carenero (18 04’ 24”N -67 11’ 43”W), and Boquerón wildlife Refuge (17 57’ 33” N -67 05’ 03”W)(Figure 2). The selection of these zones corresponds to having areas affected by the direct oscillation of the hurricane vortex as well the adjacent outer regions of the central vortex.

Acquiring Sensor Data

Acquisition of the high-resolution imagery corresponds to the planetscope satellite. The capture resolution for the areas of the study is about 3m/pixel, these images were obtained in the planet website (https://www.planet.com/products/planet-imagery/). A total of sixteen images were collected from the sites, for which eight total images were adjusted and composite together to have a complete image of the study area, allowing for two images per site for processing. These images correspond to the dates before and after the hurricane event, the dates of twenty-three august 2017 and 4 October 2017.

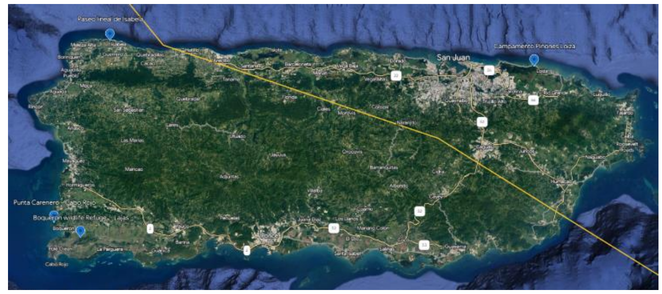

Figure 1 : Relative distance of mangrove zones from the approximate pathing of hurricane Maria

Figure 2: Selected zones of study for mangrove observations.

ENVI Processing

For each individual eight images the algorithm for NDVI was used, in the ENVI toolbox for “Band math” with the two following formulas:

$$NDVI = \frac{NIR - Red}{NIR + Red}$$

$$SNDVI = \frac{SWNIR - Red}{SWNIR + Red}$$

These two formulas, even though they are derived from the same vegetation index, the aspect of short wave near infrared (SWNIR) for the SNDVI allow for the determination of plant health/growth as well to monitor the changes in the biomass. In this study the SNDVI is used to determine decreases in biomass of the mangrove bodies and the changes to land values in geographical features. When utilizing these two algorithms, the generation of mask was needed to cover areas related to anthropogenic features/structures and large bodies of water.

In terms of other calculations performed during this study were the (FVC) Fractional vegetation coverage (L. Kaitao 2021), calculated from the NDVI values corresponding to the to the area coverage of the mangrove. This formula was also adapted for the SNDVI and was denominated the (SFVC) Short wave fractional area coverage. The formulas mentioned are the following:

$$FVC = \frac{NDVI - NDVI_{min}}{NDVI_{max} - NDVI_{min}}$$

$$SFVC = \frac{SNDVI - SNDVI_{min}}{SNDVI_{max} - SNDVI_{min}}$$

The use of these formulas was to estimate the area coverage values for the vegetation inside the selected study zones. Section ranges of 0.40-0.45 as a minimum were especially useful to cover value ranges not prudent to the areas of the study.

Many tests utilizing these values were performed to establish the best possible value range with the use of the cursor value tool. Application of the mask resulted in four masked NDVI images and Four masked SNDVI images. These new images had color pallets applied to them, for the NDVI the green-white pallet was applied and for SNDVI a custom pallet called earth was applied to better show the areas with increased soil exposure relative to the reduction in vegetation. After realizing both the index types the data for each of the index was transferred to excel to calculate the differences between each of the images and determine the average loss of vegetation for the event of hurricane Maria. Were calculations based on the covered areas were realized in respect to the NDVI and SNDVI, allowing for the determination of the loss/gain percentages for vegetation in the study areas (Table 1).

RESULTS

The NDVI and SNDVI images were used to determine the effects of the hurricane path through the adjacent areas in the island. The effects of Hurricane maria resulted in interest in the selected mangrove zones in terms of the level of reduction in biomass, especially in The Loiza Mangrove (Figure 3), the Isabela mangrove (Figure 4), the Cabo Rojo mangrove (Figure 5) and the Lajas Mangrove (Figure 6). Additional images corresponding to the analysis of NDVI are based on the short wave near infrared band, for which the formula was altered changing the original factor of NIFR to the SWIR band. For these the following corresponding images were created to calculate the biomass correspondent to the level of soil exposure in the area. The zones in question are the Loiza Mangrove (Figure 7), the Isabela Mangrove (Figure 8), the Cabo rojo mangrove (Figure 9) and the Lajas mangrove (Figure 10).

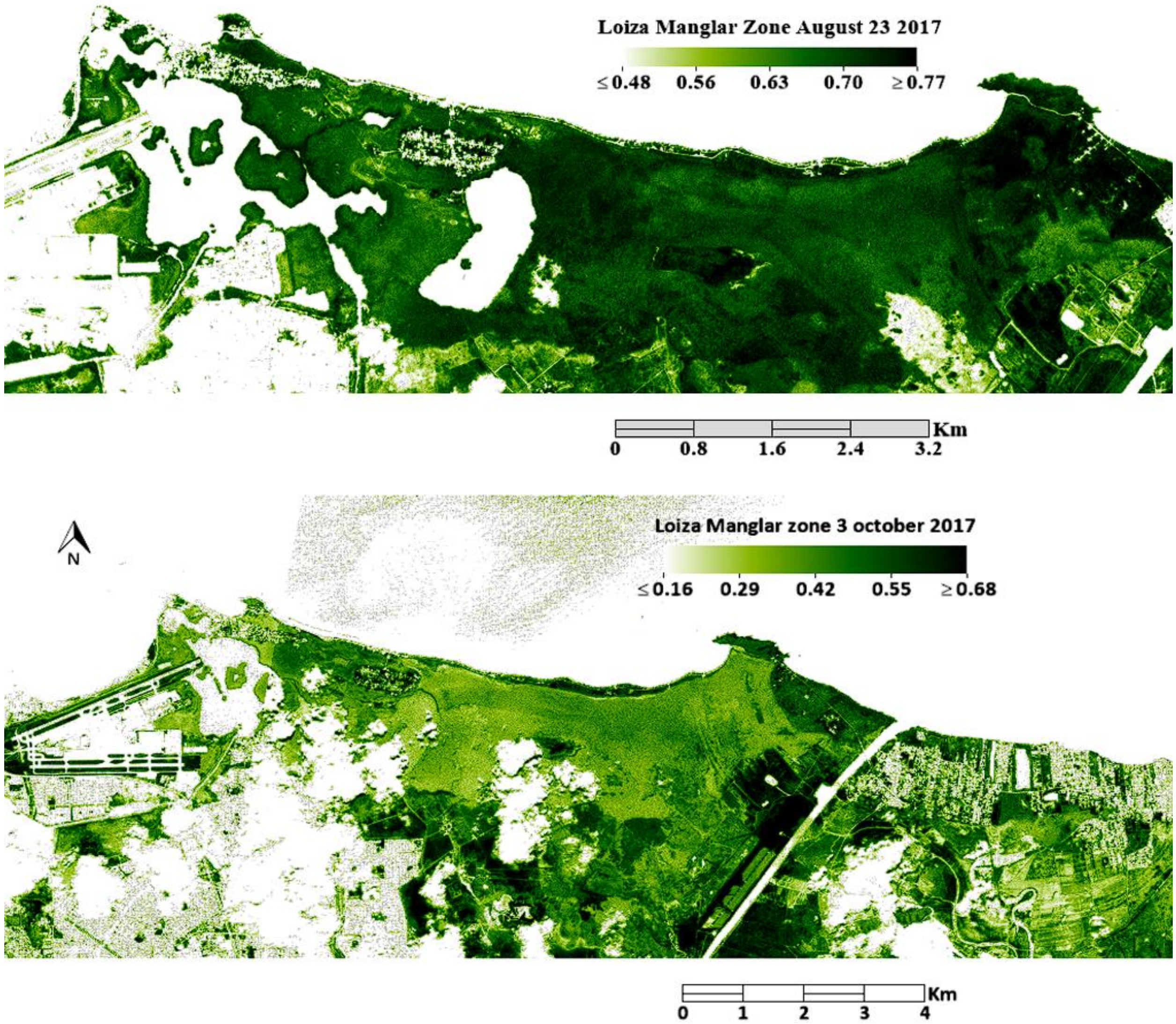

Figure 3 The Loiza Mangrove zone "Campamento Piñónes" for NDVI

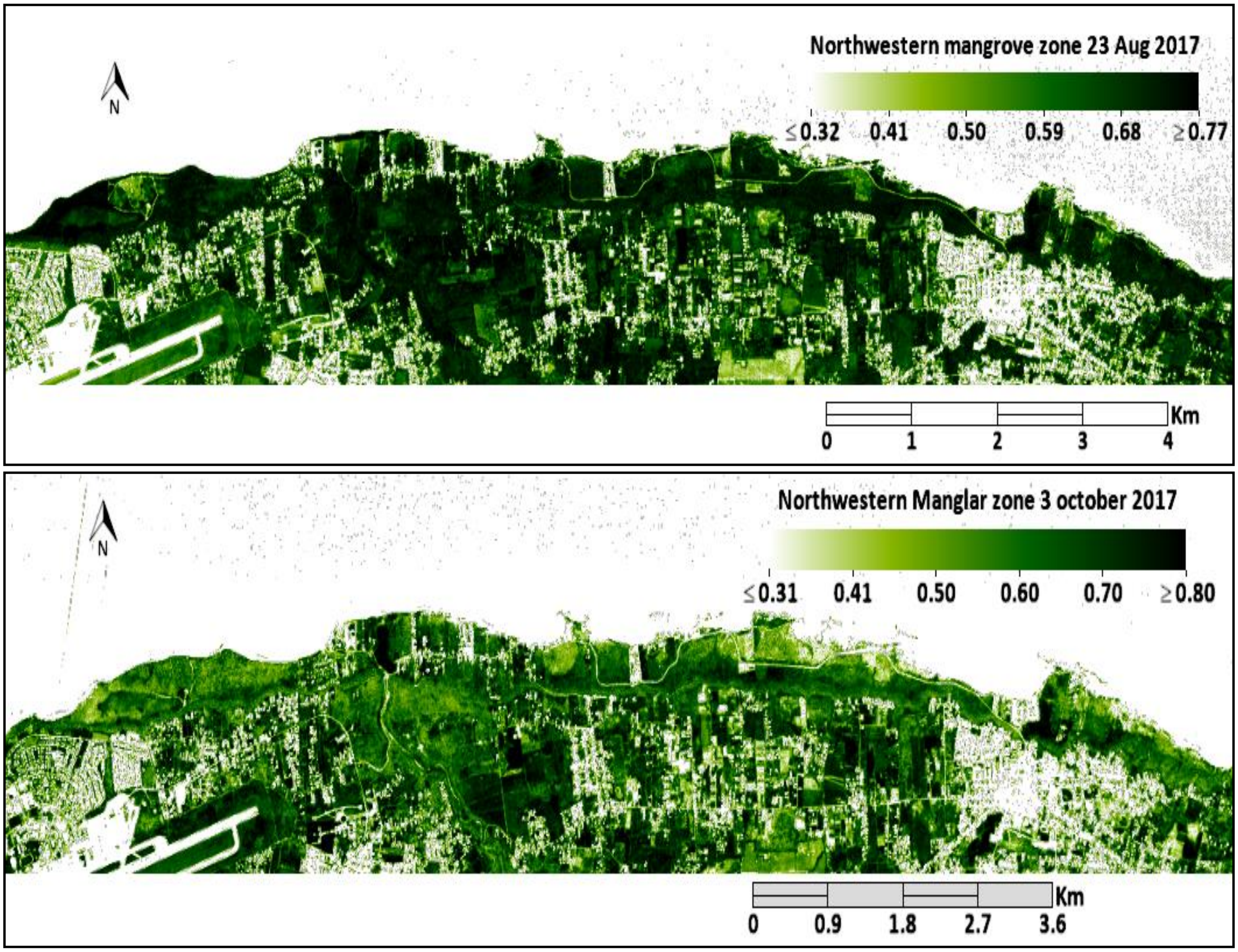

Figure 4 The Isabela Mangrove zone "Paseo lineal de Isabela" for NDVI

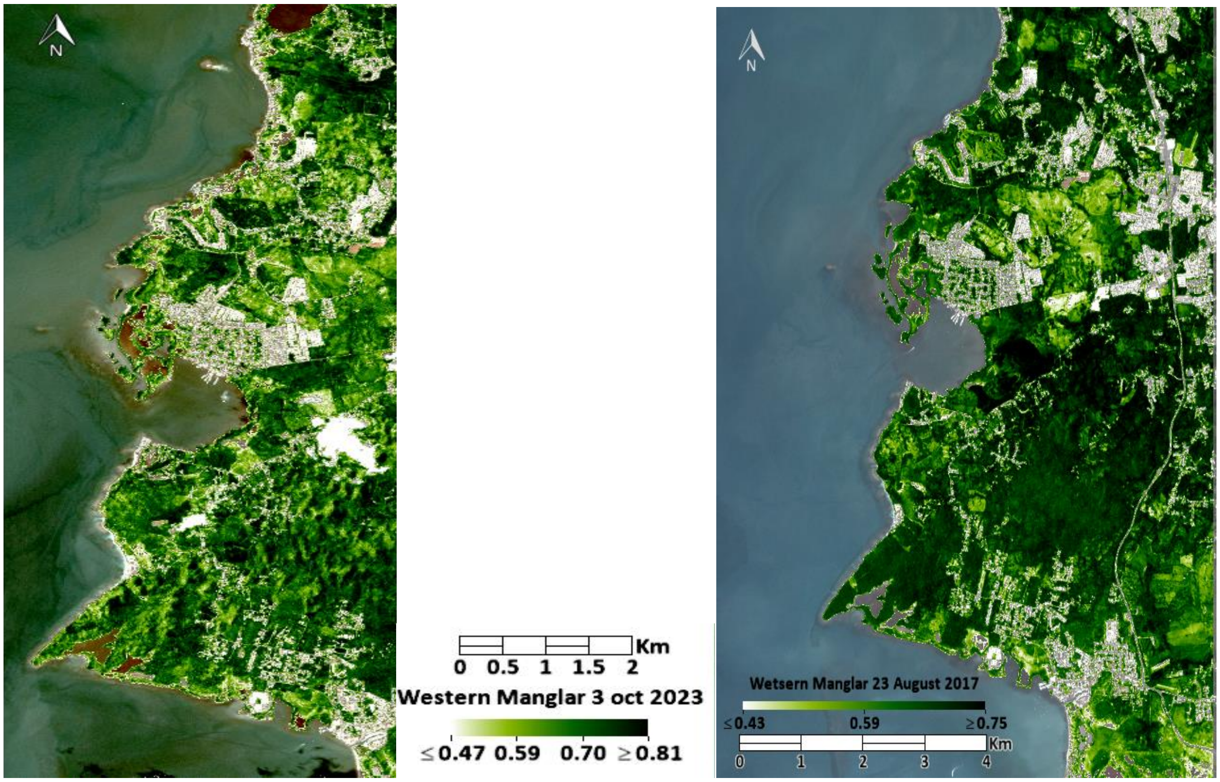

Figure 5 The Cabo Rojo Mangrove zone "Punta Carenero"

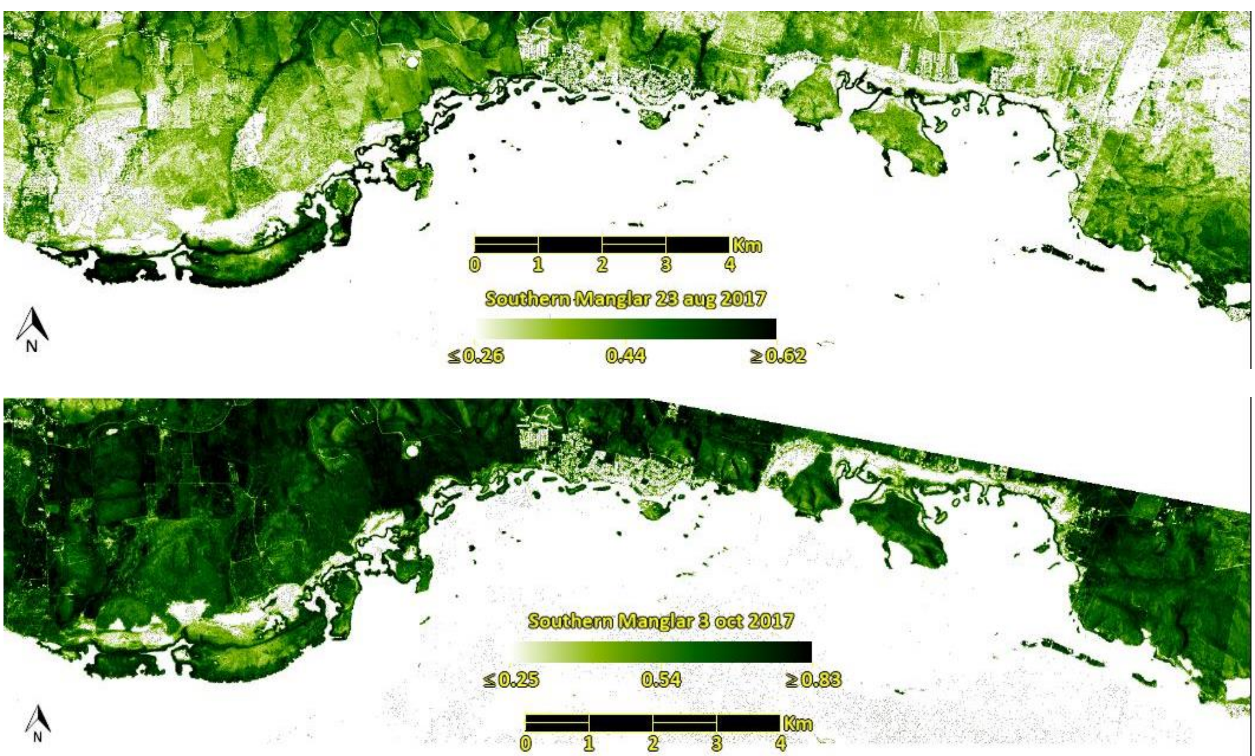

Figure 6 The Lajas Mangrove zone "Boquerón wildlife Refuge" for NDVI

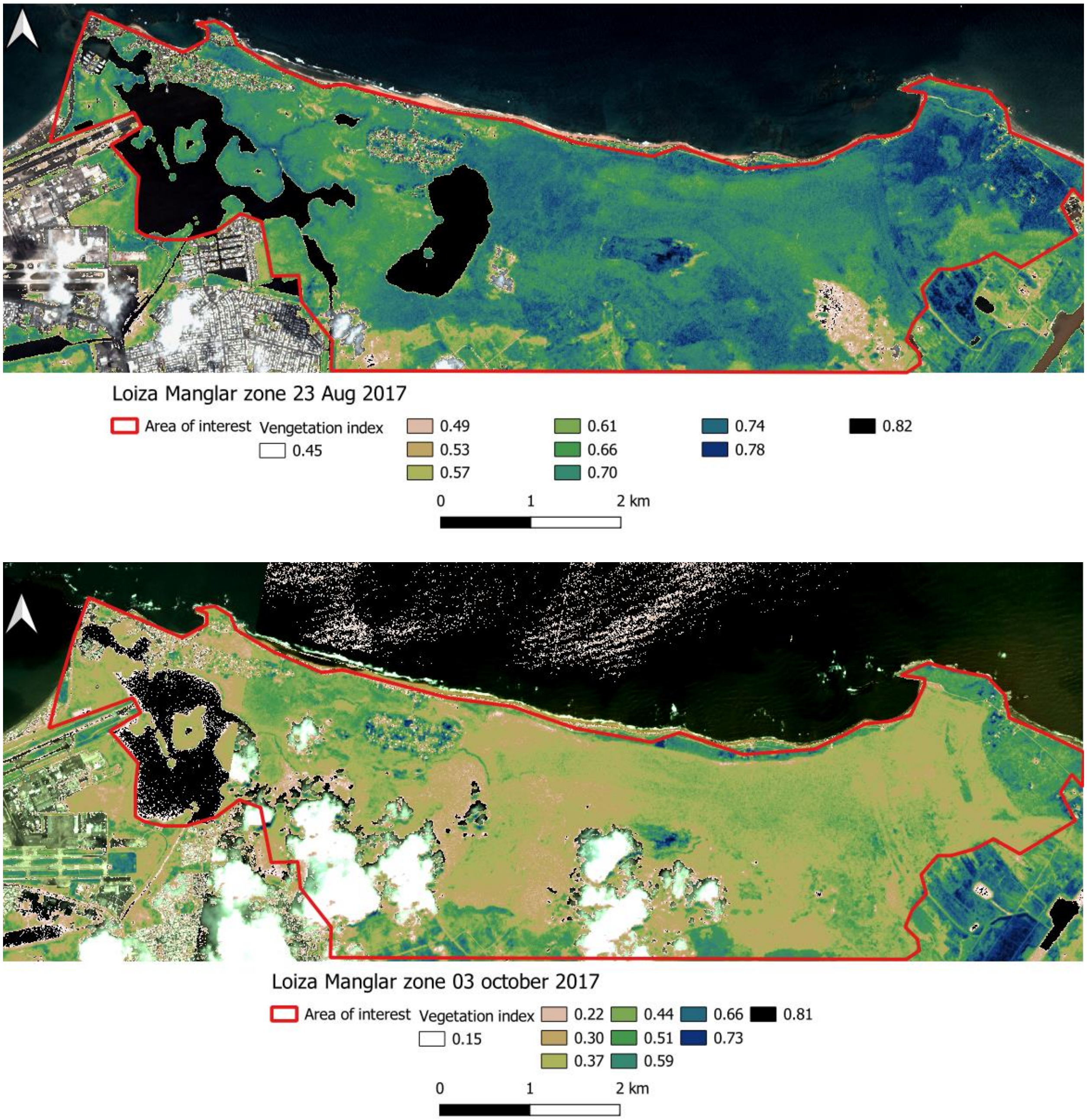

Figure 7 The Loiza Mangrove "Campamento Piñónes" for SNDVI.

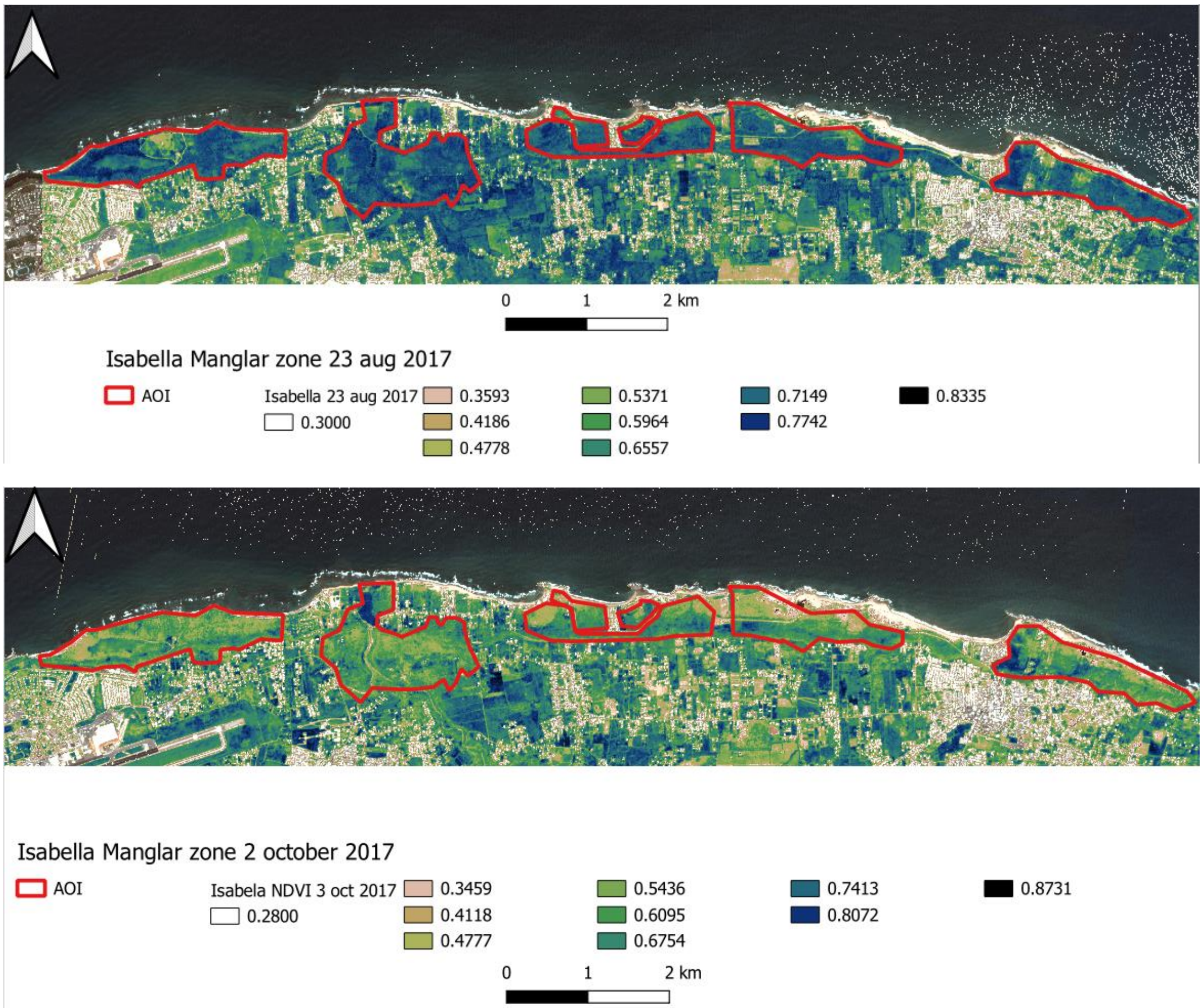

Figure 8: The Isabela Mangrove zone "Paseo lineal de Isabela" for SNDVI

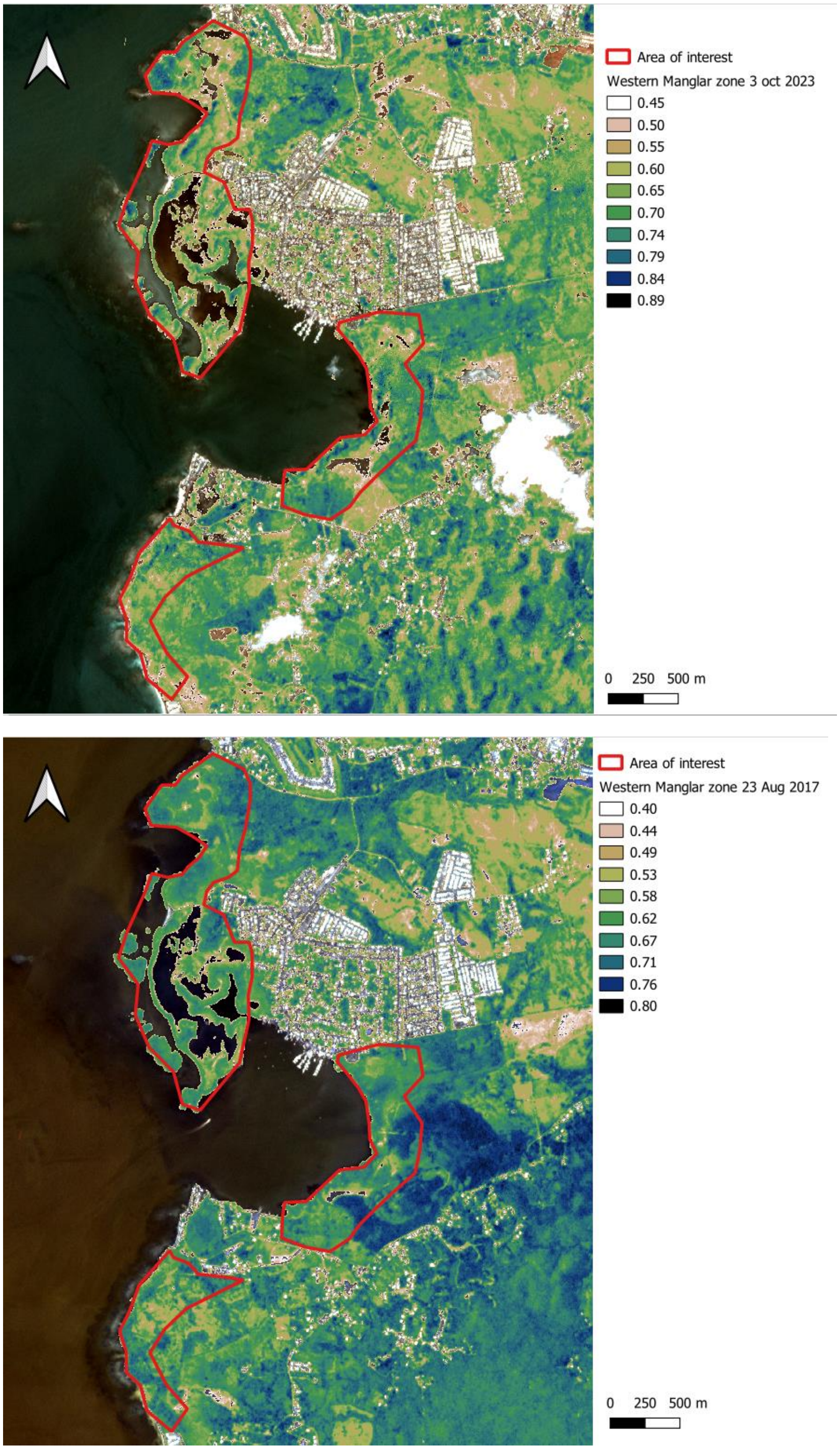

Figure 9 The Cabo Rojo mangrove "Punta Carenero" for SNDVI

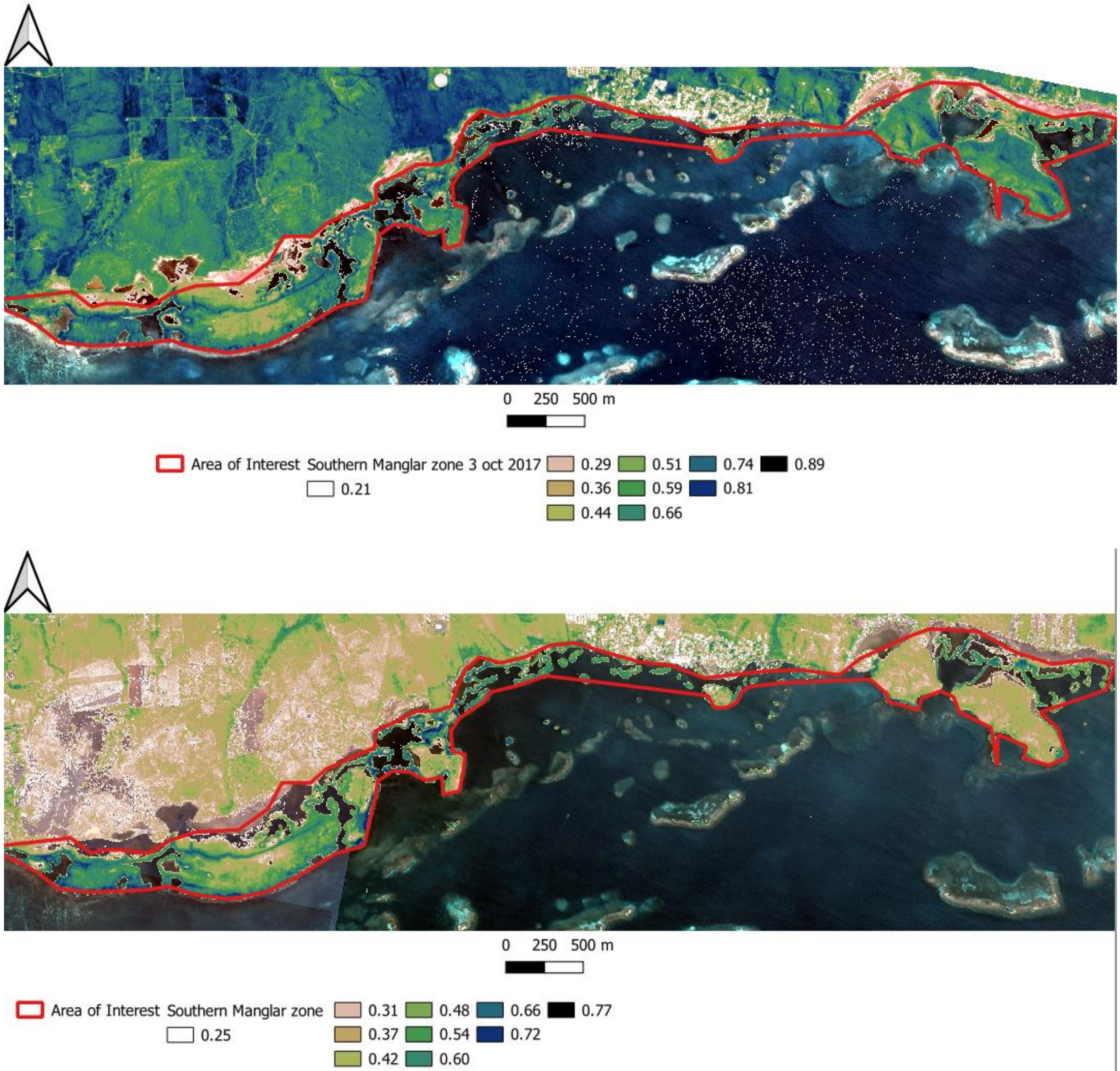

Figure 10 The Lajas Mangrove zone "Boquerón wildlife Refuge" for SNDVI

In terms of the values obtained for the NDVI and SNDVI images (Figure 11) was created for the purpose of calculating the chances in vegetation in the area as well establishing a correlation between some of the values to estimate the effective changes in the area. The values corresponding to the images yielded observable differences, these differences are observable in the graphs corresponding to the NDVI and SNDVI value ranges (Figure 12 & 13). Additional graph corresponds to the average zone differences in the values for NDVI and SNDVI, for which it can be illustrated the degree of changes form before the event of maria towards the aftereffects of this event (Figure 14).

Location	Date	FVC	NDVI midvalue	NDVI max	NDVI min	NDVI Total Area
Loiza	8/23/2017-14:12	0.47	0.625	0.725	0.51	0.215
Isabela	8/23/2017-14:15	0.49	0.52	0.69	0.34	0.35
Cabo Rojo	8/23/2017-14:17	0.48	0.595	0.7	0.48	0.22
Lajas	8/23/2017-14:19	0.50	0.44	0.6	0.28	0.32
Loiza	10/3/2017-14:12	0.50	0.425	0.63	0.22	0.41
Isabela	10/3/2017-14:15	0.45	0.54	0.715	0.33	0.385
Cabo Rojo	10/3/2017-14:17	0.49	0.625	0.746	0.5	0.246
Lajas	10/3/2017-14:19	0.51	0.55	0.78	0.325	0.455

NDVI Max avg	NDVI Min avg		SNDVI Max avg	SNDVI Min avg
0.67875	0.4025		0.725	0.41
0.71775	0.34375		0.71	0.3075

SFVC	SNDVI midvalue	SNDVI max	SNDVI min	SNDVI Total Area
0.47	0.595	0.69	0.51	0.18
0.51	0.56	0.75	0.36	0.39
0.52	0.6	0.74	0.45	0.29
0.49	0.515	0.72	0.32	0.4
0.51	0.405	0.58	0.22	0.36
0.55	0.575	0.76	0.35	0.41
0.54	0.67	0.8	0.52	0.28
0.50	0.42	0.7	0.14	0.56

Figure 11 Table Data corresponding to the NDVI and SNDVI, with the addition of the corresponding calculation values.

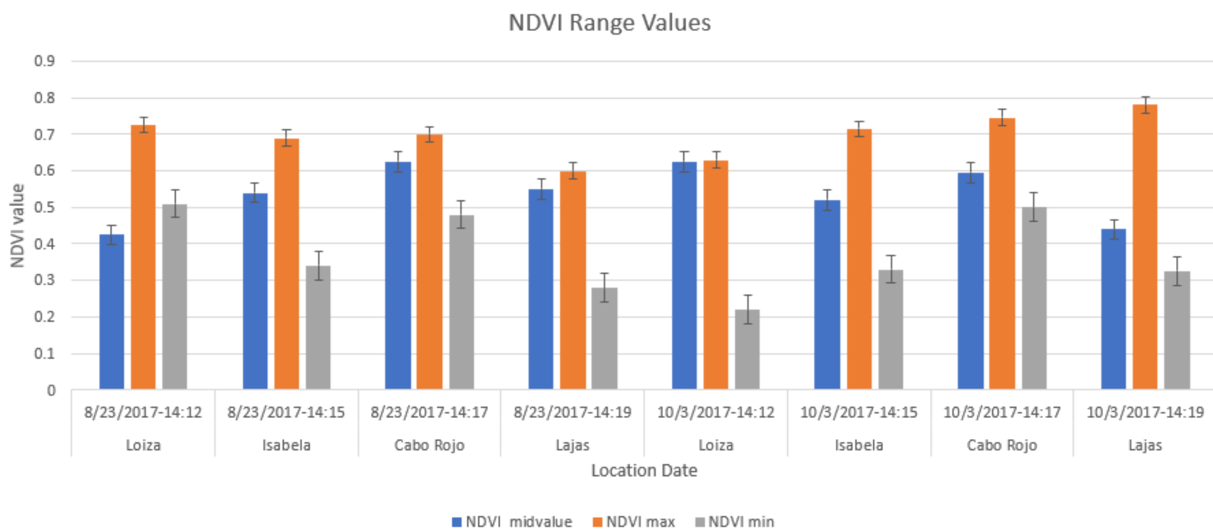

Figure 12 Bar table corresponding to the NDVI range values per zone.

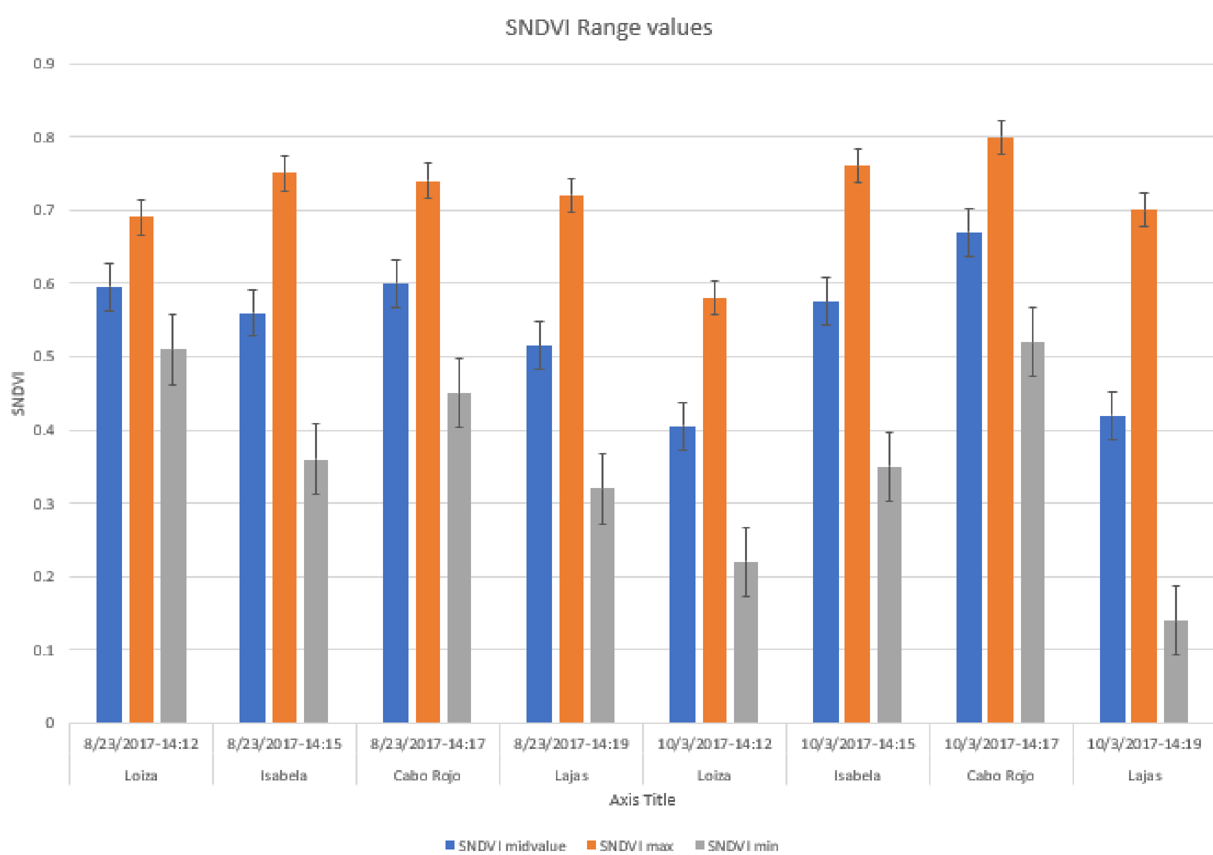

Figure 13 Bar table corresponding to the SNDVI range values per zone.

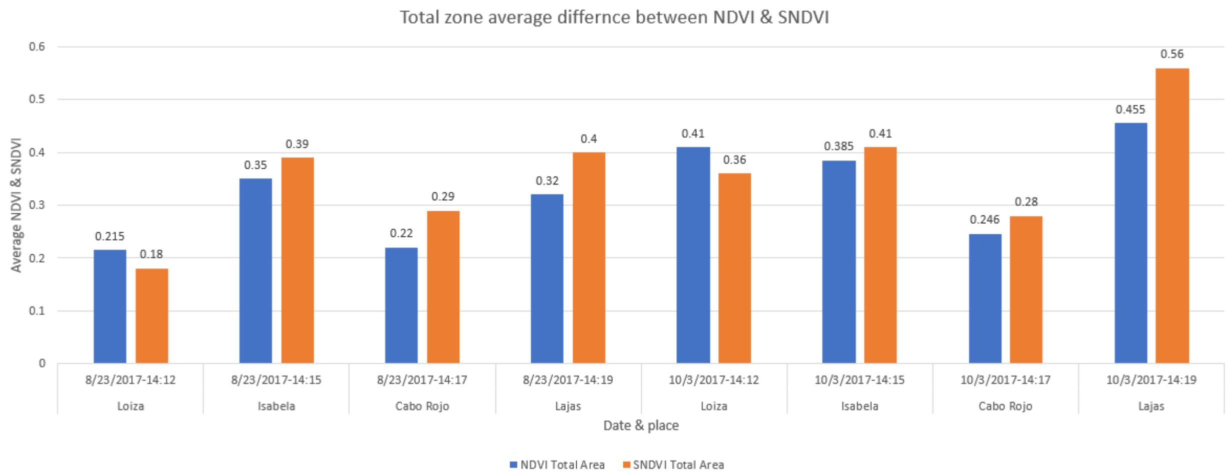

Figure 14 Total zone average for both the NDVI and SNDVI value per zone

DISCUSSION

By utilizing the images processed during the NDVI & SNDVI calculation for the 23 August 2017 before hurricane maria and 3 October 2017 after the events. It can be stated that the calculation yielded noticeable changes in the established indexes due to the aftereffects of hurricane Maria. Therefore, the ranges for each of the selected zones vary depending on the applied mask, the values correspond to the elimination of as many anthropogenic structures and bodies of water as possible without damaging the area of study. The use of the NIRF and SWIRF allowed for the visualization of areas in terms of degree of biomass related to mangrove species, as well as allowing clearer definition of the amount of soil exposure in the area. Calculations for the fractional vegetation cover yielded results with an average of about 50% in terms of the total loss in the covered biomass through the area. Initial locations through this study yielded observable differences for the mangrove zones before hurricane maria during the 23-august-2017. When observing the reductions in vegetation, it has to be considered that the zone corresponding to the Boquerón wildlife reserve in Lajas had vegetation values increasing after the events of Maria. In contrast these effects had happened due to the climate of this area during the summer to fall periods, for which after the events had vegetation recovery in which the calculation based on percentage is affected. Therefore, the value of 50% reduction has a reduction of 10-15%, when accounting the zones without this area the Total percentage of loss is about 60-65, considering the possibility of some loss being from anthropogenic interactions. Calculations for the fractional vegetation cover The Loiza Mangrove zone contains the highest vegetation index values of approximately 0.72, then the secondary values correspond to the western side of Puerto Rico in Punta Carenero with an average value of approximately 0.70. Out of all the zones the only location with a less than <50% vegetation loss before the Hurricane event was the region of the Boquerón wildlife refuge in Lajas.

Results related to the after effect of hurricane maria correspond to the values seen in **Figure 11**. The locations related to Loiza, Isabela and Cabo rojo have value reductions caused by the aftereffects of the passing of hurricane maria. While there is also another apparent difference in the values seen again for the southern region of Puerto Rico, instead of seeing a decrease in value, we can see an apparent increase in vegetation seen in the result images. Based on the previous data the sum value of the Vegetation index contains an apparent change caused by hurricane maria that is about 0.14 per mangrove cover. In terms of the SNDVI ratio determined by the applied short-wave Near infrared band, it can be established that most of the selected study sites where originally more vegetation than soil. Meaning that before the hurricane the land cover had more vegetation. These values show the effect of direct and indirect hurricane pathing, for which Isabela and Loiza has lost over 60% percent of their vegetation during the event due to it being directly in the range of path of hurricane maria. While areas like The Boquerón wildlife preserved adjacent to the storm path which allow the damage to be less than does area directly in the storm path, mainly due to the location and the rocky terrain and its elevation. This location was showered by rain for which allowed the increase in the percentage of vegetation.

CONCLUSION

Areas corresponding to the directional force of hurricane maria, in terms of mangrove wetlands or marshes, presented an observable reduction in the mangrove species. Furthermore, the direct high-speed winds seen in the zones for Loiza and Isabela are directly correspondent to the aftereffects in biomass reduction observed in the images and calculations. In contrast regions like Cabo rojo and Lajas had differing effects. Firstly, the Cabo rojo mangrove represented a reduction in terms of vegetation for both indexes as well the observable changes in the fractional vegetation cover, this is seen for all zones. Secondly the Boquerón wildlife reserve showed changes in terms of an increased vegetation growth. These values are conclusive in term of the concentration of vegetation in the areas were the mangrove zones were selected, there are still other factor that need to be considered to supply a complete assessments of the effects of theses ecosystem in relation to a storm event.

RECOMMENDATIONS

This investigation can be bettered in many ways, primordially one of these aspects can be the use of high-resolution images with a spatial resolution of 0.5m/pixel. Another factor would be to expand the project to a day-to-day index, considering the recovery times of the mangrove zones a month after the hurricane event. Lastly the acquisition of data related to molecular scattering and ozone absorption of the bands to be used with the enhanced vegetation index, to compare the data with the NDVI data.

ACKNOWLEDGEMENTS

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Works Cited

Bayouth, D., Rodríguez, C., 2018, *Event Specific and Annual Precipitation Controls on Mass Wasting Sites in Puerto Rico After the Passage of Hurricane Maria: GSA Annual Meeting Abstract*.

Campbell, J. B., and Wynne R. H. 2011. *Introduction to Remote Sensing.* The Guilford Press.

Del Valle, A., Eriksson, M., Ishizawa, O.A., and Miranda, J.J., 2019, *Mangroves for coastal protection: Evidence from hurricanes in Central America*: doi: 10.1596/1813-9450-8795.

Kumar, S., Arya, S., and Jain, K., 2021, *A SWIR-based vegetation index for change detection in land cover using multi-temporal Landsat Satellite Dataset: International Journal of Information Technology*, v. 14, p. 2035–2048, doi: 10.1007/s41870-021-00797-6.

Meresa, E., and Gebrewhid, Y., 2019, *Application of GIS and remote sensing to analyse land use land cover change detection and vegetation dynamics using multi-temporal satellite images; the case of Mariamdehan Kebele, Tigray Region, northern Ethiopia*: Asian Journal of Geographical Research, p. 1–11, doi: 10.9734/ajgr/2019/v2i230079.

Puerto Rico, Humedales [Puerto Rico, wetlands], 1999, doi: 10.3133/wsp2425_spanish.

Vincent, R. K. 1997. *Fundamentals of Geological and Environmental Remote Sensing*. Prentice Hall.