

Correlation of humpback whale sightings and concentrations of remotely sensed chlorophyll-A in the west coast of Puerto Rico during humpback whale season

Introduction:

Humpback whales, or *Megaptera novaeangliae*, is a specie that migrates from the North Atlantic (Iceland, Greenland, Canada, and Maine) to the coasts of Puerto Rico for its reproductive cycle. They travel all the way from the North Atlantic so they calves can be nursed and get stronger. Its migration begins during the winter, in the months of December until April, having its peak season during February (A.R. Martin, et. al. 1984). They have been researched before in Puerto Rico for their migration, its population size and distribution yet only a few investigations had aimed to determine whale sightings based on its location. It was demonstrated before, whales prefer continental shelves areas and in 2016, MacKay confirmed this the northwest of Puerto Rico. The purpose of this project is to identify if there is a pattern between the remotely sensed chlorophyll-A and whale sightings during past mating season in the West Coast.

For this project the area of study was the municipalities of Rincon and Aguadilla due to numerous humpback whale sightings along the years. Nevertheless, because one whale sighting was experience in Arecibo, it was also included so one can compare chlorophyll-a concentration as well. As shown of **figure 1**, humpback whales, which are considered a type of baleen whale, migrate from the up north Atlantic to the Caribbean, usually from west to east as they prefer to move close to islands.



Figure 1: Migratory destinations and population structure of humpback whales in the North Pacific and western North Atlantic Oceans. (Baker et al., 1990)

This movement was also recorded in 2013 by satellite-tracking in which whales migrated to the tropical waters starting at Dominican Republic, Puerto Rico, and the Virgin Islands.

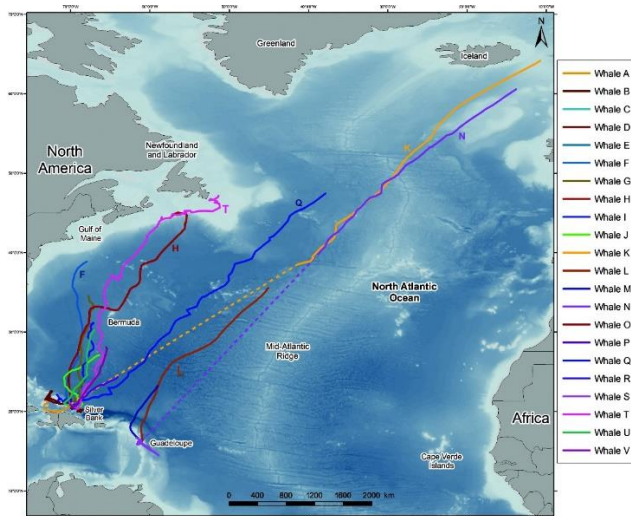


Figure 2: Local and migratory movements of humpback whales (*Megaptera novaeangliae*) satellite-tracked in the North Atlantic Ocean (A.S. Kennedy et. al., 2014)

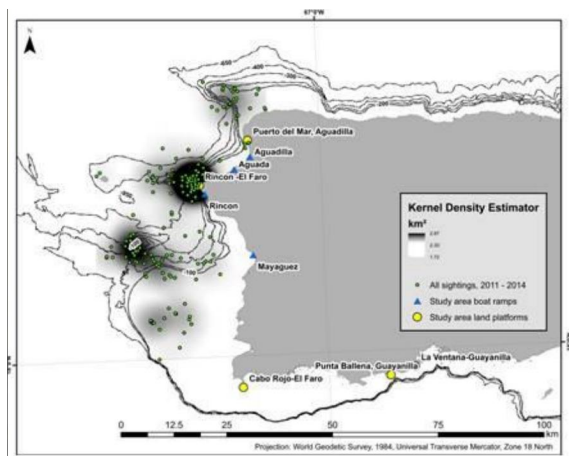


Figure 3: Whale sightings and density from 2011-2014 breeding season in the northwest coast of Puerto Rico.

Scientific Question:

Do high concentrations of chlorophyll-a in the ocean collected from SeNTiNeL Imagery has any correlation with the whale sighting

locations from Humpback whale season in Puerto Rico?

Scientific Question:

The humpback whale sightings from past whale seasons are congruent with the high levels of chlorophyll-a in the coast due its position in the food chain (primary to secondary consumers) and food availability.

Objectives:

1. Utilize learned techniques of remote sensing and apply it in ArcGIS and SNAP software.
2. Develop maps employing chlorophyll-a data collected with satellite imagery (OLCI) from Sentinel
3. Plot in the map whale sightings on the west coast of Puerto Rico, specifically Rincon and Aguadilla
4. Compare and Contrast results to identify if there is any correlation or patter

Methodology:

- (1) Collect whale sighting data
 - a. When and where

DATE	PLACE	MAP
March/2/2017	Playuela, Aguadilla	Yes
January/24/2021	Rincon	Yes
January/29/2021	Tres Palmas, Rincon	Yes
January/ 20 /2021	Borinquen, Aguadilla	NO (clouds)
February/3/2021	Arecibo	Yes
February /7 /2021	Rincon	NO (clouds)
February /14 /2021	Surfers, Aguadilla	Yes
March /5/2021	Surfers, Aguadilla	Yes
March/6 /2021	Aguadilla	NO (clouds)
March/9/ 2021	Aguadilla	Yes

- (2) Research Copernicus Data Base
 - (3) Utilize SNAP to develop chlorophyll-a maps
 - a. Add project
 - b. Show RGB image to select the desired area of the map
 - c. Raster > Subset to Create a subset with the desired area
 - d. Optical > thematic Water Processing > C2RCC > OLCI
 - e. Raster > Reproject image
 - f. Mask Manager > Cloud Risk
 - (4) Convert from SNAP to ArcGIS
 - a. Georeferenced images
 - i. Select georeferenced map of Puerto Rico
 - ii. Select PNG image downloaded from SNAP
 - iii. Georeference image by:
 1. Display layer
 2. Plot georeferencing points
 3. Update georeference
 - b. Plot whale sighting locations within the map
 - c. Create map with all its parts
 - (5) Answer scientific question
 - (6) Approve or null hypothesis
-

Results:

The results of the steps mentioned above was a series of maps in which the levels of chlorophyll-a are represented by colors in the ocean. The warmer the color, the more chlorophyll-a abundance. Black points on the ocean represent locations of the humpback whale sighting of that day.

For comparison, it was also develop two maps of two random days during rain season to compare how the concentration levels change through seasons.

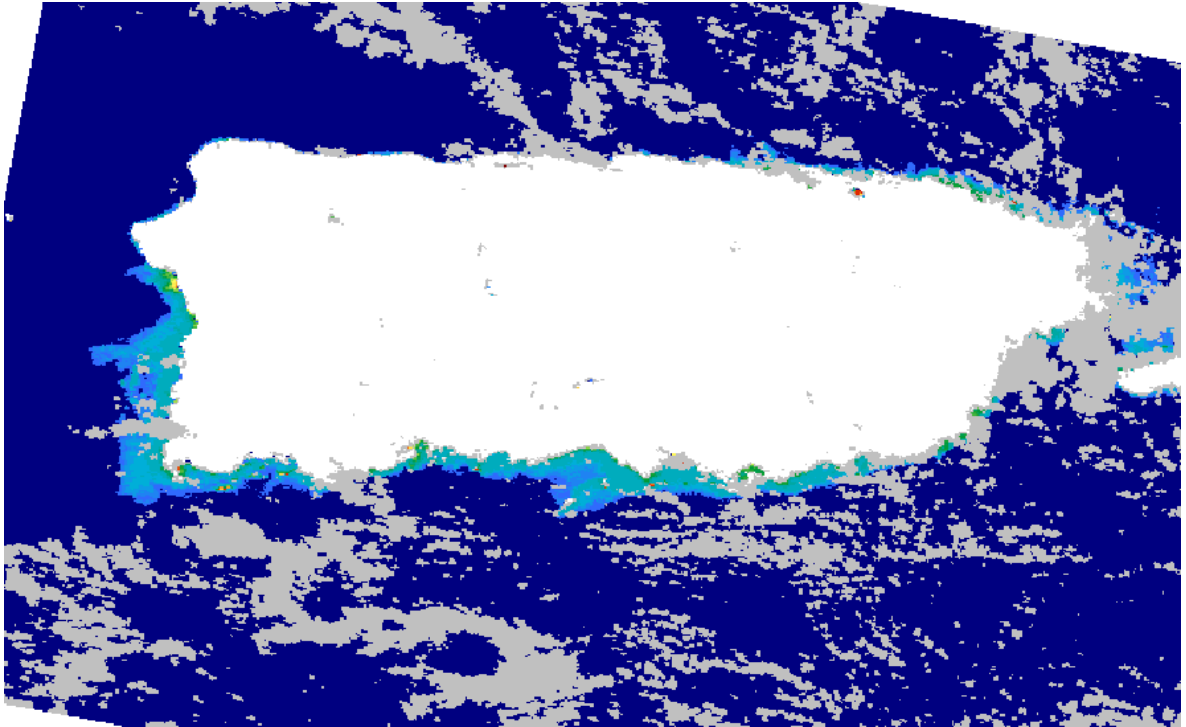
Processed Images for Chl-a concentrations on SNAP of whale season

Figure 4: Chl-a concentration map processed on ESA SNAP for 03/02/17 – Playuela, Aguadilla.

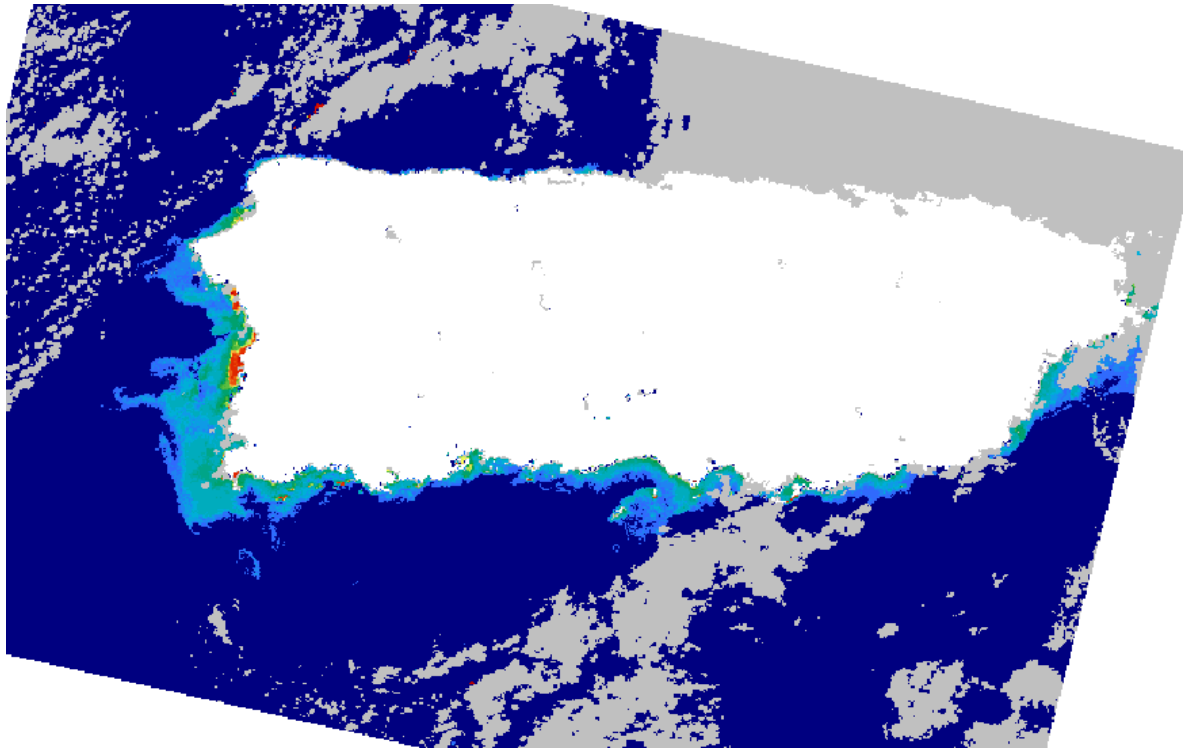


Figure 5: Chl-a concentration map processed on ESA SNAP for 01/24/2020– Rincón

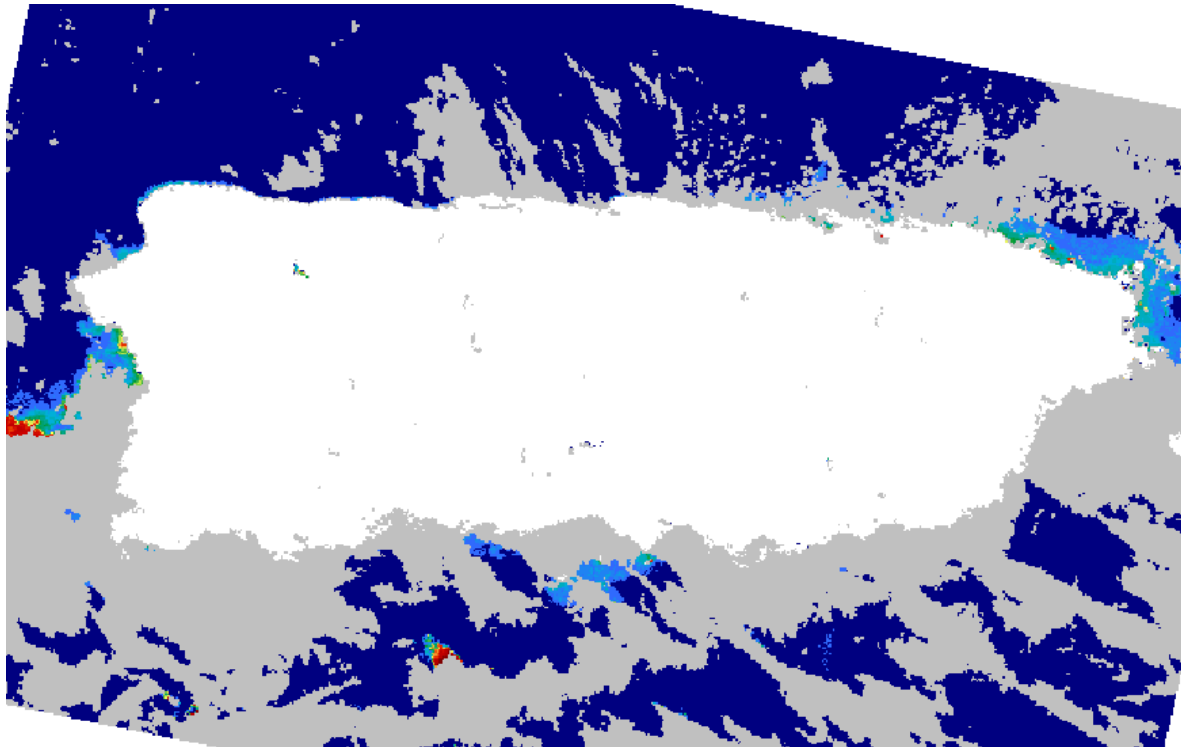


Figure 6: Chl-a concentration map processed on ESA SNAP for 01/29/2021 – Tres Palmas Marine Reserve, Rincón

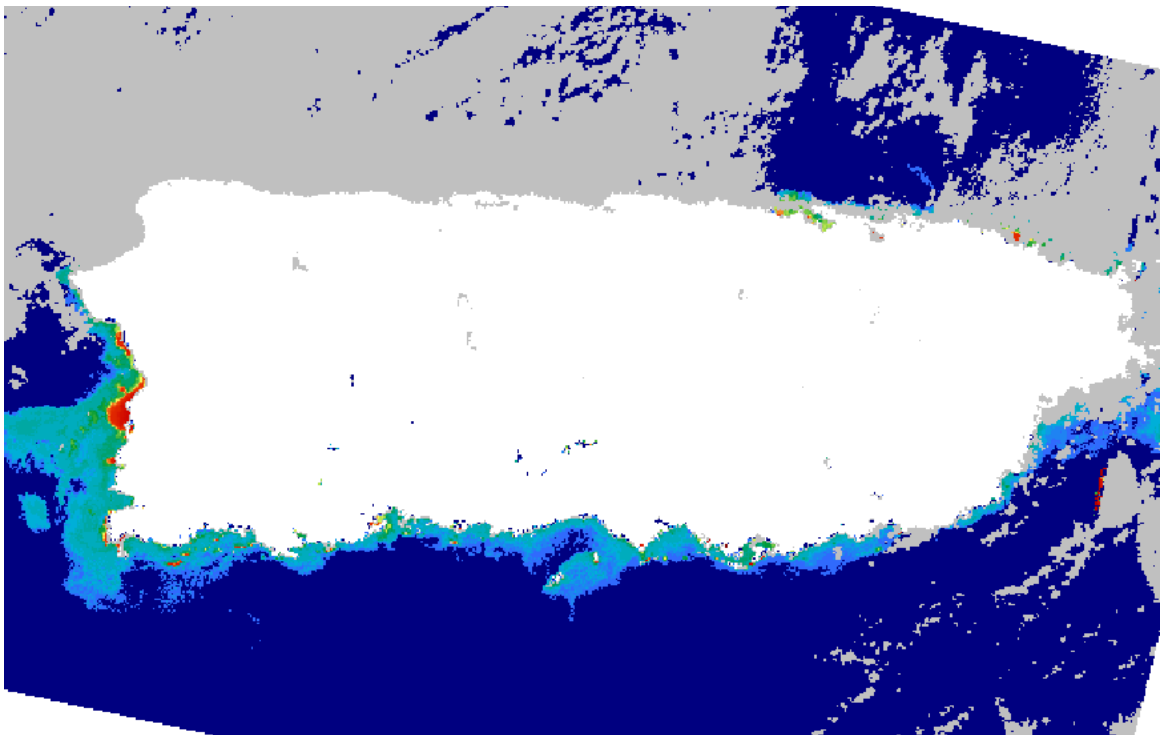


Figure 7: Chl-a concentration map processed on ESA SNAP for 01/30/2021 – Punta Borinquén, Aguadilla

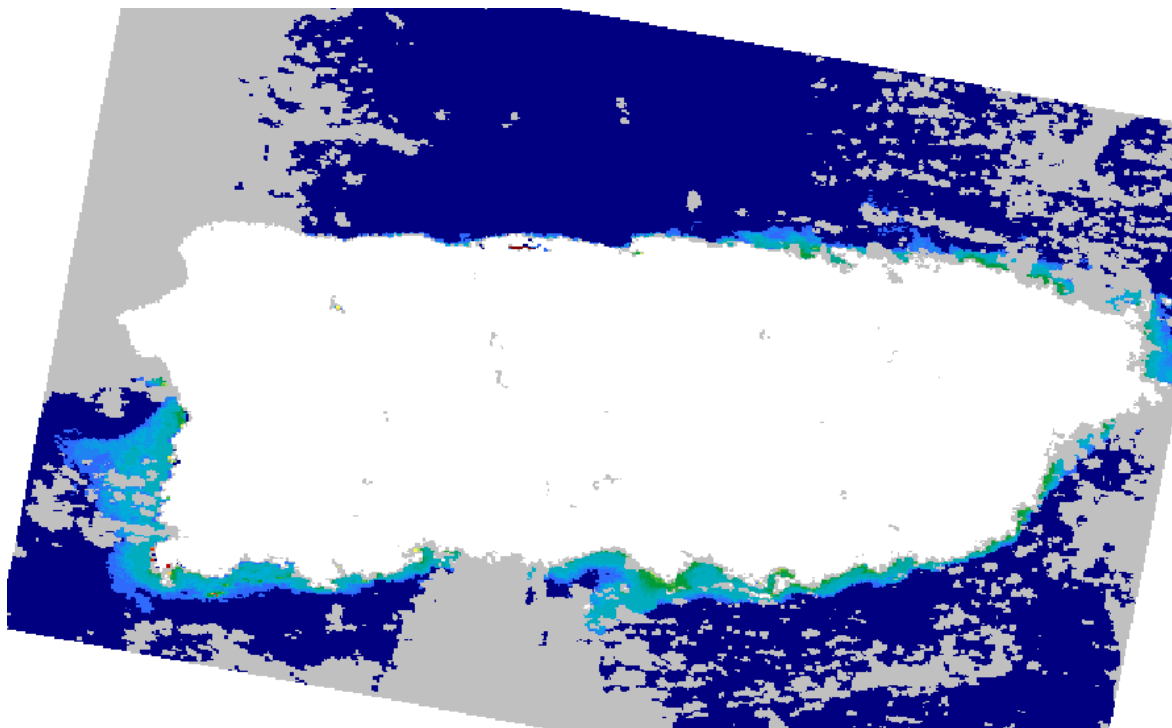


Figure 8: Chl-a concentration map processed on ESA SNAP for 02/14/21– Surfers Beach, Aguadilla

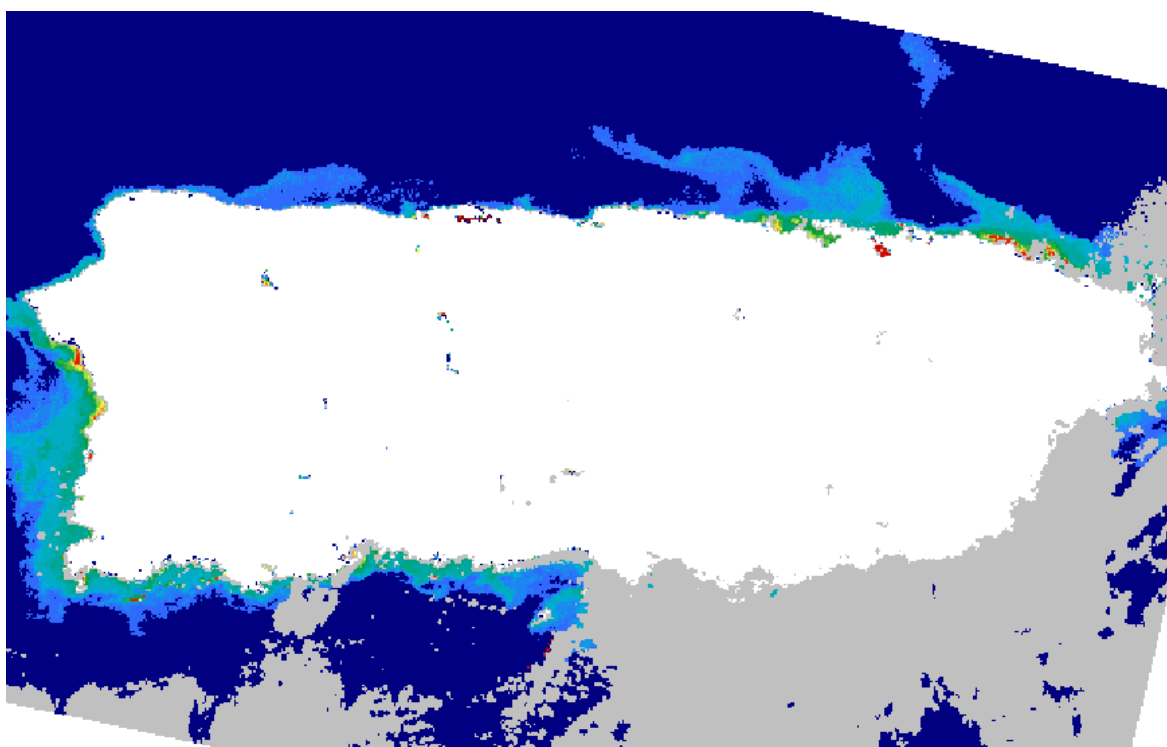


Figure 9: Chl-a concentration map processed on ESA SNAP for 02/03/2021 – Arecibo

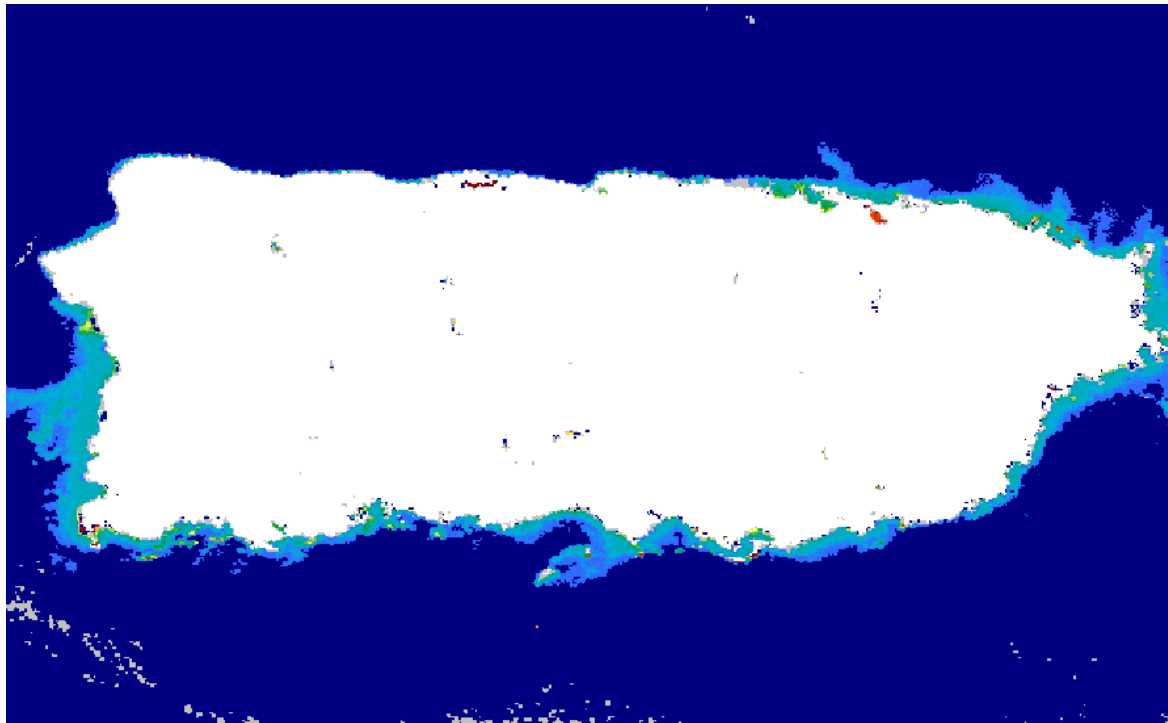


Figure 10: Chl-a concentration map processed on ESA SNAP for 03/02/2021 – Surfers Beach, Aguadilla

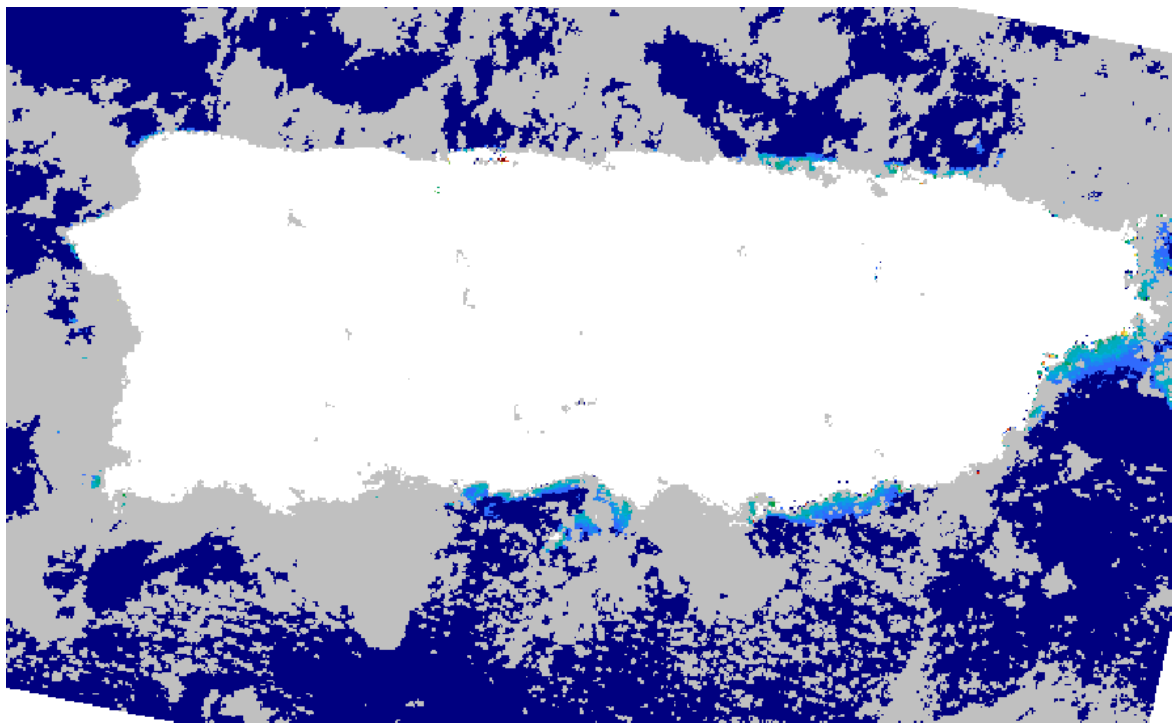


Figure 11: Chl-a concentration map processed on ESA SNAP for 03/06/2021 – Aguadilla

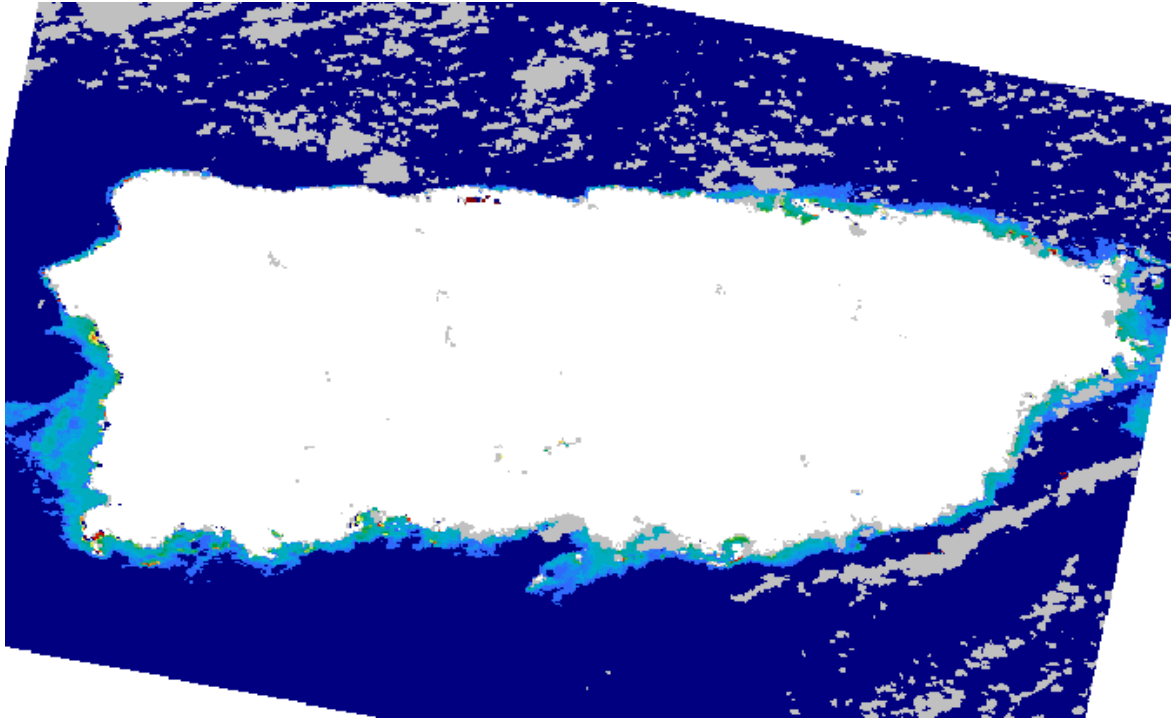


Figure 12: Chl-a concentration map processed on ESA SNAP for 03/09/2021 – Surfers Beach, Aguadilla

Processed images for Chl-a concentrations on SNAP during rainy season for comparison purposes.

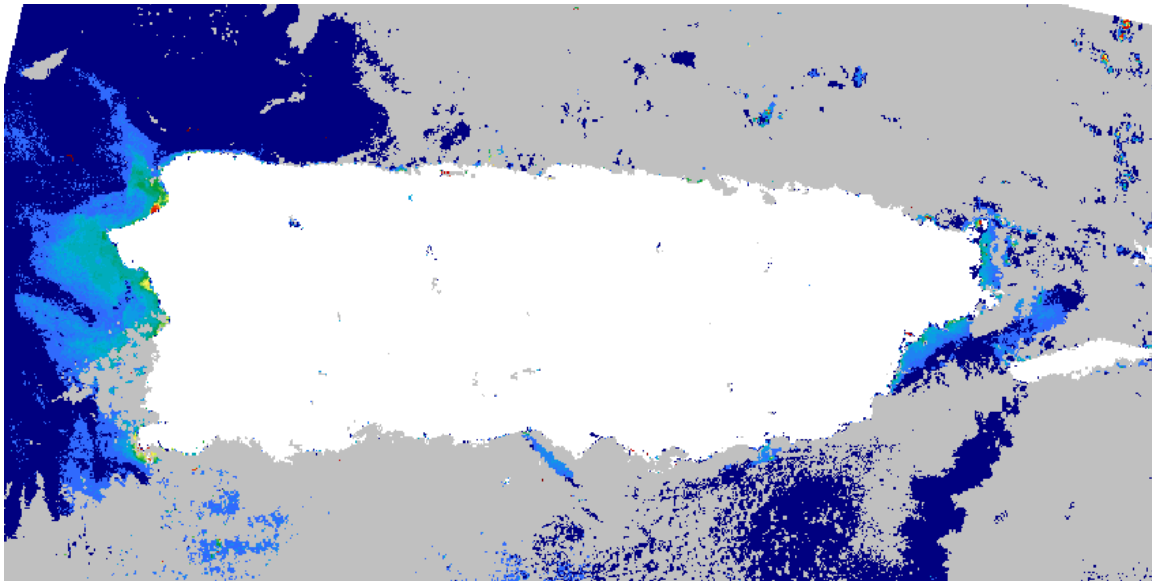


Figure 13: Chl-a concentration map from September 2, 2021.

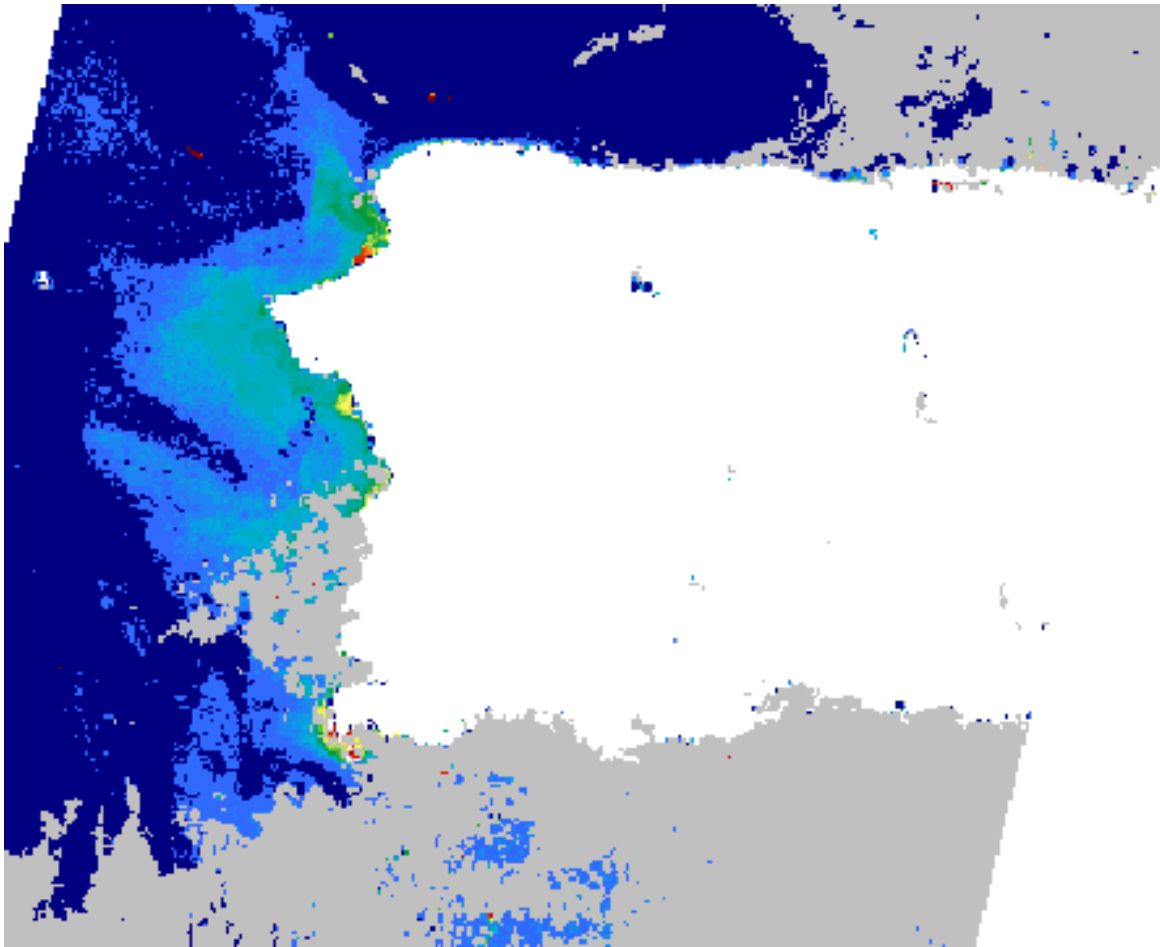


Figure 14: Chl-a concentration map from September 9, 2021

Concentrations of Chl-a in Puerto Rico maps below:

After processing the concentration maps, then a georeferenced a map was made with all its parts. The legend consists on every municipality in color black except Rincon, Aguadilla and Arecibo because whale sighting were experienced in this municipalities.

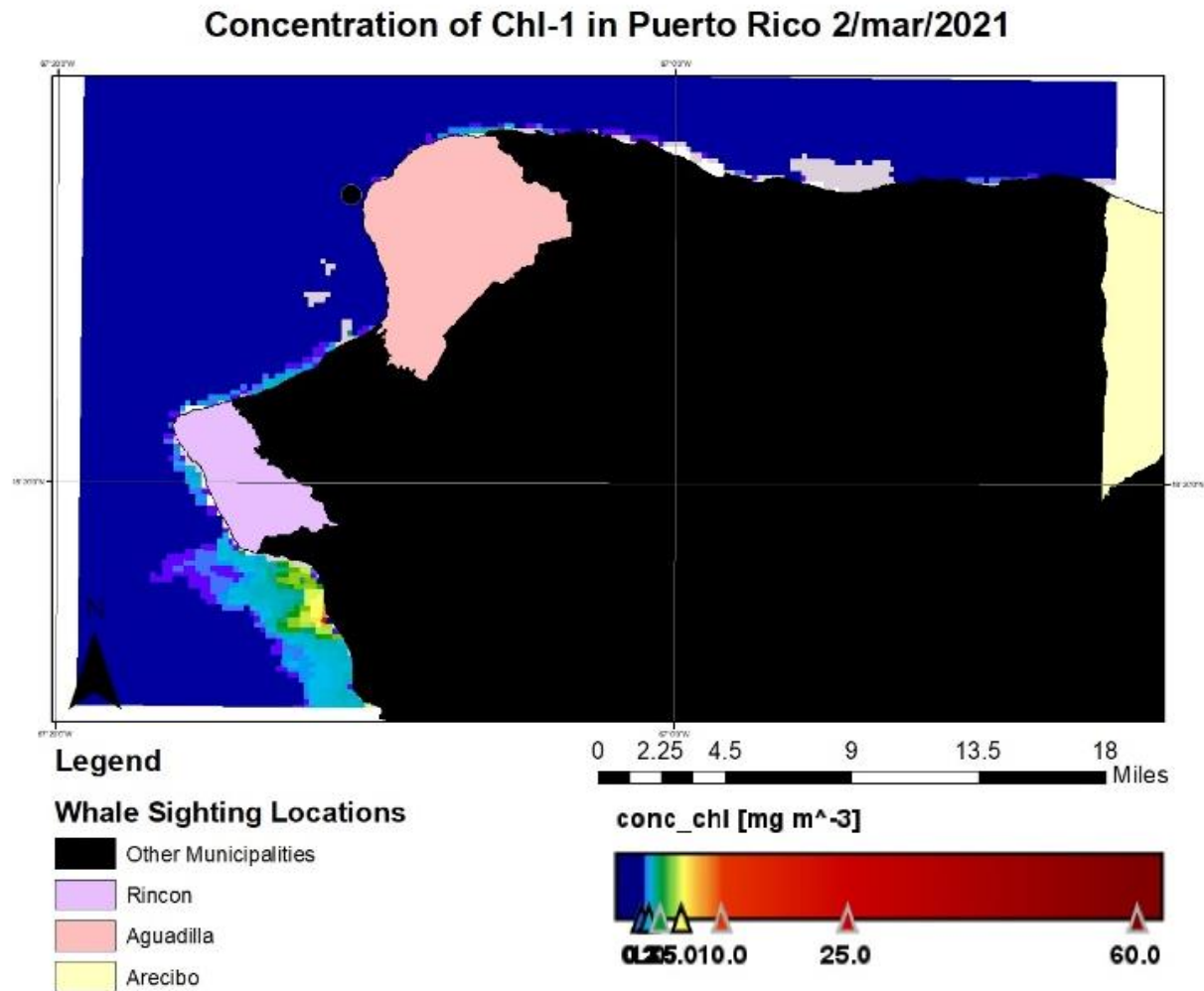


Figure 15

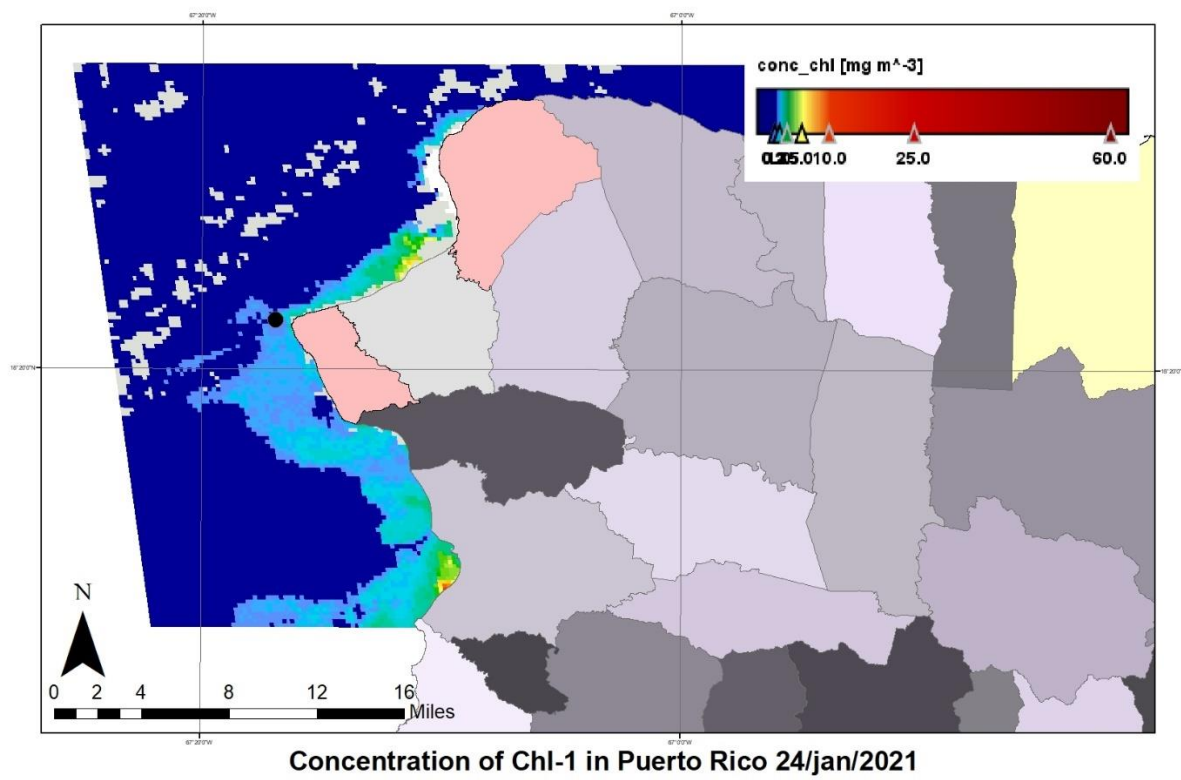


Figure 16

Concentration of Chl-1 in Puerto Rico 29/jan/2021

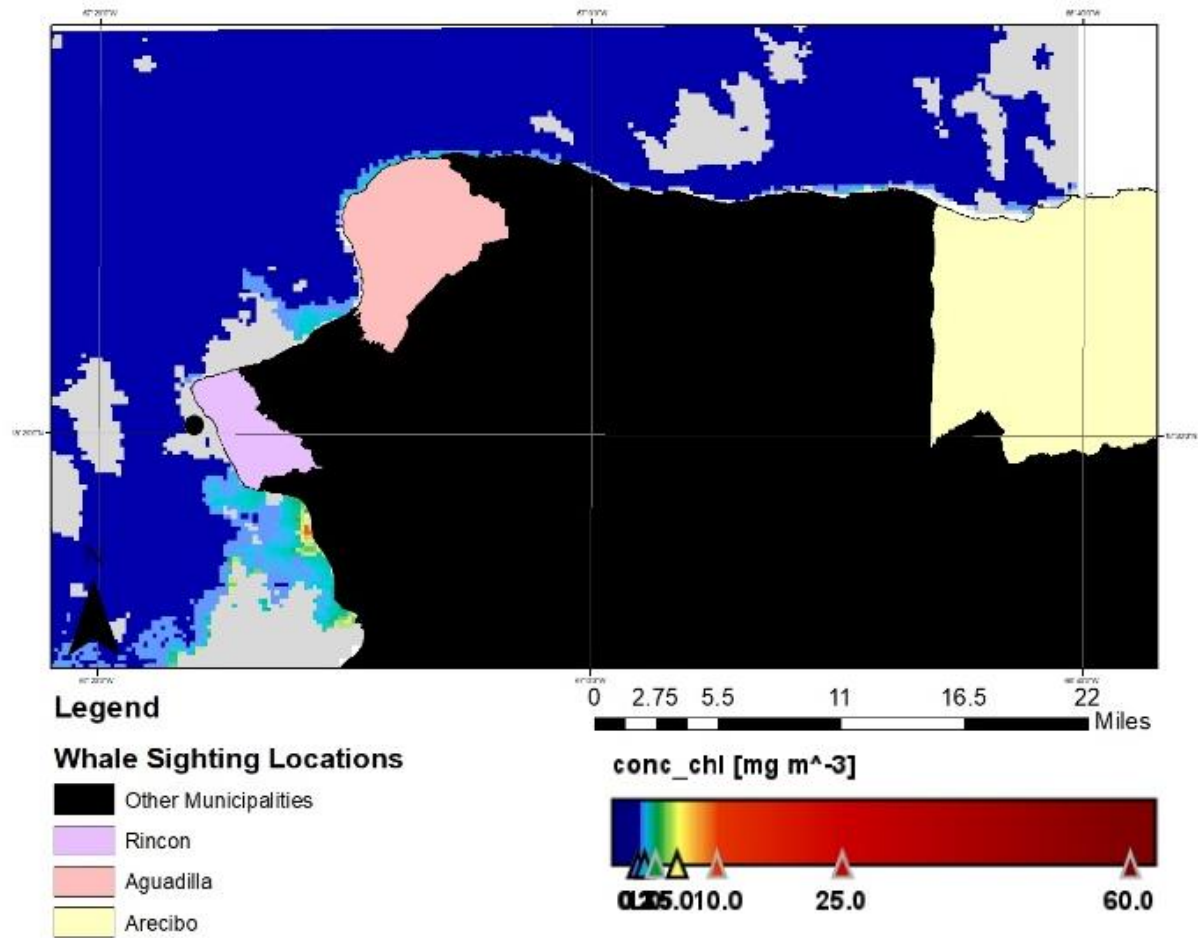


Figure 17

Concentration of Chl-1 in Puerto Rico 14/feb/2021

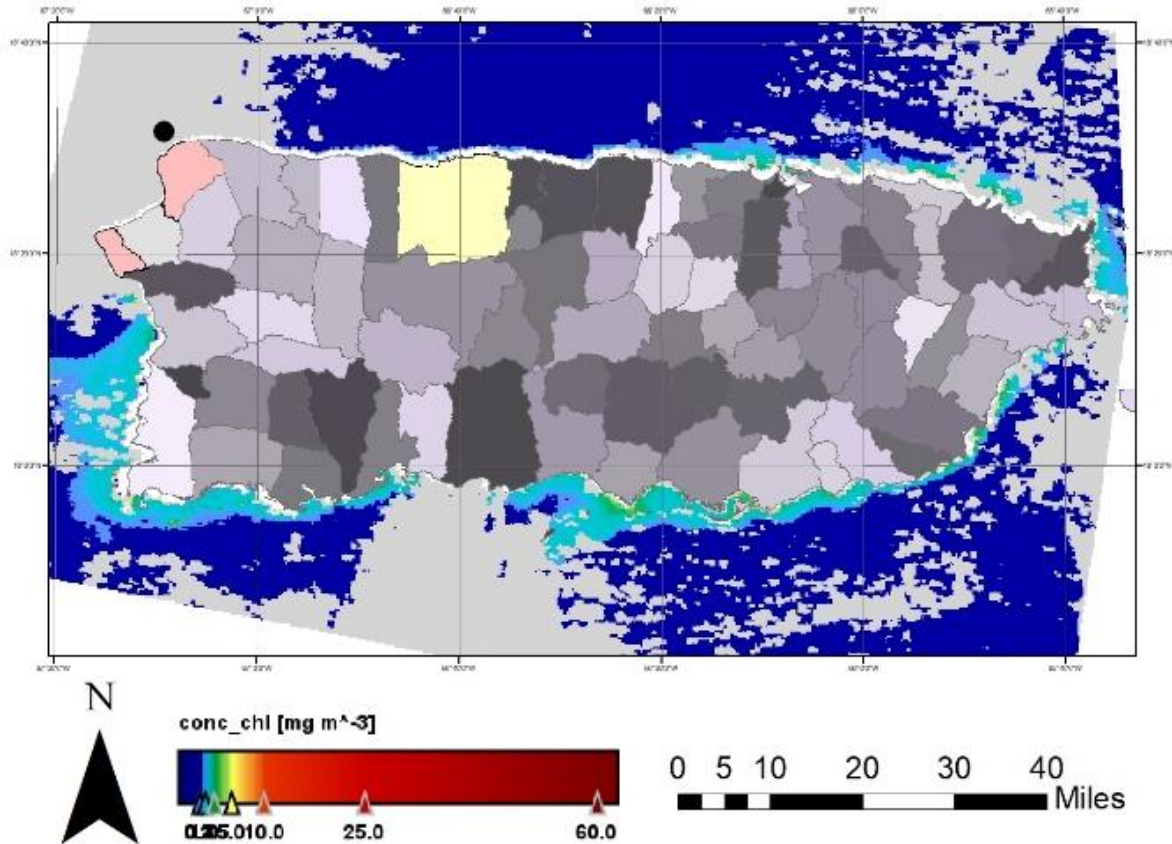


Figure 18

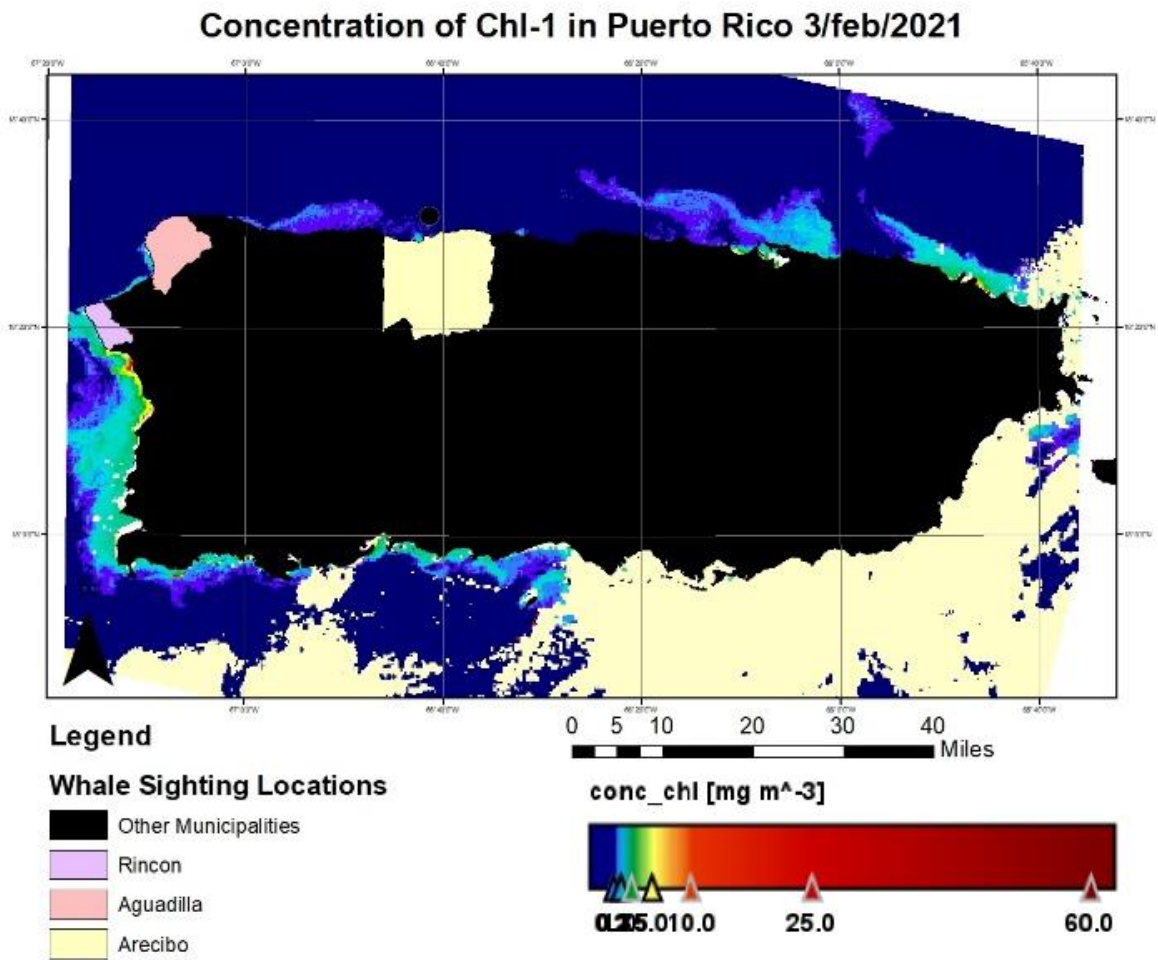


Figure 19

Concentration of Chl-1 in Puerto Rico 5/mar/2021

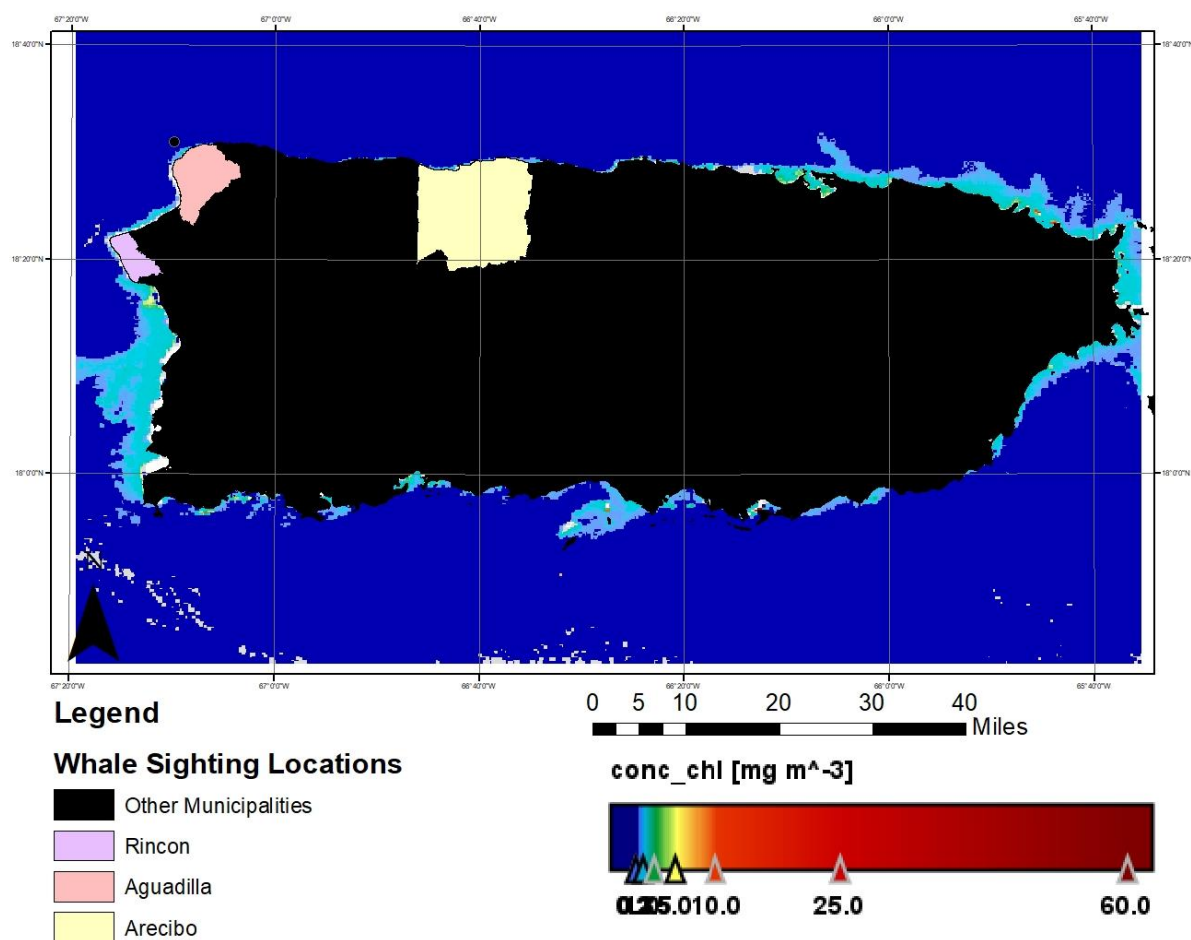


Figure 20

Discussion:

The humpback whales that visit the coasts of Puerto Rico every year have been identified the north Atlantic before. (Baker et al., 1990) *Megaptera Novaeangliae*, during the period of November until April, cruise the Caribbean islands coming from the north heading to Dominican Republic, Virgin Islands, etc. (Baker et. al. 1990). During this period, it is more common to observe said whales in 2 municipalities of the island: Rincon and Aguadilla. Although these municipalities are the one that most experience whale sighting, it is not limited to them because in the past whales have also been observed in Cabo Rojo, Dorado, Arecibo, and others. This research aimed to observe if there is a correlation between the whale sightings and the concentrations of Chlorophyll-A, which was remotely sensed by the Sentinel-3's instrument: OLCI.

Past investigation found a correlation between Chl-A distribution and sightings of baleen whales (humpbacks) and whale sharks. In this project the Chl-a concentrations and the sightings of whale seemed to have a minimal relation or influence. In the Figure it was found some coincidences in places where there were higher Chl-a concentrations, yet this was not consistent in every map. **Figures 16, 19 and 20**, it is noticeable the Chl-a concentrations and the locations agreeing, where there is more Chl-a is exactly in the area where there was a sighting that day. In other cases, the **figure 15** showed little to no Chl-a concentrations in the areas that whales were spotted. **Figures 17 and 18** were unable to detect concentrations due to the clouds that served as an obstacle for the sensors.

A paper from MacKay found that the sighting of whales was usually in the same type of bathymetric feature in the continental shelf of Puerto Rico, where there is an abrupt change of elevation of the ocean seafloor. In 2016 MacKay et. al. experienced in this area, the continental shelf, a higher density of. This area pairs up with the sighting locations in this project. This paper states that there is a sighting hotspot in: Rincon shelf, Aguadilla shelf and Cabo Rojo area. Both Rincon and Aguadilla were focus and hotspot in this project.

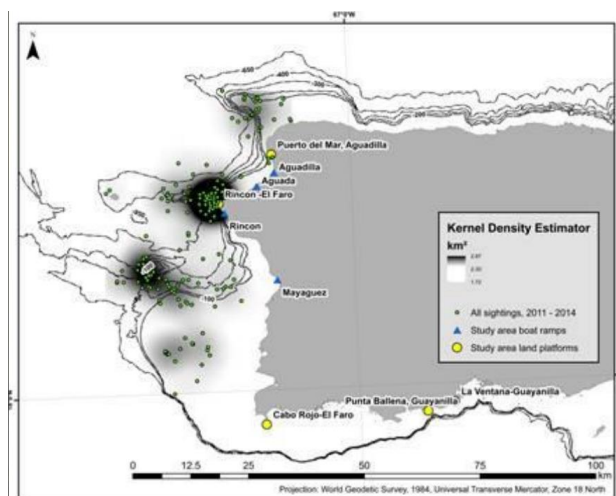


Figure 21: Whale sightings and density from 2011-2014 breeding season in the northwest coast of Puerto Rico.

In the other hand, an article from A.S. Kennedy et. al., 2014 (**Figure 2**) presents the average migratory path from the North Atlantic to de Caribbean in which it is noticeable that they get closer to Puerto Rico at northwest coast. One can say that the concentrations of Chl-a do influence the path of *Megaptera novaeangliae* through the coast of Puerto Rico, yet it is not significant since there also have been sightings in areas of the west where there was not much Chl-a concentration recorded. Summing up: the whale migratory path, the whale bathymetry

preference, and Chlorophyll-a concentrations; there could exist a path of preference of the humpback in an area that experiences chl-a small blooms and is near the Puerto Rican shelves mentioned by MacKay, 2016 on their paper.

Johnson and Wolman stated in 1984: “humpbacks fast mainly, if not entirely, during the winter and feed during the summer”. This means that when the whales arrive to the coast of Puerto Rico, they have no interest in feeding; during this period whales are focusing on breeding, nursing, and calving. It was found that *Megaptera novaeangliae* can fast for the whole months of breeding season due to their protein and fats reservoir in their skin (J Groß et. al. 2020). This statement sets an important piece for the project, as it proves wrong the hypothesis: “*The humpback whale sightings from past whale seasons are congruent with the high levels of chlorophyll-a in the coast due its position in the food chain (primary to secondary consumers) and food availability.*” Because the food chain is not a matter of fact in this period.

Conclusions:

The result of the project and research coincides in that *Megaptera novaeangliae* occupy the west coast of Puerto Rico to breed, nurse and calve, specifically the continental shelf areas in the westmost corners of Rincon and Aguadilla. It is concluded that the hypothesis is rejected because whales do not feed during their breeding season in the Caribbean, therefore the presence of Chl-a in the ocean does not matter, yet one could say that there was a slight influence because in some processed images the whale sightings coincided with

high concentrations of chlorophyll-a pigment.

The Objectives of this project were successfully completed as it was employed the learned techniques of GISystems such as: working with layer, features, georeference, changes in coordinate system, processing Chl-a images and other. More than 6 maps were created, and more than 10 images were developed.

5. Utilize learned techniques of remote sensing and apply it in ArcGIS and SNAP software.
6. Develop maps employing chlorophyll-a data collected with satellite imagery (OLCI) from Sentinel
7. Plot in the map whale sightings on the west coast of Puerto Rico, specifically Rincon and Aguadilla
8. Compare and Contrast results to identify if there is any correlation or patter

Recommendations for future research:

For future investigations, researchers recommend repeating the experiment in the North Atlantic area, specifically feeding areas. This is important since during the breeding season humpback whales do not feed, but during the feeding season one could study the relationship between Chl-a and whale sightings. Additionally, it is also recommended to carry out field data to compare to the remotely sensed data.

References:

Humpback whale global distribution. Adapted by Nina Lisowski from Jefferson, T.A., Webber, M.A. and Pitman, R.L. (2015). "Marine Mammals of the World: A Comprehensive Guide to Their Identification," 2nd ed. Elsevier, San Diego, CA. Copyright Elsevier: <http://www.elsevier.com>

Rizzo, L. Y., and D. Schulte. "A review of humpback whales' migration patterns worldwide and their consequences to gene flow." *Journal of the Marine Biological Association of the United Kingdom* 89.5 (2009): 995-1002.

Kennedy, Amy S., et al. "Local and migratory movements of humpback whales (*Megaptera novaeangliae*) satellite-tracked in the North Atlantic Ocean." *Canadian Journal of Zoology* 92.1 (2014): 9-18.

MacKay, M. M., et al. "North Atlantic humpback whale (*Megaptera novaeangliae*) hotspots defined by bathymetric features off western Puerto Rico." *Canadian Journal of Zoology* 94.7 (2016): 517-527.

Groß, Jasmin, et al. "Interannual variability in the lipid and fatty acid profiles of east Australia-migrating humpback whales (*Megaptera novaeangliae*) across a 10-year timeline." *Scientific reports* 10.1 (2020): 1-14.

Martin, A.R., Katona, S.K., Matilla, D., Hembree, D., and Waters, T.D., 1984, Migration of Humpback Whales between the Caribbean and Iceland: *Journal of Mammalogy*, v. 65, p. 330–333, doi: 10.2307/1381174.

Kumari, B., and Raman, M., 2010, Whale shark habitat assessments in the northeastern Arabian Sea using satellite remote sensing: *International Journal of Remote Sensing*, v. 31, p. 379–389, doi: 10.1080/01431160902893444.

Visser, F., Hartman, K., Pierce, G., Valavanis, V., and Huisman, J., 2011, Timing of migratory baleen whales at the Azores in relation to the North Atlantic spring bloom: *Marine Ecology Progress Series*, v. 440, p. 267–279, doi: 10.3354/meps09349.

Littaye, A., Gannier, A., Laran, S., and Wilson, J.P., 2004, The relationship between summer aggregation of fin whales and satellite-derived environmental conditions in the northwestern Mediterranean Sea: *Remote Sensing of Environment*, v. 90, p. 44–52, doi: 10.1016/j.rse.2003.11.017.

Mackay, M., Würsig, B., Bacon, C., and Selwyn, J., 2016, North Atlantic humpback whale (*Megaptera novaeangliae*) hotspots defined by bathymetric features off western Puerto Rico: *Canadian Journal of Zoology*, v. 94, p. 517–527, doi: 10.1139/cjz-2015-0198.