**Hawai’i Water Resources**

*Utilizing NASA Earth Observations to Assess Ocean Conditions Leading to the Spread of the Nuisance Red Algae (Chondria tumulosa) in Papahānaumokuākea Marine National Monument, Hawai’i*

**Project Team**

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**Project Overview**

***Project Synopsis:***

An extensive outbreak of the newly identified algae, *Chondria tumulosa,* is threatening the survival of coral reefs at Manawai Atoll (also known as Pearl and Hermes) of Papahānaumokuākea Marine National Monument (PMNM) in the Northwestern Hawaiian Island archipelago. This World Heritage site encompasses over 1.5 million km2 of uninhabited islands and atolls, protecting over 70% of total coral reefs in the United States. Due to the remote location of these atolls and the risk of further algal spread, this project created a Google Earth Engine tool that enabled our partners to remotely monitor ocean conditions utilizing NASA Earth observations.

***Abstract:***

*Chondria tumulosa*, a newly discovered red alga, was observed in low abundance in 2016 but has since proliferated and is now smothering and decimating vast expanse of coral reefs in Manawai, located in Papahānaumokuākea Marine National Monument (PMNM). If the spread persists, the outbreak of this cryptogenic species could potentially cause region-wide ecosystem degradation. In coordination with the U.S. Fish and Wildlife Service, Marine National Monuments of the Pacific and the National Oceanographic and Atmospheric Administration (NOAA) Office of National Marine Sanctuaries’ Papahānaumokuākea Marine National Monument, this project created a tool to analyze oceanographic conditions (sea surface temperature (SST), chlorophyll-a, water velocity, salinity, turbidity) across the Monument that could potentially be driving the algal spread. The Google Earth Engine tool enabled the partners to visualize oceanographic conditions and gather time-series graphs utilizing Aqua and Terra Moderate Resolution Imaging Spectroradiometer (MODIS), Suomi National Polar-orbiting Partnership (NPP) Visible Infrared Imaging Radiometer Suite (VIIRS), Sentinel-3 Ocean and Land Colour Instrument (OLCI), Hybrid Coordinate Ocean Model (HYCOM) and NOAA's Climate Data Record in a user-friendly interface. The team used *in situ* SST data from subsurface temperature recorders provided by the partners to validate the tool's accuracy. Preliminary statistical analysis of MODIS data found warming trends in SST in Manawai as well as increased chlorophyll-a levels during the summer months in contrast to the control (non-infected) Lalo atoll. The tool did not aim to classify algal presence due to limited availability of higher resolution satellite imagery but instead enabled PMNM managers to monitor conditions that may be conducive to algal growth around the monument to make informed decisions and mitigation practices.

***Key Terms:***

*Chondria tumulosa,* Papahānaumokuākea Marine National Monument, Google Earth Engine, remote sensing, coral reefs, MODIS, VIIRS

***National Application Area Addressed:*** Water Resources

***Study Location:*** Papahānaumokuākea Marine National Monument, HI

***Study Period:*** January 2013 to October 2020

***Community Concerns:***

* This newly identified nuisance red alga has blanketed much of Manawai atoll’s coral reefs and has the potential to invade nearby reefs within the next year.
* This outbreak, if not controlled, can lead to a collapse of the marine ecosystem of the region, decimating the local benthic flora and fauna, and even potentially reach the main Hawaiian Island coral reefs.
* There is much that is unknown about this species, but its sudden appearance and exponential mat-like growth which smothers the reef, threatening the survival of the pristine and uninhabited monument.

***Project Objectives:***

* Quantify variations in oceanographic conditions around the PMNM
* Create a web-based tool in Google Earth Engine (GEE) to visualize ocean conditions of interest
* Analyze the correlation between ocean conditions, (temperature, turbidity, current, etc.) and algal presence alongside *in situ* data
* Create a detailed PowerPoint tutorial to be administered by Mr. Lopes, a PMNM Affiliate, to enable monument managers to begin working with GEE JavaScript API

**Partner Overview**

***Partner Organizations:***

|  |  |  |  |
| --- | --- | --- | --- |
| **Organization** | **POC (Name, Position/Title)** | **Partner Type** | **Boundary Org?** |
| **US Fish and Wildlife Service, Marine National Monuments of the Pacific** | Dr. Kauaoa Fraiola, Fish and  Wildlife Biologist | End User | Yes |
| **NOAA, Office of National Marine Sanctuaries, Hawai’i Regional Office, Papahānaumokuākea Marine National Monument** | Dr. Jonathan Martinez, Marine Scientist | End User | Yes |

***Decision-Making Practices & Policies:***

Management of PMNM is the responsibility of four co-managing agencies, which comprise the National Oceanographic and Atmospheric Administration’s (NOAA) Office of National Marine Sanctuaries, the U.S. Fish and Wildlife Service (FWS), the Office of Hawaiian Affairs, and the State of Hawai’i. These agencies are mandated under federal law to oversee all cultural and scientific access permits, monitor and mitigate potential damage from natural and anthropogenic causes, and protect PMNM’s natural and cultural resources. Currently, data from PMNM are primarily collected by *in situ* observations during summer months field camps, SCUBA diving expeditions, instrument deployments, damage assessments (vessel and buoy grounding), and cultural practices. These field expeditions are expensive and have recently faced more constraints with shrinking budgets, an aging ship fleet, and the implementation of new guidelines in response to the global pandemic. These factors are exacerbated by rapid changes in climate including more devastating hurricanes, mass coral bleaching events, as well as the outbreak of the nuisance red algae, *C. tumulosa*.

**Earth Observations & End Products Overview**

***Earth Observations:***

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| --- | --- | --- |
| **Platform & Sensor** | **Parameters** | **Use** |
| **Aqua MODIS** | Remote Sensing Reflectance (Rrs), Chlorophyll-a, Sea Surface Temperature (SST), Diffuse Attenuation at 490nm (Kd490) | The GEE tool and subsequent analysis used Aqua MODIS to analyze a time series of reflectance, chlorophyll-a, SST, and Kd490 to correlate ocean conditions with *in situ* data of *C. tumulosa* in the Monument. |
| **Terra MODIS** | Rrs, Chlorophyll-a, SST, Kd490 | The GEE tool and subsequent analysis used Terra MODIS to analyze a time series of reflectance, chlorophyll-a, SST, and Kd490 to correlate ocean conditions with *in situ* data of *C. tumulosa* in the Monument. |
| **Suomi NPP VIIRS** | Chlorophyll-a | The GEE tool and data analysis used VIIRS to analyze a time series of chlorophyll-a and SST. |
| **Sentinel-3 OLCI** | Chlorophyll-a | The GEE tool and data analysis used Sentinel-3 to analyze chlorophyll-a. Sentinel data were obtained for dates after October 2016 at a spatial resolution of 300m. |

***Ancillary Datasets:***

* National Ocean Partnership Program (NOPP), Hybrid Coordinate Ocean Model (HYCOM) – used as an additional input to analyze water velocity as an oceanographic process that may influence the spread of *C. tumulosa*
* NOAA National Marine Sanctuaries, Hawai’i Regional Office *in situ* data of *C. tumulosa* presence – used to correlate past and present ocean conditions with the presence of *C. tumulosa* in the monument
* National Coral Reef Monitoring Program (NCRMP) Subsurface Temperature Recorders (STRs) – i*n situ* data used to validate the tool’s MODIS sea surface temperature data and analyze temperature trends
* NOAA Climate Data Record – used as an additional input for sea surface temperature

***Modeling:***

* MODIS Diffuse Attenuation at 490 nm (POC: P. Jeremy Werdell, NASA) – compute downwelling irradiance
* OC3V Algorithm (POC: P. Jeremy Werdell, NASA) – compute chlorophyll-a with the VIIRS sensor

***Software & Scripting:***

* Google Earth Engine – data acquisition and processing of MODIS, VIIRS, HYCOM, NOAA CDR, and Sentinel-3 imagery; creation of web-based ocean conditions monitoring tool
* R 3.5.0 – statistical analysis of chlorophyll-a data generated from MODIS
* Esri ArcGIS Pro 2.6.0 – generate map products
* Python 3.7 – statistically compare the *in situ* SST data from subsurface temperature recorders with the satellite derived data

***End Products:***

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| --- | --- | --- | --- |
| **End Products** | **Earth Observations Used** | **Partner Benefit & Use** | **Software Release Category** |
| **Maps and Time Series Analysis of Ocean Conditions**  **2013 – 2020** | Aqua and Terra MODIS | Statistical analysis of chlorophyll-a, sea surface temperature along with *in situ* data of algal presence within the Monument helped the partner assess past patterns, narrow down possible contributing variables, and identify future risks of *C. tumulosa* spread. | N/A |
| **Google Earth Engine**  **Conditions Observed in Red Algae Spread (CORALS)** | Aqua and Terra MODIS, Suomi NPP VIIRS, Sentinel-3 OLCI | This tool provided the partners with a user-friendly interface to assess reflectance, chlorophyll-a, turbidity, sea surface temperature, salinity, and water velocity across a time series at user-selected locations across the Monument to identify drivers of algal spread. | III |
| **Maps and Time Series Analysis of Ocean Conditions**  **2013 – 2020** | Aqua and Terra MODIS | Statistical analysis of chlorophyll-a, sea surface temperature along with *in situ* data of algal presence within the Monument helped the partner assess past patterns, narrow down possible contributing variables, and identify future risks of *C. tumulosa* spread. | N/A |

***Product Benefit to End User:***

Currently, our project partners along with the other co-managing agencies, including the Office of Hawaiian Affairs and the State of Hawai’i, collect *in situ* data ranging from seal and turtle counts to oceanographic measurements, on-site during annual expeditions to the extremely remote PMNM. With dwindling budgets and pandemic restrictions, access to the site is increasingly challenging. Therefore, this project utilized remote sensing tools to enable our partner organizations to monitor the monument remotely and more frequently. Our tool will allow our project partners the ability to create a time series of previous and current oceanographic conditions utilizing sea surface temperatures, chlorophyll-a concentrations, turbidity, salinity, and water velocity to assess conditions that have been conducive to the spread of the nuisance algae *C. tumulosa* decimating the coral reefs in the Manawai atoll. This tool will allow the partners to remotely monitor the conditions and potential spread to nearby atolls or even as far as the main Hawaiian Island reefs while limiting the risk of anthropogenic disturbance from frequent site visitations.

**References**

Sherwood, A. R., Huisman, J. M., Paiano, M. O., Williams, T. M., Kosaki, R. K., Smith, C. M., Giuseffi, L., & Spalding, H. L. (2020). Taxonomic determination of the cryptogenic red alga, *Chondria tumulosa* sp. nov., (Rhodomelaceae, Rhodophyta) from Papahanaumokuakea Marine National Monument, Hawai’i, USA: A new species displaying invasive characteristics. *PLoS ONE*, *15*(7), 1–16. <https://doi.org/10.1371/journal.pone.0234358>