Using Remotely Sensed Phenology to Monitor Biodiversity and Ecosystem Services in Wetlands

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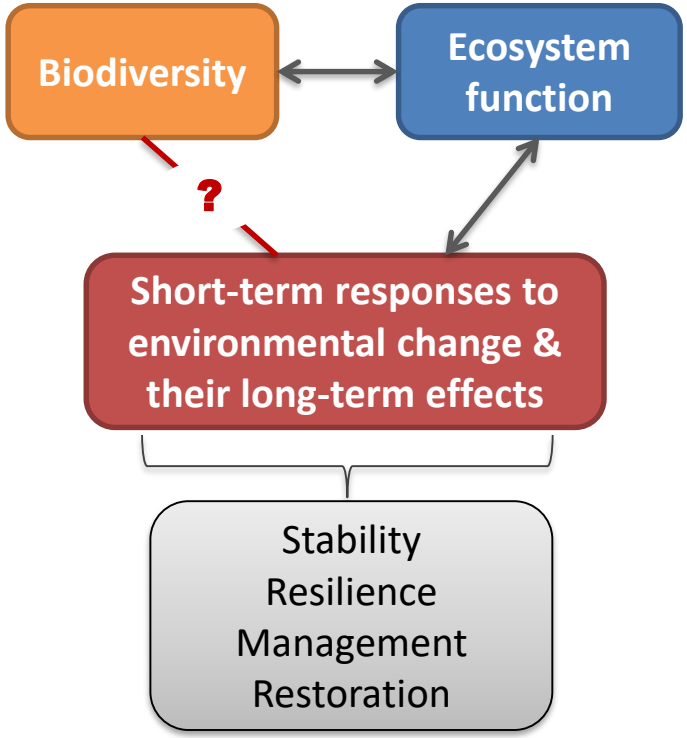
Biodiversity at national & global scales

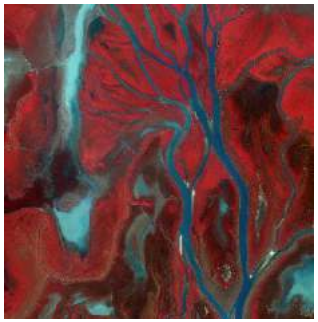
- Global efforts towards biodiversity indicators increasingly utilize remote sensing data
- Still limited understanding of biodiversity relationships with phenological variability
  - Long-term stability & diversity of responses to stressors
  - Short-term variation & tipping points (Botero et al. 2015 PNAS)
- Potential for cost-effective "leading" indicators of change & biodiversity



Wetlands as a ‘model’ study system

Wetlands as a 'model' study system

- Critical global losses of wetland area & ecosystem services:
  - ~64–71% of wetlands lost since 1900 AD (Davidson 2014)
  - >50% U.S. wetlands lost in the 19-20th century (Klemas 2013)
- Scenarios of both **diversity** and spatio-temporal **heterogeneity**
  - Land-water ecotone gradients
  - Inundation, invasions, disturbance
- Difficult to monitor with field methods alone
  - Need for cost effective remote sensing-based indicators for conservation & restoration efforts at different scales



Poyang Lake, PR China

Suisun Marsh, CA, USA

Photo by Sophie Taddeo

Key research targets

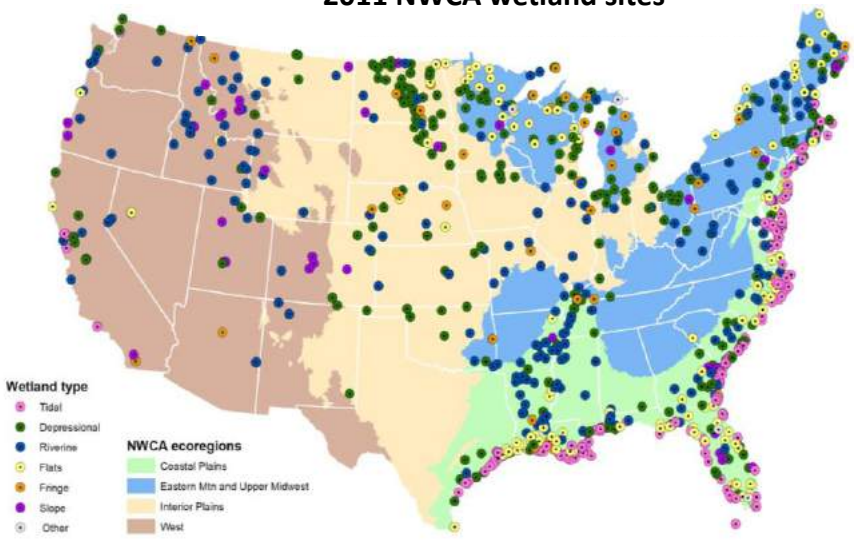
1) **Potential of broadband multi-spectral multi-date imagery for monitoring wetland plant diversity**
   - How does biological diversity of vegetation in wetland ecosystems affect spatio-temporal variation in their phenological characteristics?

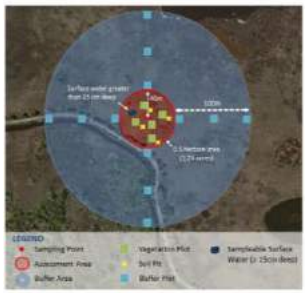
2) **Potential for detecting & predicting ecosystem changes that may affect diversity shifts over time**
   - Can phenological characteristics of wetlands elucidate their ecological condition, stability and response to stressors affecting their ecosystem services at different scales?

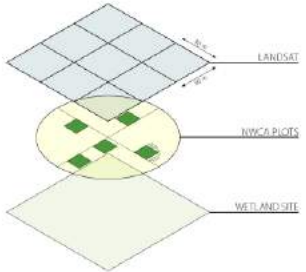
National Wetland Condition Assessment (NWCA)

- Collaborative wetland survey effort led by U.S. Environmental Protection Agency
- 1,138 field sites from 4 major wetland types & 4 ecoregions
- Comprehensive data on vegetation composition, diversity, site conditions & aggregate disturbance status
- Surveys: spring-summer 2011
  - follow-up survey in 2016 (not yet released)

2011 NWCA wetland sites







Sampling design of NWCA sites (US EPA 2016)
https://www.epa.gov/national-aquatic-resource-surveys/nwca

Remote sensing products

Disturbance status as defined in NWCA	Sensor or product	Spatial resolution, m	Spectral regions
Primary (2011 & later NWCA)	**Landsat**	**30**	**Visible, NIR, SWIR**
	MODIS	**250**	**Red,NIR**
	MODIS	**500**	**Visible, NIR, SWIR**
Secondary (2016 & future NWCA)	Sentinel-2	10-30	Visible, NIR, SWIR
	Harmonized Landsat+ Sentinel-2	10	Visible, NIR, SWIR
	PlanetLabs satellites	3-5	Visible, NIR, red edge
Ancillary (intermittent & geographically variable)	NAIP aerial imagery	1	Visible, NIR

Diversity-spectral indicator models using 2011 data

- **Spectral greenness:** expect positive effect on plant diversity
  - Diversity effects on biomass & productivity, complementarity

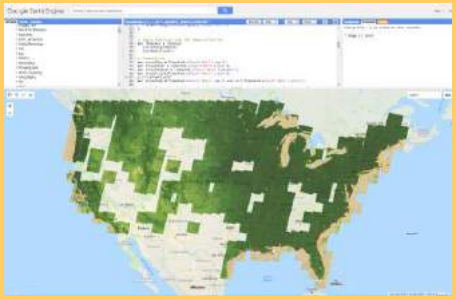
$$NDVI = \frac{NIR - Red}{NIR + Red} \qquad LSWI = \frac{NIR - SWIR1}{NIR + SWIR1}$$

$$GNDVI = \frac{NIR - Green}{NIR + Green} \qquad SAVI = \frac{1.5 * (NIR - Red)}{(NIR + Red + 0.5)}$$

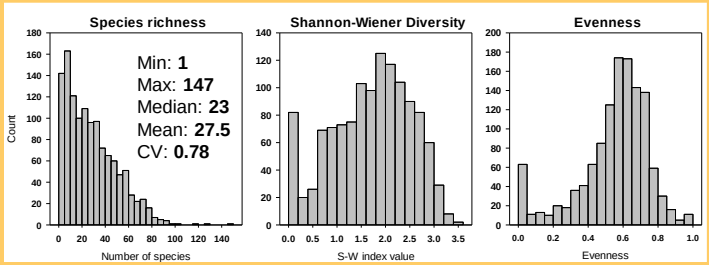
$$EVI = 2.5 * \frac{NIR - Red}{NIR + 6 * Red - 7.5 * Blue + 1} \qquad GCC = \frac{Green}{(Red + Blue)}$$

- **Spectral heterogeneity:** expect positive effect on plant diversity
  - Environmental & compositional gradients, zonation of plant communities

- **Greenness & heterogeneity: annual maximum** of per-pixel index value (site-averaged) & its **standard deviation**
- **RS data:** 2011 Landsat 5 TM & 7 ETM+
  - **#images:** ~298 tiles, ~22 dates per year before cloud masking
  - processing: Google Earth Engine API

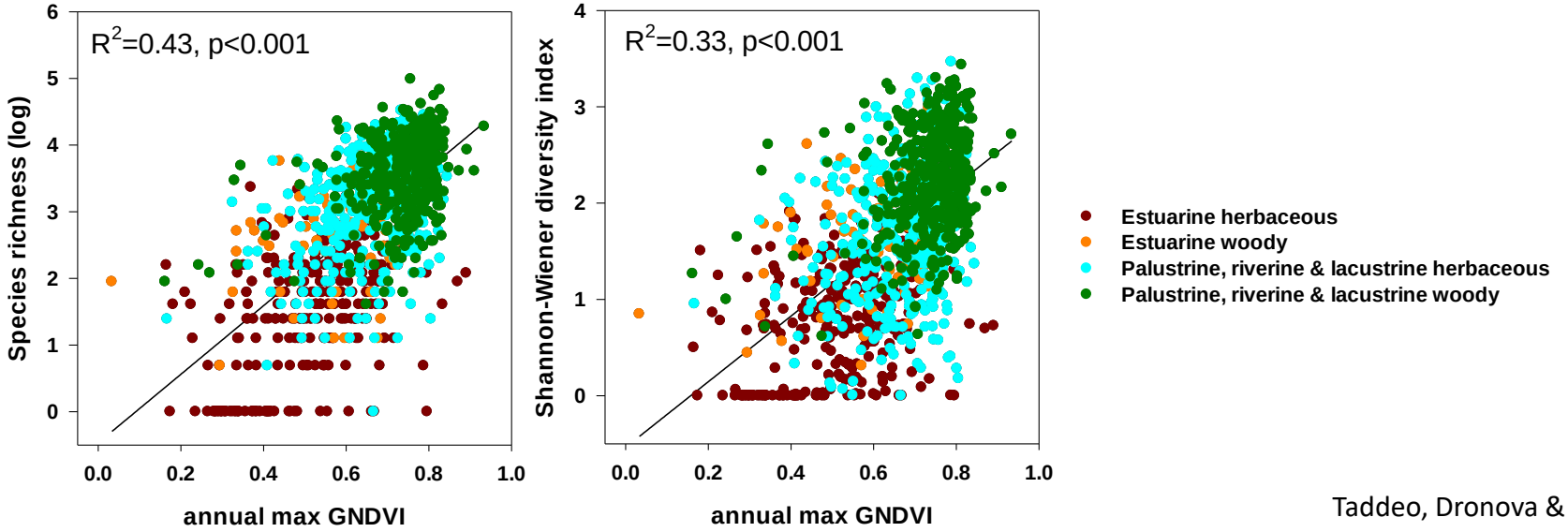


- **Response:** selected NWCA diversity metrics



Plant diversity & greenness

- Significant positive associations of annual-maximum, site-average greenness proxies with different proxies of diversity
  - Stronger effects for species richness than Shannon diversity
  - Stronger effects with native species diversity
  - Stronger effects in least disturbed systems
- GNDVI and EVI performed consistently better than NDVI, GCC, SAVI or LSWI



Taddeo, Dronova & Harris
Revisions under review, Ecological Applications

Multivariate models for total species richness & diversity

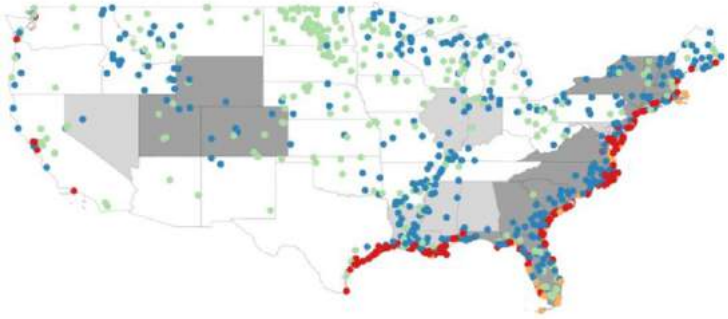
- Heterogeneity, though significant ($p<0.001$), added only 1-2% variance to greenness models
- Spectral greenness & heterogeneity explain more variation than non-spectral abiotic factors taken alone

Predictor sets	%Variance explained
Annual composite of greenness	up to 42%
Spectral heterogeneity + greenness	up to 43-44%
Non-spectral abiotic factors (elevation, climate, soil pH & selected site features)	up to **30-35%**
Multivariate models with both spectral & abiotic variables	up to **61%**

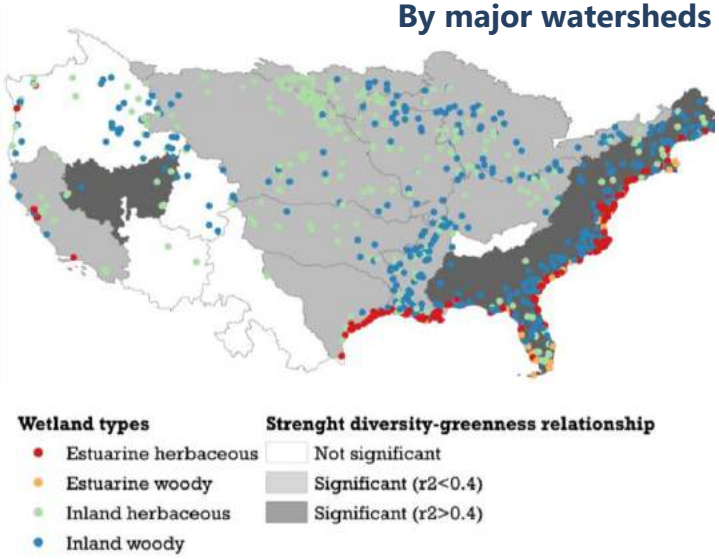
Similar models at other levels of regional aggregation

- Conterminous U.S. states
  - adjR^2 up to 61-73%
- Major watersheds
  - adjR^2 up to 77-80%
- Stronger fit in units with more wetland types
  - the importance of gradients & local hydrological networks (Bedford 1996 Ecol Appl)
- Potential for monitoring at local management & restoration scales

By U.S.A. states



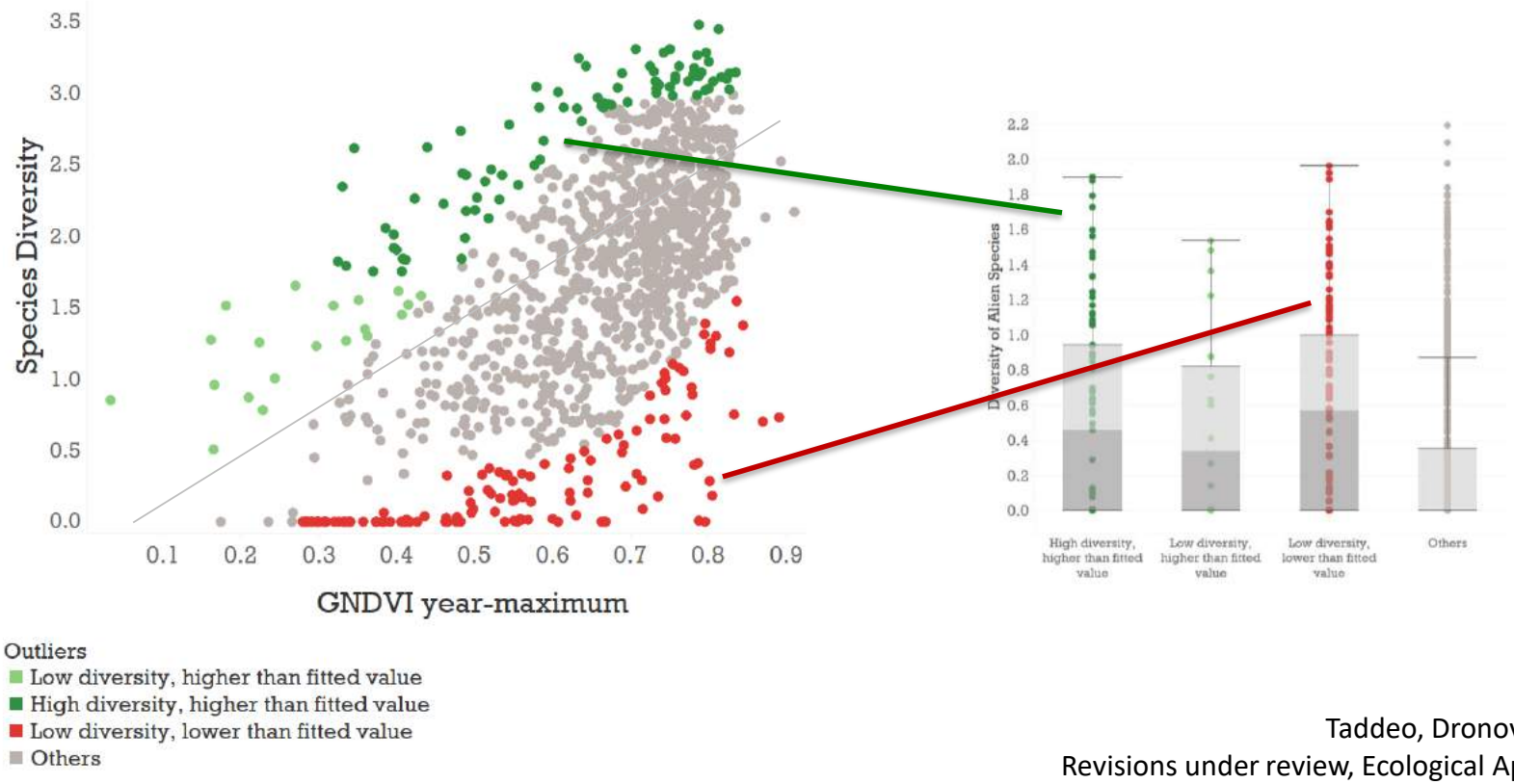
By major watersheds



Taddeo, Dronova & Harris, under review

Other insights: informative outliers

- Both high diversity, higher than expected and low div, lower than expected are characterized by higher diversity of non-native species
- Current work: investigating the effects of specific alien taxa



Taddeo, Dronova & Harris
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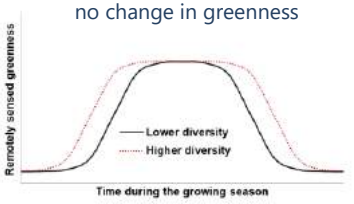
Current work: plant diversity, phenology & long-term ecosystem change

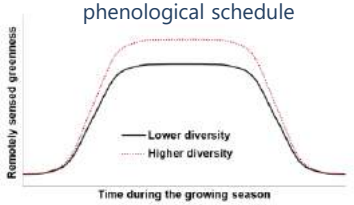
- **Seasonal:** does greater plant diversity increase phenological complementarity?
  - Controversial evidence to date
  - Anticipating climate change effects on phenology, diversity & stability
- **Inter-annual:** does greater plant diversity translate into inter-annual stability of phenological responses?
- **Long-term:** do long-term trends in wetland phenology elucidate vulnerability to stressors?
  - Using satellite data series since 1985 & disturbance status in NWCA surveys

Potential diversity effects on seasonal greenness

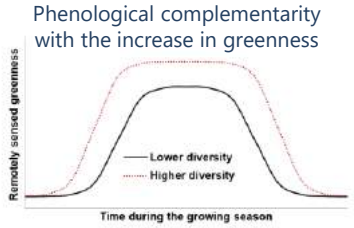
Phenological complementarity, no change in greenness



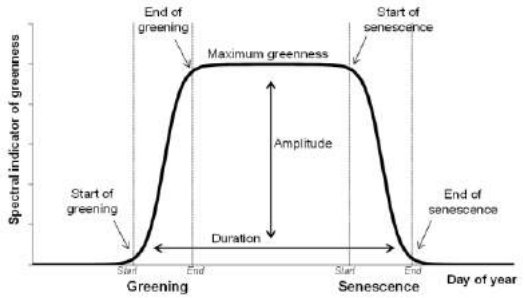
Increase in greenness, similar phenological schedule

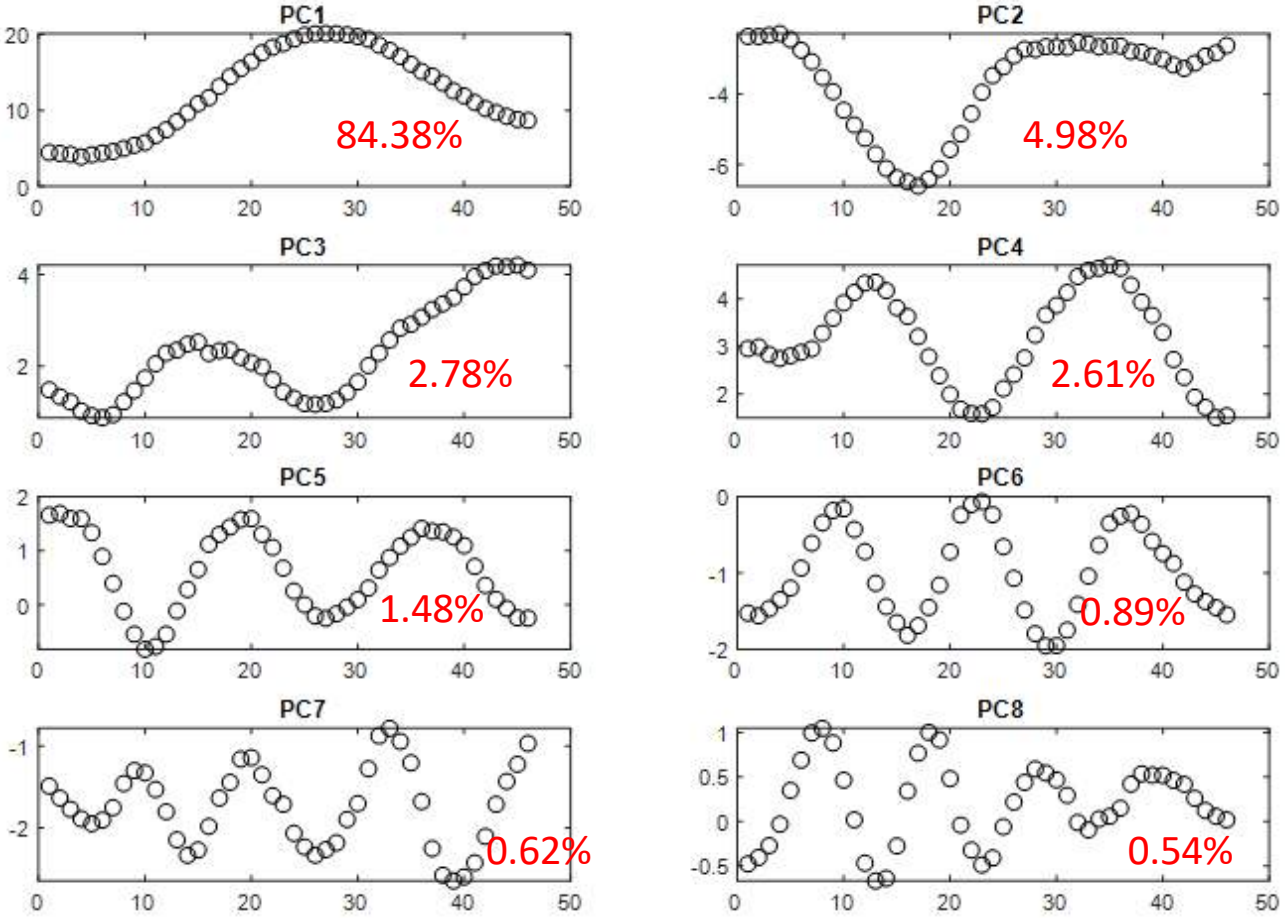


Phenological complementarity with the increase in greenness



Phenological typologies of NWCA wetlands





Uncertainty assessments

The effects of image availability

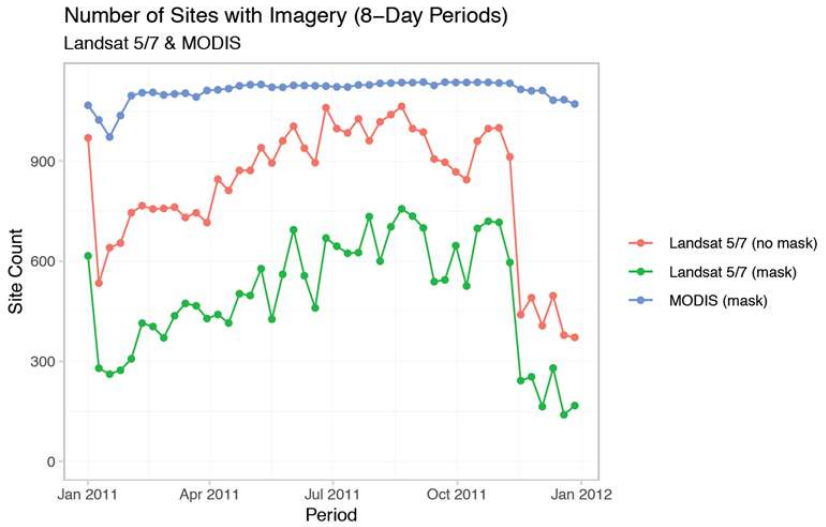
- Variation in frequency & seasonal coverage of cloud-free images in space & among different years

Temporal consistency of metrics & ecological relationships

- Sites surveyed twice in 2011 (~7%)
- 2016 NWCA survey+future

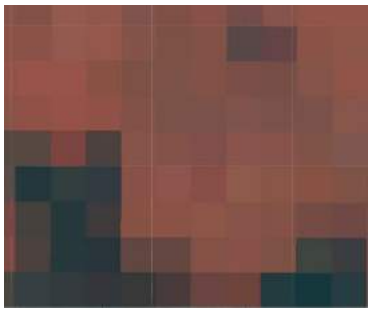
The effects of spatial resolution

- Higher-resolution phenology for selected geographic regions (PlanetLabs, Sentinel-2)



Aerial (1m)

Landsat (30m)



Thank you!

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