Monitoring Aquatic Vegetation with Remote Sensing

Juan L. Torres-Pérez, Amber McCullum

July 12, 2022

Course Structure and Materials

- Three, 1.5 -hour sessions on July 12, 14, and 19
- The same content will be presented at two different times each day:
  - Session A: 11:00-12:30 EDT (UTC-4) (English)
  - Session B: 14:00-15:30 EDT (UTC-4) (Spanish)
  - Please only sign up for and attend one session per day.
- Webinar recordings, PowerPoint presentations, and the homework assignment can be found after each session at:
  - https://appliedsciences.nasa.gov/join-mission/training/english/arset-monitoring-aquatic-vegetation-remote-sensing
- Q&A following each lecture and/or by email at:
  - juan.l.torresperez@nasa.gov or
  - amberjean.mccullum@nasa.gov

Homework and Certificates

- Homework:
  - One homework assignment
  - Answers must be submitted via Google Forms
  - HW Deadline: Tuesday, August 2nd

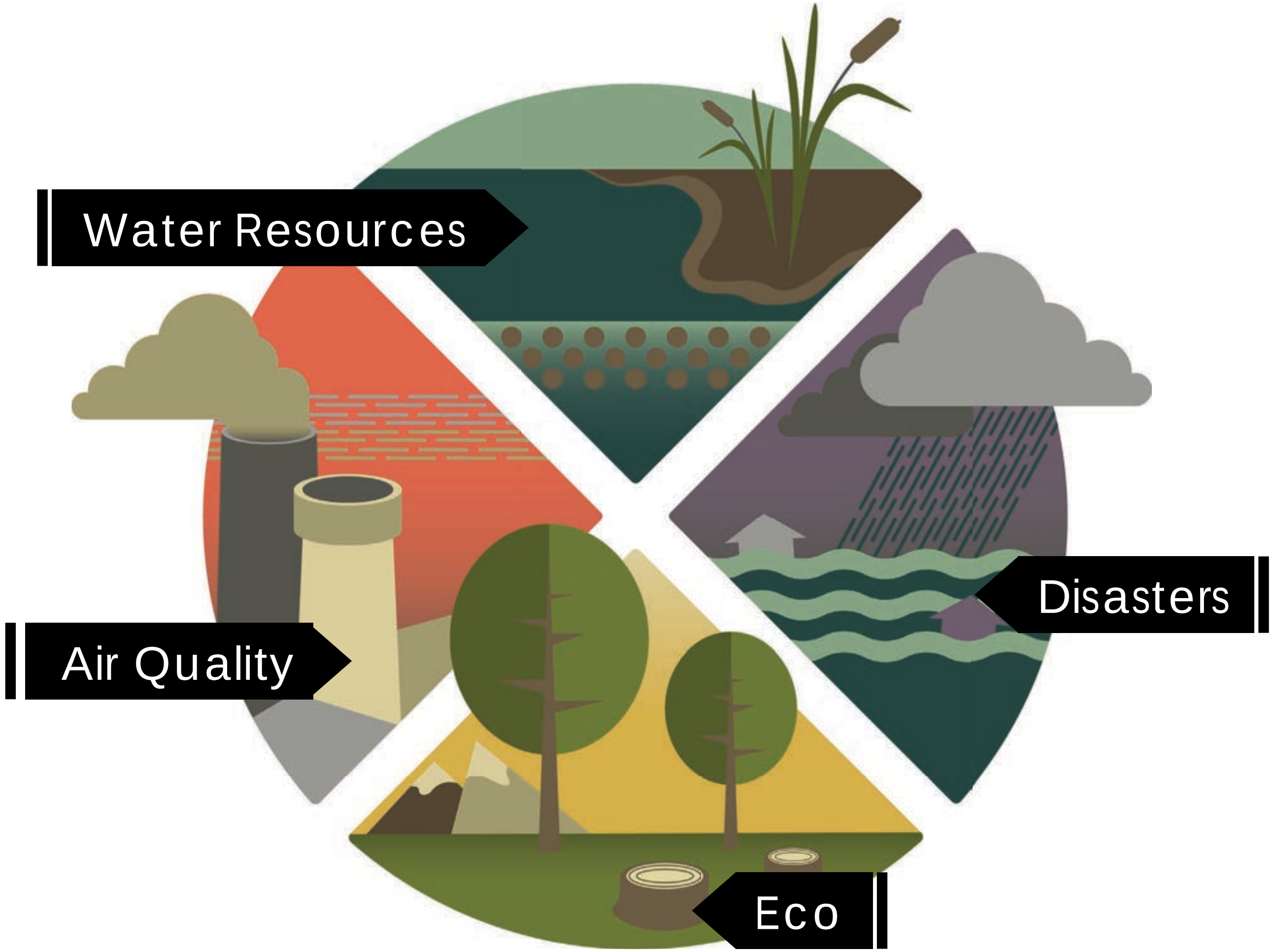
- Certificate of Completion:
  - Attend all three live webinars
  - Complete the homework assignment by the deadline (access from ARSET website)
  - You will receive certificates approximately two months after the completion of the course from: marines.martins@ssaihq.com

Prerequisites

- Prerequisites:
  - Please complete Sessions 1 & 2A of Fundamentals of Remote Sensing or have equivalent experience.
- Course Materials:
  - https://appliedsciences.nasa.gov/join-mission/training/english/arset-monitoring-aquatic-vegetation-remote-sensing

NASA's Applied Remote Sensing Training Program (ARSET)

- Part of NASA's Applied Sciences Program
- Empowering the global community through remote sensing training
- Seeks to increase the use of Earth science in decision-making through training for:
  - Policy makers
  - Environmental managers
  - Other professionals in the public and private sector



Learning Objectives

By the end of this session, you will become familiarized with:

- Coastal/marine submerged and floating aquatic vegetation species from temperate and tropical waters (seagrasses, kelp, *Sargassum*)
- Primary satellites/sensors used to study aquatic vegetation remotely
- Spectral signatures of plants and algae
- Remote sensing of seagrass meadows

Mixed seagrass and green algae in northern PR. Credit: Juan L. Torres-Pérez

Brief Overview of Some Important Submerged Aquatic Vegetation (SAV) Types

Seagrass Meadows

- Phylum: Plantae (Angiosperms) – Flowering plants
- About 60 described species in four different families
- Evolved from land plants that recolonized the ocean about 70-100 million years ago
- Most species occur in shallow and sheltered coastal zones anchored in sandy or muddy bottoms
- Rhizomes or underground stems help in anchoring the plants

Turtle Grass (*Thalassia testudinum*). Credit: Juan L. Torres-Pérez

Seagrass Meadows

Ecology:

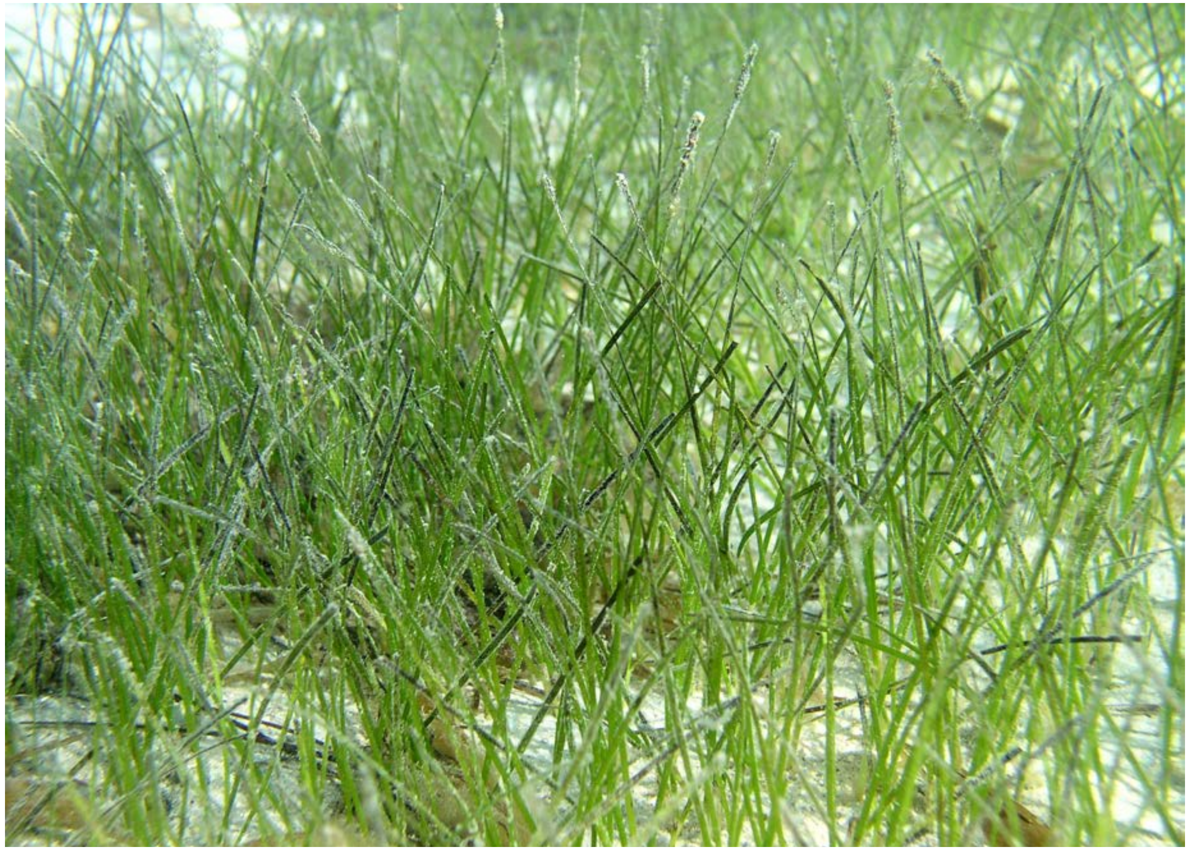
- Commonly associated with other tropical coastal ecosystems such as coral reefs and mangrove forests
- Extremely important shallow-water ecosystems in the tropics
- Provide habitat for reproduction and nursery for invertebrates, fishes, reptiles, and marine mammals including sharks, sea turtles, and manatees
- Rhizomes and root system aid in cementing sediments and reduce resuspension of particulate matter

Top: Star Coral (*Orbicella annularis*); Bottom: Reticulated Starfish (*Oreaster reticulatus*). Credit: Juan L. Torres-Pérez

Seagrass Meadows

Human Benefits:

- Highly important in carbon sequestration
- Coastal protection
- Function as natural barriers against wave action and storm surge
- Direct food source for commercially and ecologically important fish and shellfish and endangered species
- Recreation
- Tourism
- Provide food source for millions of people



Manatee Grass (*Syringodium filiforme*). Credit: Juan L. Torres-Pérez

Kelp Forests

- Class: Phaeophyceae (Brown algae)
- One of the most important benthic SAVs in temperate seas around the World
- Occur in shallow subtidal rocky reefs
- Each "plant" life span is about 2.5 years
- Each frond life span is about 4 months
- Under ideal conditions, individuals can grow up to 0.5m per day!
- Many species have pneumatocysts (gas-filled bladders) that aid in their buoyancy.
- Giant species such as *Macrocystis* can reach more than 30m in length!

Credit: Kyle Cavanaugh (UCLA)

Kelp Forests

Ecology:

- Ecosystem engineers and foundational species
- They harbor a diversity of other organisms including invertebrates, fishes, birds, and marine mammals.
- Many mammals and birds use the kelp forest for protection and finding food.
- They are recognized as one of the most productive and dynamic ecosystems on the planet.

Credit: www.flickr.com

Kelp Forests

- Human Benefits:
  - Coastal protection against wave action
  - Fisheries
  - Food source
  - Commercial products such as soap and glass production
  - Recreational
  - Tourism
  - Symbolic and spiritual aspects of indigenous cultural systems

Top: Sea Anemone (*Anthopleura* sp.). Bottom: Kelp Anchoring System. Credit: Juan L. Torres-Pérez

Sargassum Floating Mats

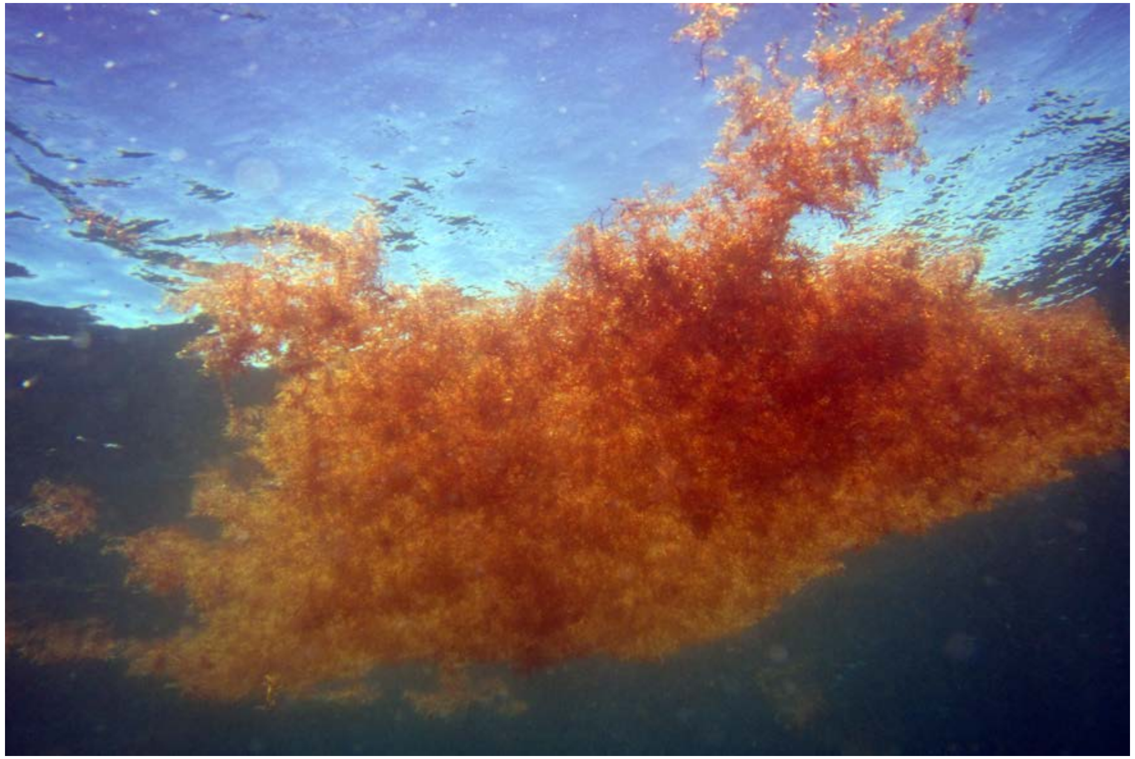
- Class: Phaeophyceae (brown algae)
- Most species are planktonic (free-floating); a few are benthic.
- Named originally by Portuguese sailors who found it in the Sargasso Sea in the Atlantic Ocean.
- Some species have berry-like gas-filled bladders to aid in floatation.
- Individuals may grow up to several meters in length.

Credit: Juan L. Torres-Pérez

Sargassum Floating Mats

Ecology:

- *Sargassum* mats provide habitat to many invertebrates and fishes.
- Higher taxa (e.g., sea turtles) feed on invertebrates and fish communities associated with *Sargassum*.
- The Sargasso Sea plays a major role in the migration of some catadromous eel species from Europe and North America.
- Massive mats may block light penetration, thus affecting important benthic organisms such as corals and seagrasses.



Credit: Juan L. Torres-Pérez

Sargassum Floating Mats

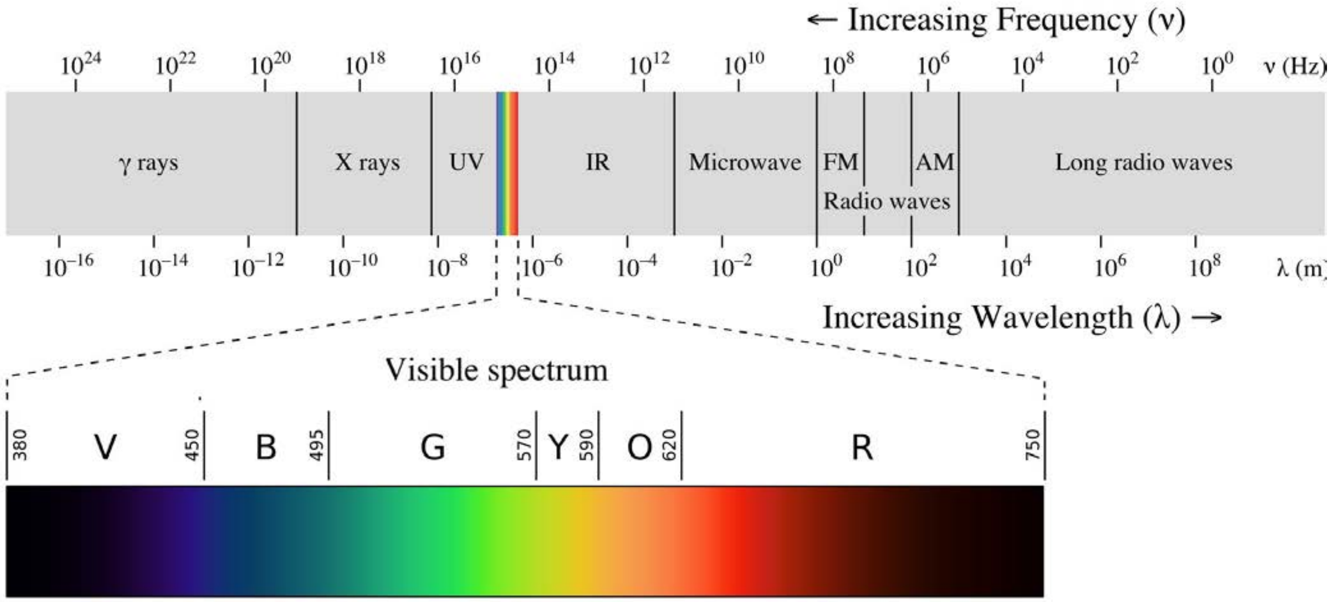
Societal/Economic Impact:

- Since 2011, massive events have occurred from the Southern Caribbean to Mexico and Florida.
- Impacts to local fisheries, tourism, and economies
- Local governments spend millions of dollars each year in cleanup activities.
- Decomposing *Sargassum* creates hydrogen sulfide gas, affecting human health.

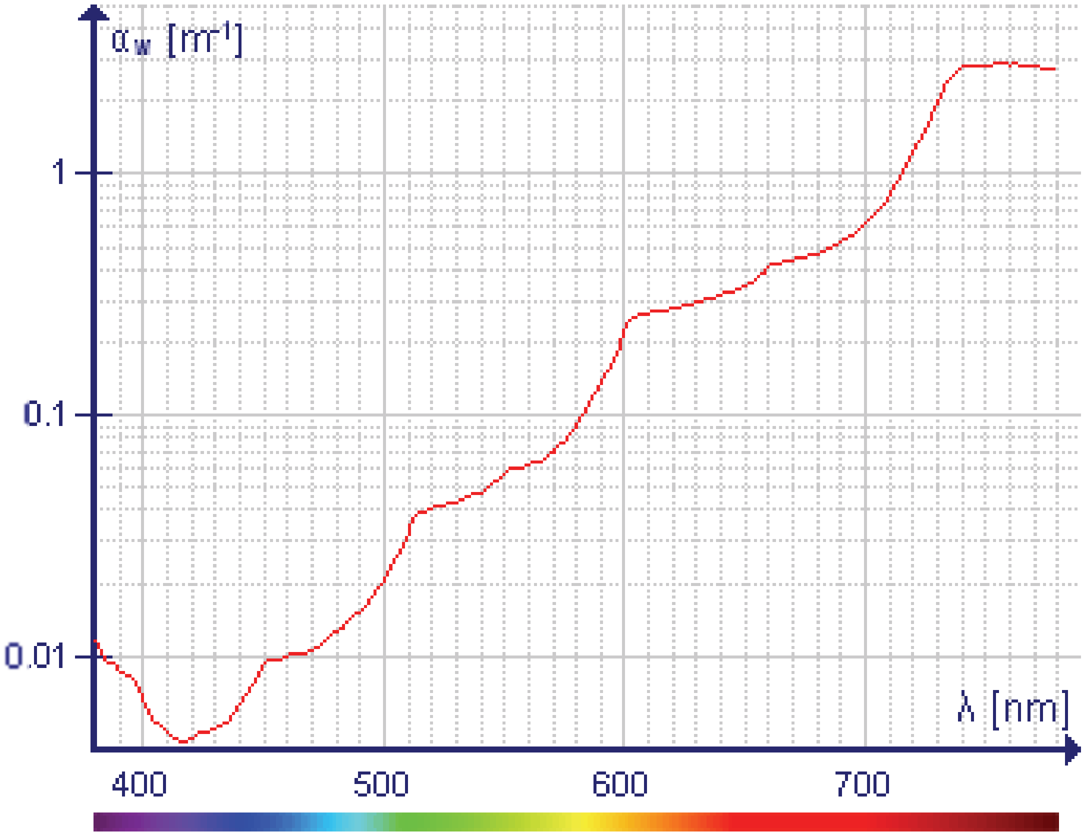
Credit: Pixabay

Water Column Considerations when Mapping SAV

Light in the Aquatic Environment



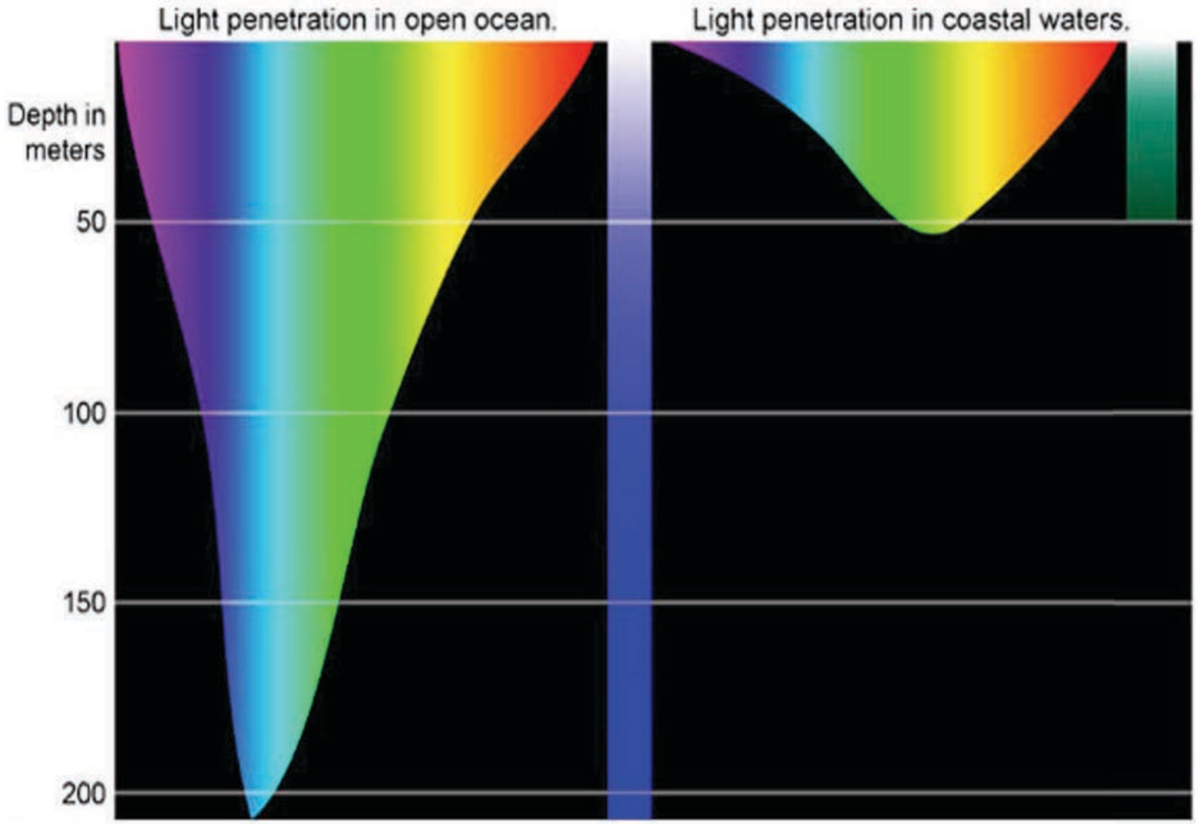
Credit: Wikimedia Commons

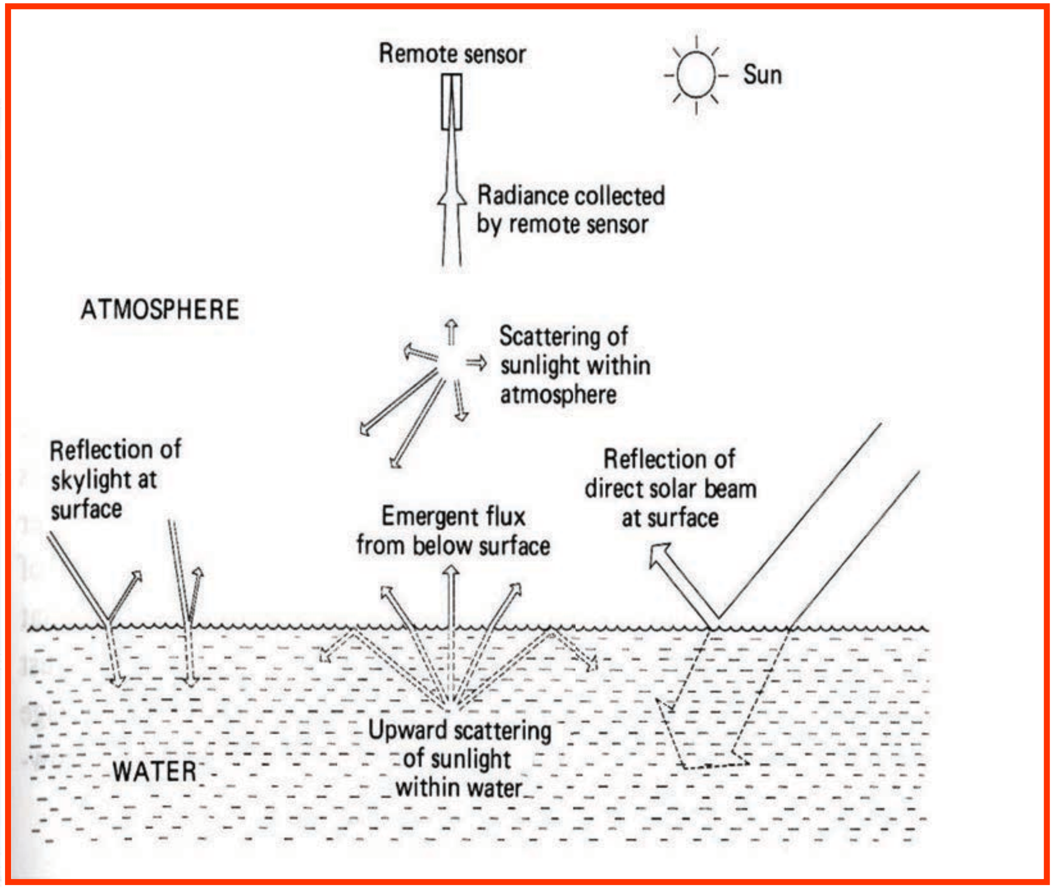


Credit: Jonasz 2007

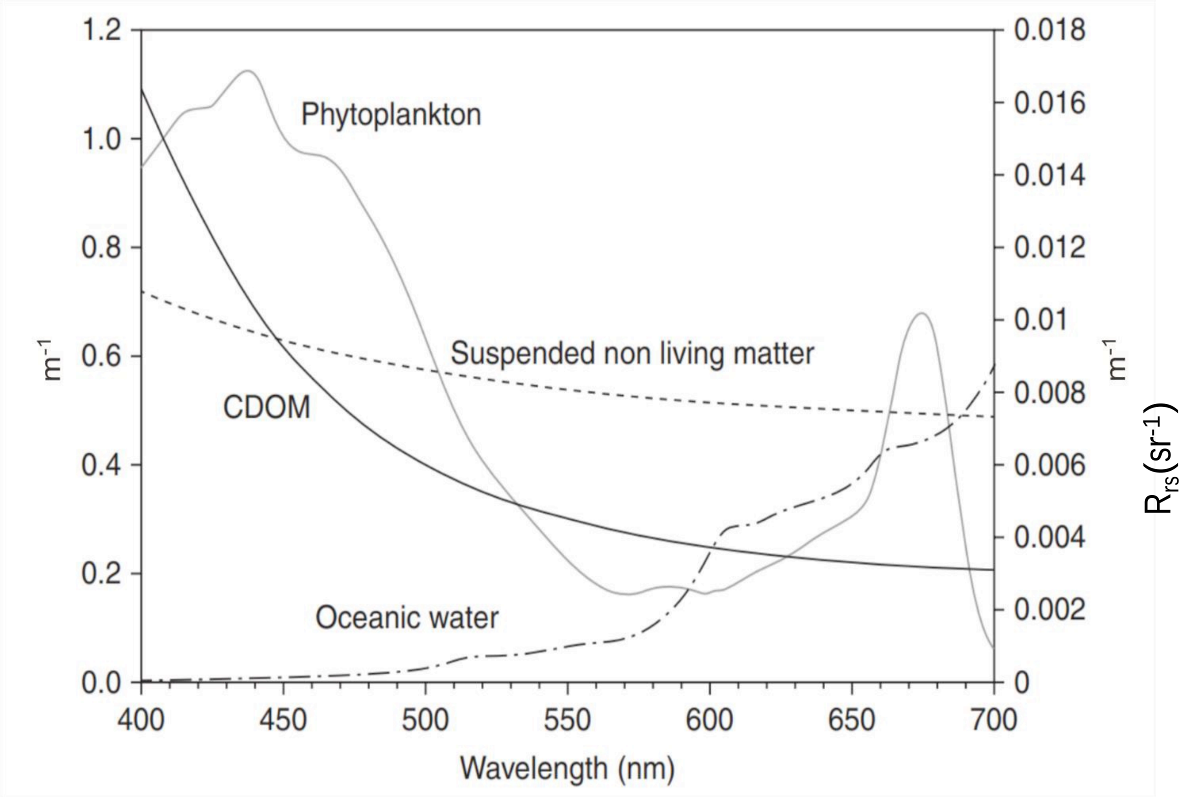
Light in the Aquatic Environment

The water column contains material that is optically active. Monitoring SAVs from the water surface with remote sensing requires correcting for these issues.

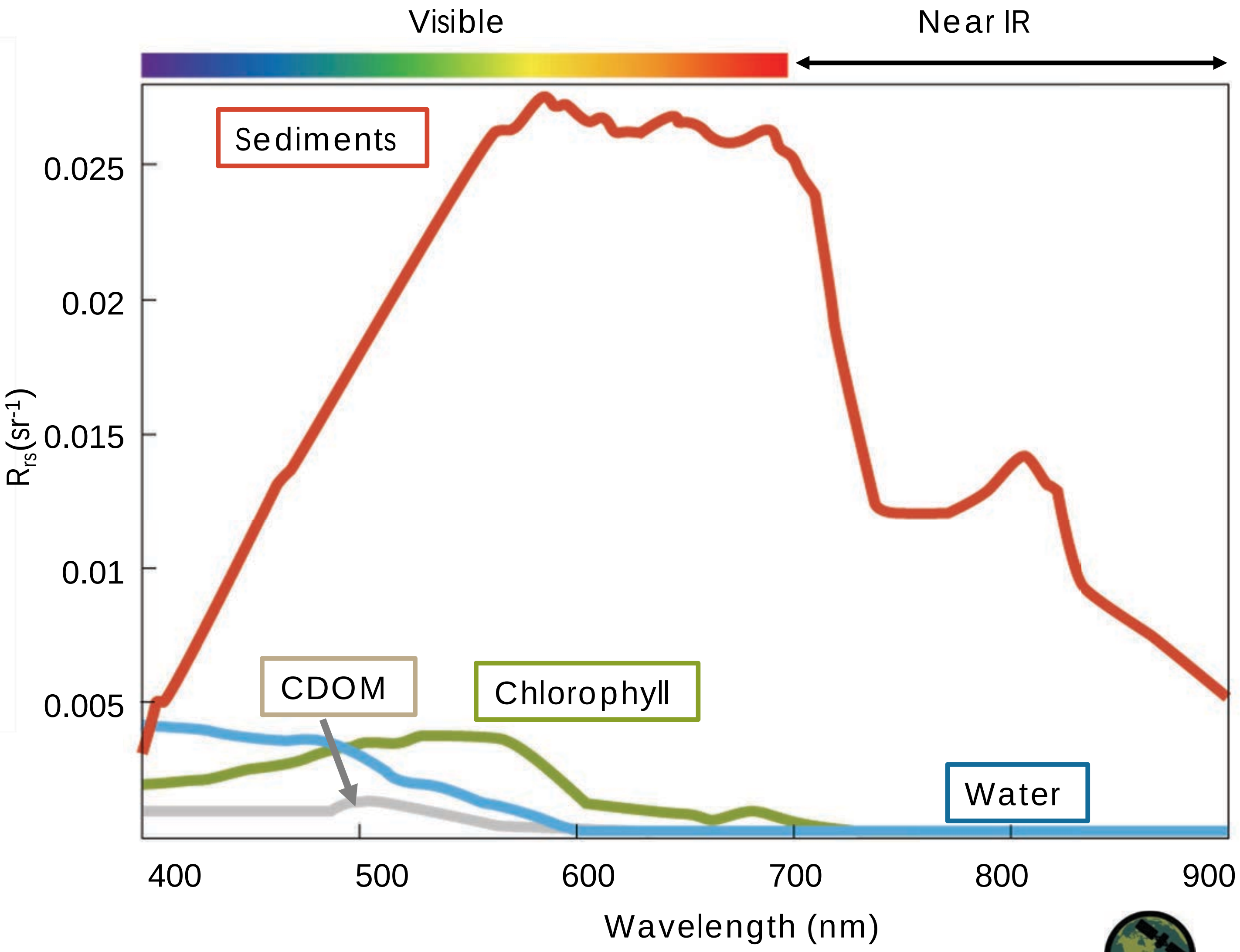




Light Absorption of Water Column Components



Credit: Johnsen et al 2013



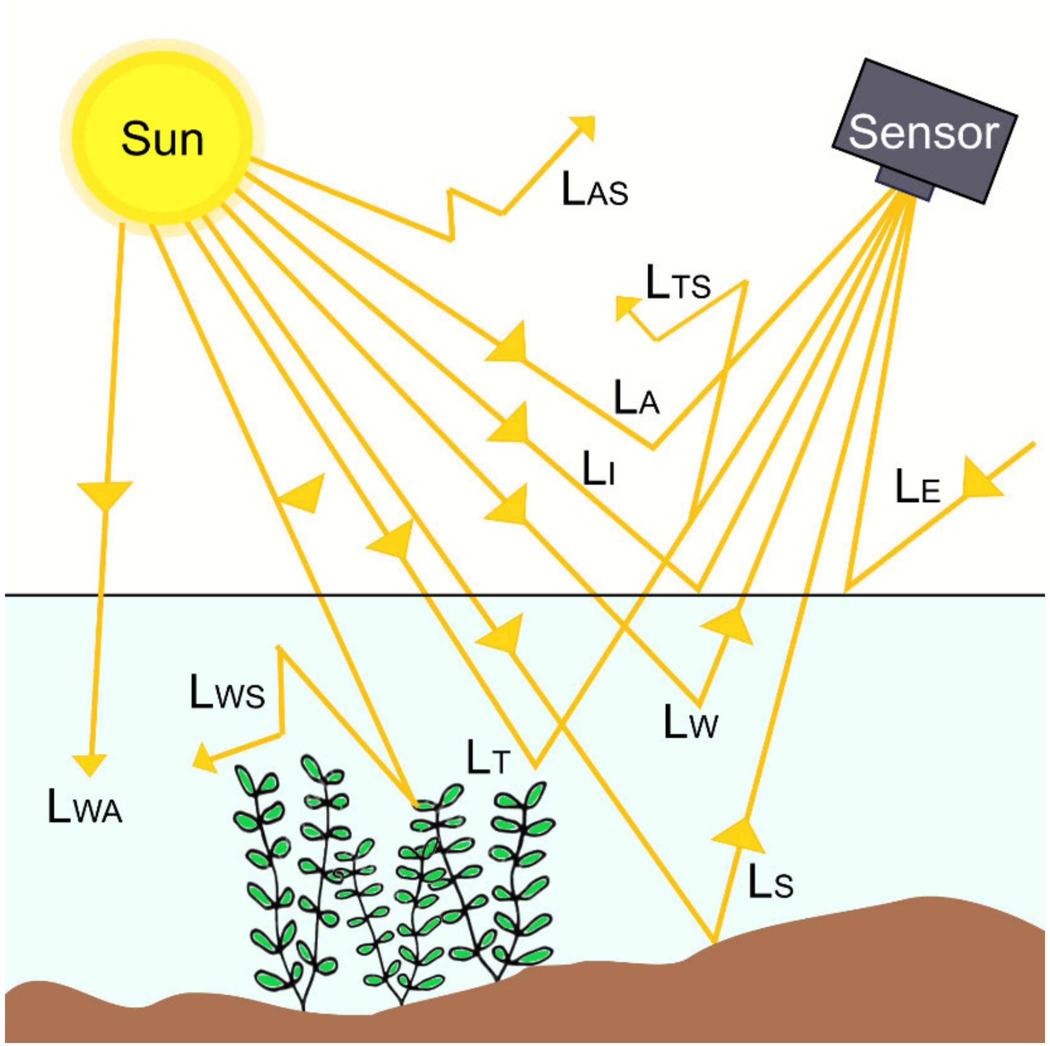
Water Column Correction

- Unless SAV are exposed, it is necessary to conduct a water column correction process to estimate the amount of light attenuation and its effect on the reflection of benthic components such as seagrasses, kelps, and other types of SAV.
- One of the most common methods is the one proposed by Lyzenga (1978, 1981, 1985, and Lyzenga et al 2006), who suggested the calculation of a depth-invariant index (DII) to remove the scattering and absorption effects within the water column.
  - The DII works well in clear waters (Case I) but is less reliable in more complex waters (Case II).
- More recently, Sagawa et al (2010) proposed an alternative Bottom Reflectance Index (BRI) which seems to work better in Case II waters.
- Other commonly used approaches include the subtraction of a deep water reflectance value from each pixel (Louchard et al 2003) and to use a logarithmic transformation and regression analysis for each band (Conger et al 2006).

Light Interactions in the Atmosphere, Water Column, and Benthos

Radiances reflected or scattered:

- LT = By the target (SAV)
- LTS = By the target and scattered out of the path of the sensor
- LS = By sand
- LA = By the atmosphere to the sensor
- LAS = By the atmosphere
- LW = By the water column into the sensor
- LWS = By the water column
- LI = By the air-water interface
- LE = Into the scene by the ambient environment



Credit: Rowan & Kalacska 2021

Satellites Commonly Used for Assessing Aquatic Vegetation

Considerations for Choosing Appropriate Satellite Data

- Temporal Resolution of Data Acquisition – Daily? Weekly? Monthly?
- Spatial Resolution – Depends on the satellite: meters to km
- Spectral Resolution – Multispectral vs. hyperspectral
  - Where in the electromagnetic spectrum are the satellite bands? Visible? IR? SWIR?
- Longevity of the Satellite Mission
  - Landsat has the longest record of satellite data (since the 1970’s).
- Geographical and Atmospheric Conditions at the Study Site
  - Coastal ecosystems in general tend to be small (seagrass beds) or narrow (beaches).
  - Tropical zones typically have more cloud cover year-round.
- Is the data freely available, or is there a cost associated with data acquisition?
- Are there any future missions being planned?
  - Surface Biology and Geology (SBG)
  - Plankton, Aerosol, Cloud, Ocean Ecosystem (PACE)

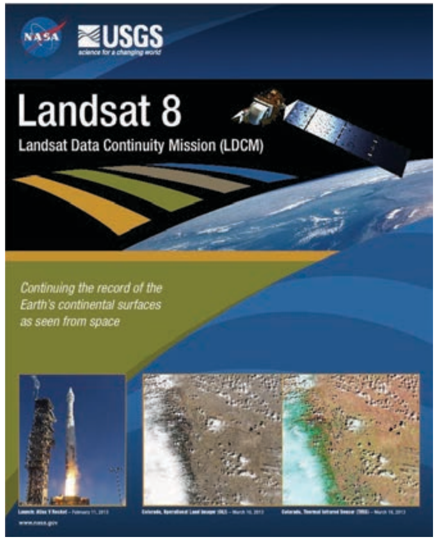
Advantages of Satellite Observations

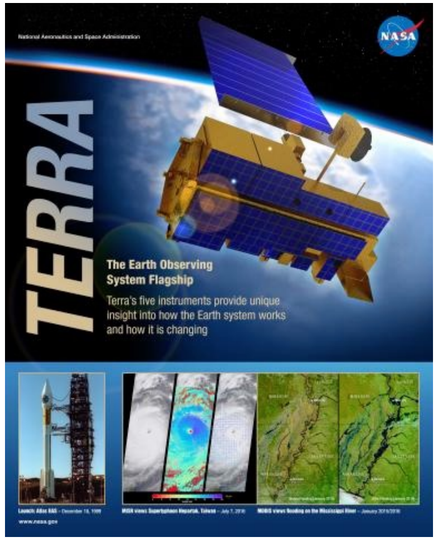
- Available for large regions
  - Only source of global information for some parameters
- Long time series and data continuity
  - Tracks progress
  - Establishes baselines and trends
- Consistency and comparability
  - Among multiple countries
- Diversity of measurements
  - Many different physical parameters
- Complements traditional statistical methods
  - Cross-check with in-situ data
- Mostly free and open access

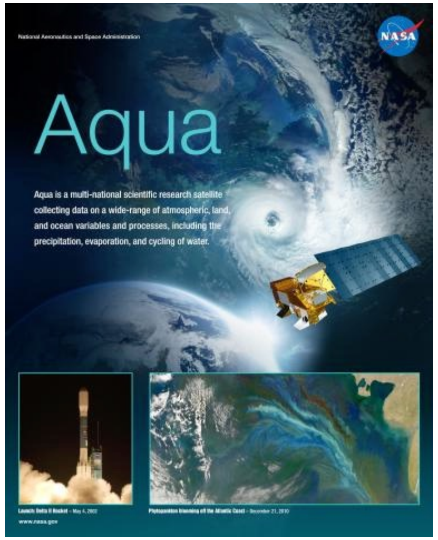
Curtis Island, Australia. Credit: NASA Earth Observatory

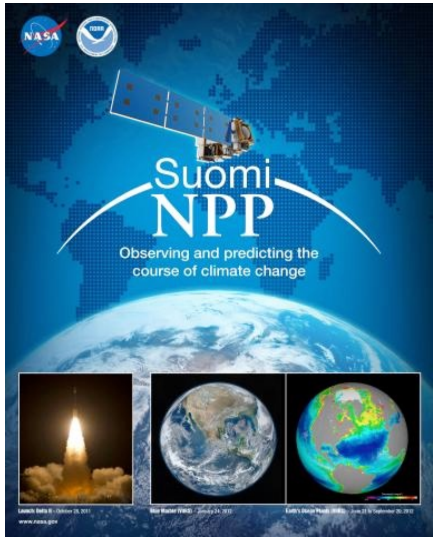
Current Satellite Missions

- Landsat 7 (4/15/1999 – Present)
- Landsat 8 (2/1/2013 – Present)
- Landsat 9 (10/31/2021 – Present)
- Terra (12/18/1999 – Present)
- Aqua (5/4/2002 – Present)
- Suomi National Polar Partnership (SNPP) (11/21/2011 – Present)
- Sentinel-2A (6/23/2015 - Present)
- Sentinel-2B (3/7/2017 – Present)
- Sentinel-3A (2/16/2016 – Present)









Specifications of Commonly Used Sensors for Aquatic Vegetation

Satellites	Sensors	Resolution
Landsat 7	Enhanced Thematic Mapper (ETM+)	185 km swath; 15 m, 30 m, 60 m; 16-day revisit
Landsat 8	Operational Land Imager (OLI)	185 km swath; 15 m, 30 m, 60 m; 16-day revisit
Terra & Aqua	MODerate Resolution Imaging Spectroradiometer (MODIS)	2330 km swath; 250 m, 500 m, 1 km; 1-2-day revisit
Suomi NPP	Visible Infrared Imaging Radiometer Suite (VIIRS)	3040 km swath; 375 m – 750 m; 1-2-day revisit
Sentinel 2A and 2B	Multi Spectral Imager (MSI)	290 km swath; 10 m, 20 m, 60 m; 5-day revisit
Sentinel 3A	Ocean and Land Color Instrument (OLCI)	1270 km swath; 300 m; 27-day revisit

Sensor's Spectral Resolution

Multispectral

- Has been the norm with satellite sensors
- Limited in the number of spectral bands that can be used
- Has the advantage of longevity of datasets in some cases (Landsat, MODIS)
- Fairly high temporal resolution (days to weeks)

Hyperspectral

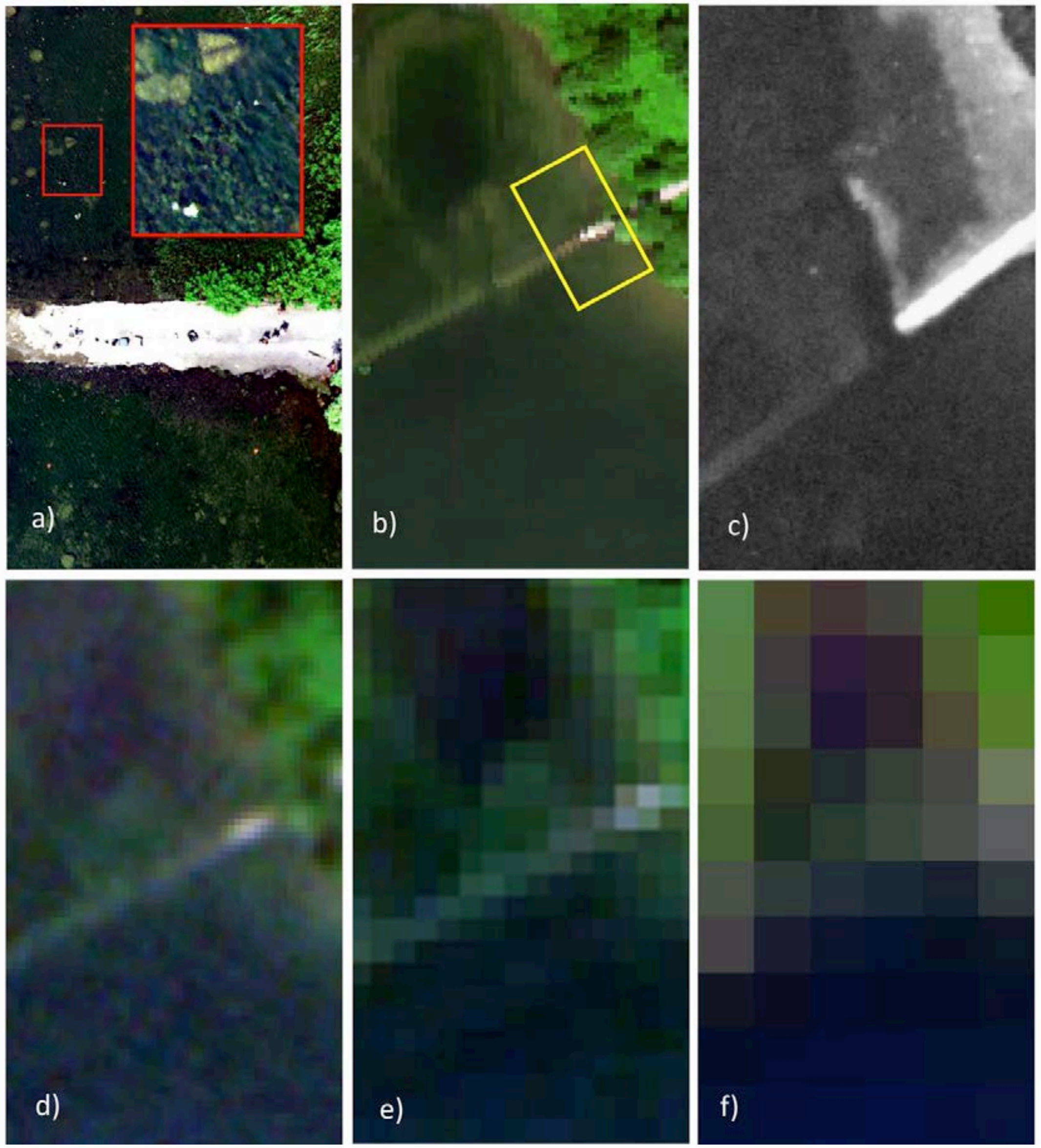
So far, very limited in numbers of satellite-based sensors

- – Hyperion – (Decommissioned in 2017); 30m resolution, 220 bands @10nm bandwidth

- Some are mission specific
  - – Hyperspectral Imager for the Coastal Ocean (HICO); Limited data set (2009-2014)
- Airborne Sensors
  - – Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) and AVIRIS-New Generation (AVIRIS-NG)
  - – Portable Remote Imaging Spectrometer (PRISM)
- Lately, development of hyperspectral cameras for Unmanned Airborne Systems (UAS) look promising

Effects of Spatial Resolution on SAV Classification

A. 3cm – Hyperspectral CASI sensor on UAV platform
B. 1m – CASI sensor (at higher altitude) on UAV platform
C. ~1-1.5m – Panchromatic photograph
D. 3m – Planet Scope image
E. 10m – Sentinel-2 image
F. 30m – Landsat 8 image



Credit: Rowan & Kalacska 2021

Future Satellite Missions with Potential Use for SAV Monitoring

PACE: Plankton, Aerosol, Cloud, ocean Ecosystem
https://pace.oceansciences.org/mission.htm

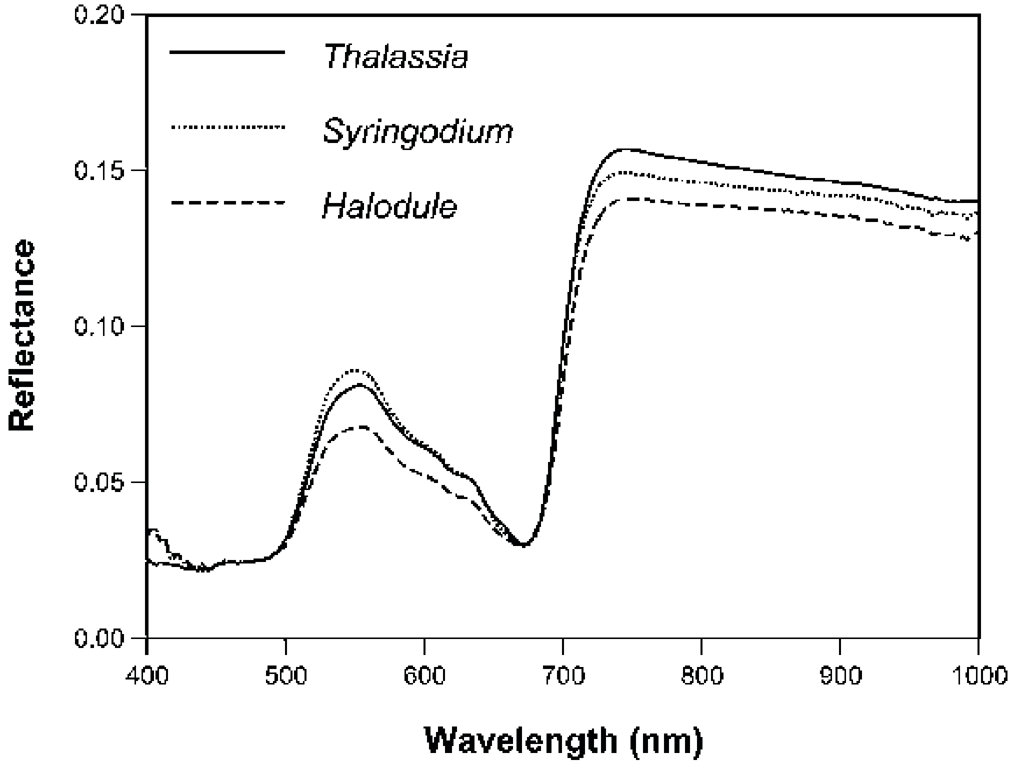
- Planned for launch in 2023
- Advanced optical spectrometer, Ocean Color Instrument (OCI)
  - Hyperspectral measurements for water quality products (ultraviolet to near-infrared range)

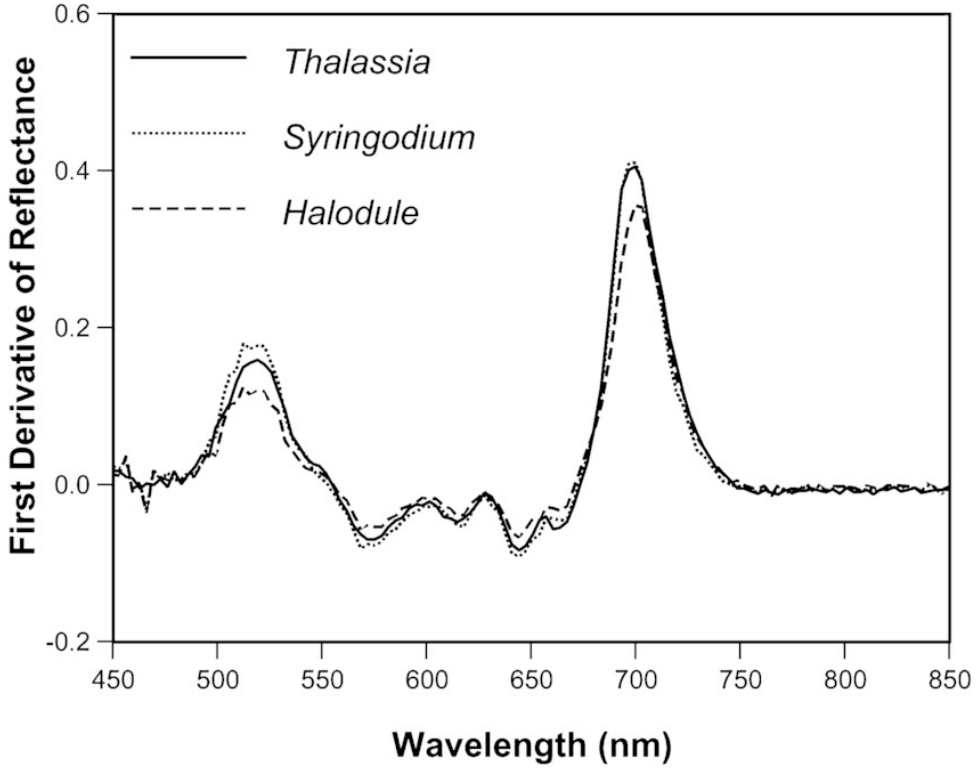
SBG: Surface Biology and Geology
https://sbg.jpl.nasa.gov/

- In the initial phase of development
  - Hyperspectral imagery in the visible and shortwave infrared; multi-or hyperspectral imagery in the thermal IR

Remote Sensing of Seagrass Beds

Spectral Signatures of Seagrasses

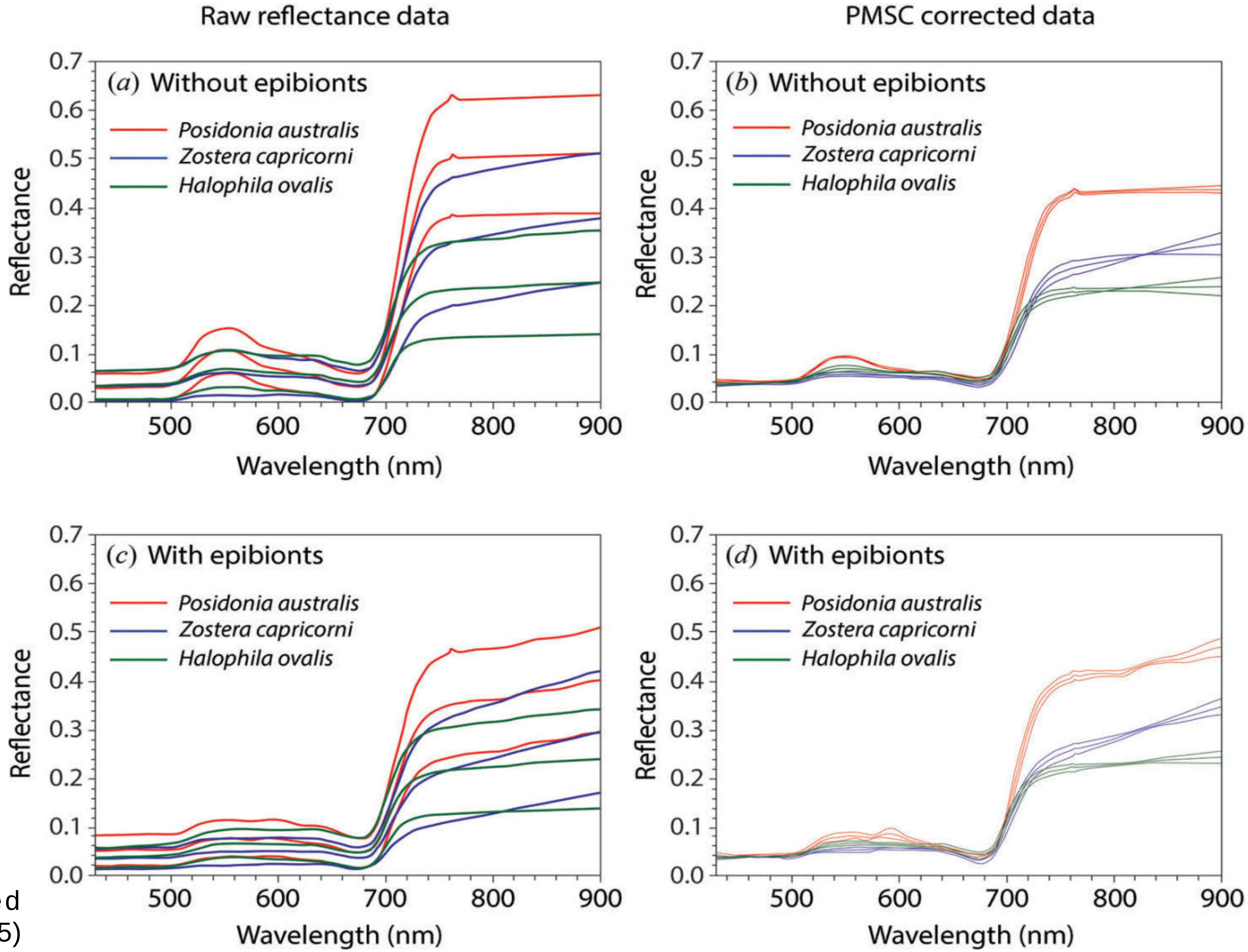




From: Thorhaug et al 2005 Int. J. Remote Sens.

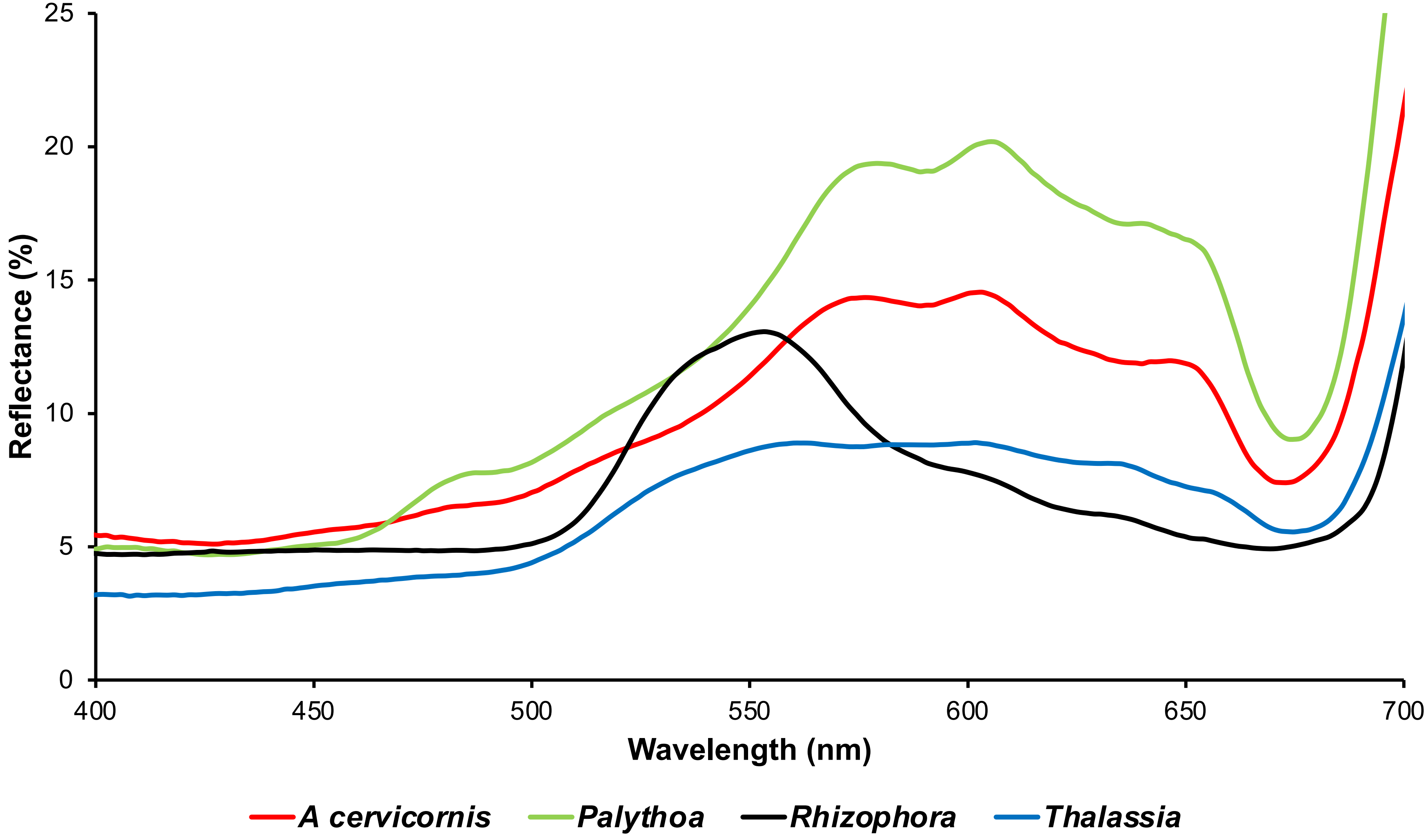
Seagrass Species Spectral Discrimination

- The presence/absence of epibionts in the leaves of seagrasses influence the spectral response, and therefore the potential discrimination between species.



Credit: Data from Fyfe (2003) as modified by Hossain et al (2015)

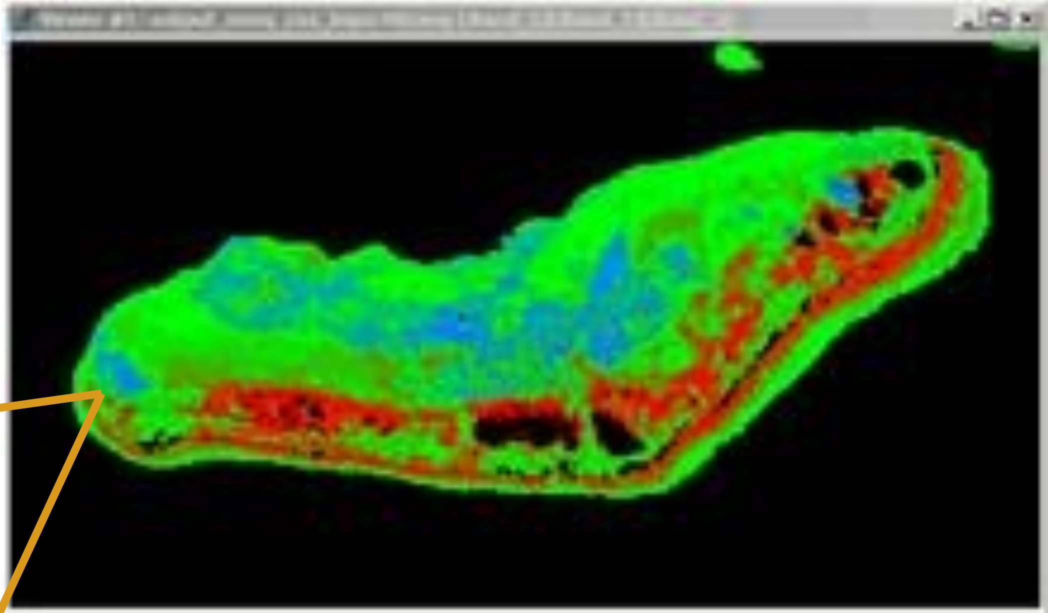
Spectral Differences of Submerged and Other Coastal Components



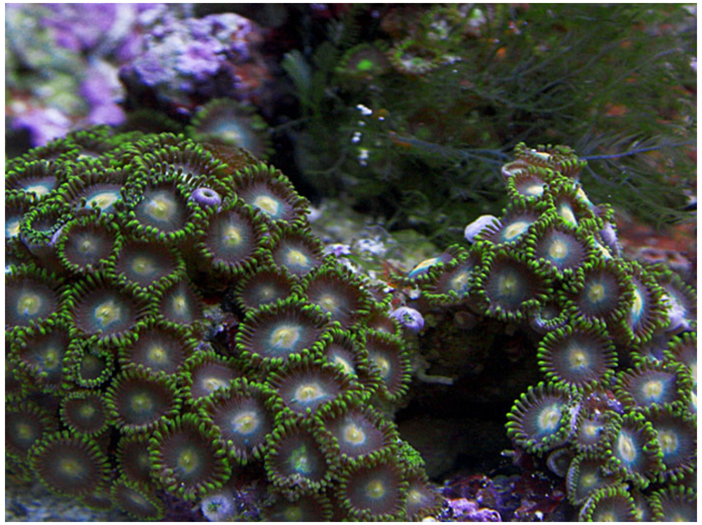
Credit: Torres-Pérez (Unpublished Data)

Spectral Differences of Visually Similar Benthic Components

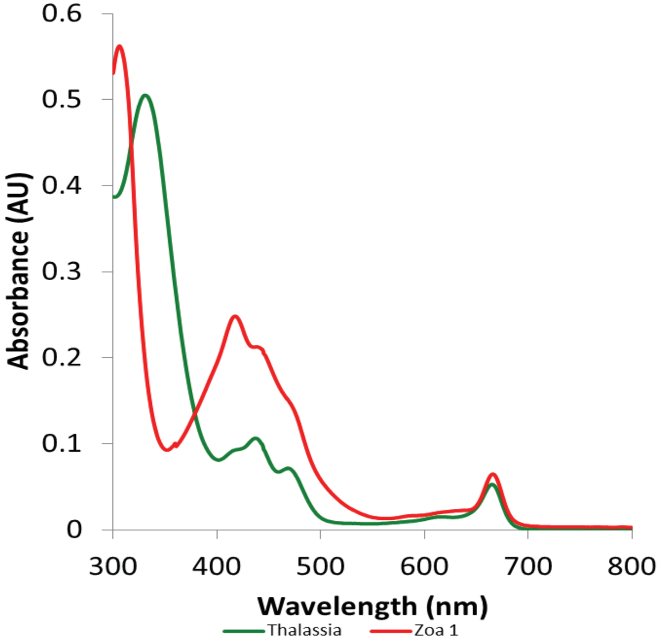
Benthic components may have similar colors, but may be spectrally different.



Turtle Grass (*Thalassia testudinum)*



Green Sea Mat (*Zoanthus sociatus*)
Credits: Juan L. Torres-Pérez

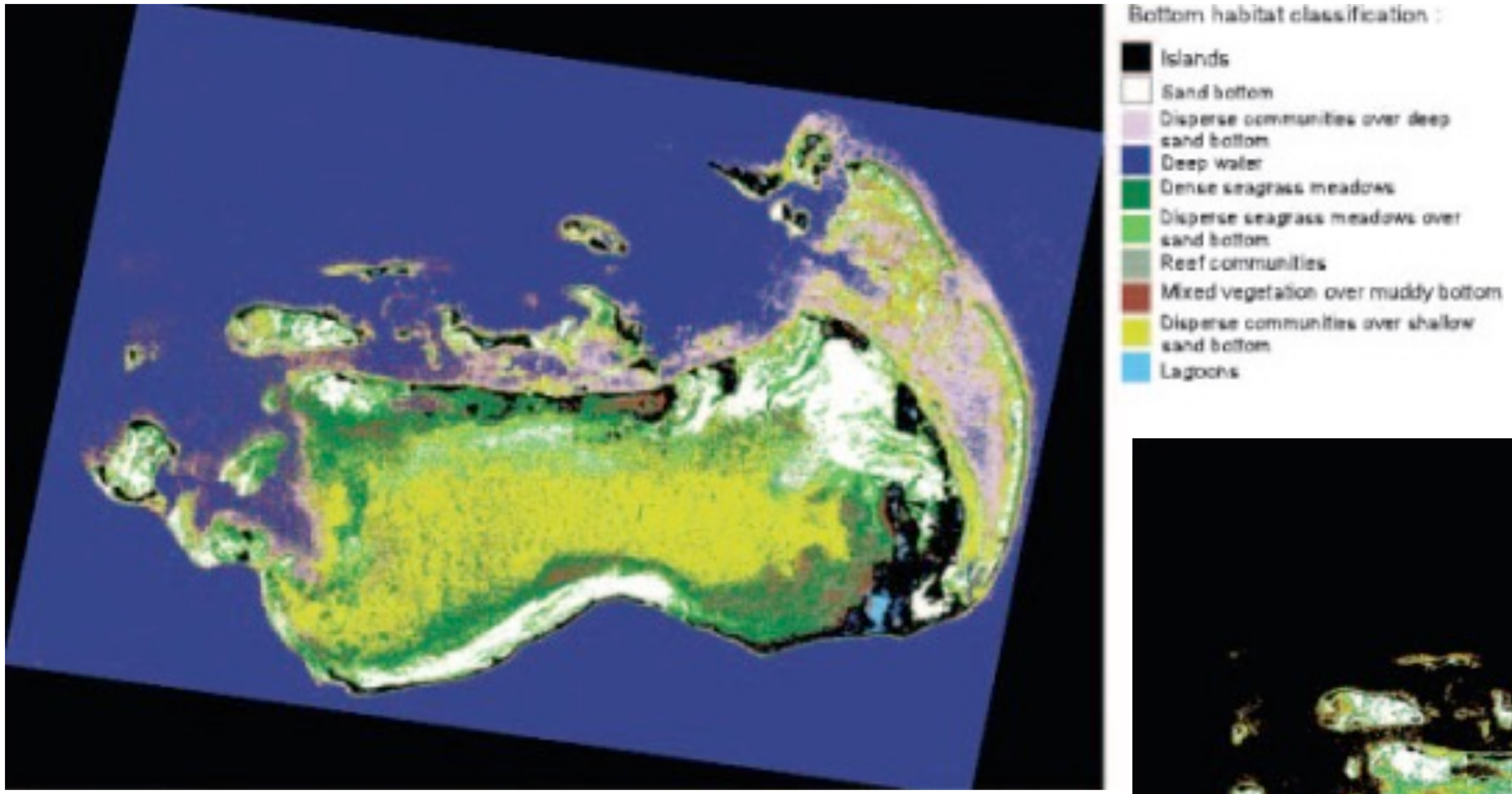


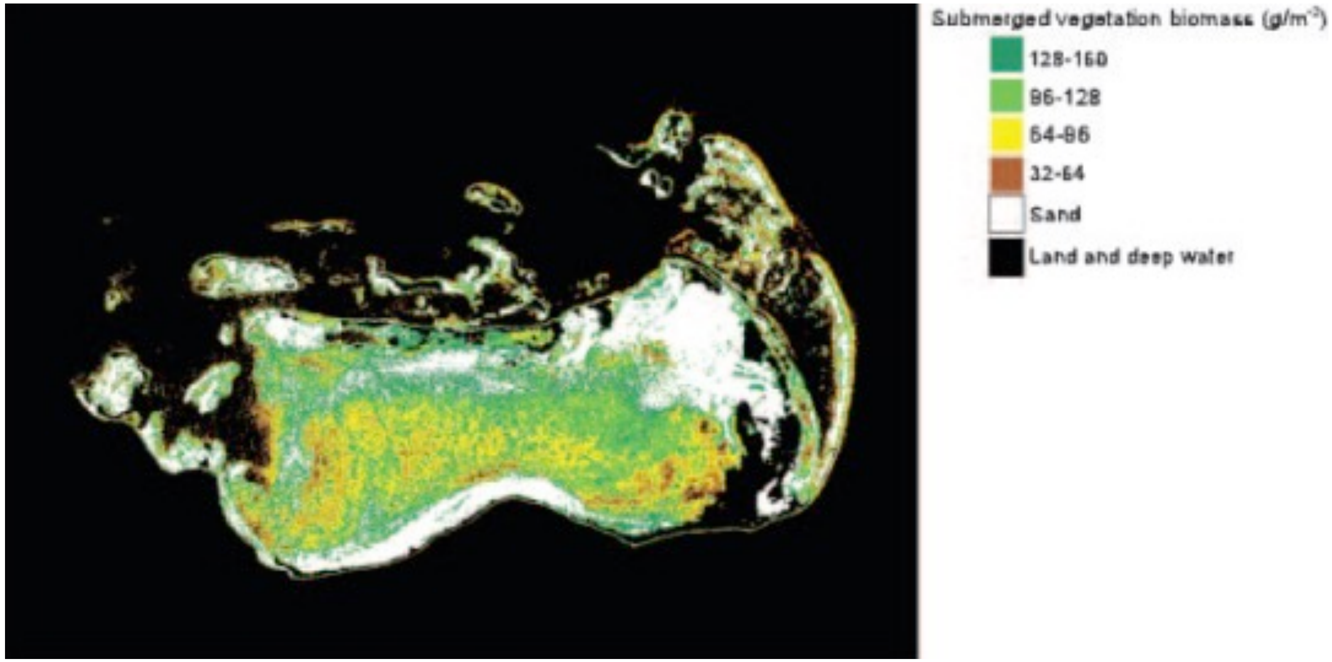
Torres-Pérez (Unpublished)

Methods for Seagrass Classification

- In an extensive review paper on remote sensing of seagrass beds, Hossain et al (2015) found that the most common methods used for seagrass classification were:
- Manual delineation (for aerial photos)
- Supervised classification
- Radiative transfer modeling
- Recently, the use of linear spectral unmixing (Uhrin & Townsend 2016) and machine learning techniques (Pérez et al 2020) have become more common.

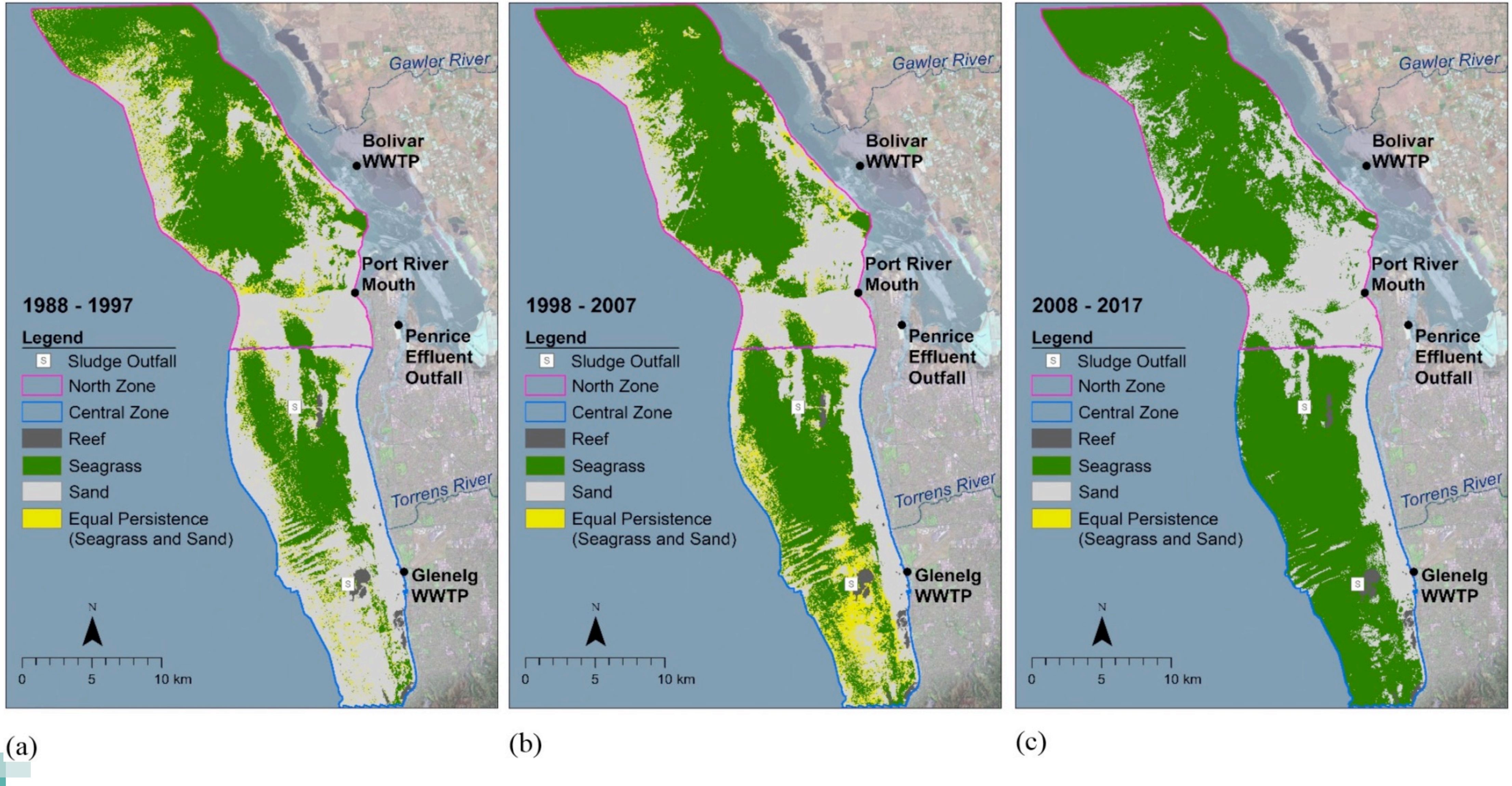
Seagrass Habitat Classification with Landsat 7





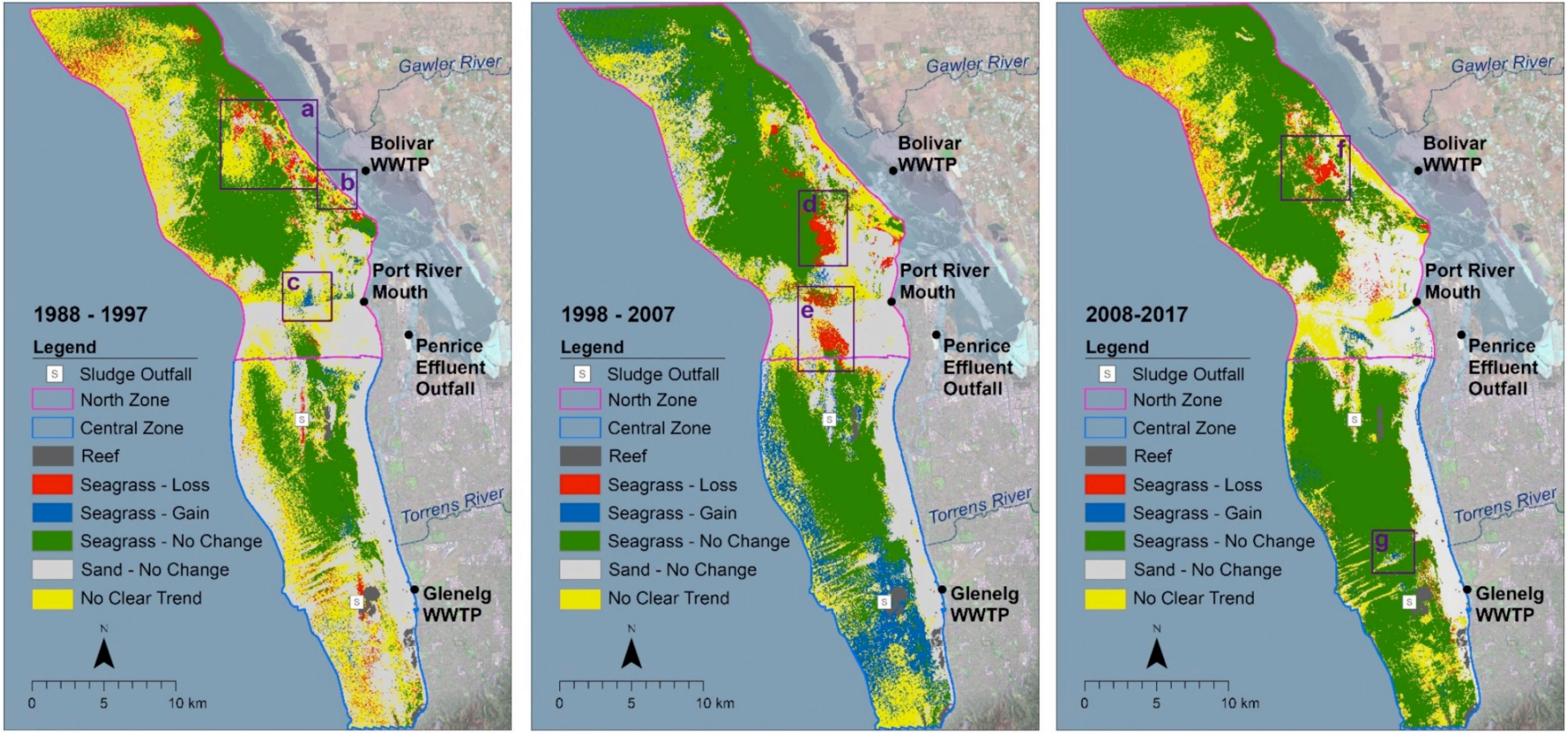
Credit: Schweizer et al (2005)

30 Years of Seagrass Changes Monitored with Landsat Series



Credit: Fernandes et al, 2022

30 Years of Seagrass Changes Monitored with Landsat Series

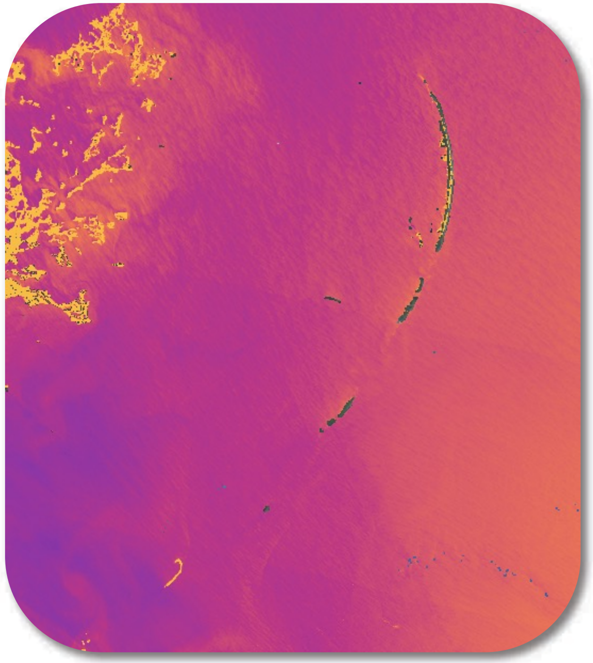


(a) (b) (c)

Credit: Fernandes et al, 2022

NDAVI – A Spectral Index Useful for Seagrass Monitoring

Near Infrared Band



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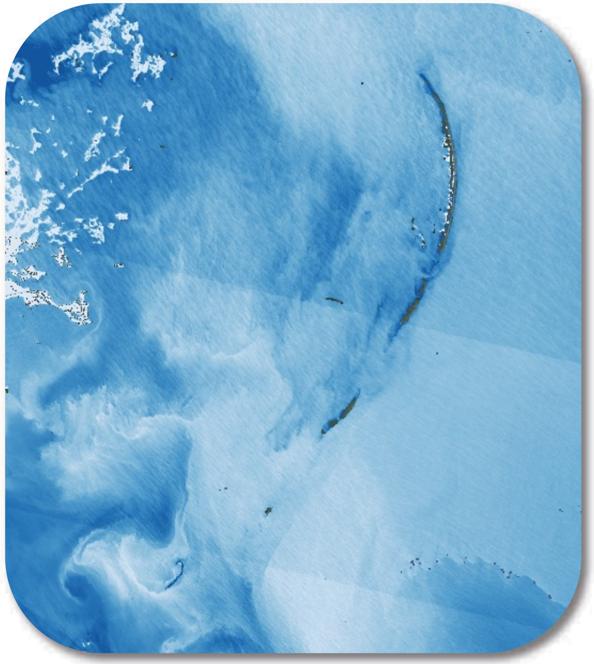
Blue Band



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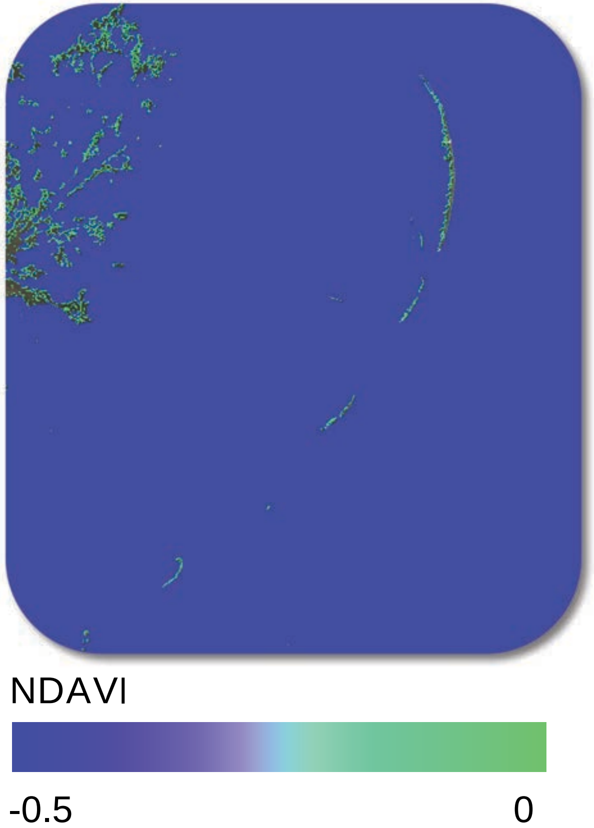
Aquatic Vegetation

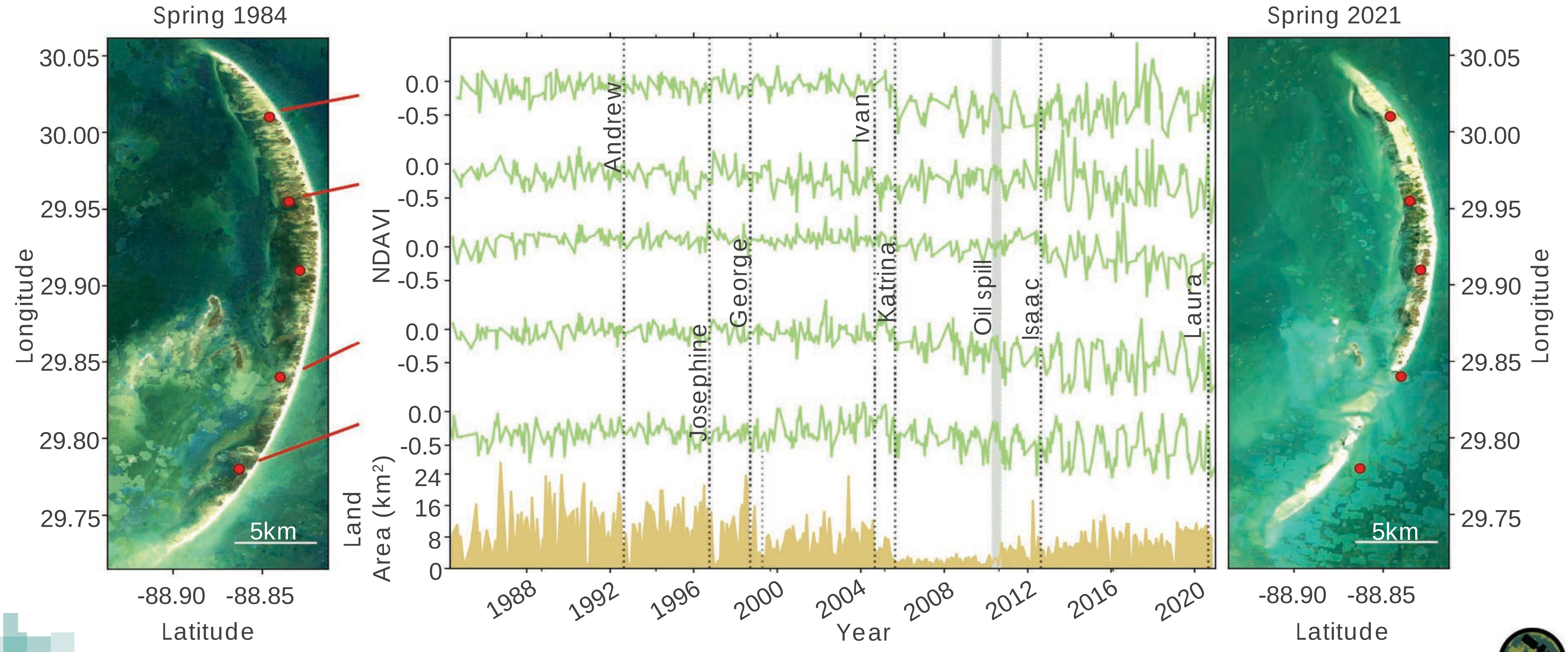


Spring 2019 over the Chandeleur Sound

Normalized Difference Aquatic Vegetation Index = (NIR – Blue)/(NIR + Blue)

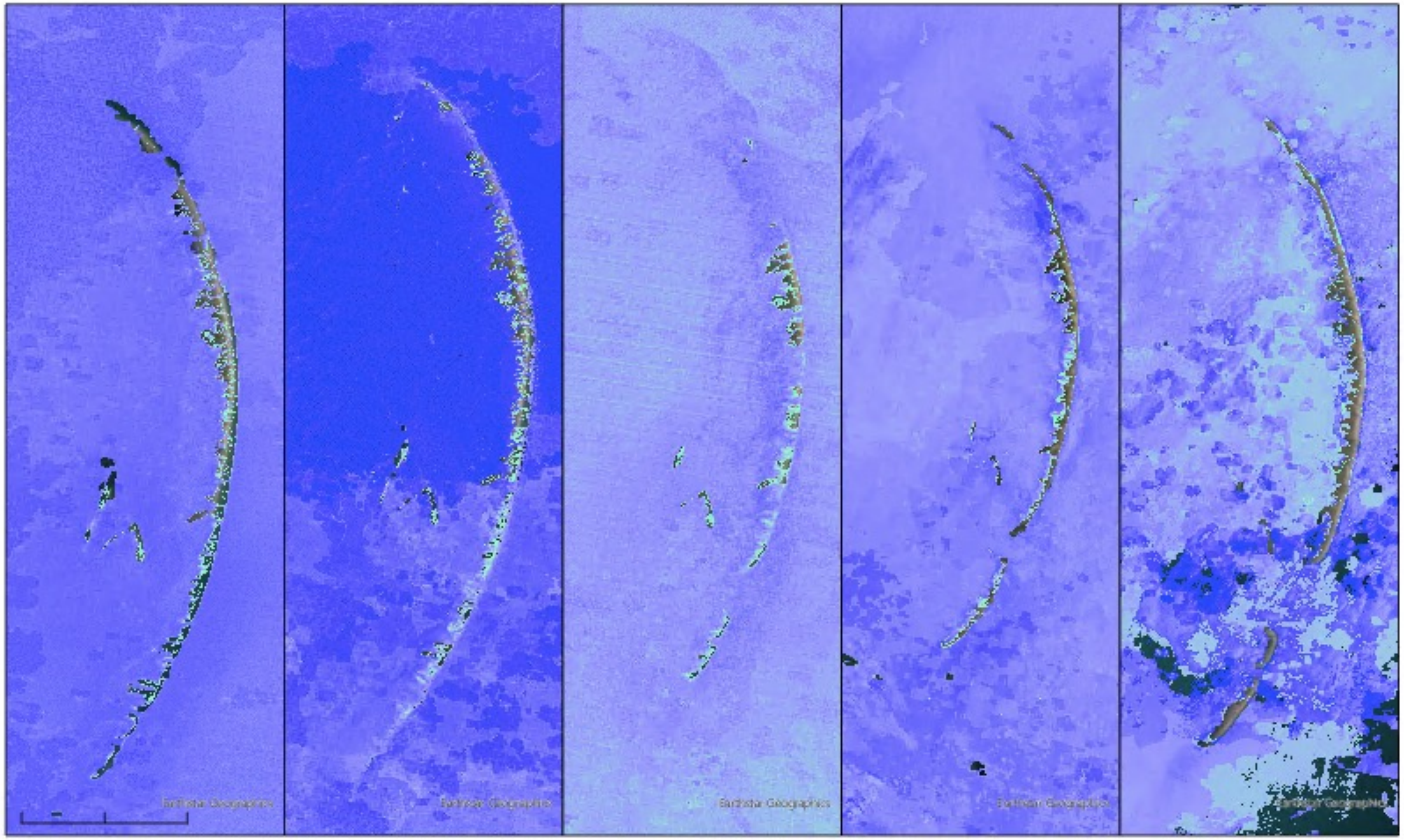
NDAVI to Follow Specific Human/Climate Events Effects on Seagrasses

NDAVI and land area from 1984 to 2021 at five locations along the islands.

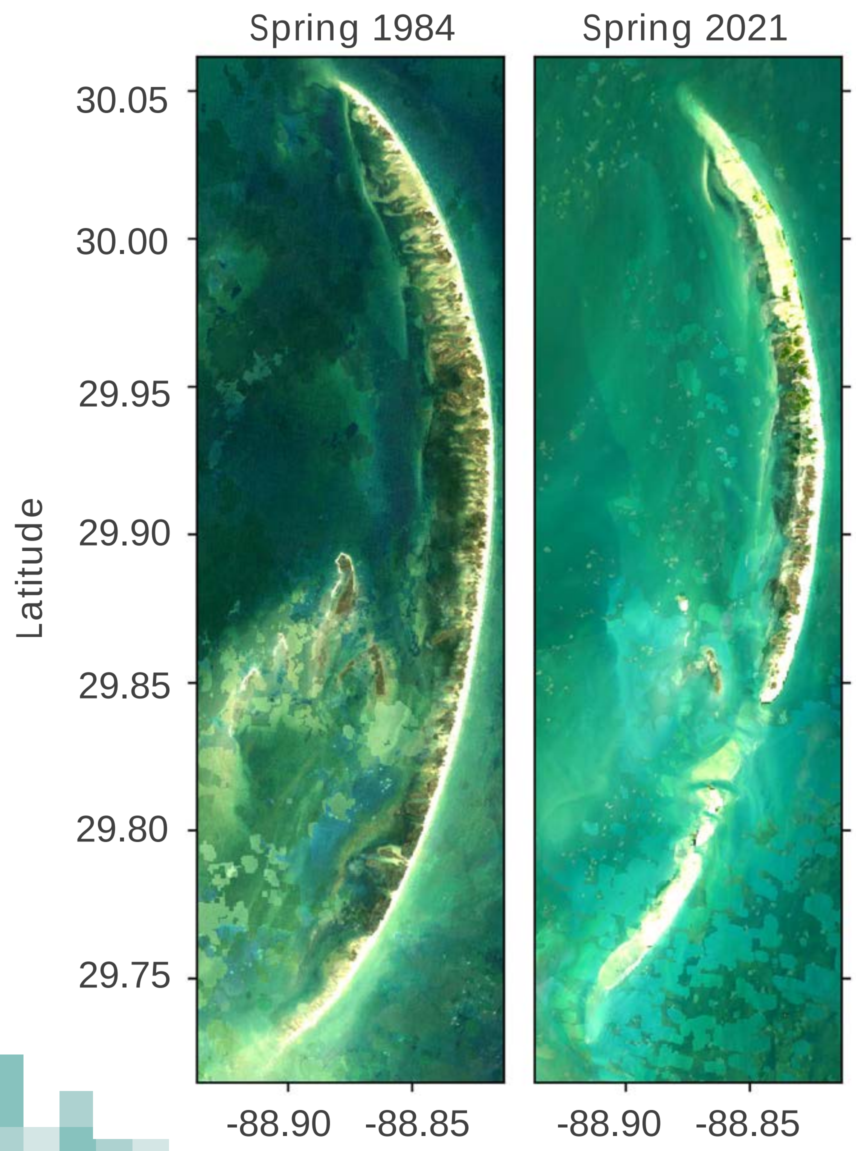


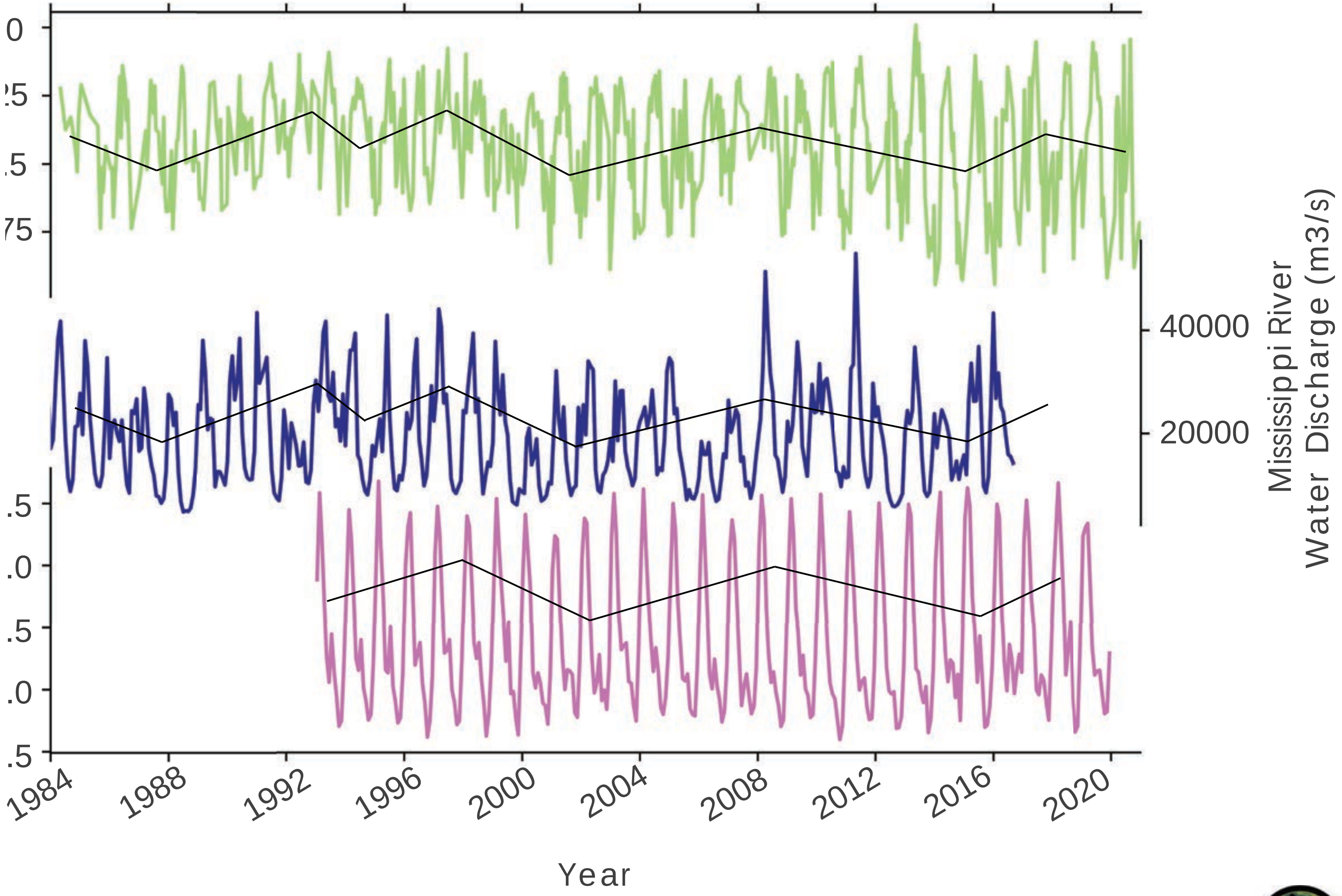
NDAVI to Follow Specific Human/Climate Events Effects on Seagrasses

NDAVI around the Chandeleur Islands from Summer 2000 – Summer 2020



NDAVI to Follow Specific Human/Climate Events Effects on Seagrasses





Concluding Remarks

- The accuracy of seagrass and other SAV mapping will depend on methodological factors such as the use of an appropriate water column correction algorithm, cloud cover correction, and the incorporation of other physical, biological, chemical, and geological considerations into the analysis.
- Despite some efforts at local or regional levels, spectral libraries of SAV are still limited and in need of expansion. These should also include data that incorporates the presence/absence of epibionts and how the spectral signatures is affected.
- There is need of standardization among field spectral collection methods.
- Current satellite data can be used for the mapping of SAV at different levels, but the incorporation of new satellite- or airborne-based hyperspectral imagery at increased spatial resolutions may prove useful when mapping different species of SAV and other benthic components.

Contacts

- ARSET Contacts
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  - Juan Torres-Pérez: juan.l.torresperez@nasa.gov

- ARSET Website:
  - https://appliedsciences.nasa.gov/what-we-do/capacity-building/arset

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