Cyanobacteria Bloom Assessment using Satellite Observations

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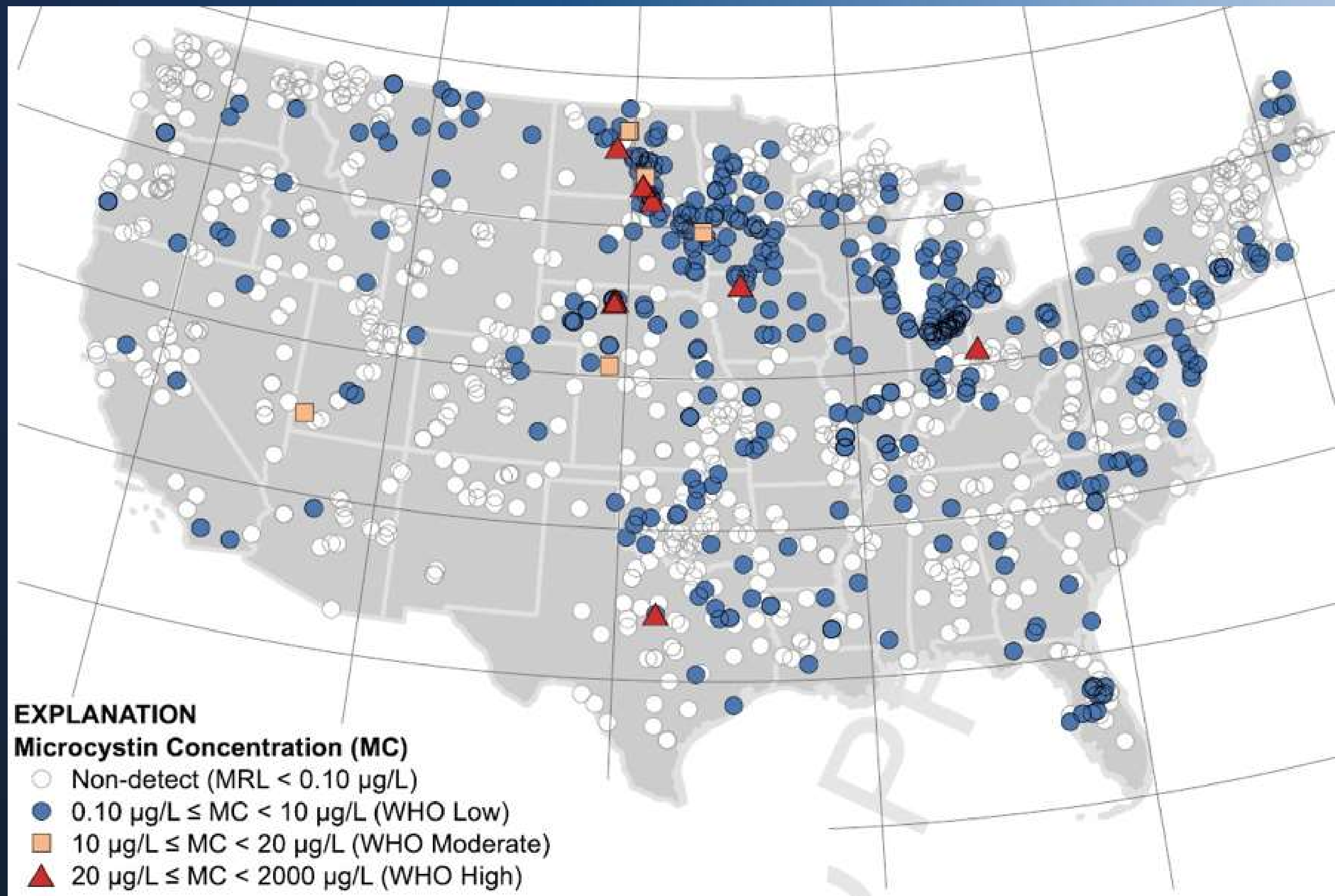
Overview

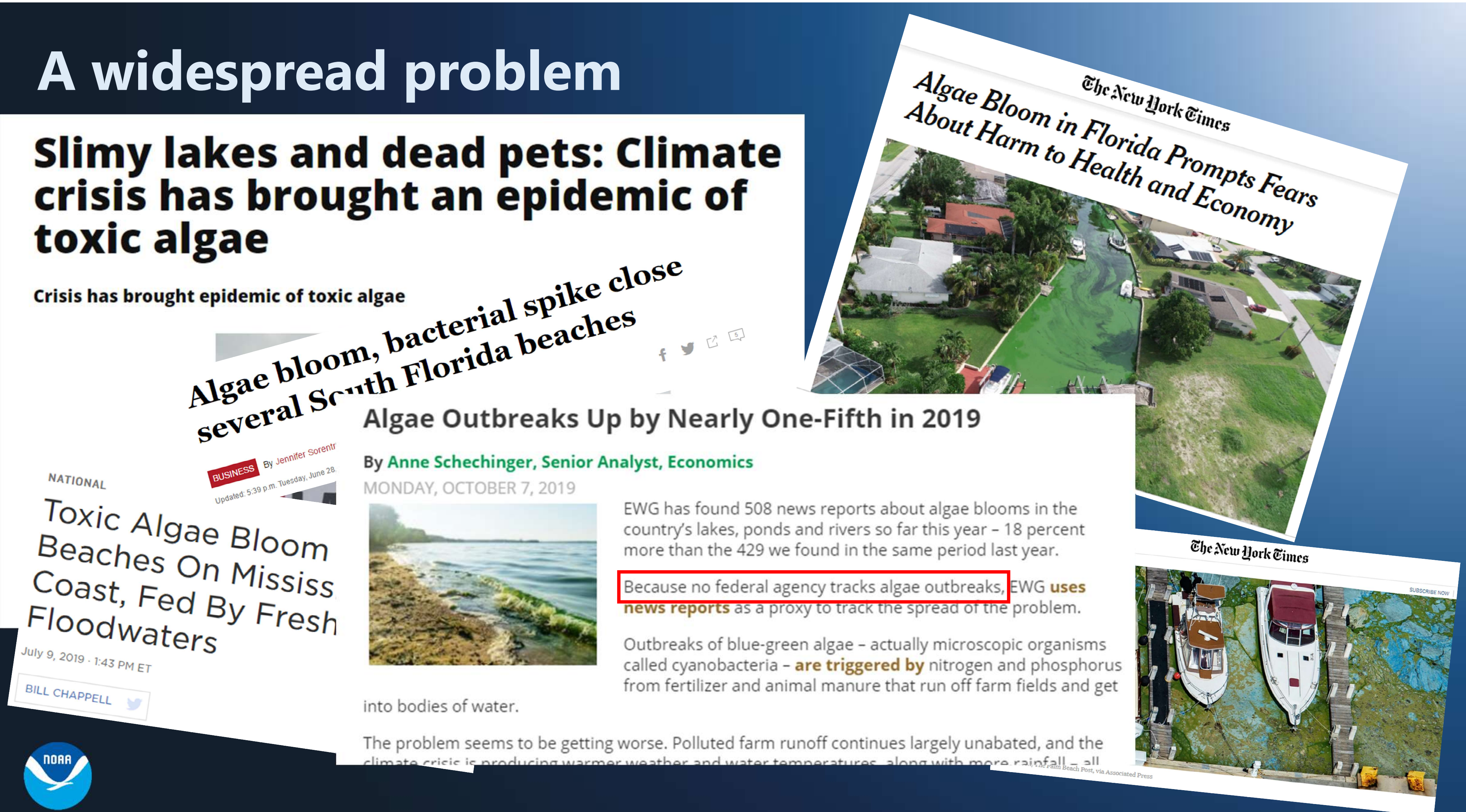
- CyanoHABs as a widespread problem
- Satellite data and methods for CyanoHAB assessment
- Introducing a new bloom metric - **Bloom Magnitude**
- A case study in Florida and Ohio
- What is the current status of the CyanoHABs in the U.S.?
- How it has changed since the last decade?

Distribution of HABs in the U.S.



Loftin et al. (2016)
https://toxics.usgs.gov/highlights/2016-05-31-cyanotoxins_in_lakes.html

A widespread problem



Slimy lakes and dead pets: Climate crisis has brought an epidemic of toxic algae

Crisis has brought epidemic of toxic algae

Algae bloom, bacterial spike close several Sc…uth Florida beaches

BUSINESS By Jennifer Sorentr…
Updated: 5:39 p.m. Tuesday, June 28…

NATIONAL

Toxic Algae Bloom … Beaches On Mississ… Coast, Fed By Fresh… Floodwaters

July 9, 2019 · 1:43 PM ET

BILL CHAPPELL

Algae Outbreaks Up by Nearly One-Fifth in 2019

By Anne Schechinger, Senior Analyst, Economics

MONDAY, OCTOBER 7, 2019

EWG has found 508 news reports about algae blooms in the country's lakes, ponds and rivers so far this year – 18 percent more than the 429 we found in the same period last year.

Because no federal agency tracks algae outbreaks, EWG **uses news reports** as a proxy to track the spread of the problem.

Outbreaks of blue-green algae – actually microscopic organisms called cyanobacteria – **are triggered by** nitrogen and phosphorus from fertilizer and animal manure that run off farm fields and get into bodies of water.

The problem seems to be getting worse. Polluted farm runoff continues largely unabated, and the climate crisis is producing warmer weather and water temperatures, along with more rainfall – all…

The New York Times

Algae Bloom in Florida Prompts Fears About Harm to Health and Economy

The New York Times

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…The Palm Beach Post, via Associated Press

Cyanobacteria Assessment Network (CyAN)

- A multi-agency project carried out by EPA, NOAA, NASA, and USGS
- Goal: Create a national assessment and monitoring capability for cyanobacterial blooms in lakes using satellite observations
- Uses cyanobacteria Index (CI) products from MERIS and Sentinel-3 Ocean Land Color Imager   (OLCI)

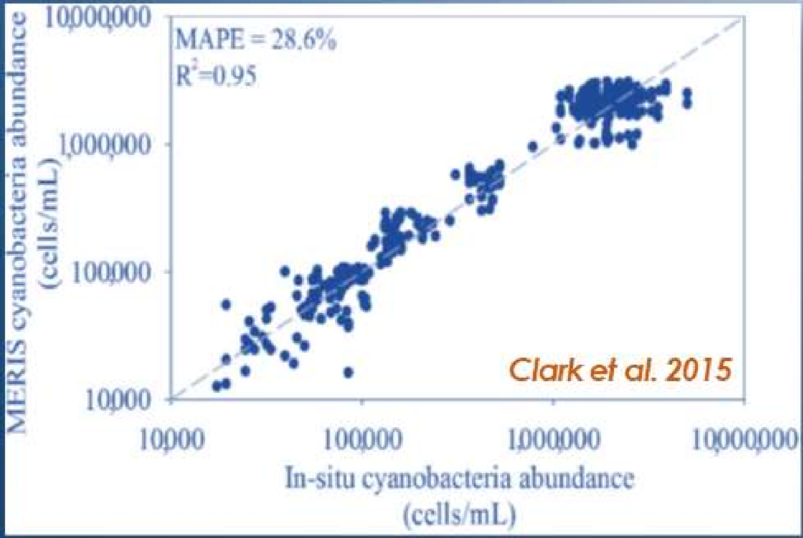
Why do we need a new bloom metric?

- Most of the existing remote sensing research focused on detecting and quantifying the cyanobacteria biomass
- Resource managers have limited resources for assessment and monitoring of lakes for public and environmental health
- There was a need of a metric that focuses on the magnitude of CyanoHABs for determining viable lake management strategies

Cyanobacteria Index (CI)

A CyanoHAB biomass indicator

- Spectral shape based algorithm to detect and quantify cyanobacteria
  (Wynne et al, 2008; Stumpf and Werdell, 2010)



$$SS(\lambda) = \rho_S(\lambda) - \rho_S(\lambda_-) + \{\rho_S(\lambda_-) - \rho_S(\lambda_+)\}\frac{(\lambda - \lambda_-)}{(\lambda_+ - \lambda_-)}$$

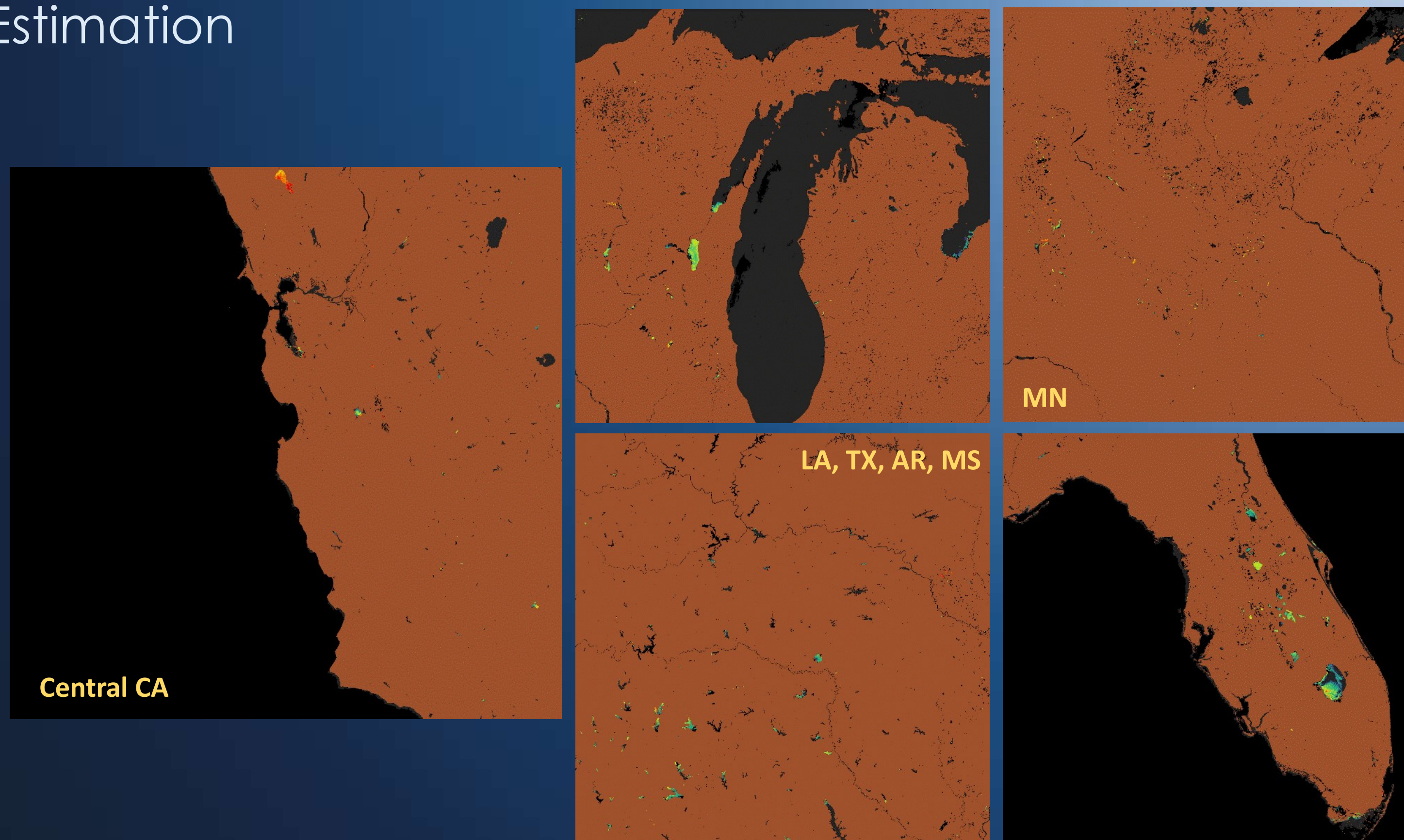
- It has been used for bloom monitoring in the Lake Erie, lakes in California, and Florida

- Correlates very well with cyanobacterial chl-a concentration and cell density

Satellite Data

For Bloom Magnitude Estimation

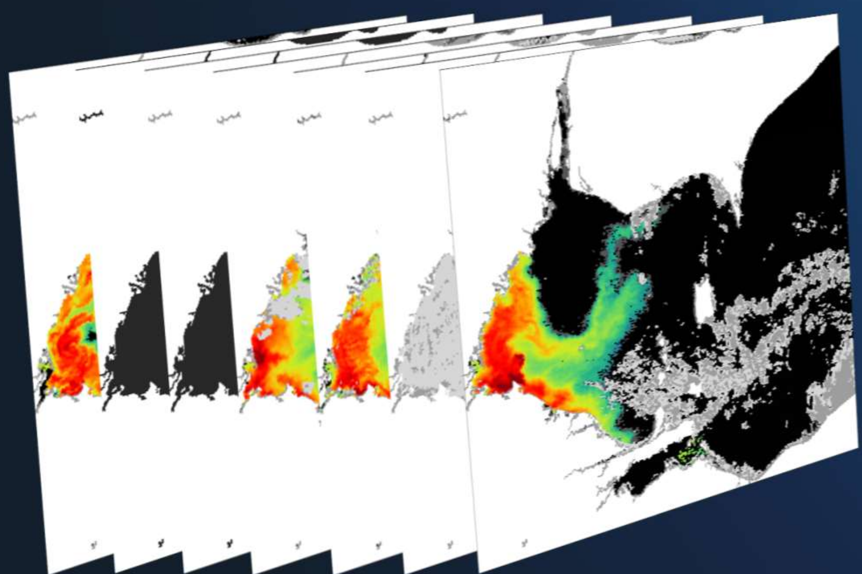
- *Rayleigh-corrected* Surface Reflectance (ρ_s)
- Sensors
  - MERIS: (2008-2011)
  - OLCI: (2016-2018)
- Daily CI to composites
  - 7 Day max (2008-2011, 2016-2018)
- CI composites provides estimates of areal cyanobacterial biomass



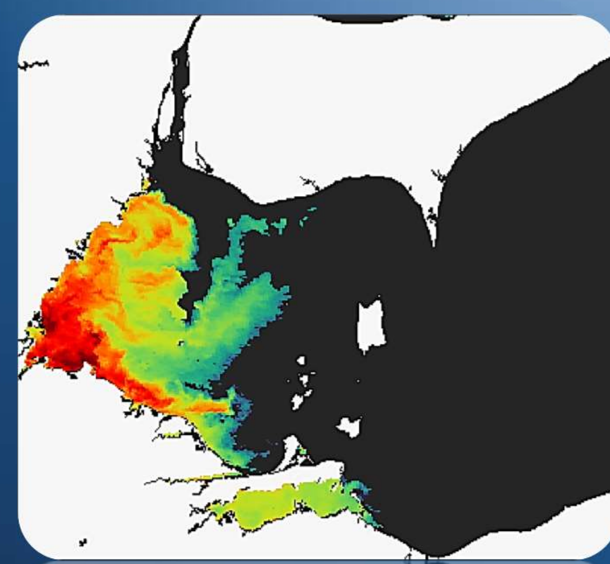
7-day Max Composite of Cyanobacteria Index (CI)
300x300 m pixel resolution

CI-max Composite

Compositing method



July 30 2019 … … … … … … … … … Aug 05 2019



Defining Bloom Magnitude

Addresses three key characteristics

- Intensity (biomass, concentration)
- Duration
- Time representation (seasonal/summer, annual)

Daily CI Images
Biomass (cells ml^{-1})

→ **CI Max Composite**
7-day | 14-day

→ **Spatiotemporal seasonal mean**

Defining Bloom Magnitude

Bloom Magnitude

Spatiotemporal mean of cyanobacteria biomass in a lake over a time period

$$\frac{1}{M}\sum_{m=1}^{M}\frac{1}{T}\sum_{t=1}^{T}\sum_{p=1}^{P} CI\text{-}cyano_{p,t,m}$$

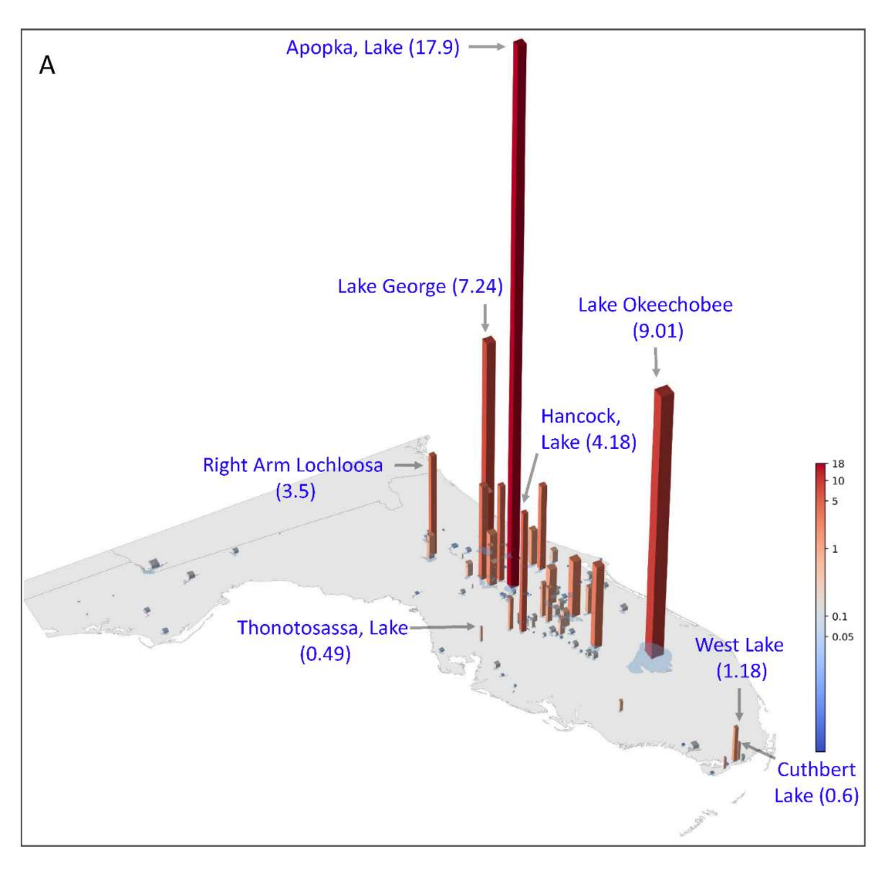
Area-normalized magnitude

Bloom magnitude normalized by the lake area (km^2)

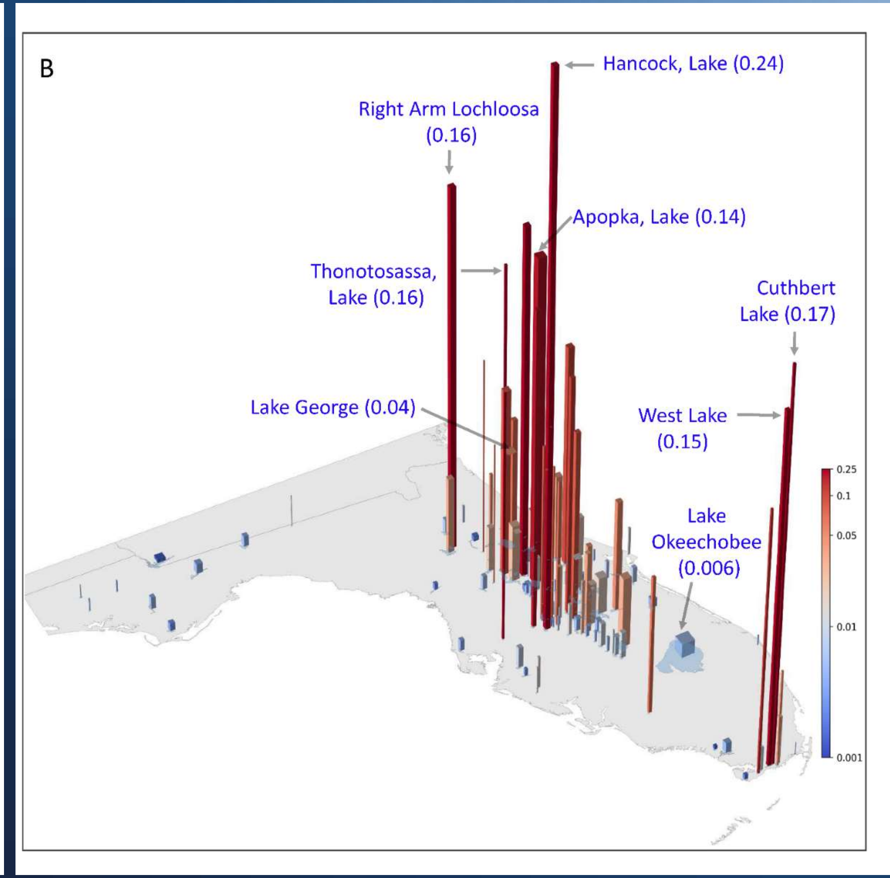
Scientific Reports, Mishra et al. 2019

Comparing 'Total' and Area-normalized Magnitude

Bloom magnitude
2011



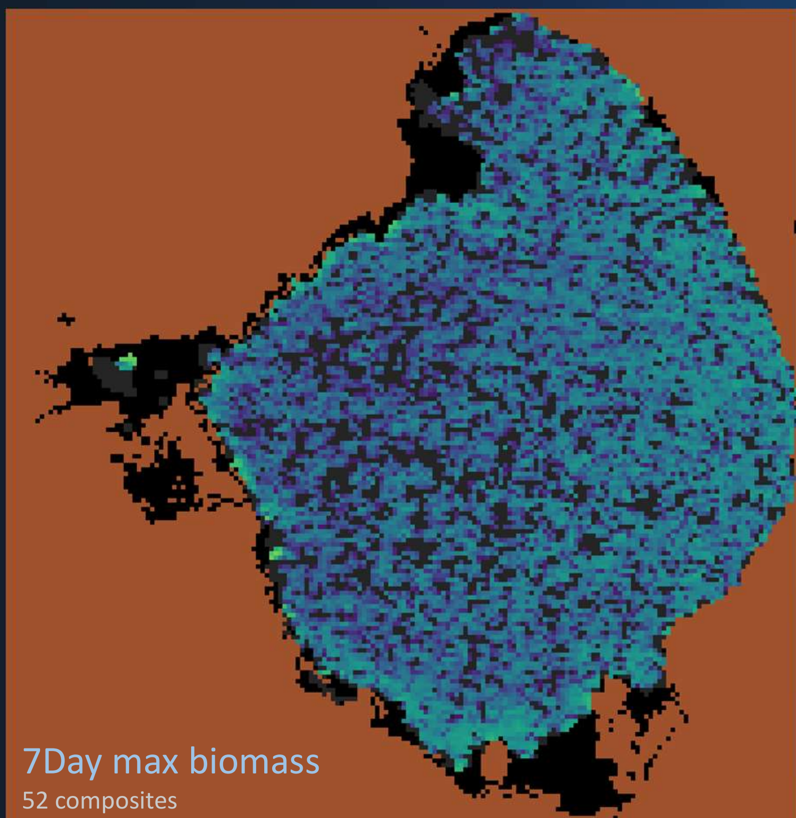
Area-normalized magnitude
2011



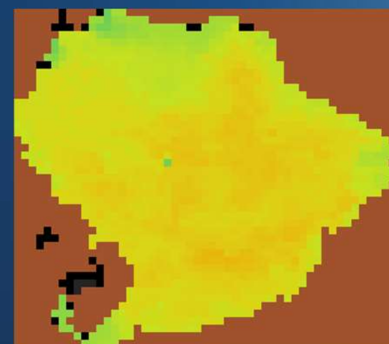
Scientific Reports, Mishra *et al.* 2019

Cyanobacterial Biomass Time series (2011)

Lake Okeechobee, FL
551 sq. miles

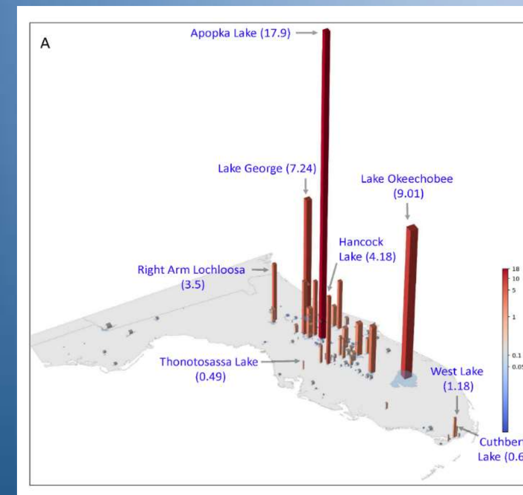


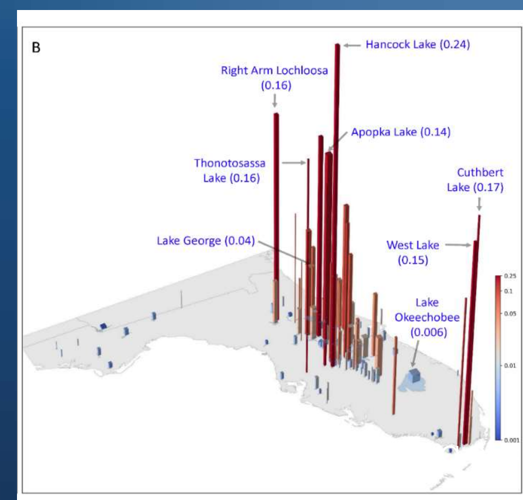
Lake Apopka, FL
46.9 sq. miles



Lake Hancock, FL
17 sq. miles

(Not to scale)





Ranking of Lakes

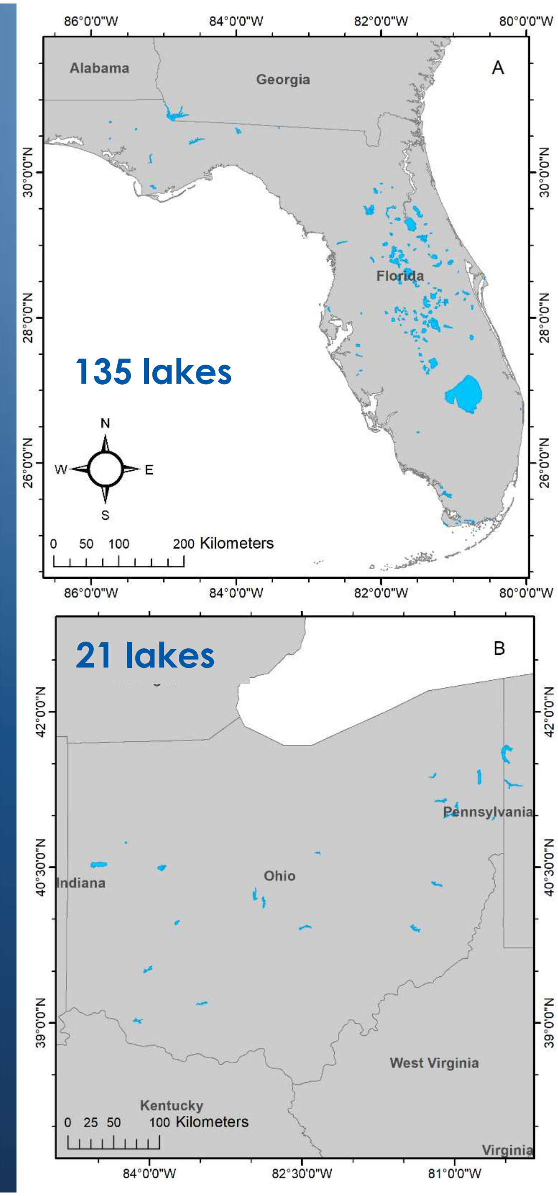
- Lakes were ranked based on their seasonal or annual area-normalized magnitude (Rank 1: Most severe CyanoHAB issue)
- Each lake's median rank for the observational period was used to summarize across years
- Non-parametric statistic such as, Theil-Sen's slope was used for assessing trends in the lake ranks; and Kendall's τ for strength of the trend
- Ranking addresses unequal data coverage issue across states

Case Study
in
Florida and Ohio

Study Area

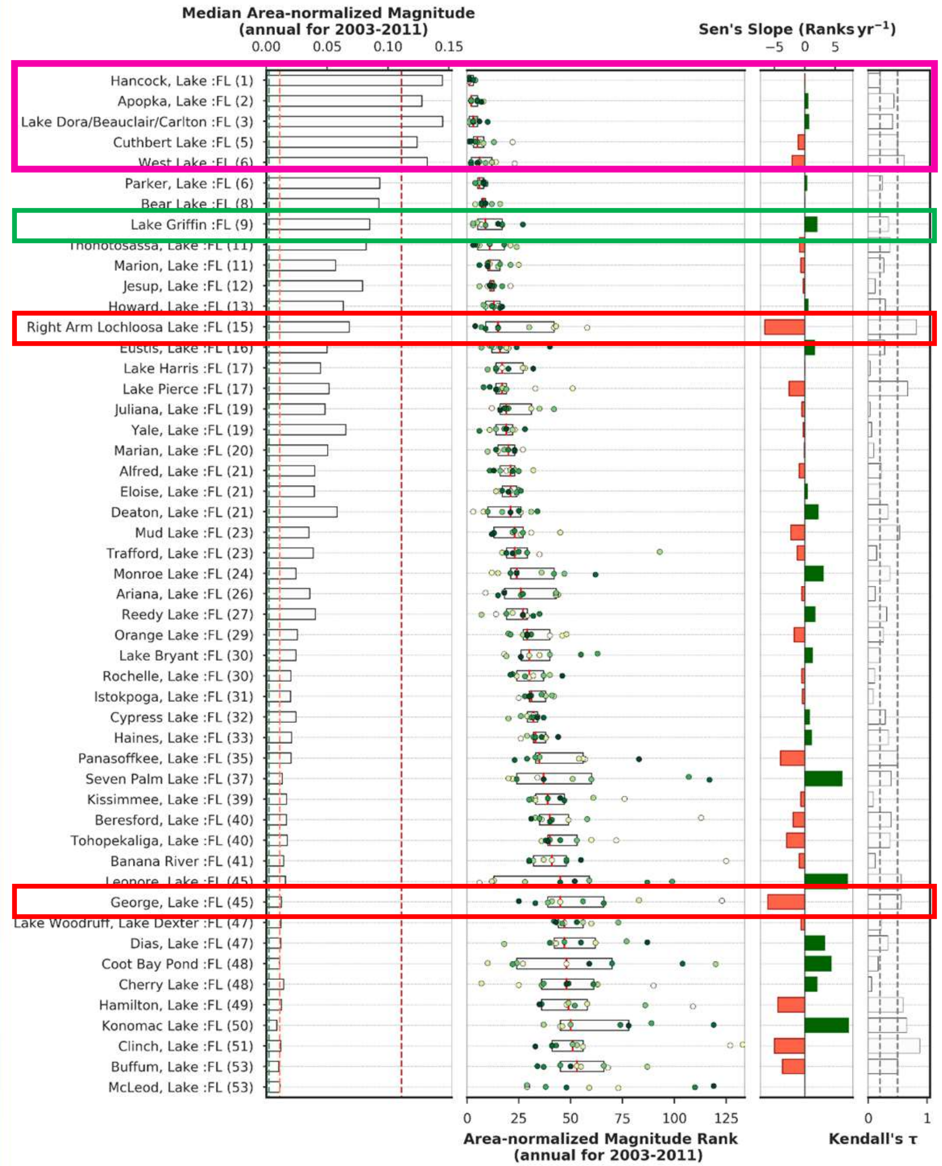
Florida and Ohio were selected

1. Lakes are known to have CyanoHAB related water quality issues
2. Different geographic and climatic regimes.



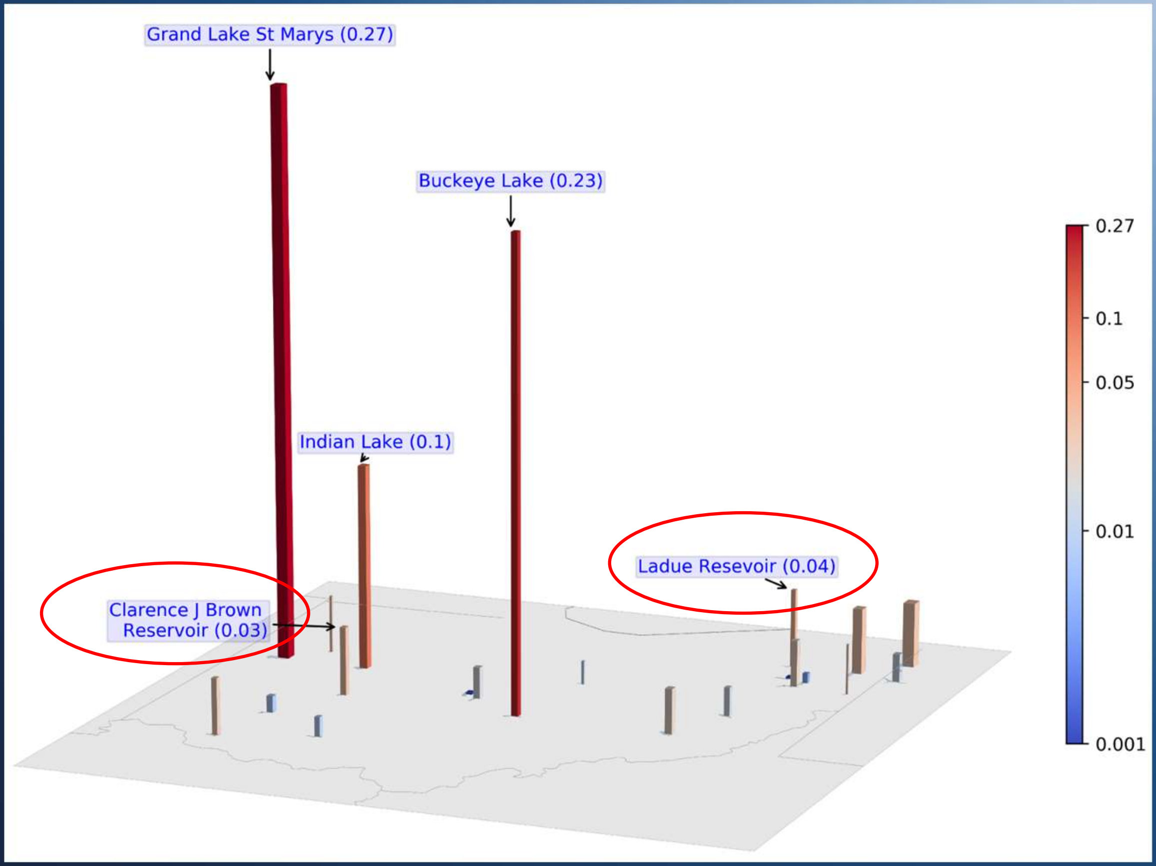
Normalized Bloom Magnitude in Florida

- Hancock Lake, Lake Apopka, Lake Dora/Beauclair/Carlton, Cuthbert Lake, and West Lake were the top five lakes based on annual area-normalized magnitude
- Top-ranked Florida lakes exhibited little variation over time
- Right Arm Lochloosa and Lake George declined at ~6 ranks yr^{-1}

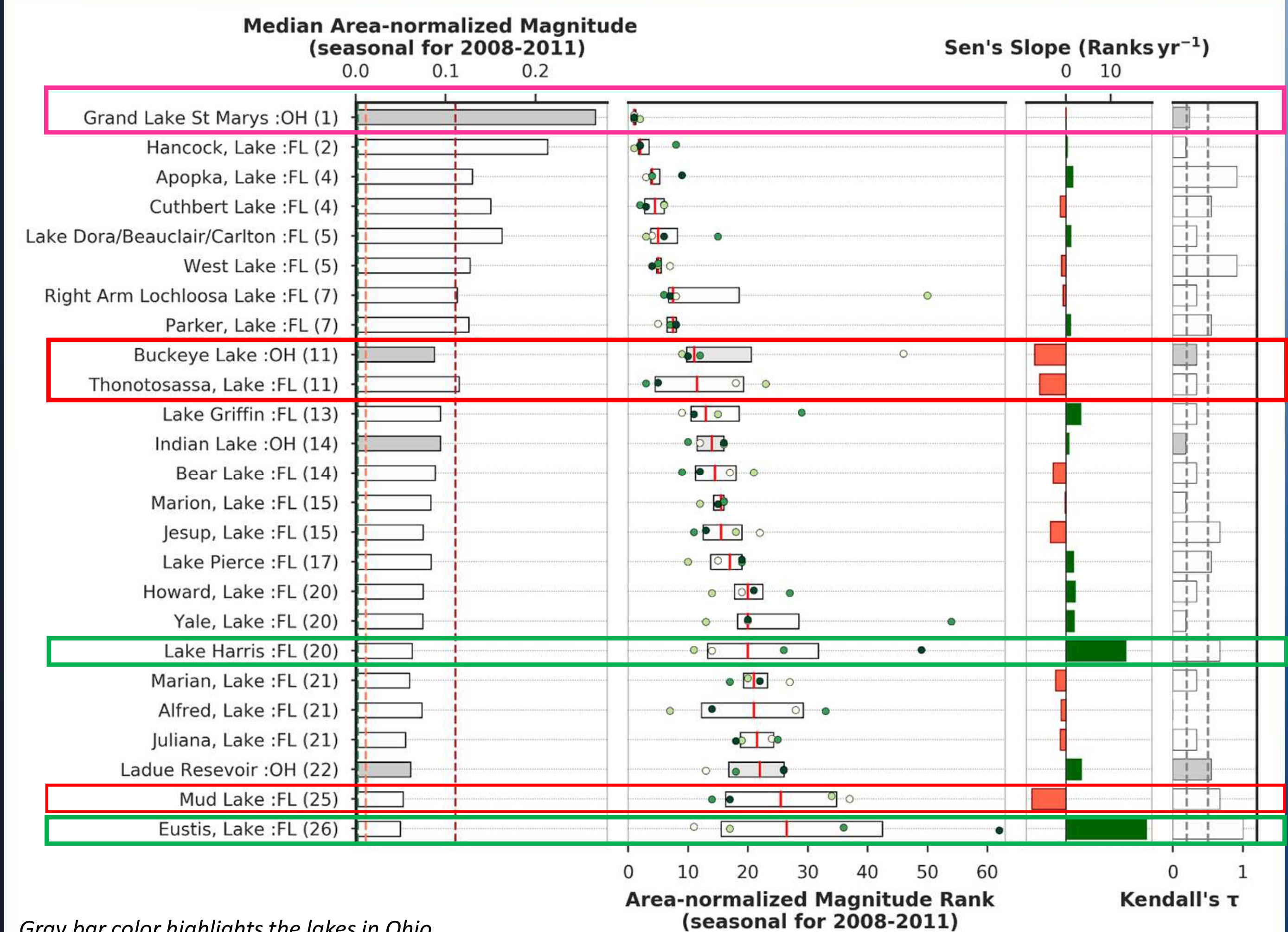


Normalized Bloom Magnitude in Ohio

- Grand Lake St. Marys, Buckeye Lake, and Indian Lake were the top three lakes by median area-normalized magnitude ranks
- Substantial differences in CyanoHAB magnitude among different Ohio Lakes
- Ladue Reservoir and Clarence J. Brown Reservoir deteriorated over time (~1–1.5 ranks yr^{-1}).



Bloom Magnitude in Florida and Ohio



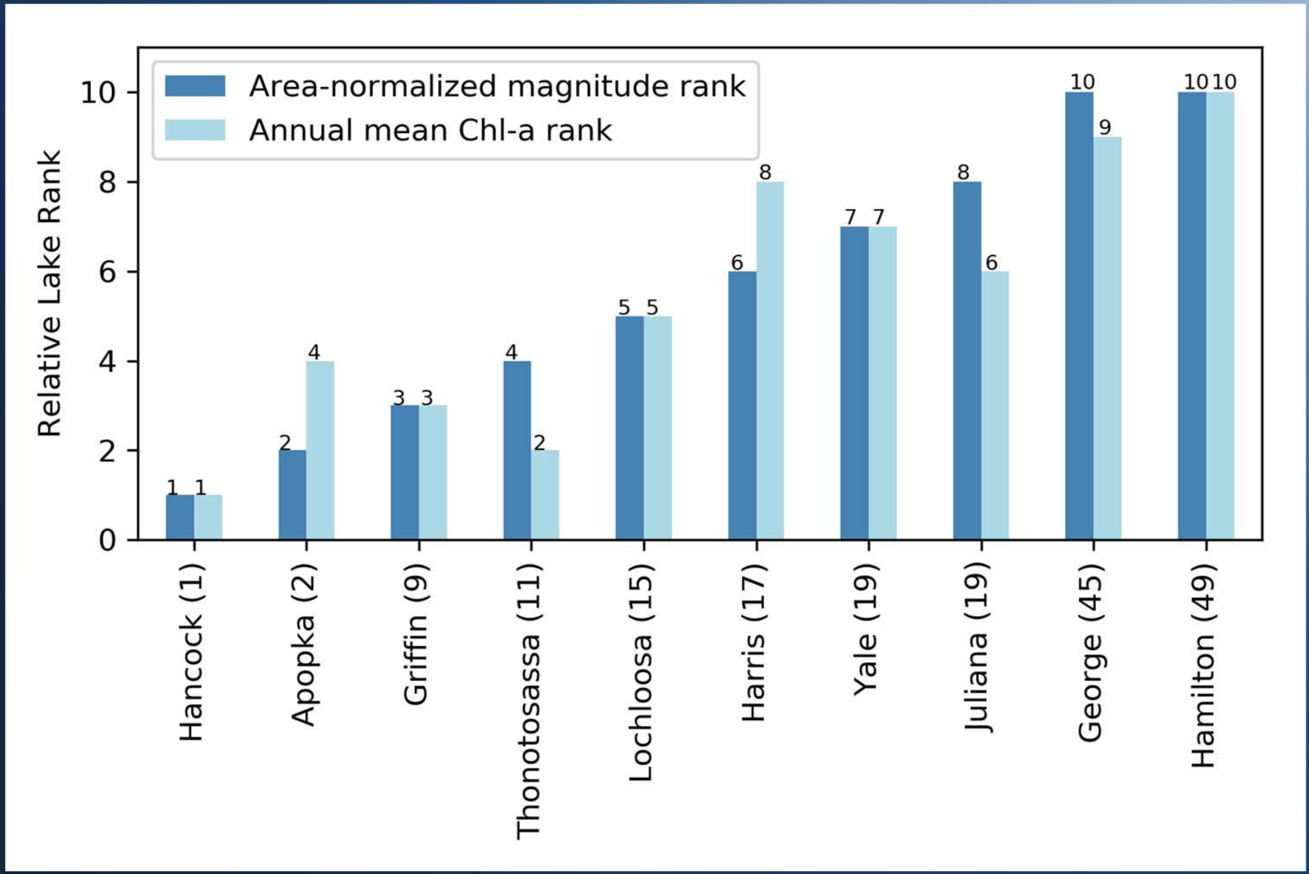
Gray bar color highlights the lakes in Ohio

Lake Rank Validation in Florida

based on field-measured mean Chl-*a* concentration

Lake Management Implications

Given there was no field observations, could the lake manager prioritize key lakes based solely on satellite-derived bloom information?



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Measurement of Cyanobacterial Bloom Magnitude using Satellite Remote Sensing

Sachidananda Mishra[1,2*], Richard P. Stumpf[2], Blake A. Schaeffer[3], P. Jeremy Werdell[4], Keith A. Loftin[5] & Andrew Meredith[1,2]

Bloom Assessment in the Lakes of the Contiguous United States (CONUS)

CONUS Satellite Dataset

Historical

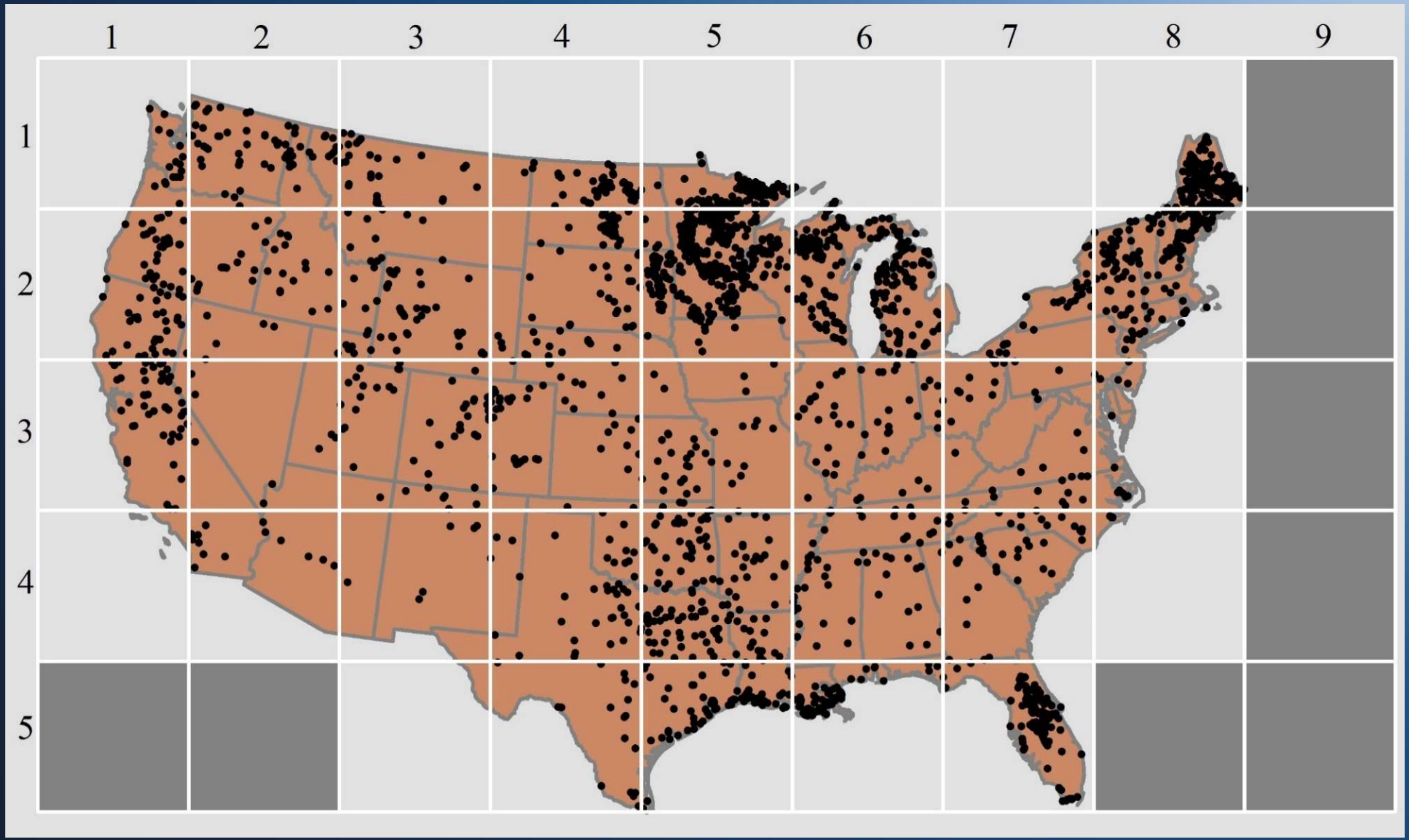
Timeframe: 2008-2011
Sensor: MERIS
Resolution: 300x300 m

Current

Timeframe: 2016-2018
Sensor: OLCI
Resolution: 300x300 m

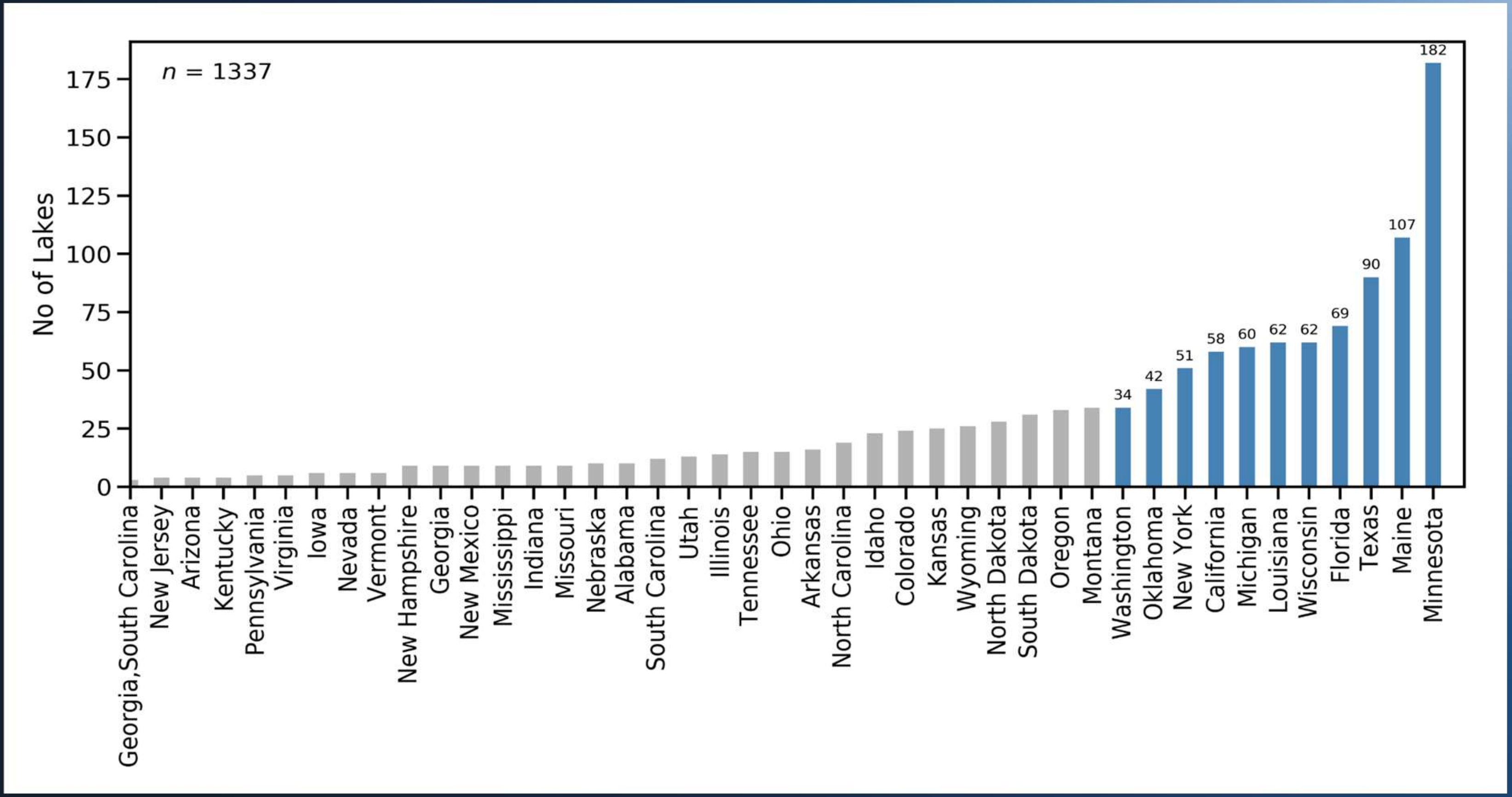
CONUS Coverage

37 tiles covering CONUS



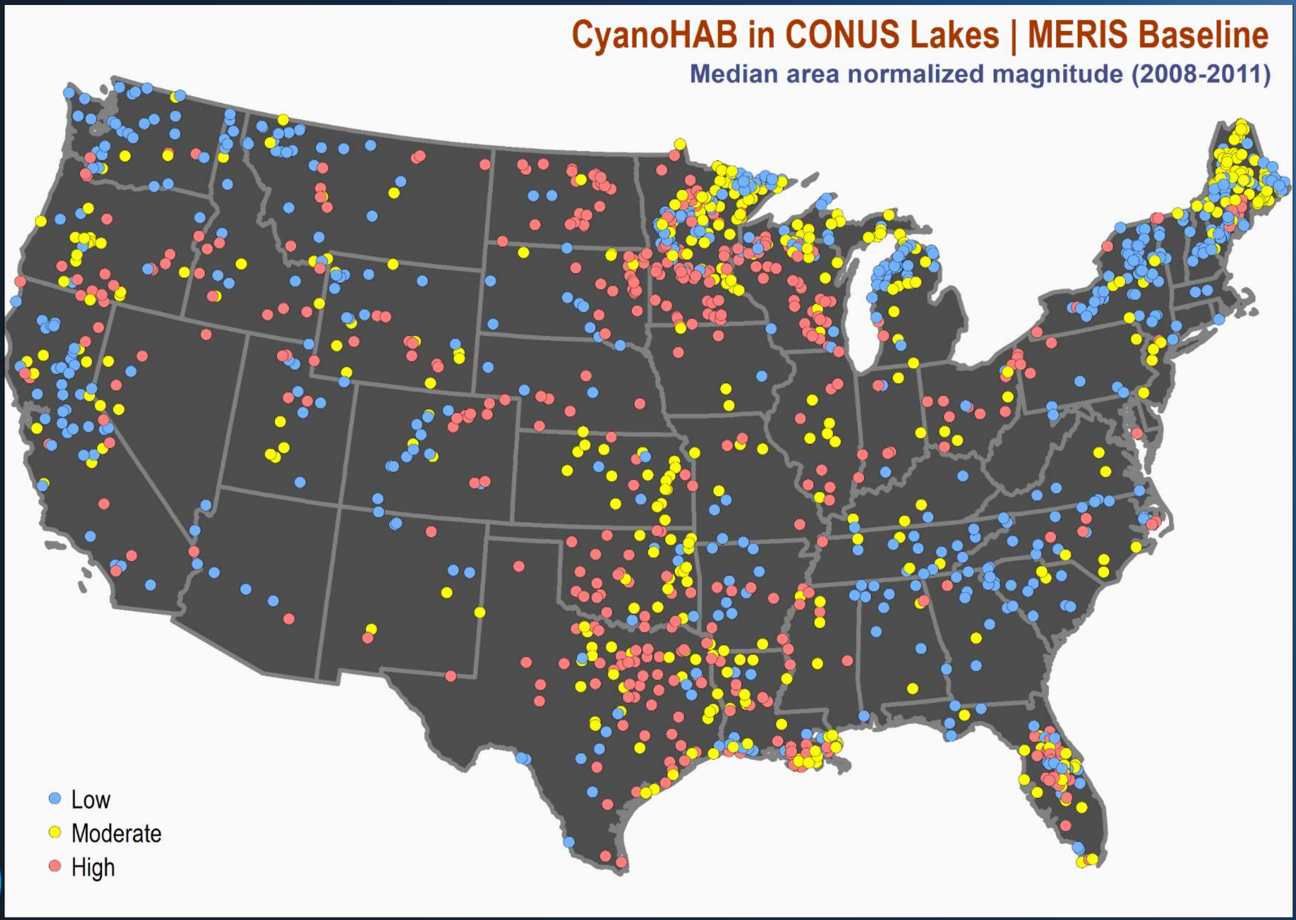
How many lakes we can resolve in each state

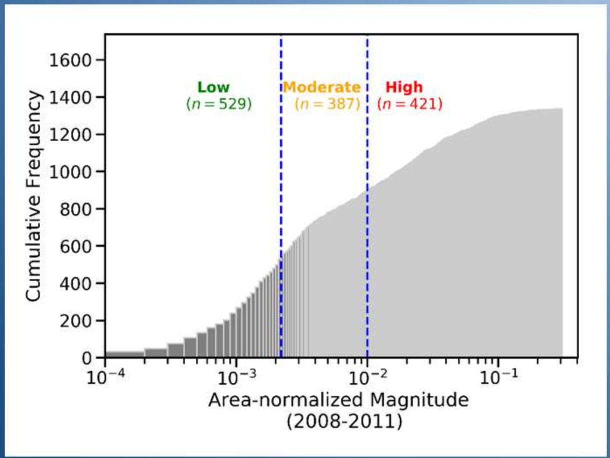
Lake area > 1.93 $mile^2$

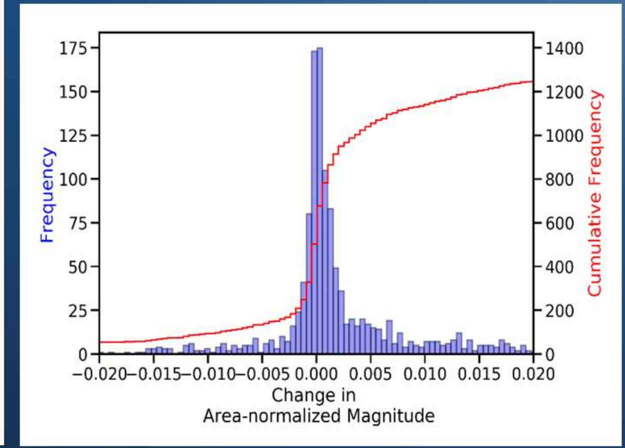


Historical Baseline

2008-2011

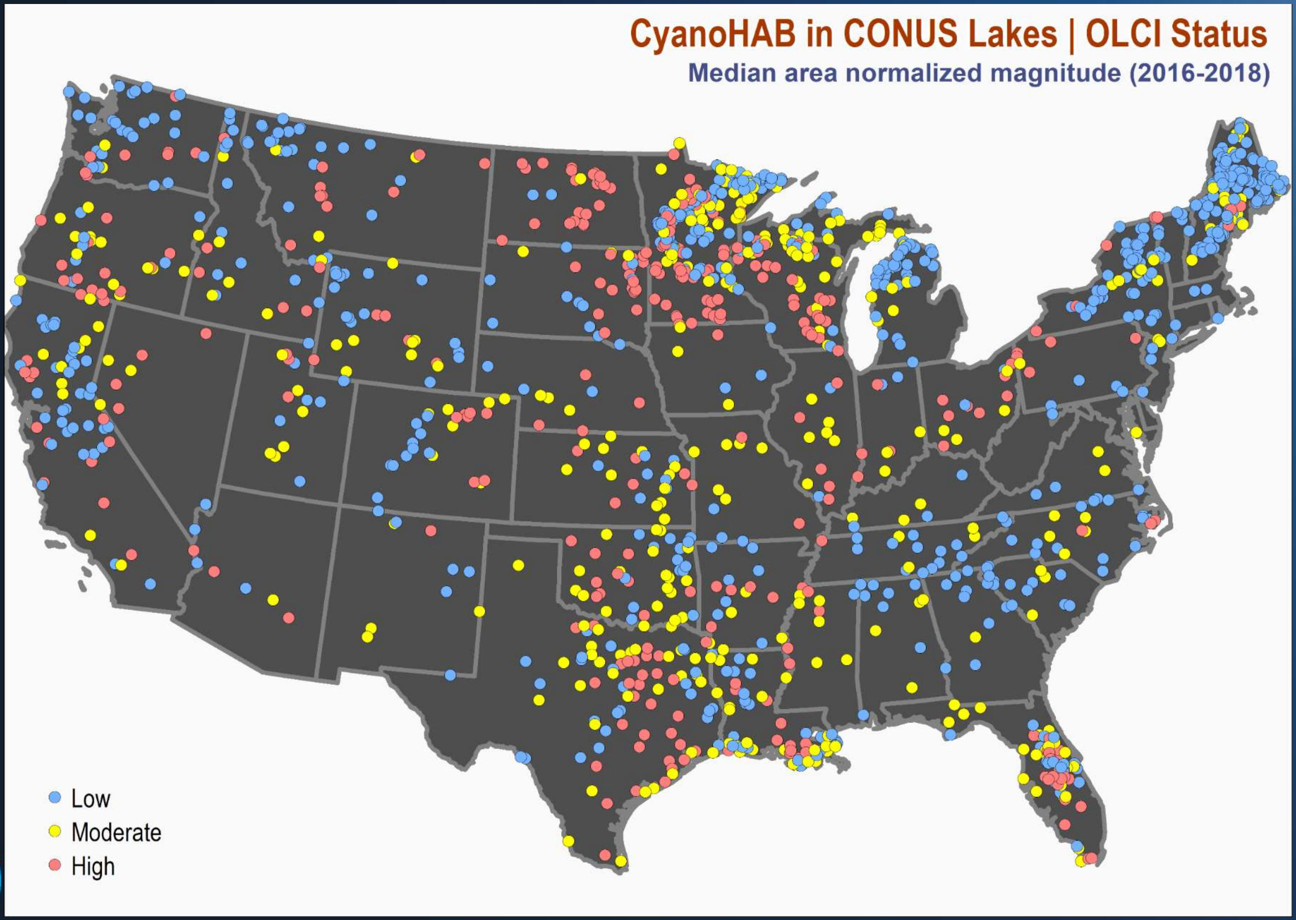


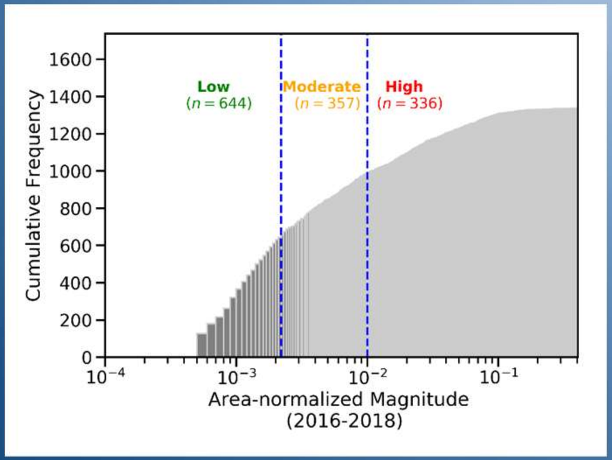


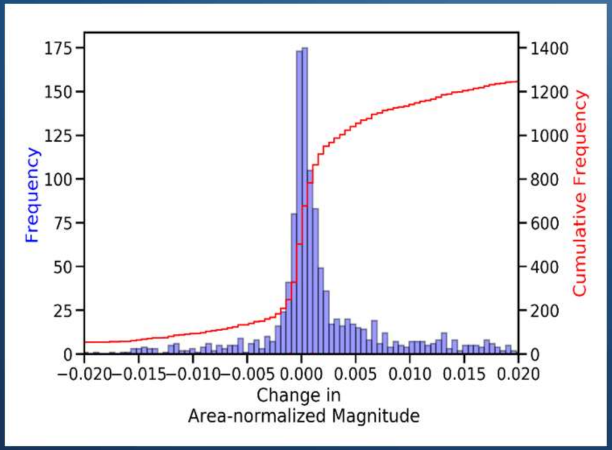


Current Status

2016-2018

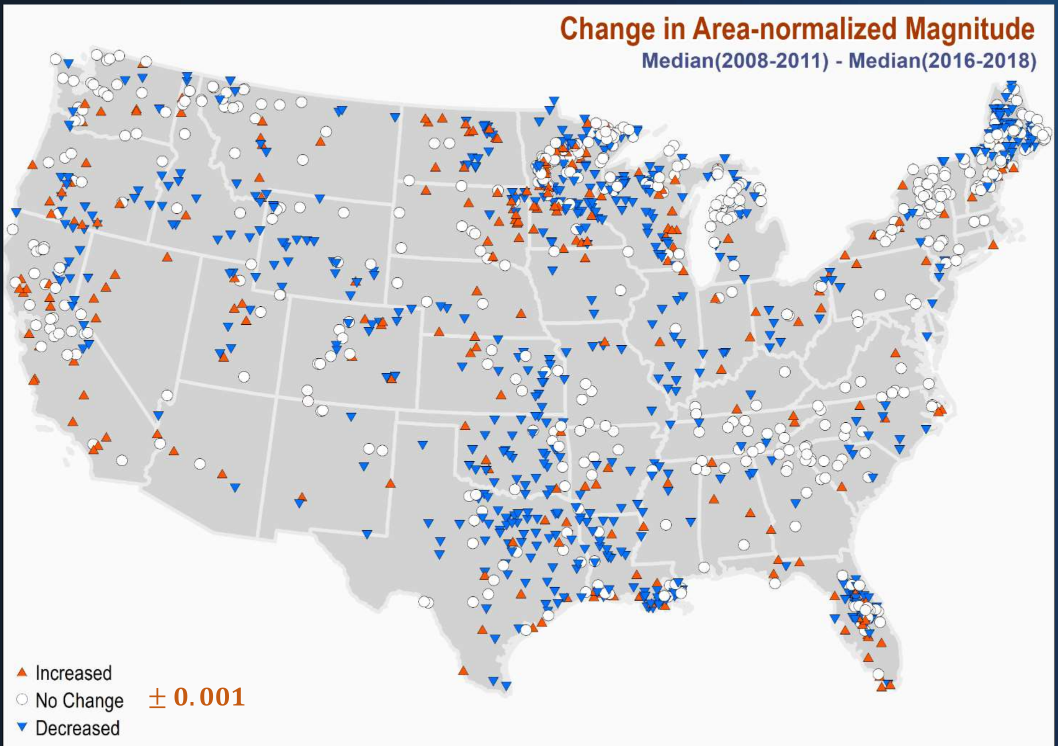


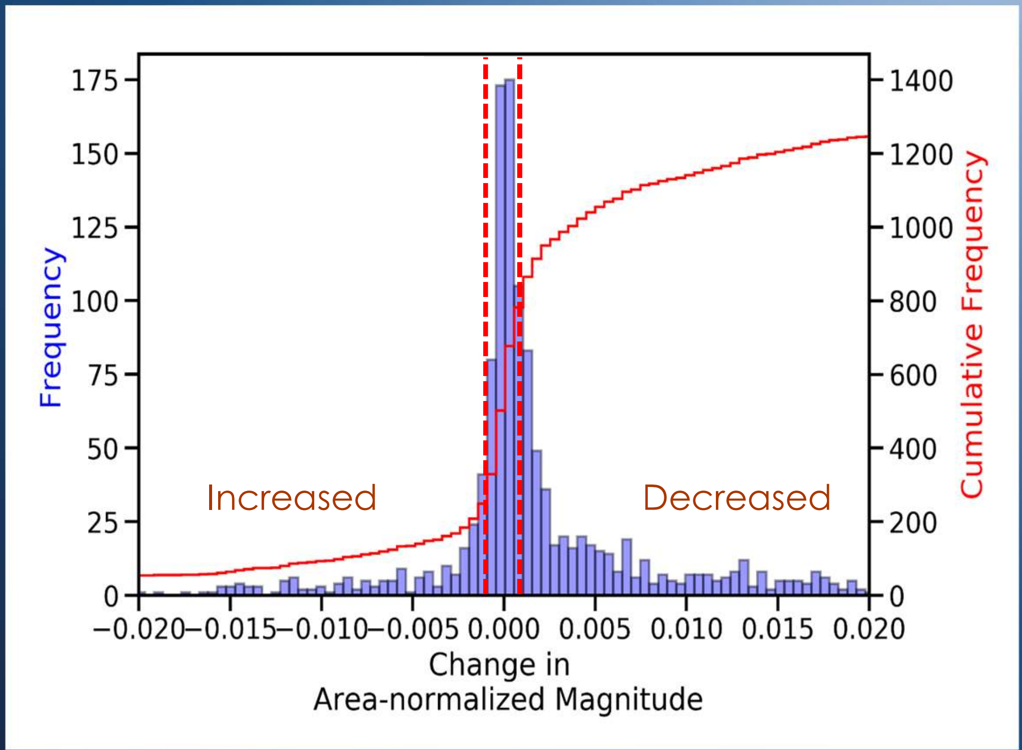




How the CyanoHAB has changed since then?

The difference between the medians





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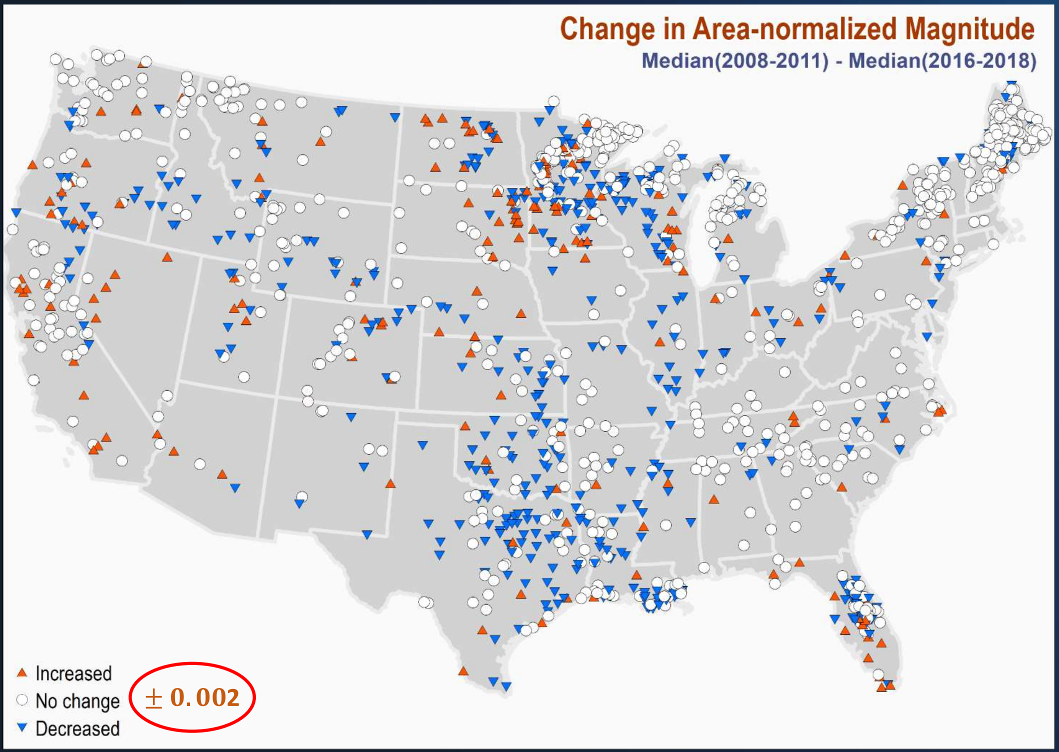

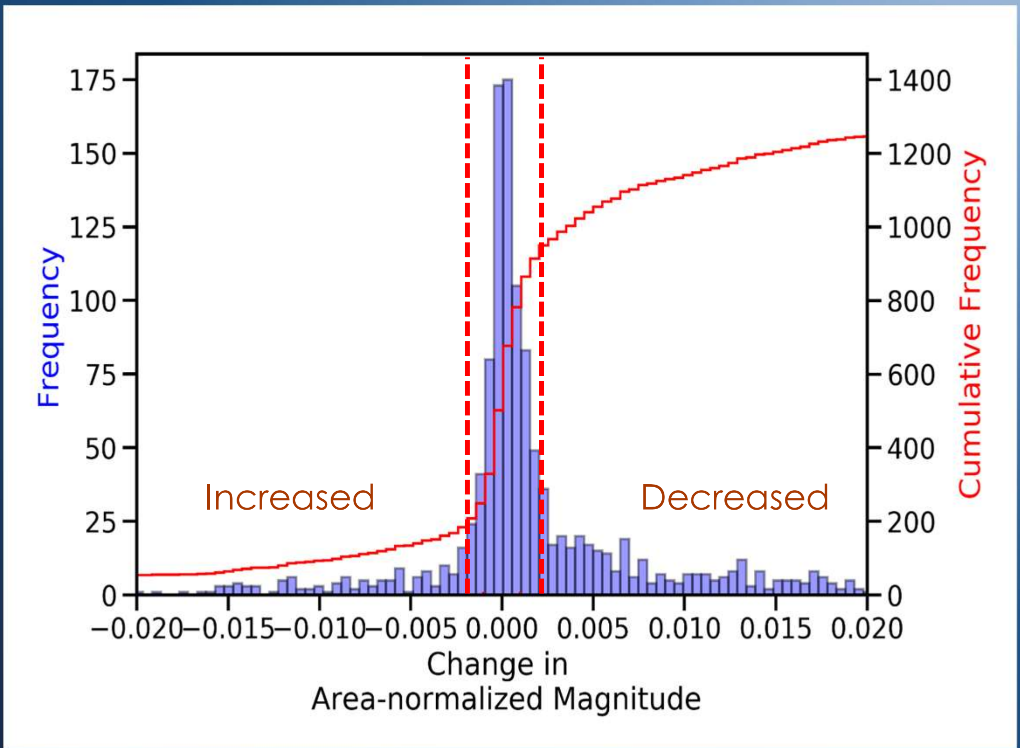

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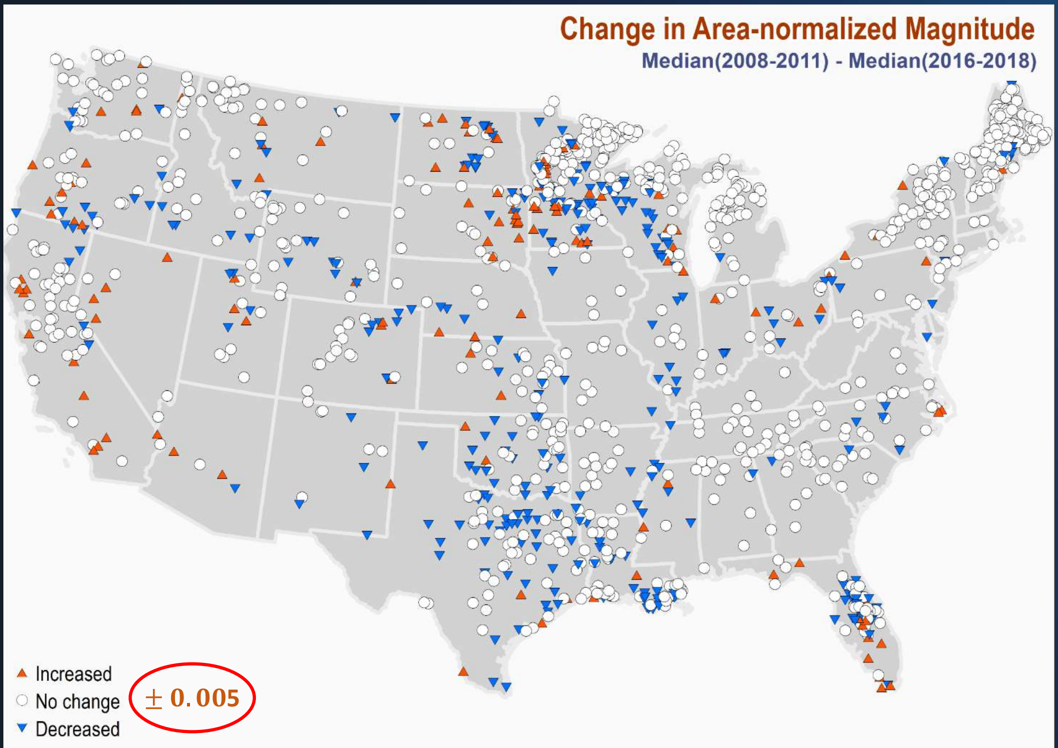
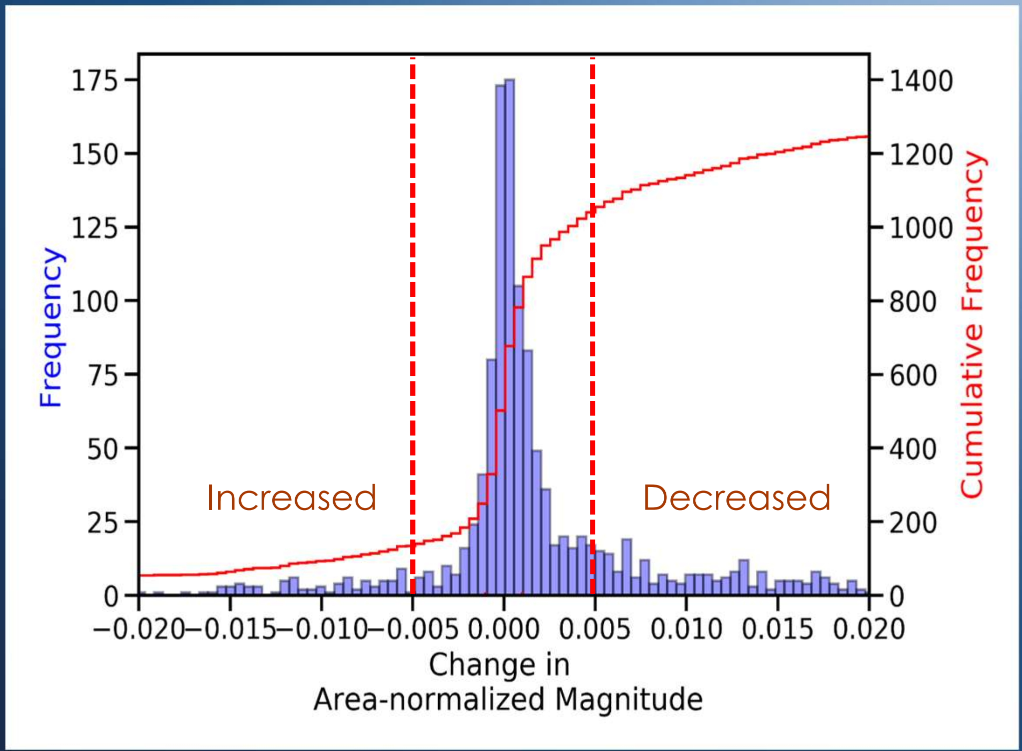
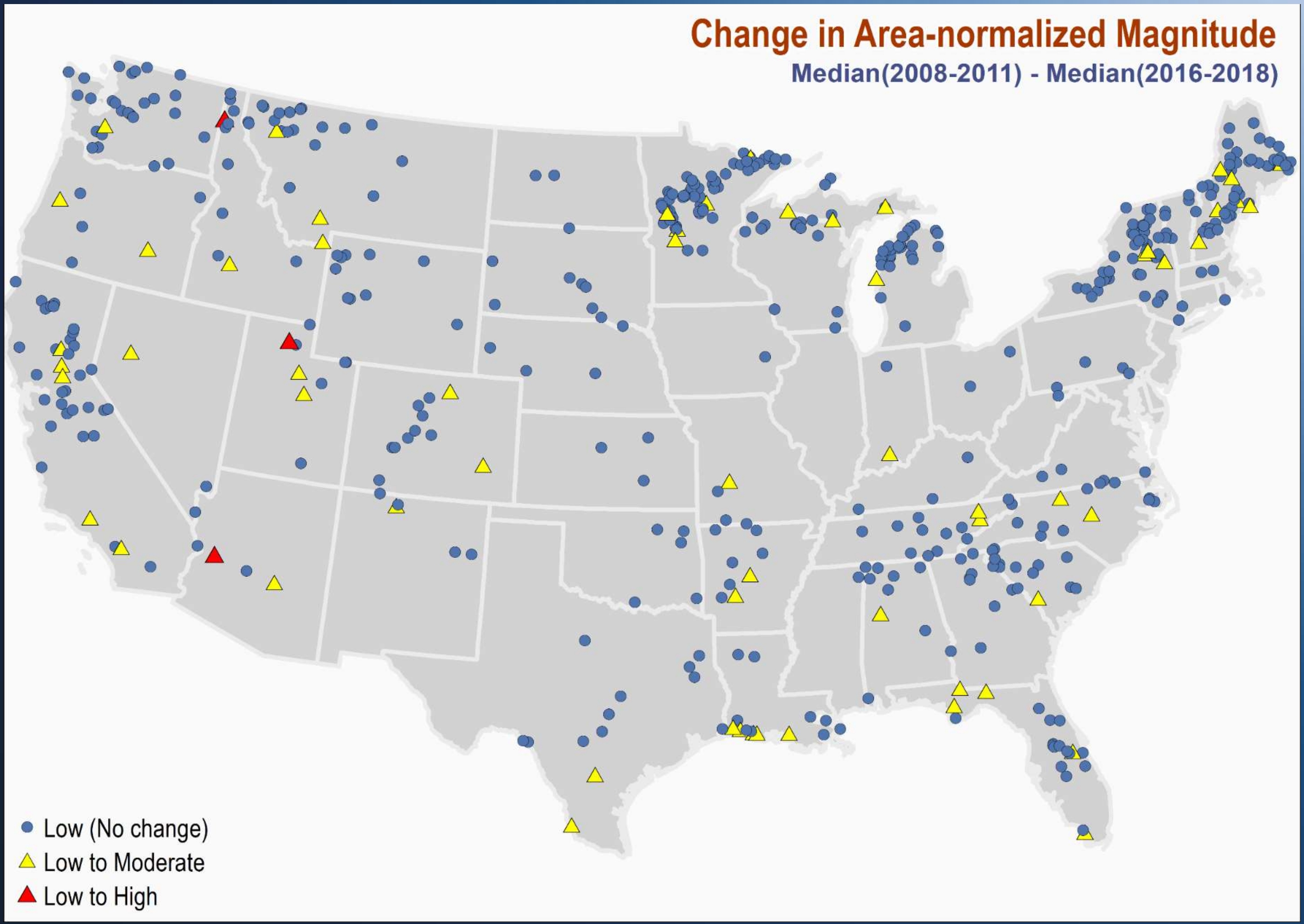




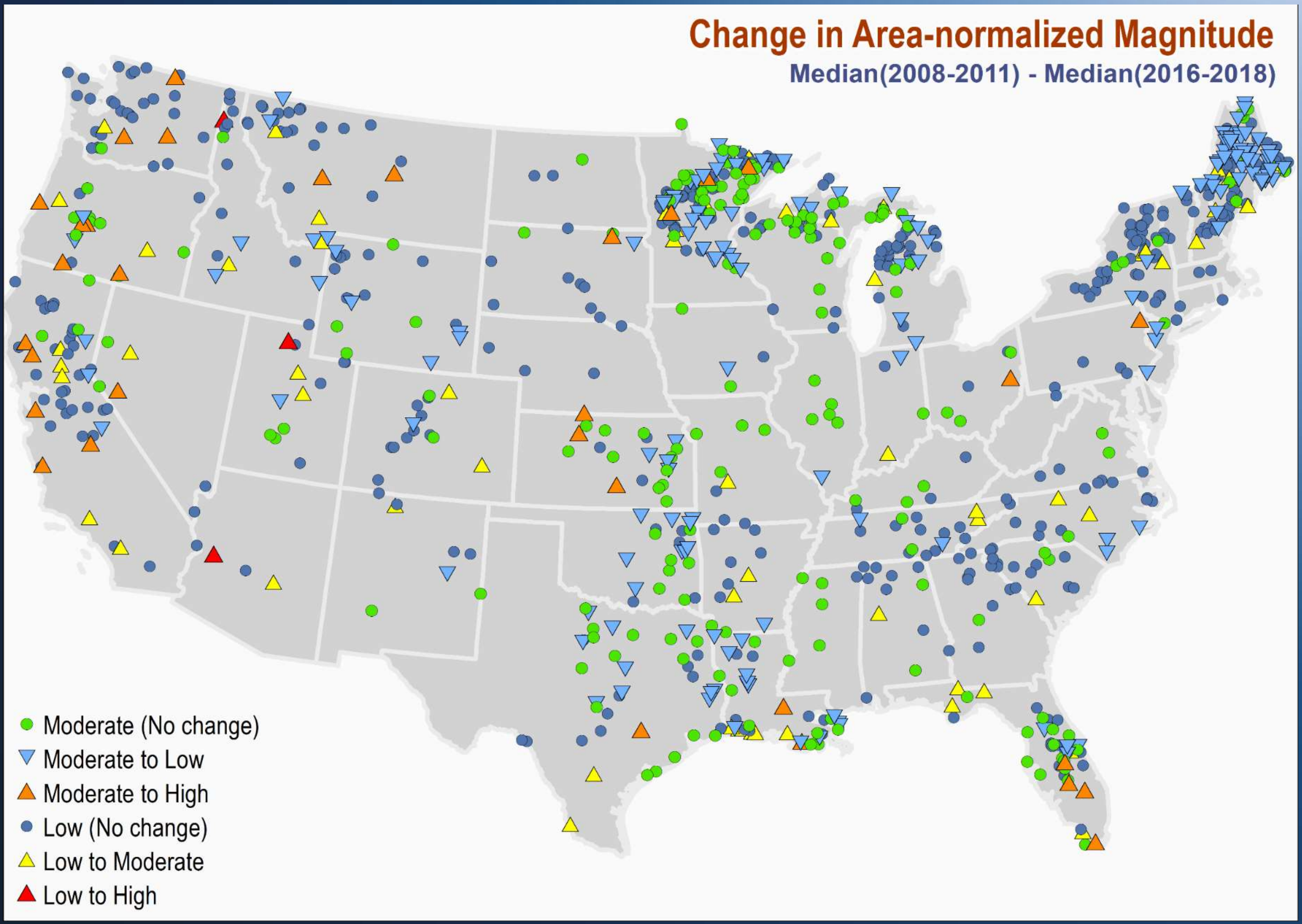
Change Dynamics in Low Risk Category

Change dynamics highlights how the lakes have changed from one risk category to another



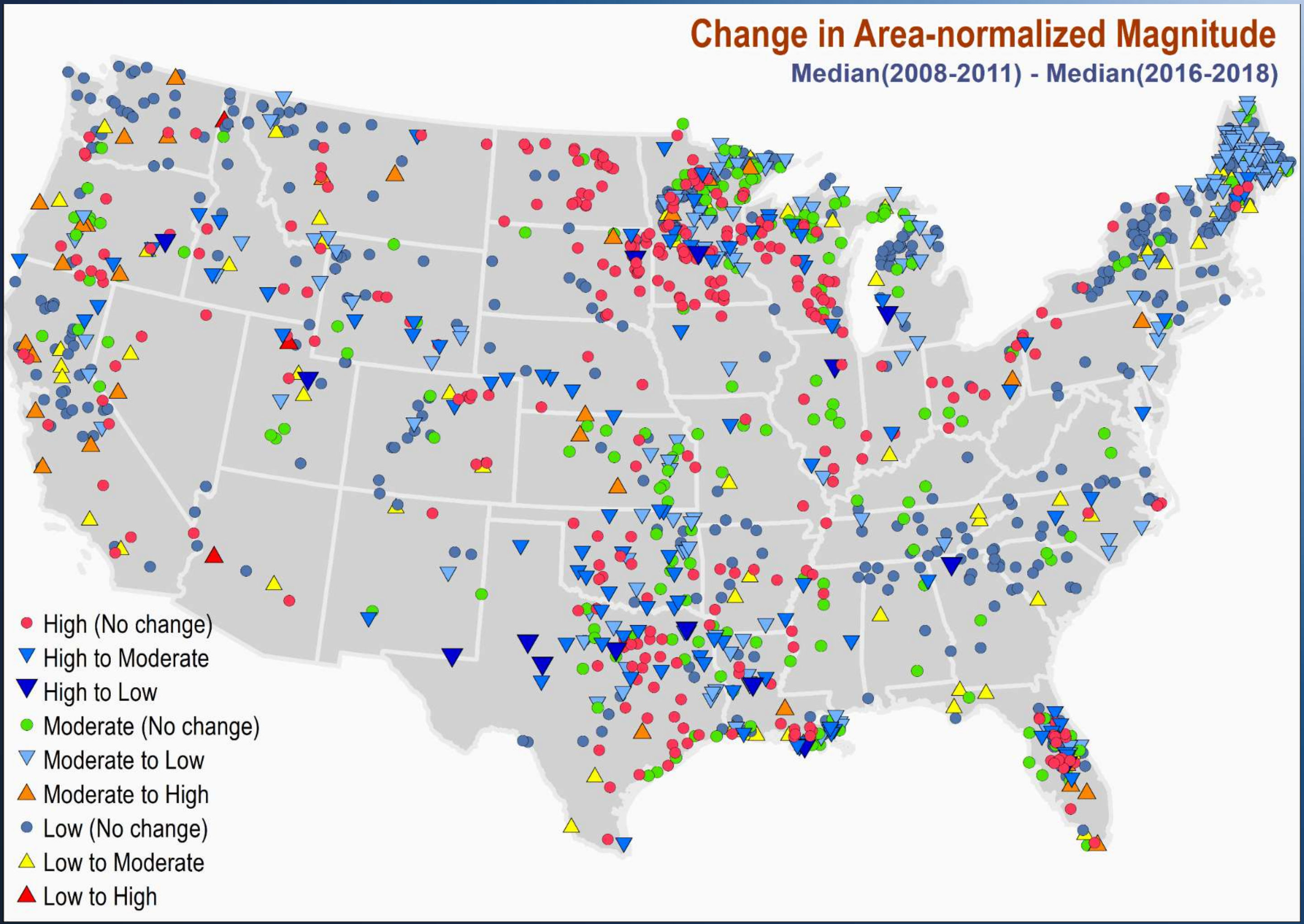
Change Dynamics in Low & Moderate Risk Categories

Change dynamics highlights how the lakes have changed from one risk category to another



Change Dynamics in all Risk Categories

Change dynamics highlights how the lakes have changed from one risk category to another



Concluding Thoughts

- Total bloom magnitude highlights CyanoHAB issues in large lakes whereas normalized magnitude highlights issues in smaller lakes
- Overall decrease in lake number in ‘**High**’ and ‘**Moderate**’ risk classes
- Significant increase in lake number in ‘**Low**’ risk class during 2016-2018
- 15 lakes moved from ‘**High**’ to ‘**Low**’ risk class
- 163 lakes moved from ‘**Moderate**’ to ‘**Low**’ risk class
- 301 lakes in ‘**High**’ are still in ‘**High**’ risk class
- Satellite data can produce actionable information that can be used for prioritizing CyanoHAB Management in Inland lakes

Acknowledgement

Stakeholders and participants

EPA Office of Water

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- Office of Science and Technology
- Office of Ground Water and Drinking Water

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State collaborators

NASA Ocean Biology and Biogeochemistry Program/

Applied Sciences Program