National Aeronautics and Space Administration

Invasive Species Monitoring with Remote Sensing

Part II: Aquatic Invasive Species

Erin Hestir (University of California Merced)

August 21, 2024

Invasive Species Monitoring with Remote Sensing

Overview

Invasive Species

In Alaska's 'last frontier,' climate change provides new horizons for invasive species - NASA Science

Non-native organisms whose introduction causes, or is likely to cause, harm to the environment, human health, or the economy.

Training Learning Objectives

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

- Recognize the extent and impacts of invasive species on biodiversity and a changing climate.
- Identify the types of remote sensing data and products that can be used for invasive species mapping and monitoring.
- Explore key considerations, benefits and limitations of remote sensing data sets for invasive species.
- Identify where to access remote sensing data for monitoring invasive species and mapping relevant habitat and climate variables.
- Evaluate remote sensing methods used to monitor aquatic and grassland invasive plant species.

Prerequisites

- Fundamentals of Remote Sensing

Training Outline

Part 1

An Introduction to the Monitoring of Invasive Species with Remote Sensing Tools

August 14, 2024

10-11:30 PT (1-2:30pm ET)

Part 2

Monitoring of Aquatic Invasive Species with Remote Sensing

August 21, 2024

10-11:30 PT (1-2:30pm ET)

Part 3

Monitoring Invasive Grassland Species with Hyperspectral Remote Sensing

August 28, 2024

10-11:30 PT (1-2:30pm ET)

Homework

Opens August 28 – Due September 11 – 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

Erin Hestir

Associate Professor

UC Merced

Justin Fain

Research Scientist

BAER/NASA Ames Research Center

Invasive Species Monitoring with Remote Sensing

Part 2: Monitoring of Aquatic Invasive Species with Remote Sensing

Part 2 Objectives

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

- Describe the extent and impacts of aquatic invasive species on biodiversity, ecosystem functions, and nature's contributions to people.
- Describe key considerations, benefits and limitations of remote sensing of invasive species.
- Identify applications of airborne data for monitoring aquatic invasive species.
- Identify relevant NASA multispectral and hyperspectral data for mapping and monitoring or invasive species.
- Compare remote sensing methods used to monitor aquatic invasive species.

What Makes an Invasive Species?

- The definition of invasive species is context specific.
- All invasive species are native to *somewhere* but can become invasive when removed from their native ecosystem.
- May outcompete native species, exert new pressures, disrupt ecosystem services

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.

An Introduction to Aquatic Invasive Plant Species

MONGABAY

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From Egypt to Syria, ‘water cancer’ chokes waterways

ABD ALMAJED ALKARH, LYSE MAUVAIS

30 MAY 2024 AFRICA

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Impacts of Invasive Aquatic Plants

Photo Credit: California Dept of Parks and Recreation, Division of Boating and Waterways

- Compared to terrestrial environments, freshwater aquatic habitats are:
  - Disproportionately more vulnerable to invasive species.
  - Disproportionately more negatively affected by invasive species (Moorhouse and Macdonald 2015).
- "Ecosystem engineers" affect environmental conditions.
  - Changes in light availability
  - Change water temperature and water chemistry
  - Change water flow, nutrient and carbon cycling
  - Alter species and communities

Impacts of Invasive Aquatic Plants

Photo Credit: Danny Pata, GMA News, Philippines

- Impede water movement
  - Negatively affect flood control irrigation & hydropower
- Affect recreational uses
  - Impacts boating, fishing, wildlife viewing
- Aesthetic value (Horsch & Lewis 2009)
  - Declines in property values
  - Impacts tourism
- Bad for human health (Prabhat & Singh 2020)
  - Traced to malaria outbreaks
  - Vector for spread of schistosomiasis

Main Growth Forms

Floating

Eichhornia crassipes (Water hyacinth)
Photo credit: বিতোপন গগৈ (https://commons.wikimedia.org/wiki/File:MetekaPhool.jpg), "MetekaPhool", https://creativecommons.org/licenses/by-sa/3.0/legalcode

Submersed

Egeria densa (Brazilian waterweed)
Shruti Khanna, CDFW, Photo Credit: USGS

Emergent

Phragmites australis (Common reed/Danube grass)
Photo Credit: NASA/Elizabeth Banda

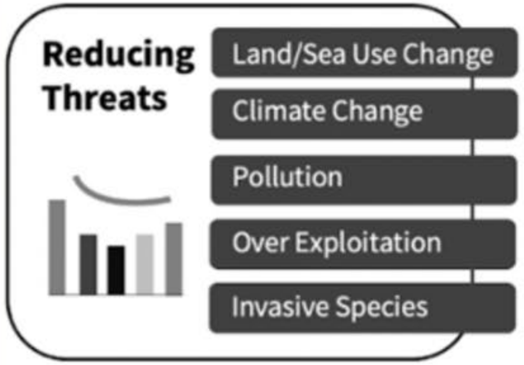
Invasion Pathways and Mechanisms

- Human-mediated introductions
  - Shipping & navigation canals
  - Aquaculture
  - Aquarium trade & water gardens
  - Boating & fishing
- Invasibility of degraded habitats
  - Nutrient pollution
  - Hydrologic alterations
  - Increasing temperatures
- Invasion mechanisms
  - Genetic traits
  - Clonality & propagule pressure
  - Biological interactions

Stopping the Global Loss of Biodiversity

Convention on Biological Diversity

G. Action Targets
Reducing threats to biodiversity



1. Ensure that all land and sea areas globally are under integrated biodiversity-inclusive spatial planning addressing land- and sea-use change, retaining existing intact and wilderness areas
2. Ensure that at least 20% of degraded freshwater, marine and terrestrial ecosystems are under restoration, ensuring connectivity among them and focusing on priority ecosystems.
3. Ensure that at least 30% globally of land and sea areas, especially areas of particular importance for biodiversity and its contributions to people, are conserved through effectively and equitably managed, ecologically representative and well connected systems of protected areas and other effective area-based conservation measures, and integrated into the wider landscapes and seascapes
4. Ensure active management actions to enable the recovery and conservation of species and the genetic diversity of wild and domesticated species, including through ex situ conservation, and effectively manage human-wildlife interactions to avoid or reduce human-wildlife conflict.
5. Ensure that the harvesting, trade and use of wild species is sustainable, legal, and safe for human health
6. Manage pathways for the introduction of invasive alien species, preventing, or reducing their rate of introduction and establishment by at least 50%, and control or eradicate invasive alien species to eliminate or reduce their impacts , focussing on priority species and priority sites.
7. Reduce pollution from all sources to levels that are not harmful to biodiversity and ecosystem functions and human health, including by reducing nutrients lost to the environment by at least half, and pesticides by at least two thirds and eliminating the discharge of plastic waste.
8. Minimize the impact of climate change on biodiversity, contribute to mitigation and adaptation through ecosystem-based approaches, contributing at least 10 $GtCO_2e$ per year to global mitigation efforts, and ensure that all mitigation and adaptation efforts avoid negative impacts on biodiversity.

BD Post 2020 Process

SUSTAINABLE DEVELOPMENT GOALS

A Case Study in Remote Sensing of Aquatic Invasive Plants: California’s Sacramento-San Joaquin River Delta

California is a Global Leader in Nature-based Solutions

Wetlands: A Great Opportunity for Nature-based Solutions

The San Francisco Estuary & the Sacramento-San Joaquin River Delta

The Sacramento-San Joaquin River Delta – One of the Most Invaded Ecosystems in the World

California’s water hub. Supplies freshwater to 27 million people

Fuels California’s $3 trillion economy

Home to > 600,000 people in rural agriculture communities

Global biodiversity hotspot: >750 plant and animal species

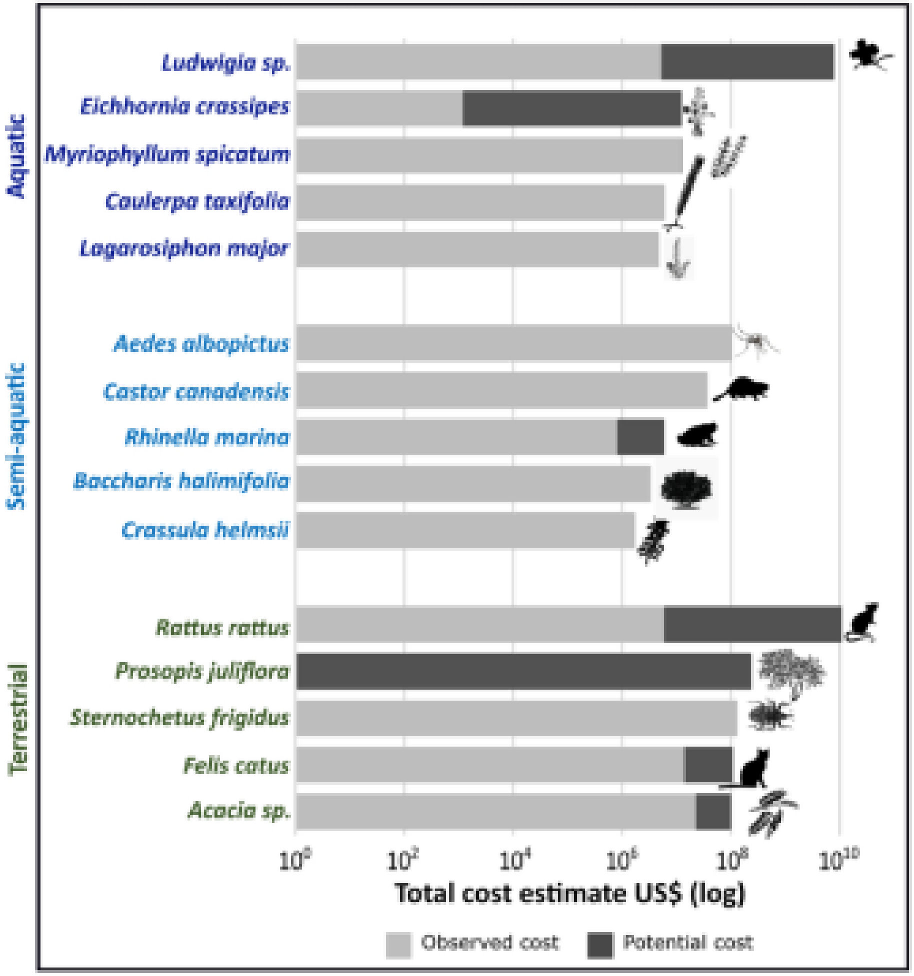
Highly vulnerable: > 50 native species listed under ESA

Cohen & Carlton 1998; Luoma et al. 2015

California's EcoRestore Investments: 12,000 ha & $950M USD

https://water.ca.gov/Programs/All-Programs/EcoRestore

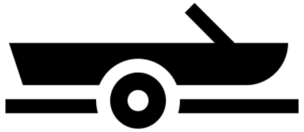
Biological Invasions Threaten the Benefits from Protected Areas – And They Cost a Lot $$!

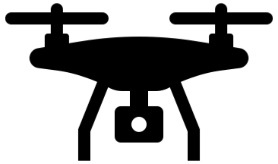


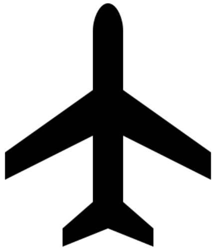
Moodley et al. 2022 Biol. Invasions

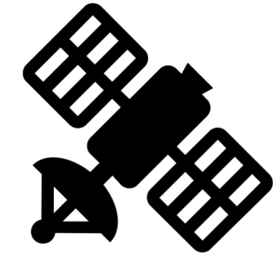
Water primrose (Ludwigia spp.) invades wetlands in the Sacramento-San Joaquin River Delta. Photo Credit: Erin Hestir

Methods for Mapping and Monitoring Invasive Aquatic Plants





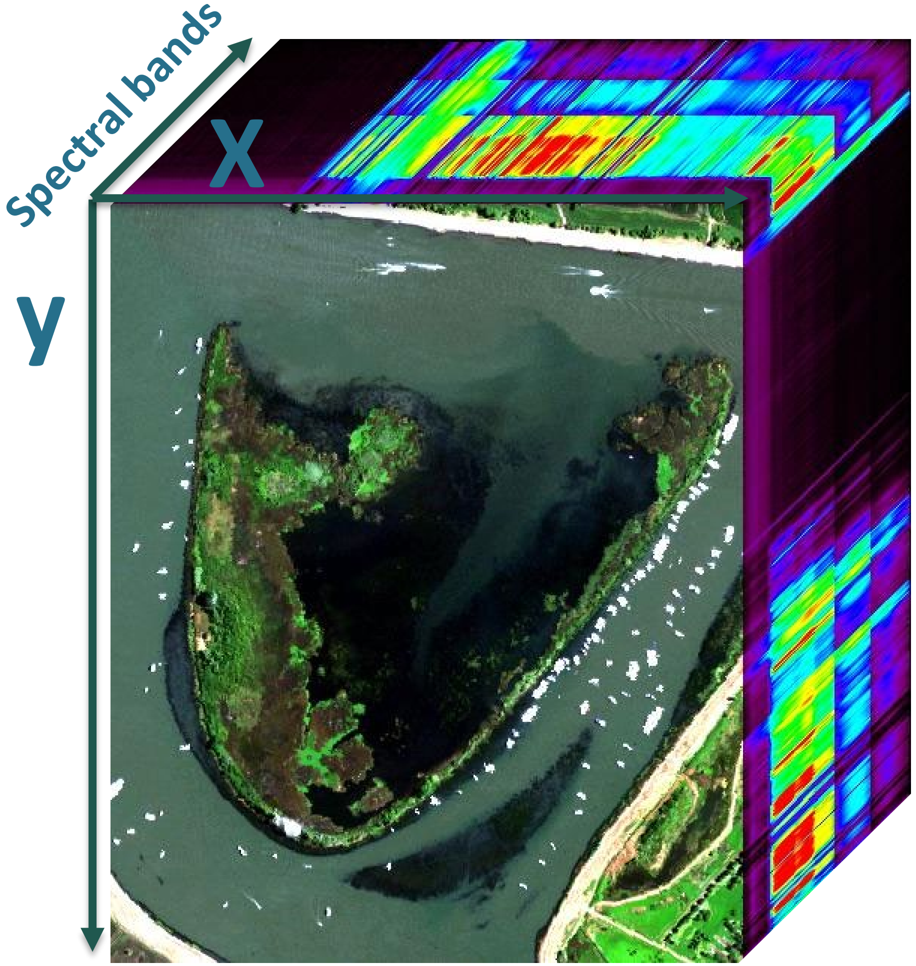


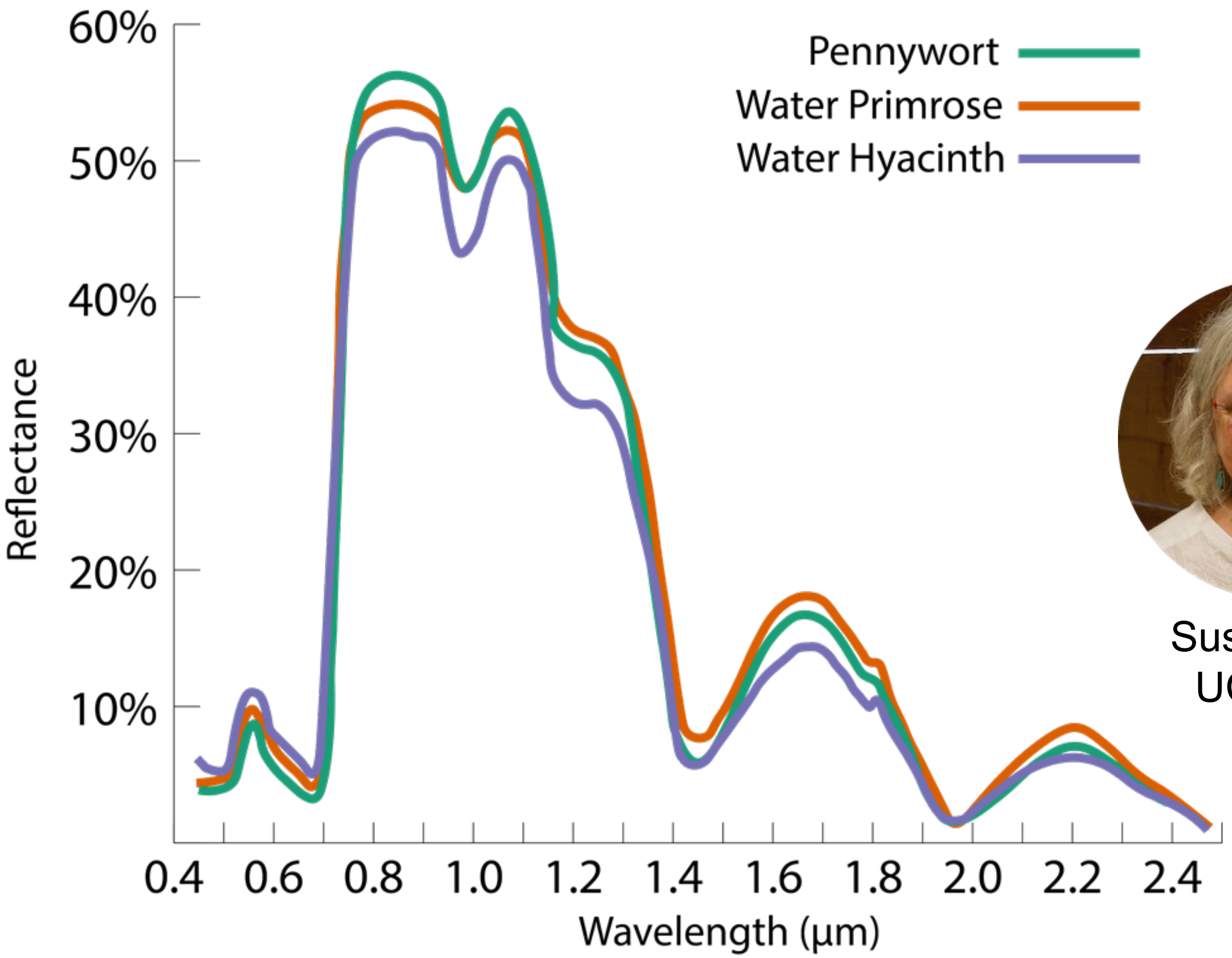


Boat surveys

✓ High precision data at fine scale

Two Decades of Airborne Imaging Spectroscopy





Susan Ustin
UC Davis

[Hestir et al. 2008, 2012, 2016; Khanna et al. 2011, 2012, 2018; Kimmerer et al. 2019, Santos et al. 2009, 2012, 2016]

Two Decades of Imaging Spectroscopy

2004-2008
HyMap
3.0 m
Summer acquisition.
64 flightlines

2009-2014
Recession
No data acquired due to loss of funding.

2015-2017
AVIRIS-NG
2.5 m
Autumn acquisition.
22-61 flightlines

2018-2019
HyMap
1.7 m
Autumn acquisition.
41-71 flightlines

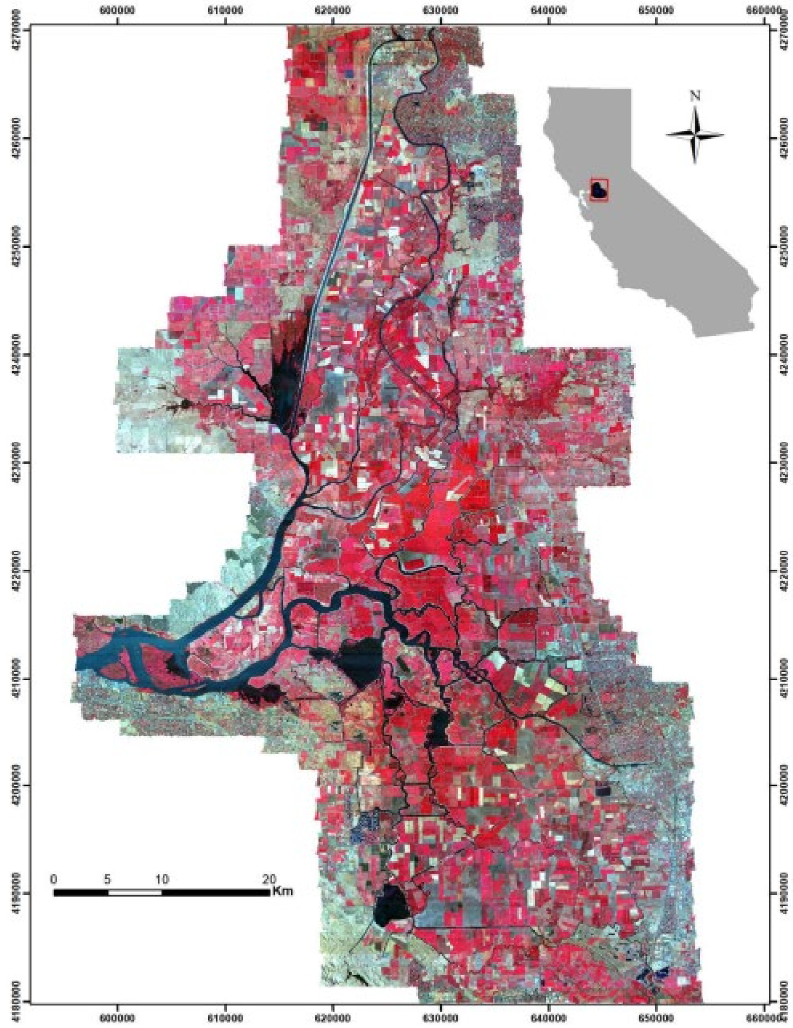
2020-2022
AISA Fenix
2.0 m
Summer acquisition.
57-58 flightlines

2023-2024
AVIRIS 3
2.5 m
Summer acquisition.
49-50 flightlines

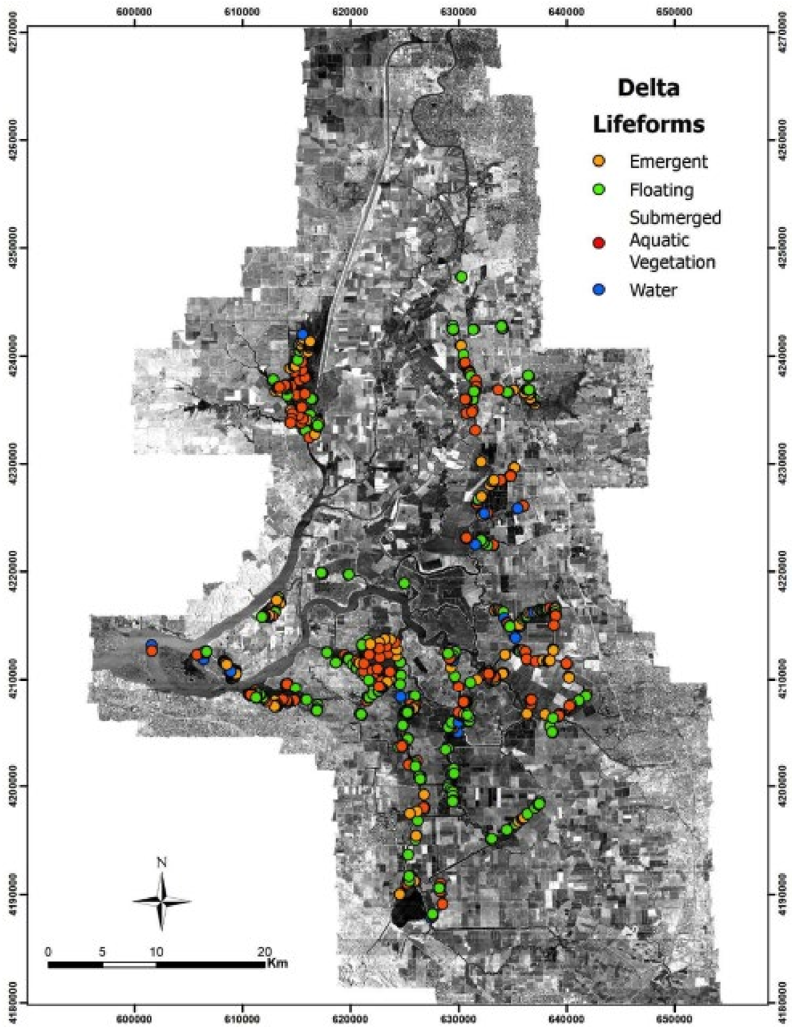
JPL Jet Propulsion Laboratory California Institute of Technology
HyVista Corporation
SpecTIR

Machine Learning to Map Species and Life Forms

Annual flightline mosaic

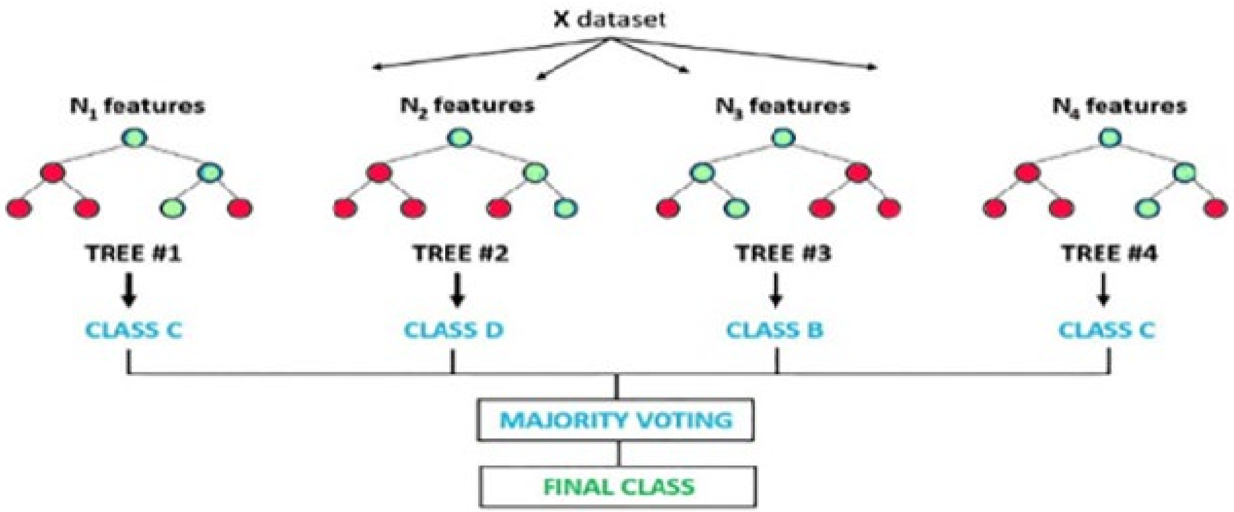


Coincident field survey

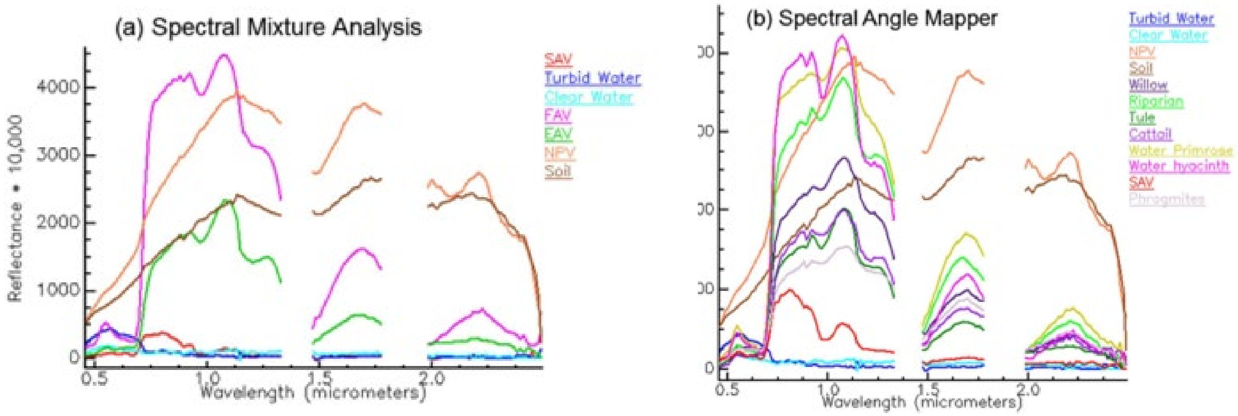


Shruti Khanna et al. 2022. doi:10.5063/F1N014ZX.

Random Forest Classification Model



Surbakti & Prashaya (2024) TEM Journal

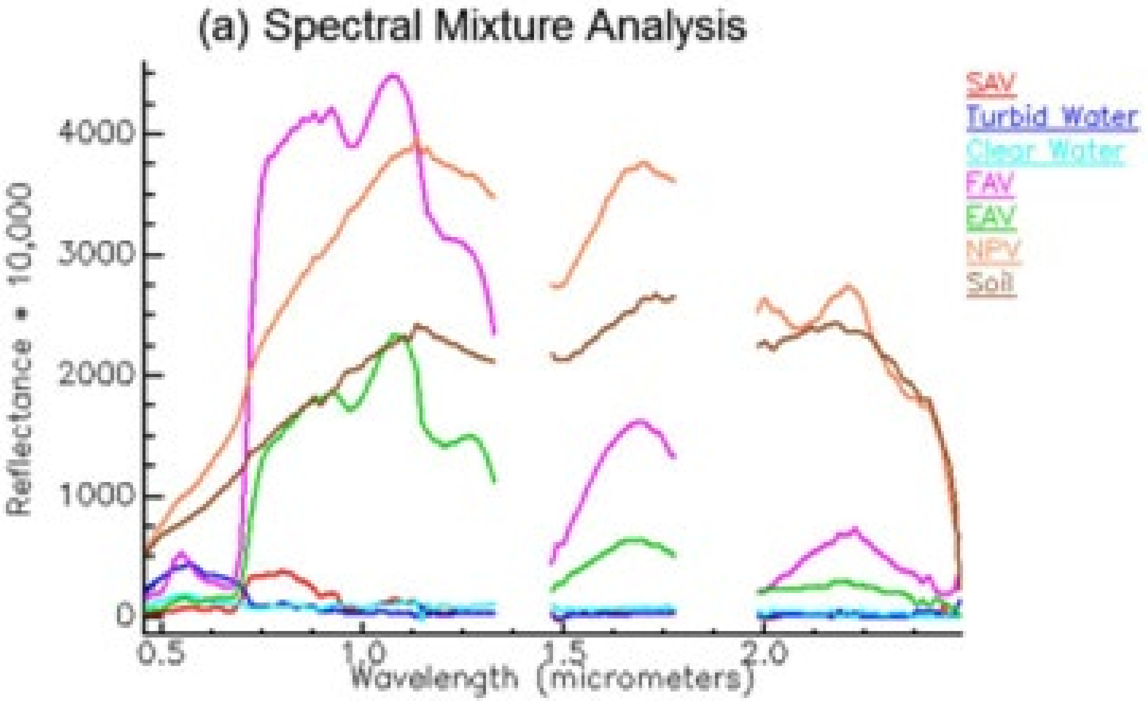


Inputs into the classifier:

- Broad band spectral indexes (e.g., NDVI, mNDVI)
- Narrow band (hyperspectral) indexes (e.g., PRI CAI)
- Spectral mixture abundance raster
- Spectral angle rule image raster
- Continuum removal 907-1047 nm, 1073-1293 nm & 2200-2384 nm

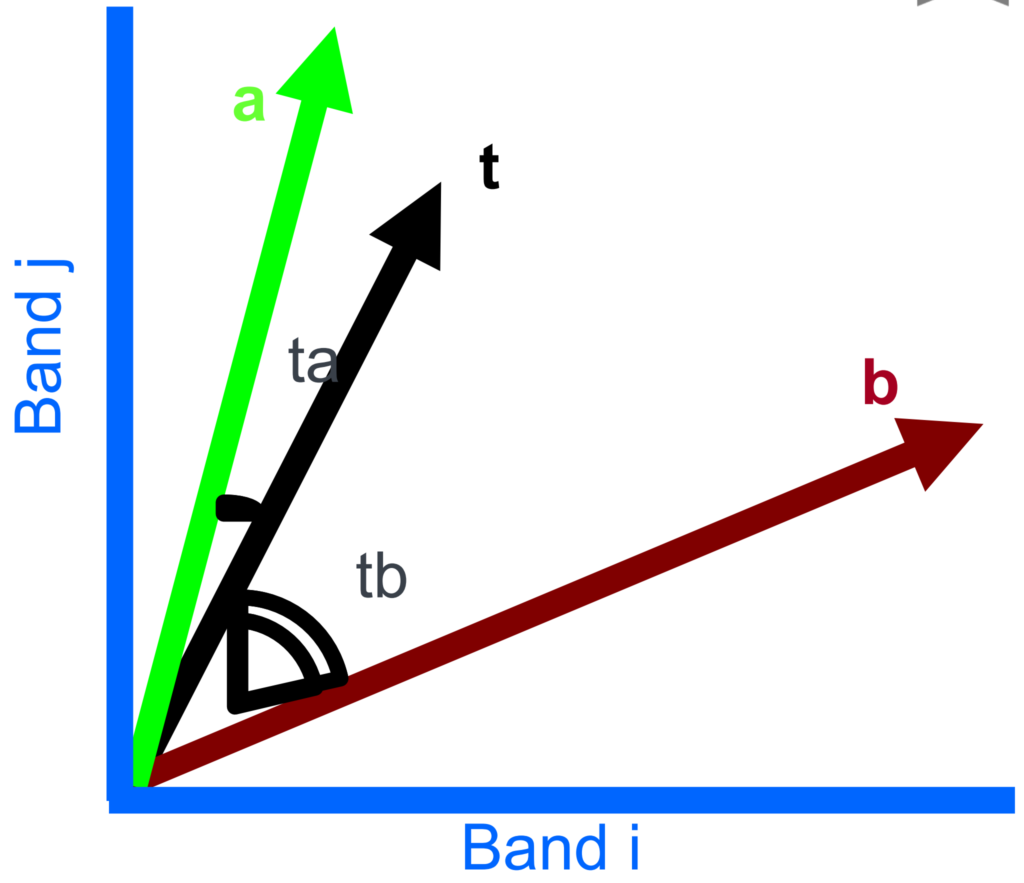
Spectral Mixture Analysis

- Decomposes a mixed pixel into a collection of constituent spectra, or **endmembers**, and a set of fractional **abundances** that indicate the proportions of each endmember
- Assumptions:
  - The pixel is a **linear** mixture of endmember constituents
  - All endmembers possibly contained in the pixel have been included in the analysis



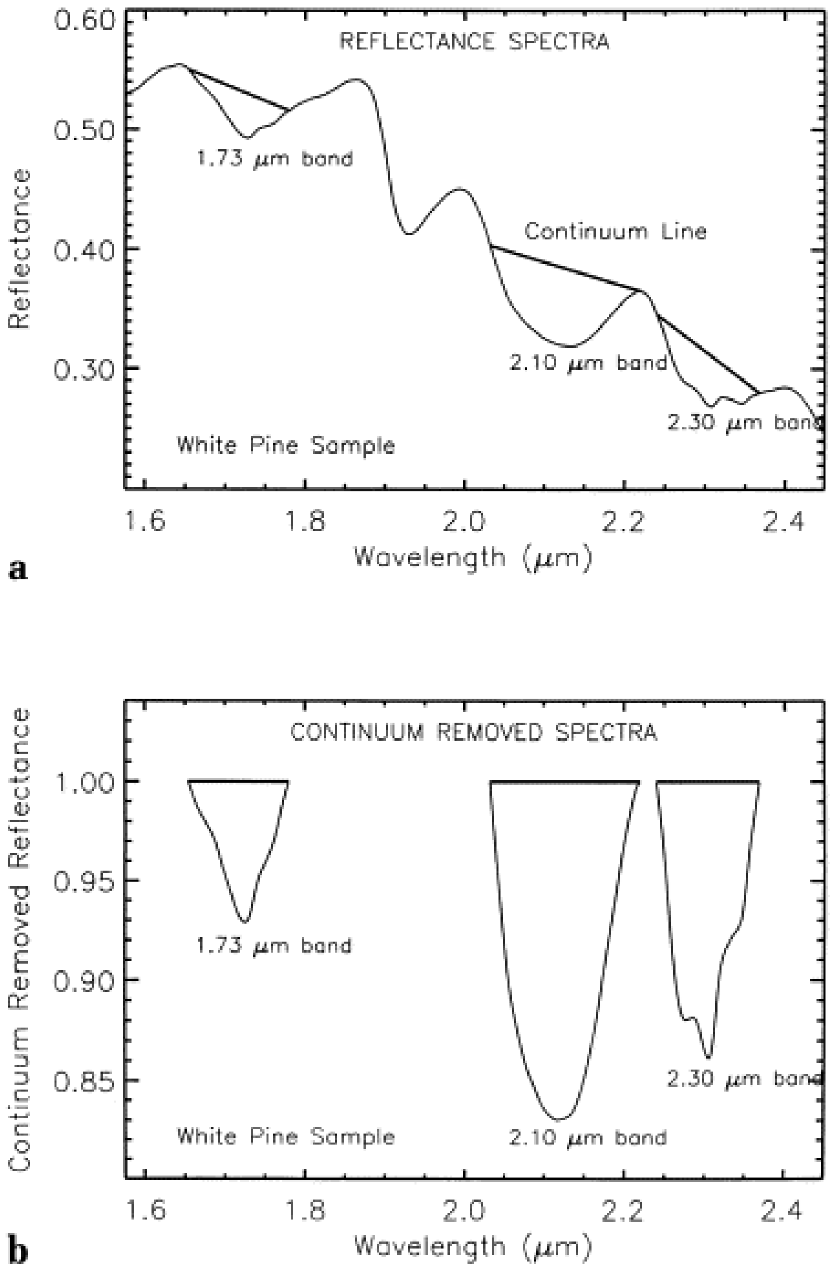
Spectral Angle Mapping

- The spectral signature of every endmember can be considered a unique vector in space.
- "**Spectral angle**" is determined for every pixel relative to the reference spectra in n-dimensional space.
- Value (in radians) is assigned to all pixels.
- Pixels within a user-specified threshold angle of the reference spectra are placed in that class.
- Rule images contain the angle difference between reference spectra and pixel spectra.



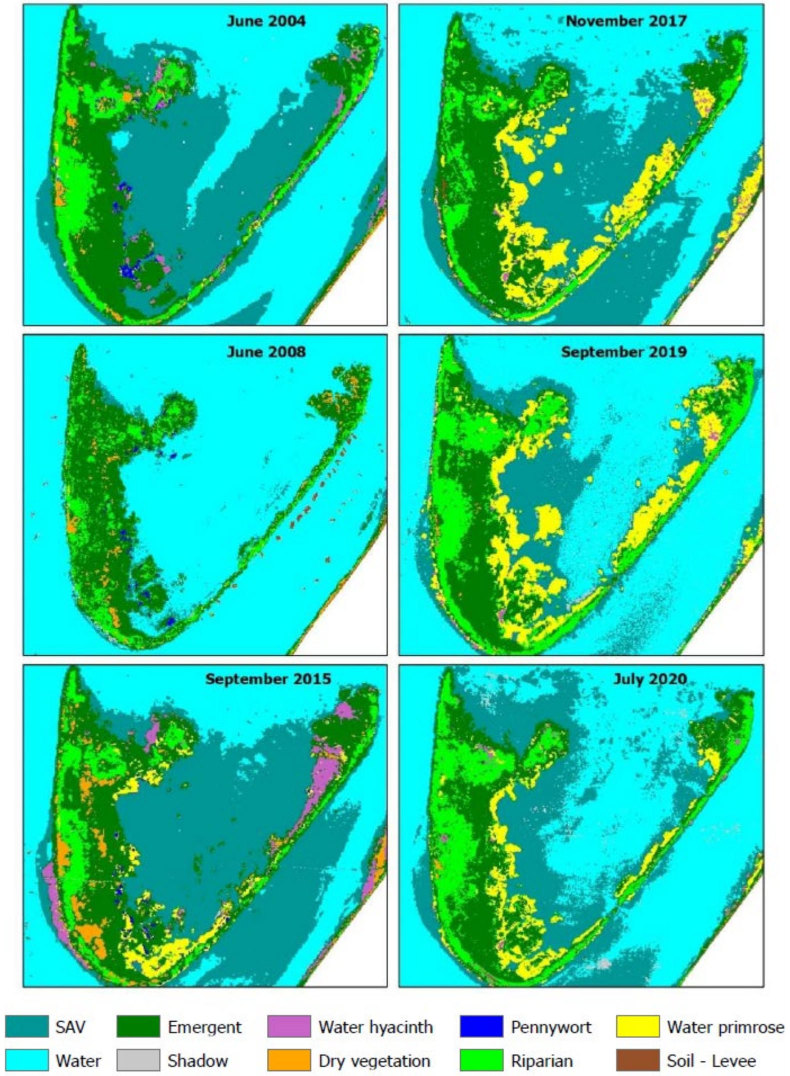
Continuum Removal

- Allows us to compare individual absorption features using a common baseline
- Normalizes reflectance spectra
  - Fits a convex hull over top of the spectra using local spectra maxima
  - Continuum is "removed" by dividing the original spectrum by the continuum/hull

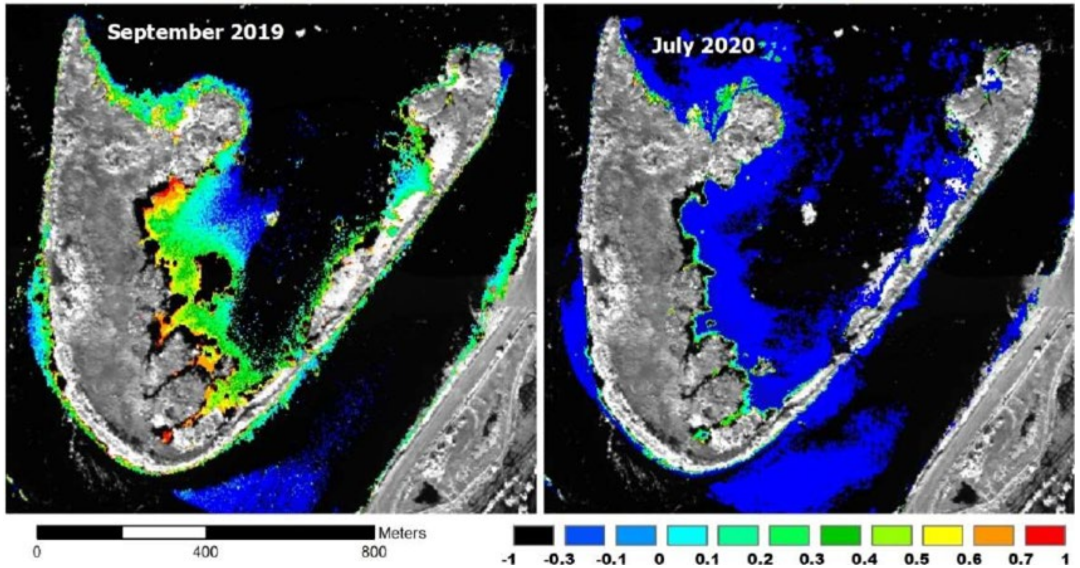


Kokaly & Clark 1999

Results: Two Decades of Aquatic Plant Maps at Species, Genus and Life-Form Level

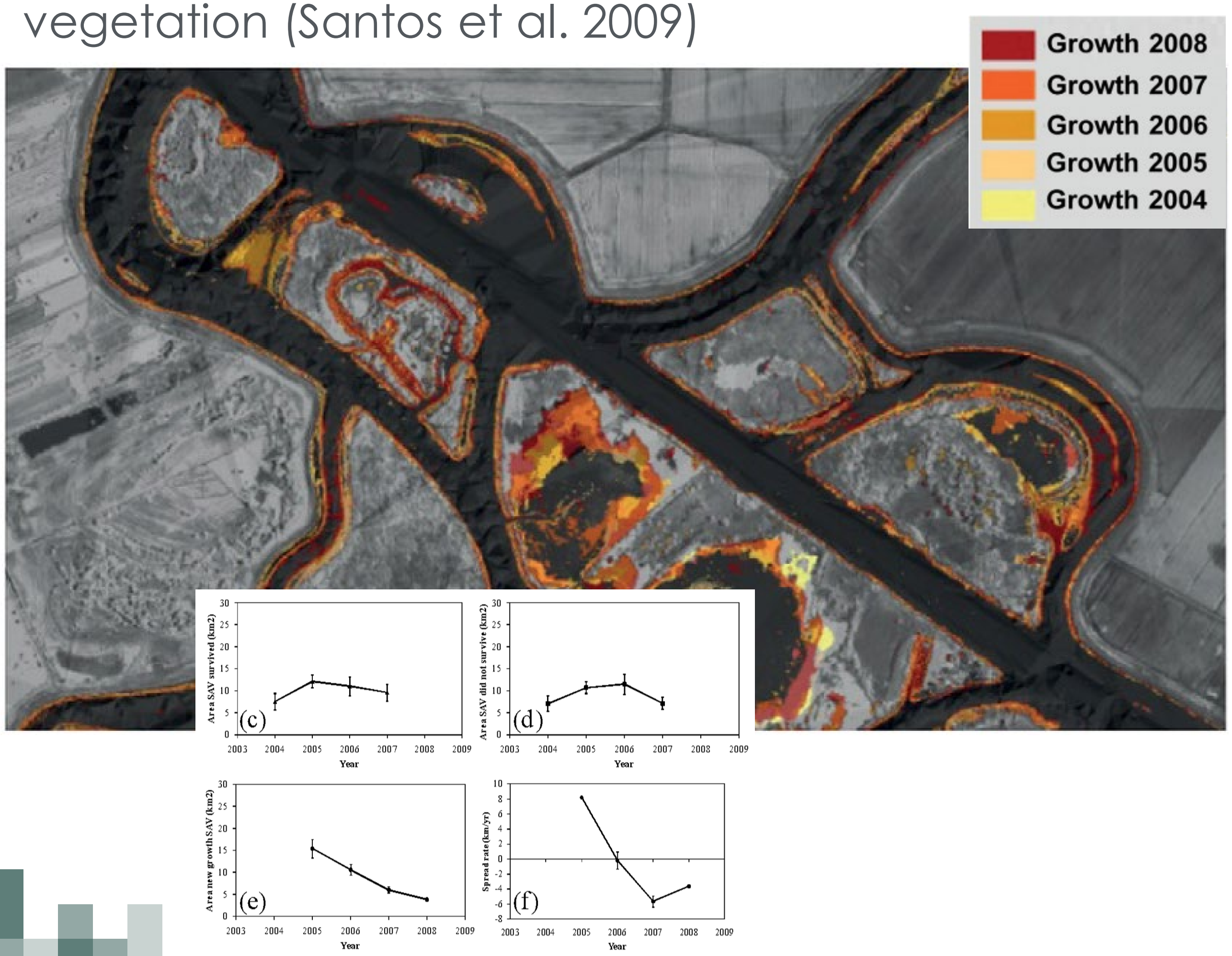


- Accuracies range between 89-92% over the time series.
- Maps enable many science questions and support management decision-making.

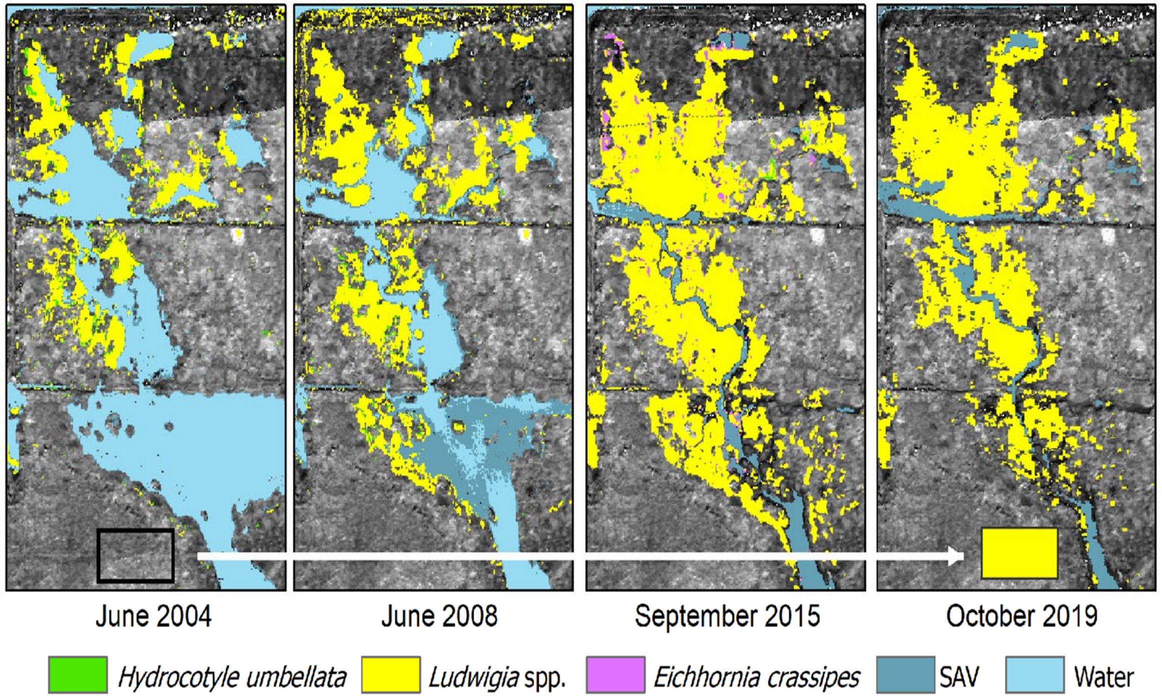


Invasion Biology & Ecosystem Engineering Studies

Spread and persistence of submerged aquatic vegetation (Santos et al. 2009)

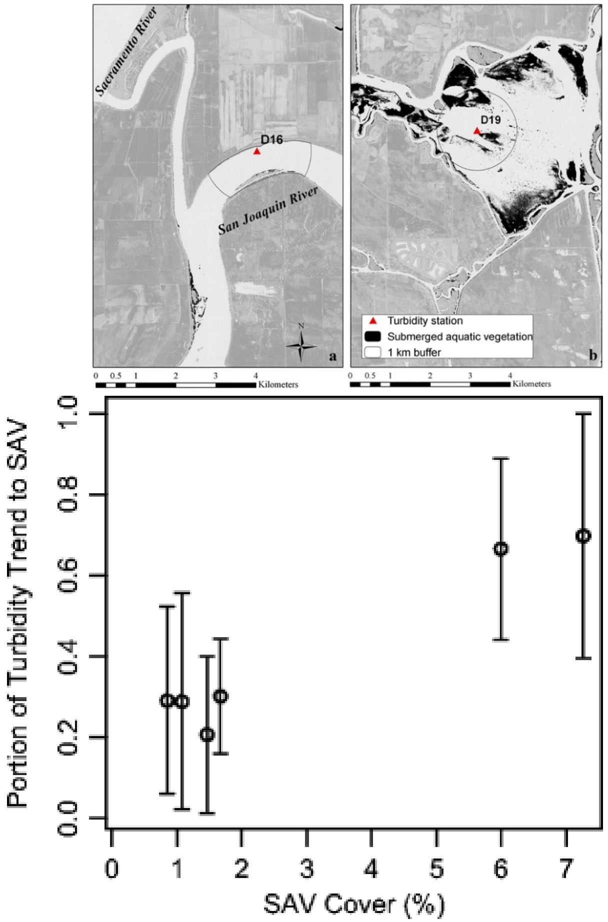


Encroachment of water primrose into native marsh habitat (Khanna et al. 2018)

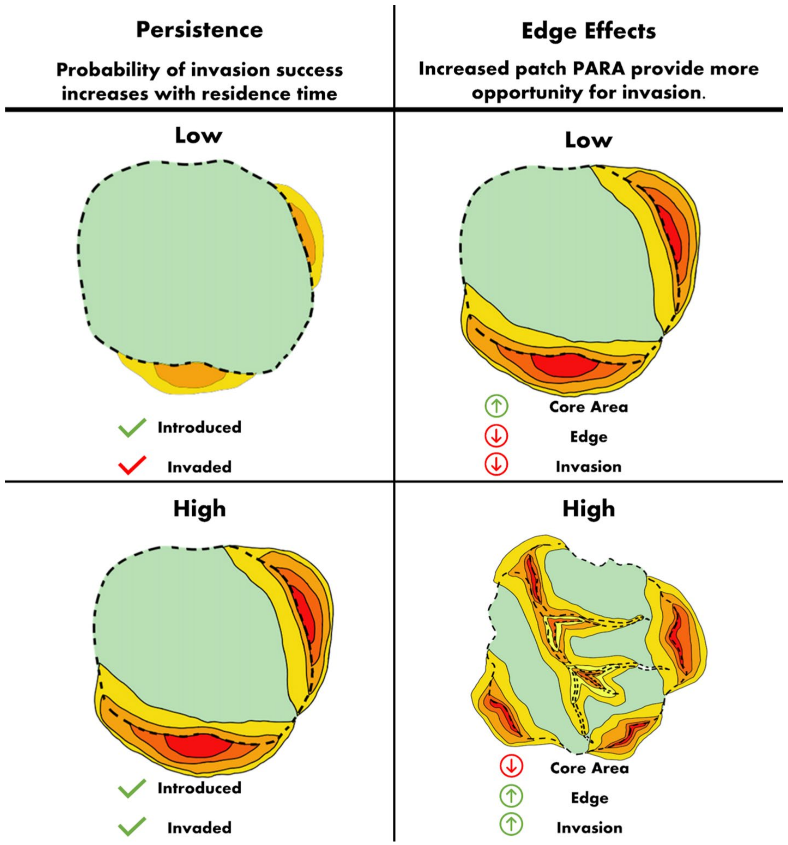


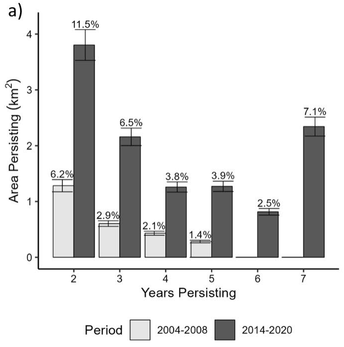
Invasion Biology & Ecosystem Engineering Studies

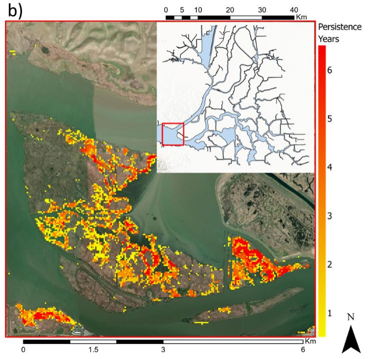
Submerged aquatic vegetation shown to increase water clarity (Hestir et al. 2016)

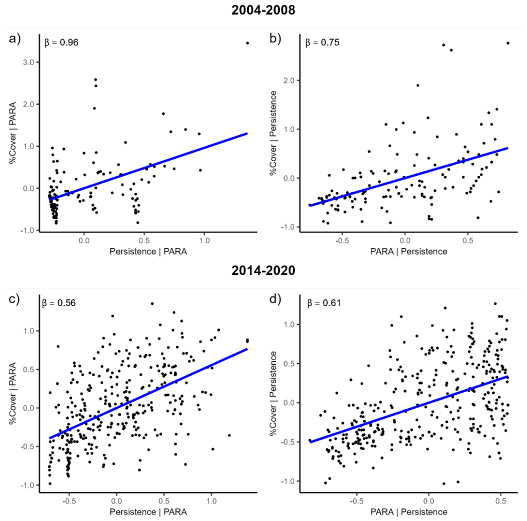


Water primrose persistence and marsh spatial complexity lead to replacement of marsh by water primrose (Morrison et al. in prep)



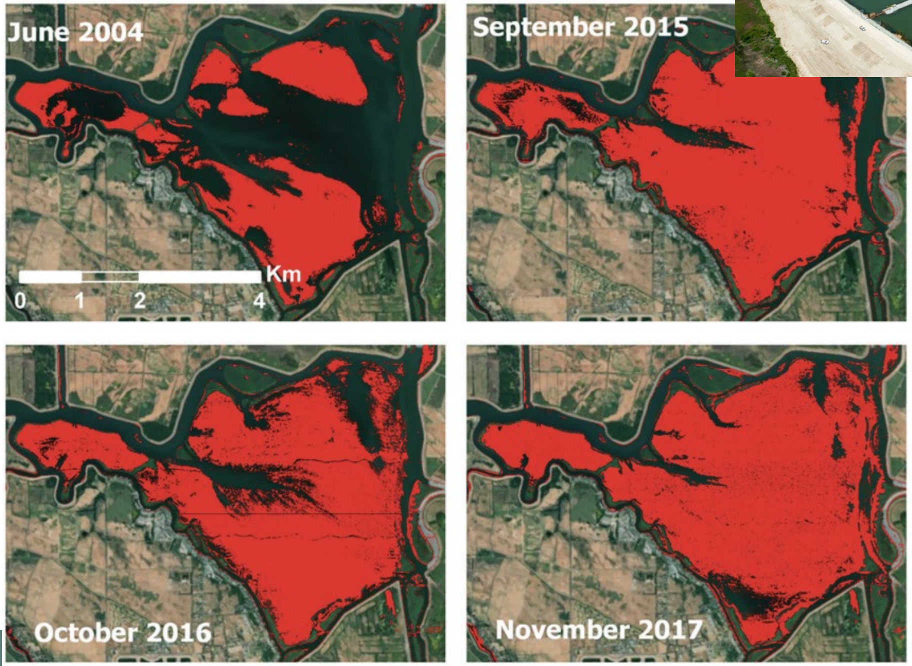




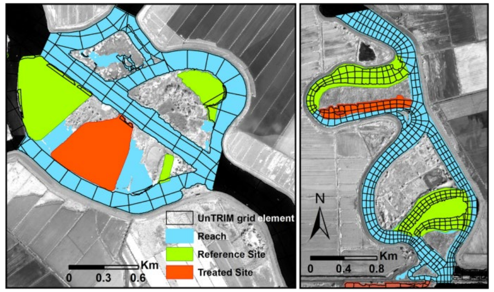


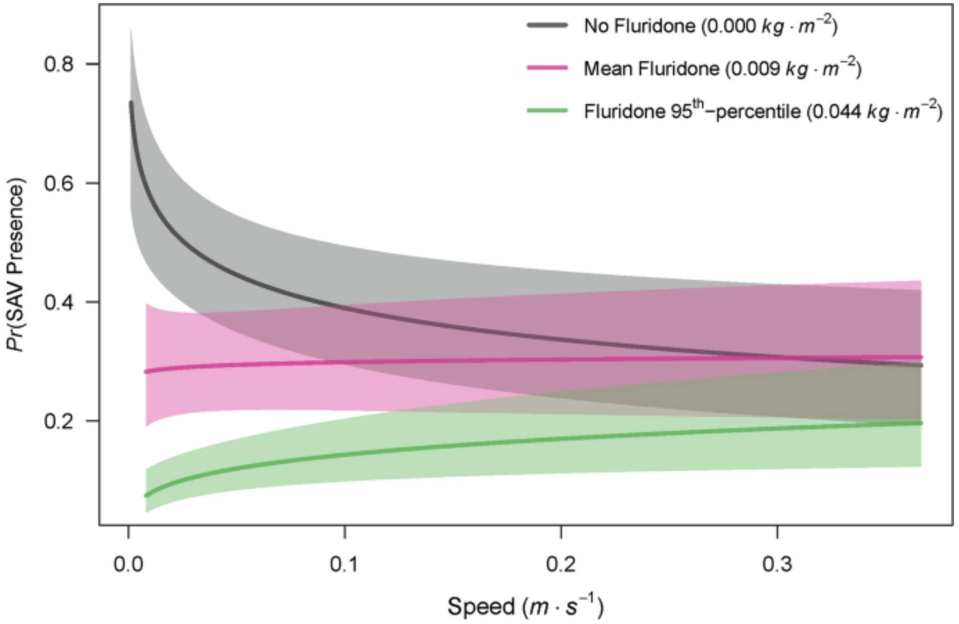
Evaluating Management Efficacy

Installation of the emergency drought barrier to prevent salinity intrusion increases submerged aquatic vegetation coverage (Kimmerer et al. 2019).

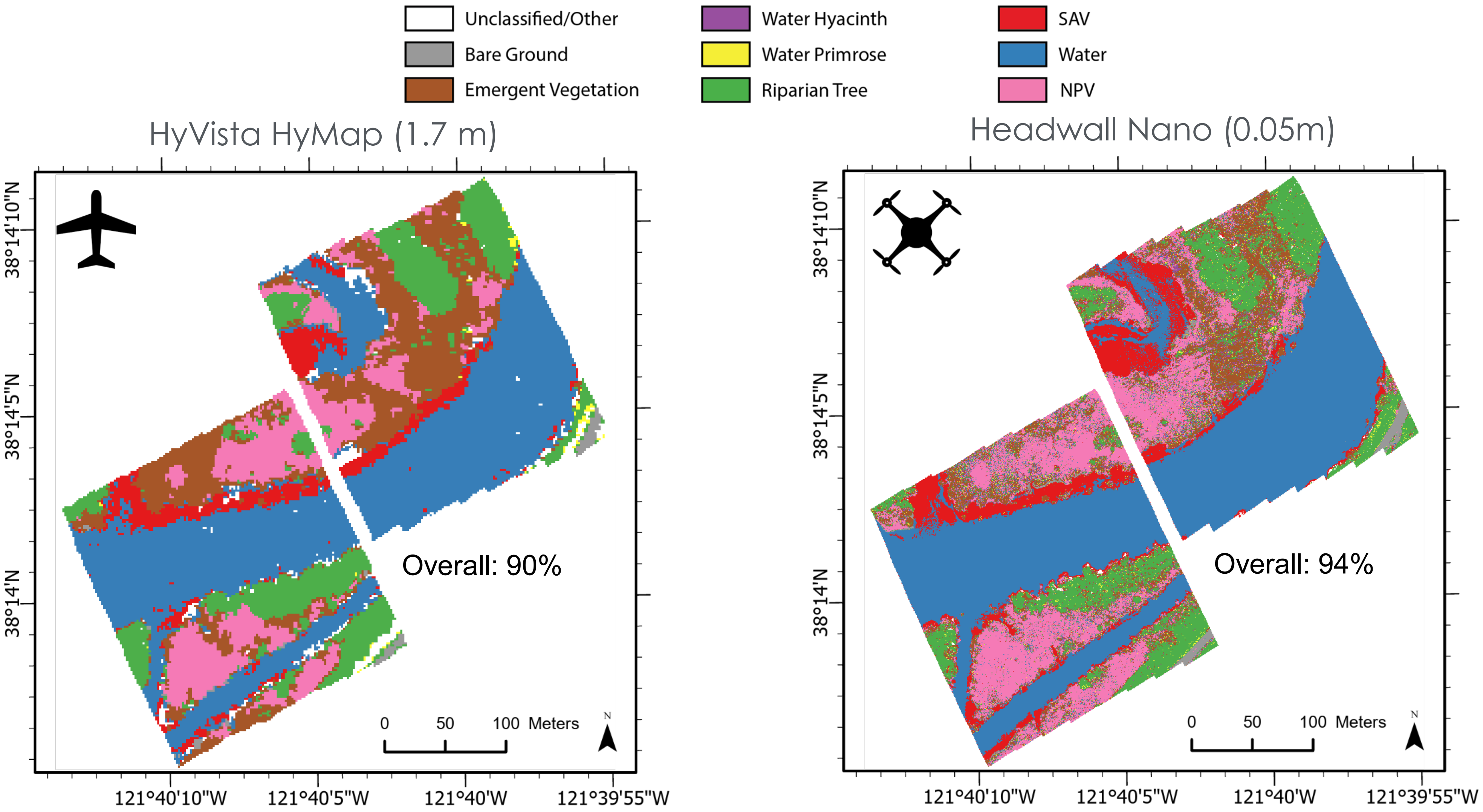


Fluridone herbicide treatments are not effective under high water current speeds, and multiple years of treatment are not effective (Khanna et al. 2023).





Can We Improve Mapping Spatial Resolution Using UAS?



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Bolch et al. 2020, *Remote Sens.*

UAS Operational Considerations

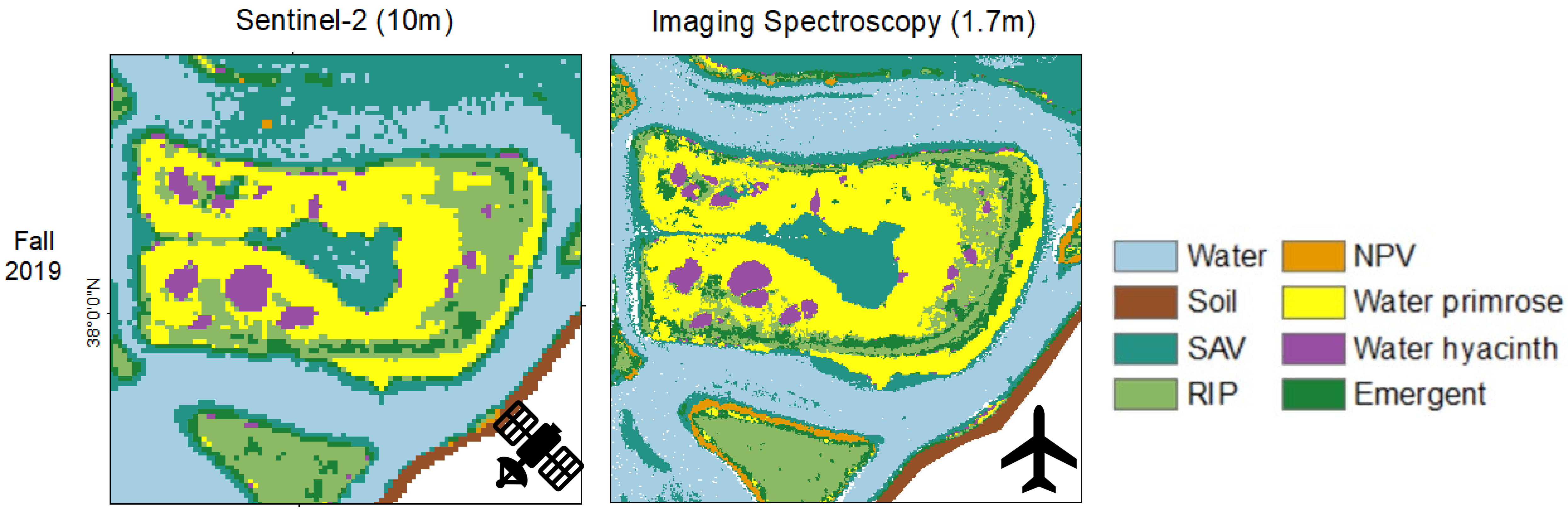
- Capability to detect rare and sparse classes is valuable.
- Recommend targeted deployment at sites of high concern/value

Sensor	Area Covered (ha)	Flight Time Estimate (h)	Approx. Data Volume (GB)	Approx. Deployment Costs
HyMap	74,123	16	700	$150,000
Nano – this study	10.53	1	600	$62,780
Nano – Entire Delta	74,123	7040	2,111,880 (2 PB)	$865,014

Bolch et al. 2020, *Remote Sens.*

Can We Improve the Temporal Density of Maps with Satellite Data?

Water hyacinth and water primrose can be distinguished with Sentinel-2 data.

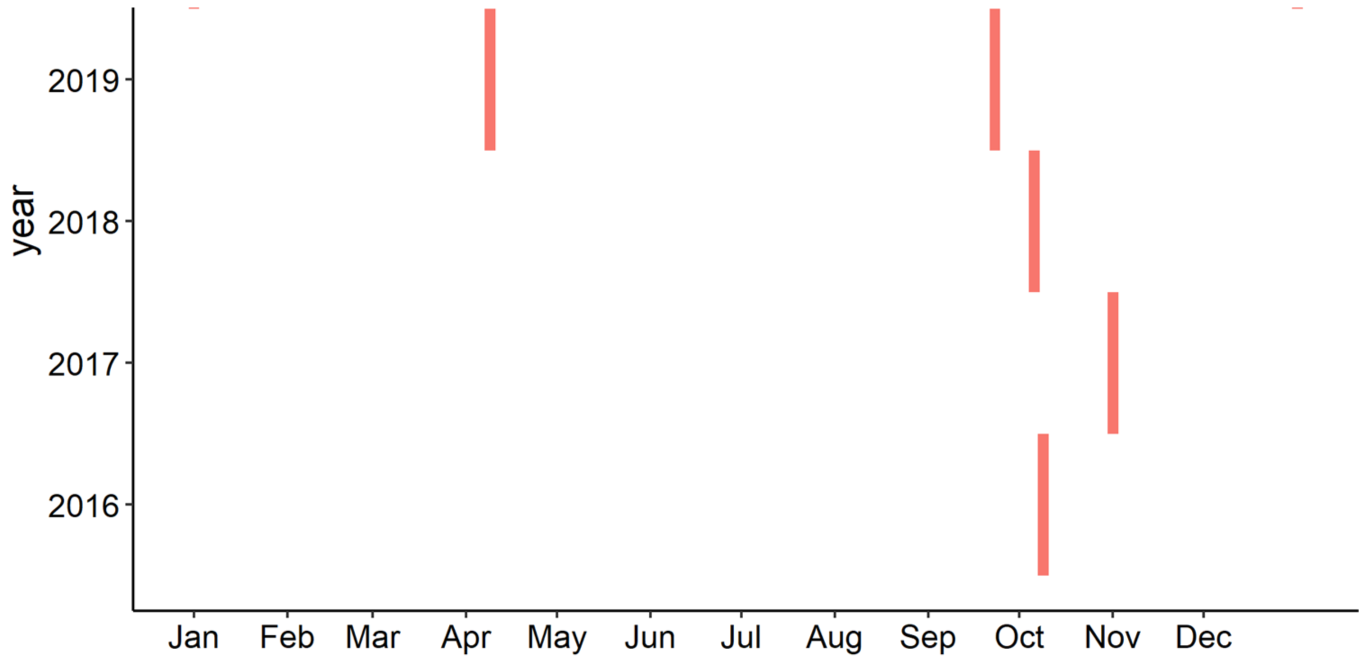


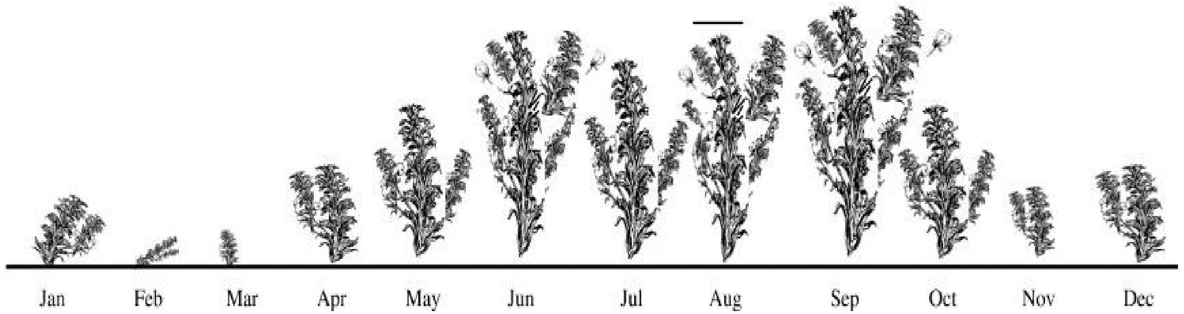
Overall: 89%
WH: 78% (PA), 85% (UA)
WP: 94% (PA), 92% (UA)

Overall: 90%
WH: 94% (PA), 89% (UA)
WP: 95% (PA), 95% (UA)

Ade et al. 2021, *Remote Sens*

Sentinel-2 Offers Ability to Fill Temporal Gaps

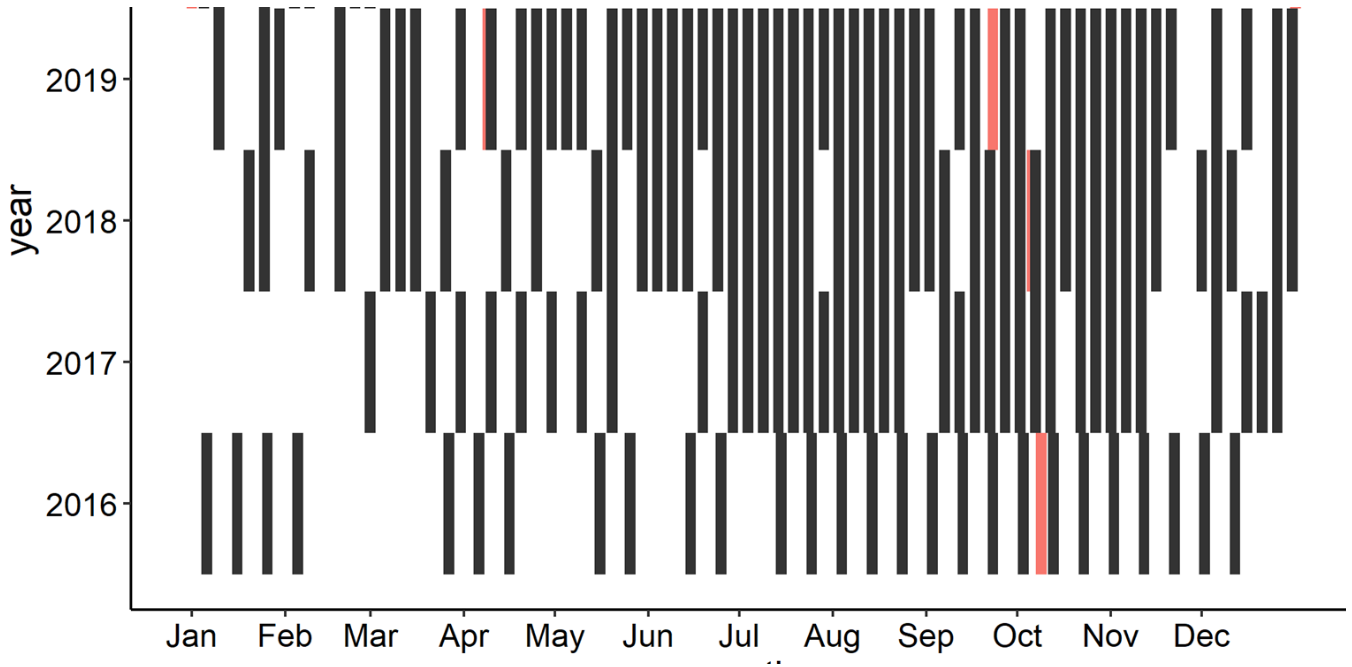


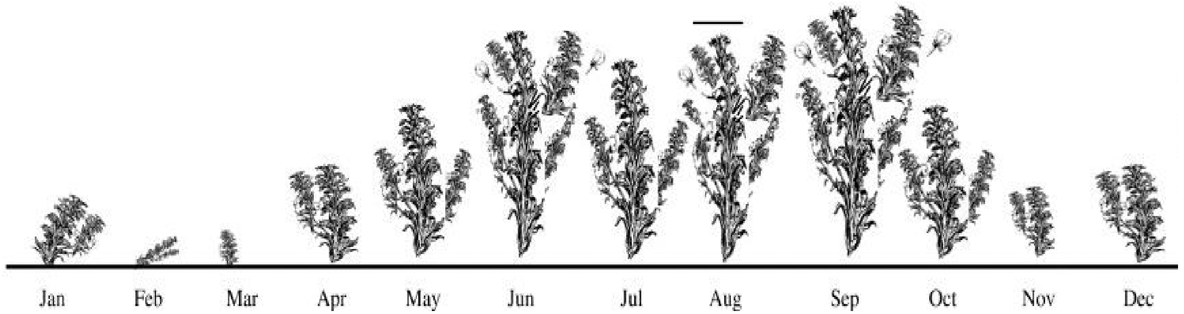


Annual or biannual snapshots from airborne imagery might miss key stages in vegetation growth cycle.

Ade et al. *In Prep*

Sentinel-2 Offers Ability to Fill Temporal Gaps

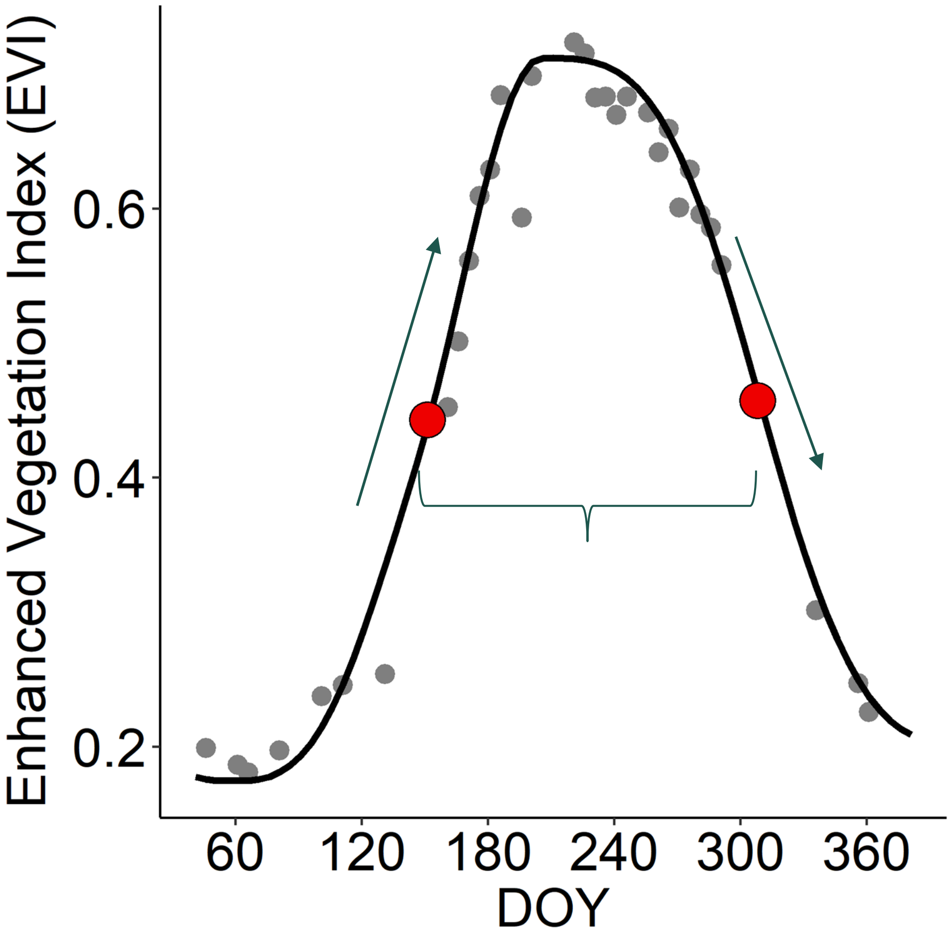




Annual or biannual snapshots from airborne imagery might miss key stages in vegetation growth cycle.

Ade et al. *In Prep*

High Temporal Frequency Allows us to Track Phenology



1) EVI for each date (2018 – 2020)
2) Gaussian asymmetric fitting function
3) Extract phenology metrics

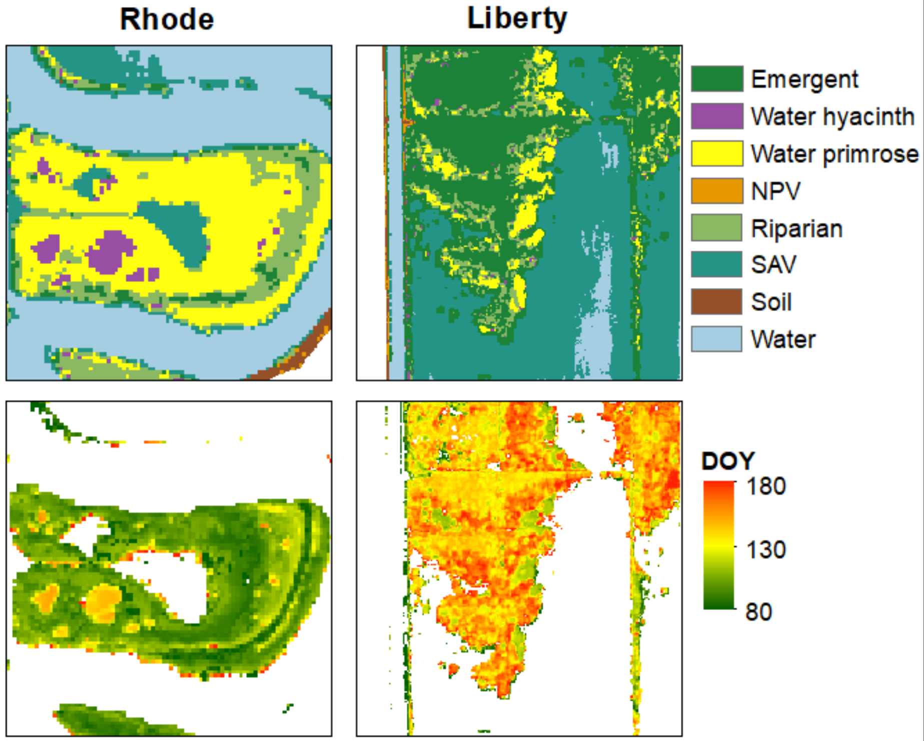
TIMESAT for five phenology metrics

1) Start of growing season – left edge 50% of amplitude
2) End of growing season – right edge 50% of amplitude
3) Length of growing season – difference in start and end
4) Rate of increase - ratio left 20% and 80%
5) Rate of decrease - ratio right 20% and 80%

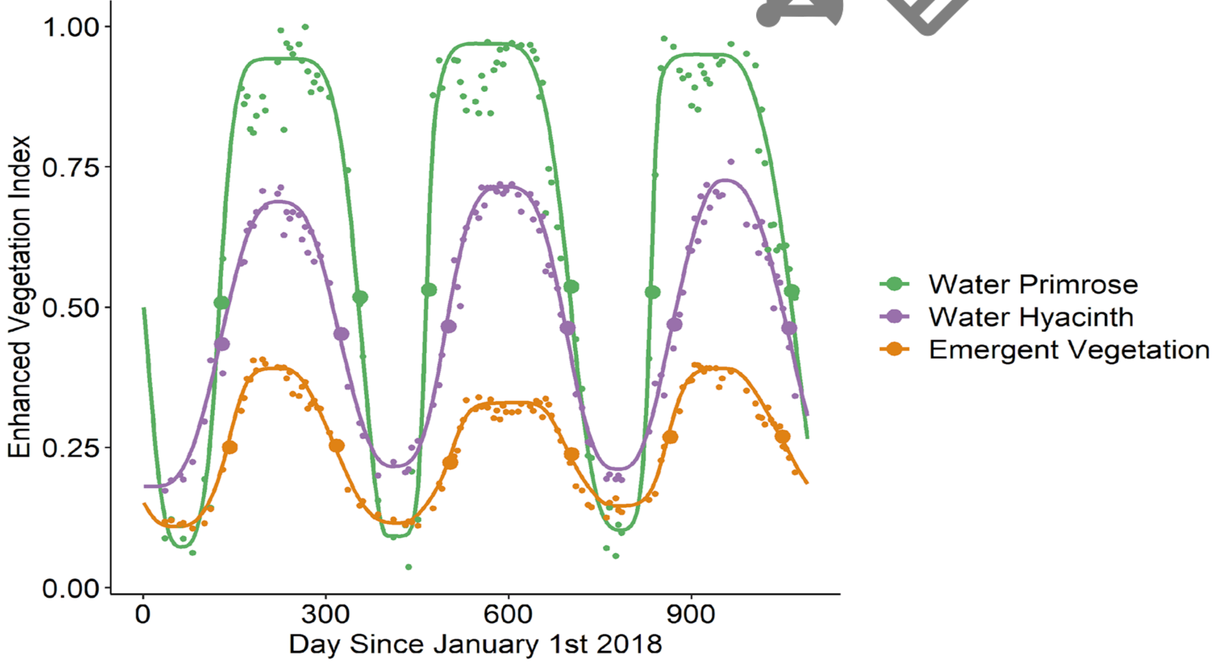
Ade et al. *In Prep*

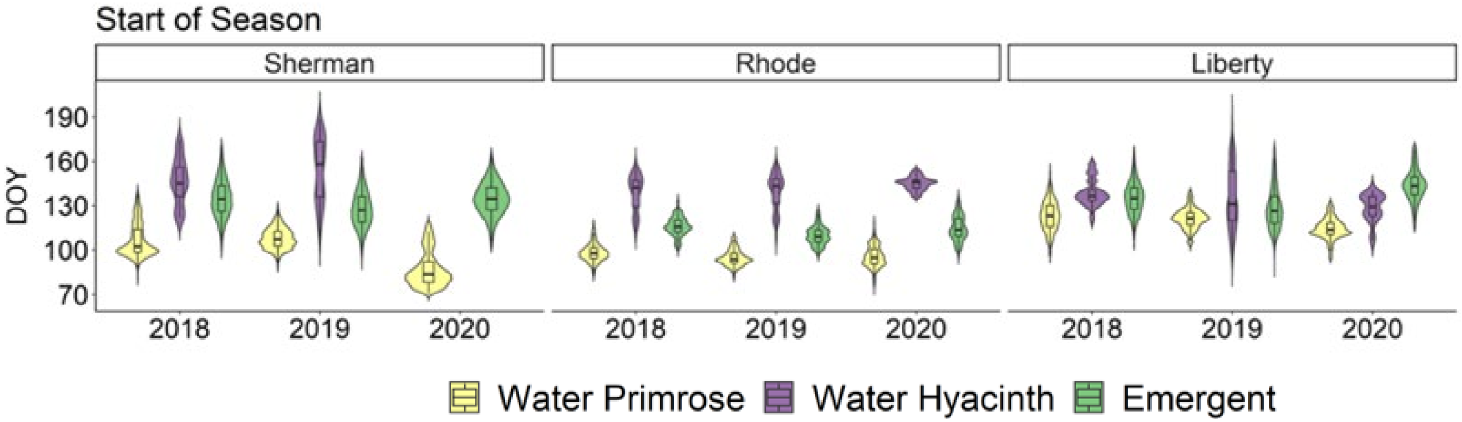
Phenology Characteristics Vary Across Vegetation Type

- Water primrose starts growing significantly earlier and has a longer growing season.
- Spatial variability in phenology indicates multiple invasion strategies.



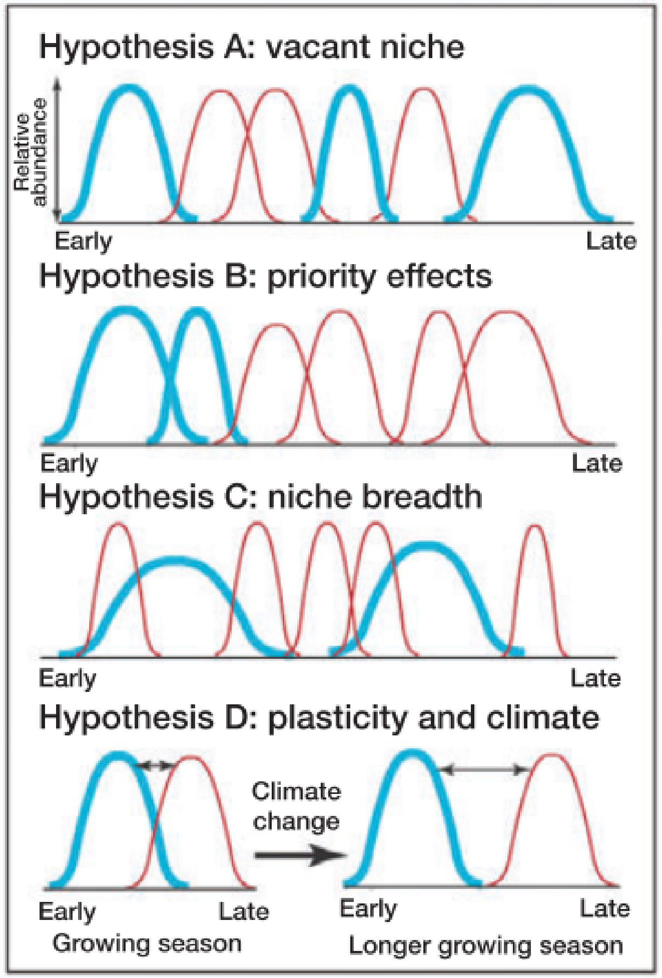
Start of Season 2020 (SoS)





Ade et al. *In Prep*

Phenology Implications for Management



Hypotheses	Predictions	Management opportunities
Hypothesis A: vacant niche	**A: vacant niche** Exotic species tend to leaf/bloom when native species are not in leaf/bloom	**A: vacant niche** Herbicide, grazing, fire and other removal programs targeted when exotic species are active and native species inactive
Hypothesis B: priority effects	**B: priority effects** Exotic species leaf/bloom earlier than native species	**B: priority effects** Targeted removal programs in the early season
Hypothesis C: niche breadth	**C: niche breadth** Length of leafing/ blooming period of exotic species is greater than for native species	**C: niche breadth** Targeted removal when exotic species are active and native species inactive
Hypothesis D: plasticity and climate	**D: plasticity and climate** Leafing/blooming of exotic species varies across seasons, covaries with climate	**D: plasticity and climate** Management programs when climate events increase phenological gap between native and exotic species

Wolkovich and Cleland (2011)

Part 2:
Summary

Summary

- Invasive aquatic plants modify environments, change ecosystem, and threaten biodiversity.
- Invasive aquatic plants have significant impacts to human health, livelihoods and economics.
- Remote sensing provides large scale, repeatable, consistent monitoring of vegetation functional types, and invasive genera and species.
  - Airborne imaging spectroscopy provides high-quality, high-resolution data for baseline maps and monitoring.
  - Drone data infeasible to deploy across scales – useful for sampling at high priority sites and monitoring targeted interventions.
  - Satellite data coupled with ML misses new invasions and small patches, but fills in temporal gaps for phenology and invasion dynamics.
  - Field surveys provide a critical link between and across datasets and scales and quantify uncertainty for managers.

Looking Ahead to Part 3

Monitoring of Invasive Grassland Species with Hyperspectral Remote Sensing

- Identify basic considerations for the application of hyperspectral data for mapping invasive plants.
- Outline the key benefits of remote sensing for mapping invasive plants compared to field-based techniques.
- Identify the limitations of remote sensing for mapping invasive plants.

Homework and Certificates

- **Homework:**
  - One homework assignment
  - Opens on 08/28/2024
  - Access from the training webpage
  - Answers must be submitted via Google Forms
  - **Due by 09/11/2024**

- **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.

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Resources

- Access aquatic plant maps from the Sacramento-San Joaquin River Delta here
- Access AVIRIS-NG data here
- Access AVIRIS-3 data here
- Access TIMESAT software here
- Link to Mongabay article.

Some Interesting References

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