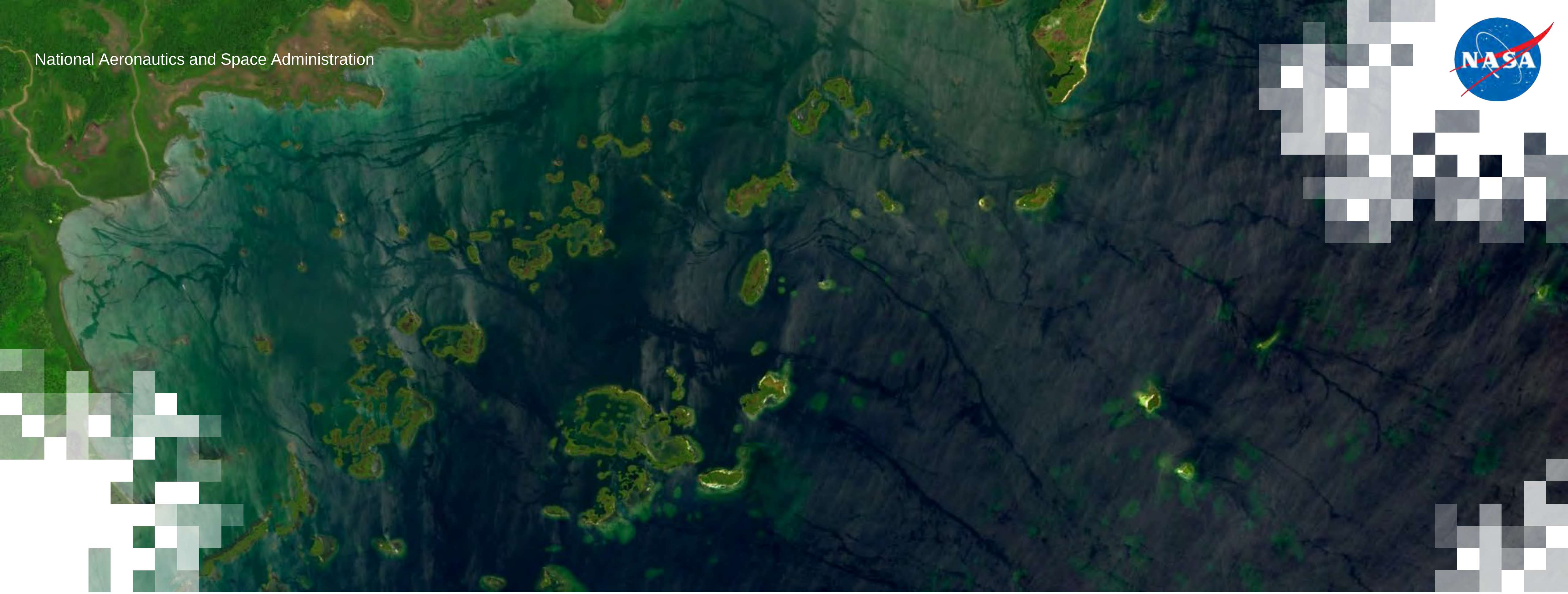
National Aeronautics and Space Administration



Earth Observations of Blue Carbon Ecosystems

Part 2: Mapping Salt Marsh and Seagrass with Earth Observations

Brock Blevins (NASA ARSET), Kelly Luis (NASA JPL), Anthony Campbell (NASA GSFC), Cheryl Doughty (NASA JPL)

December 5, 2024

Training Outline

Part 1

Overview of Blue Carbon Ecosystems & Mapping Mangrove Ecosystems with Earth Observations

December 03, 2024

14:00-15:30 EST (UTC-5)

Part 2

Mapping Salt Marsh and Seagrass with Earth Observations

December 5, 2024

14:00- 15:30 EST

(UTC-5)

Homework

Opens December 5, 2024 – Due December 19, 2024 – Posted on Training Webpage

A certificate of completion will be awarded to those who attend all live sessions and complete the homework assignment(s) before the given due date.

Part 2 – Trainers

Dr. Anthony Campbell

Assistant Research Scientist & Geospatial Analyst

NASA Goddard Space Flight Center

Dr. Cheryl Doughty

Assistant Research Scientist

NASA Goddard Space Flight Center

Dr. Kelly Luis

Scientist

NASA Jet Propulsion Laboratory

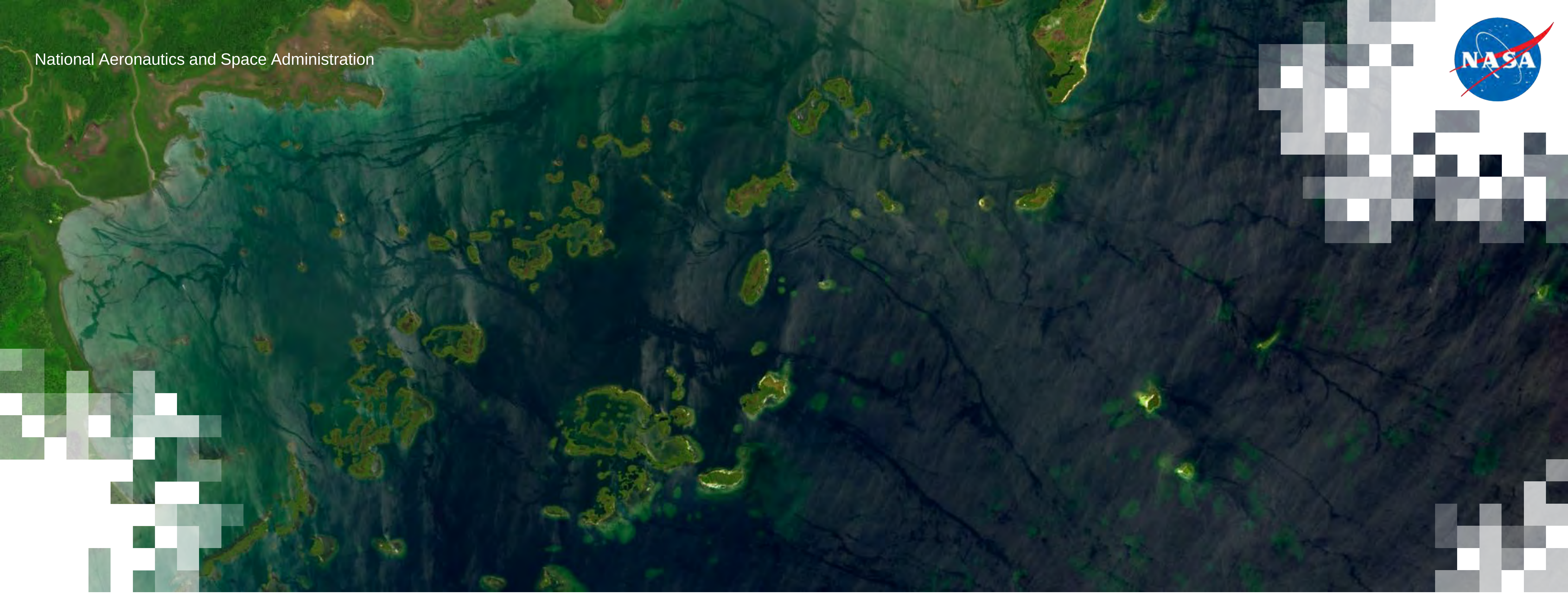
Part 2 Objectives

By the end of Part 2, participants will be able to:

- Map the extent of salt marsh and seagrass ecosystems using satellite observations
- Calculate the carbon stocks of mapped salt marsh and seagrass ecosystems
- Explore synthesis methods to estimate blue carbon across ecosystems

How to Ask Questions

- Please put your questions in the Questions box and we will address them at the end of the webinar.
- Feel free to enter your questions as we go. We will try to get to all of the questions during the Q&A session after the webinar.
- The remainder of the questions will be answered in the Q&A document, which will be posted to the training website about a week after the training.



Earth Observations of Blue Carbon Ecosystems

Part 3: Salt marsh

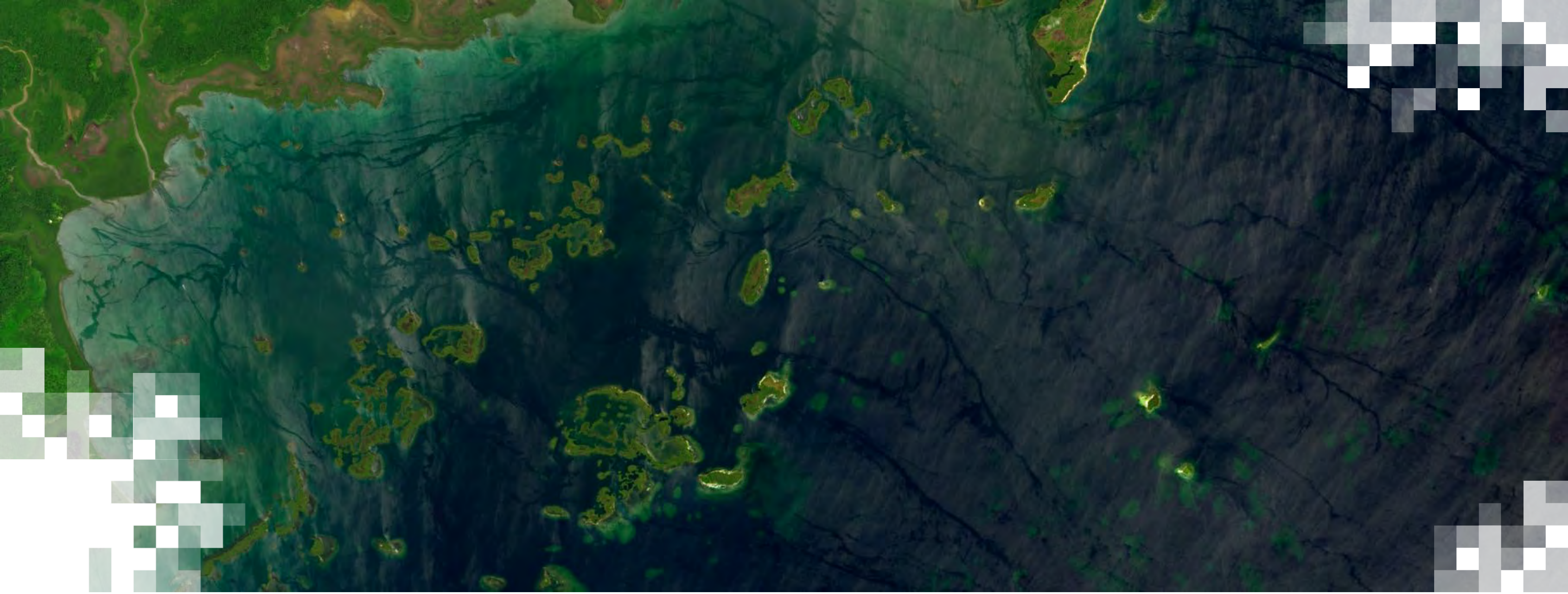
Anthony Campbell (GSFC/UMBC)

December 5, 2024

Training Learning Objectives

By the end of this training, participants will be able to:

- 1. Map the extent of salt marsh and seagrass ecosystems using satellite observations
- 2. Calculate the carbon stocks of mapped salt marsh and seagrass ecosystems
- 3. Understand synthesis methods to estimate blue carbon across ecosystems

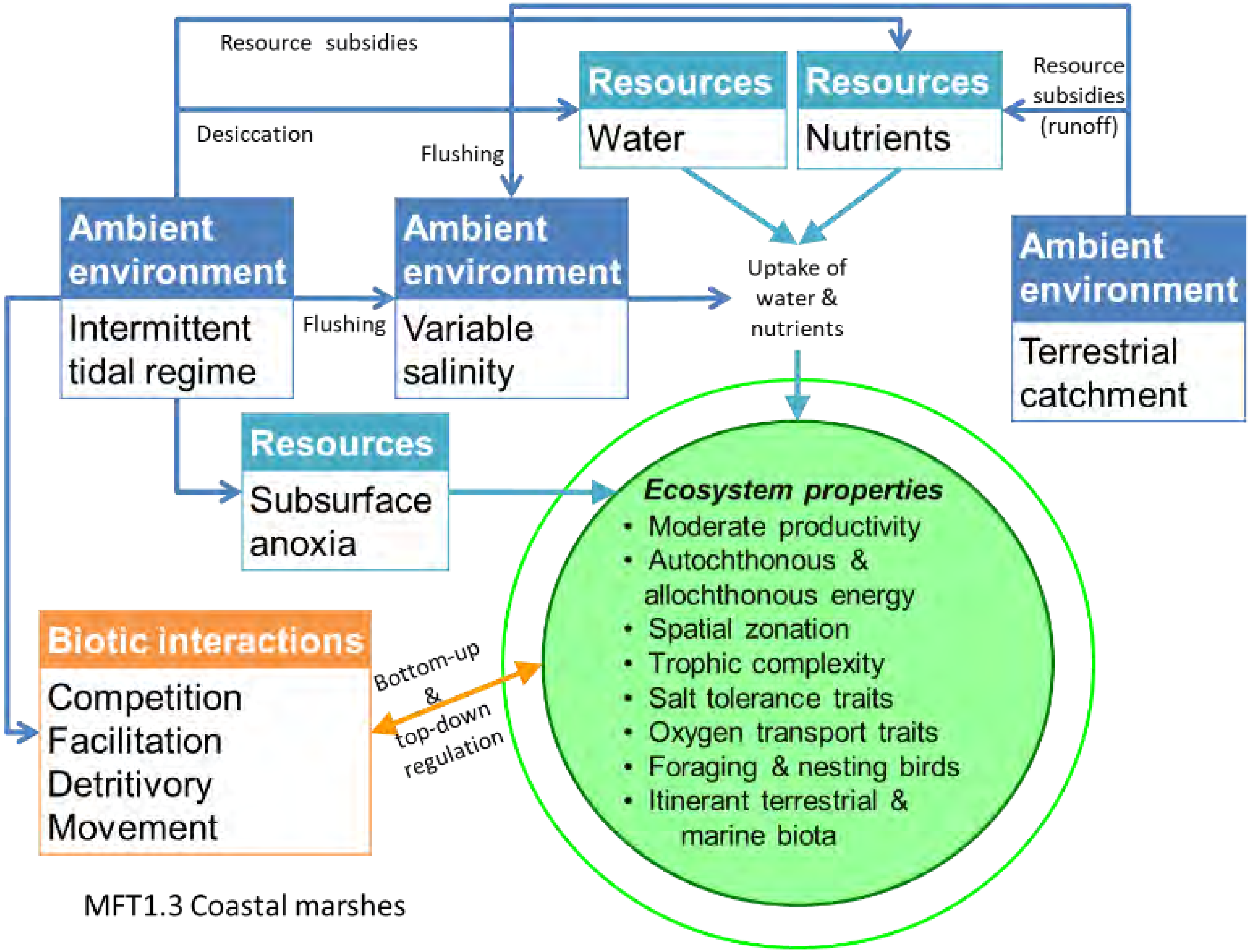


Salt marsh

What is a salt marsh?

Defined as Coastal saltmarsh and reedbeds in the Global ecosystem typology.

- Salinity
- Tidally inundated
- Low energy



MFT1.3 Coastal marshes

Global datasets for salt marsh blue carbon

- Global 10 m map for 2020 (Worthington et al. 2023; Data)
- Global 30 m map of tidal marsh, tidal flats and mangroves 2000-2020 (Murray et al. 2022; Data)
- Global 30 m map of wetlands 2000-2022 (Zhang et al. 2024; Data)
- Global 30 m change and emissions from 2000-2019 (Campbell et al. 2022; Data)
- Global soil organic carbon map (Maxwell et al. 2024; Data).
- Global approach with Google Earth Engine for mapping tidal wetlands (https://zenodo.org/records/5968865 from Murray et al. 2022)

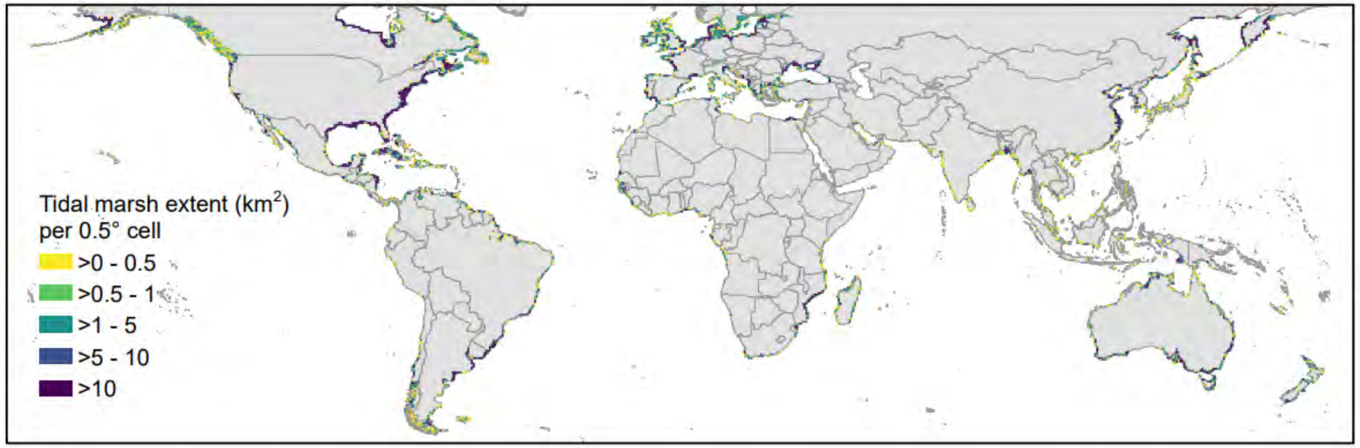


Figure 1: The 2020 distribution of tidal marshes, with darker colours representing greater extents of tidal marshes (km²) within a 0.5° grid cell.

- (Worthington et al. 2023)

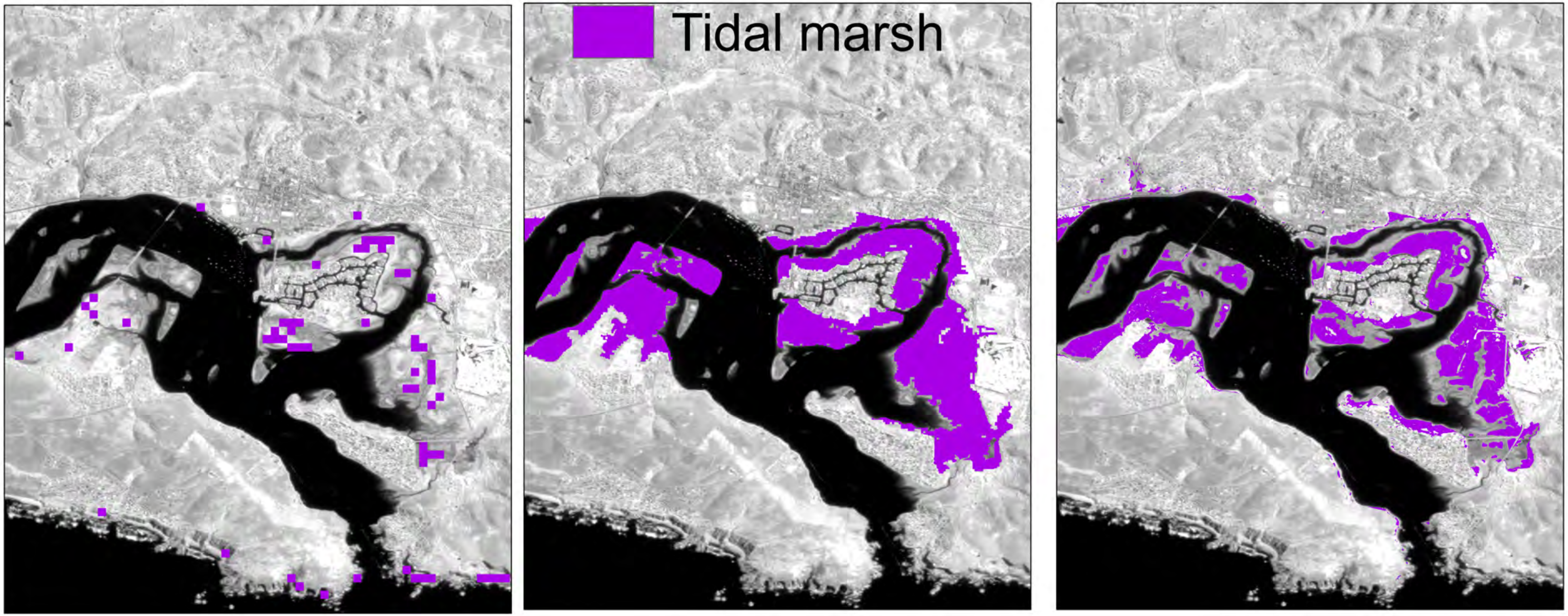
Sensor properties and salt marsh mapping needs

- Spatial resolution
- Temporal resolution (Revisit time)
- Spectral resolution
- Elevation

Example site: Knysna Estuary, South Africa

- Estuarine Bay
- Temperate climate
- Microtidal (1.36 m tidal range)
- Semidiurnal – two low and two high tides daily
- Example wetland vegetation species includes: *Zostera capensis (Seagrass), Spartina martima, Bassia diffusa, Triglochin buchenai, Salicornia tegetaria, and Juncus Kraussi*.

Sensor properties – spatial resolution

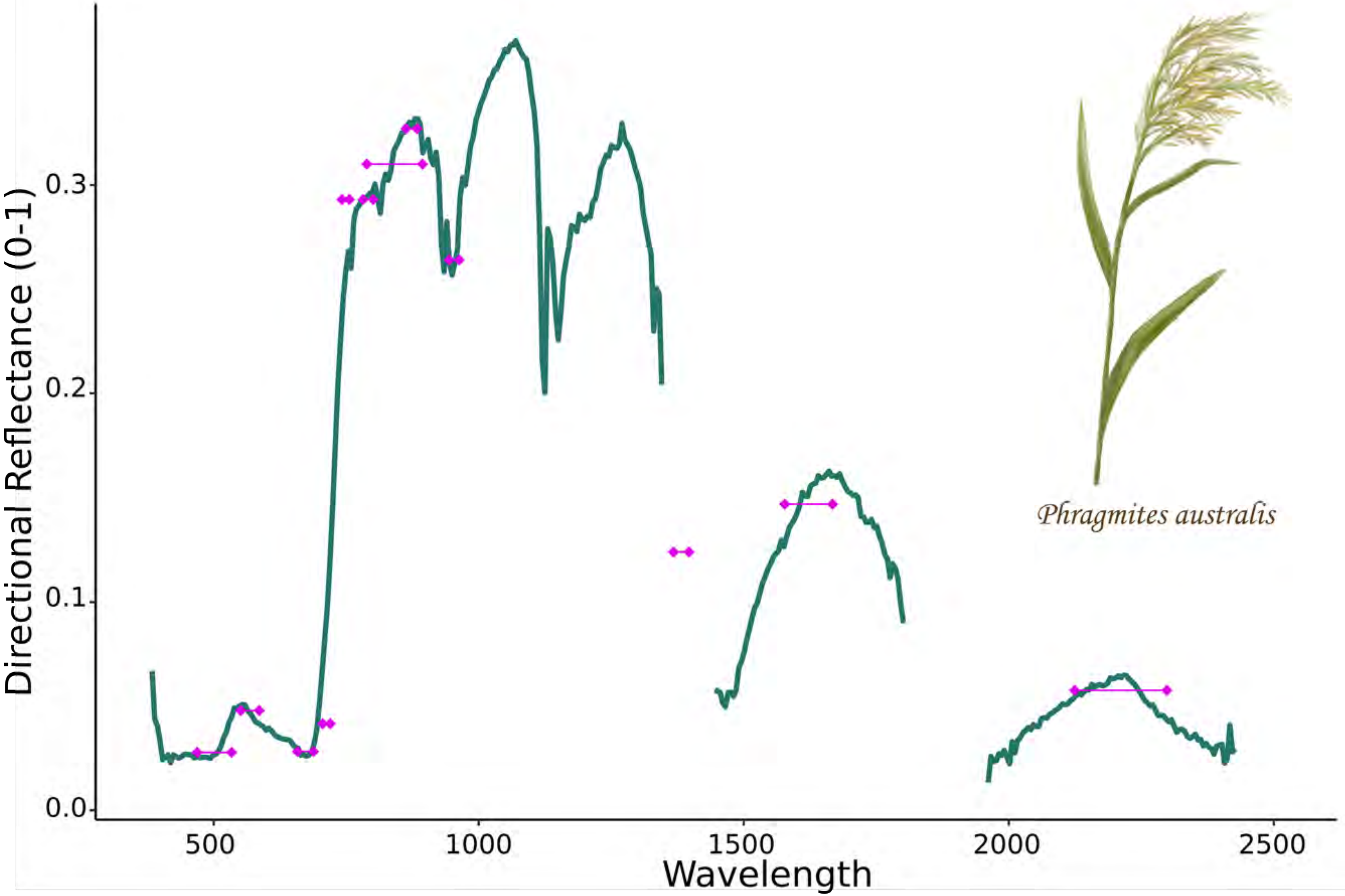


100 m 10 m 3 m

Data: [100 m](); [10 m]()

Sensor Properties – Spectral resolution

- Band width
- Spectral coverage
- Spectral ranges of interest (Red-edge)

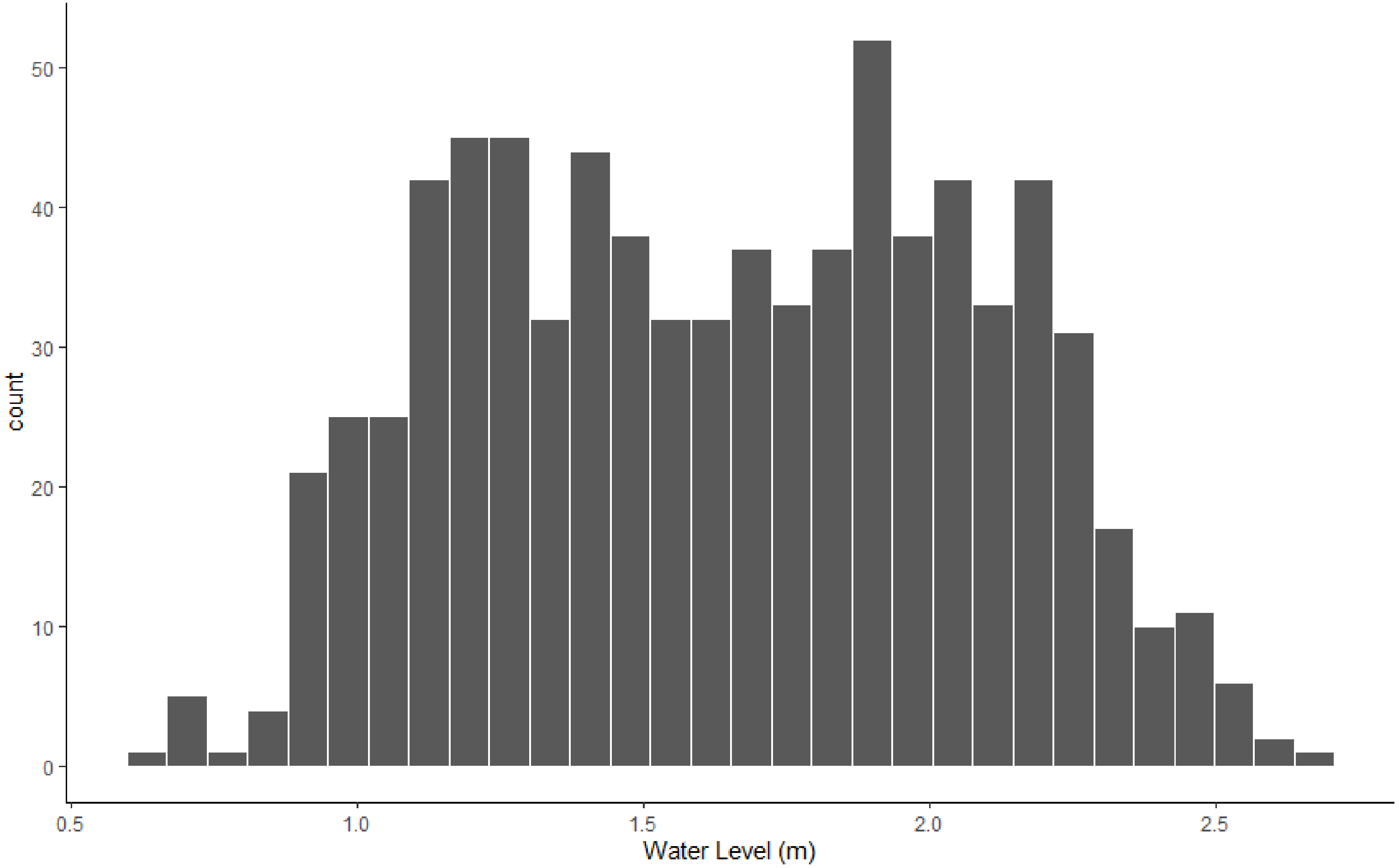


Sensor Properties – Temporal resolution

- Temperate salt marsh phenology - seasonality
- Spectral coverage
- For minimal inundation of the vegetation - ideal image is close to mean low water during the growing season

Sensor Properties – Temporal resolution

- What tidal stage is necessary for mapping?
- High tide imagery can be filtered out of the mapping effort but includes important information on coastal processes and ecosystem distribution.
- Mean Lower Low Water (MLLW) in Knysna is 1.2 m
  - 17% of Sentinel-2 imagery was collected below 1.2 m.
  - 24% of Landsat-8 and 9 imagery were collected below 1.2 m



Tidal Inundation

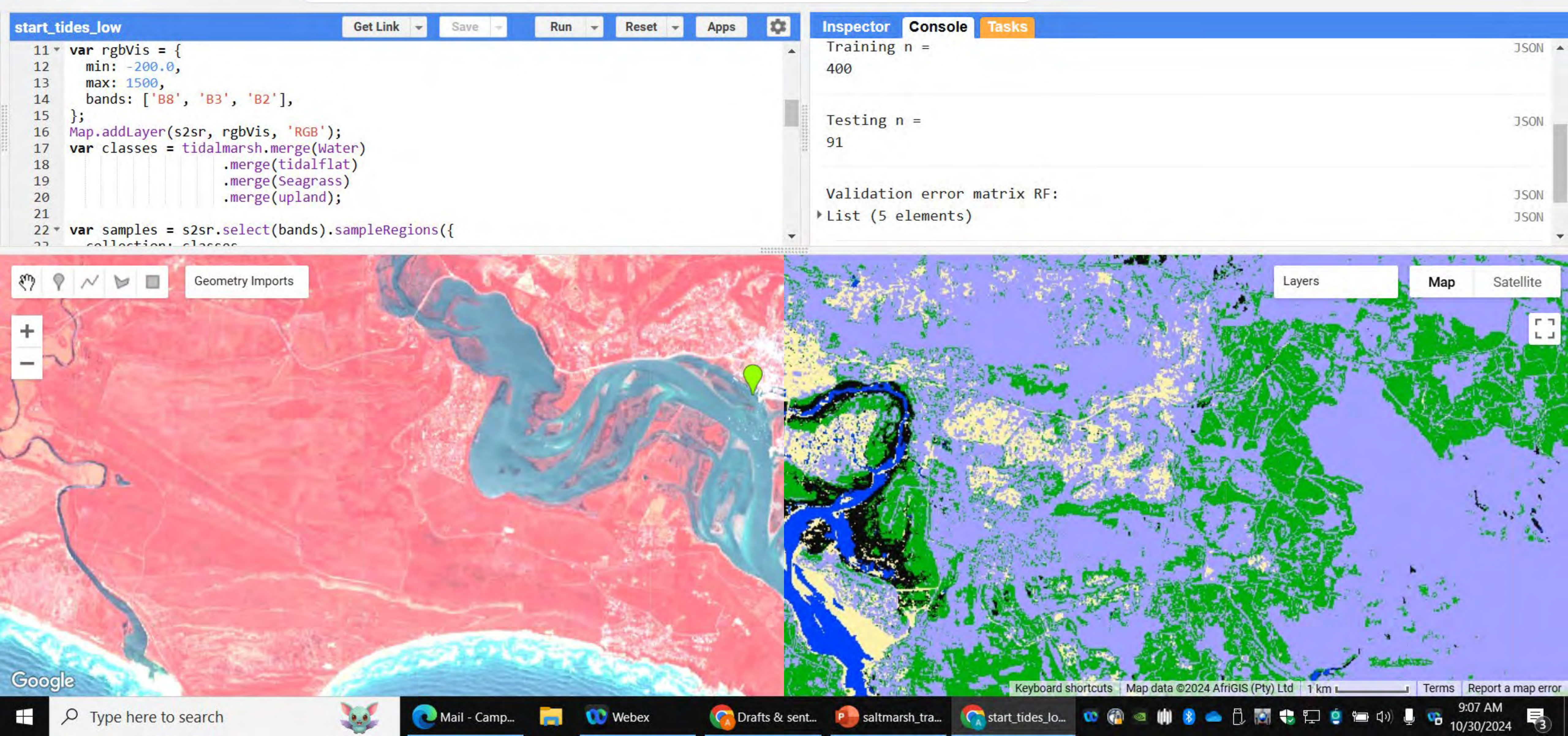
- Limited penetration of the water
- Dependent on tidal range
  - Variable across the marsh
  - Impact differs with percent cover and vegetation height
  - Informative for classification with a risk of misclassification

(https://phenocam.nau.edu)

Demo summary

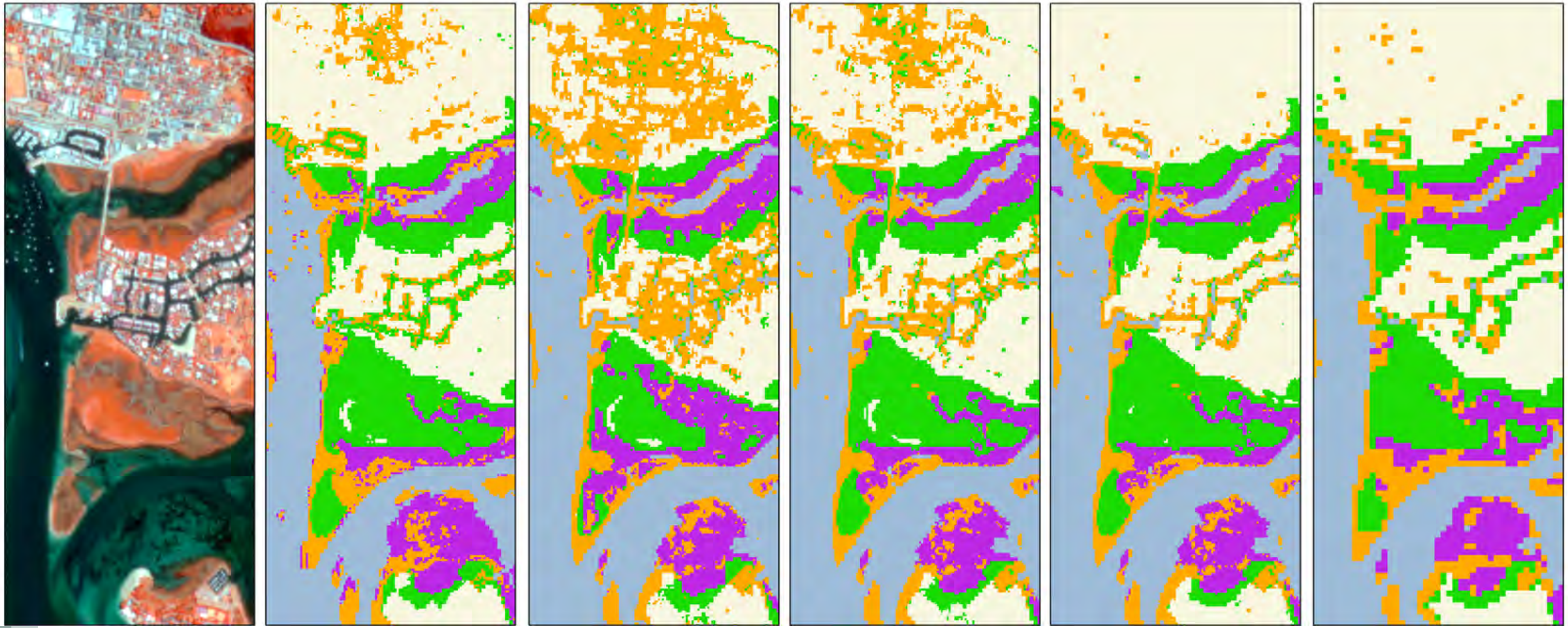
1. Map at high tide – Sentinel-2
2. Map at low tide – Sentinel-2
3. Multidate classification – Sentinel-2
4. Multidate classification – Landsat-9
5. Add elevation

Demo – salt marsh extent mapping



Demo summary

Classification	Sentinel-2 High Tide	Senitnel-2 Low Tide	Multidate	Multidate + Elevation + NDVI	Landsat 9 + Elevation + NDVI
Overall Accuracy	90.17	92.85	93.75	95.54	92.86



Key considerations for mapping ecosystems

The mapping objective may impact the “tier” of data required

Excerpts from IPCC (2003) Good Practice Guidance for LULUCF, Ch. 3

Tier 1 Use of default / Global data	Methodologies usually use activity data that are spatially coarse, such as nationally or globally available estimates.
Tier 2 Use of country-specific data	Tier 2 applies emission factors and activity data which are defined by the country; Higher resolution activity data are typically used
Tier 3 Use of advanced methods and detailed country-specific data	Tier 3 – including models and inventory measurement systems tailored to address national circumstances, repeated over time, and driven by high resolution activity data and disaggregated at sub-national to fine grid scales.

Area and carbon estimates -

1. Determine area uncertainty
2. Landsat 9
    1. Salt marsh: 534 ± 107 ha
    2. Seagrass : 281 ± 56 ha
3. Sentinel-2
    1. Salt marsh: 549 ± 110 ha
    2. Seagrass: 242 ± 48 ha
4. Global tidal marsh layer: 653 ha
5. Global estimates of seagrass carbon are: 196.7 ± 20.7[1]
6. Global estimates of salt marsh carbon are: 334.4 ± 35[2]
7. Regional estimates of seagrass carbon are: 177.7 ± 122.3[3]
8. Regional estimates of salt marsh carbon are 441.5 ± 198.6[4]

Carbon accounts

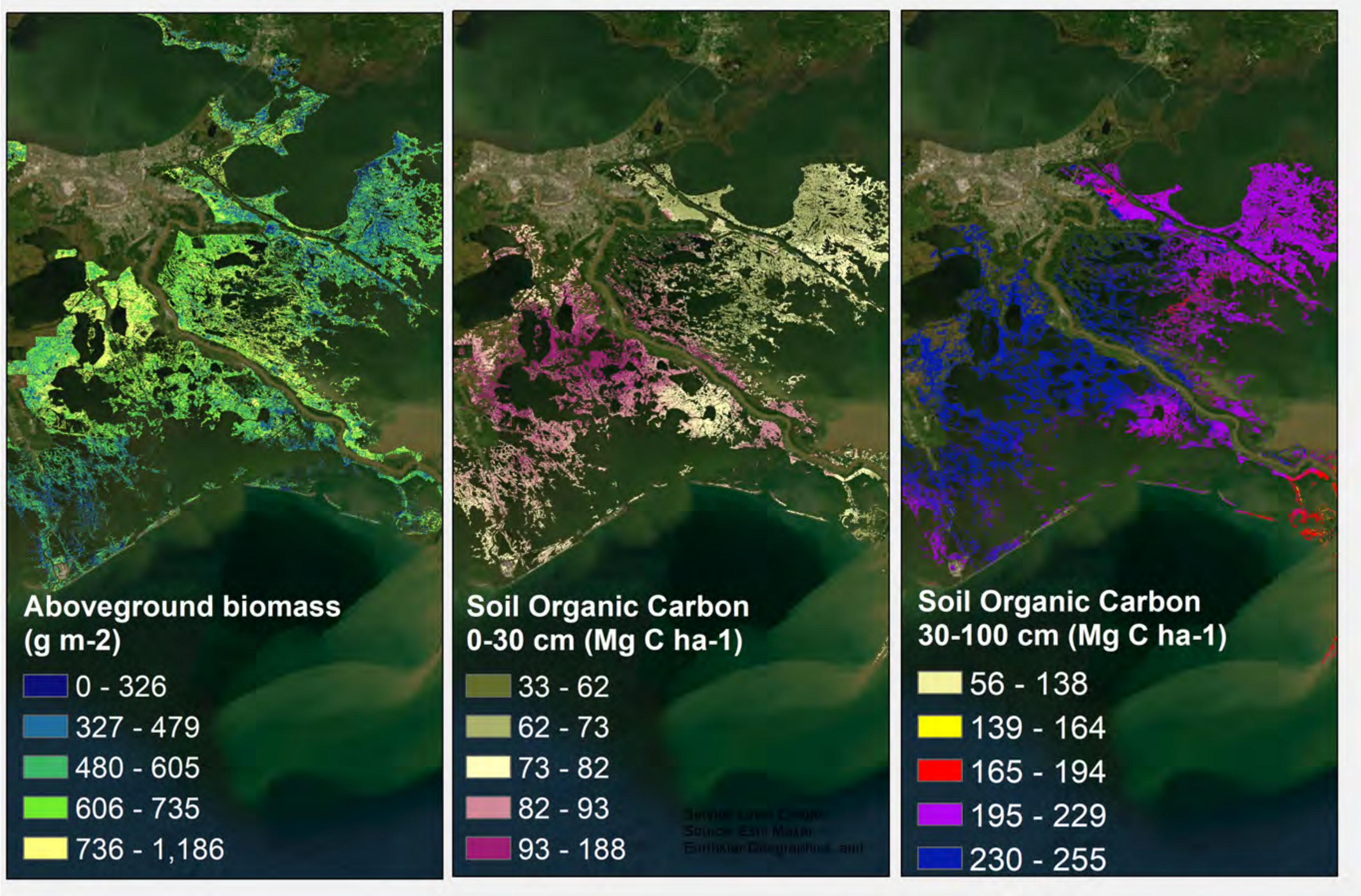
- Uncertainty propagation with the propagate package in R
  - $Carbon\ Stock = Area\ (ha) * Carbon\ per\ ha$

	Landsat 9 (Tg)	Sentinel-2 (Tg)	Global Tidal marsh (Tg)
Tidal marsh (Tier 1/Global)	0.179 ± 0.04	0.184 ± 0.04	0.218
Tidal marsh (Tier 2/Local)	0.236 ± 0.12	0.243 ± 0.12	0.288
Seagrass (Tier 1/Global)	0.055 ± 0.012	0.047 ± 0.036	NA
Seagrass (Tier 2/Local)	0.050 ± 0.036	0.043 ± 0.031	NA

Overlapping ecosystems – Knysna

- Global tidal marsh layer
- How does this overlap with seagrass maps created in our analysis?
  - Tidal marsh – seagrass overlap is 55.8 ha
  - Tidal marsh – Tidal marsh overlaps 432 ha
- Handling overlap is important for accurate accounts

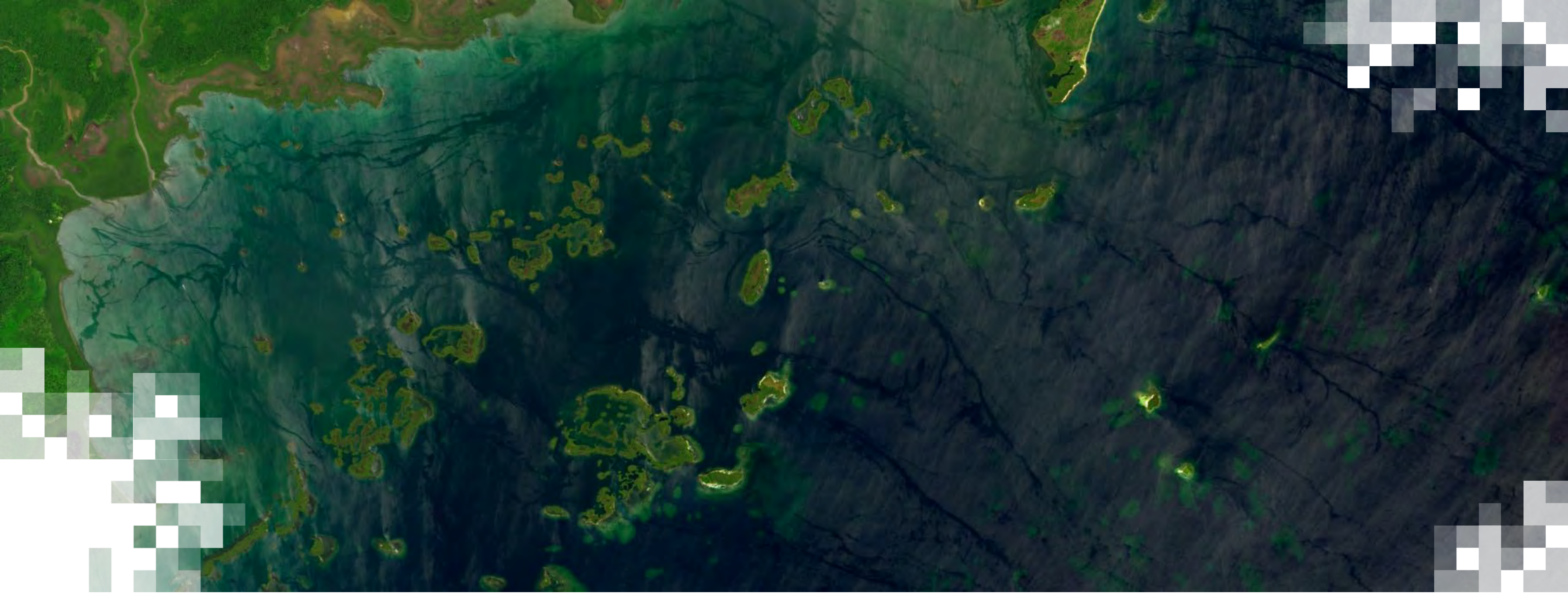
Spatial prediction of AGB and Soil



[Aboveground biomass](); [Soil Organic Carbon Data]()

Summary

- Introduced salt marsh ecosystems
- Discussed available global resources
- Salt marsh remote sensing needs
- Utilized Google Earth Engine for classification of salt marsh
- Reviewed carbon accounting approach



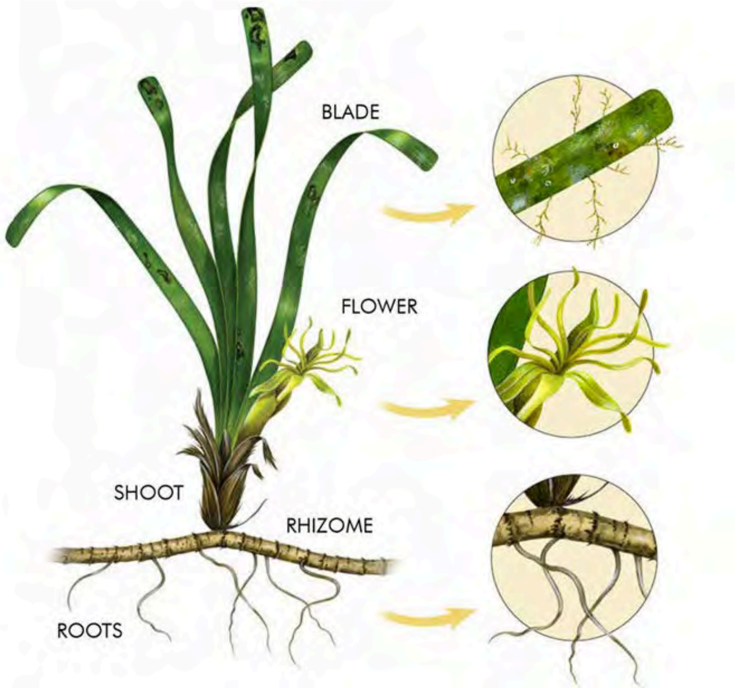
Beyond the Surface: Exploring Seagrass Mapping with Earth Observations

Outline

- Background
- Remote Sensing
- Demonstration in Google Earth Engine
- Key Takeaways

Background: What is seagrass?

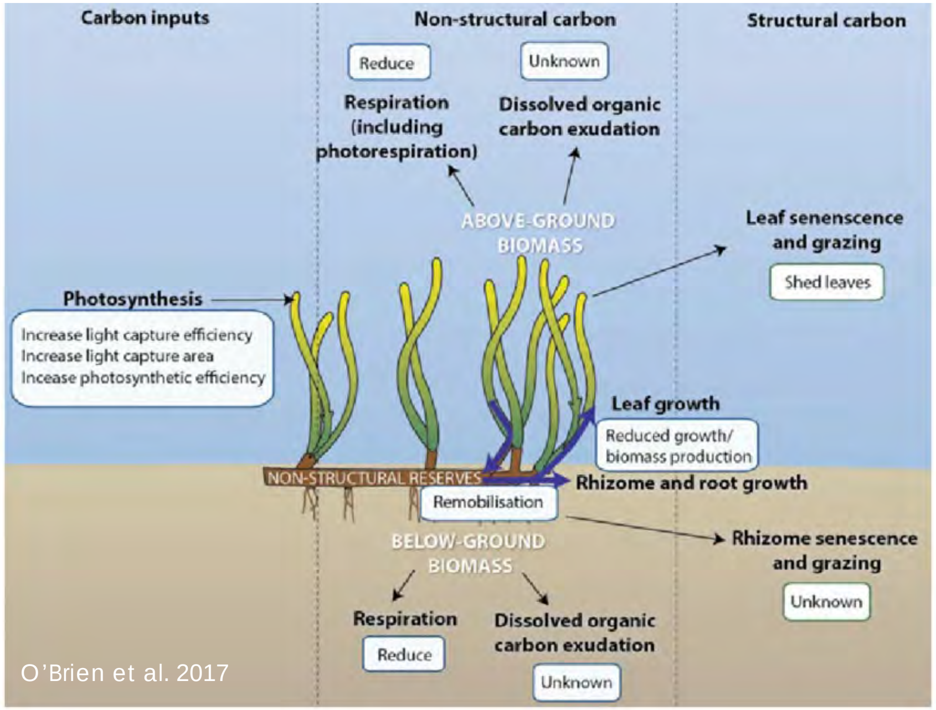
- Marine flowering plants
- Diverse species
- Ecosystem engineers
- Biodiversity hotspots



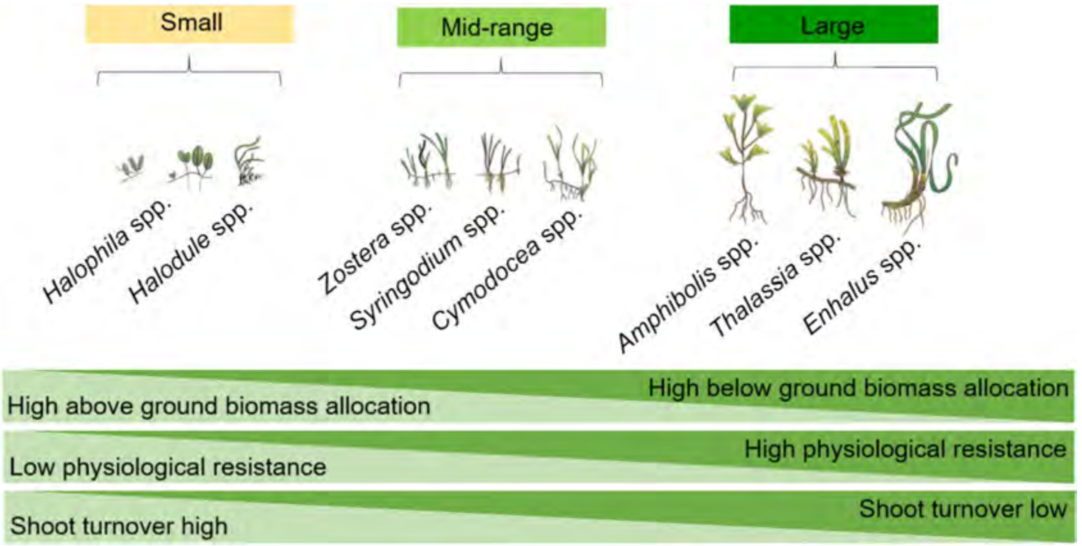
Dawn Witherington

Background: Carbon Sequestration

- ~10-18% Carbon Burial in Oceans
- Biomass primarily stored belowground
- Differences in Carbon Burial by Size and Environmental Conditions



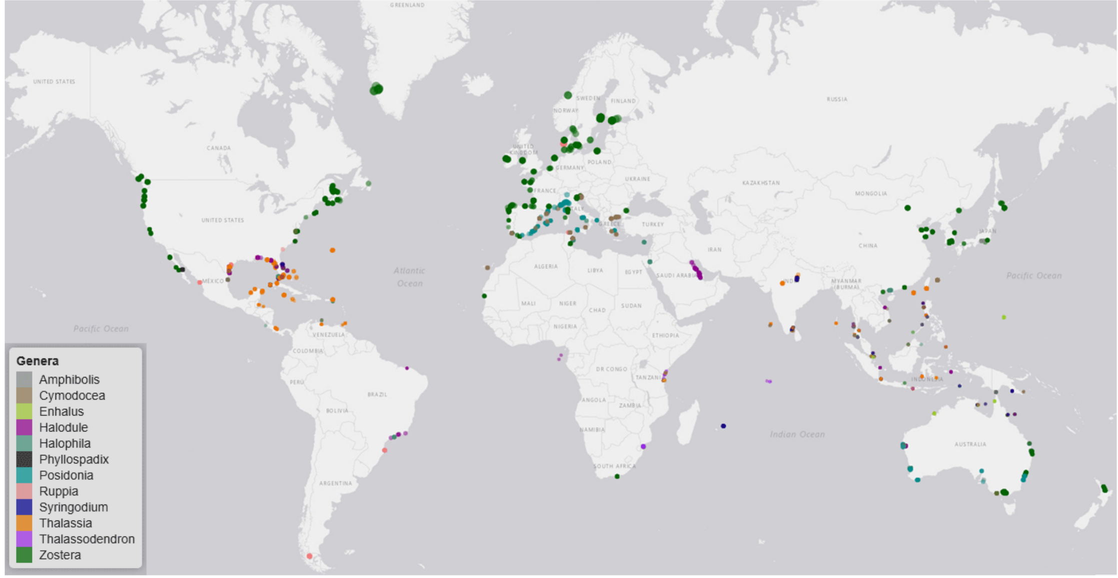
O'Brien et al. 2017

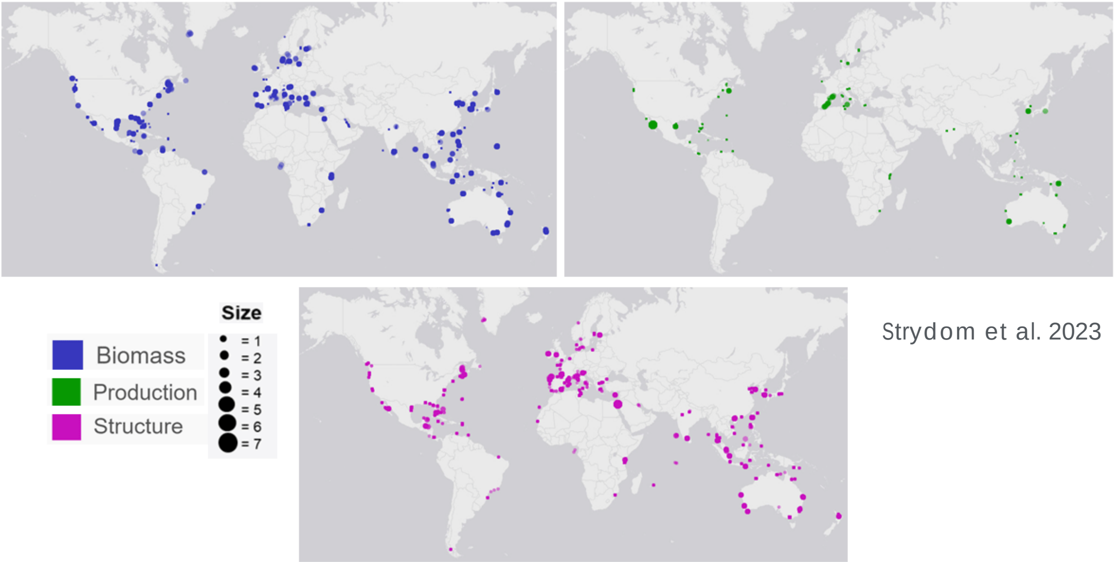


Ward et al. 2024

Background: Datasets Available

- Global Distribution of Seagrasses (UNEP-WCMC, Short FT, 2021)
- Meadow structure, biomass, and production (Strydom et al. 2023)

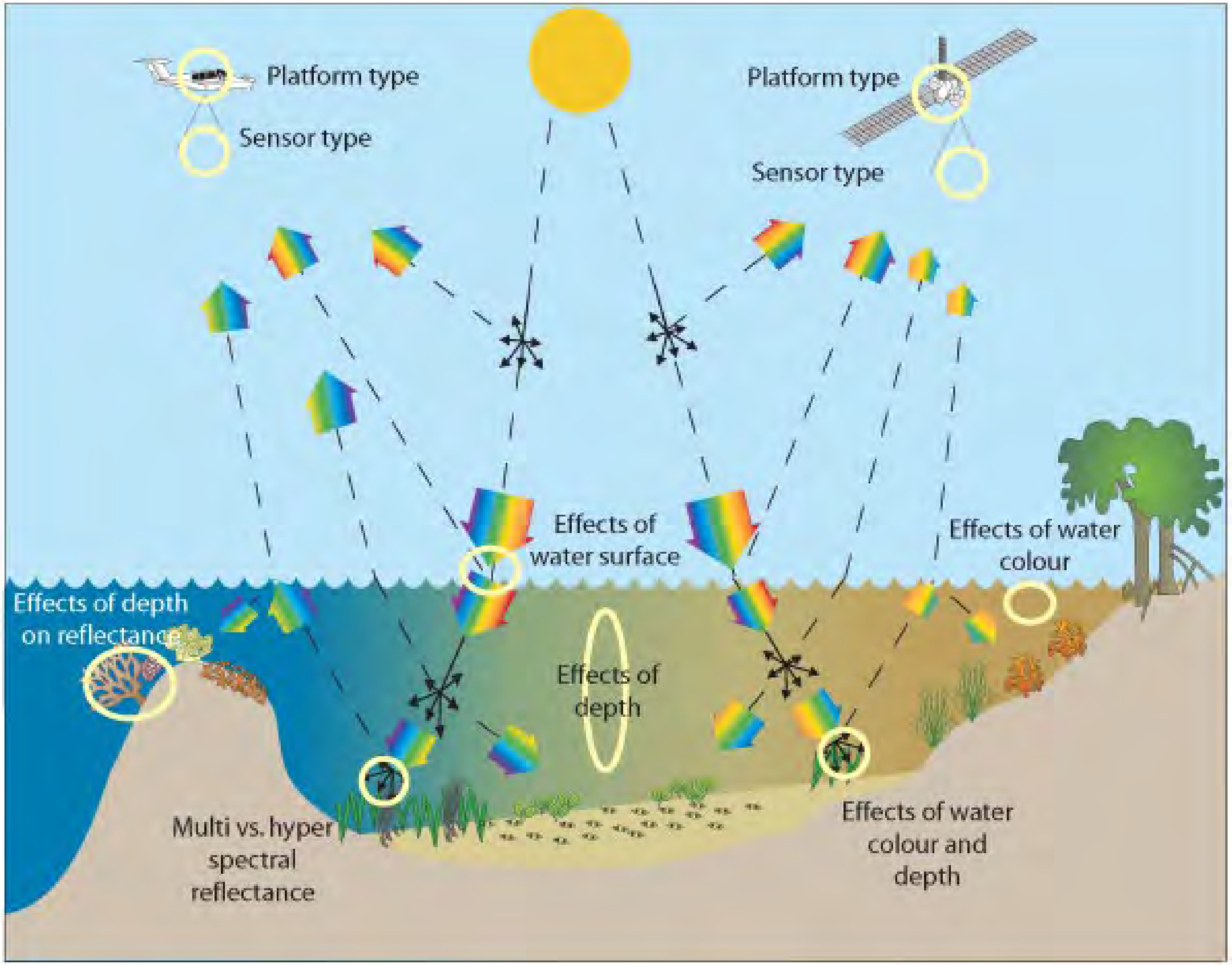




Strydom et al. 2023

Remote Sensing: Seagrass

- Passive, optical remote sensing
- Exposed canopy or low tide conditions ideal for seagrass detection
- Need to account for atmosphere and water column impacts



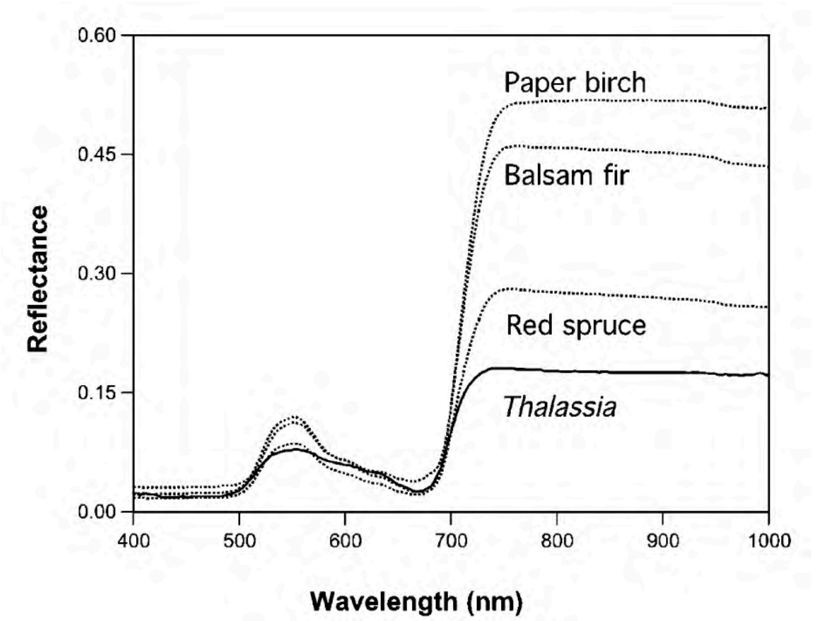
University of Queensland, Australia

Remote Sensing: Current and Upcoming Satellite Missions

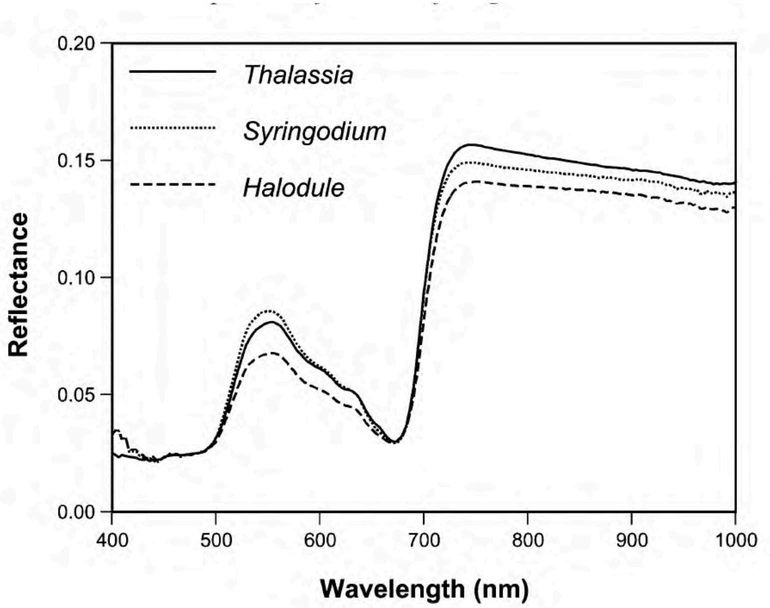
Mission	Availability	Sensors	Resolution
Landsat 7-9	1999-Present	Enhanced Thematic Mapper (ETM+), Operational Land Imager (OLI)	Multispectral, 185 km swath; 15 m, 30 m, 60 m; 16-day revisit
Sentinel 2 A/B/C	2015-Present	Multi Spectral Imager (MSI)	Multispectral, 290 km swath; 10 m, 20 m, 60 m, 5-day revisit
Surface Biology and Geology	No earlier than 2032	Visible to Shortwave Infrared (VSWIR)	Hyperspectral, 31-35 m, 16-day revisit

Remote Sensing: Spectral Resolution

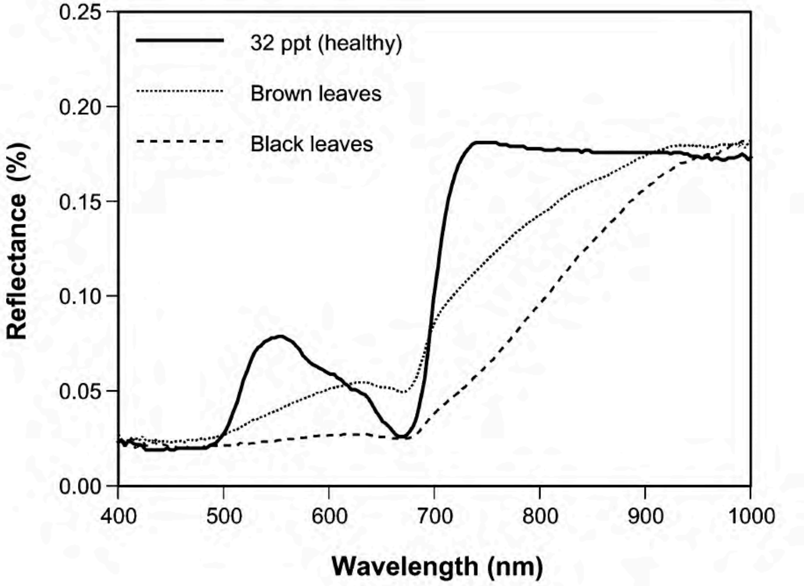
Aquatic versus Terrestrial Vegetation Targets



Subtle Species Differences

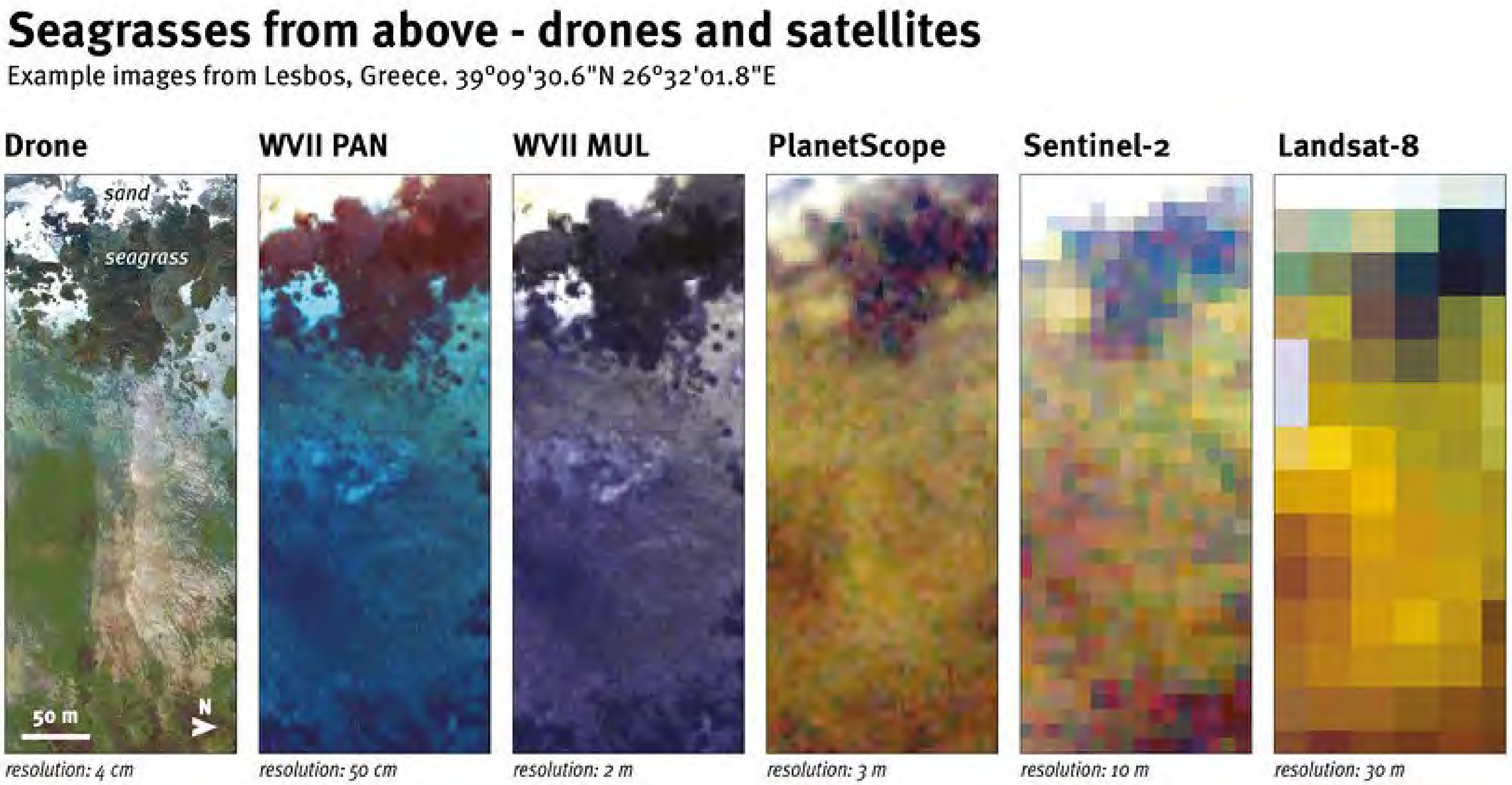


Differences between healthy and stressed leaves



Thorhaug et al. 2007

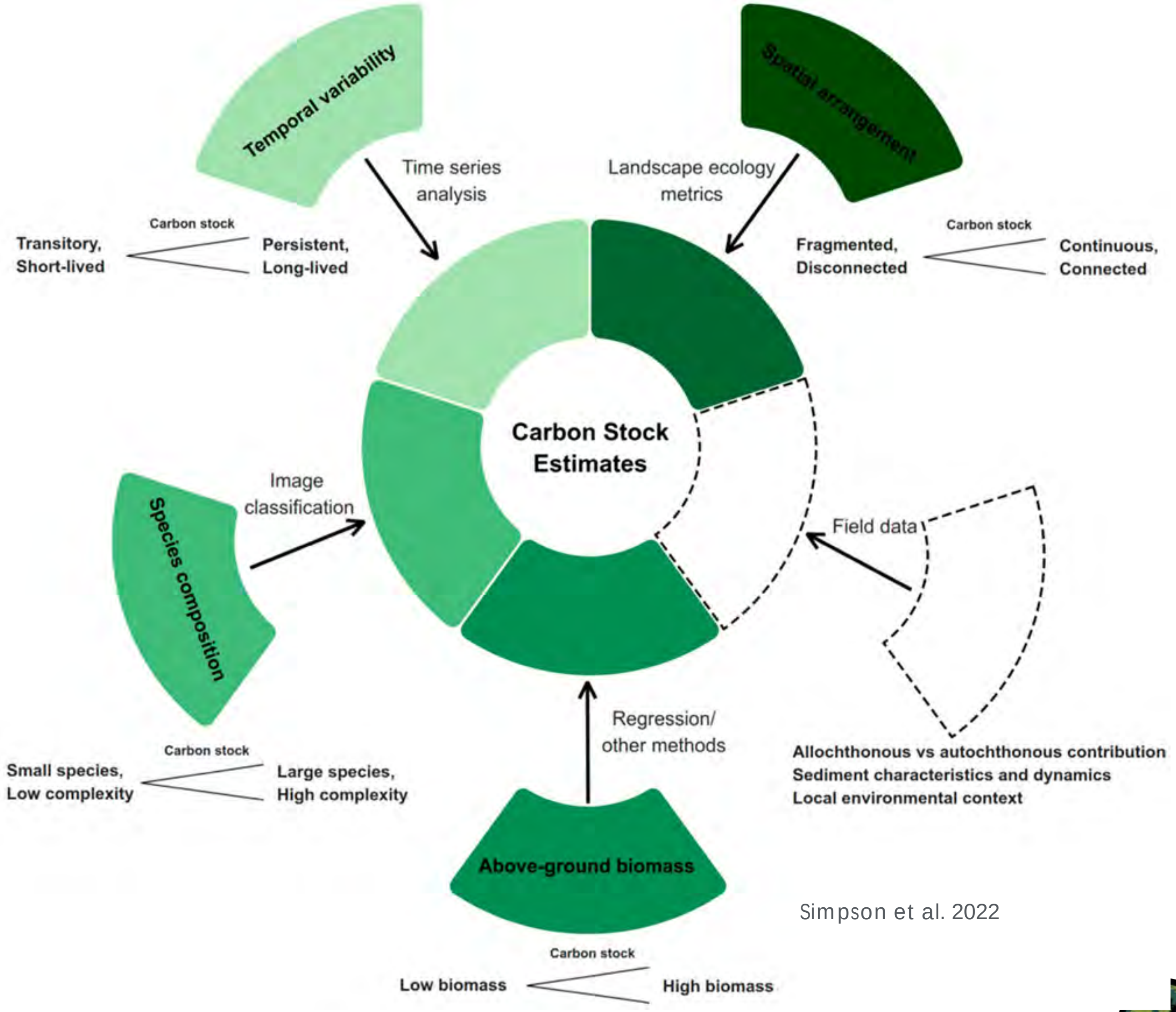
Remote Sensing: Spatial Resolution



Topouzelis et al. 2018

Remote Sensing - Proxies of Carbon Sequestration

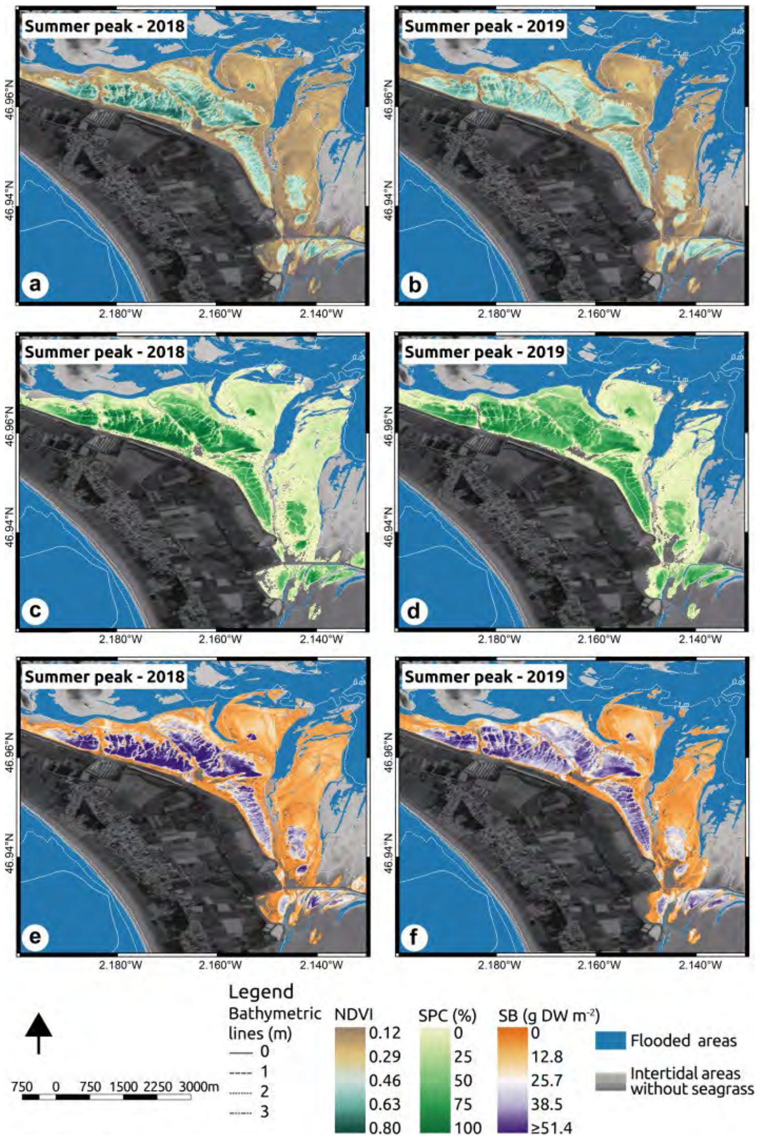
- Above-ground biomass & Spatial Arrangement – Normalized Difference Vegetation Index (NDVI), Leaf Area Index (LAI), and more!
- Composition – Image Classification via Enhanced Spectral Information
- Temporal Variability – Time Series Analysis



Simpson et al. 2022

Remote Sensing – Above Ground Biomass & Spatial Arrangement

- Region: European Atlantic Coast
- Species: *Zostera Noltei*
- Sensor: Sentinel 2 MSI
- Satellite Product: NDVI (NIR-Red)/(NIR+Red)
- Generated Products via In Situ Data: Seagrass Percent Cover (SPC) and Seagrass Leaf Biomass (SB)

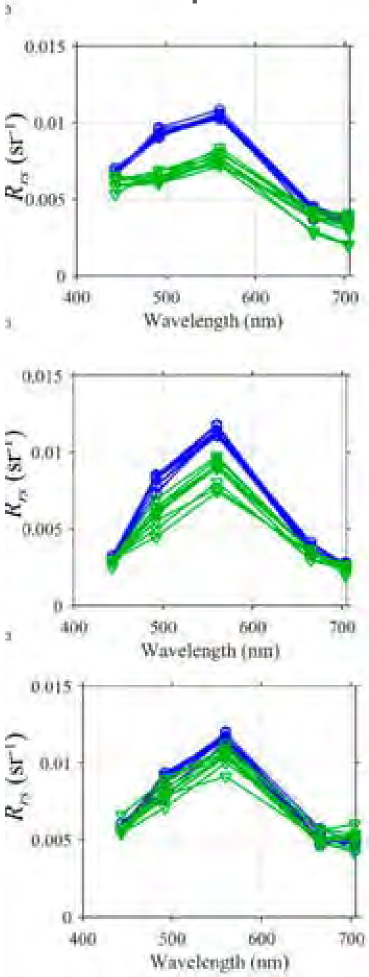


Zoffoli et al. 2020

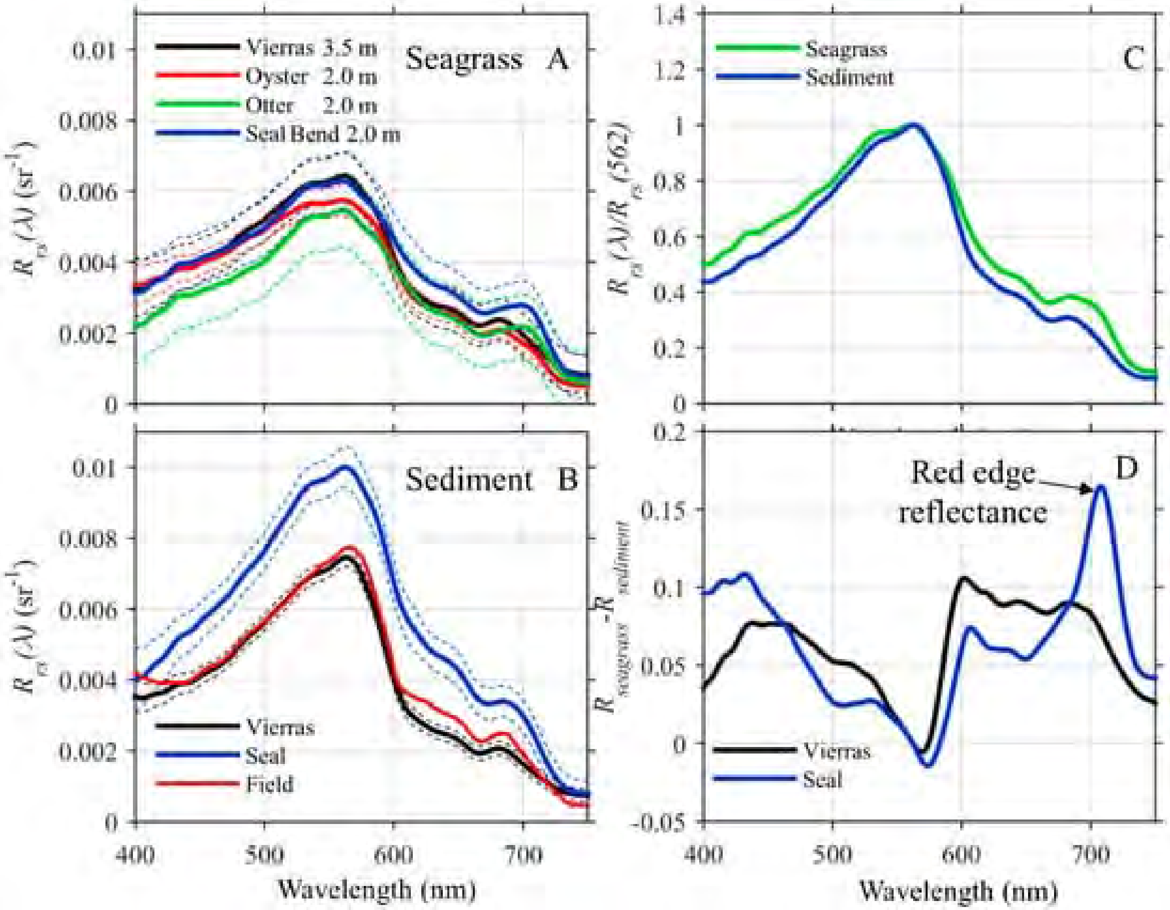
Remote Sensing – Composition

- Region: Elkhorn Slough, CA, USA
- Species: *Zostera marina*
- Sensor: Sentinel 2, PRISM (airborne)
- Satellite Product: Remote Sensing Reflectance

Multispectral



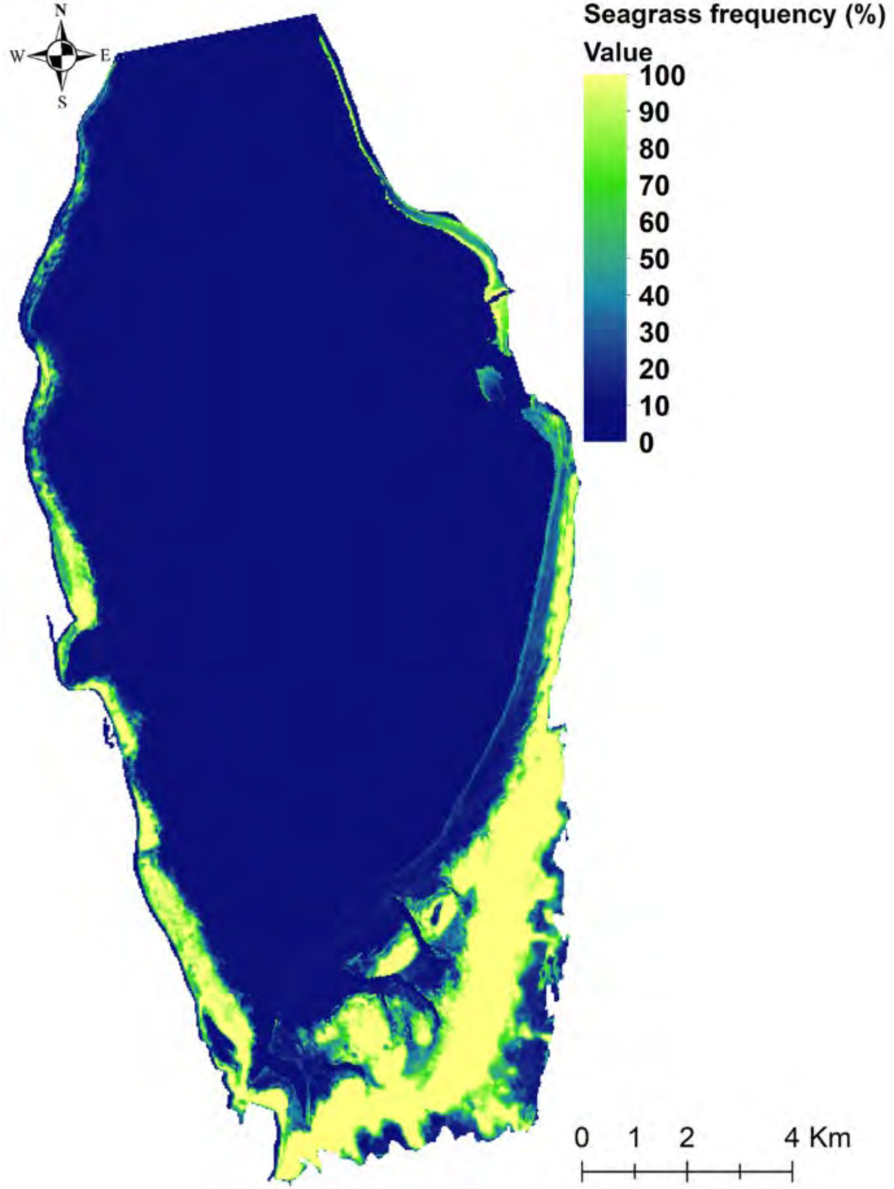
Hyperspectral



Dierssen et al. 2019

Remote Sensing – Temporal Variability

- Region: St. Joseph Bay, Florida, USA
- Species: *Thalassia testudinum, Halodule wrightii, Syringodium filiforme, Halophila spp.*
- Sensor: Landsat 5-8
- Satellite Product: Seagrass Presence and Extent
- Generated Products via In Situ Data: Leaf Area Index, Biomass Belowground Carbon



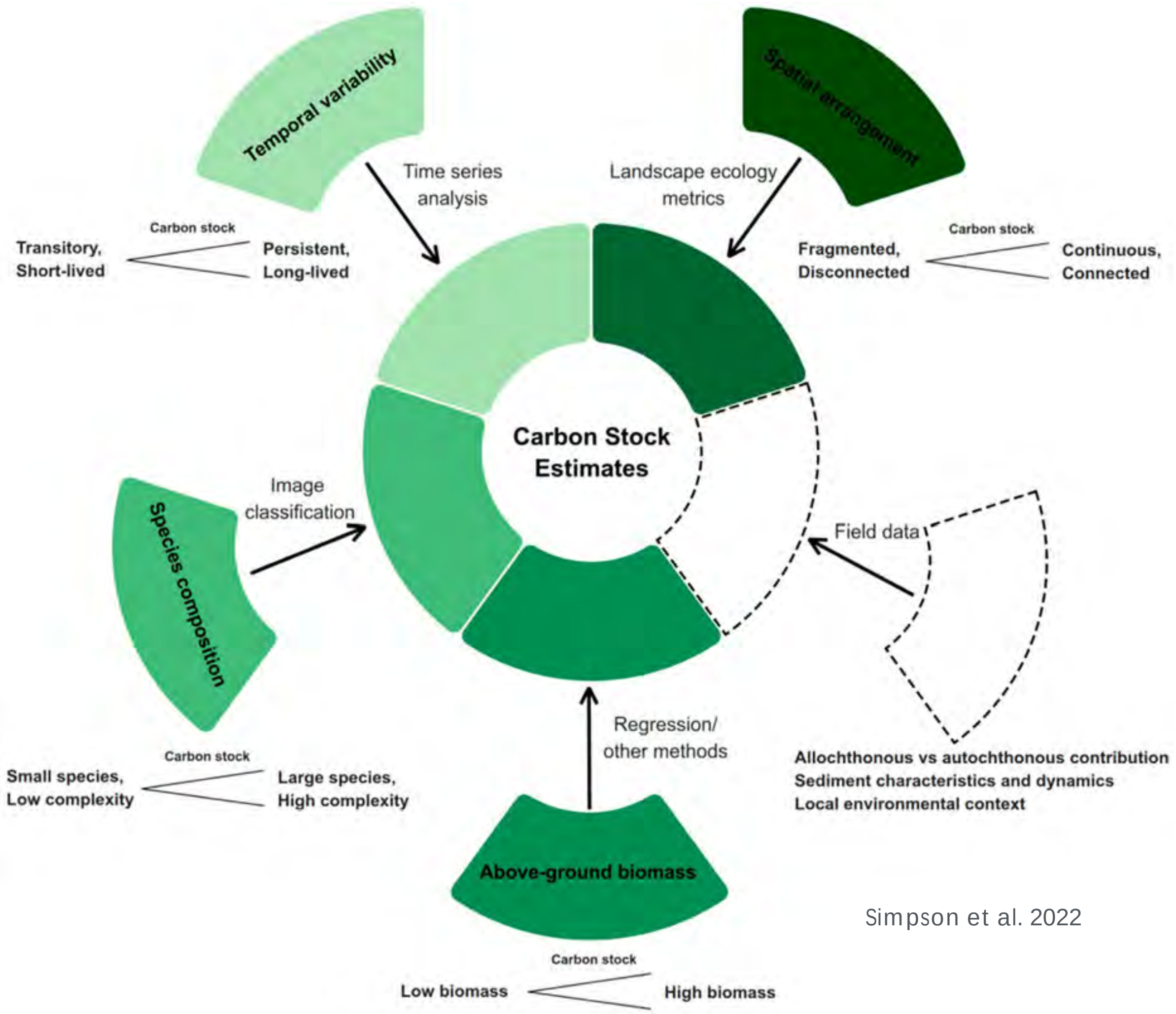
Lebrasse et al. 2022

Demonstration in Google Earth Engine

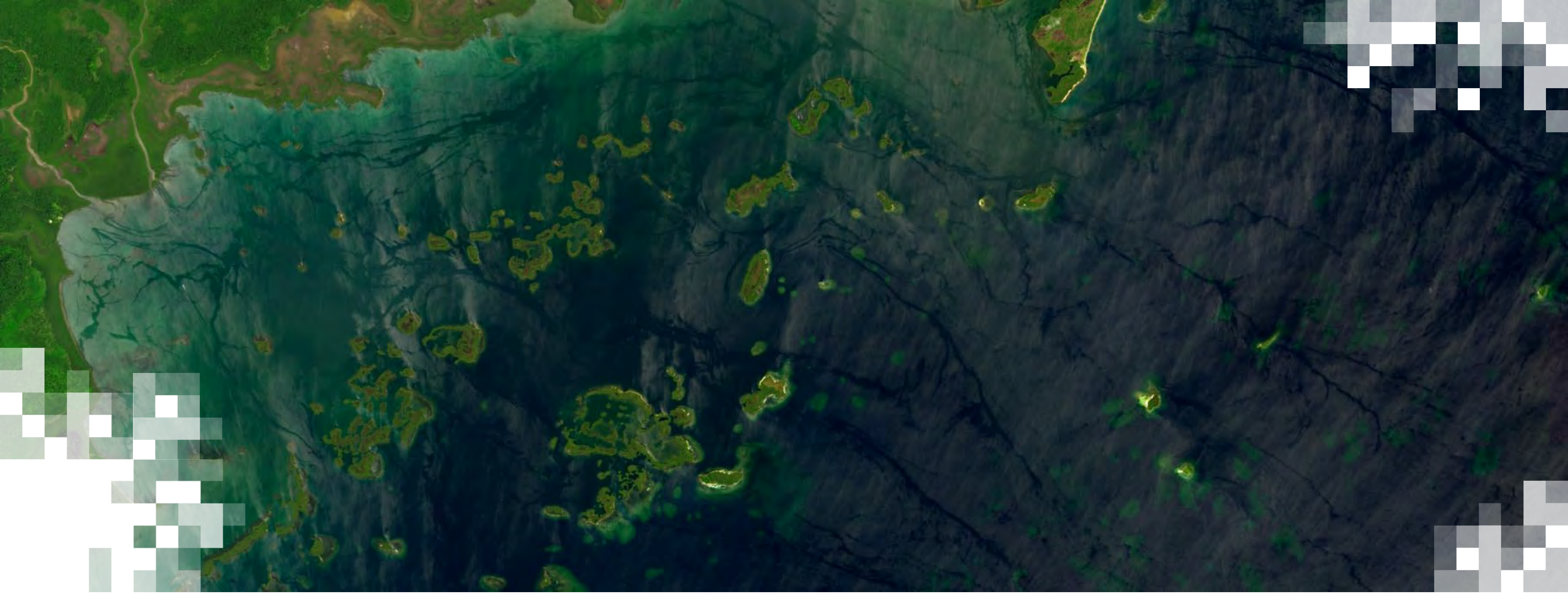
- Calculate seagrass area with Allen Coral Atlas
- Time Series Analysis with Sentinel 2

Key Takeaways

- Seagrass meadows are vital blue carbon ecosystems and are threatened by global climate change and anthropogenic activities
- Remote sensing tools have bee used to detect, quantify, and evaluate spatial and temporal dynamics of seagrass meadows
- Pairing field data of seagrass habitat and carbon dynamics with remote sensing observation is crucial for accurate seagrass carbon sequestration estimates



Simpson et al. 2022



Measuring Co-Occurrences of Blue Carbon Ecosystems

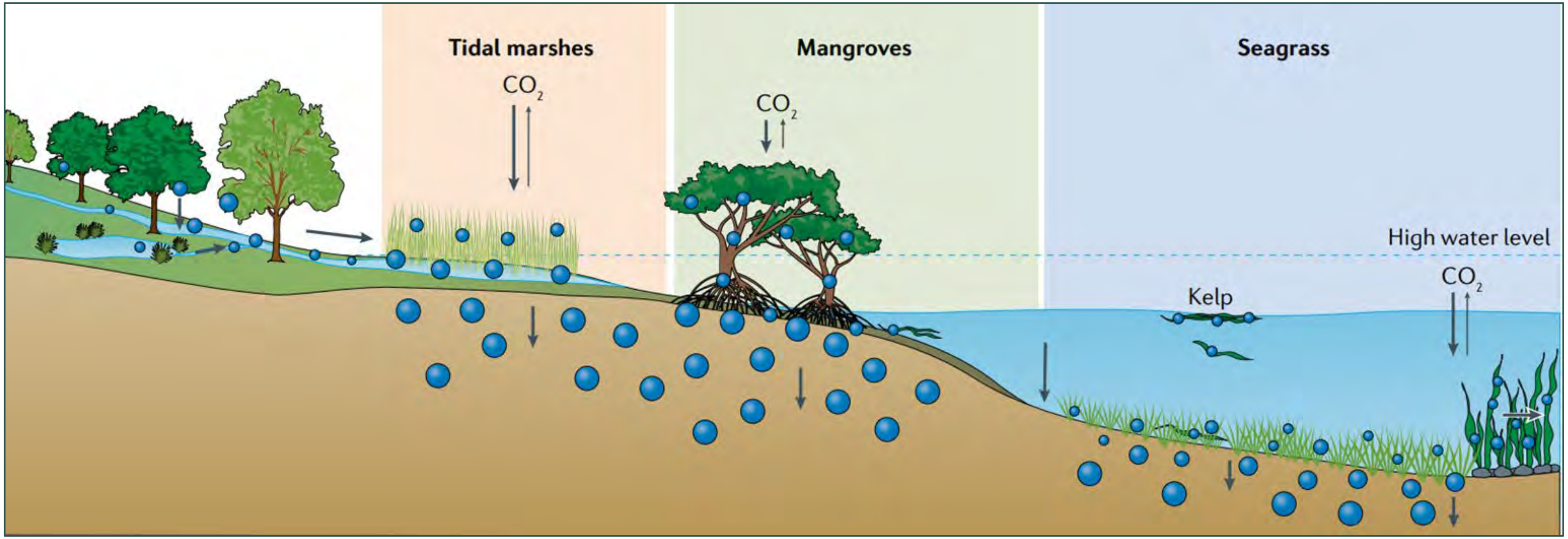
Learning Objectives

By the end of this presentation, you will

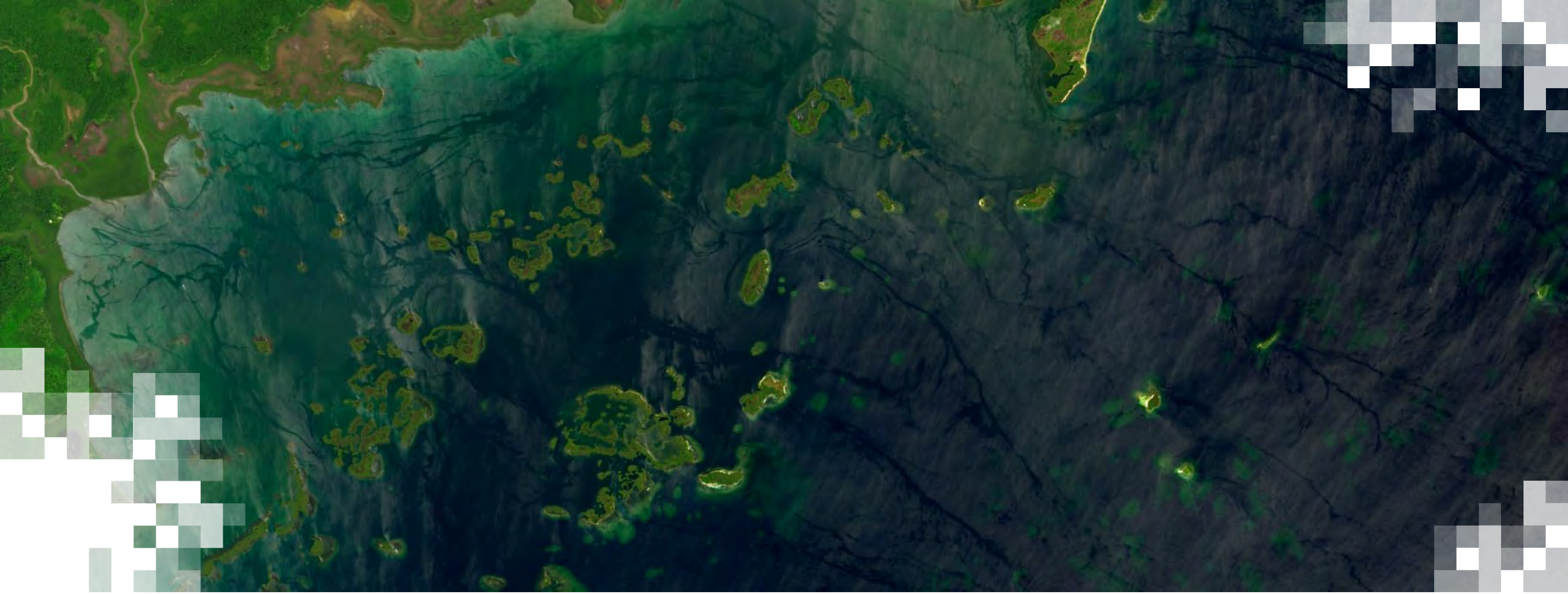
- Define a blue carbon ecosystem based on ecosystem characteristics
- Map the extent of mangrove ecosystems using satellite observations
    - Explore existing global datasets showing mangrove extent, canopy height and biomass
    - Use Google Earth Engine to generate mangrove extent data
- Calculate the carbon stock of mapped mangrove ecosystems
    - Apply basic criteria for accessing the suitability of data for your purposes
    - Estimate mangrove canopy height, biomass and carbon stocks in your area of interest
    - Evaluate data sources for a more precise mangrove ecosystem carbon stock estimate

Outline

1. How to synthesize blue carbon estimates across ecosystems
   – Importance of scope and scale
   – Merging maps and identifying overlap
2. Blue carbon reporting, monitoring, and accounting
   – Examples from a saltmarsh-mangrove ecotone
3. Combining methods for future blue carbon accounting

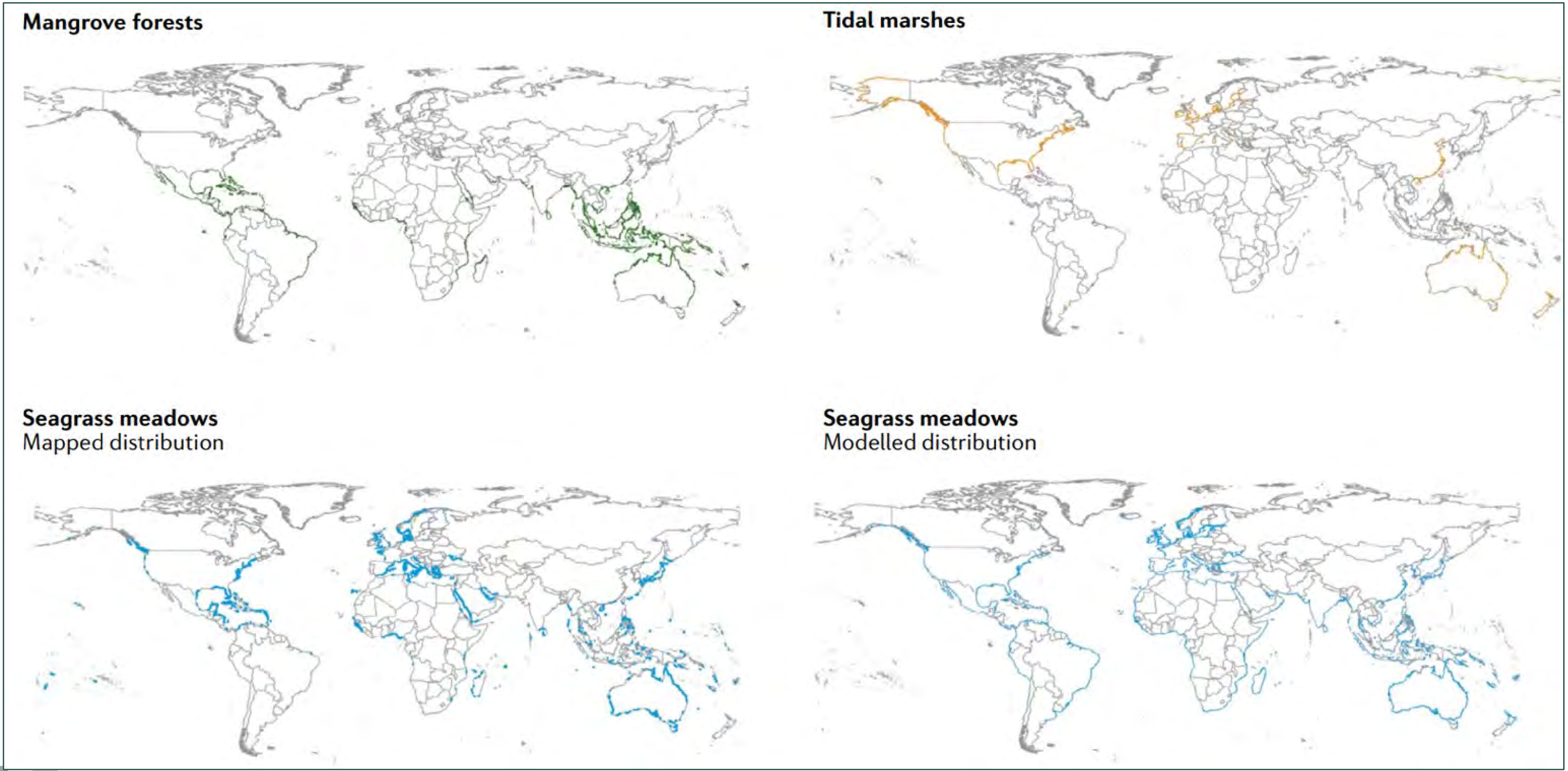


Macreadie et al. 2021. Blue carbon as a natural climate solution



How to Synthesize Blue Carbon Estimates Across Ecosystems

How to synthesize blue carbon estimates across ecosystems



Macreadie et al. 2021. Blue carbon as a natural climate solution

Global datasets for blue carbon ecosystems

Salt marsh

- Global 10 m map for 2020 (Worthington et al. 2023; Data)
- Global 30 m map of tidal marsh, tidal flats and mangroves 2000-2020 (Murray et al. 2022; Data)
- Global 30 m map of wetlands 2000-2022 (Zhang et al. 2024; Data)
- Global 30 m change and emissions from 2000-2019 (Campbell et al. 2022; Data)
- Global soil organic carbon map (Maxwell et al. 2024; Data).
- Global approach with Google Earth Engine for mapping tidal wetlands (https://zenodo.org/records/5968865 from Murray et al. 2022)

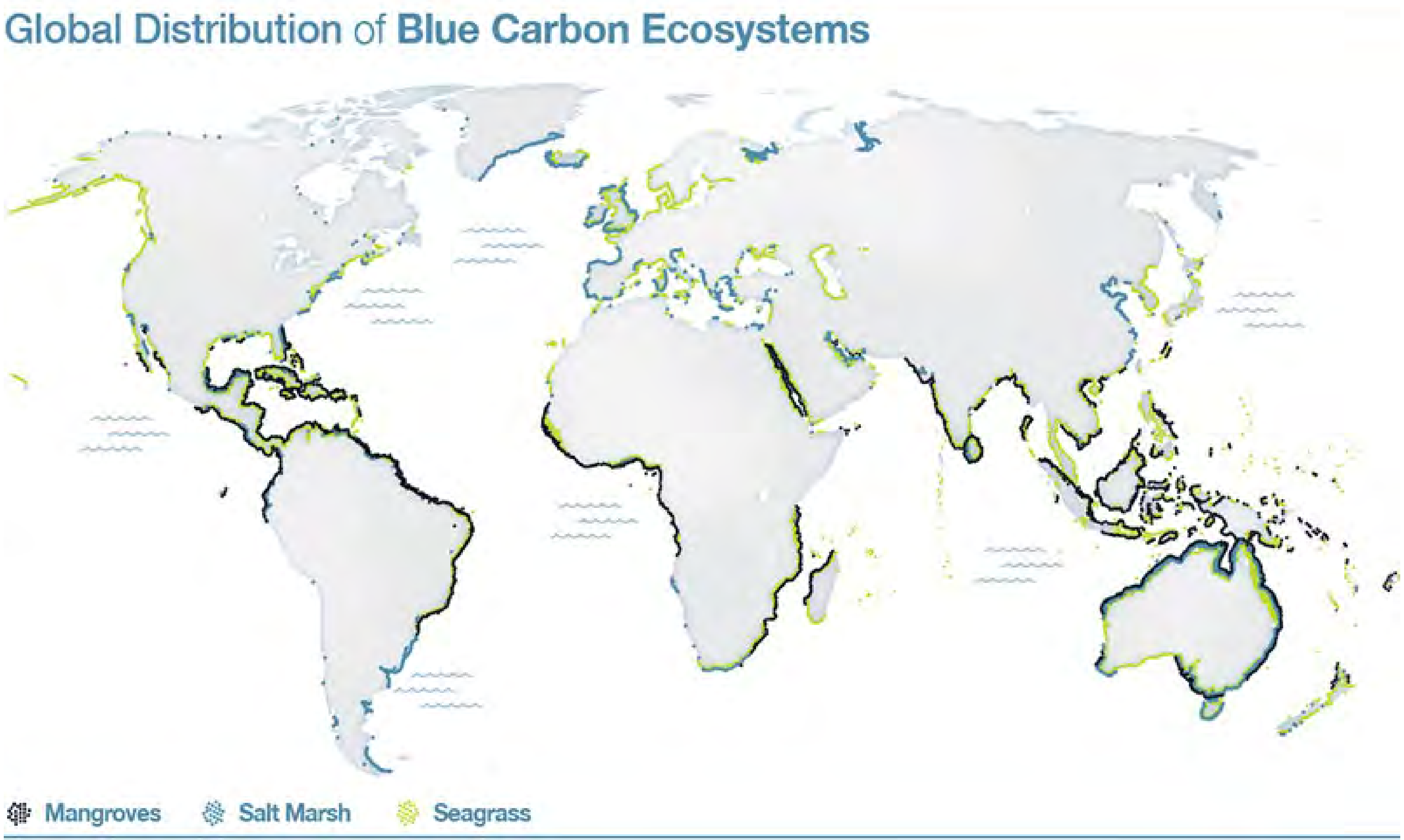
Mangrove

- Mangrove Forests of the World MFW, Giri et al. 2010
- Global Mangrove Watch GMW, Bunting et al. 2022
- Continuous Global Mangrove Forest Cover for the 21st Century GCMFC-21, Hamilton and Casey 2016
- Global Wetlands Distribution CIFOR
- Mangrove Atlas Spalding et al. 2010
- Aboveground Biomass Hutchison et al. 2014;
- Canopy Height and Biomass Simard et al. 2019 (data)
- Soil Organic C Sanderman et al. (2018); Rovai et al. (2018); Atwood et al. (2017)

Seagrass

- Global dataset on seagrass meadow structure, biomass and production, Strydom et al. 2022
- UNEP WCMC Global distribution of Seagrasses, Green and Short 2003

Merging maps and identifying overlap



The Blue Carbon Initiative

Merging maps and identifying overlap

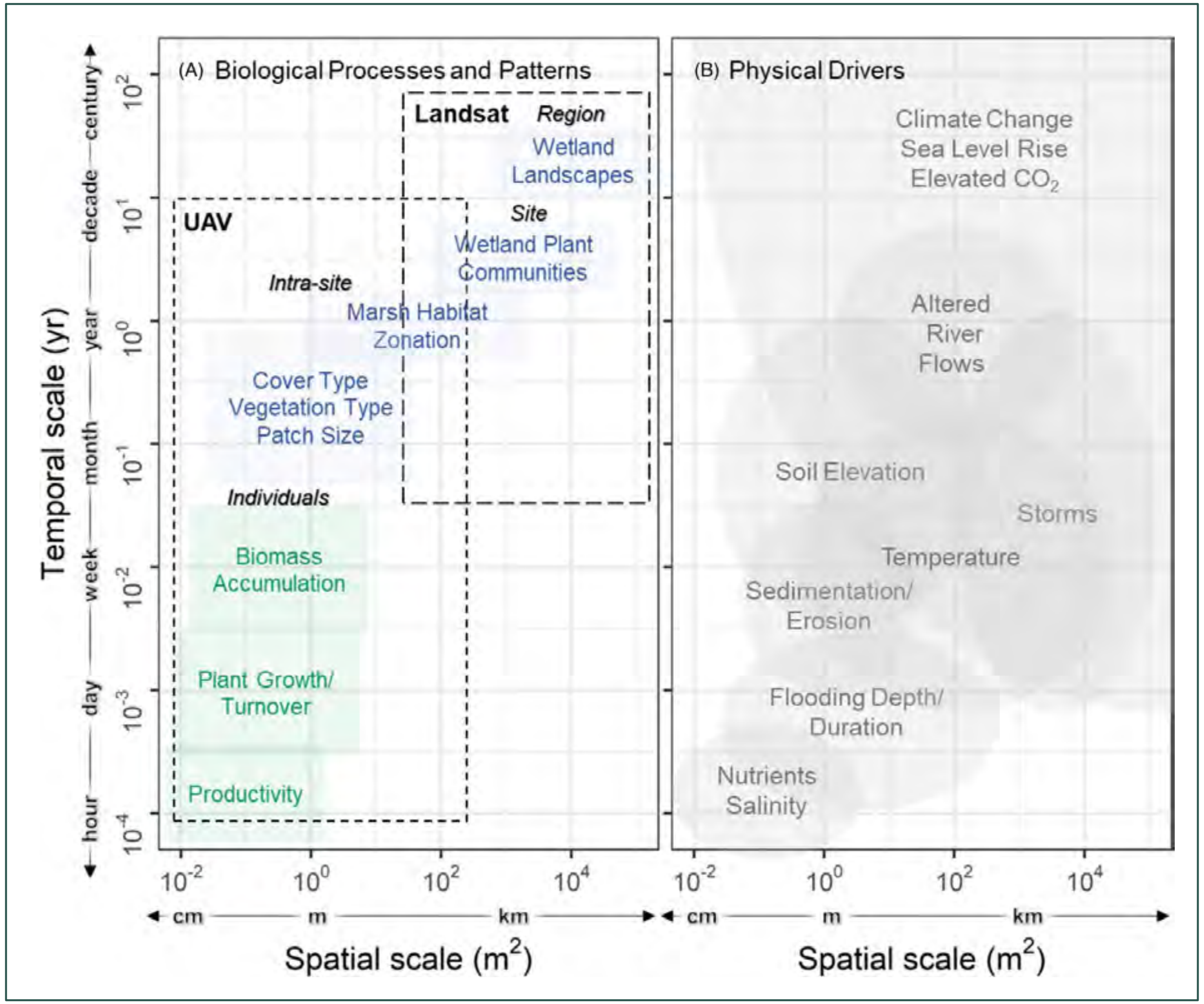
- Advantages and disadvantages of existing global maps

- Merging existing maps and identifying overlap is a good start to
  - Test existing data for your needs, questions, study
  - Identify needs in spatial data and/or data resolution
  - Cater mapping approaches to co-existing blue C ecosystems

How to synthesize blue carbon estimates across ecosystems

The Importance of Scope and Scale

- The scope of the study domain
- Tradeoffs in spatial, temporal, and spectral resolution
- Scope of analysis
  - What data is available?
  - What blue carbon metric is measured?
  - What drivers are important?



Doughty et al. 2021. RSEC

The Importance of Scope and Scale

Maxar WorldView-2 18 January 2022	PlanetScope SuperDove 29 January 2022	ESA Sentinel-2 18 January 2022	NASA/USGS Landsat-8 15 January 2022

Maxar WorldView-2

Spectral Region	Wavelengths (nm)	Resolution (m)
Coastal	400 - 450	1.85
Blue	**450 - 510**	**1.85**
Green	**510 - 580**	**1.85**
Yellow	585 - 625	1.85
Red	**630 - 690**	**1.85**
Red edge	705 - 745	1.85
NIR1	**770 - 895**	**1.85**
NIR2	860 - 1040	1.85

PlanetScope SuperDove

Spectral Region	Wavelengths (nm)	Resolution (m)
Coastal	431 - 452	3
Blue	465-515	**3**
Green I	513-549	3
Green	**547-583**	**3**
Yellow	600-620	3
Red	650-680	**3**
Red edge	697-713	3
NIR	845-885	**3**

ESA Sentinel-2

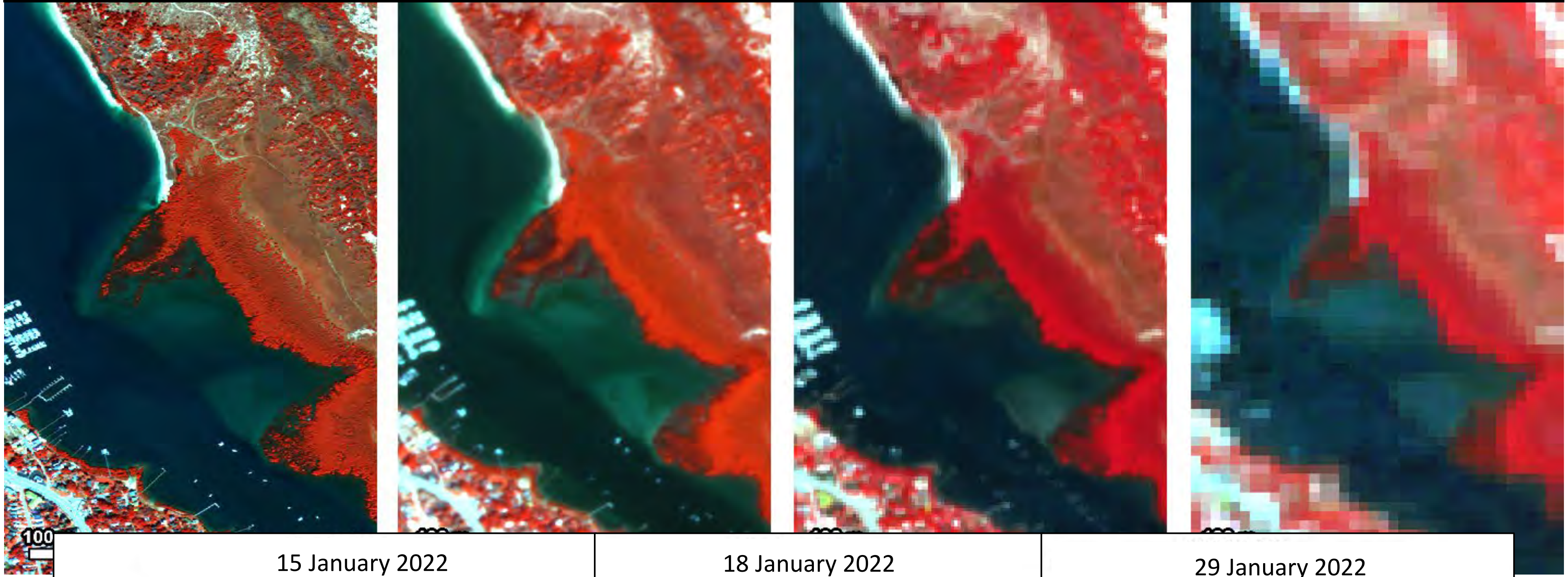
Spectral Region	Wavelengths (nm)	Resolution (m)
Coastal	433-453	60
Blue	**458-523**	**10**
Green	**543-578**	**10**
Red	**650-680**	**10**
Red edge	698-713	20
Red edge	733-748	20
Red edge	773-793	20
NIR	**785-899**	**10**
NIR	855-875	20
SWIR/Water	9435-955	60
SWIR/Cirrus	1360-1390	60
SWIR	1565-1655	20
SWIR	2100-2280	20

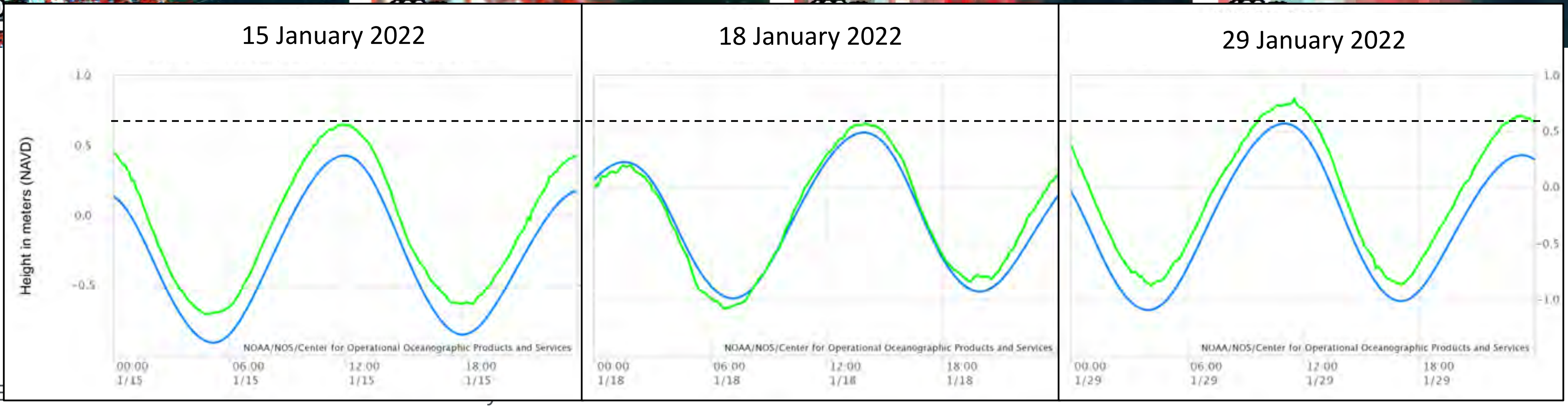
NASA/USGS Landsat-8

Spectral Region	Wavelengths (nm)	Resolution (m)
Coastal	433-453	30
Blue	**450-515**	**30**
Green	**525-600**	**30**
Red	**630-680**	**30**
NIR	**845-885**	**30**
SWIR/Cirrus	1360-1390	30
SWIR	1560-1660	30
SWIR	2100-2300	60
Pan	500-6800	15

The Importance of Scope and Scale

Maxar WorldView-2 18 January 2022	PlanetScope SuperDove 29 January 2022	ESA Sentinel-2 18 January 2022	NASA/USGS Landsat-8 15 January 2022





How to synthesize blue carbon estimates across ecosystems

Adapting supervised learning approaches to co-existing blue ecosystems

INPUTS

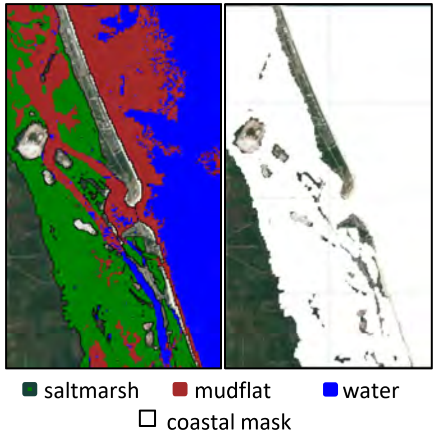
Satellite Data

Worldview-2, Planet Superdove, Sentinel-2, Landsat

Cloud-free images or composites, Orthorectified, optically calibrated to surface reflectance

Coastal AOIs

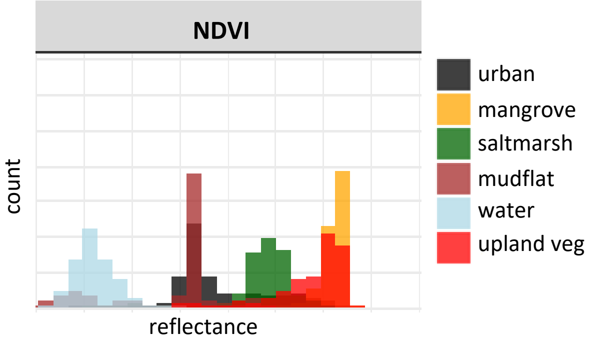
Global Coastal layers (30m), elevation, distance to shore



Training Data

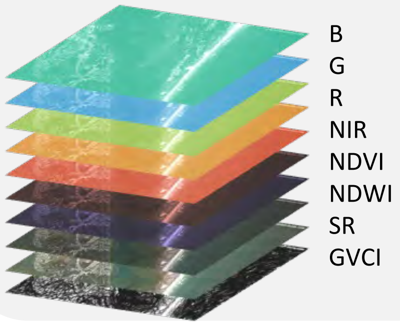
n samples per habitat class, randomly stratified samples per habitat class

Trainer verified



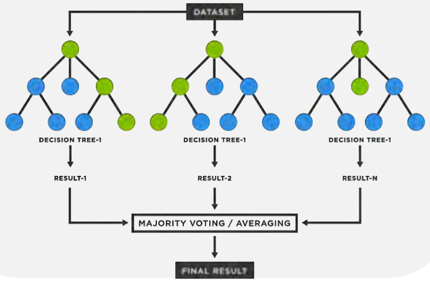
CLASSIFICATION

Band & Indices Selection

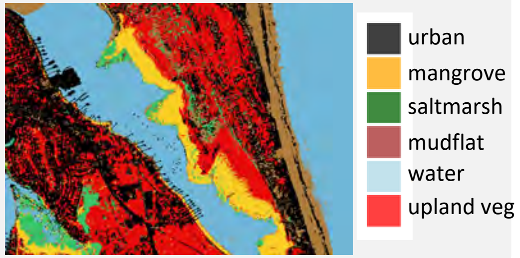


Classification Algorithm

RF, XGBoost, K-NN, Neural Net



Landcover Prediction



Cleaned, Accuracy assessed

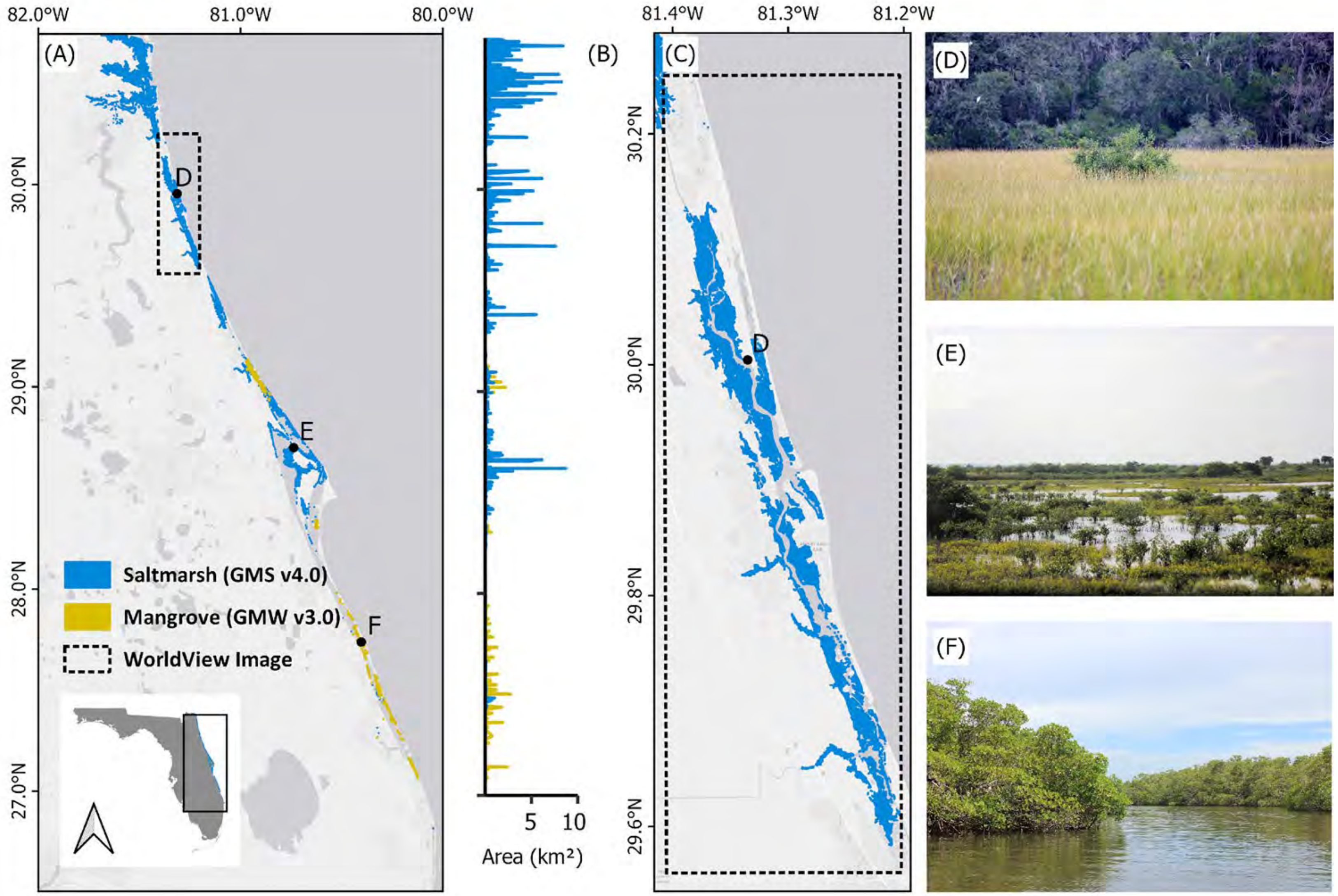
How to synthesize blue carbon estimates across ecosystems

Examples from a salt marsh-mangrove ecotone

Merging maps and identifying overlap

Examples from a salt marsh-mangrove ecotone

- Ecotone = a transitional area
- Sensitive to environmental change
- Mangrove expansion with warming climate
- At the leading edge of range limit,
  - Fine-scale changes in blue C habitats
  - Changes outpacing detection with current EO



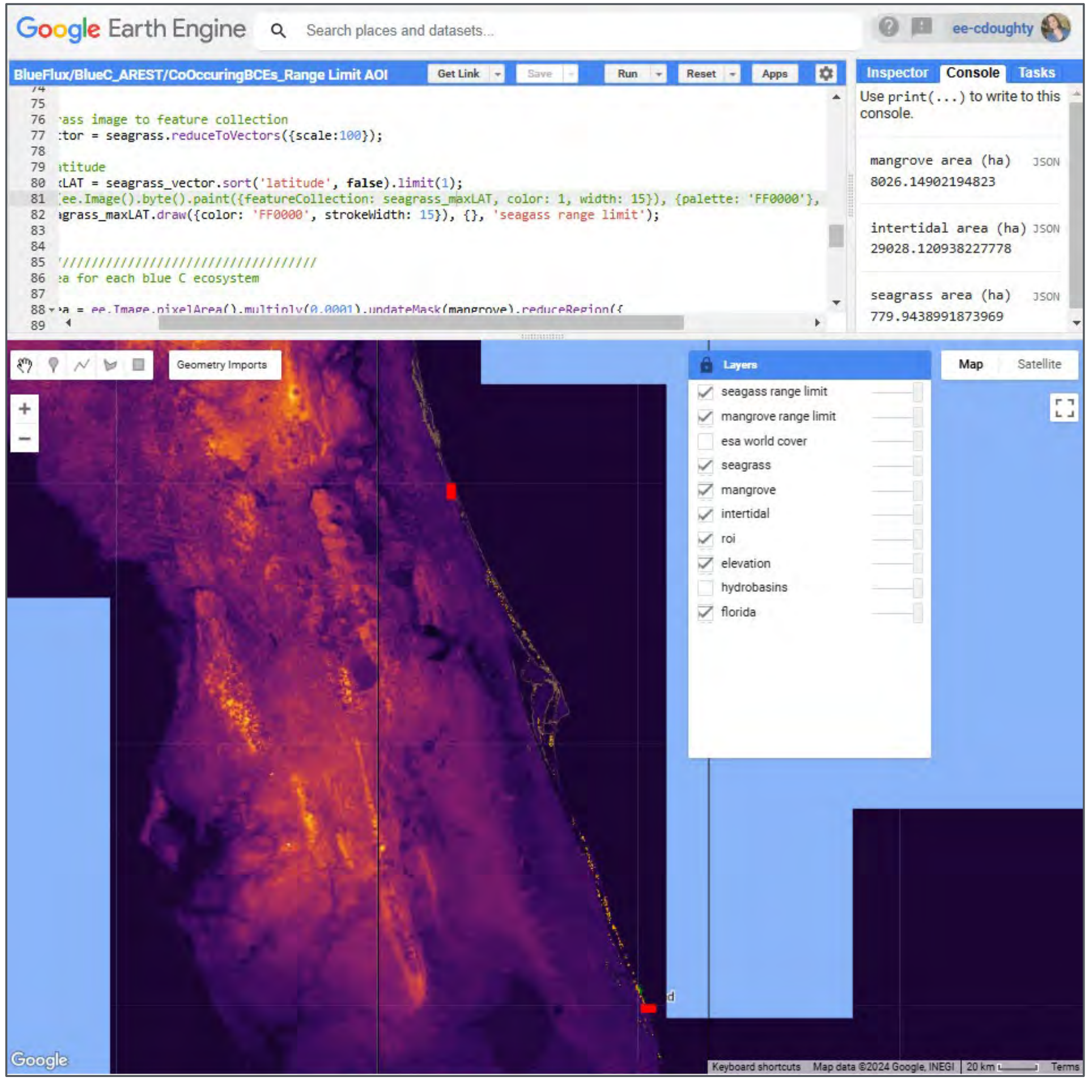
Doughty et al. 2024. RSEC

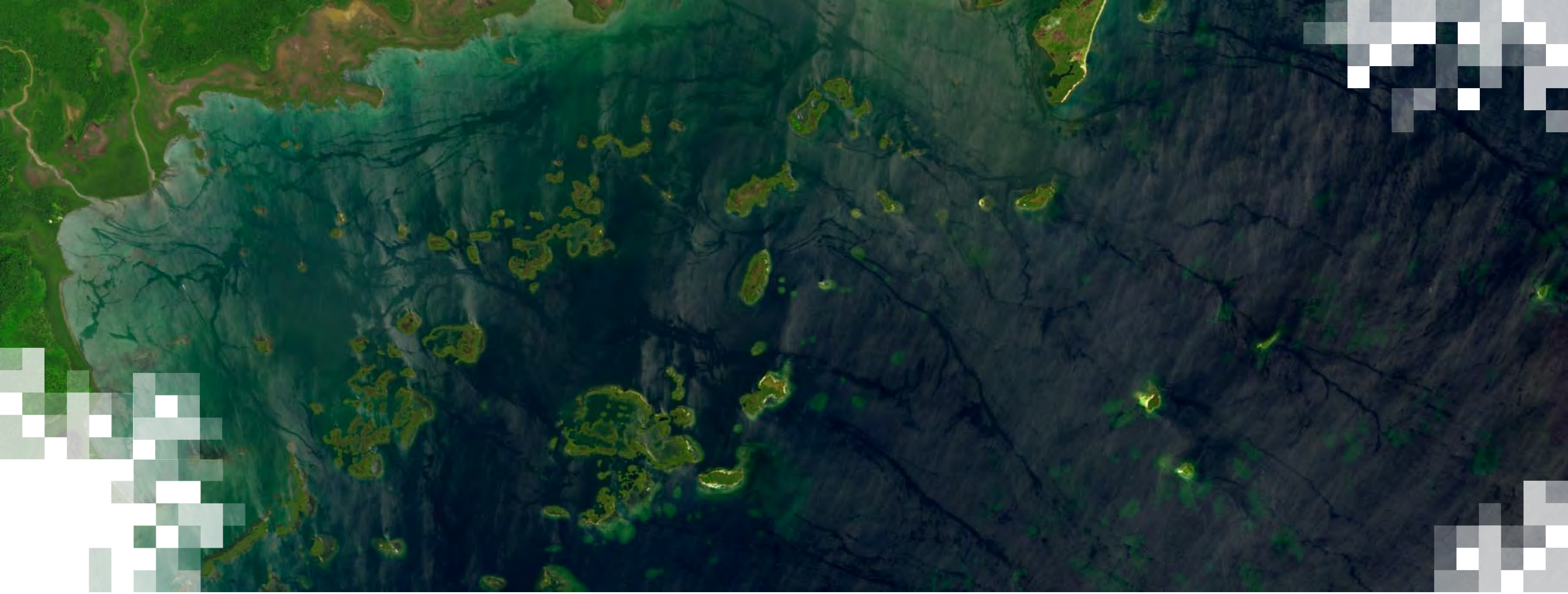
Merging maps and identifying overlap

GEE DEMO

[Link to GEE script]

1. Set the scene
   – Import helpful underlying ancillary data
2. Define your region of interest (ROI)
   – Draw a geometry to begin exploring
3. Import blue C layers
   – GEE assets or upload your own
4. Identify the limits of blue C ecosystems
5. Extract blue C system extents
6. Optional Exercises

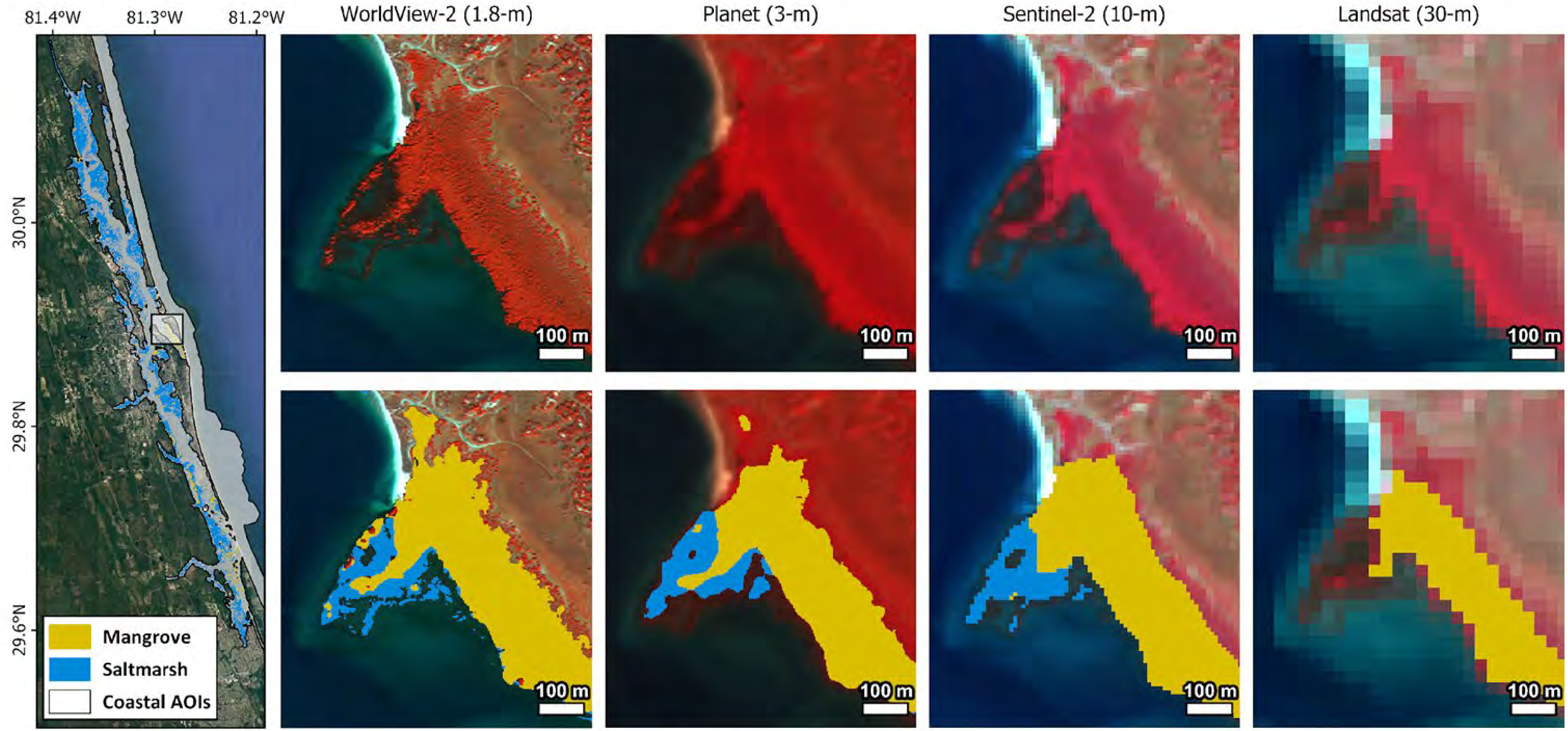




Blue Carbon Reporting, Monitoring, and Accounting

Blue carbon reporting, monitoring, and accounting

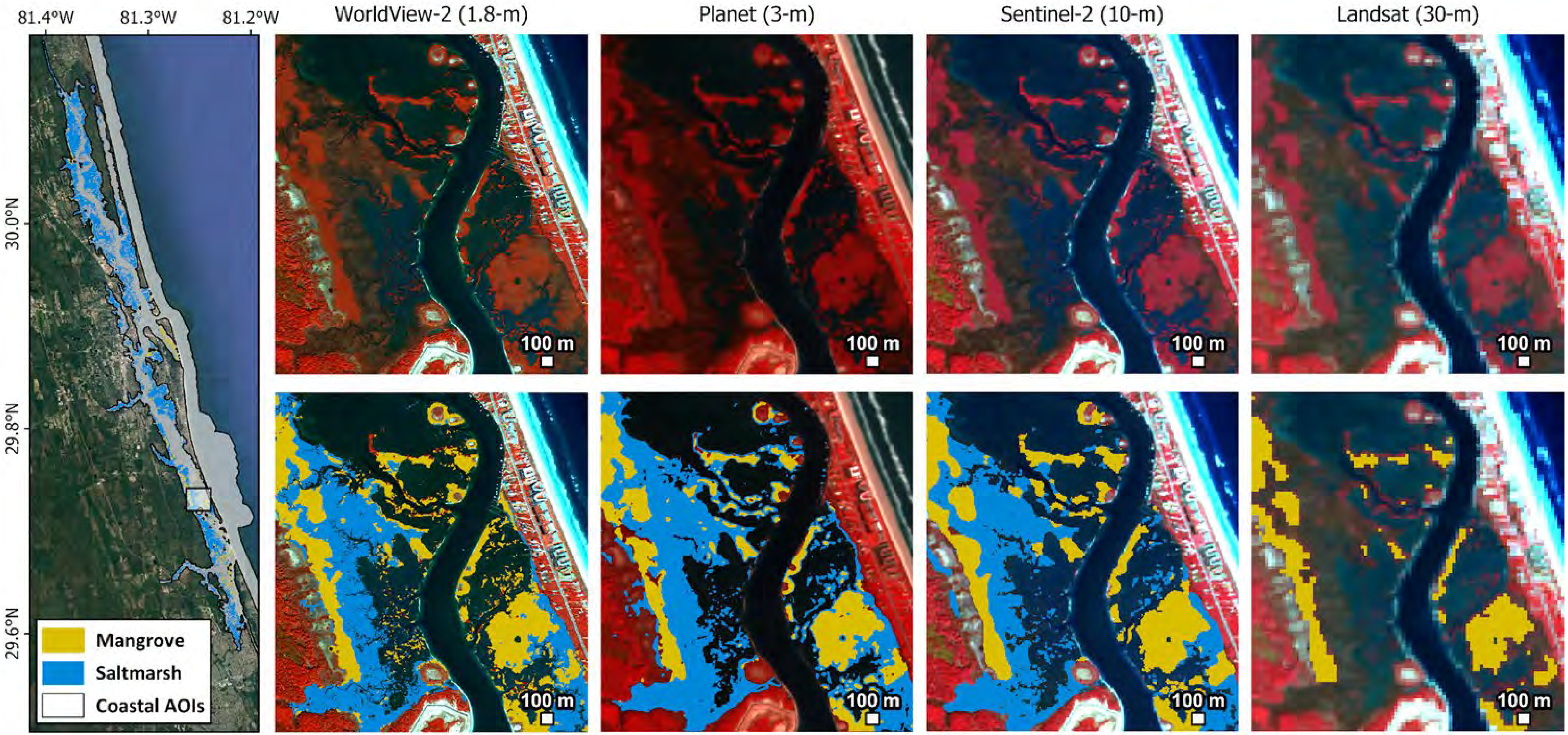
Examples from Florida's mangrove-saltmarsh ecotone



Doughty et al. 2024. RSEC

Blue carbon reporting, monitoring, and accounting

Examples from Florida's mangrove-saltmarsh ecotone



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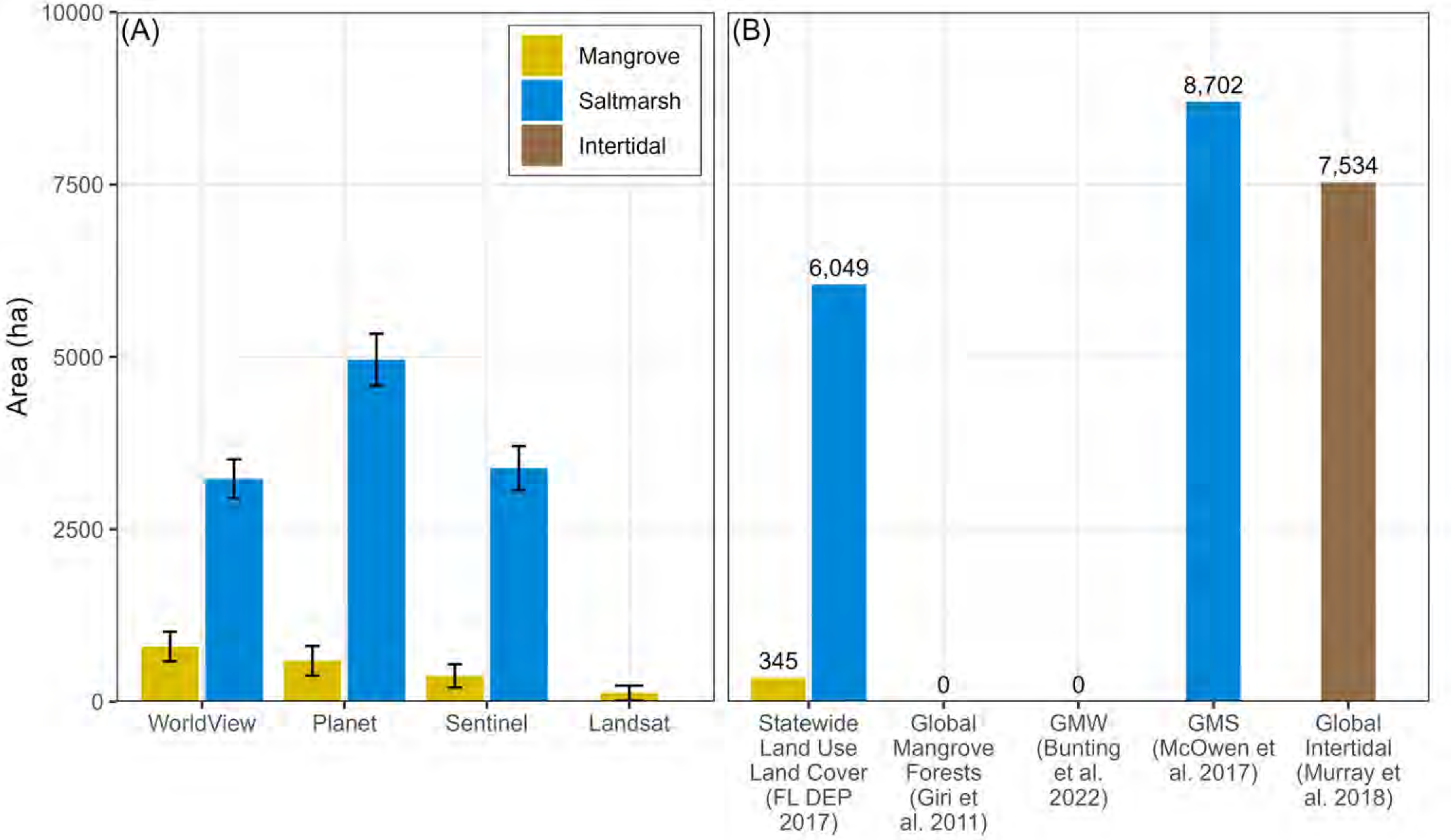
Blue carbon reporting, monitoring, and accounting

Examples from Florida's mangrove-saltmarsh ecotone



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Blue carbon reporting, monitoring, and accounting

Examples from Florida's mangrove-saltmarsh ecotone

$$Carbon\ Stock = Area\ (ha) * Carbon\ per\ ha$$

- Tier 1 global estimates:
  Alongi. 2020. Carbon Balance in Salt Marsh and Mangrove Ecosystems: A Global Synthesis.

Mangrove
739
Mg C_{ORG} ha^{-1}

Salt Marsh
334
Mg C_{ORG} ha^{-1}

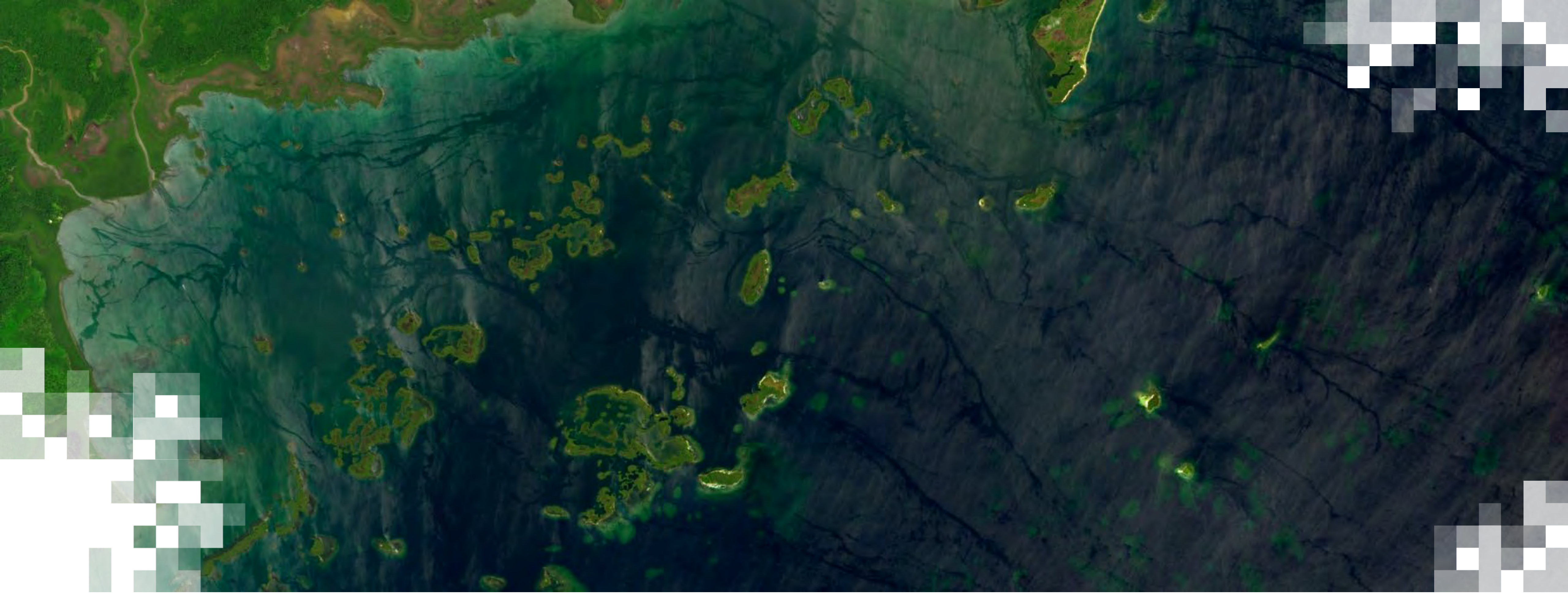
	WorldView (1.8 m)	Sentinel (10 m)
Mangrove (Tg C)	0.59 ± 0.16	0.28 ± 0.13
Tidal marsh (Tg C)	1.08 ± 0.09	1.13 ± 0.11
Total Blue C (Tg)	1.67 ± 0.25	1.41 ± 0.24

Key considerations for mapping ecosystems

The mapping objective may impact the "tier" of data required

Excerpts from IPCC (2003) Good Practice Guidance for LULUCF, Ch. 3

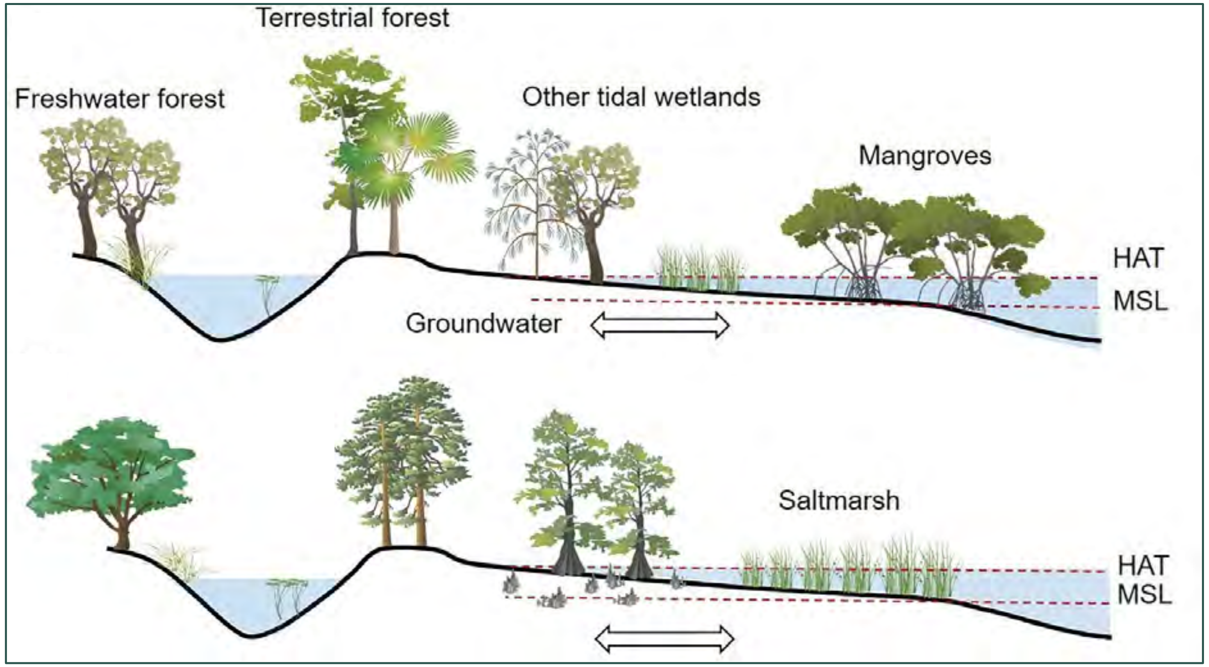
Tier 1 Use of default / Global data	Methodologies usually use activity data that are spatially coarse, such as nationally or globally available estimates.
Tier 2 Use of country-specific data	Tier 2 applies emission factors and activity data which are defined by the country; Higher resolution activity data are typically used
Tier 3 Use of advanced methods and detailed country-specific data	Tier 3 – including models and inventory measurement systems tailored to address national circumstances, repeated over time, and driven by high resolution activity data and disaggregated at sub-national to fine grid scales.



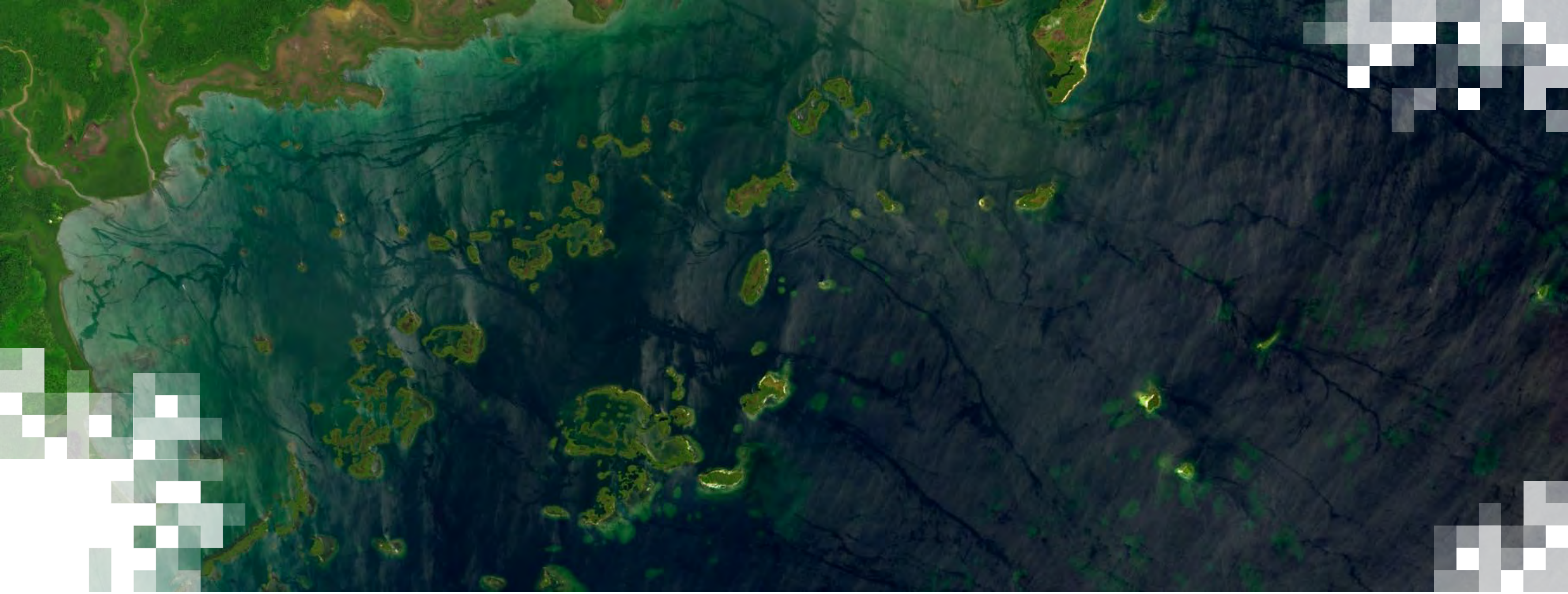
Combining Methods for Future Blue Carbon Accounting

Combining methods for future blue carbon accounting

- Ongoing needs and areas of research:
  - Improved Blue C ecosystem area extent estimates
    - ➢ Ongoing advancements in mapping
  - Reduced Uncertainty in Blue Carbon Flux
    - ➢ More in situ data
    - ➢ Data-driven modelling to upscale wetland carbon dioxide uptake and methane emissions using EO
  - Holistic Quantification of System Blue C
    - High resolution data on extent, biomass, height, carbon stock & flux
  - Inclusion and mapping of all co-occurring blue C systems



Adame et al. 2024. All tidal wetlands are blue carbon ecosystems.

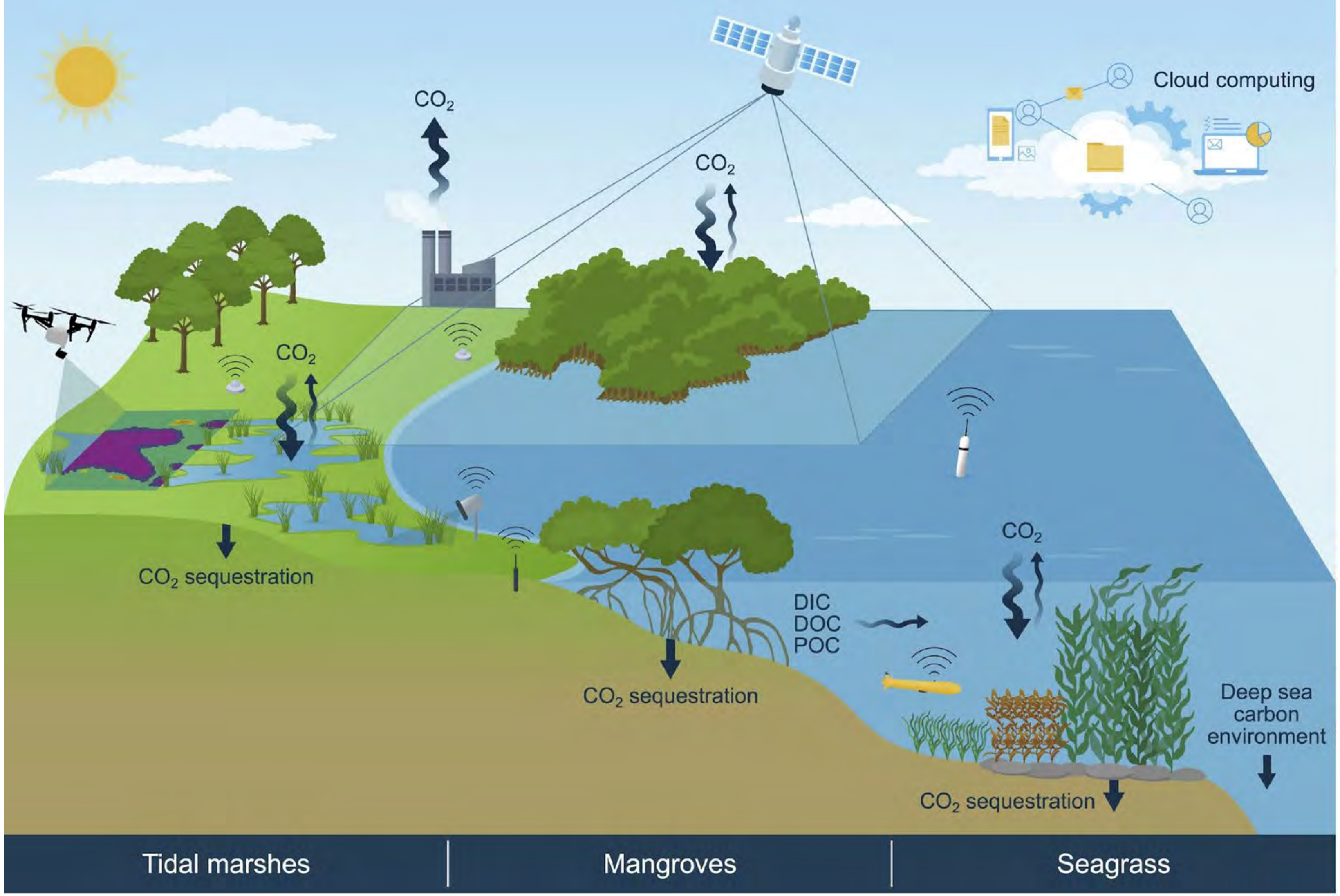


Measuring Co-Occurrences of Blue Carbon Ecosystems

Summary

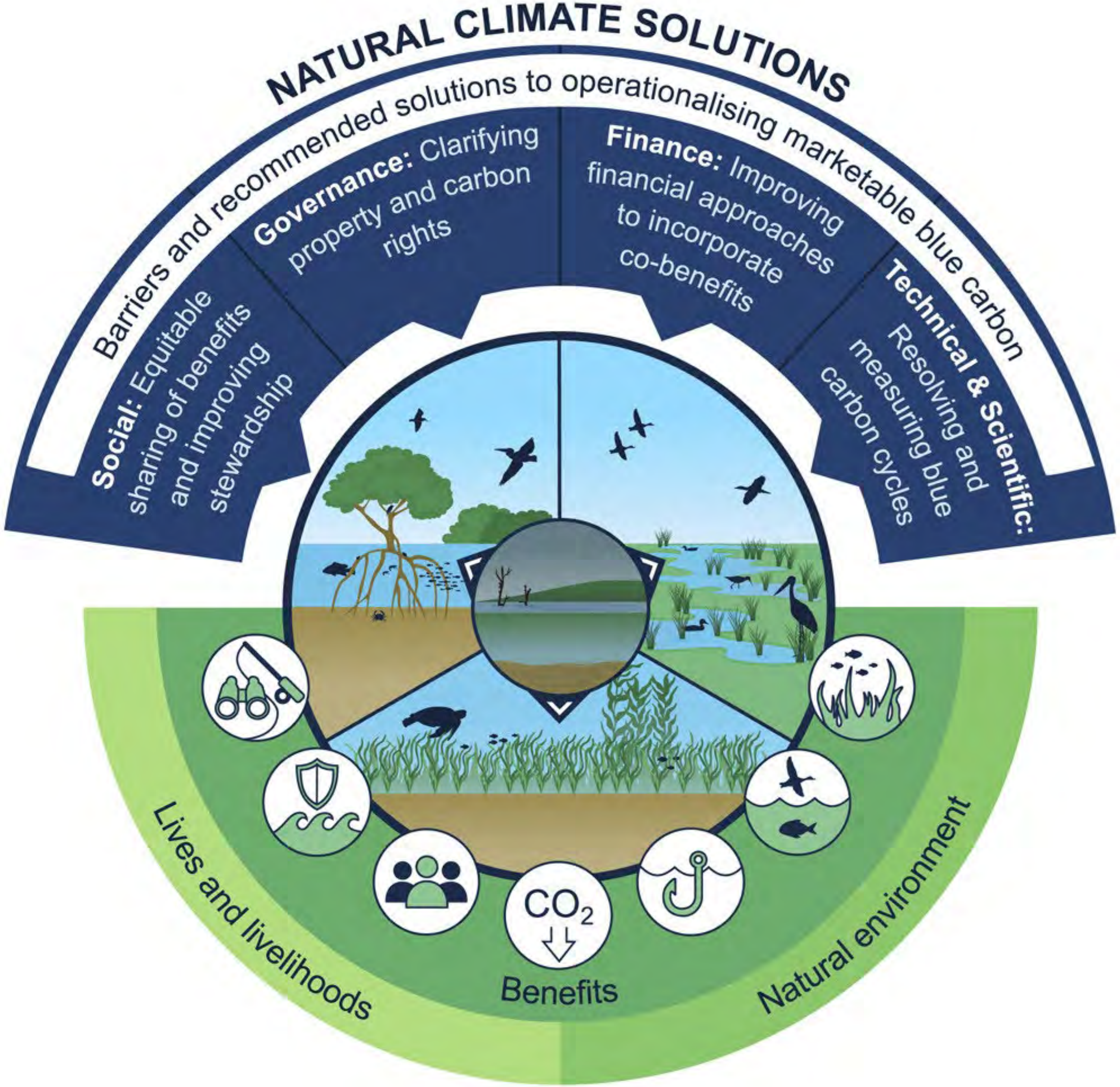
Summary

Improving understanding of Blue C with advancing tools for observation and analysis

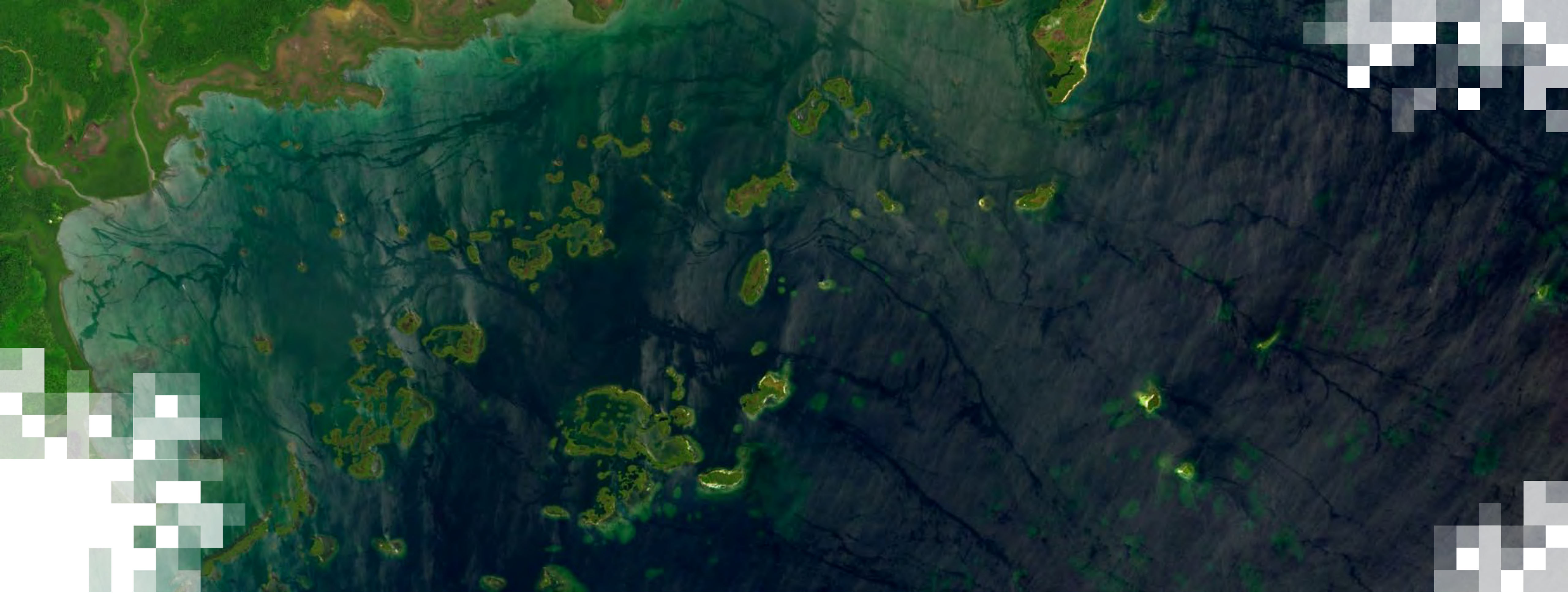


Macreadie et al. 2022. One Earth. Operationalizing marketable blue carbon

Summary



Macreadie et al. 2022. One Earth. Operationalizing marketable blue carbon



Part 2:
Summary

Training Summary

- Blue carbon is carbon that is captured, removed and stored by ocean systems, both in the biotic and the abiotic components
- Mangroves, seagrass and salt marshes share the following traits:
  - presence of high carbon stocks
  - evidence of long-term carbon storage
  - capacity to manage and effectively measure GHG emissions and removals resulting from changes to these ecosystems.
- Blue Carbon has climate mitigation value, but also other functions and co-benefits.
- Urgent action is needed to conserve, protect and restore blue carbon ecosystems and we need to develop effective policies that can support this.
- Global datasets are openly available that show mangrove extent, canopy height and biomass.
- Basic criteria for assessing the suitability of datasets and how to use google earth Engine to generate your own mangrove extent data.
- Estimate mangrove canopy height, biomass, and carbon stocks for more precise mangrove ecosystem carbon stock estimate.
- Use of spatial data to parameterize the various components of blue carbon (extents, biomass, height, carbon stocks, cycling or carbon fluxes).
- How to Map the extent of salt marsh and seagrass ecosystems using satellite observations
- Approaches and considerations to calculate the carbon stocks of mapped salt marsh and seagrass ecosystems
- Explored synthesis methods to estimate blue carbon across ecosystems.

Homework and Certificates

- **Homework:**
  - One homework assignment
  - Opens on 12/05/2024
  - Access from the training webpage
  - Answers must be submitted via Google Forms
  - **Due by 12/19/2024**

- **Certificate of Completion:**
  - Attend all three live webinars (attendance is recorded automatically)
  - Complete the homework assignment by the deadline
  - You will receive a certificate via email approximately two months after completion of the course.

Acknowledgements

The Mangrove Science Team


Lola Fatoyinbo, Ph.D.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Atticus Stovall, Ph.D.


Abigail Barenblitt


Cheryl Doughty Ph.D.


Adia Bey, Ph.D.


Anthony Campbell, Ph.D.


Liza Goldberg


David Lagomasino, Ph.D.


Nathan Thomas, Ph.D.

Contact Information

Trainers:

- Dr. Anthony Campbell
  - anthony.d.campbell@nasa.gov
- Dr. Cheryl Doughty
  - cheryl.l.doughty@nasa.gov
- Dr. Kelly Luis
  - kelly.m.luis@jpl.nasa.gov
- Brock Blevins
  - brock.blevins@nasa.gov

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Thank You!