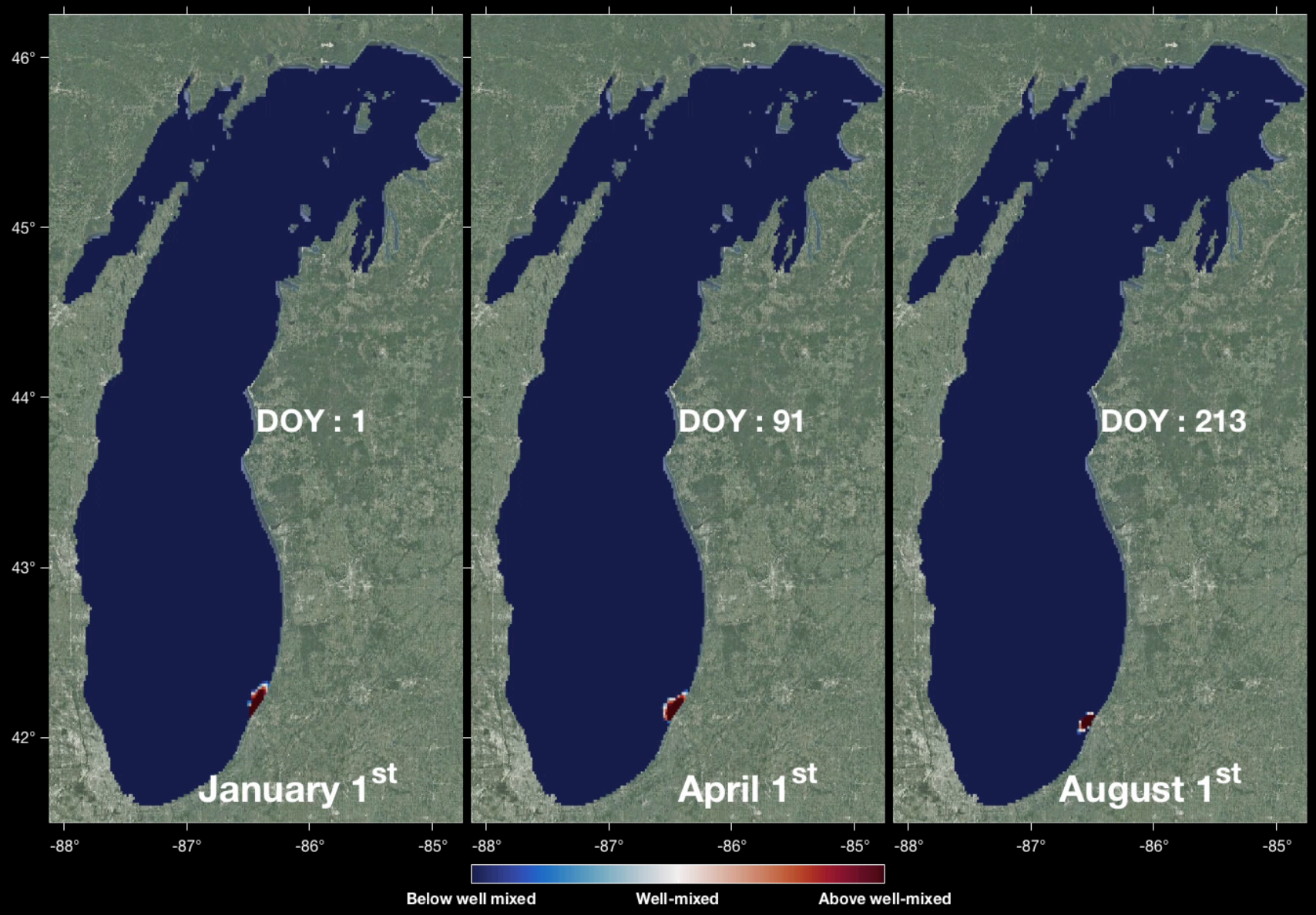
# Dye release at start of three months in 2007



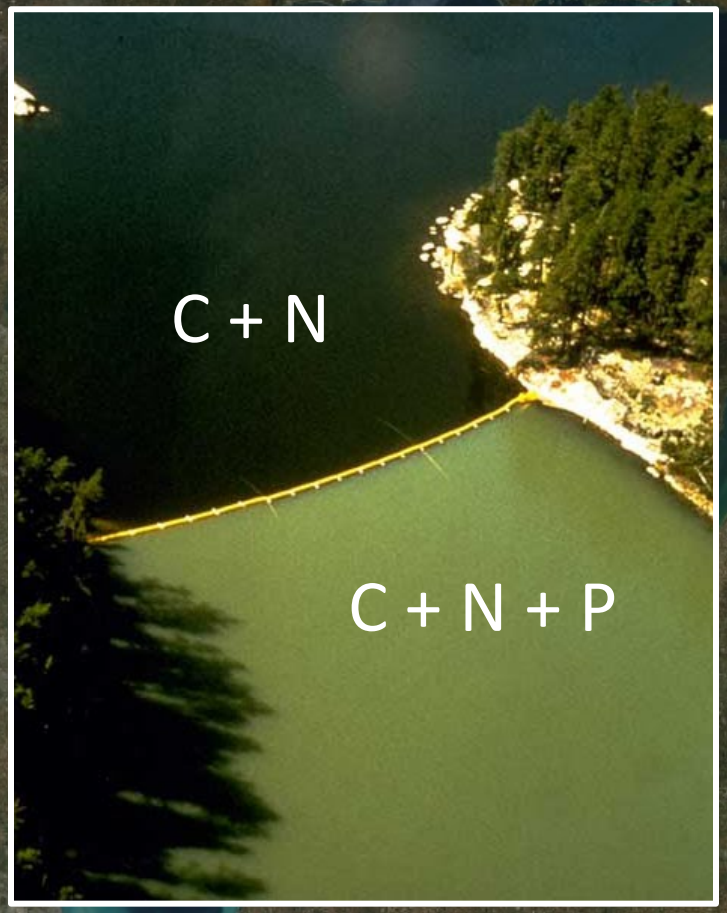
# Potential impacts of tributary loads on coastal ecosystem services in Lake Michigan

Luke Gloege

Galen McKinley, Robert Mooney, J. David Allan,

Matthew Diebel, Peter McIntyre

Lake 226

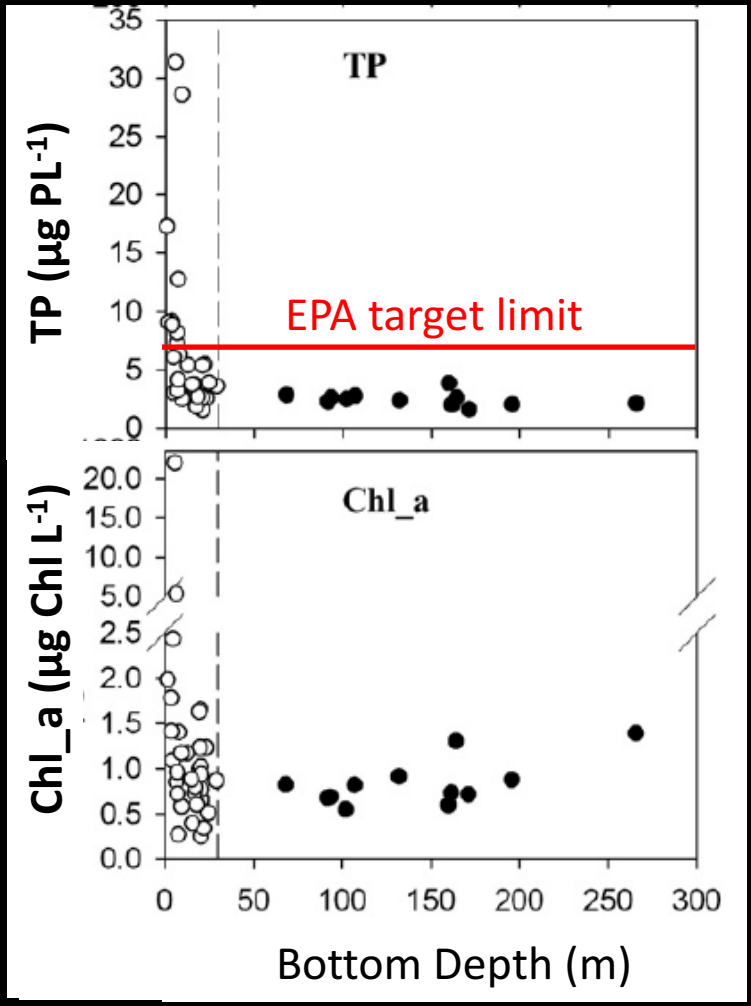



Schindler 1974, Science

Excessive phosphorus drives eutrophication

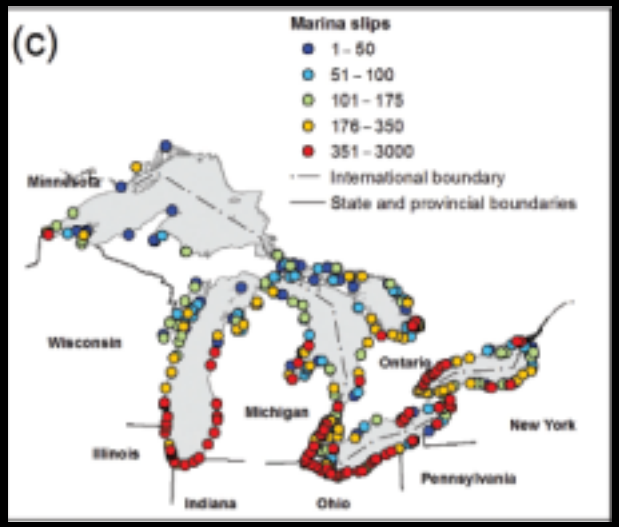
# Lake Michigan Phosphorus levels

- Phosphorus not well mixed
- Elevated phosphorus in nearshore (open circles)
- Phosphorus depletion offshore (closed circles)

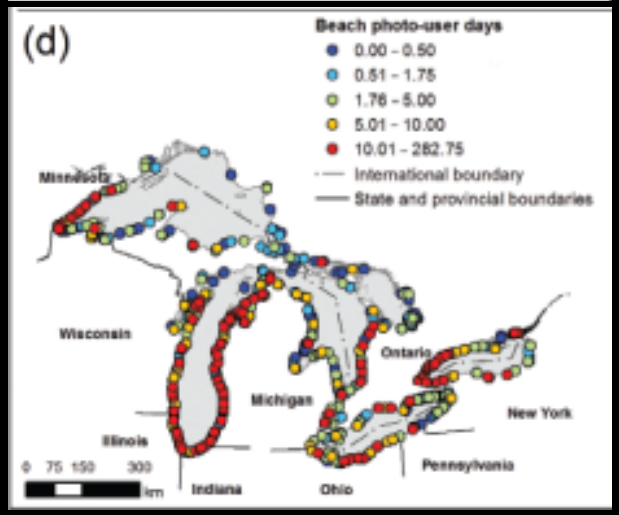



Yurista et al. 2015 JGLR

# Great Lakes ecosystem services




Marina slips



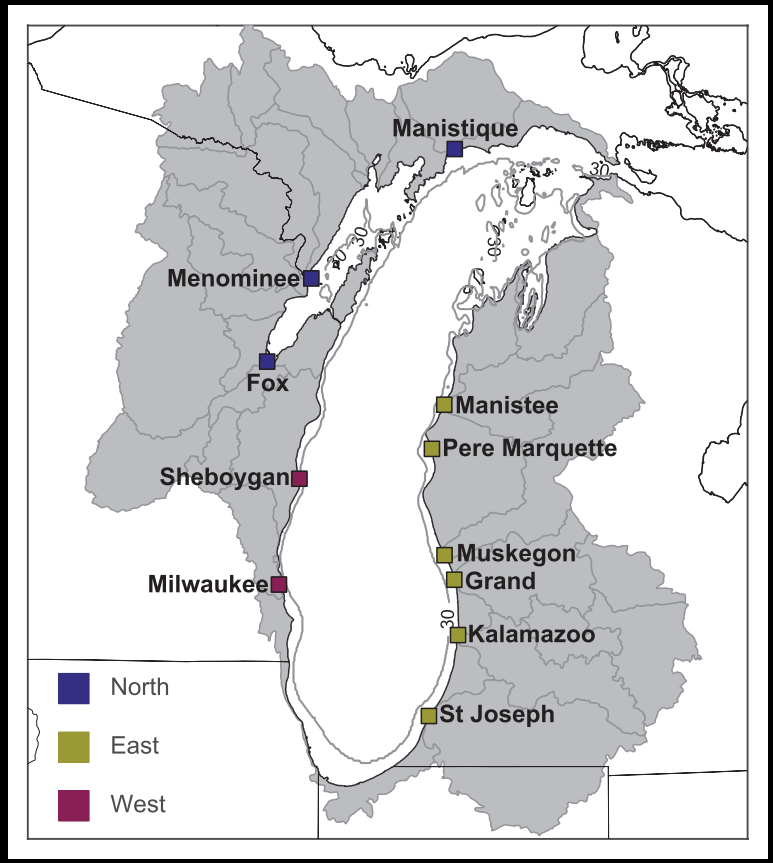

Beach usage

- Spatial distribution of ecosystem services
- Service use is quantified at each site
- Complement ecosystem stress assessment

Allan et al. 2015 Front. Ecol. Environ.

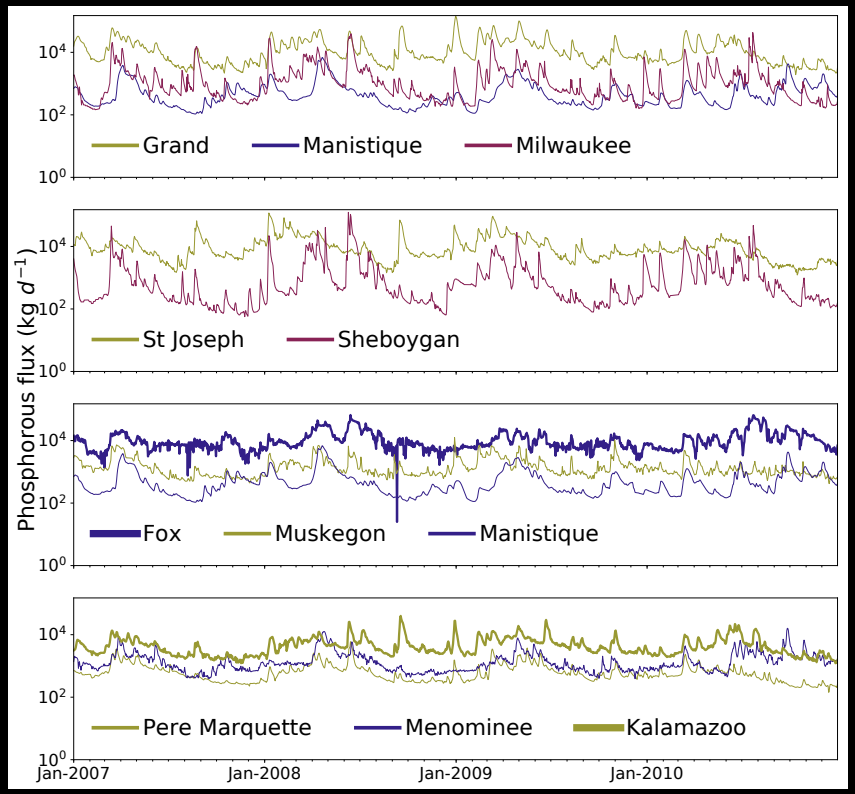
# Model Experiment

- MIT general circulation model
- 3D hydrodynamic model
- Closed basin
- 1/60 degree (~2km) horizontal res.
- 28 vertical layers (5 m – 31 m)
- Forced at surface with meteorological and radiative fields every 3 hours
- Simulated 2007 - 2010
- Phosphorus from 11 rivers



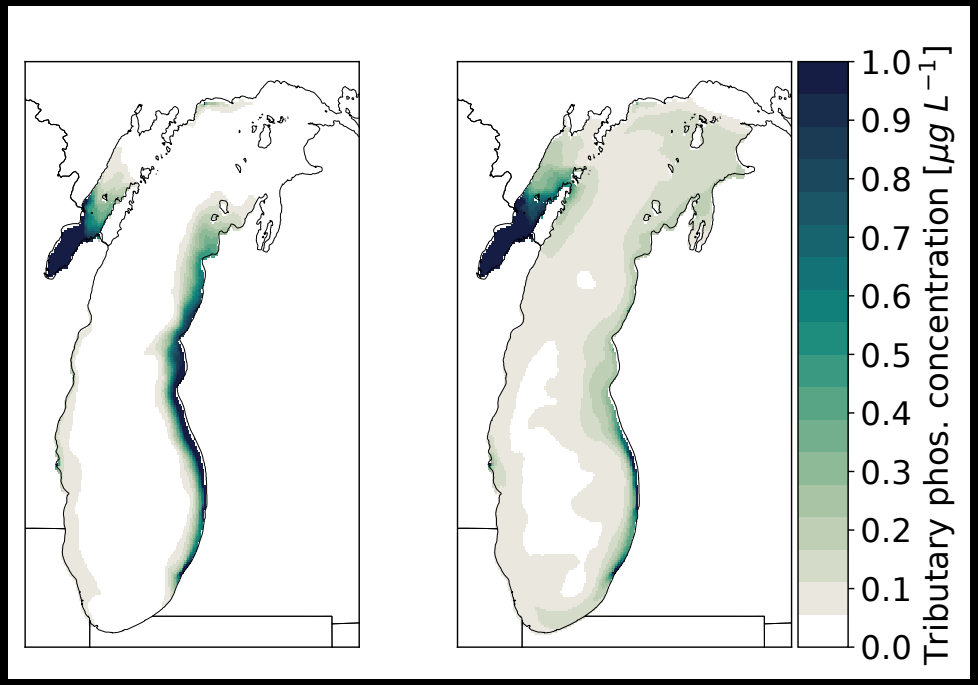
# Realistic Phosphorus fluxes

- Phosphorus flux calculated from discharge and phosphorus concentration [Hirsch et al. 2010 JAWRA]
- Captures 70% of the observed phosphorus load
- Annual loads compare well to estimates by [Dolan and Chapra 2012 JGLR]



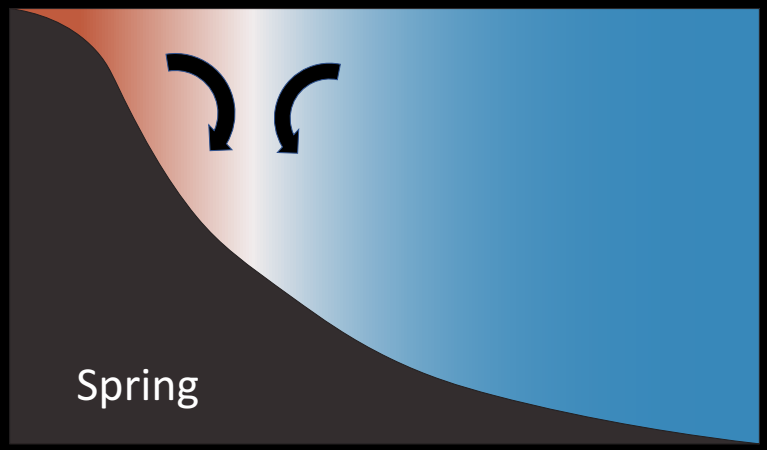
# Phosphorus Concentration

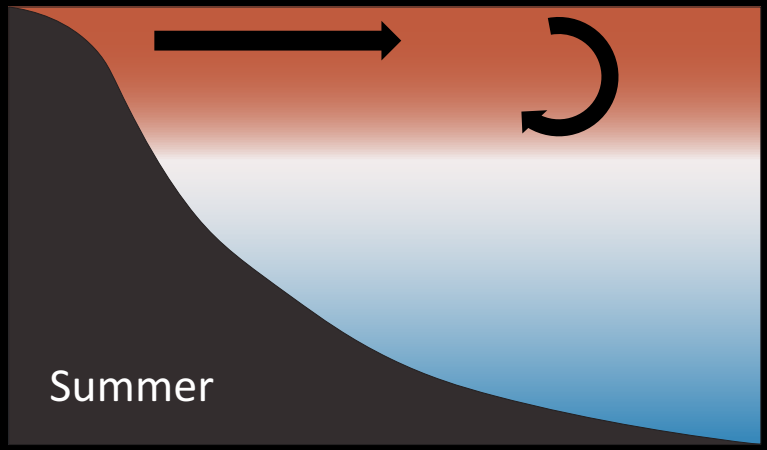
May August




- Average concentration in May and August across all years
- Seasonal variation in concentration

# Temperature gradients are a barrier to mixing



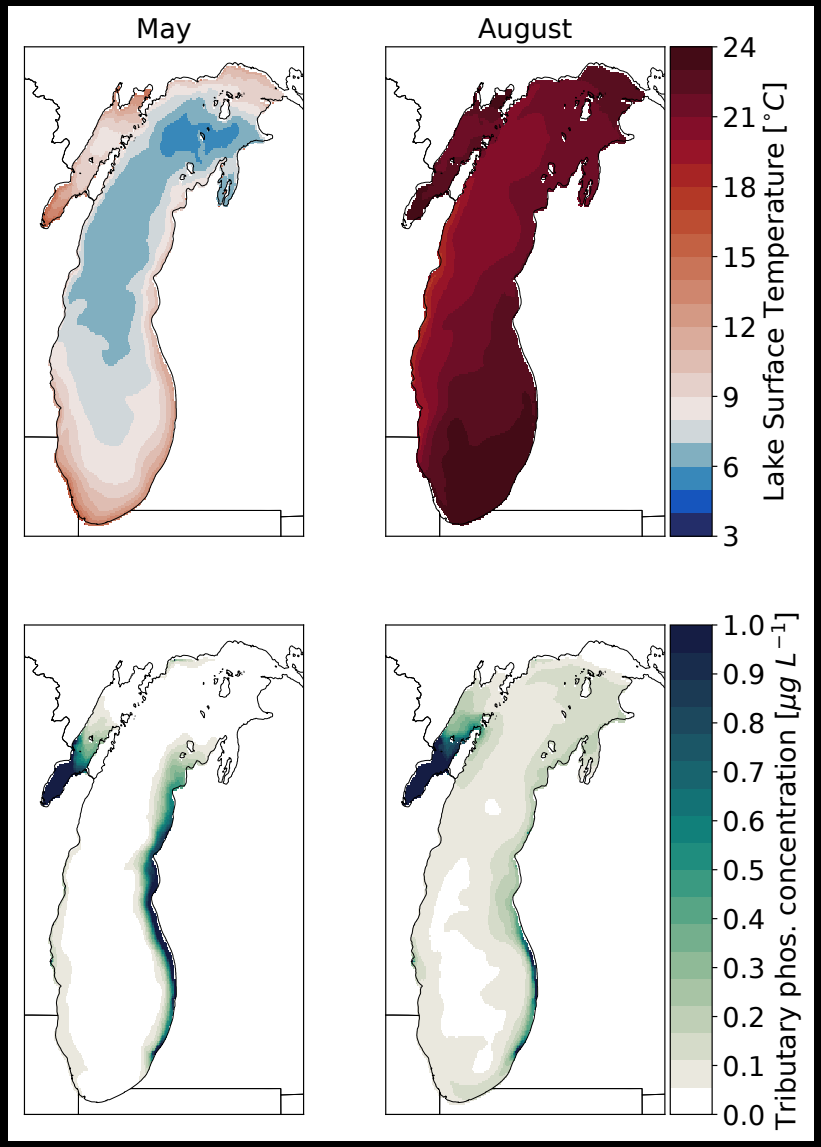




- Strong horizontal density gradient
- Inhibits offshore transport

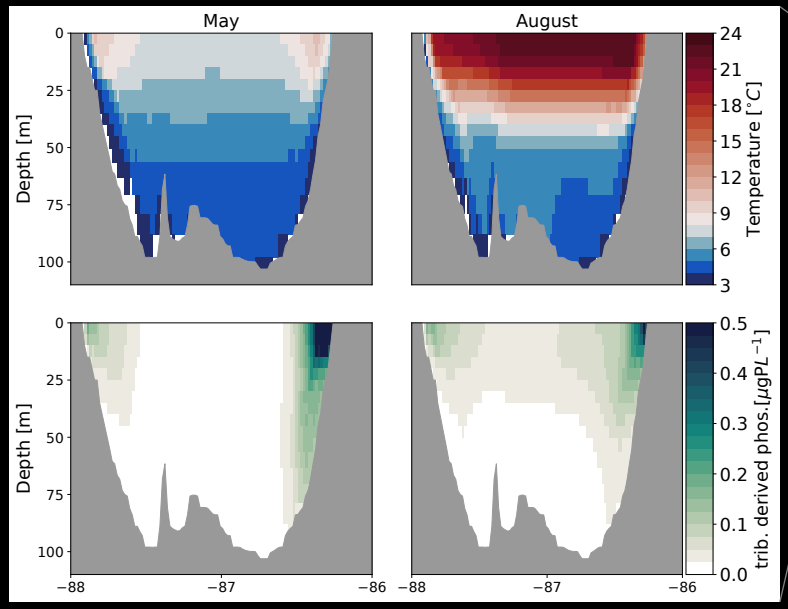
- Weak horizontal density gradient
- Thermocline is barrier mixing

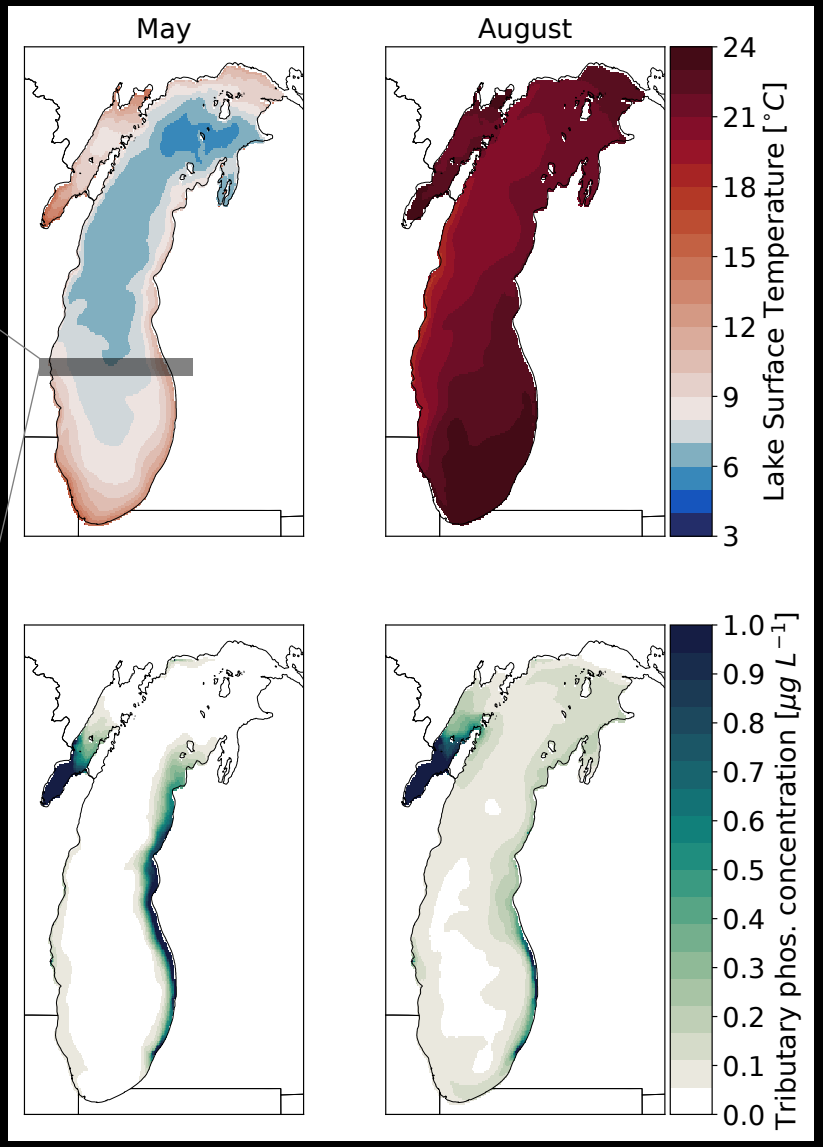
# Model output

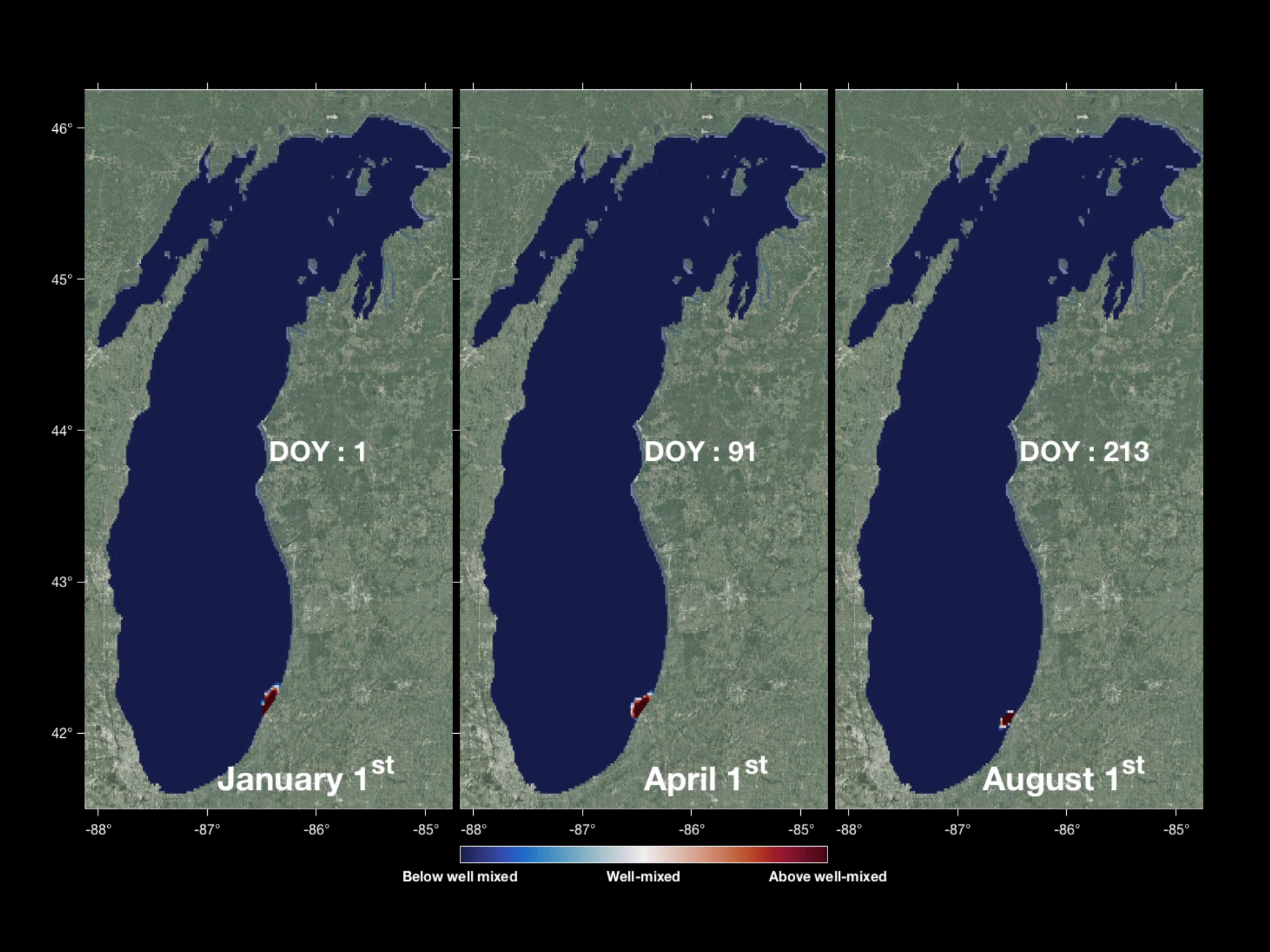
- Coastal trapping in May
- Offshore spreading in August



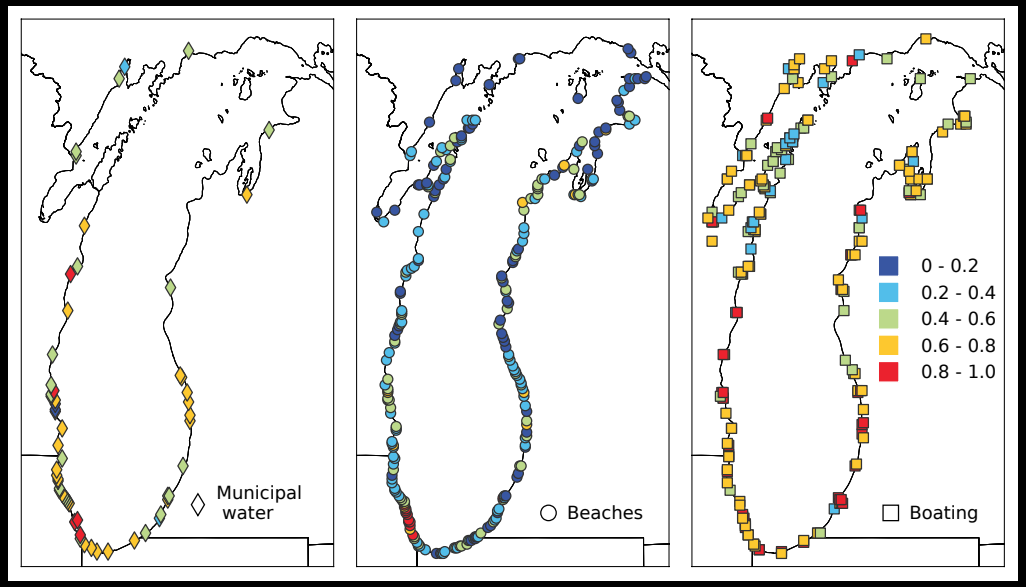
# Model output




46°
45°
44°
43°
42°
-88°
-87°
-86°
-85°
DOY : 1
January 1st
DOY : 91
April 1st
DOY : 213
August 1st
Below well mixed
Well-mixed
Above well-mixed

# Ecosystem Service use around Lake Michigan




Annual water withdrawals

Unique FLICKR uploads

Number marina slips and parking spaces

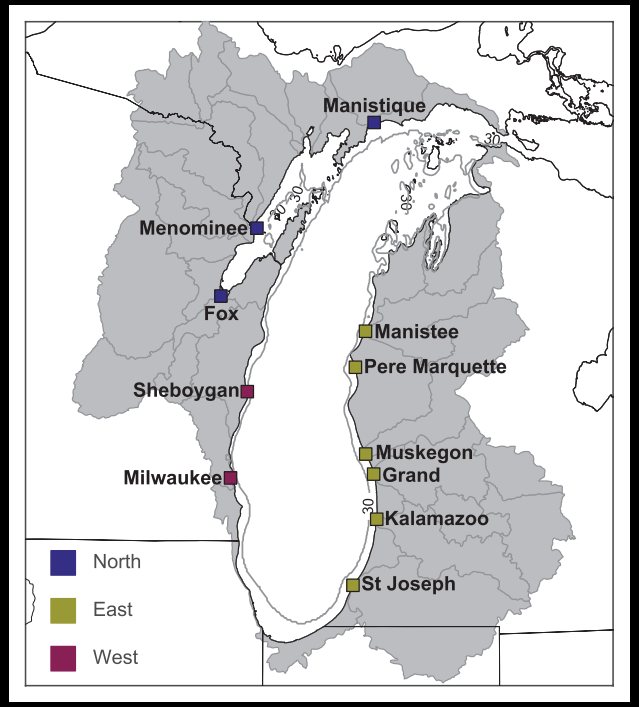
- Usage index for each service
- Normalized each index between [0, 1]

Allan et al. 2015 Front Ecol Environ

# Cumulative stress days (CSD)

$$CSD = \sum_{\text{Plume in region}} [(ED * Muni.Water) + (ED * Beaches) + (ED * Boating)]$$

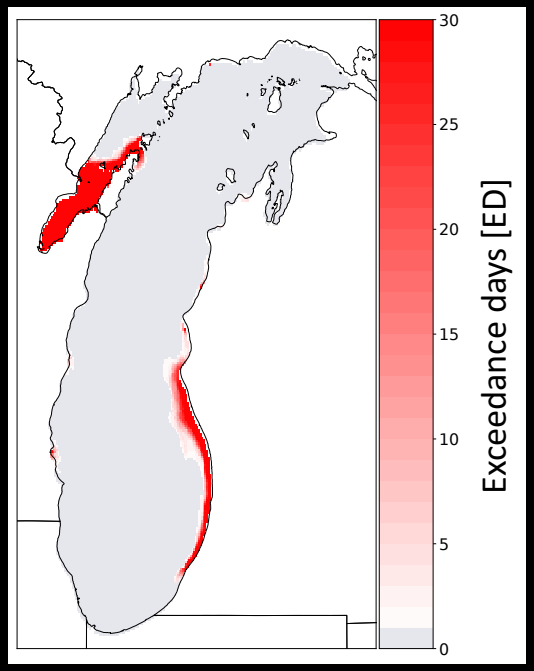
- ED quantifies severity of the phosphorous concentration
- Multiply ED by adjacent service cells
- Sum across plume in each region (North, East, West)



# Cumulative stress days (CSD)

$$CSD = \sum_{\text{Plume in region}} [(ED * Muni.Water) + (ED * Beaches) + (ED * Boating)]$$

July




**Exceedance Days (ED)**
number days threshold concentration is exceeded at each grid cell

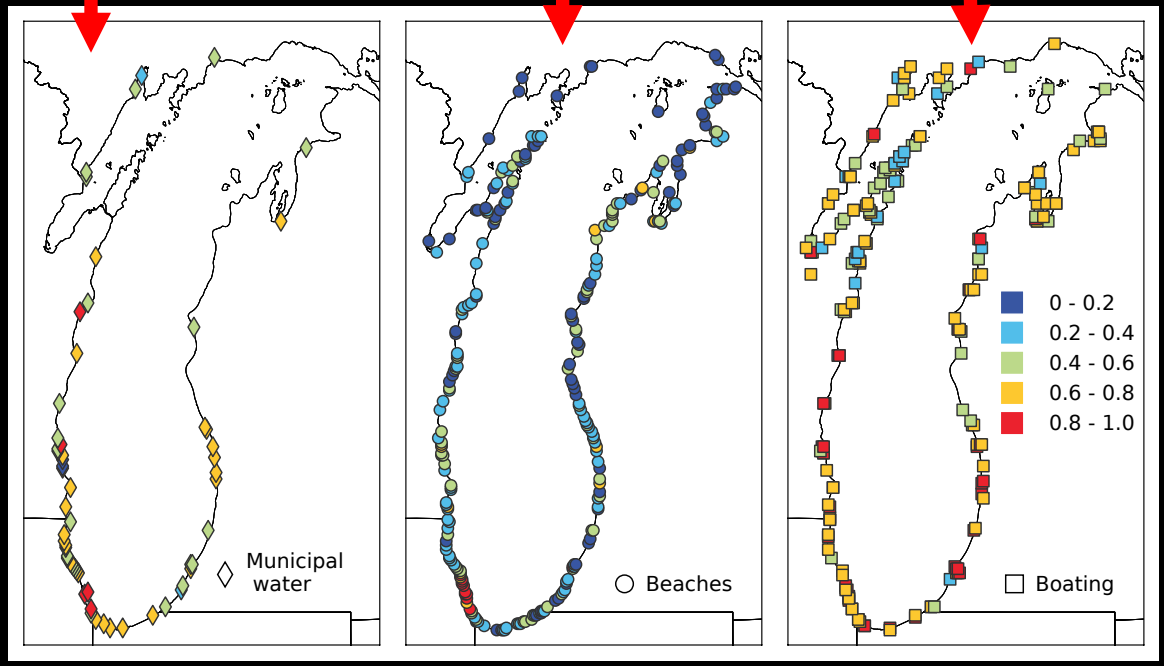
**Threshold Concentration**
0.4 µgPL$^{-1}$

# Cumulative stress days (CSD)

$$CSD = \sum_{\text{Plume in region}} [(ED * Muni.Water) + (ED * Beaches) + (ED * Boating)]$$

1. Multiply ED by adjacent normalized service index

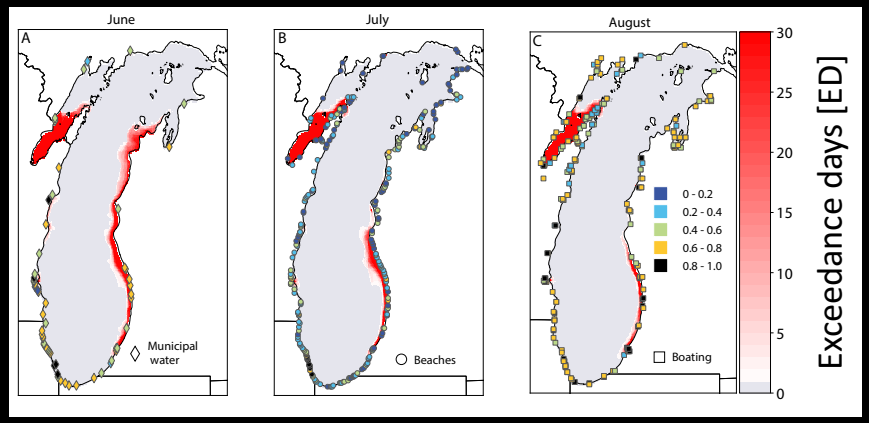
2. Sum across plume in each region

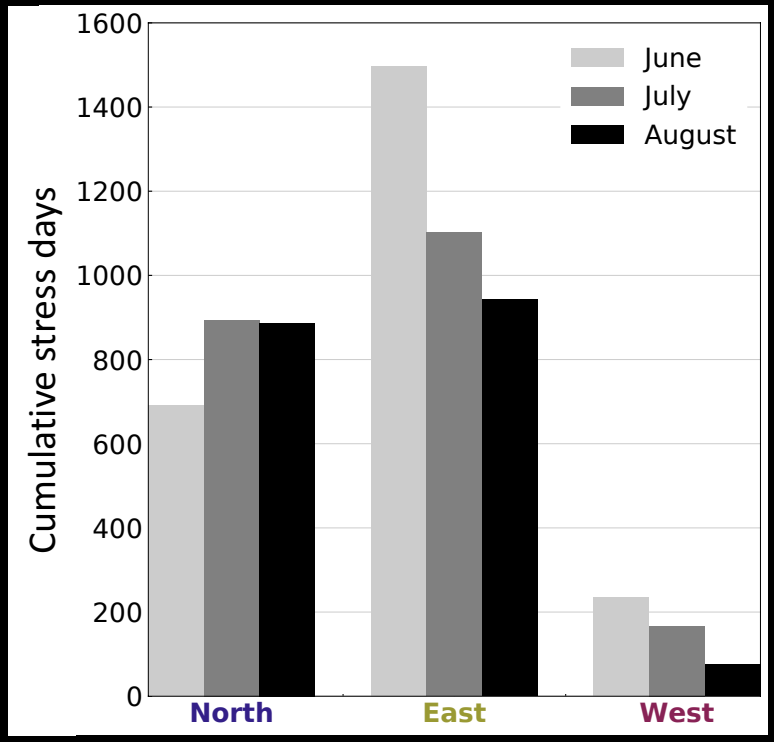


# Cumulative stress days (CSD)

$$CSD = \sum_{\text{Plume in region}} [(ED * Muni.Water) + (ED * Beaches) + (ED * Boating)]$$

Services in East and North have potential to be compromised



# Conclusions

- Lake Michigan is not well mixed
- In-lake physics influence redistribution
- Combination of non well-mixed lake, physics, and large loads have potential to regionally compromise ecosystem services
- Potential to contribute to more effective coastal management

# Acknowledgements

Galen McKinley

Robert Mooney

J. David Allan

Matthew Diebel

Peter McIntyre

Lamont-Doherty Earth Observatory
COLUMBIA UNIVERSITY | EARTH INSTITUTE

WISCONSIN
UNIVERSITY OF WISCONSIN-MADISON

UNIVERSITY OF MICHIGAN

WISCONSIN
DEPT. OF NATURAL RESOURCES

Luke Gloege
gloege@ldeo.columbia.edu

GitHub repository
github.com/lgloege/MITgcm-Michigan-Phosphorus