# Restoring Balance:
# Tracing Nutrient Patterns from Ridge to the Reef

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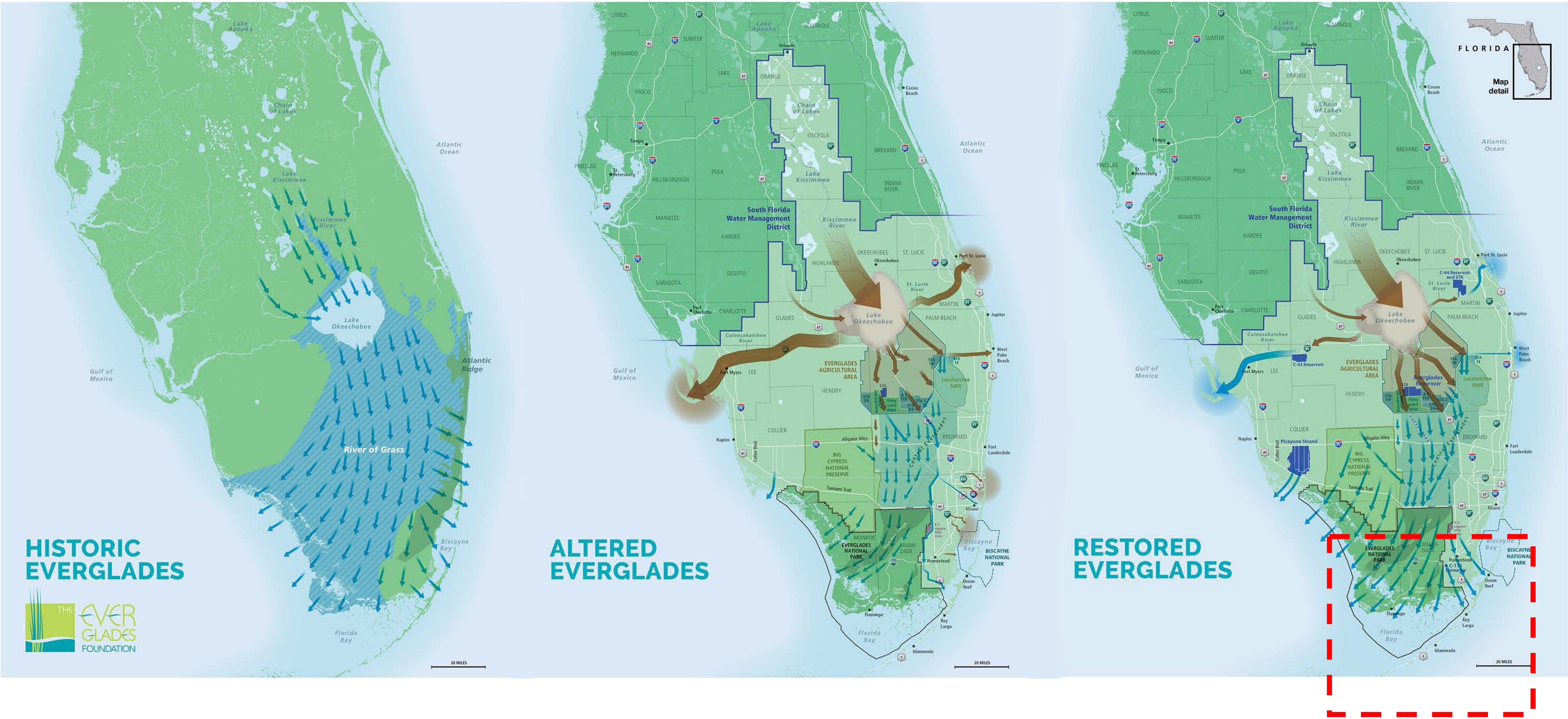
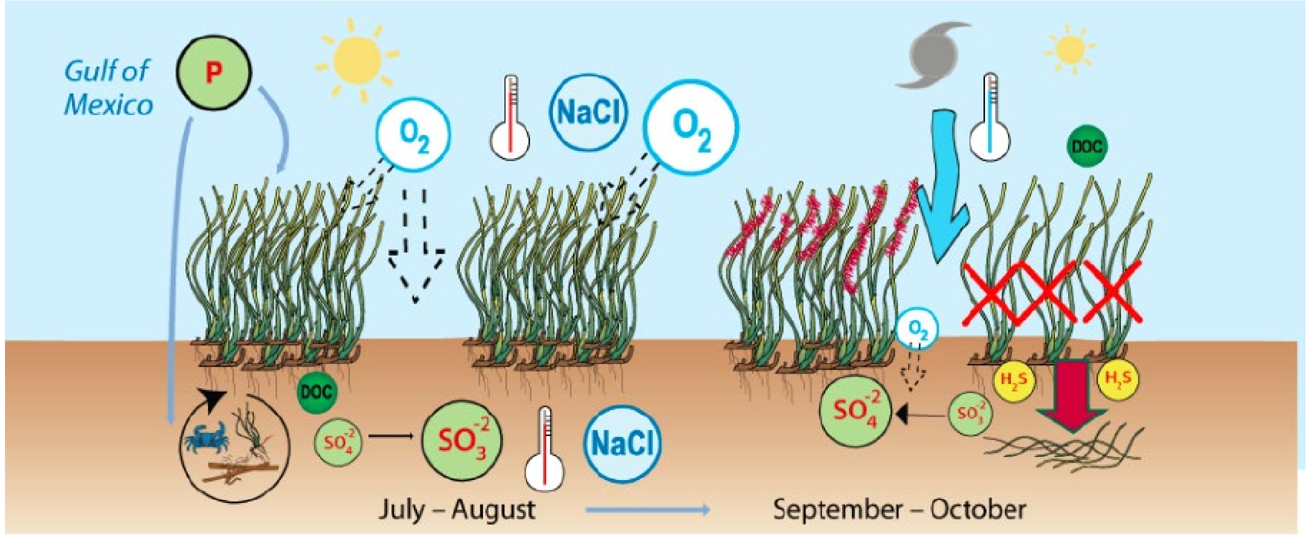
THE EVERGLADES FOUNDATION

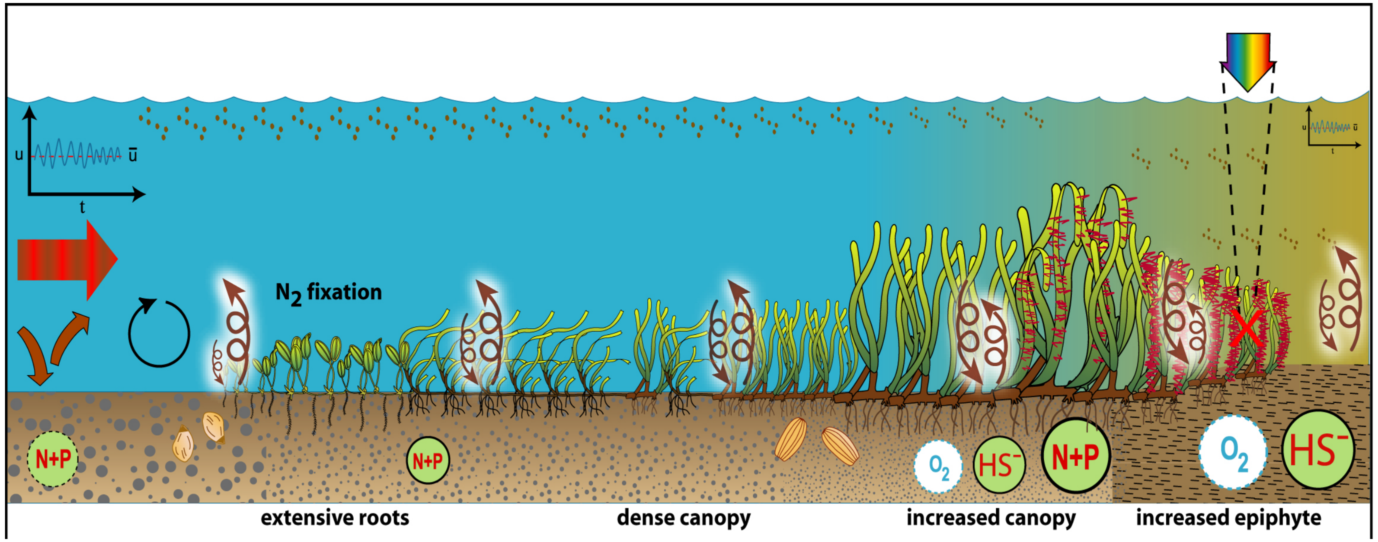
# Everglades Restoration



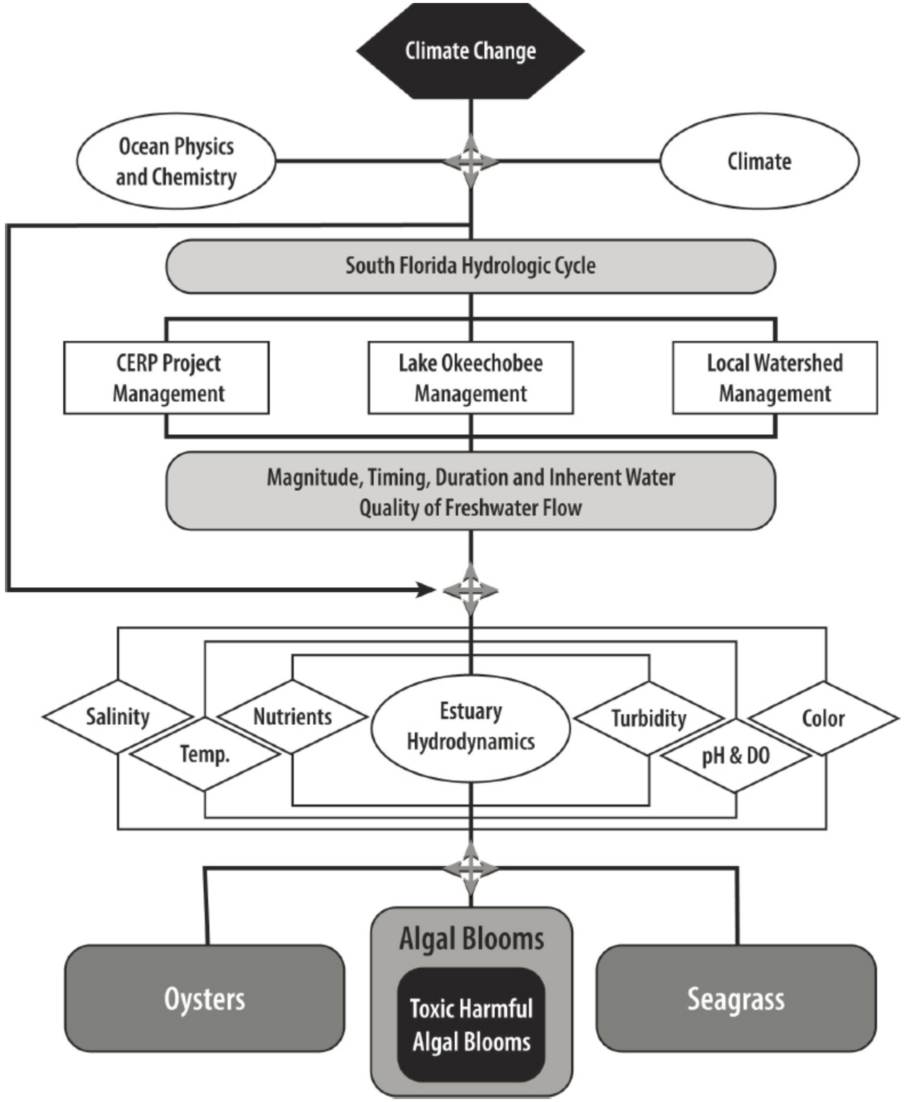
# Seagrass



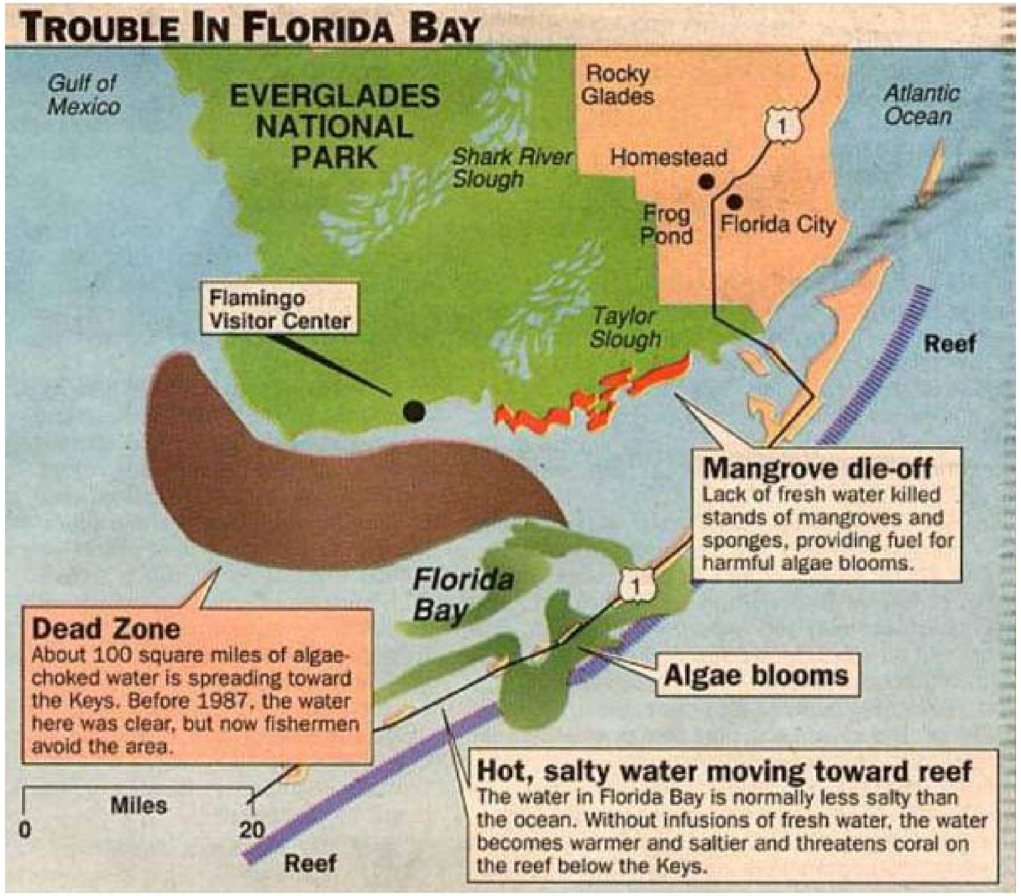

*Kruczynski WL, Fletcher PJ (eds) (2012) Tropical Connections: South Florida's marine environment. University of Maryland, Cambridge MA*



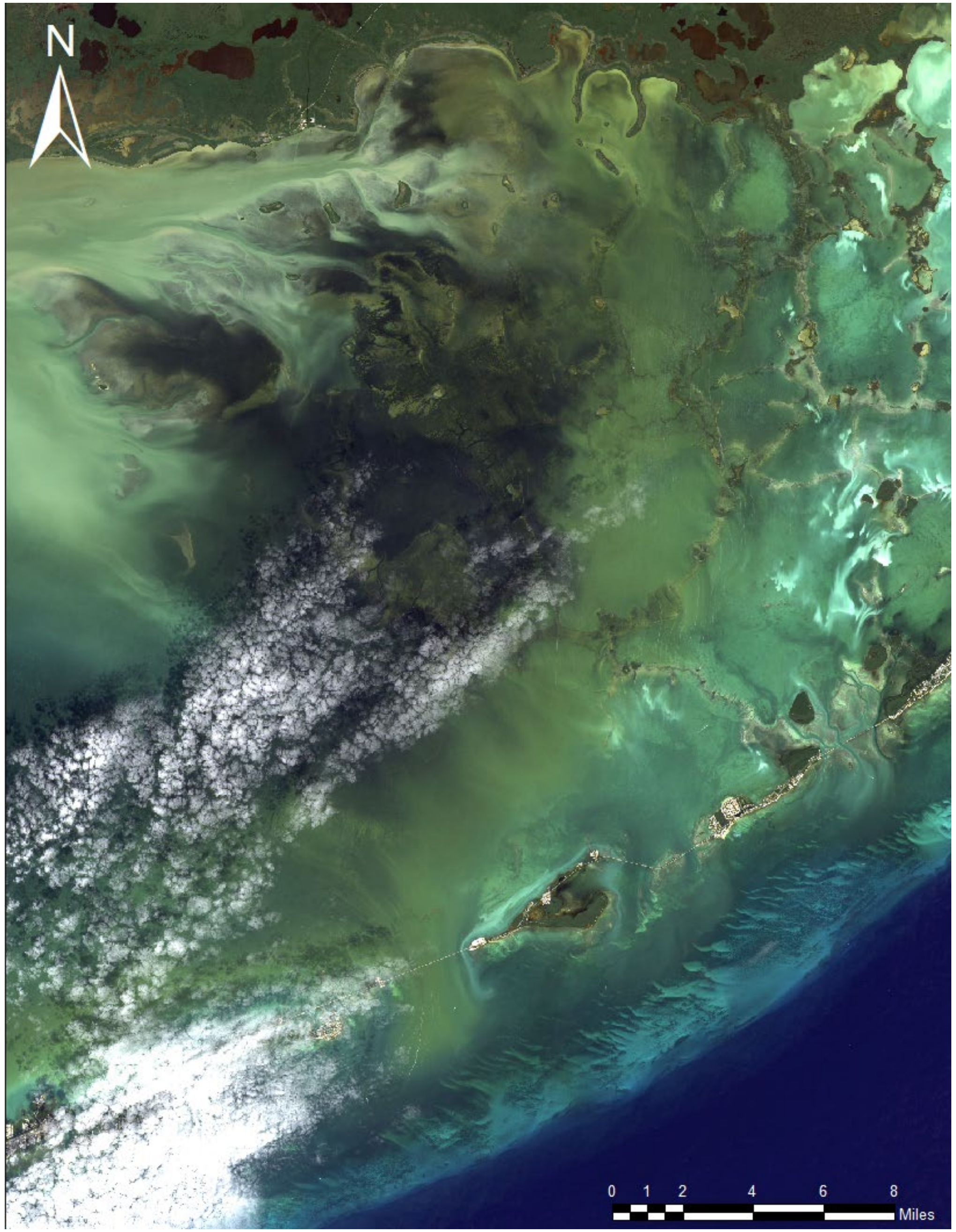

*McKenzie L (2007) Relationships between seagrass communities and sediment properties along the Queensland coast. Progress report to the Marine and Tropical Sciences Research Facility. Reef and Rainforest Research Centre Ltd, Cairns*




*National Academies of Sciences, Engineering, and Medicine. 2021. Progress Toward Restoring the Everglades: The Eighth Biennial Review - 2020. Washington, DC: The National Academies Press. https://doi.org/10.17226/25853.*




*Miami Herald*




*Landsat – 22 Oct 2017*

# Algae

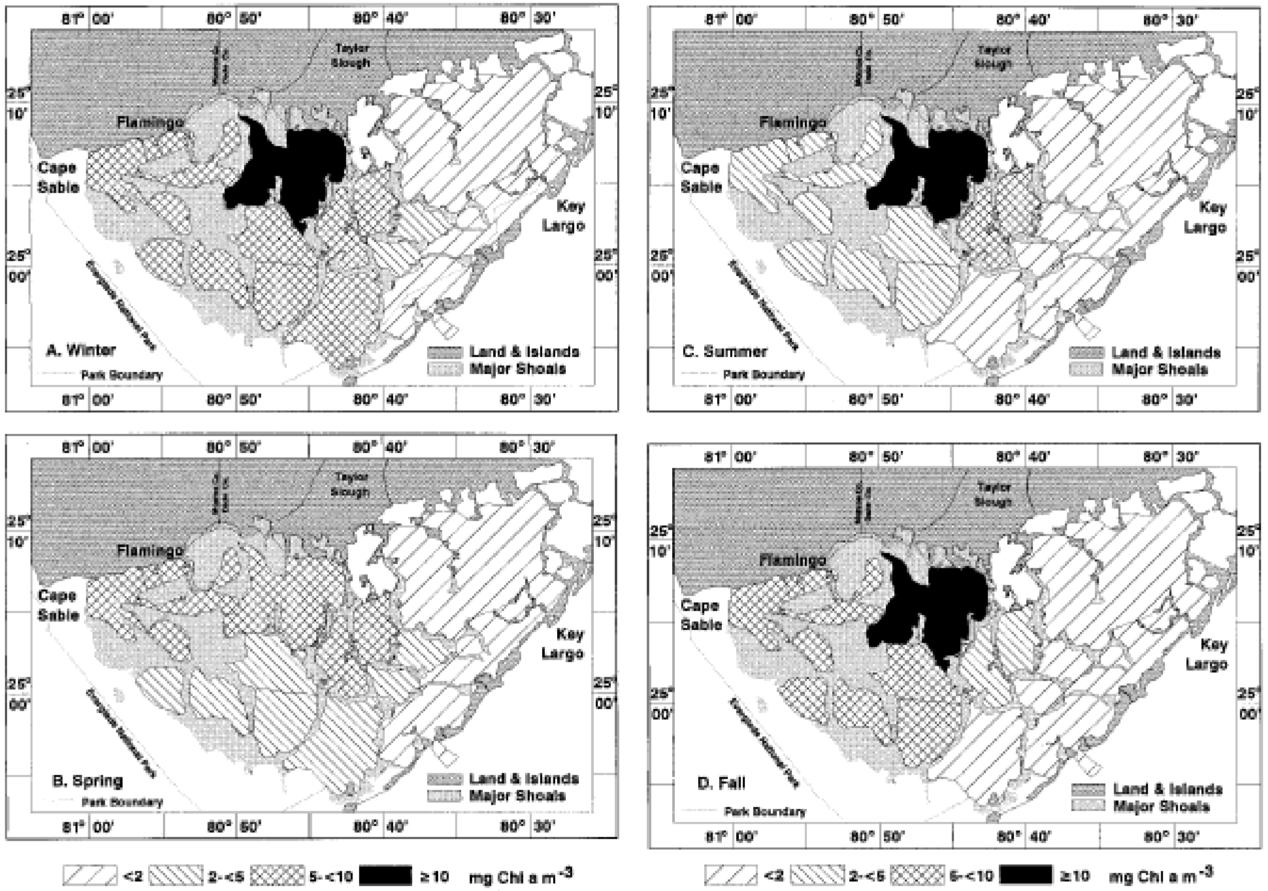



Fig. 2. Seasonal mean Chl *a* concentrations in Florida Bay in winter (A), spring (B), summer (C), and fall (D). Mean values for each of the 17 sampling sites included in this study were used as the basis for the shading patterns in the various distinct basins within the bay. Chl *a* values for the 3 months of each season were used to generate mean values. Unshaded areas are regions not included in the sampling effort.

*Phlips EJ, Badylak S, Lynch TC (1999) Blooms of the picoplanktonic cyanobacterium Synechococcus in Florida Bay, a subtropical inner-shelf lagoon. Limnology and Oceanography 44:1166–1175. doi: 10.4319/lo.1999.44.4.1166*

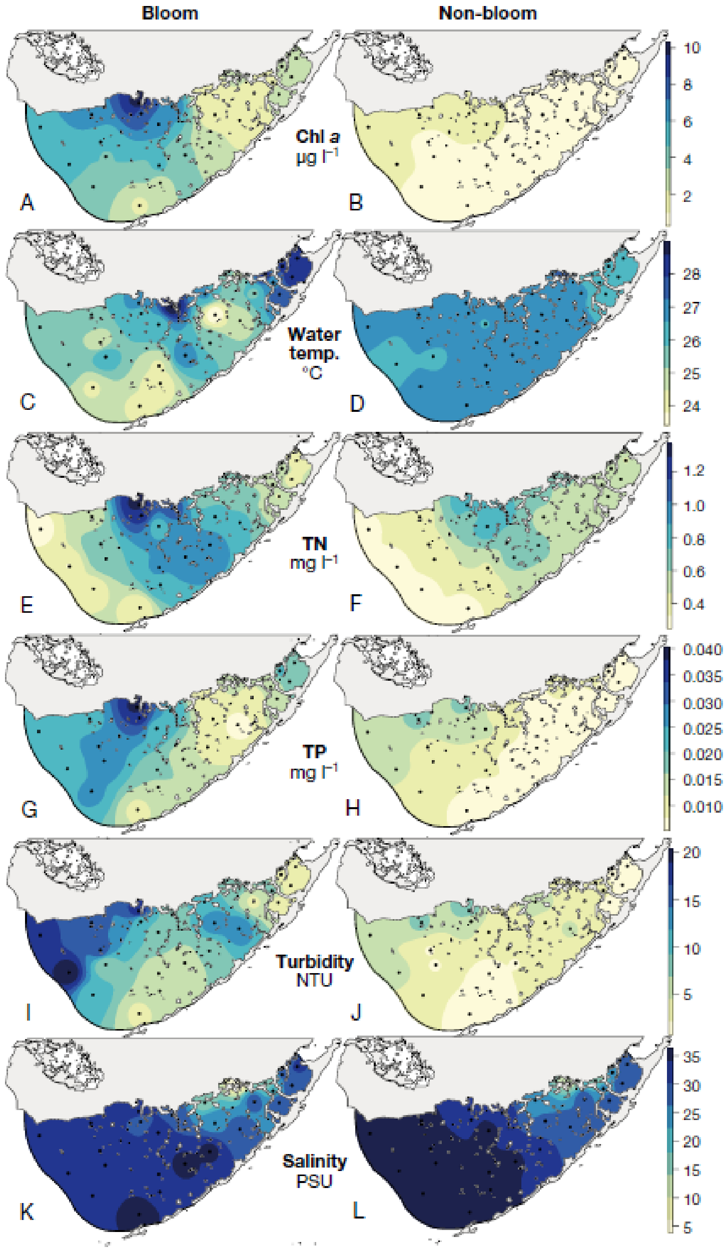
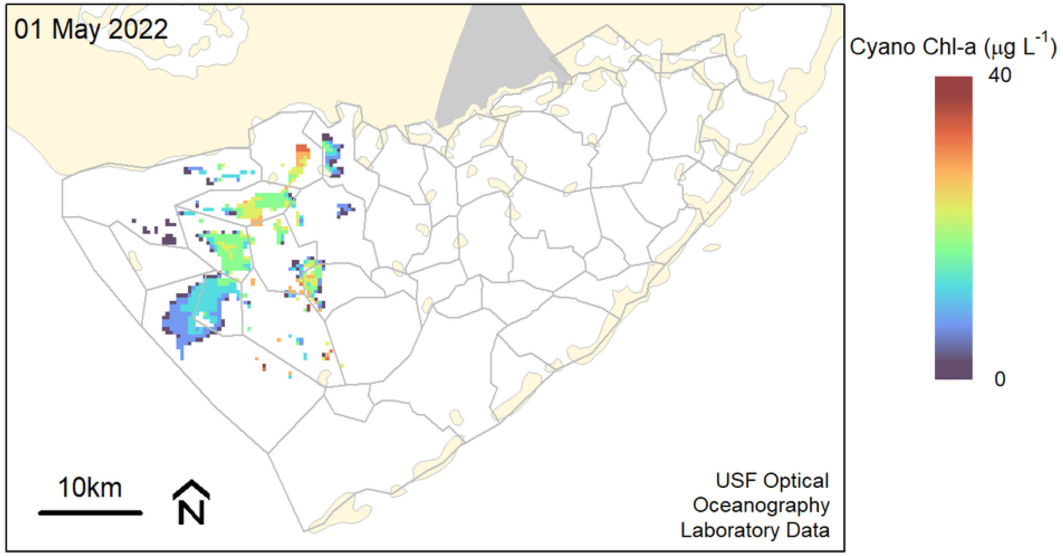



Fig. 5. Bloom (left column) and non-bloom (right column) quantile medians of observed (A,B) chlorophyll *a* (chl *a*; µg l$^{-1}$), (C,D) water temperature (°C), (E,F) total nitrogen (TN; mg l$^{-1}$), (G,H) total phosphorus (TP; mg l$^{-1}$), (I,J) turbidity (NTU), and (K,L) salinity (PSU). Observed values were spatially interpolated between the 28 stations

*Nelson NG, Muñoz-Carpena R, Phlips EJ (2017) A novel quantile method reveals spatiotemporal shifts in phytoplankton biomass descriptors between bloom and non-bloom conditions in a subtropical estuary. Marine Ecology Progress Series 567:57–78. doi: 10.3354/meps12054*

# Algae



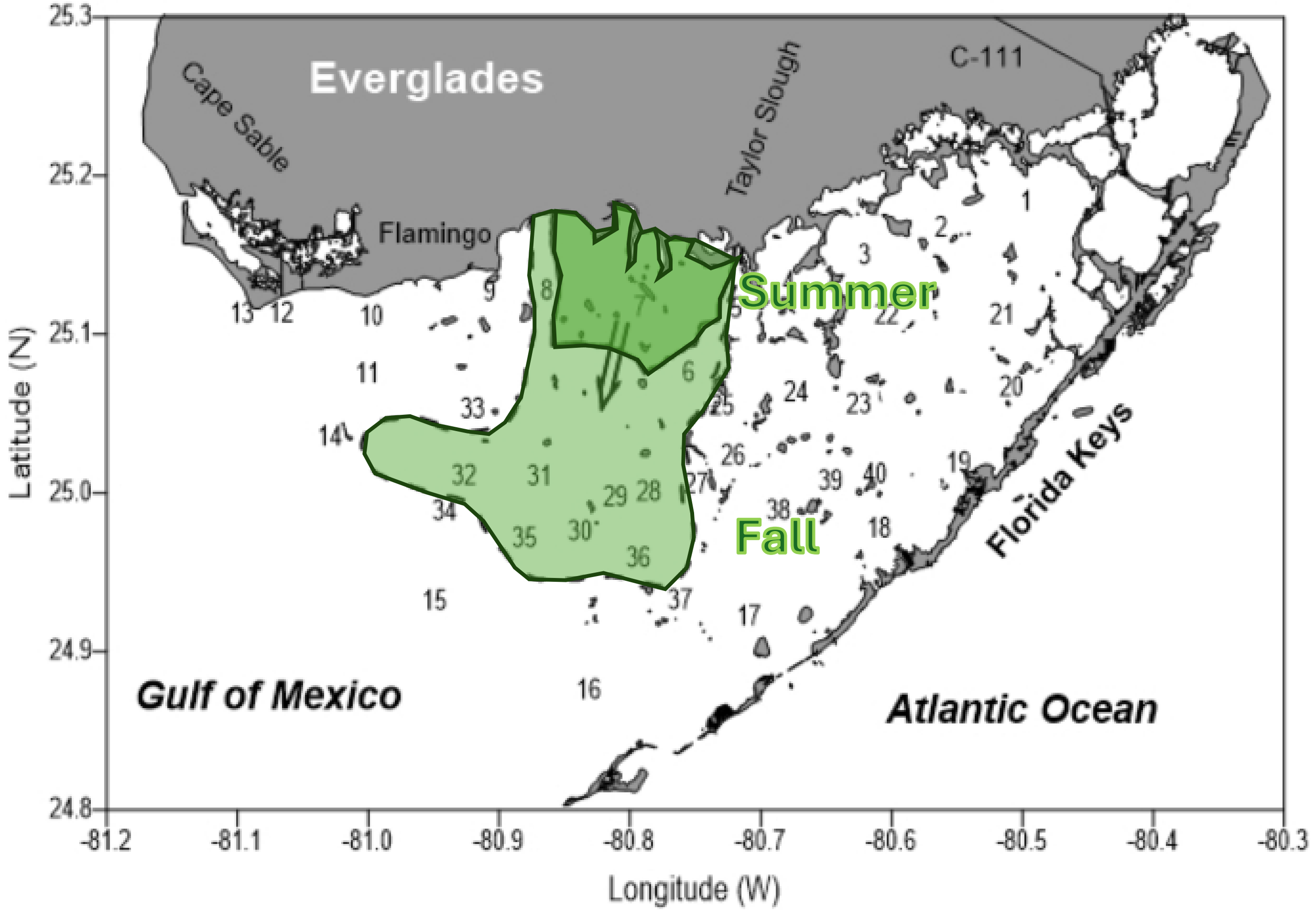
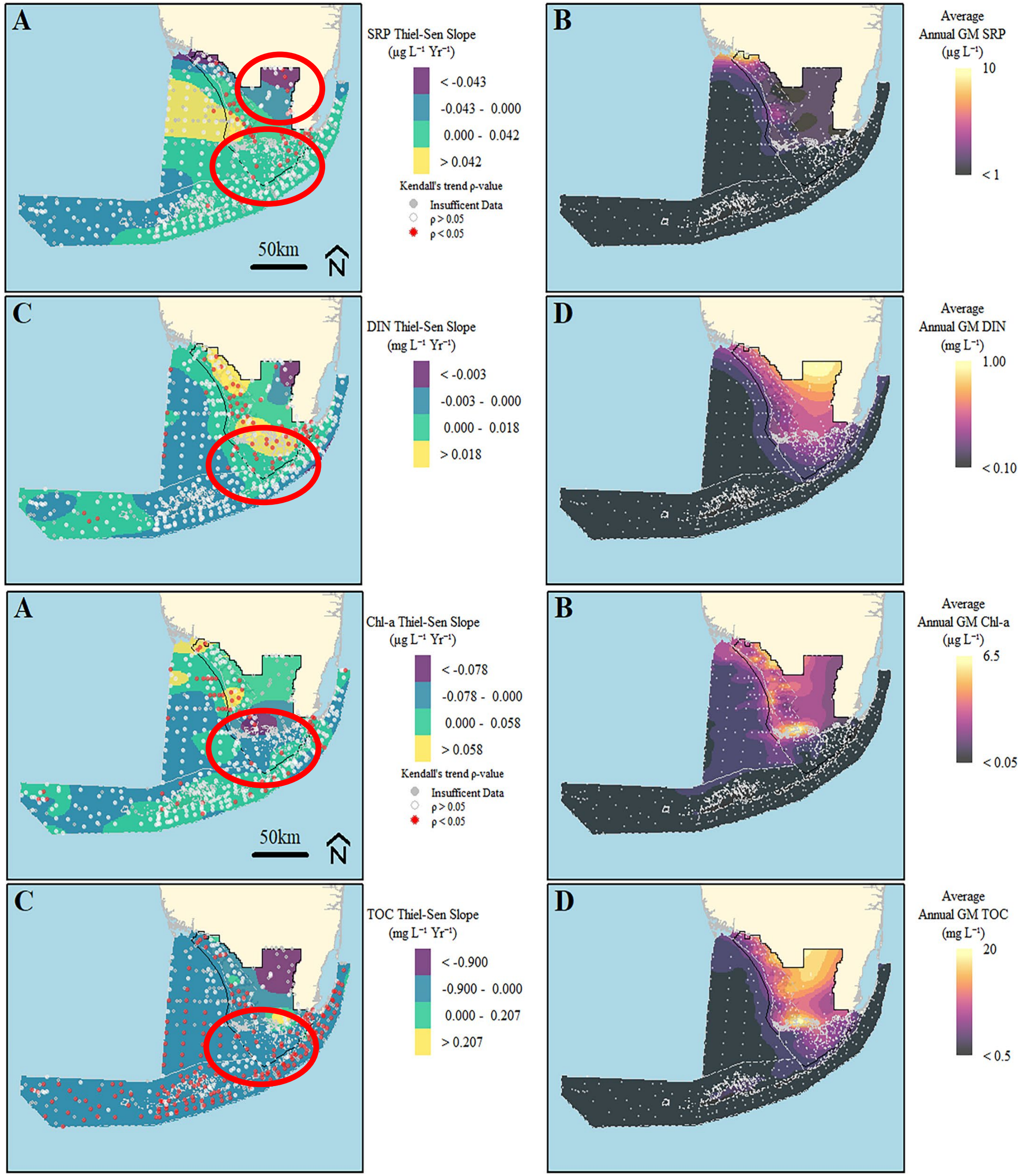




Figure 1. Locations of 40 sampling stations in Florida Bay. Seasonal progression of cyanobacteria bloom is indicated by the arrow and contour lines: summer in solid line and fall in dash line (after Phlips et al. 1999).

*Zhang J-Z (2023) Cyanobacteria blooms induced precipitation of calcium carbonate and dissolution of silica in a subtropical lagoon, Florida Bay, USA. Scientific Reports 13:4071. doi: 10.1038/s41598-023-30905-4*




Long Term Trends (May 1995 – April 2019)

- Freshwater Everglades ↓ SRP with low TP and SRP concentrations

- Florida Bay ↑ SRP and DIN, on average low concentrations

- Florida Bay Chl-a spatially variable (western ↓, eastern ↑)
- TOC ↓ nearly system wide
  (except Taylor River, browing?)
- Florida Bay is very dynamic with large pools of OM and nutrients

*Julian et al (2024) Long-term patterns and trends in water column biogeochemistry in a changing environment. Estuarine, Coastal and Shelf Science 306:108896. doi: 10.1016/j.ecss.2024.108896*

## Chlorophyll Seasonality

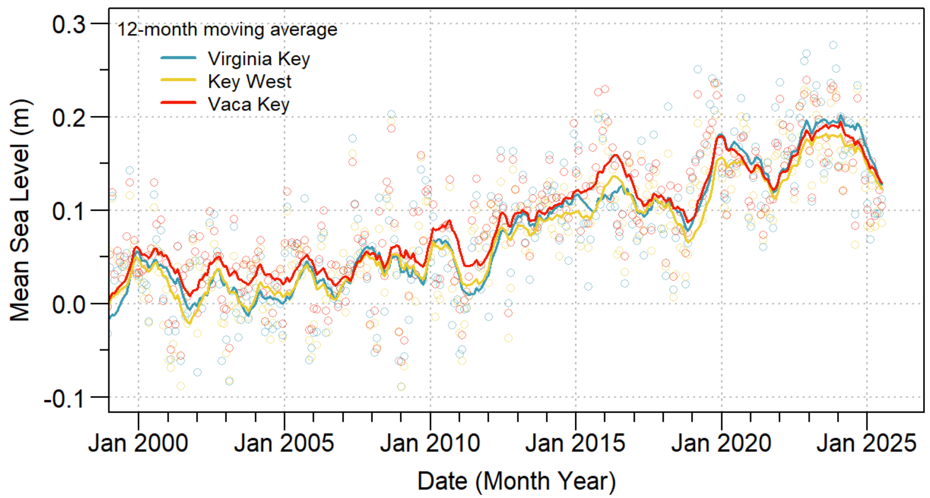
- Prior trend analysis looked at unimodal trend (up or down)
- Next step, non-linear spatio-temporal trends using a generalized additive model approach (1991 – 2025)

| Model | Generalized GAM Equation | $R^2_{adj}$ | Dev Expl | AIC |
|---|---|---|---|---|
| 1 Space+Time | $E(Chla) = s(month) + s(yr) + ti(month, yr) + s(X, Y) + ti(X, Y, yr)$ | 0.47 | 0.67 | 11596.68 |
| 2 Space+Time+SLR | $E(Chla) = s(SLR_{vaca}) + s(month) + s(yr) + ti(month, yr) + s(X, Y) + ti(X, Y, yr)$ | 0.48 | 0.68 | 11138.36 |
| 3 Space+Time+SLR+Climate | $E(Chla) = s(SLR_{vaca}) + s(ENSO_{mei}) + s(month) + s(yr) + ti(month, yr) + s(X, Y) + ti(X, Y, yr)$ | 0.48 | 0.68 | 11134.91 |

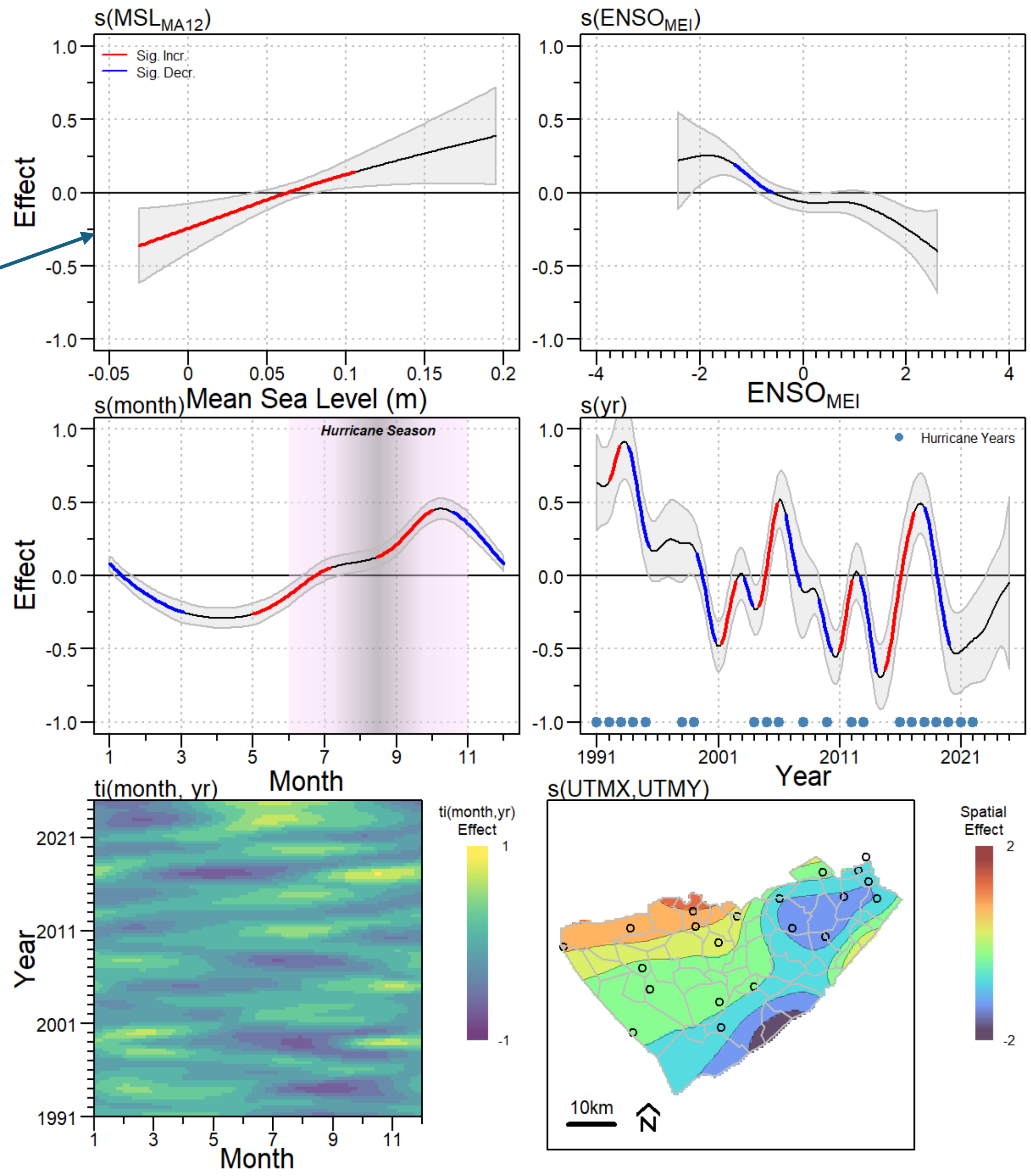
| Model 1 | Model 2 | ΔAIC |
|---|---|---|
| Space+Time | Space+Time+SLR | 458.3 |
| Space+Time | Space+Time+SLR+Climate | 461.8 |
| Space+Time+SLR | Space+Time+SLR+Climate | 3.5 |

- Models with SPEI and coastal creek net discharge also considered.
  - Marginal/no improvement in explanatory power BUT were significant effects in explaining variation in Chl-a
  - Different period of records, therefore models not compared.

# Chlorophyll Seasonality




- Sea level rise accelerating (~2017)




- ENSO effect on Chl-a moving out of La Niña (to neutral)
  - Timing matters Winter/Spring vs Summer/Fall
- Strong within-season effect and variability long term
- Month x Year synchrony (and shifts)
- Location, location, location!

# Alternate Stable States

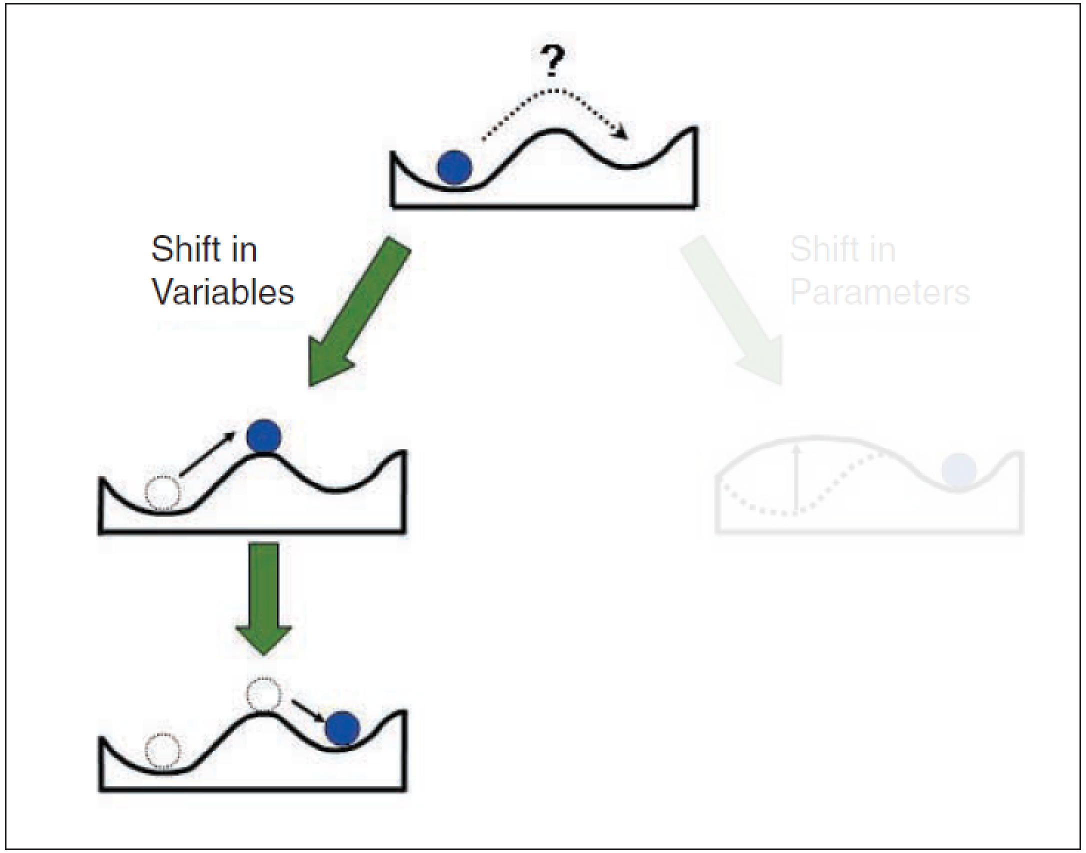
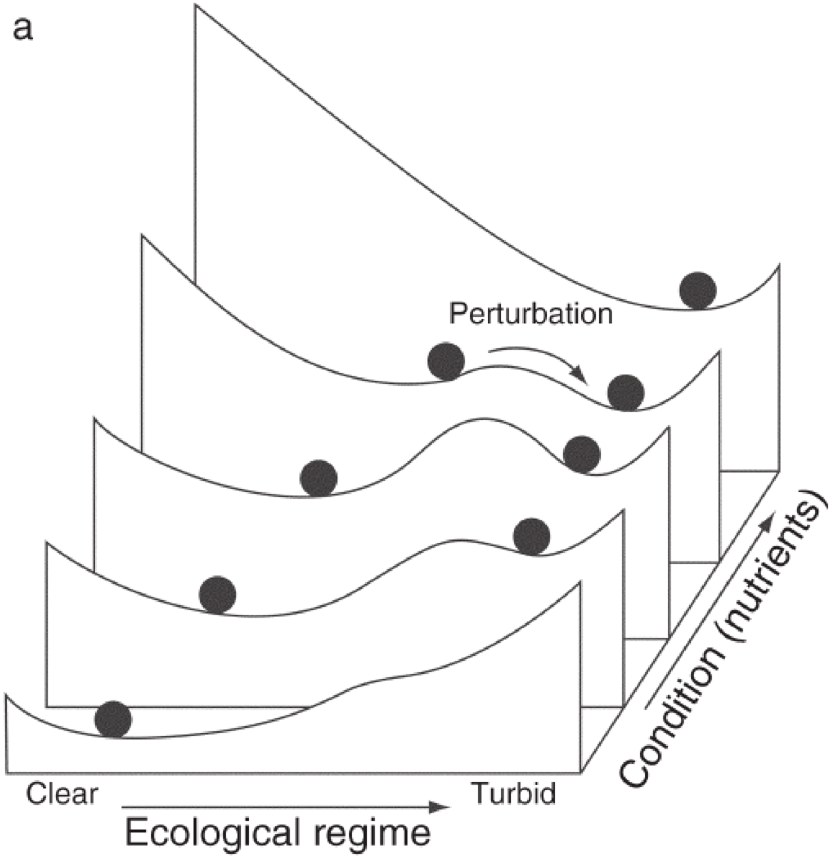


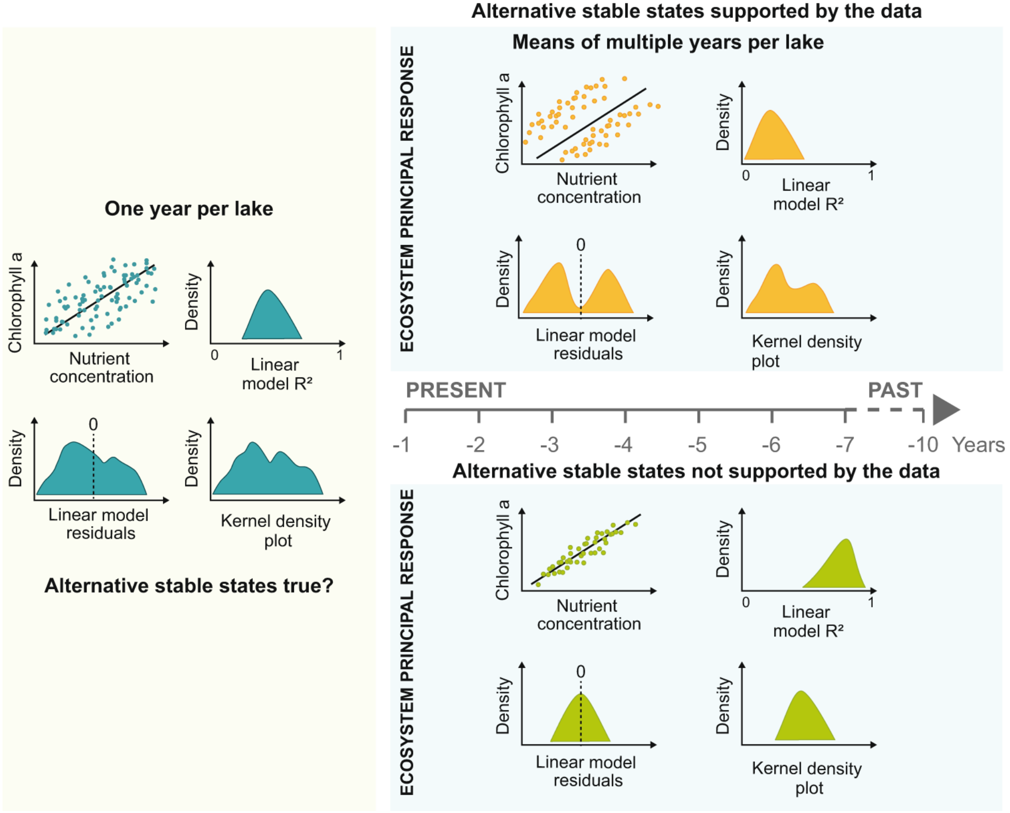

*Figure 1. Two-dimensional ball-in-cup diagrams showing (left) the way in which a shift in state variables causes the ball to move, and (right) the way a shift in parameters causes the landscape itself to change, resulting in movement of the ball.*

*Beisner B, Haydon D, Cuddington K (2003) Alternative stable states in ecology. Frontiers in Ecology and the Environment 1:376–382. doi: 10.1890/1540-9295(2003)001[0376:ASSIE]2.0.CO;2*




*Hobbs WO, Hobbs JMR, LaFrançois T, et al (2012) A 200-year perspective on alternative stable state theory and lake management from a biomanipulated shallow lake. Ecological Applications 22:1483–1496. doi: 10.1890/11-1485.1*

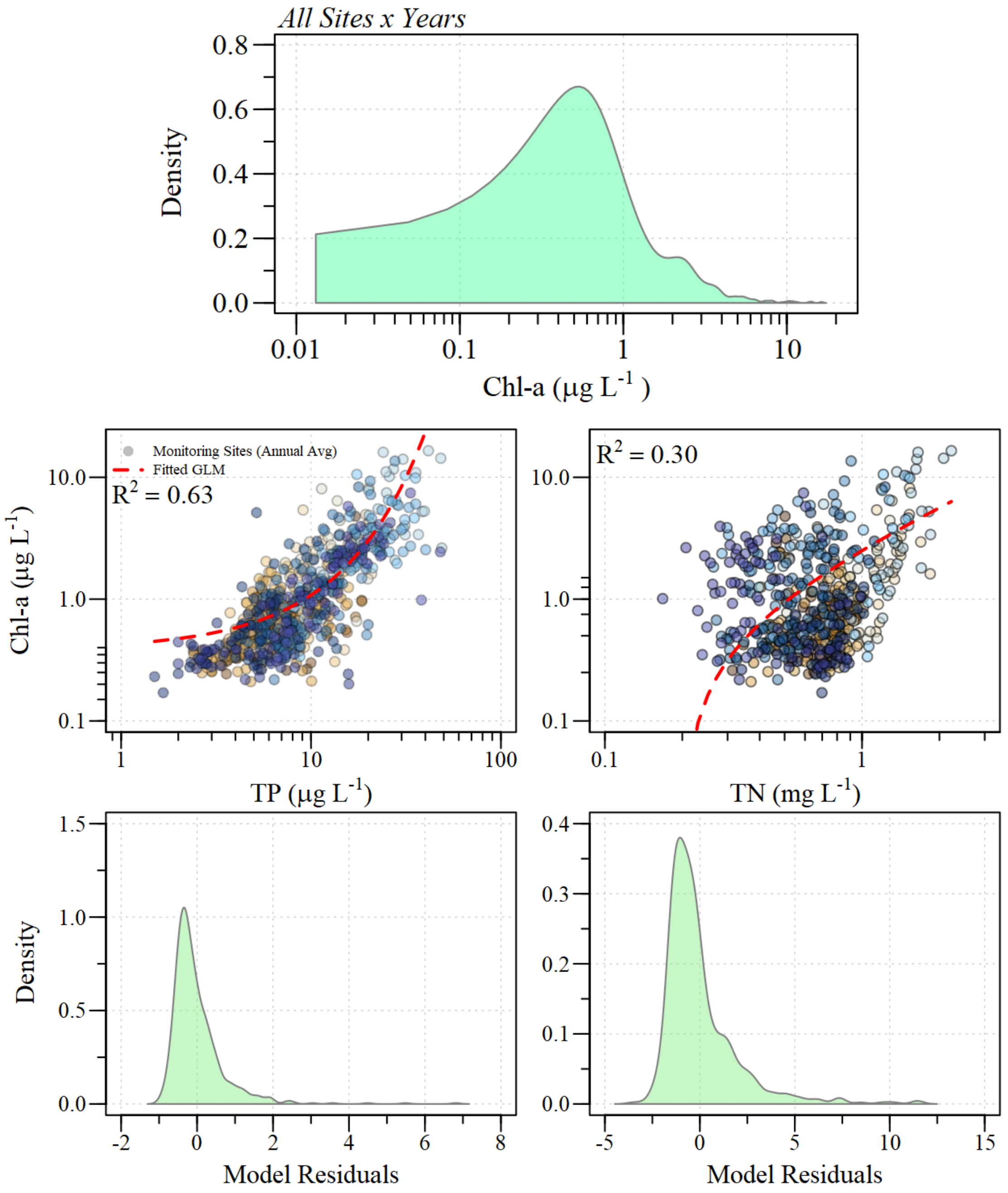
# Alternate Stable States?




*Davidson TA, Sayer CD, Jeppesen E, et al (2023) Bimodality and alternative equilibria do not help explain long-term patterns in shallow lake chlorophyll-a. Nature Communications 14:398. doi: 10.1038/s41467-023-36043-9*

GLM models (Gamma log link distribution) for

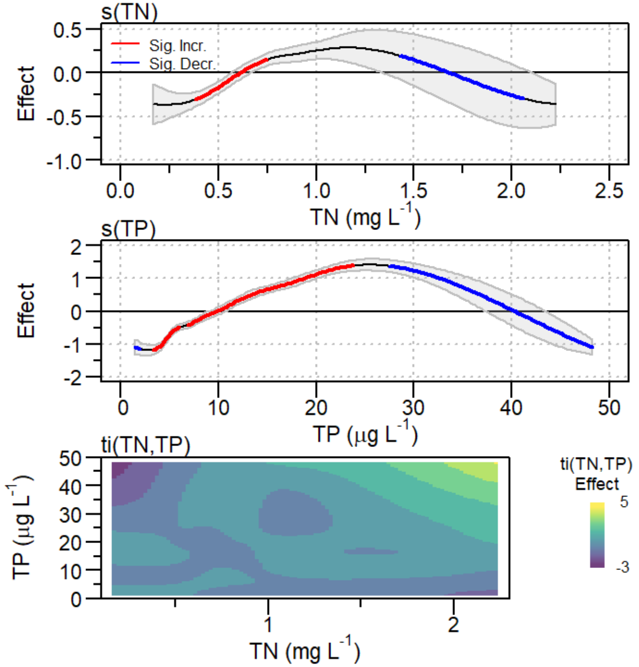
- Chl-a ~ TP
- Chl-a ~ TN
- Chl-a ~ TP+TN+TN:TP (not shown)




Chl-a ~ TP+TN+TN:TP $R2 = 0.79$

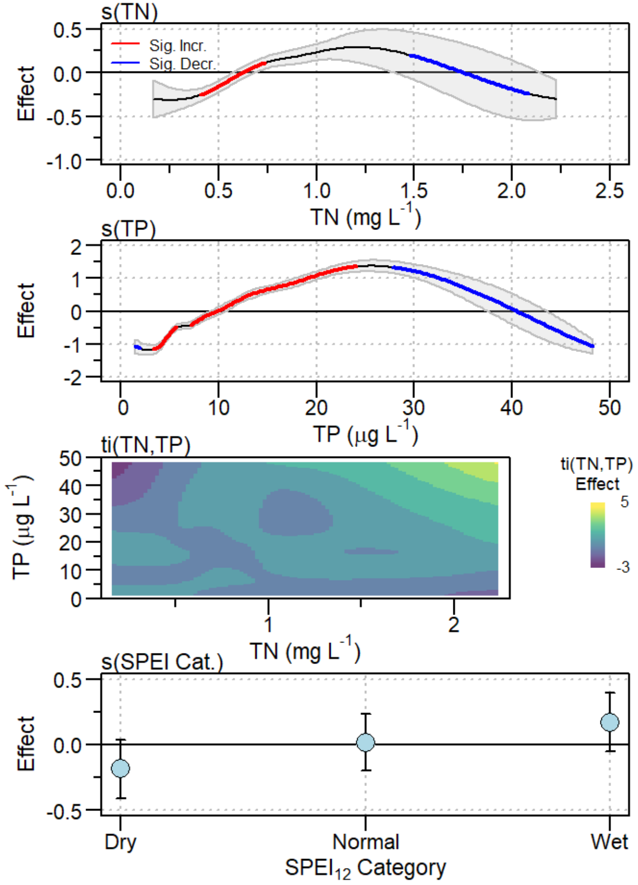
# Alternate Stable States GAM approach

$$E(Chla) = s(TN) + s(TP) + ti(TN, TP)$$



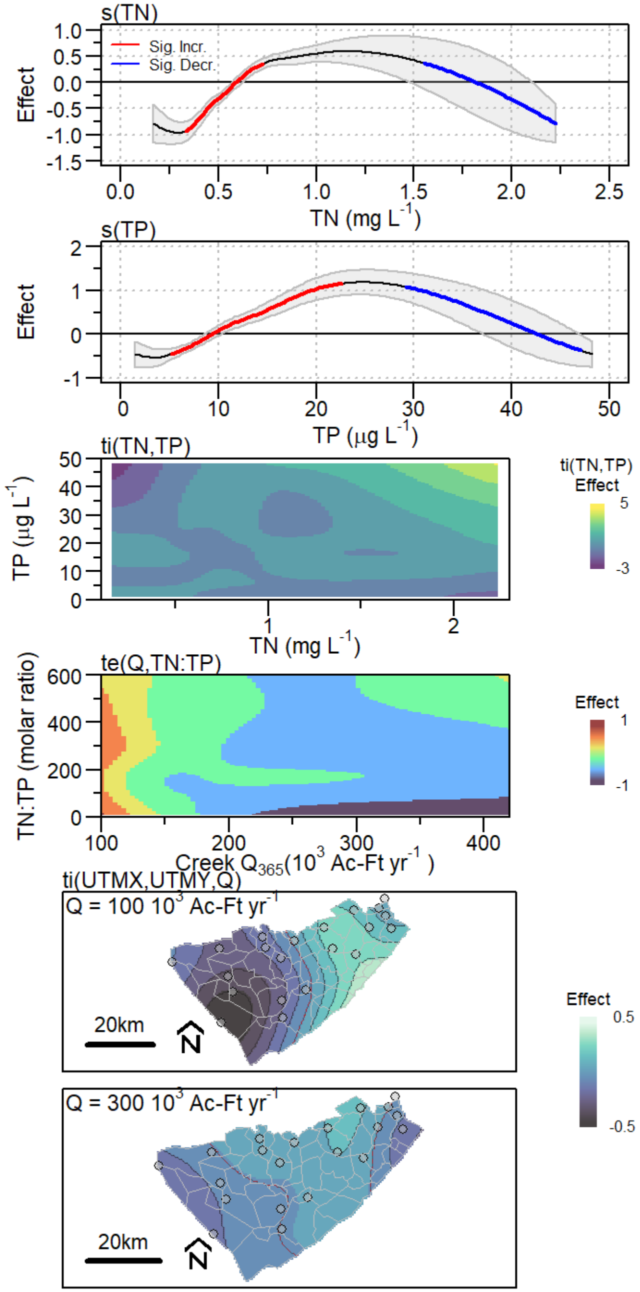

$R^2_{adj}$ = 0.70; Dev Exp = 0.80

$$E(Chla) = s(TN) + s(TP) + ti(TN, TP) + s(SPEI_{12}Cat.)$$

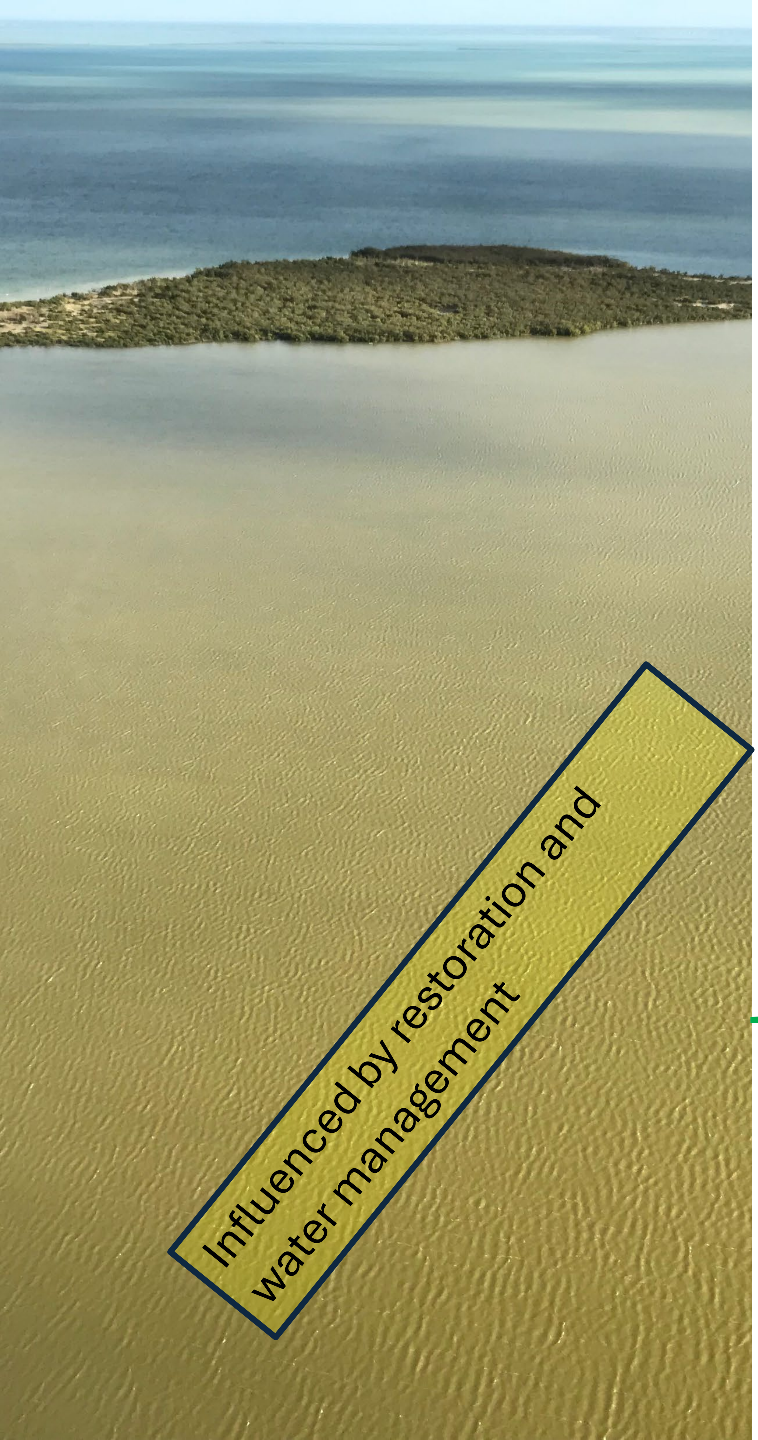



$R^2_{adj}$ = 0.72; Dev Exp = 0.80

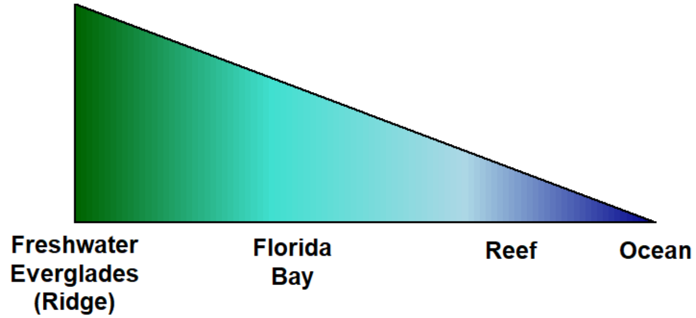
$$E(Chla) = s(TN) + s(TP) + ti(TN, TP) + te(Q, TN{:}TP) + s(UTMX, UTMY) + ti(UTMX, UTMY, Q)$$




$R^2_{adj}$ = 0.91; Dev Exp = 0.93




- Ridge to Reef is a gradient of nutrient pools and material, affected by various forcing factors resulting in varying levels of reactivity




- Climate, sea-level rise and disturbance influence chlorophyll concentrations (i.e. agal biomass) in Florida Bay

- Maybe not classic alternate stable state but ecological regime is dynamic with changing conditions

- Chlorophyll (algae) & nutrient relationship varies spatially influenced by input conditions (i.e. creek flow)