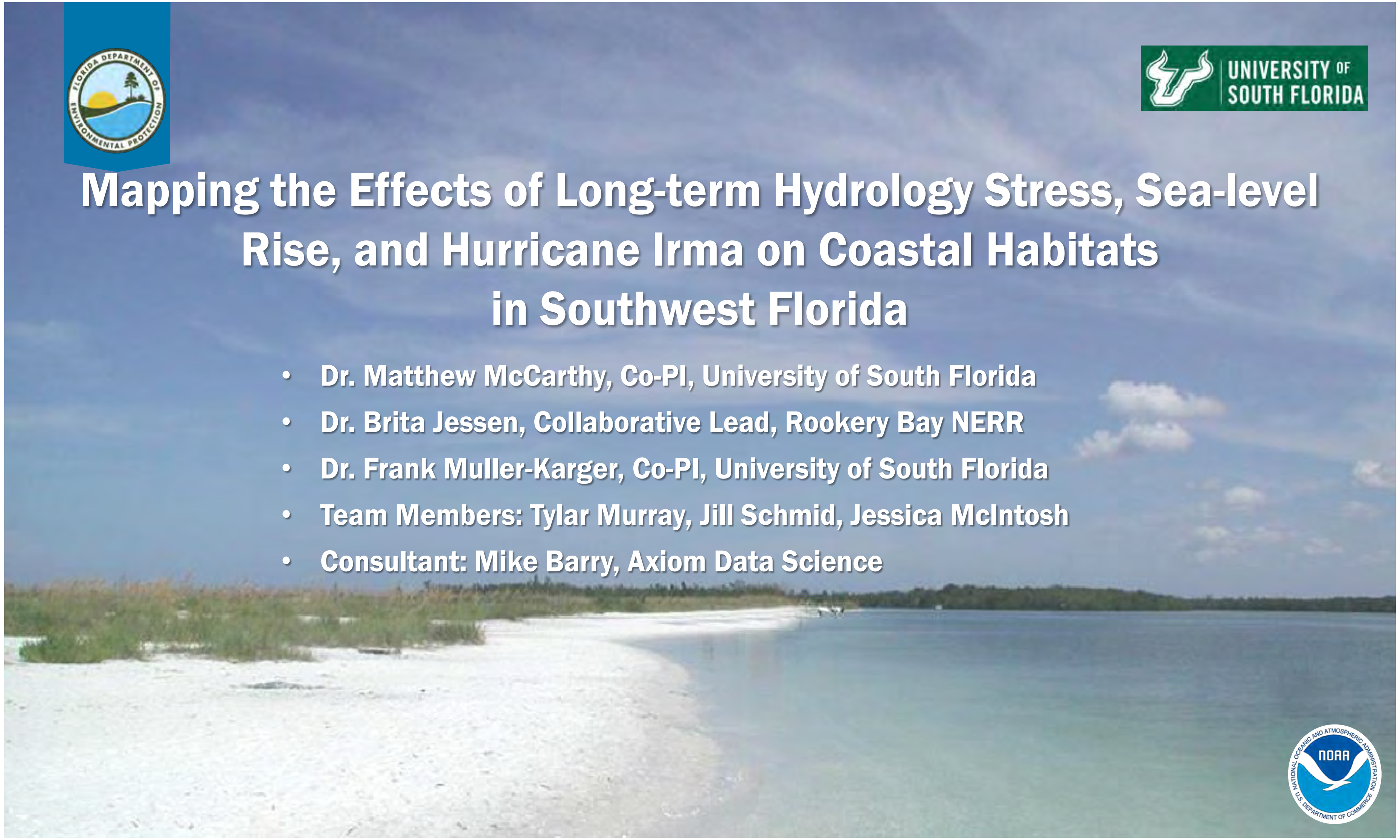
Summary Points:

Hurricane Irma made landfall in southwest Florida within the Rookery Bay National Estuarine Research Reserve in September of 2017 as a Category 3 storm with winds in excess of 115 mph. For some areas within the reserve, the impact of the storm compounded the stress caused by decades of human development and changes to water flow patterns. Managers of the reserve want to better understand the synergistic effects of chronic stress from human modification or other drivers - e.g., sea level rise - and acute impacts from Hurricane Irma. One approach is to measure habitat structure and change in the time preceding and following the major storm event.

Dr. Matthew McCarthy is a postdoctoral researcher at the University of South Florida's College of Marine Science. He specializes in remote sensing and large-scale coastal mapping with supercomputing technologies and advanced image processing techniques. He has applied remote sensing methods to study a variety of issues, including mangroves, seagrasses, coral reefs, coastal geomorphology, sea-level rise, aquaculture and public health.

Dr. Brita Jessen is the research manager at the Rookery Bay National Estuarine Research Reserve. She specializes in ecosystem ecology of coastal wetlands. As the research team lead, Dr. Jessen supports long-term monitoring programs related to water quality, sea level rise, habitat change, and wildlife, and works across departments to facilitate the translation of current research into management and policy.



Summary Points:

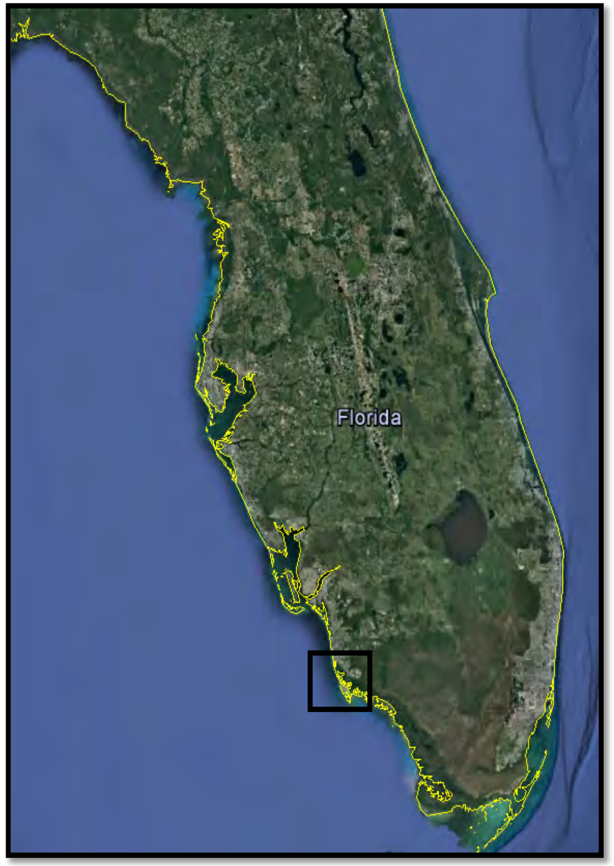
This webinar described the use of advanced satellite imagery to map the damage, death, and recovery of mangroves with a time series of images from 2010 to 2018. Dr. Matt McCarthy shared the methods used to map the landscape and evaluate change. Dr. Brita Jessen provided background for the study and discussed the management implications for the reserve and other coastal areas. Matt and Brita have been collaborating on a one year-year catalyst project that has relevance to coastal land managers interested in mapping habitat change.

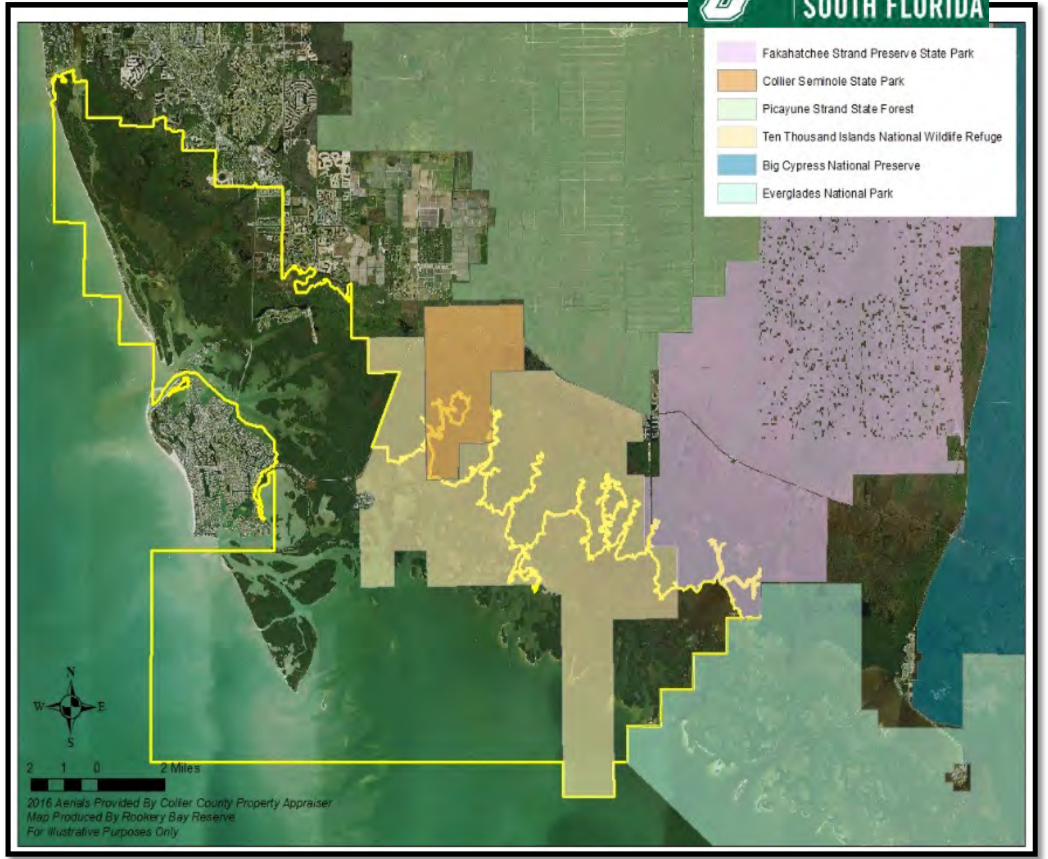
- Introduction to Rookery Bay NERR (Brita)
- Study goals and methods (Matt)
- Results (Matt)
- Next steps (Matt and Brita)

Summary Points:

Rookery Bay's coastal fringe habitat is geologically complex and dominated by mangrove vegetation. It is also very flat; inches of elevation change will have a significant impact on habitat types - leading to a mosaic of complex and diverse habitats behind the mangroves - which can be easily altered by environmental drivers.

Rookery Bay





Summary Points:

Rookery Bay reserve is located in Collier County in southwest Florida, and encompasses 110,000 acres. The reserve manages 40% of the coastline for Collier County.

The yellow line indicates the bounds of the reserve.

Rookery Bay National Estuarine Research Reserve

MISSION

To serve Southwest Florida as a trusted resource for science-based information to foster connected human and ecological communities.

VISION

Communities in Southwest Florida value nature and prosper in concert with healthy estuaries.

Summary Points:

Summary Points:

National Estuarine Research

Research

Education

Stewardship

Coastal Training Program

Coastal Training

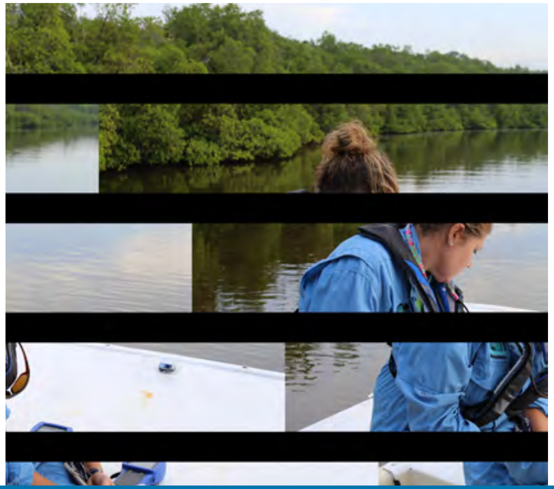
Training Environmental Professionals

Facilitating Collaborative Processes

Educating Policy Makers

Summary Points:

Rookery Bay's Coastal Training Program is headed by Jessica McIntosh. The CTP provides critical and necessary links between scientists and stakeholders.



System-Wide Monitoring Program (SWMP)

Summary Points:

The System-Wide Monitoring Program is standardized across the reserve system, which conducts water quality, weather, and habitat monitoring. The most recent component is the Sentinel Site Program, developed by NOAA, which is currently examining vegetation and elevation change in relation to sea level rise. These data are available here: nerrsdata.org.

Water Chemistry, Nutrients, Weather

Sentinel Sites & Vertical Control

Habitat Mapping and Change

www.nerrsdata.org

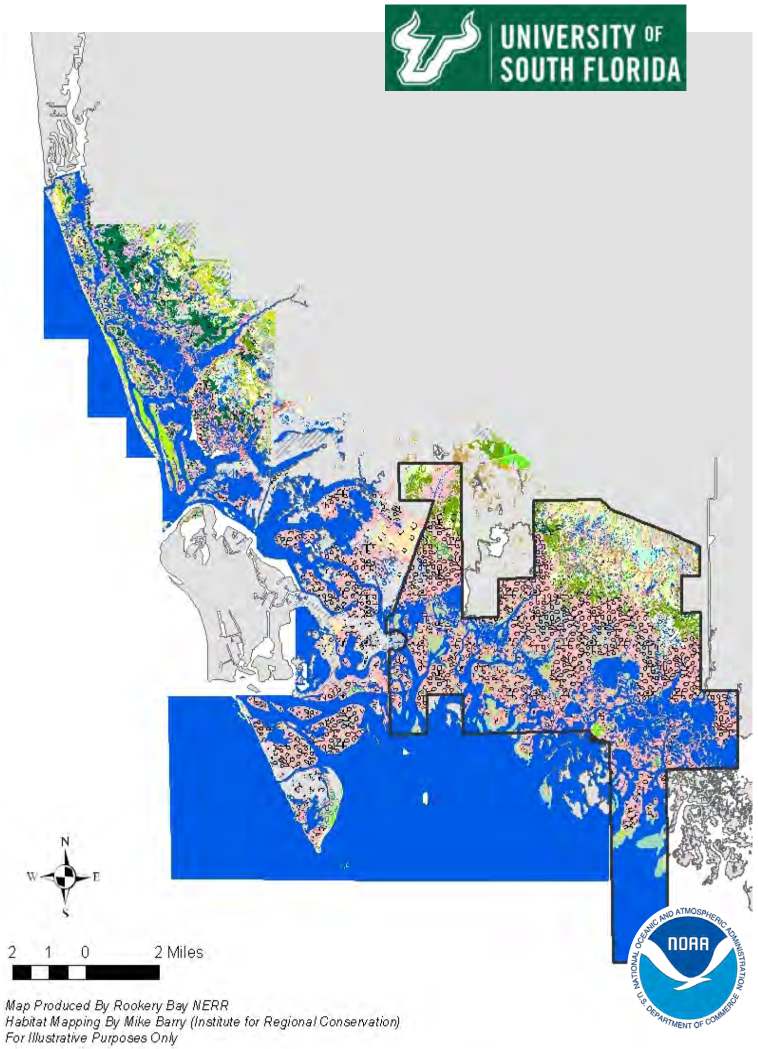
Habitat Mapping

Terrestrial and Submerged

Dynamic Shoreline, Change Events

Habitat Transition Zones

rookerybay.org/learn/research.html



Summary Points:

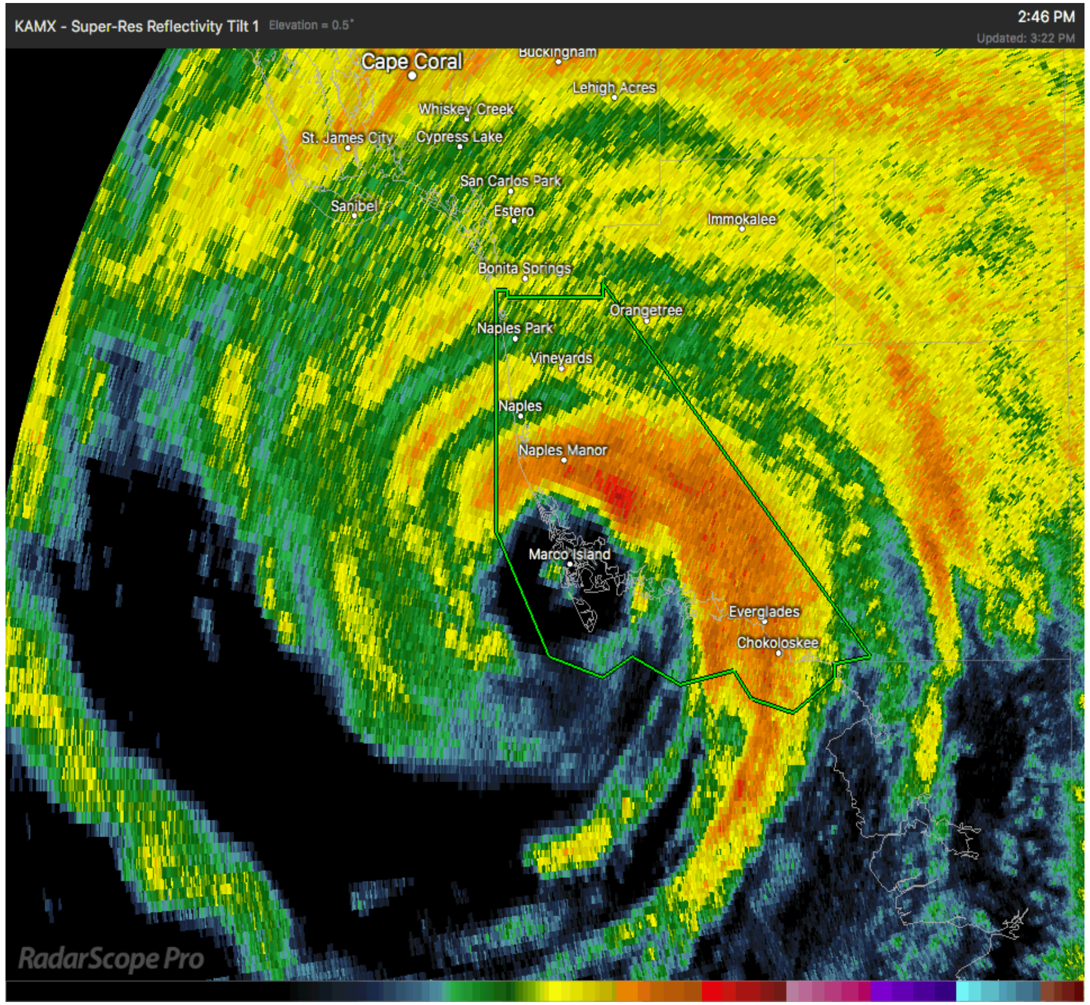
The reserve produced the initial habitat in 2013 in partnership with Mike Barry at the Institute for Regional Conservation, and relied on extensive field observation, historic and current aerial photography, and hand digitization. The project used the Comprehensive Everglades Restoration Plan Classification system, which yielded 117 vegetation types within the reserves, and took 5 years to complete. The website shown here provides an interactive map and other GIS features.

Challenges

Sea Level Rise & Erosion	Watershed Alterations
Invasive Species	Stochastic Events

Summary Points:

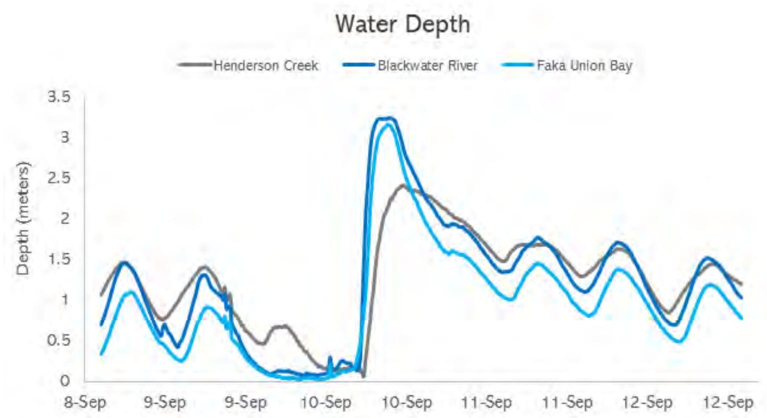
Habitats still experienced ongoing changes during the multi-year time frame of the mapping effort. The slide lists some chronic and acute drivers of change.

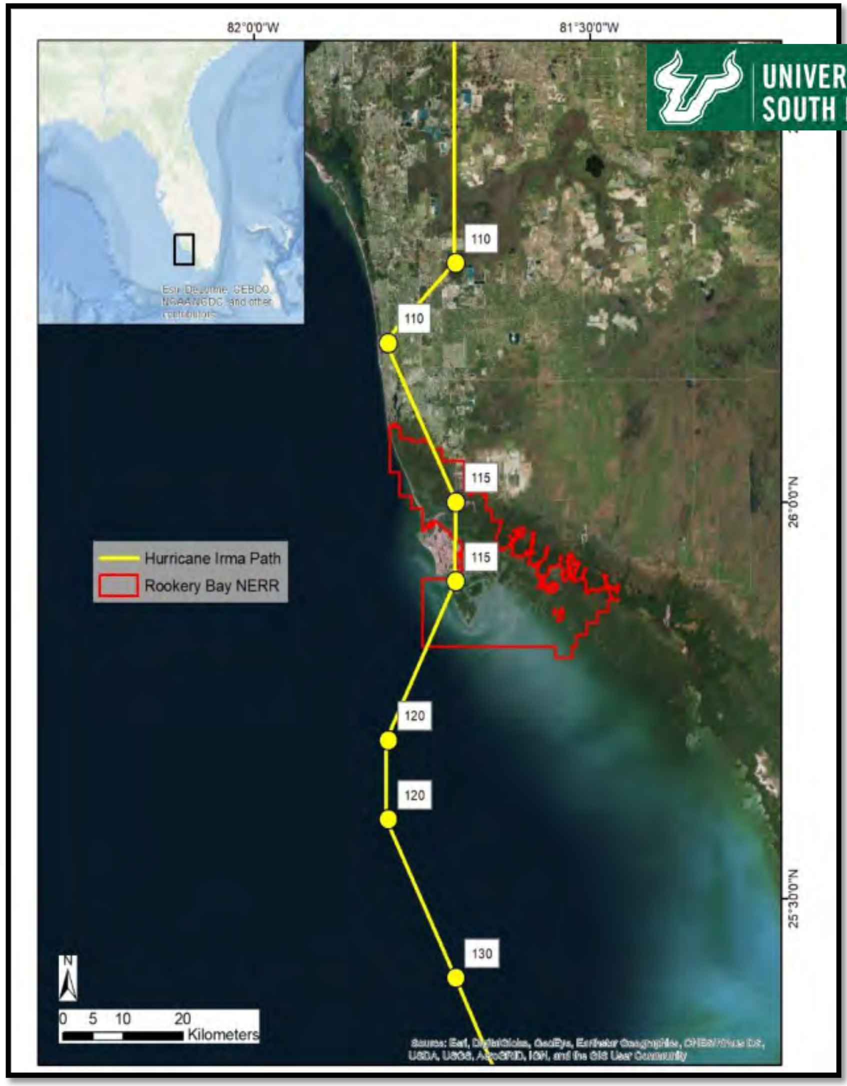


Summary Points:

Hurricane Irma passed over the Rookery Bay reserve on September 10, 2017 as a category 3 storm. Maximum sustained wind speeds measured 140 mph. During the storm, 3 of 5 water quality monitoring stations remained online, measuring approximately 3 meters of storm surge that deposited a thick layer of marine sediment through sections of the backwaters and up into the mangroves.

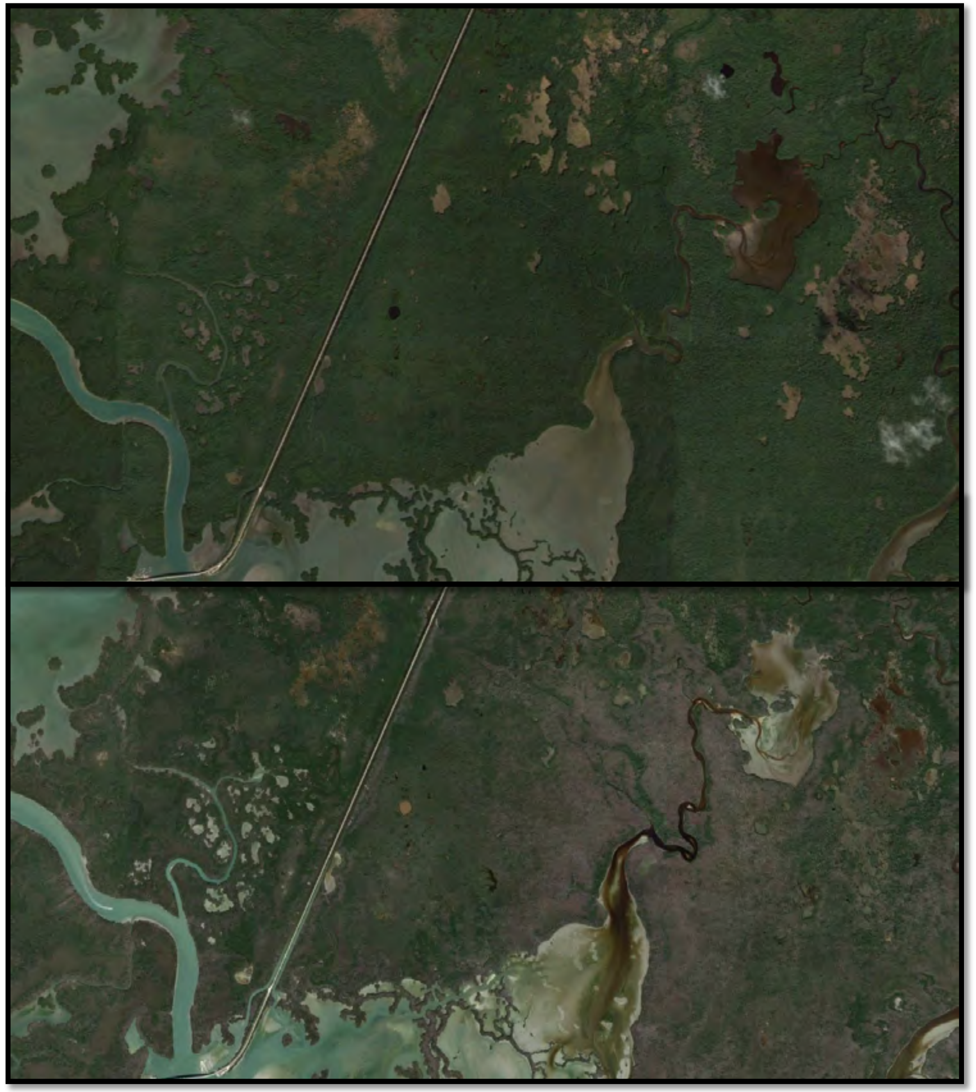
Summary Points:





January 2017

January 2018



Summary Points:

The images shown on the slide demonstrate extensive canopy loss in the mid region of the reserve. Mangroves in subtropical regions are adapted to large storm events, and typically recover within 10 to 20 years given appropriate environmental conditions.

Management Need

- Identify location, extent, and timeframe of coastal wetland degradation
  - Determine chronic vs acute drivers
  - Help managers determine how to mitigate loss, understand recovery, and improve resiliency

Summary Points:

However, mangrove wetlands at Rookery Bay - and globally - have been increasingly altered due to land use, watershed modification, and other exacerbating conditions such as sea level rise. In this new anthropic era, recovery and resilience may not follow historic patterns. Resource managers depend on rapid information production about the extent of change, the drivers of change, and the potential for recovery.

Project Goals

1. Map land and aquatic habitats for years 2010, 2013, 2016, 2017, 2018
2. Detect change location and extent
3. Attribute changes
4. Share information with regional resource managers through facilitated meetings and mapping products

Data

- High-resolution WorldView-2 satellite imagery
- Medium-resolution Landsat satellite imagery
- LiDAR data: 2007
- Field surveys (M. Barry)

Summary Points:

Matt approached Brita to partner with Rookery Bay, with the objectives of mapping and assessing the damage caused by Hurricane Irma. They chose to examine specific years coinciding with the existing 2010 Rookery Bay baseline map because the imagery used in the project began in 2009 for WorldView-2 and in 2013 for the Landsat sensor.

The team then mapped the area for the 2016-2018 time frame to derive baseline change, post-Irma, and Irma-recovery assessments. These assessments allowed the team to detect the location and extent of habitat change, then attribute changes to various environmental and anthropogenic drivers.

Collaborative Process

- Kick-off meeting
  - Introduction to the project and methods
  - Management applications of habitat change maps
  - Participants shared management issues and how they plan to use the information from this project

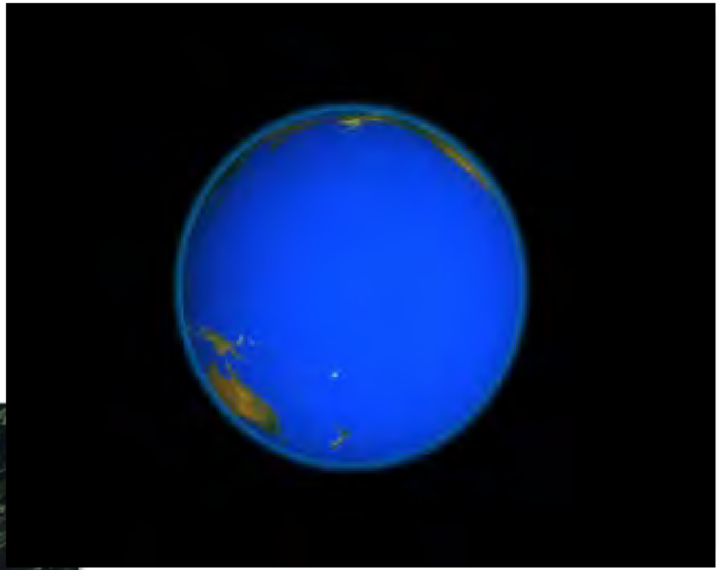
- Three web-based meetings
  - Review of the results
  - Follow-up field work

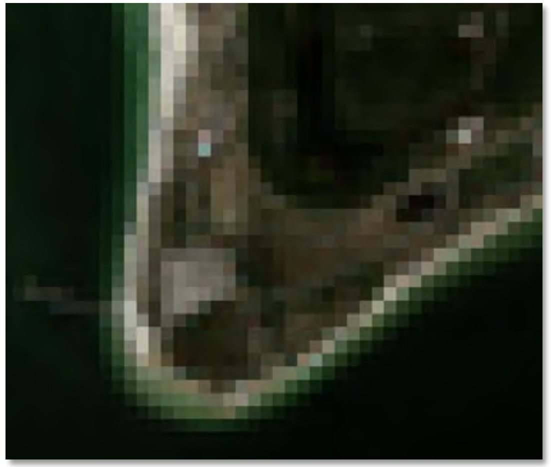
Summary Points:

The team has engaged in collaborative processes throughout the project. Kick-off meetings allowed stakeholders to become familiar with the project, and discuss management applications for habitat maps, management issues, and uses for habitat maps. The subsequent web-based meetings provided an opportunity to review preliminary results from the work, and allowed local experts to give feedback about which maps were correct and which needed revision.

Wetland Classification Challenges

- Misclassification with adjacent vegetation
- Sparse Aerial Imagery
- Spatial Resolution





Summary Points:

When manually digitizing, an analyst examines an aerial image and traces the areas believed to be a particular habitat using ground truth or reference data. Even with high-resolution images, it can be difficult to correctly distinguish adjacent vegetation.

Another challenge with aerial imagery is that it is collected inconsistently and sparsely, and depends on funding availability and mission targets; this contrasts with satellite imagery - as used in this project - which is collected continuously.

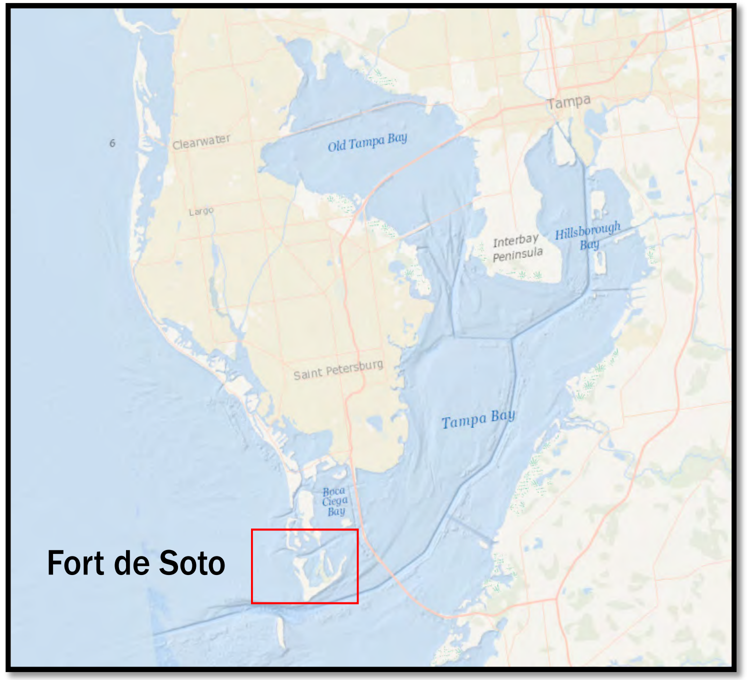
However, there is a tradeoff - in the form of inconsistency - among different satellite sensors, as shown by the example images on the slide. The pixelated image on the left is from Landsat and has a spatial resolution of 30 meters (1 pixel = 900 square meters), while the image on the right is from the WorldView-2 satellite, and has 2 meters of spatial resolution (1 pixel = 4 square meters). The benefit of using satellite imagery over aerial photography, in addition to repeated acquisition, is that analysts can use digital mapping methods by exploiting the digital data contained within each pixel.

Terminology:

- **Ground truth data**: Information collected on location to calibrate remote sensing and assist in interpretation and analysis.
- **Manual digitization**: A digitization method in the analyst uses a graphic tablet with a stylus or other tracing tool to trace the points, lines, and shapes of a hard-copy map.

Wetland Map Inconsistencies

Summary Points:



Wetland Map Inconsistencies

NOAA Coastal Change Analysis Program (CCAP) 2010

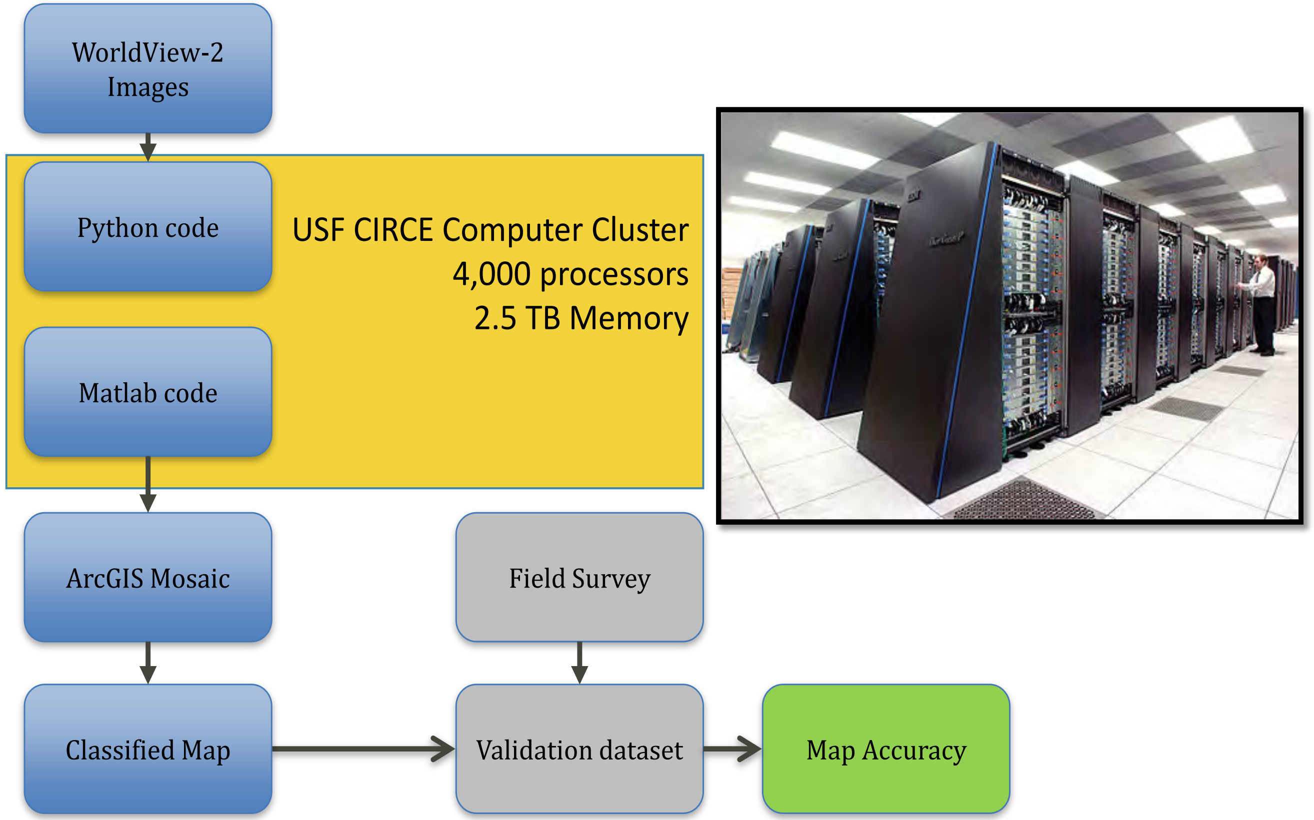
Southwest Florida Water Management District (SWFWMD) 2011

National Wetland Inventory (NWI) 2009

Summary Points:

The images show differences in identified wetlands because the data and methods used to map wetlands, as well as the definition of wetlands, varies from one mapping program to the next. For this project, the team sought to standardize mapping protocols by defining wetlands - specifically mangroves - as red, white, black, and buttonwood mangroves. They used digital data to duplicate methods and exploit computational resources.

Methodology



Summary Points:

The team analyzed 92 WorldView-2 images using the University of South Florida's Central Instructional and Research Computing Environment (CIRCE) High-Performance Computing Cluster, which is made up of 4000 processors strung together such that each image can be processed on a separate computer.

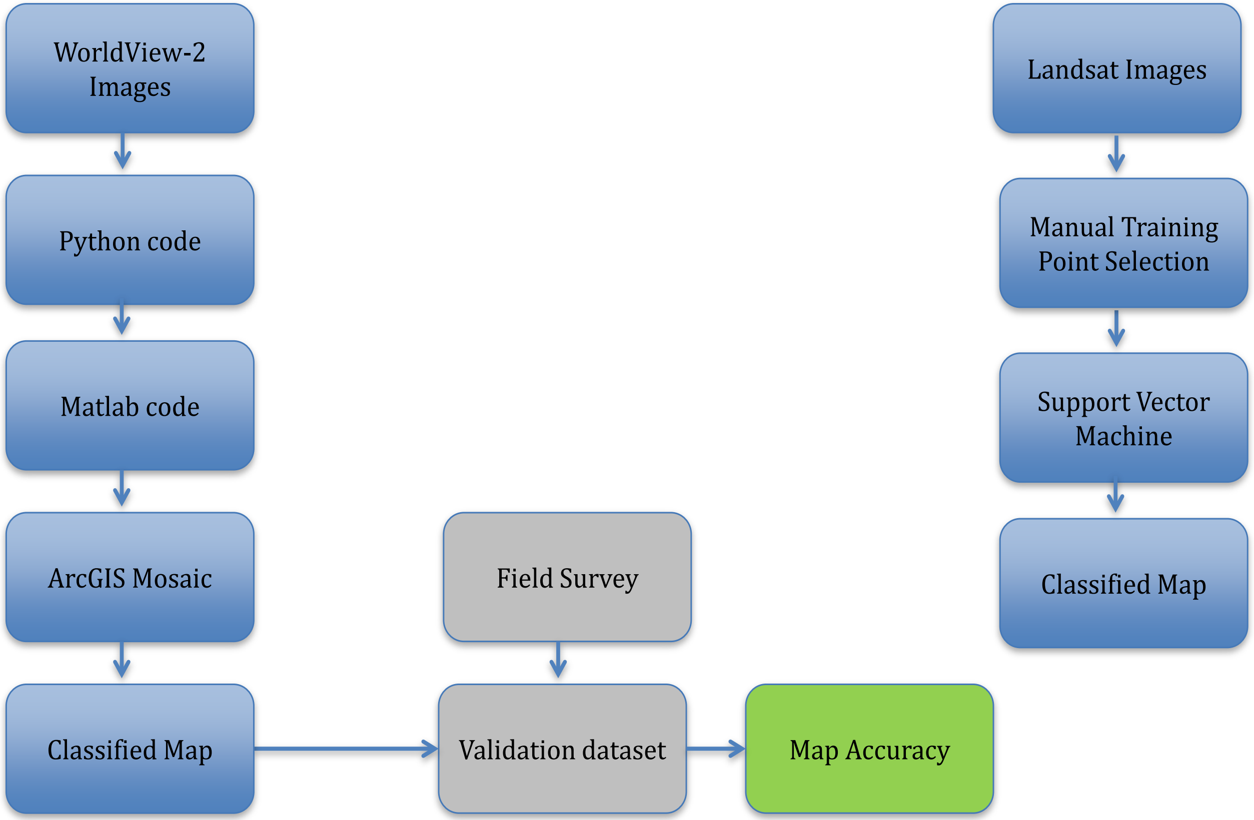
The fully automated computing protocol uses Python and MATLAB to calibrate each image, then perform a series of calculations on about 500 million data points per image. The product is a classified map from each image, which Matt combines with other classified maps to stitch a cohesive mosaic for each time period using ArcGIS.

Simultaneously, Mike Barry collected field data to validate the maps and compute their accuracy.

Terminology:

- **Classified map**: In geographic information systems, a map showing labeled groups or categories to generalize complexity and assist in the extraction of meaning from geospatial data.

Methodology



Summary Points:

Landsat images relied on a regular PC running a program called ENVI, which contains existing codes that calibrate and map images using a machine learning classifier called support-vector machine (SVM).

Terminology:

- **ENVI**: Software used to extract meaningful information from an image for analysis.
- **Support-vector machine**: A machine learning model that uses algorithms to analyze data used in classification. SVMs are considered supervised learning models because they rely on training, or "example," data; i.e., input-output pairs that allow the algorithm to infer and map new examples.

Field Survey

Consultant Mike Barry

September-November 2018

992 Total Points

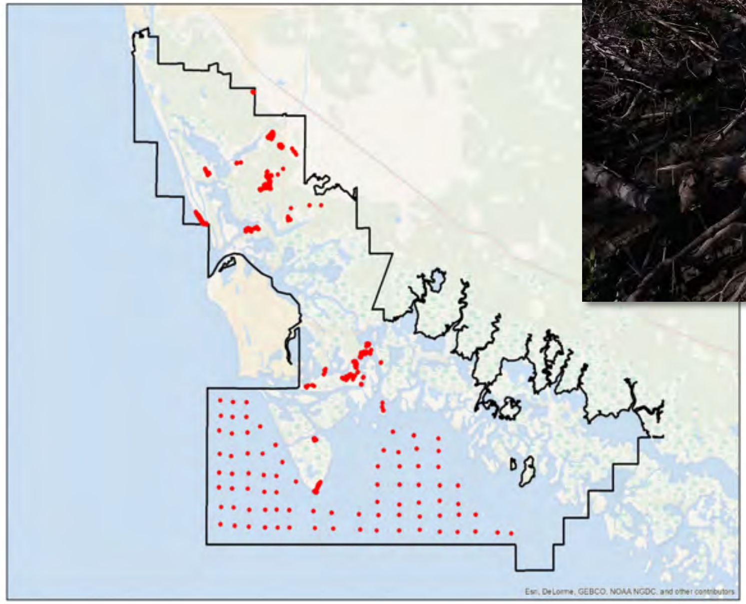
Soil: 334

Degraded mangrove: 50

Healthy mangrove: 328

Upland: 197

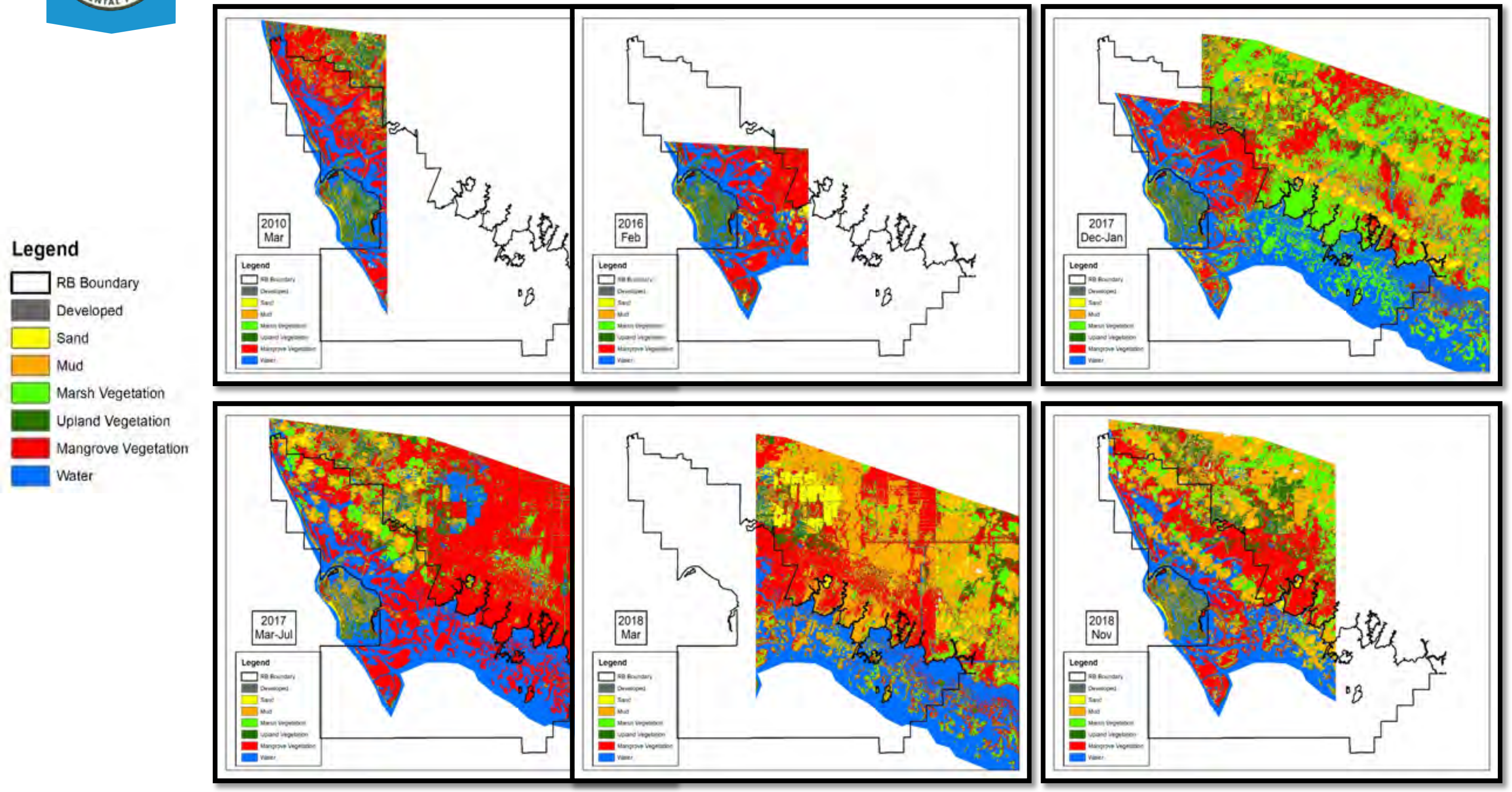
Water: 83



Summary Points:

Mike Barry collected data on 992 points throughout the reserve from September to November of 2018. The team then used these points to map habitats targeting the following classes: soil; degraded mangrove; healthy mangrove; upland; and water.

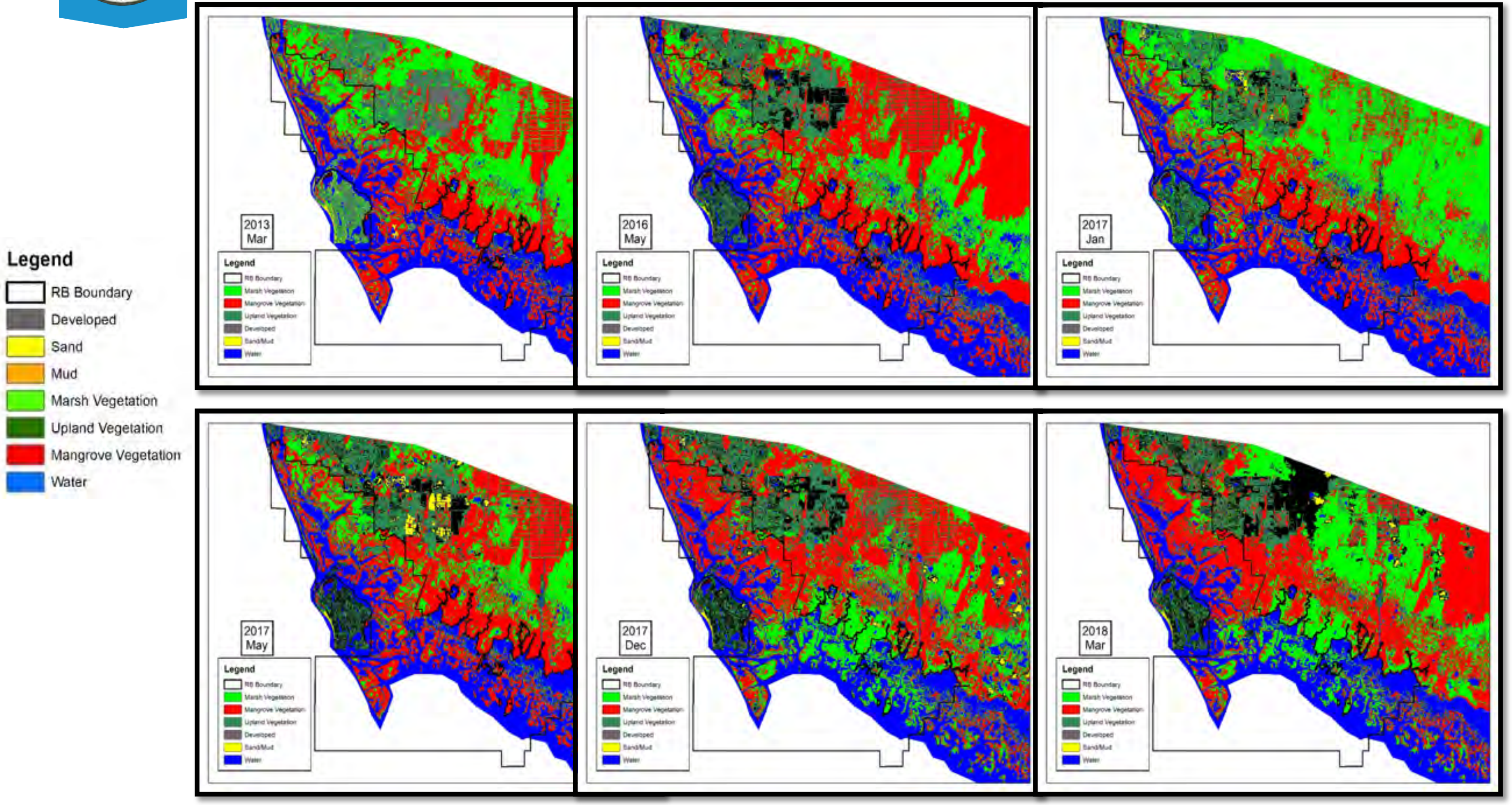
Worldview Geographic Image



Summary Points:

The figure shows geographic coverage of the WorldView-2 maps. Not every map covers the entire reserve, because WorldView-2 images cover a relatively small area per image; thus the necessity of collecting a total of 92 images.

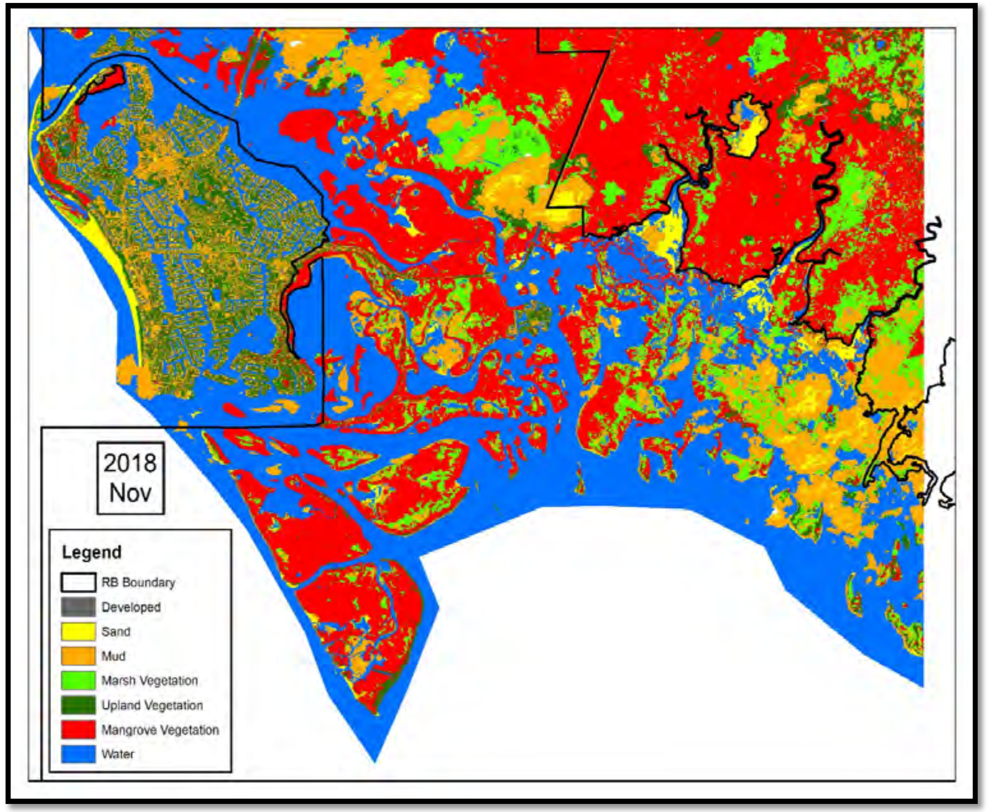
Landsat Geographic Image



Summary Points:

Landsat coverage is much greater, but each image has lower resolution. With this tradeoff, the team could map the full reserve with a single image at a time - using a total of 6 images - but each image has lower resolution than the WorldView-2 images.

Accuracy Assessment: Worldview Nov 2018



- Soil: 95%
- Degraded mangrove: 56%
- Healthy mangrove: 78%
- Upland: 68%
- Water: 100%
- Overall accuracy: 82%

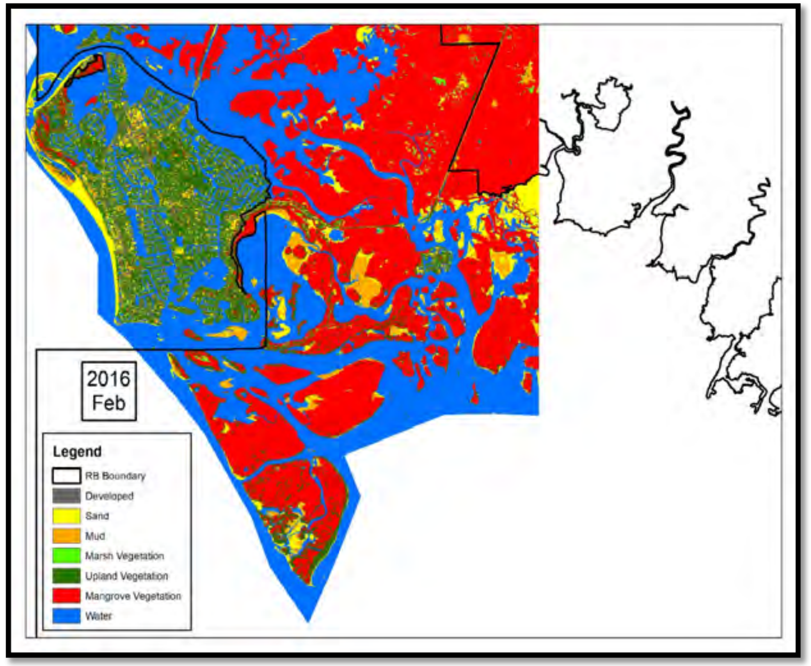
Summary Points:

With the data the team collected, they can statistically assess the accuracy of the image shown because it coincides with the period during which the points were collected. Field survey results validate the accuracy of the various components of the mapping.

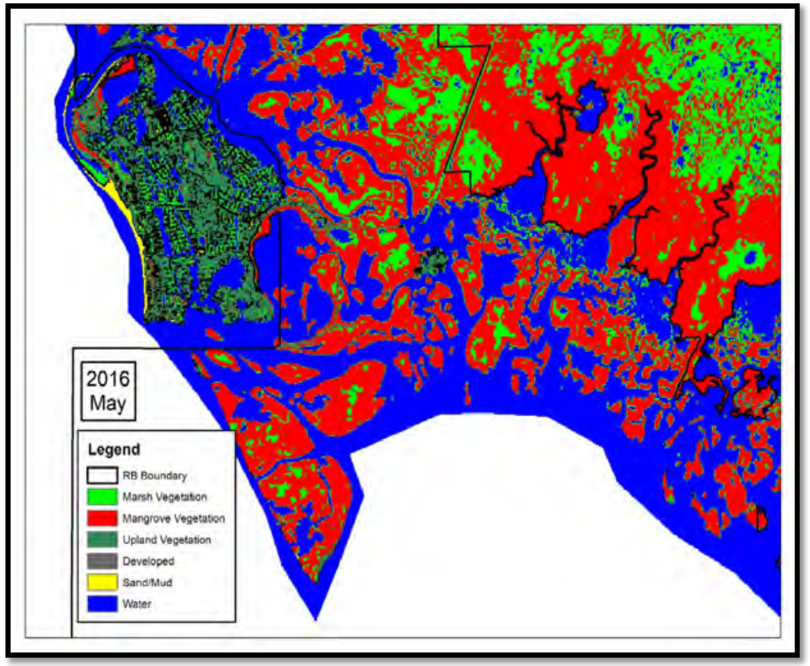
Note: In some cases, orange spots indicate cloud coverage, which confounds imagery but is a common challenge with satellite imaging.

Results

WorldView



Landsat



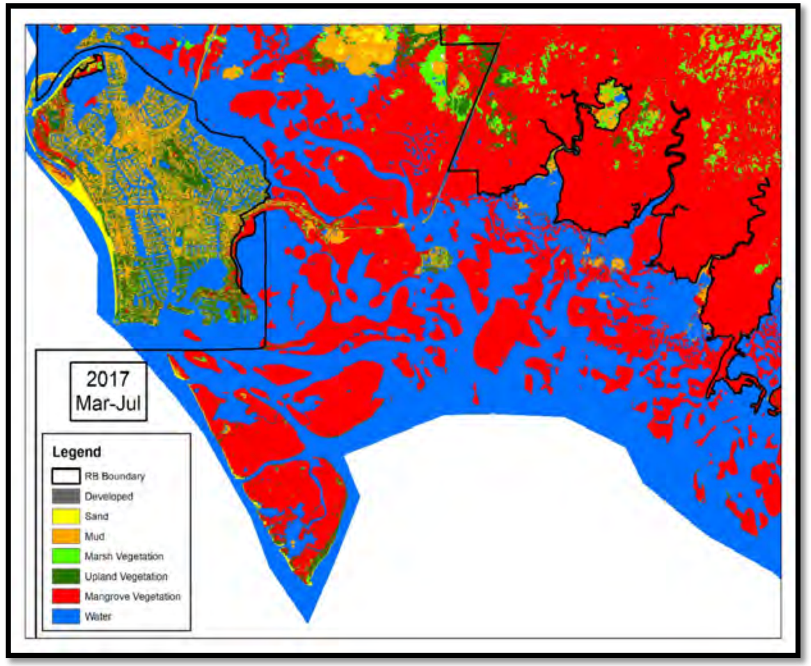
Summary Points:

The WorldView-2 image classifications show more areas of healthy mangrove vegetation, but the two images disagree in some areas that differentiate mangrove vegetation and marsh vegetation.

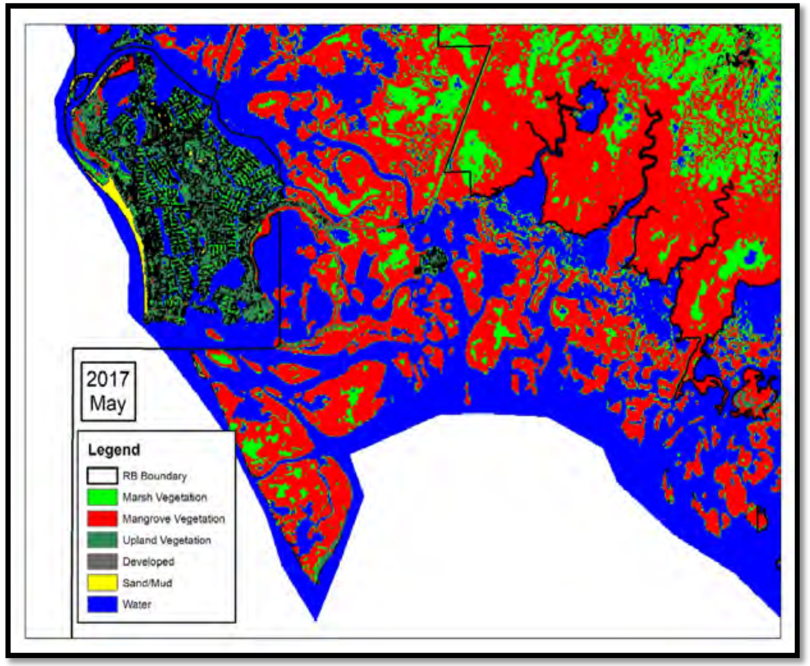
Unfortunately, the team is unable to validate the accuracy of this Landsat map due to a lack of corresponding field survey data for that time; however, later analyses will indicate that degraded mangroves can be misclassified as marsh vegetation according to the imagery tools.

Results

WorldView



Landsat

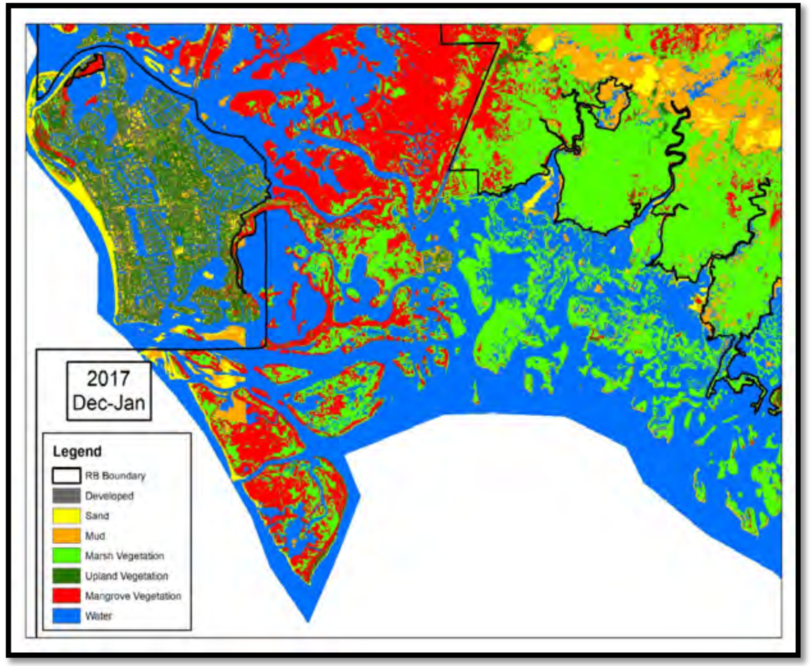


Summary Points:

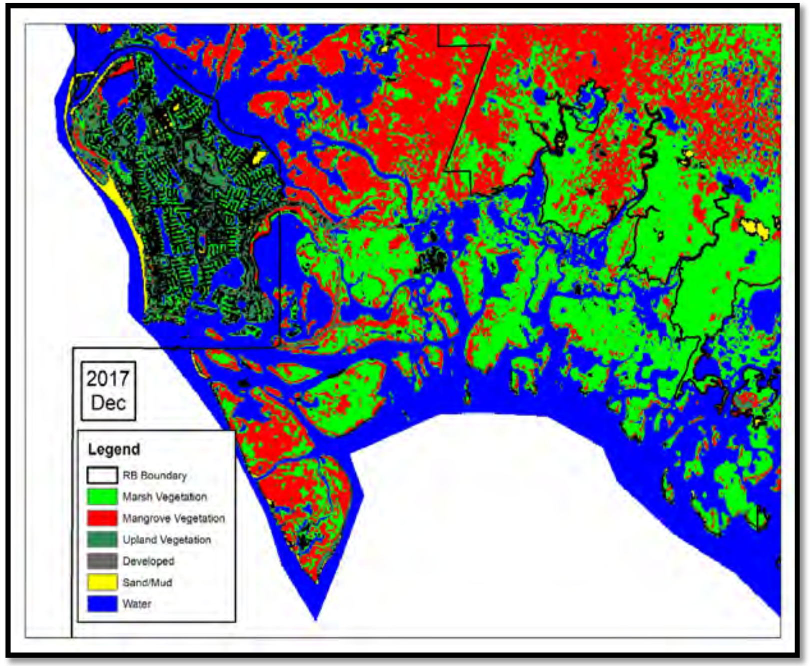
Pre-Irma maps indicate primarily healthy mangrove vegetation throughout much of the reserve area.

Results

WorldView



Landsat

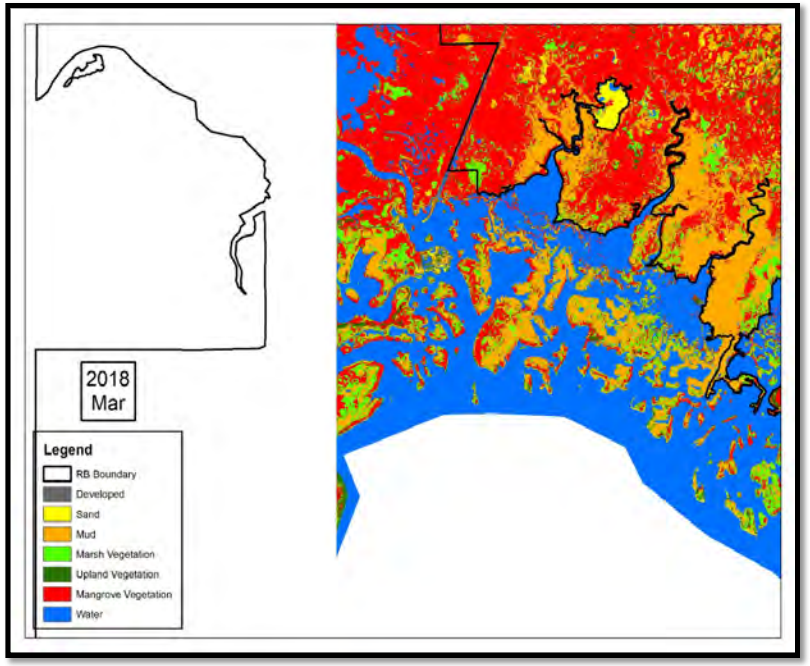


Summary Points:

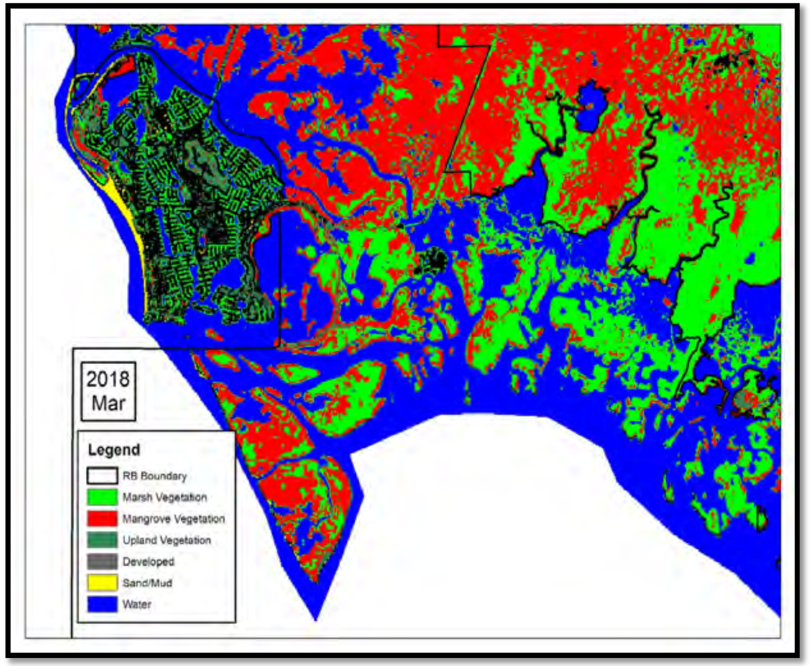
Post-Irma maps indicate many areas of healthy mangrove vegetation experienced degradation as a result of Hurricane Irma. Mangrove stands still existed here, but they had generally become defoliated; thus, the satellite imagery detected a combination of the remaining leaf cover, as well as tree trunks and branches. Imagery classification identified this combination of defoliated mangroves, sparse leaf coverage, tree trunks, and branches as marsh vegetation.

Results

WorldView



Landsat



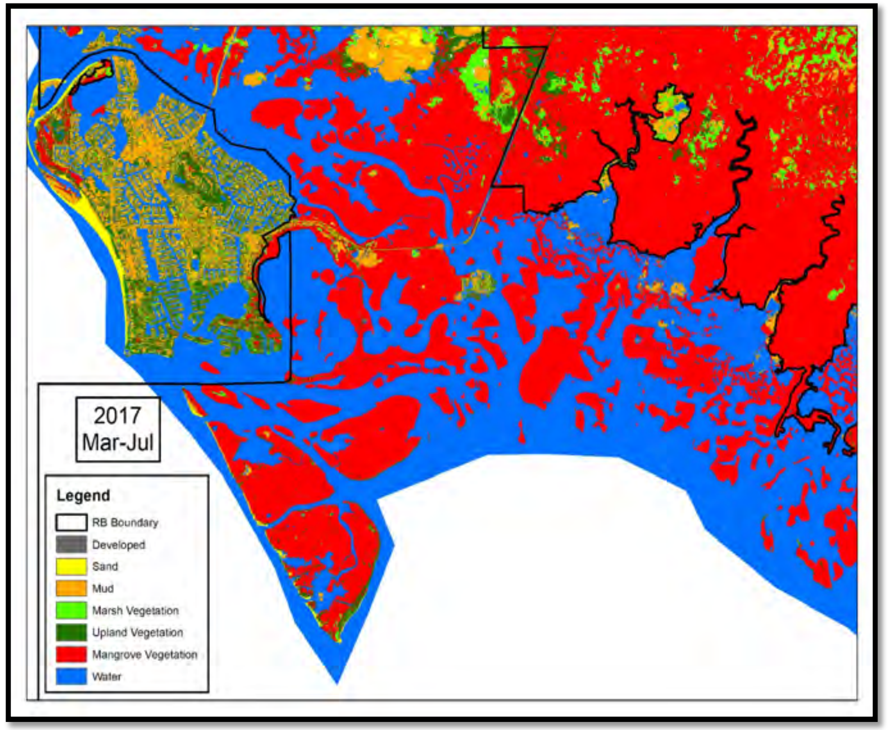
Summary Points:

The images shown here are from early 2018, approximately five or six months after Irma. The WorldView-2 image shows incomplete coverage of the area, but corroboration between WorldView-2 and Landsat images shows that while some areas have shifted in favor of healthier vegetation - indicating recovery - other areas showed evidence that degraded areas experienced further death, in turn enabling the sensors to detect exposed soil.

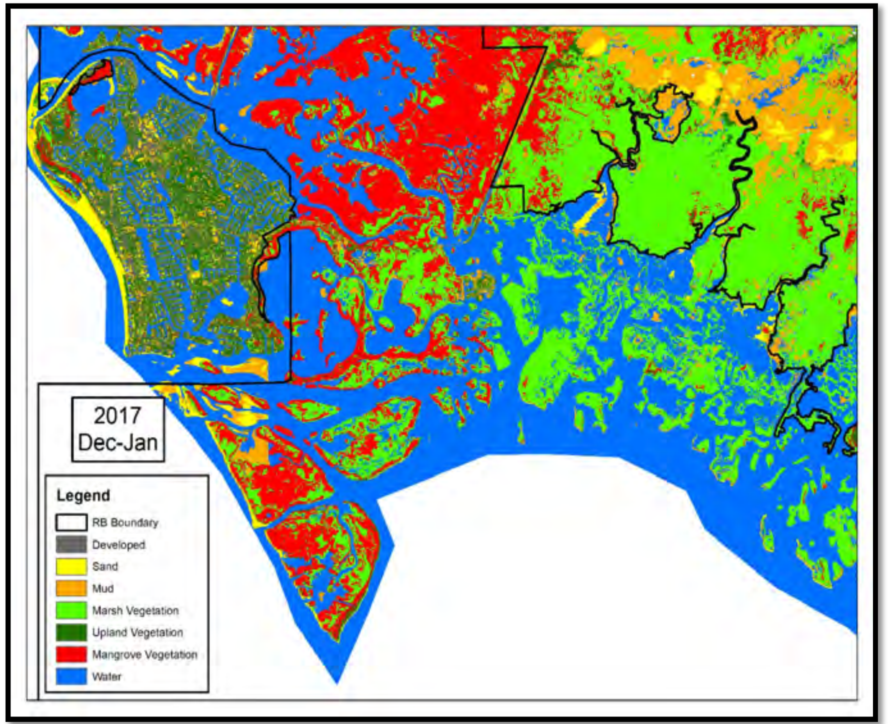
Irma Damage via Worldview

Summary Points:

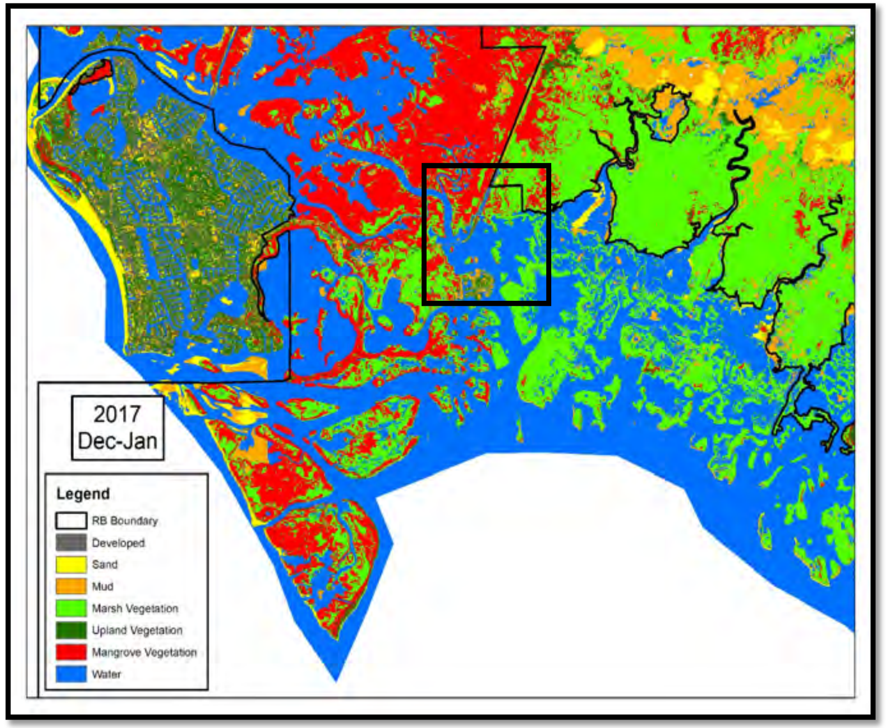
Pre-Irma

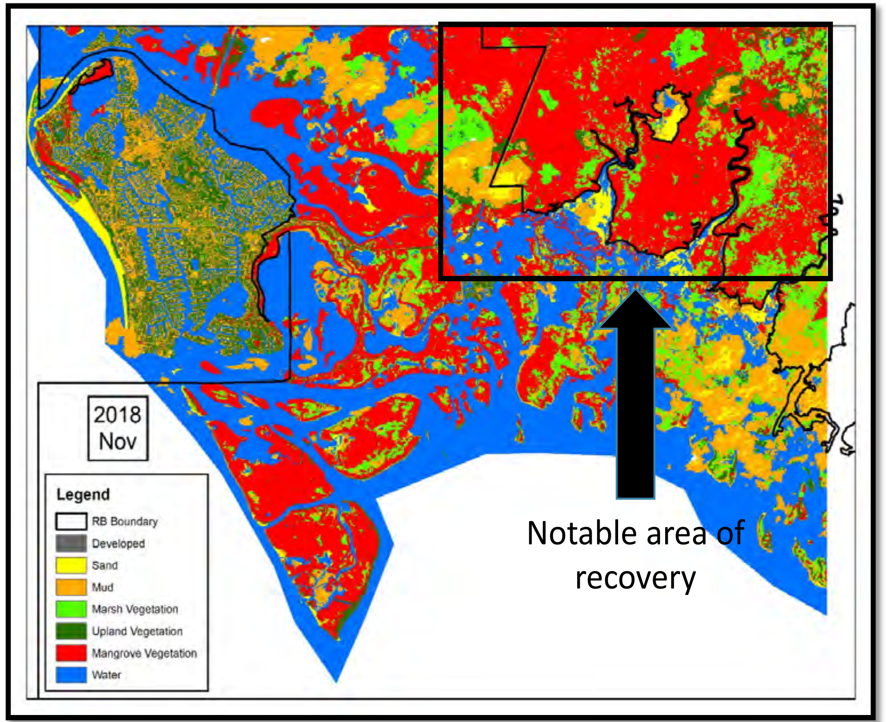


Post-Irma



Recovery at Irma via Worldview



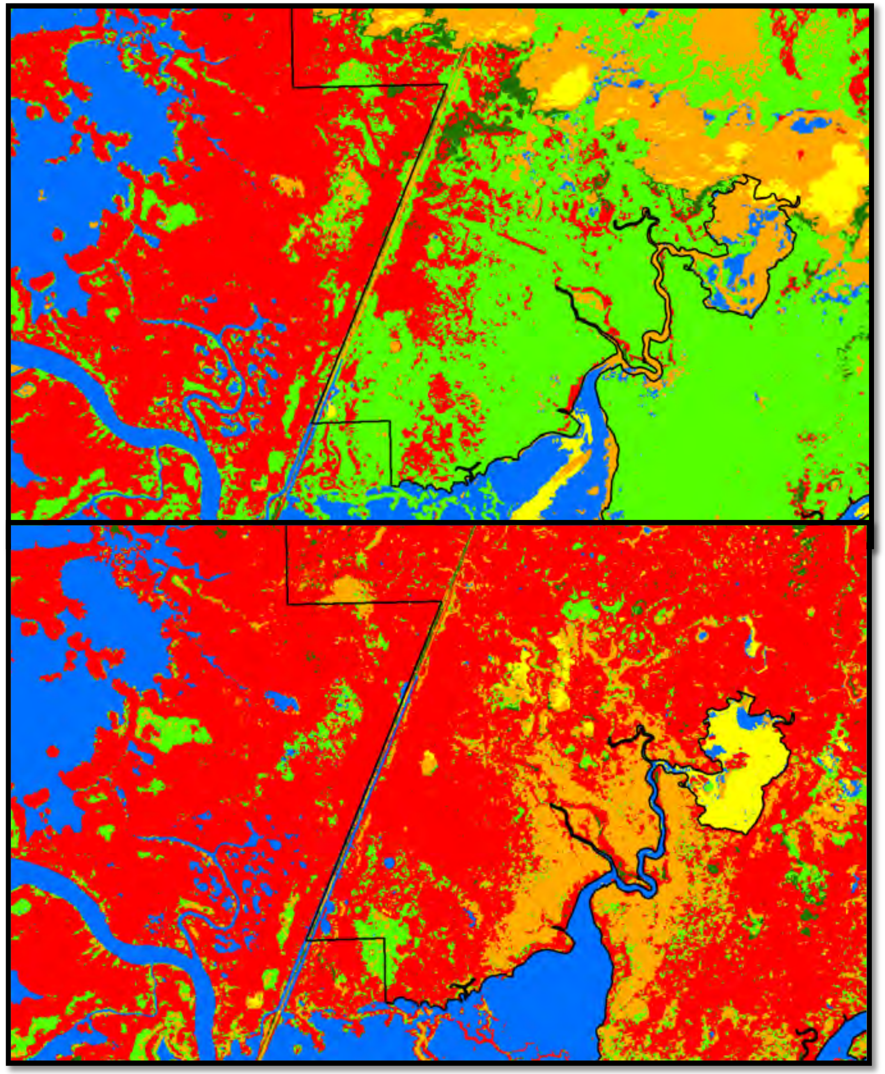


Summary Points:

The image on the right is from November 2018, more than a year after Irma. The image on the left shows the same area post-Irma. Comparing these maps allows an assessment of which areas recovered.

As previously noted, cloud coverage confounds some spots on the map; despite this, the maps show much of the reserve did recover over the year following Irma.

Three months post Irma (WorldView)



Five months post Irma (WorldView)

Recovery

- Some mangrove rebound
- Some mangrove die-off

Summary Points:

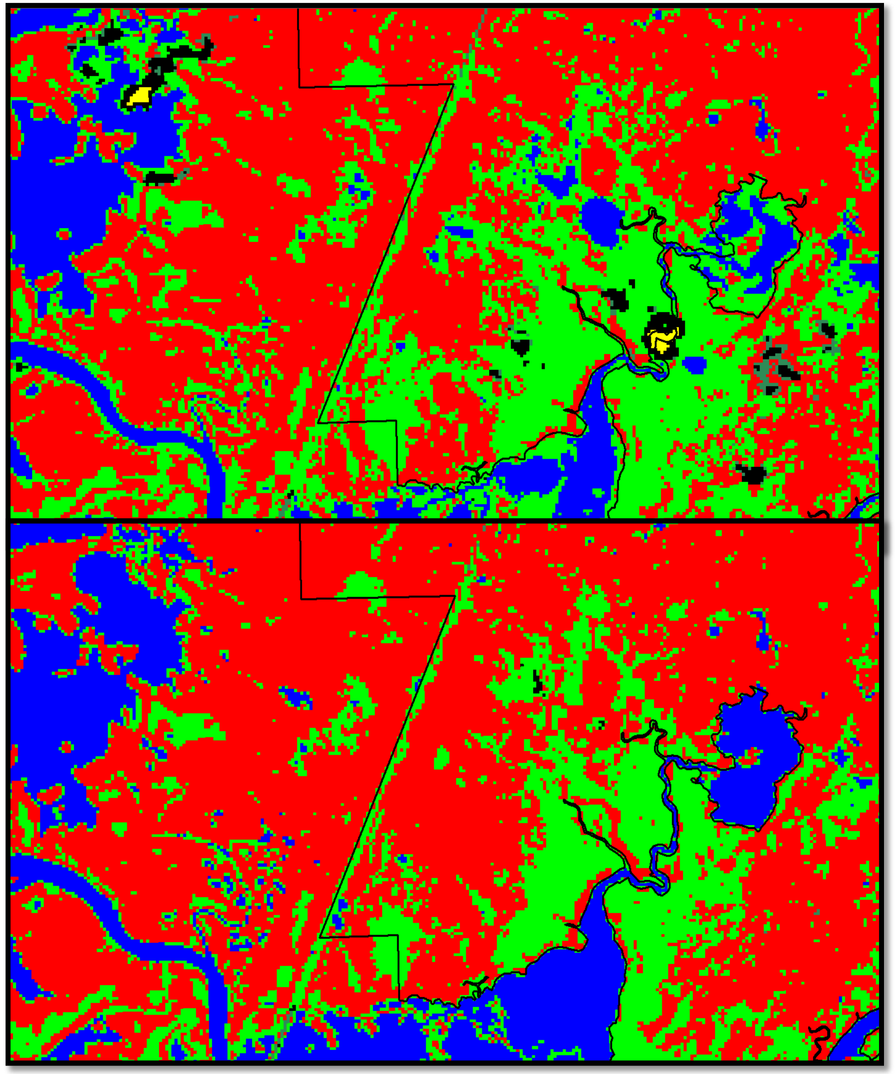
The top and bottom maps show a transition, in some areas, in which mangroves degraded by Irma (green) eventually recovered (red).

Green areas in the top image that changed to orange (mud) or yellow (sand) indicate areas where degraded mangroves later died off, with the satellite detecting uncovered ground.

Again, in some cases, orange coloration also represents results that are confounded by cloud coverage.

Three months post Irma (Landsat)

Five months post Irma (Landsat)



Recovery

- **Some mangrove rebound**

Summary Points:

Comparing WorldView-2 to Landsat imagery, analysis suggests that some areas recovered, but the lack of soil signature in the Landsat images is likely due to differences in resolution rather than the true conditions of the location.

Reminder - it is more difficult for Landsat to detect soil on the ground due to its coarser resolution.

Change Detection: Baseline (2016 to 2017)

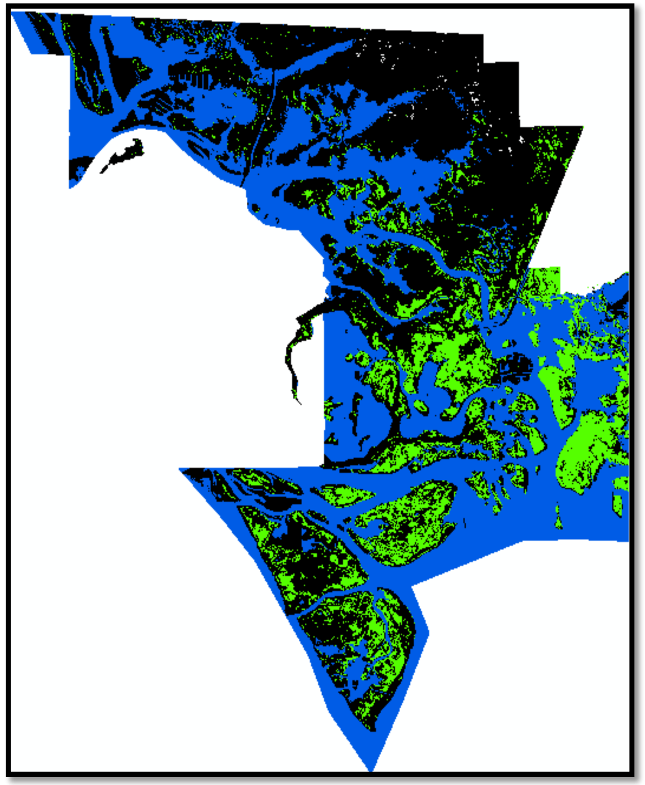
Summary Points:

After creating maps, the team “subtracted” classified maps from each other to assess overall change. Areas that showed no change are shown in black. Areas that did change are marked in other colors in the following slides.

Note: The blue coloration in the image here helps to distinguish land from water.

Change Detection: Baseline (2016 to 2017)

Healthy to Degraded Mangrove
13.8 km^2



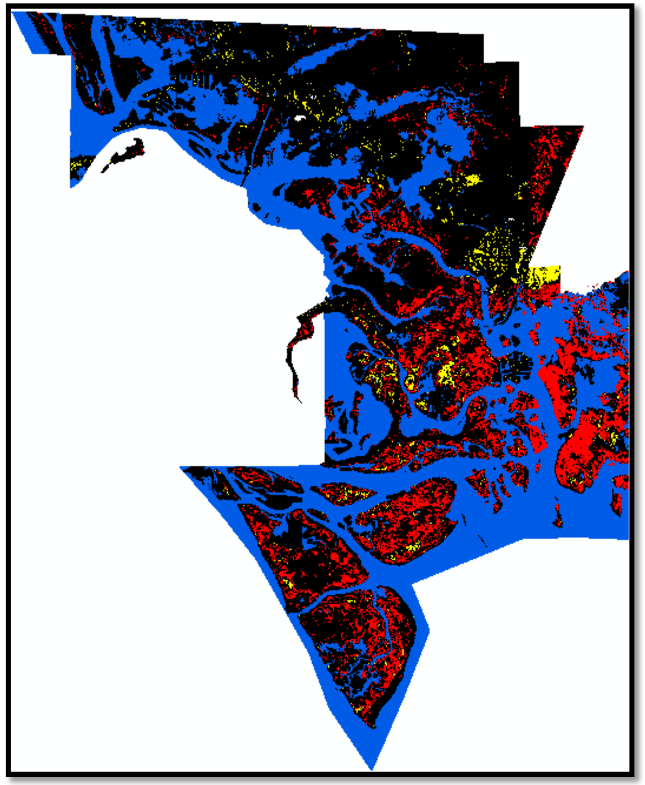
Summary Points:

Bright green areas represent a transition from healthy mangroves to degraded mangroves. The image here shows the section of the reserve that received consistent remote sensing with the high-resolution WorldView-2 imagery from 2016 to 2018.

Change Detection: Irma Recovery December 2017 to November 2018

Degraded to Healthy Mangrove
10.1 km²

Degraded Mangrove to Soil
1.5 km²



Summary Points:

About 10 square kilometers of mangrove rebounded after Irma (red dots on map), but about 1.5 square kilometers of degraded mangrove completely died off (yellow dots on map).

Mangrove Loss

Summary Points:

Unusually, one location appeared to have gained water according to the change-detection imaging. The team went into the field and photographed the area, which they found to be a region where black mangroves had died off before Irma. As a result of sea level rise, the relatively lower-lying area - which is still exposed to tidal variations - is retaining more water than it once did, which has slowly killed off the existing black mangroves that once lived there.

From 1966 to 2017, sea levels rose at a mean rate of 3 mm per year, in agreement with the global long term average. From 2000 to 2017, that rate increased to 7 mm per year. From 2010 to 2017, the rate increased to 13 mm per year. Rapid and accelerating sea level rise in this area is affecting inland areas and compounding effects from Hurricane Irma.

Acute Drivers of Loss

Marl overwash starving mangroves

- *Radabaugh et al. 2019*
  - 11% mortality 2-3 months post-Irma
  - 20% mortality 9 months post-Irma

Summary Points:

The team used change detection results to evaluate drivers of loss. Some of the results of the mangrove die-off corroborate results from a 2019 study by Radabaugh et al, which found that the mortality of mangroves increased from 11 to 20 percent following Irma. The authors posited that a measured 10+ centimeters of marl overwash caused the delayed loss. Marl overwash, brought up from the bottom of local waterways onto mangrove roots by hurricane storm surge, starved the mangroves of oxygen, and eventually resulted in mortality.

Terminology:

- **Marl**: A calcium carbonate-rich mud or mudstone containing variable amounts of clays and silt.

Mangrove Recovery

Radabaugh et al. 2019

60% canopy cover
3 to 9 months post-Irma

Sunlight reaching seedlings

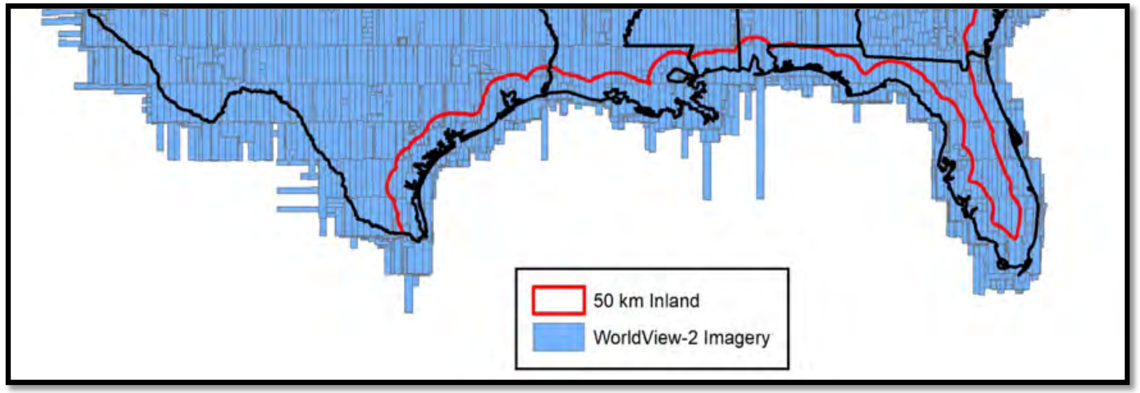
Summary Points:

The team also noted areas of recovery, in which sunlight reached through otherwise thick mangrove canopy, allowing seedlings to grow in areas they otherwise would not have been able to grow if Irma had never degraded existing foliage.

Implications and Next Steps

Summary Points:

- What does this mean for your reserve or study area?
  - Replicable: Landsat (free) or WorldView (via collaboration with USF)
  - WorldView-2 + WorldView-3 + 2009-present time frame
  - Modeling uses
- Ongoing NSF Spoke Hub mapping work



Rookery Bay and Jobos Bay NERR Capacity Enhancement

Summary Points:

- Hurricanes Irma and Maria occurred approximately one week apart
- Scientists and managers conducted cross-site visits to view impacts and recovery
- Stakeholder workshops discussed recovery process, expectations, and needs for informed resource management and information sharing

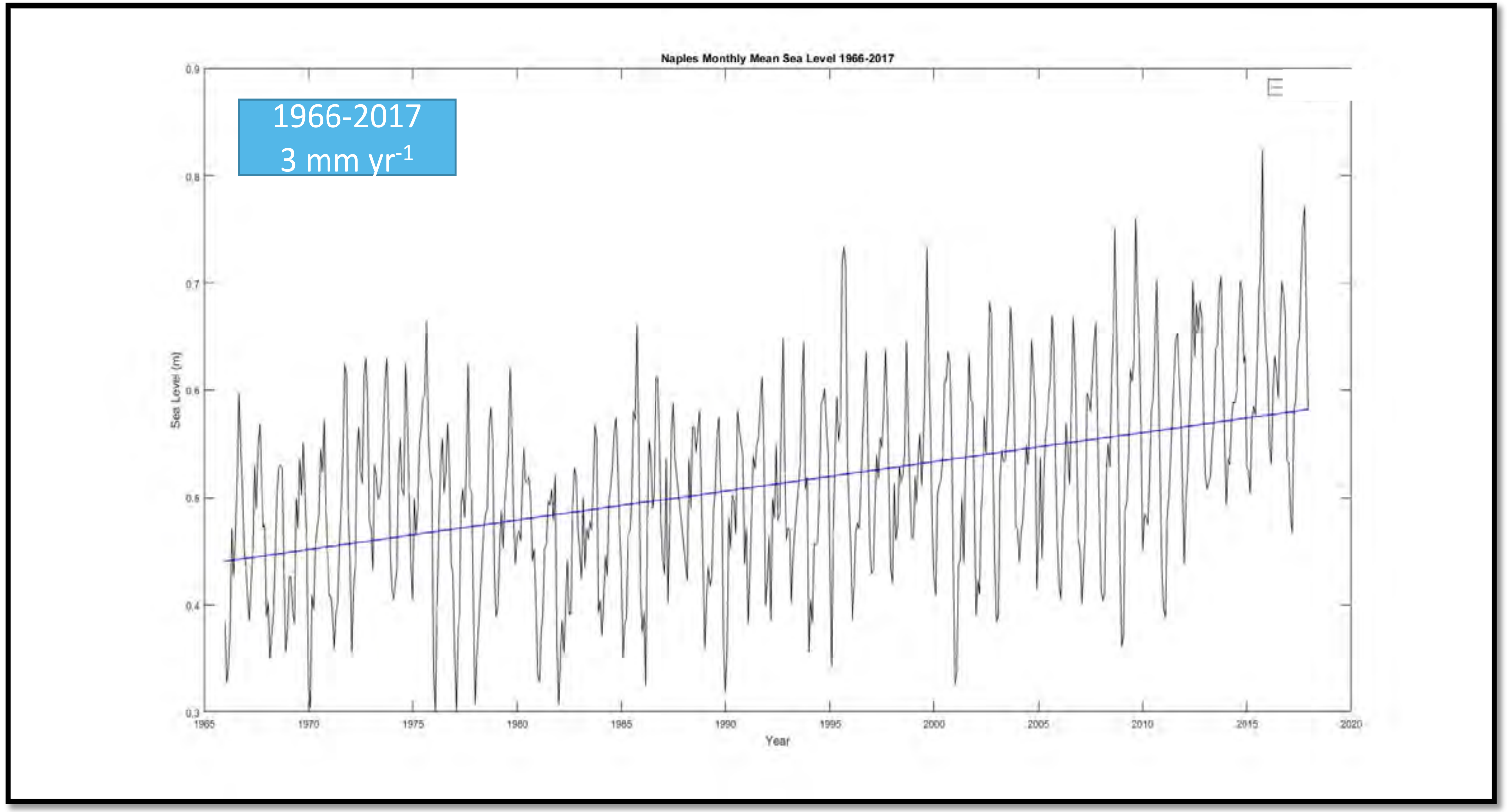
Questions:

Are there any plans to expand Spoke Hub mapping?
Mapping the entire gulf of mexico coastline has been a challenge in and of itself. We're dealing with several dozen terabytes of data and approximately 200,000 WorldView images. Doing this in a way that overlaps with existing LIDAR data so that we can do 3D maps will be a priority for next two years. The ultimate goal is to map the entire coastal US and beyond. Anyone who would like to partner for collaborating and expanding certain areas sooner can reach out to Matt (mjm8@mail.usf.edu) and Brita (Brita.Jessen@dep.state.fl.us).

How do we get ahold of WorldView Images?
You can purchase them through DigitalGlobe, the company that owns them. Otherwise, collaboration with USF is also possible, and many institutions can obtain licenses via a NASA or NSF grant.

Did red tide have any effect on the mangroves?
We did not have that much issue with red tide in this region of the southwest Florida coast.

Local Sea Level

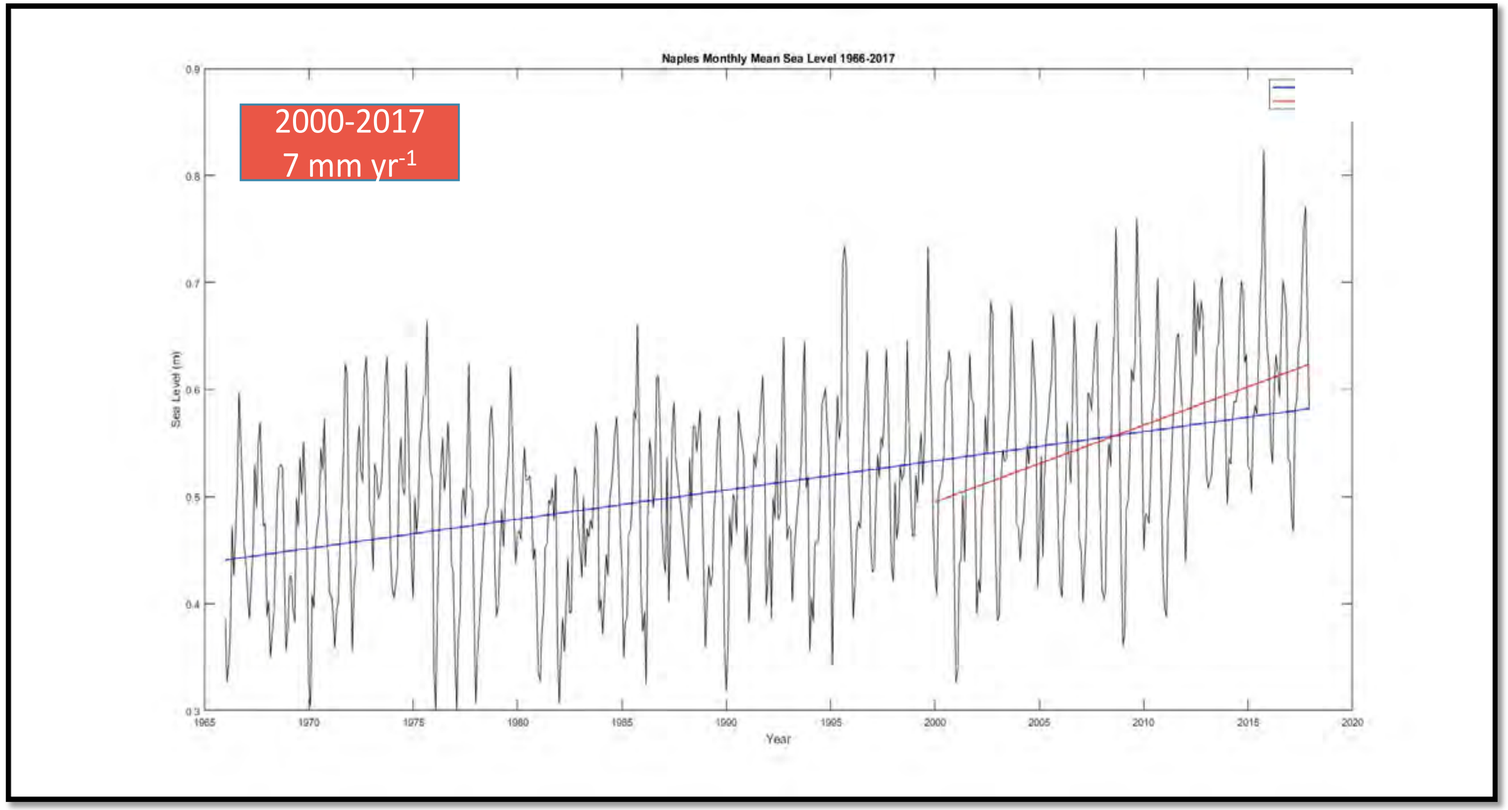


Questions:

Without historic data dating back several decades, to what extent could climate change and the ensuing sea level rise be implicated in net mangrove loss?
The longer data record we have, the better job we can do attributing loss. We could expand this or other projects using the Landsat time series, which dates back to 1972, to produce a coarser but still valid assessment of mangrove change over time. This project was intended as a short term mapping change assessment, but we're interested in longer term mapping projects as well. Without a long term baseline, it is difficult to attribute any changes we're seeing. We're comfortable attributing Irma changes because they were driven by an acute event. By using a baseline from 2010-2016, we can assess relative change and attempt to attribute it to drivers for which we have data. During one of our field visits, we learned about ongoing restoration efforts, such as swales and culverts which will help direct water out of areas that are now impounded or into areas through tidal exchange. Those areas are difficult to identify using remote sensing imagery; local expert knowledge really helps us attribute some of the more localized changes.

When can we expect the final project report?
The project is wrapping up at the end of August, with the final report due 60 days from then. One manuscript is ready for publication and another is coming out. Protocols and manuscripts will be done by the end of this year.

Local Sea Level



Local Sea Level