Detection and temporal comparison of surface anomalies associated with Sargassum in Coastal Areas of Santa Isabel, Puerto Rico

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1. Abstract:

This study evaluates the use of multispectral satellite imagery for the detection and temporal comparison of surface anomalies potentially associated with floating sargassum along the coastal region of Santa Isabel, Puerto Rico. Sentinel-2B and Sentinel-2A images from July 27, 2018, and August 24, 2025, were processed using ENVI to analyze spectral differences between open water, coastal landforms, and suspected floating material. Three spectral indices were applied: the Normalized Difference Vegetation Index (NDVI), the Normalized Difference Water Index (NDWI), and the Floating Algae Index (FAI). The combined use of indices improved the interpretation of potential sargassum-related features compared to any single index alone. The study demonstrates the importance of multi-index analysis for coastal remote sensing applications and highlights the need for improved masking, additional dates, and field validation to confirm the presence of sargassum.

Keywords: Sargassum, Sentinel-2, NDVI, NDWI, FAI, Santa Isabel, ENVI

2. Introduction:

Sargassum is a floating brown macroalgae widely distributed across tropical and temperate oceans. It develops when fragments of mature Sargassum detach and, under suitable environmental conditions, continue to grow by absorbing solar radiation and nutrients. The main factors required for its growth include sunlight, warm ocean temperatures, and appropriate salinity levels. Sargassum provides ecological benefits, particularly as a food source and habitat for a variety of marine organisms. However, it can also generate environmental and socioeconomic impacts, especially in coastal regions. When Sargassum accumulates along shorelines and decomposes, it releases hydrogen sulfide, a gas characterized by a strong and unpleasant odor that may pose health risks to nearby coastal populations. In addition, large accumulations can reduce the penetration of sunlight into coastal waters, potentially affecting coral reef ecosystems and contributing to coral stress or mortality.

Sargassum primarily originated in the southern Atlantic Ocean, between Africa and South America. From this region, it is transported westward by ocean currents, passing through the Caribbean Sea and eventually reaching the Gulf of Mexico. This large-scale transport pathway, characterized by extensive accumulations of Sargassum across the Atlantic basin, is known as the Great Atlantic Sargassum Belt. In addition, Sargassum is also present in the central Atlantic Ocean, an area commonly referred to as the Sargassum Sea. This distribution is influenced by the rotational pattern of Atlantic currents, which circulate clockwise and can transport floating Sargassum from regions near the Gulf of Mexico back toward the central Atlantic.

The objective of this project was to compare satellite images from 2018 and 2025 of Santa Isabel using different ENVI software tools in order to analyze potential increases or decreases in Sargassum following the impacts of Hurricane Maria. The satellite data used in this study were acquired from Sentinel-2A and Sentinel-2B sensors, which provide spatial resolutions of 10 m, 20 m, and 60 m. These sensors are commonly used for applications such as agricultural monitoring, natural disaster assessment, and land-use planning. The expected outcome of this analysis is to identify detectable changes in Sargassum presence between 2018 and 2025.

3. Methods:

Multispectral imagery from Sentinel-2A and Sentinel-2B satellites was selected for the coastal study area in Santa Isabel, Puerto Rico. Images from 2018 and 2025, shown in Figures 1 and 2, were used to enable a temporal comparison of spectral characteristics within the region. All images were processed using ENVI software. First, basic preprocessing steps were applied to enhance image interpretability and ensure consistency across datasets. These steps included radiometric visualization adjustments to support qualitative and quantitative spectral analysis. For the study of floating vegetation on oceanic surfaces, three spectral indices were derived using ENVI Band Math.

Figure 1, Image of Sentinel 2B (2018)

Figure 2, Image of Sentinel 2A (2025)

3.1 NDVI:

The Normalized Difference Vegetation Index (NDVI) was computed as a reference for terrestrial vegetation. NDVI is defined as:

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

This index was used to characterize vegetation presence and density on land surfaces and to provide contextual information for coastal interpretation. NDVI was included as contextual information to support the interpretation of terrestrial vegetation and to help differentiate land features from aquatic signals.

3.2 NDWI:

The Normalized Difference Water Index (NDWI) was used to delineate water bodies and separate aquatic from terrestrial features. NDWI is defined as:

$$NDWI = \frac{Green+NIR}{Green-NIR}$$

This index was used to identify and isolate aquatic regions within the study area, supporting subsequent analysis of surface anomalies. NDWI was applied to distinguish water bodies from land and coastal features, ensuring that subsequent FAI analysis was restricted to aquatic regions.

3.3 FAI:

The Floating Algae Index (FAI) was computed to detect anomalies in surface reflectance potentially associated with floating material such as sargassum. FAI is defined as:

$$FAI = NIR - [Red + (SWIR - Red)\,\frac{\lambda NIR - \lambda Red}{\lambda SWIR - \lambda Red}]$$

This index was used to identify spectral deviations within aquatic environments indicative of floating organic material.

Representative pixel sampling and visual inspection were used to compare spectral signatures among water, coastal landforms, and suspected floating material. This approach allowed for qualitative and quantitative assessment of spectral differences across the study area. Finally, all output maps were annotated with legends and visual markers to facilitate interpretation and presentation of results.

4. Results:

The first image used for analyzing possible floating vegetation signals was a Sentinel-2B Level 1C image acquired on July 27, 2018. This image was used as the base scene for the spectral index analysis since it contained oceanic areas where floating vegetation, such as possible sargassum, could be detected by spectral variations. Starting with the NDVI in Figure 1.1, small patches with positive NDVI values were observed near the coastline and in selected ocean areas approximately 0 and 0.1. These values can be associated with floating vegetation, including possible sargassum, but they can also be referred to as shallow water, suspended sediments, sea foam, or mixed pixels. However, NDVI results provide a preliminary indicator of sargassum presence for comparison with the NDWI and FAI indices.

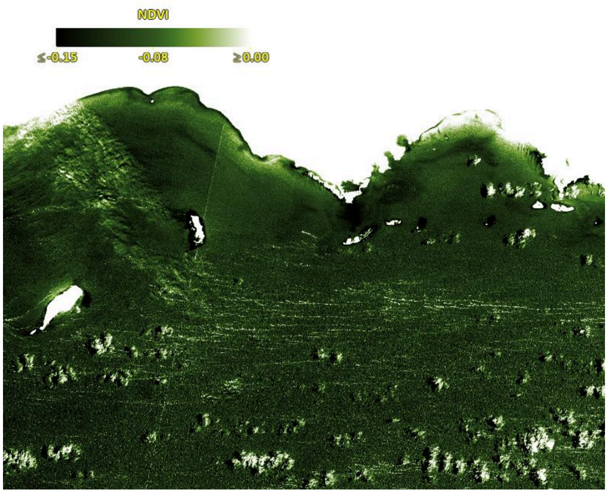

Figure 1.1, NDVI Image (2018)

The next index worked on Figure 1.2 is the Normalized Difference Water Index. The NDWI result showed spatial variability along the coastal region, but bigger differences were observed near the shoreline and shallow-water areas where the spectral response can be affected by bottom reflectance, sediments, and coastal mixing. When compared with the NDVI image, some of the NDWI anomalies appear in similar coastal or nearshore areas. This supports that certain pixels may be influenced by floating material or potential sargassum. Nevertheless, NDWI alone is not specifically designed to detect sargassum but to support the interpretation by identifying water-related variations and helping distinguish ocean areas from other surface types.

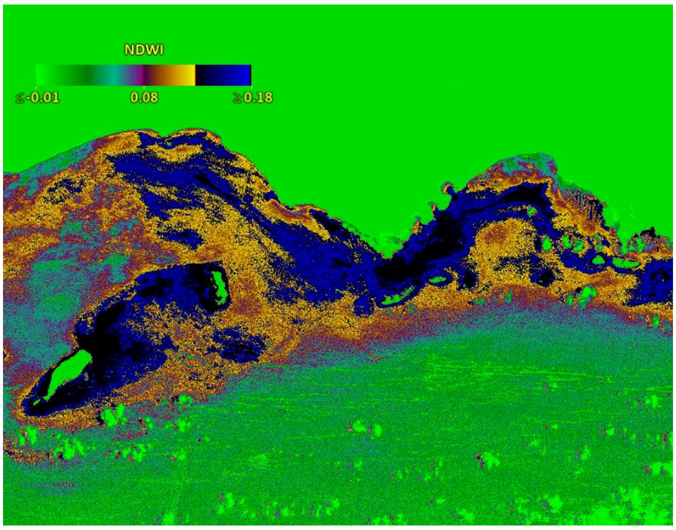

Figure 1.2, NDWI Image (2018)

Finally, the FAI was applied to enhance the detection of floating vegetation over water. This image in Figure 1.3 presents processing limitations related to mask application and value scaling. Therefore, the FAI result of this image should be considered a qualitative and preliminary result rather than a final confirmation. Figure 5 remains useful because it helps compare whether the anomalies observed in NDVI and NDWI are also reflected in an index more sensitive to floating vegetation.

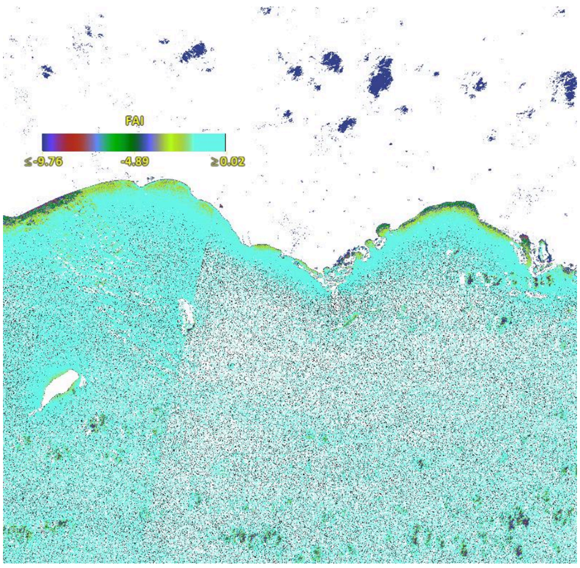

Figure 1.3, FAI Image (2018)

The results indicate that the July 27, 2018, Sentinel-2B scene contains several spectral anomalies that may be compatible with possible sargassum presence. However, these results should be classified as preliminary. Finally, on Table 1, a representative pixel-based comparison was performed for three classes: open water, suspected anomalies, and masked coastal landforms. The open-water pixel showed a negative NDVI value, positive NDWI, and a near-zero FAI, consistent with water behavior. On the other hand, the suspected sargassum presented a slightly positive NDVI value, suggesting a weak vegetation signal, while NDWI remained positive, indicating possible sargassum. Finally, the FAI presented some values, but since there were limitations and problems with the ENVI software, these are not accurate.

Class	NDVI	NDWI	FAI	Interpretation
Water	-0.13965	0.095675	-0.02051	Water
Suspected Sargassum	0.022256	0.067227	-3.23065	Potential Sargassum
Cay	0	0	0	Eliminated by mask

Table 1, Spectral index values and corresponding classification

The next study area corresponds to the Sentinel-2A multispectral imagery acquired on August 24, 2025, in Figure 2. This dataset provides medium-resolution optical imagery suitable for coastal and ocean color analysis, allowing the assessment of spectral indices related to vegetation, water bodies, and floating surface anomalies.

NDVI was used as a reference indicator for terrestrial vegetation within the study area. This index allowed for the characterization of vegetation presence and density on land surfaces, particularly in cays and coastal zones. High NDVI values corresponded to densely vegetated areas, while intermediate values observed near coastal regions may have been influenced by pixel mixing effects and spectral interactions between land and water. Due to these limitations in coastal environments, NDVI was not considered a reliable indicator for detecting floating marine material such as sargassum and was used only as a contextual reference.

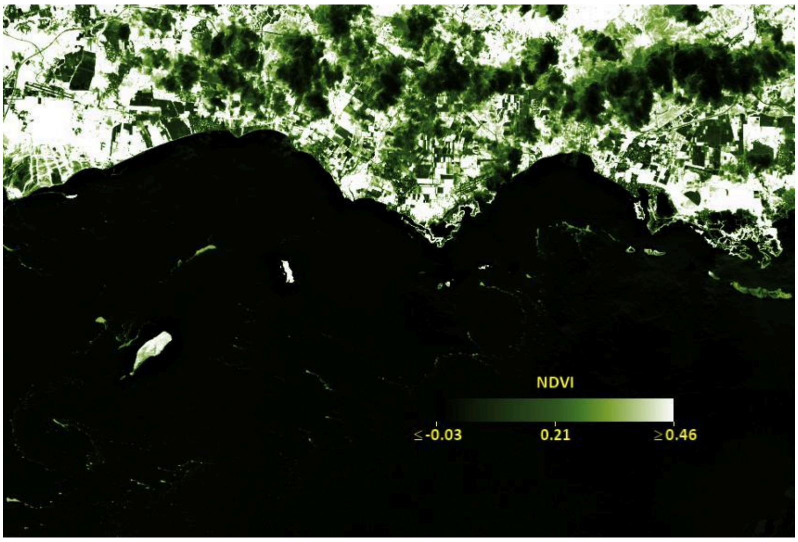

Figure 2.1, NDVI Image (2025)

NDWI was applied to differentiate water bodies from land surfaces and coastal features within the study area. The results showed a clear separation between water and land, where pixels corresponding to water bodies exhibited values close to zero or slightly positive. In contrast, cays and terrestrial formations displayed more negative values, allowing for proper delineation of aquatic regions for subsequent FAI analysis.

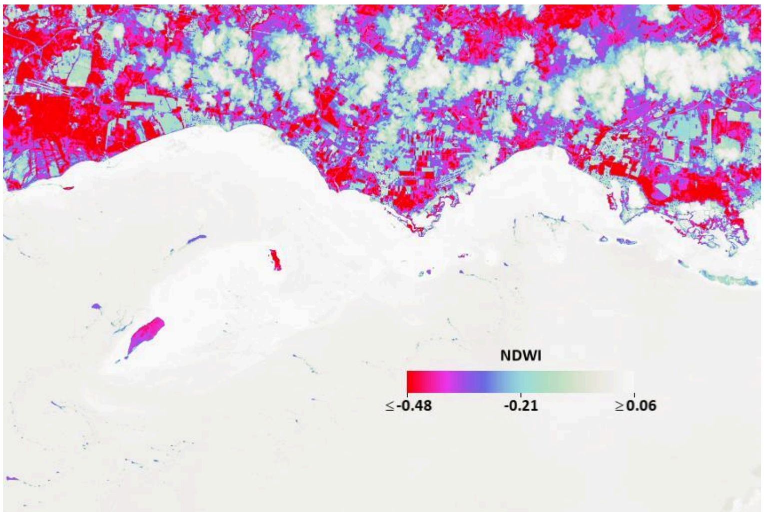

Figure 2.2, NDWI Image (2025)

The FAI was used to identify anomalies in surface reflectance within aquatic areas, which may be associated with floating material such as sargassum. The analysis revealed the presence of significant spectral anomalies within the study area. Background water exhibited relatively low FAI values, while the area identified as a potential accumulation of floating material showed considerably higher values. These anomalies were spectrally distinct from the surrounding water, suggesting the presence of floating organic material on the water surface.

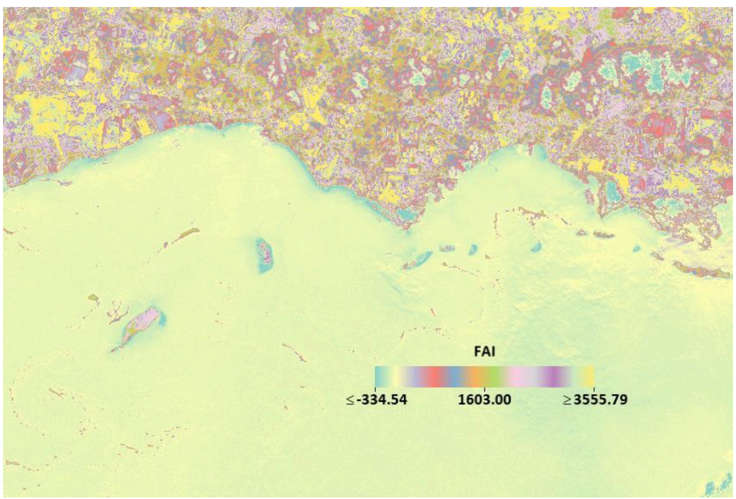

Figure 2.3, FAI Image (2025)

A comparison of representative pixels corresponding to water, a region identified as potential sargassum, and a nearby cay was conducted. This comparison allowed for the evaluation of spectral differences between terrestrial and aquatic surfaces within the study area. The results showed clear differences among the three analyzed classes. Both the cay and the suspected sargassum area exhibited elevated FAI values compared to water. However, NDWI provided additional information that helped distinguish between terrestrial surfaces and floating material, reducing ambiguity in the interpretation of the results.

Class	NDWI	FAI	Interpretation
Water	.026	29	Water
Suspected Sargassum	-.32	1671	Potential Sargassum
Cay	-.52	373	Land

Table 2, Spectral index values and corresponding classification

Overall, these findings indicate that the combination of multiple spectral indices improves the interpretation of complex coastal environments.

5. Conclusion:

Using a single parameter to determine the presence of Sargassum is not sufficient due to the potential for errors and uncertainty in the derived values. Therefore, it is important to use multiple indices to improve accuracy and interpretation. In this case, NDVI, NDWI, and FAI were used to obtain a more comprehensive analysis of Sargassum presence along the coast.

The NDVI was used to assess terrestrial vegetation and its overall health. The NDWI was applied to distinguish and separate aquatic regions from terrestrial features. The FAI was used to detect anomalies in reflectance associated with floating materials in the study areas, including Sargassum. In addition to the use of these spectral indices, Sargassum can also be visually interpreted based on expected reflectance patterns, since it does not fully behave as either land or water. Unlike water, it does not typically exhibit strong NDWI values, and unlike terrestrial vegetation, it does not consistently align with NDVI responses for land features. This is because Sargassum is a floating vegetative material, which produces intermediate or mixed spectral behavior that can be identified through both index-based analysis and visual interpretation of reflectance patterns.

For future work, it is recommended to apply the same methodology using additional satellite sensors in order to compare results with Sentinel imagery and evaluate which sensor provides higher data quality for Sargassum detection. The same indices can also be applied to different time periods to support temporal analysis. Additionally, further research should investigate the effects of climate change on Sargassum distribution, as well as its impacts on coastal environments, including how hurricanes may alter Sargassum presence and associated vegetation index responses over time.

6. References:

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7. Appendix:

The images were provided on the Copernicus Sentinel's website: https://browser.dataspace.copernicus.eu/?zoom=13&lat=17.95824&lng=-66.38248&themeId=DEFAULT-THEME&visualizationUrl=U2FsdGVkX19YvUE4xVsyGTGarHCKb8bEZbcAY%2FR0LjdfwUwM0Kcj3s1yGxc0GIhHnKuPULoTYGgosv4UKCzoelI5SjPyoYJyQIrcJpFv7XwGl1FtxyKPUhli3KLeSddx&datasetId=S2_L2A_CDAS&fromTime=2018-06-17T00%3A00%3A00.000Z&toTime=2018-06-17T23%3A59%3A59.999Z&layerId=1_TRUE_COLOR&demSource3D=%22MAPZEN%22&cloudCoverage=24&dateMode=TIME%20RANGE