Flow, Biology, and Diel Oxygen Variability in a Shallow Estuary:

Insights from the Patuxent River

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UMCES
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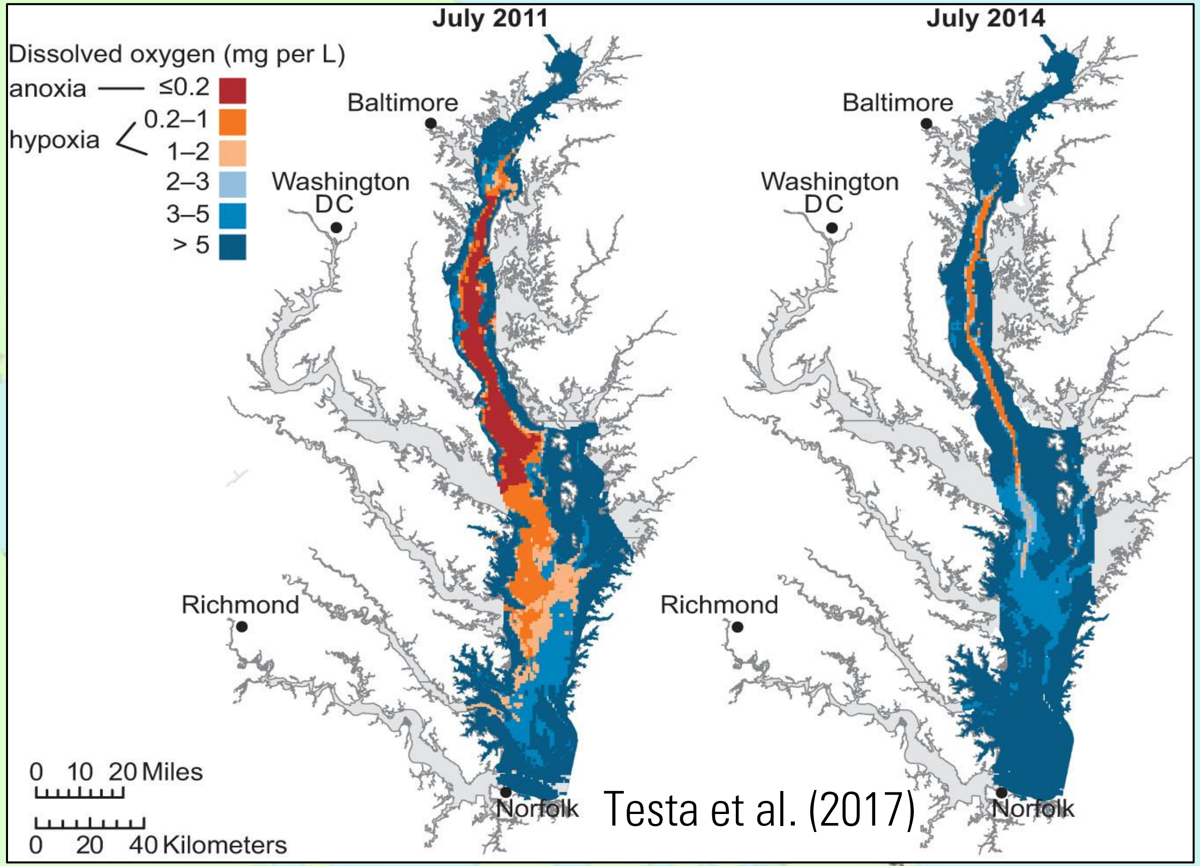
100 YEARS OF SCIENCE

Oxygen Dynamics in Estuaries

- Oxygen depletion remains a global threat to estuarine ecosystems

- Most hypoxia research focuses on deep, stratified systems

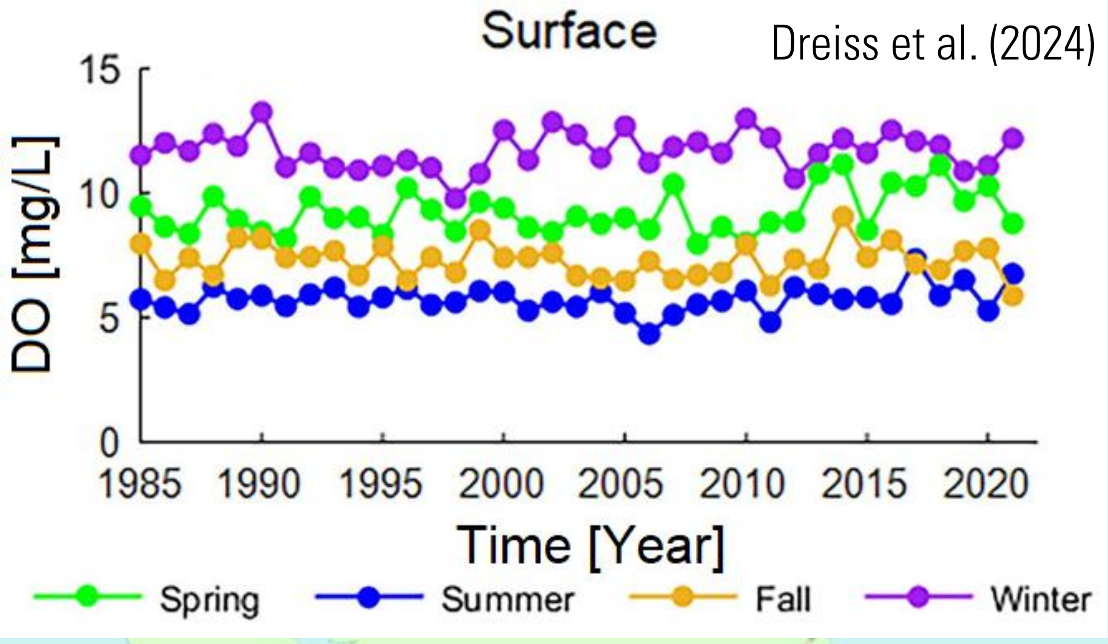


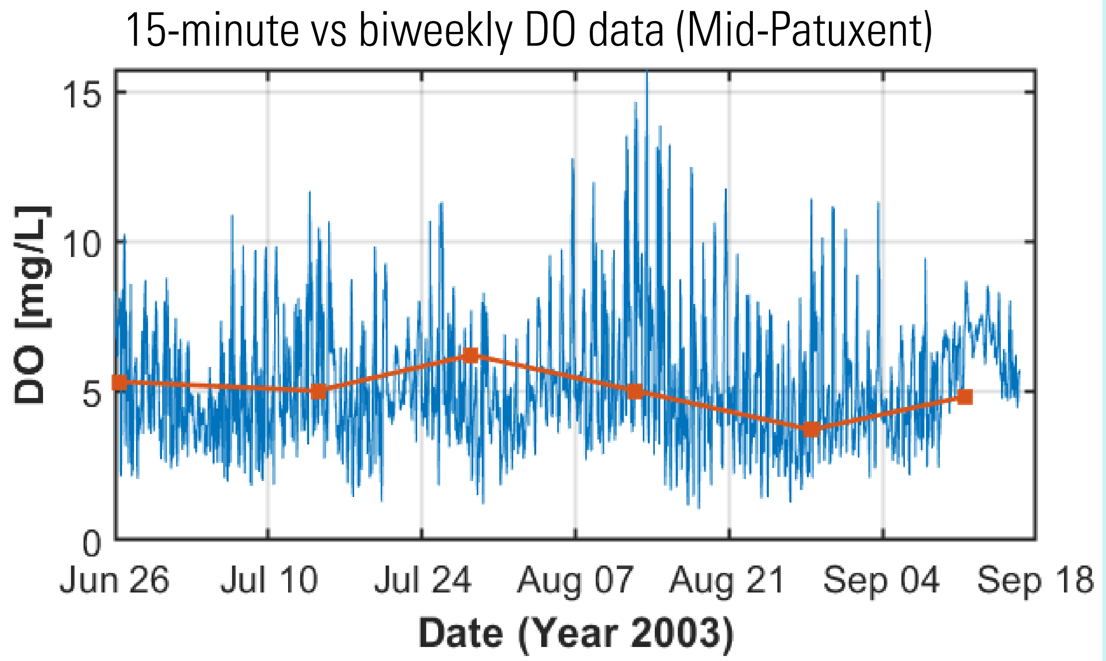
Testa et al. (2017)

Oxygen Dynamics in Estuaries

- Broad-scale approaches miss short nighttime low-oxygen events
- DO can change rapidly on hourly timescales
- High-frequency datasets now reveal these short-term dynamics

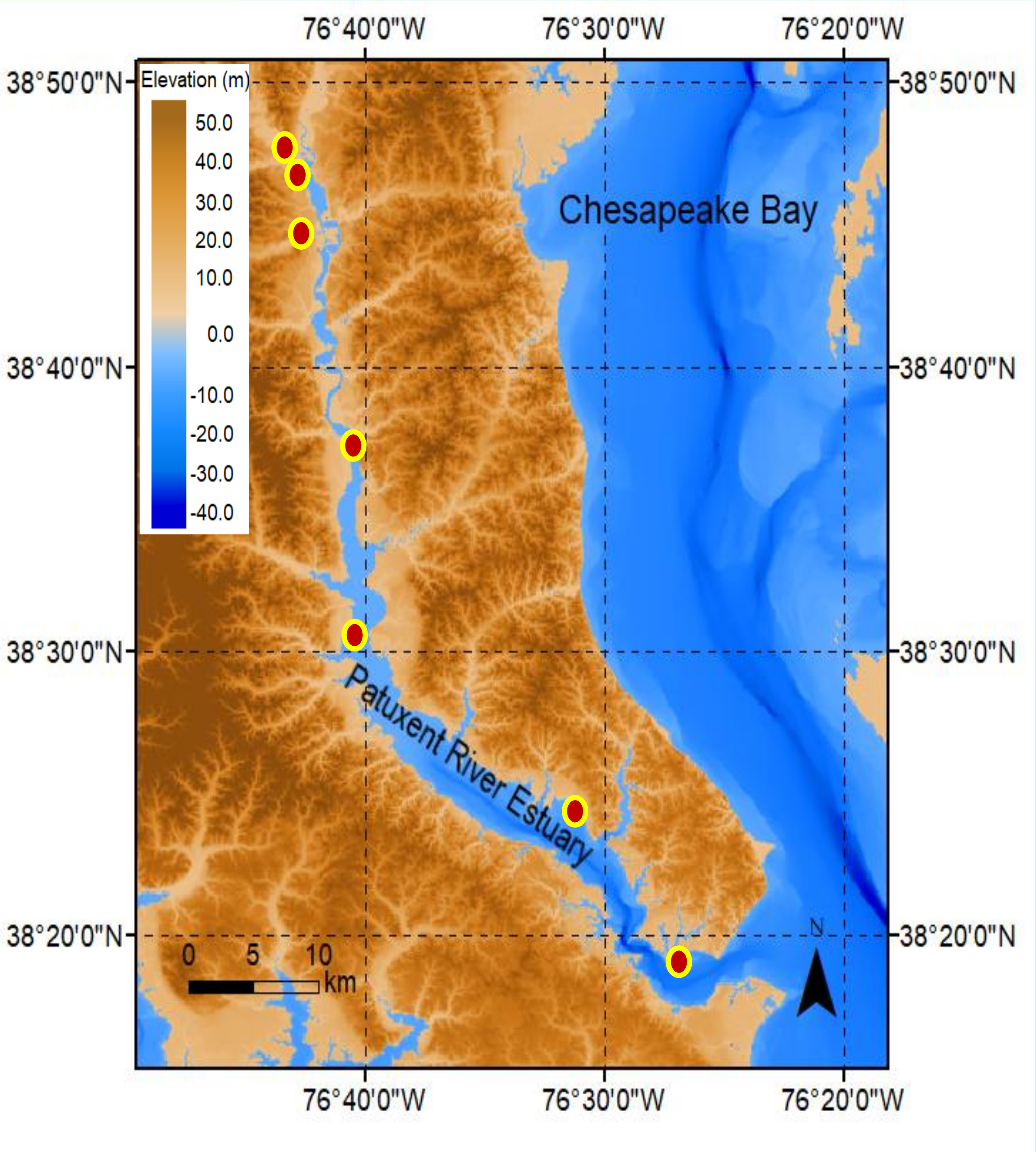
But very few studies examine long-term changes and their controls on these short-term fluctuations

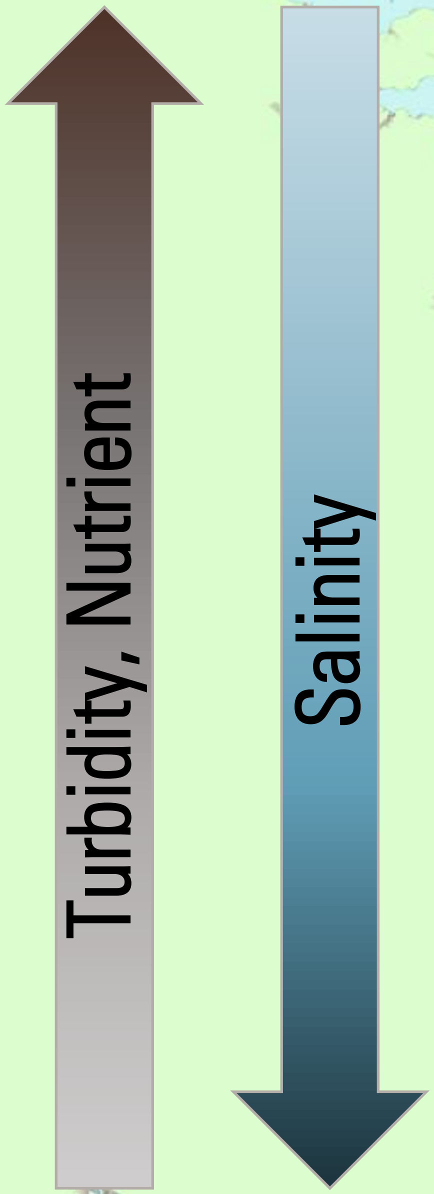




Unique Long-term Dataset in The Patuxent River Estuary

- Long-term, high-frequency DO records across diverse habitats
- Stations span tidal freshwater to mesohaline regions
- Several sites have > 20 years of data; one extends to the 1960s
- Strong gradients in nutrients, turbidity, depth, and flow





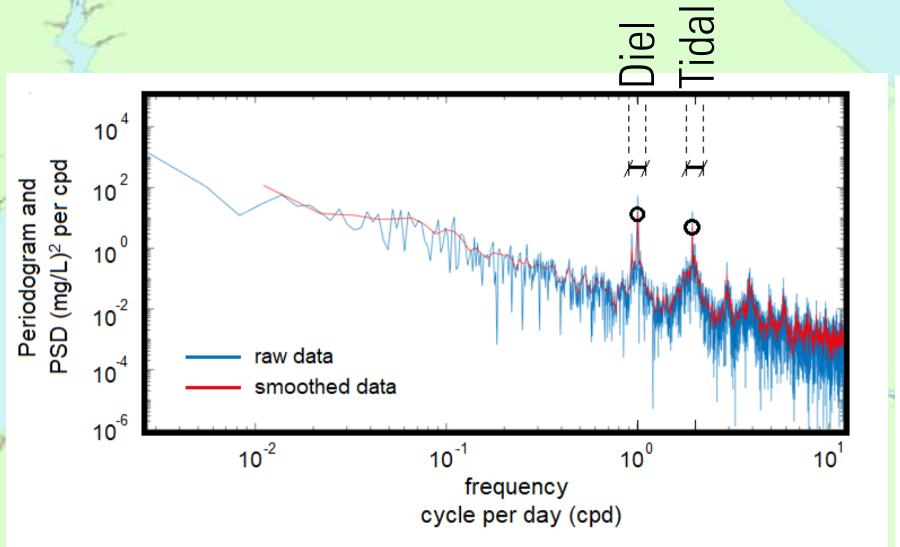
Data sources: NERRS, MDDNR, CBL.
Riverine flow from USGS gauge at Bowie, MD.

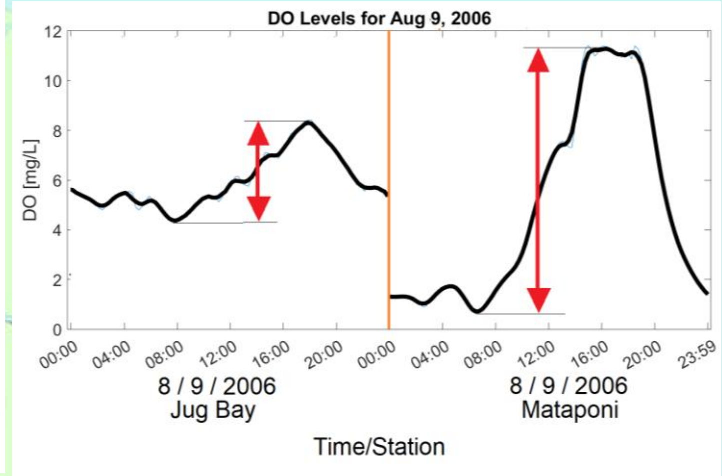
Three Stories Emerging from the Patuxent

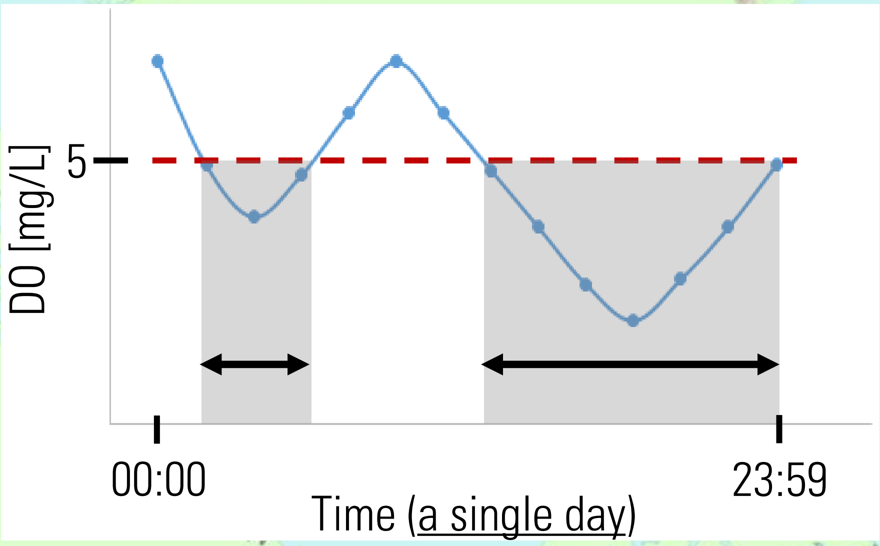
I	Long-Term Increase in Diel Variability	(BENEDICT STORY)
II	Hotspot of Variability and Nighttime Hypoxia	(MATAPONI STORY)
III	Long-Term Reduction in Diel Variability with Nutrient Load Reduction	(IRON POT LANDING STORY)
IV	Strong Short-Distance DO Gradients and Tidal-Scale Variability	(Up Estuary Marsh Creek Sub-story)

Methods

- Data Handling
  - High-frequency DO data (15-min intervals)
  - Gaps filled via linear interpolation
- Power Spectrum Analysis
  - Evaluated diel (1 cycle/day) and tidal (2 cycles/day) DO variability
  - Periodogram (measure of variance) used to estimate power spectral density (PSD) across sites and years
  - PSD is considered as a metric indicating the variability
- Hypoxia Duration
  - Defined as DO < 5 mg/L
  - Calculated annually using 15-min data (±7.5 min = one observation)







Benedict Story
(Long-Term Increase in Diel Variability)

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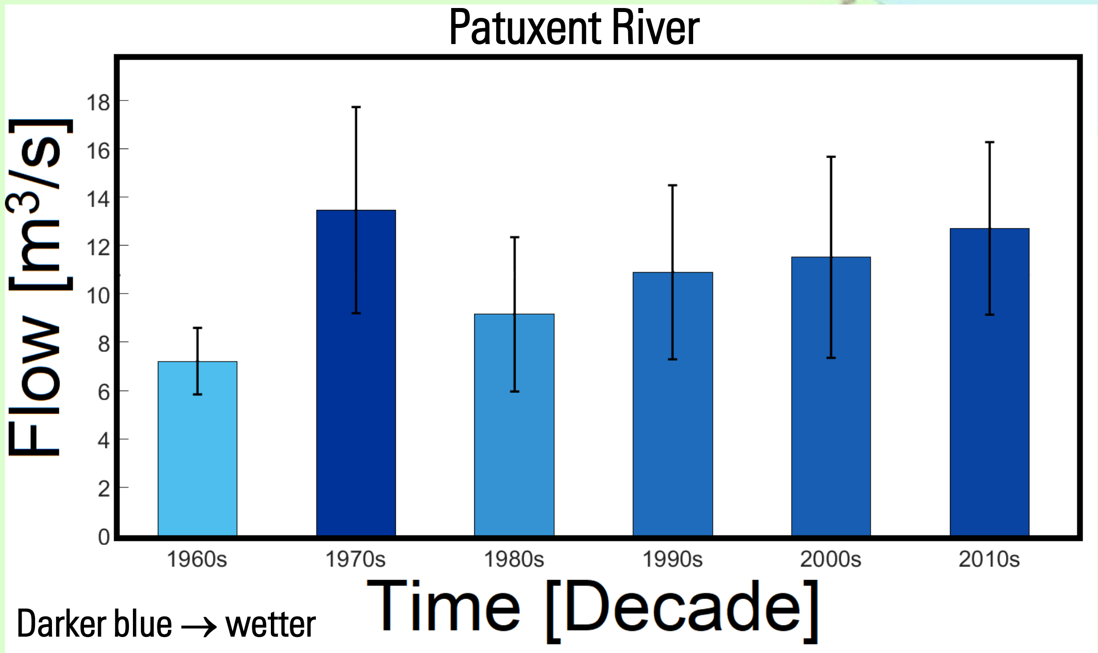
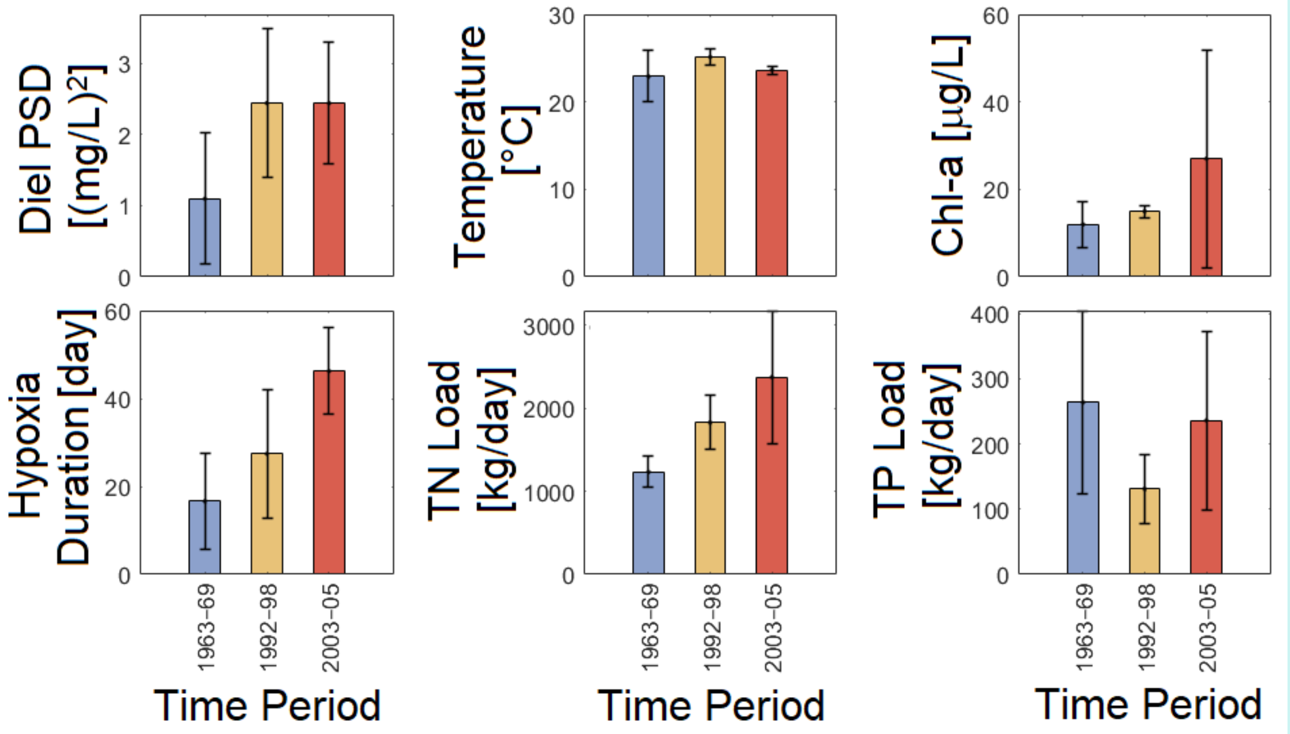
- Increasing river flow since 1960
- Increasing diel DO variability over time
- Higher temperatures, more chl-a, more hypoxia
- TN increasing; TP decreasing



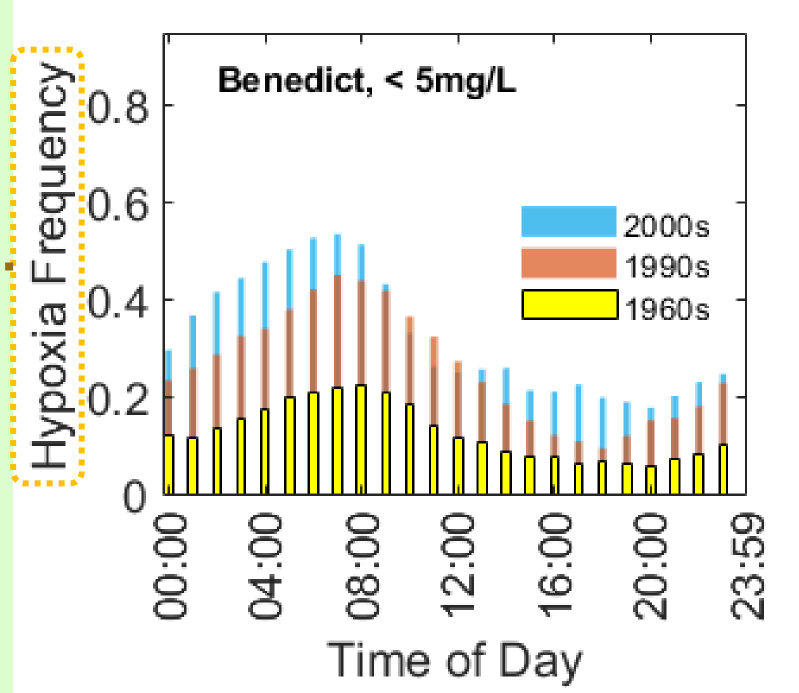


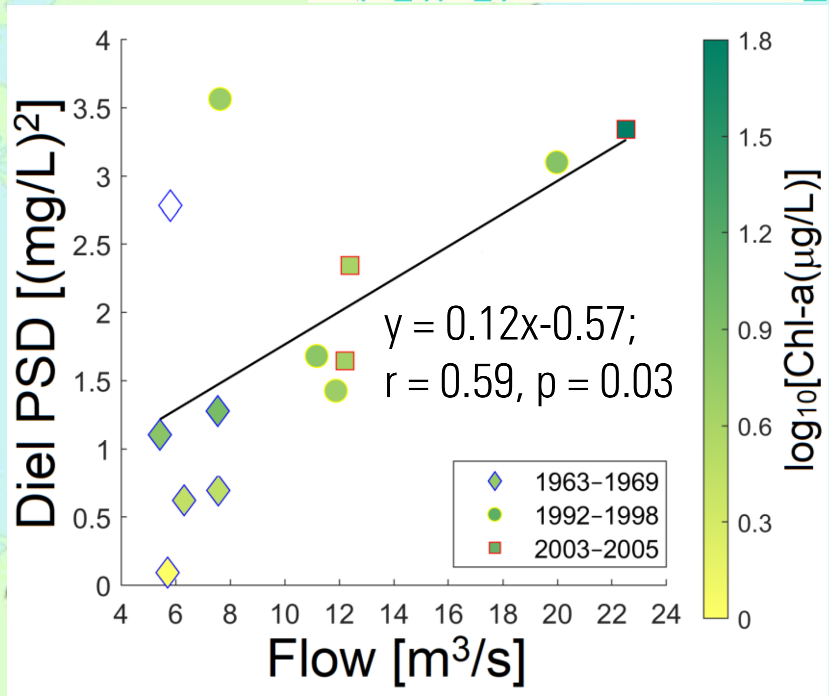
Benedict Story (Long-Term Increase in Diel Variability)

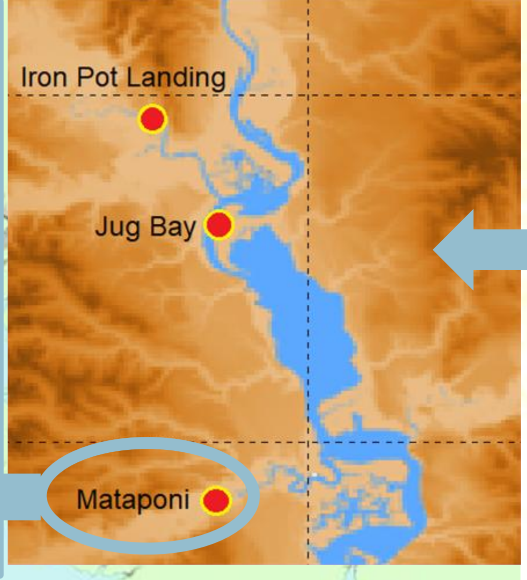
- Higher river flow → Higher diel DO variability
- Higher chl-a → Higher diel DO variability
- Hypoxia most frequent near sunrise (~06:00-07:00)
- Diel timing stable, but hypoxia frequency increasing

Relative frequency of hypoxia

$$= \frac{\#\ (< 5mg/L\ records\ at\ each\ hour\ of\ day)}{\#\ (total\ records\ at\ each\ hour\ of\ day)}$$







Mataponi Story

(Hotspot of Variability and Nighttime Hypoxia)

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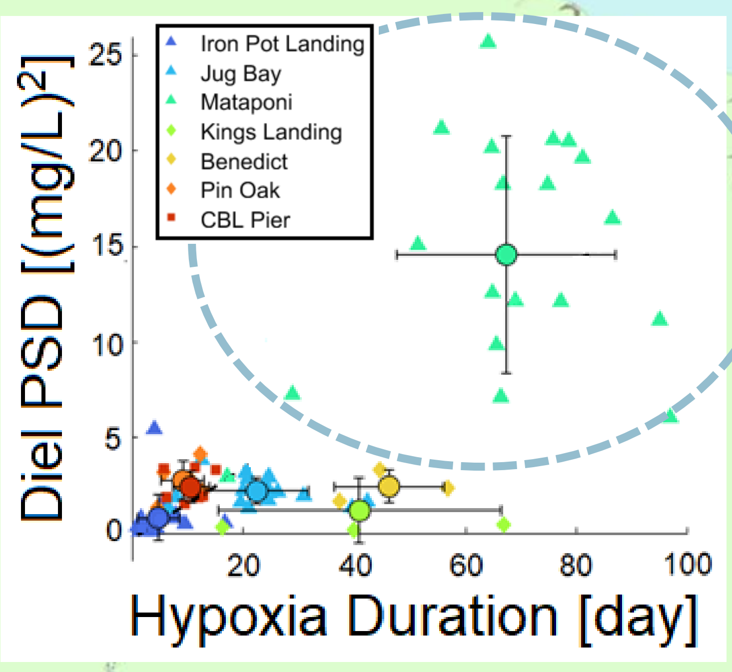
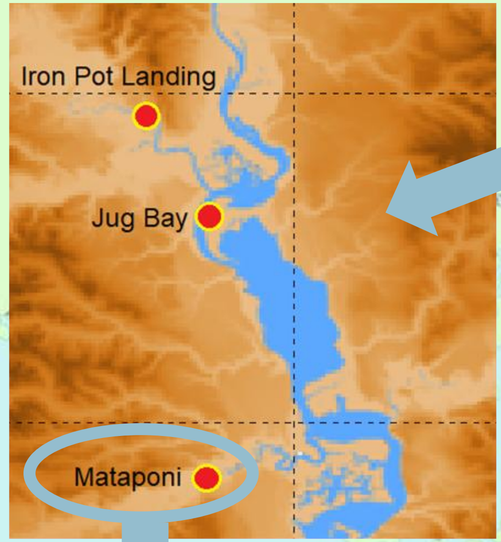
- Shallowest station; located in a marsh-fringed side creek
- Distinct from main-channel sites
- Historically supported SAV beds (lost ~2019)
- Since 2019: frequent chl-a > 100 μg/L

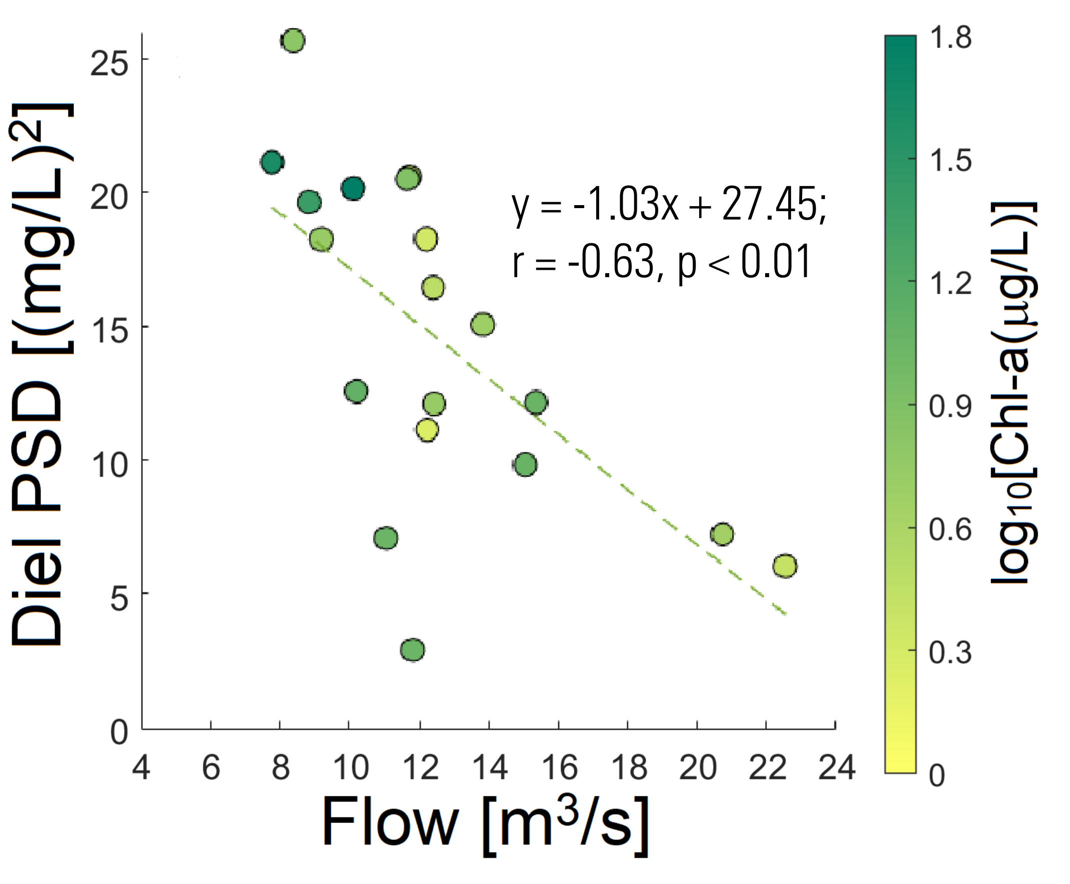
- Mataponi Creek stands out with highest diel DO variability and hypoxia duration





Mataponi Story (Hotspot of Variability and Nighttime Hypoxia)

- Extremely high diel PSD compared to other sites
- Diel variability decreases with increasing flow
- High flows reduce chl-a due to strong flushing and turbidity
- Opposite response to downstream, deeper stations



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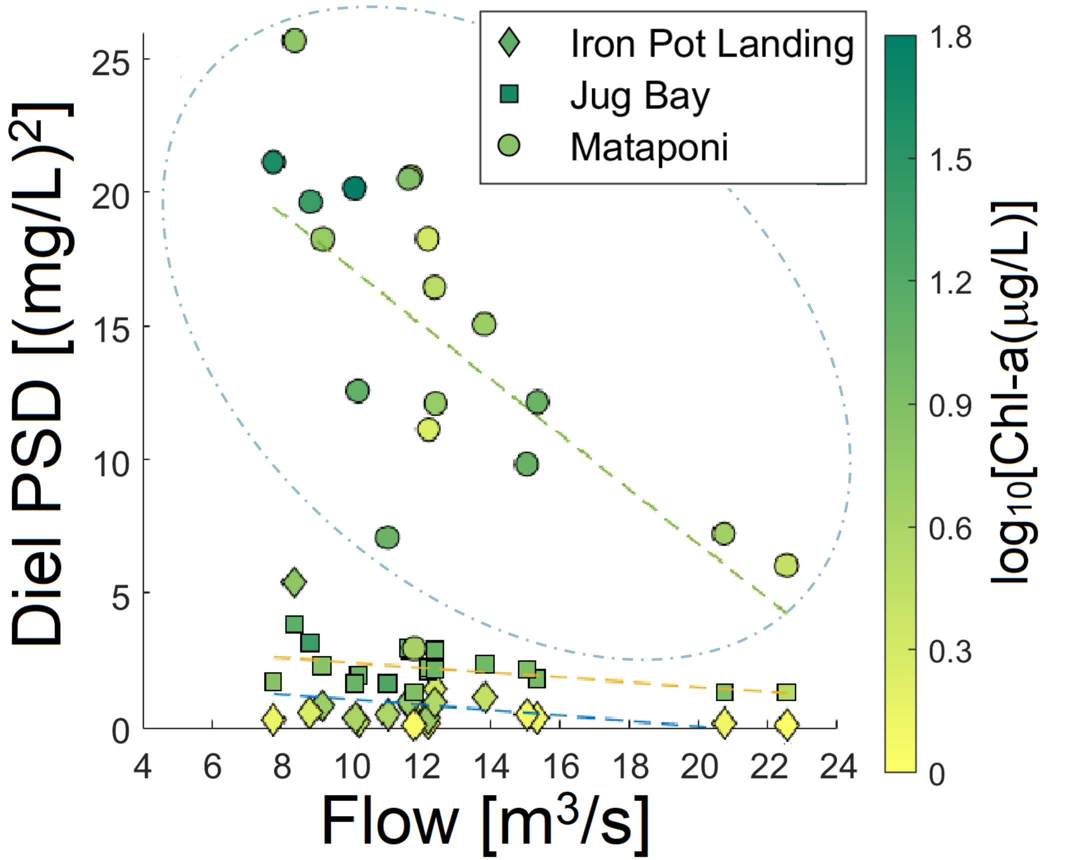

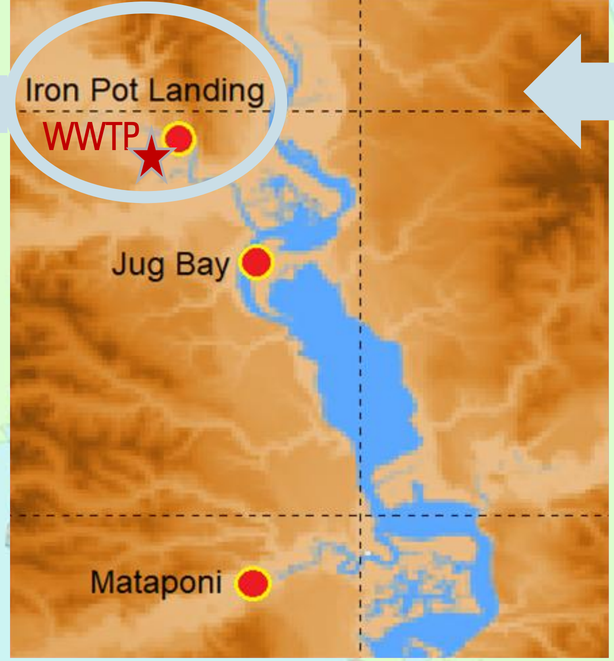

Iron Pot Landing Story

(Long-Term Reduction in Diel Variability with Nutrient Load Reduction)

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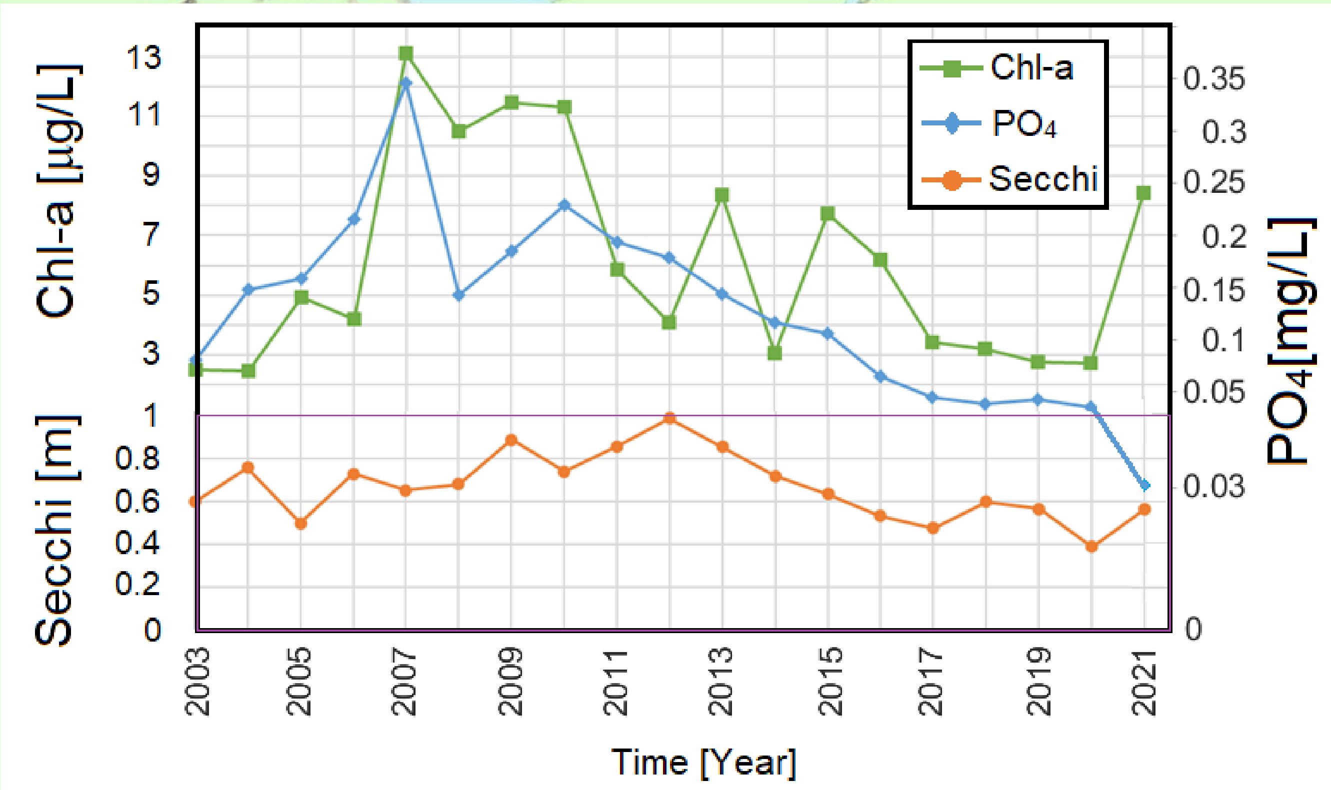
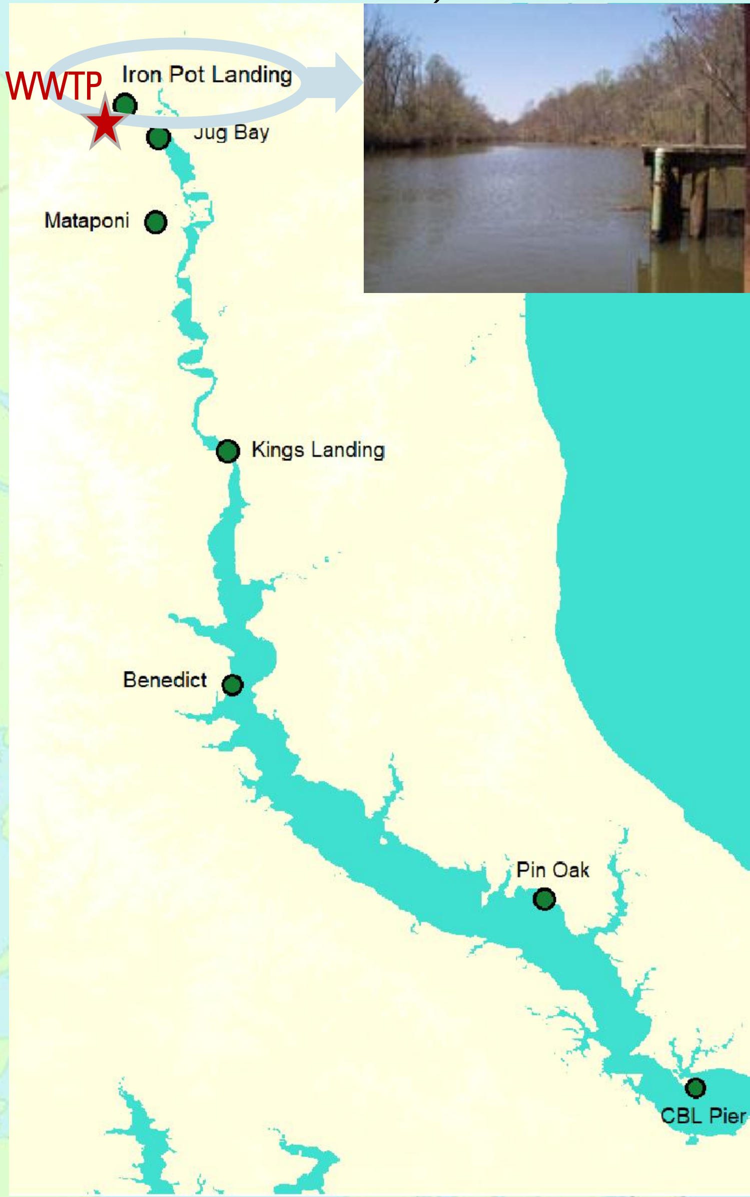




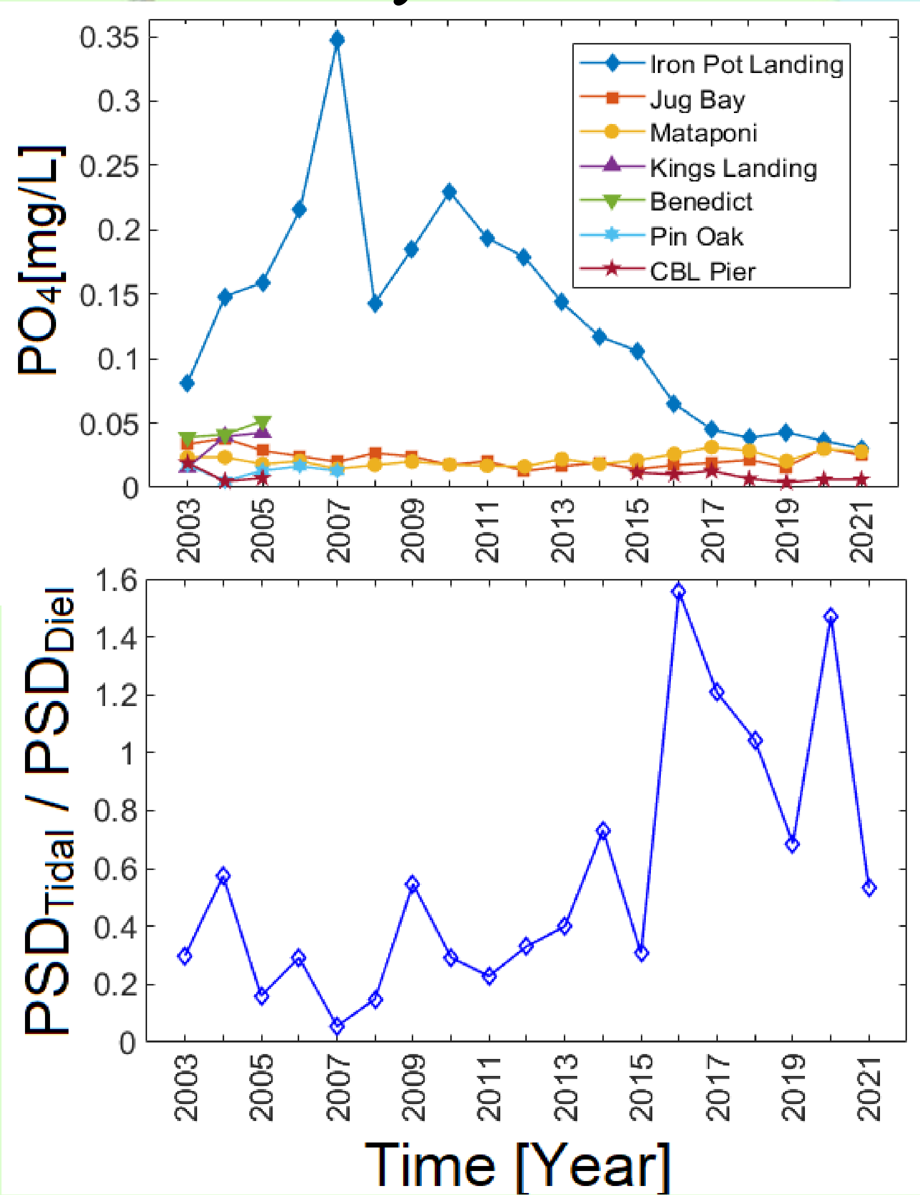
- Downstream of a major WWTP
- Very low light → low productivity
  - Orthophosphate decreased markedly after 2007 ($r = -0.89$, $p < 0.01$)
  - Chl-a concentrations also decreased ($r = -0.70$, $p < 0.01$)

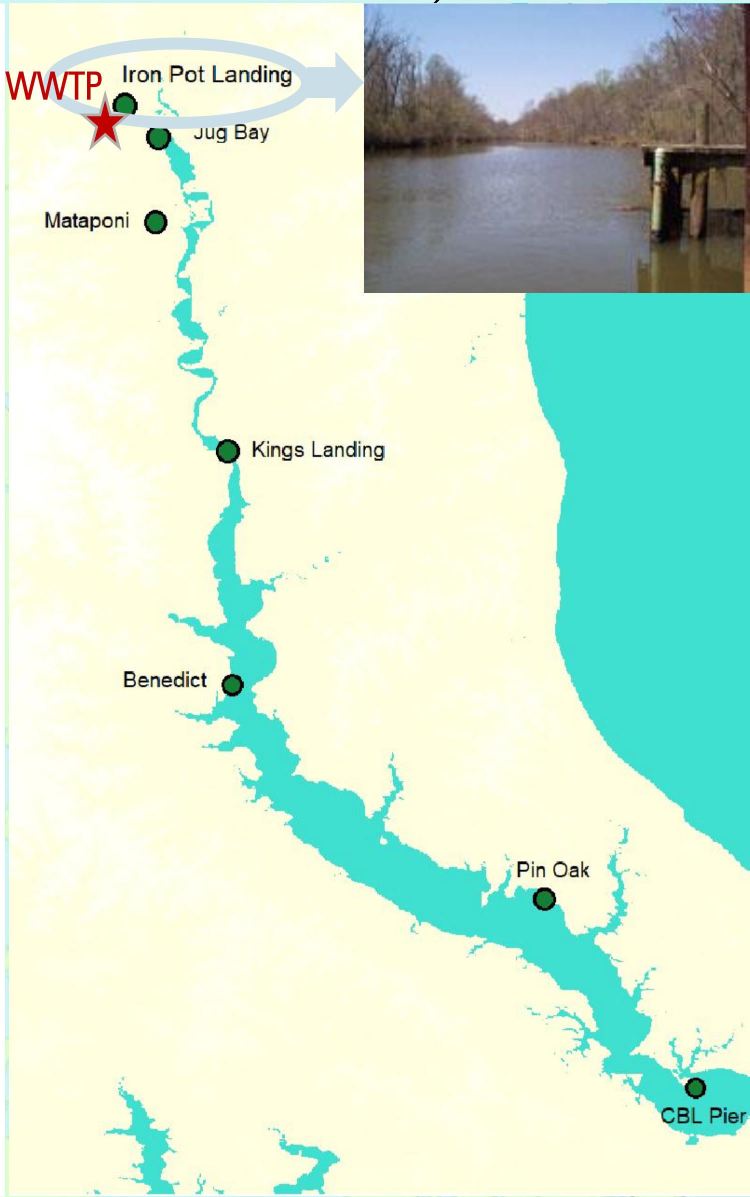
Iron Pot Landing Story

(Long-Term Reduction in Diel Variability with Nutrient Load Reduction)

- Tidal/Diel PSD ratio increased sharply after major WWTP upgrade in 2006-2007
- Lower PO_4 reduces diel DO signal; tidal influence becomes dominant

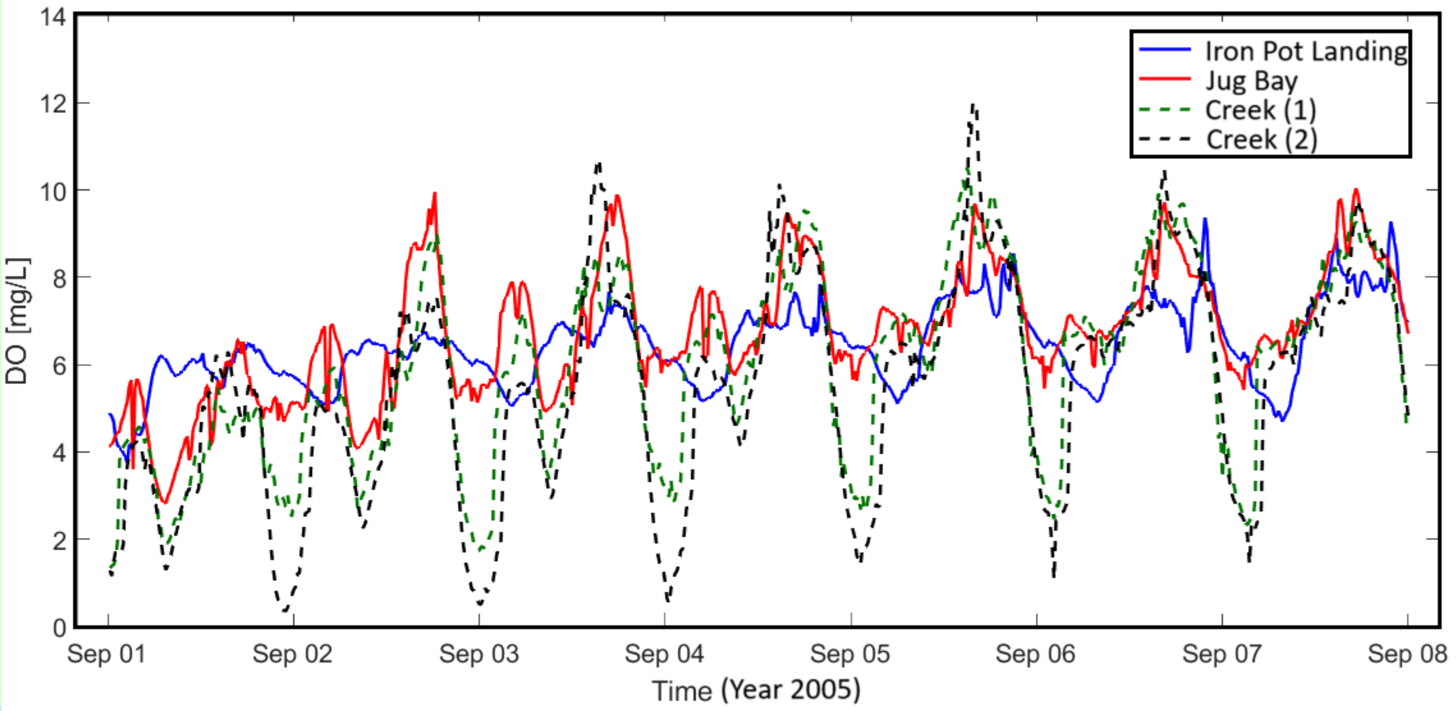
Inverse correlation ($r = -0.68$, $p < 0.01$) between PO_4 and tidal/diel ratio





Up Estuary Marsh Creek Sub-story
(Strong Short-Distance DO Gradients and Tidal-Scale Variability)

- 2005 high-frequency dataset at Iron Pot Landing, Jug Bay, and two adjacent marsh creeks
- Small-scale spatial heterogeneity can be large enough to influence tidal-frequency DO variability



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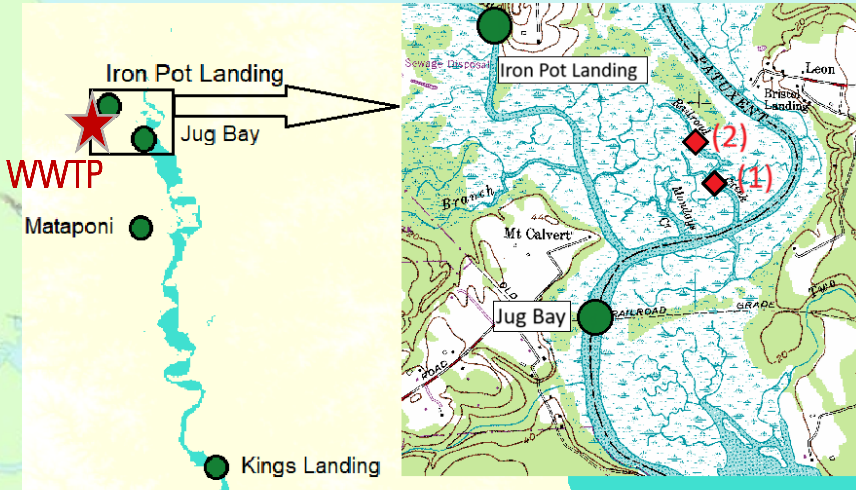
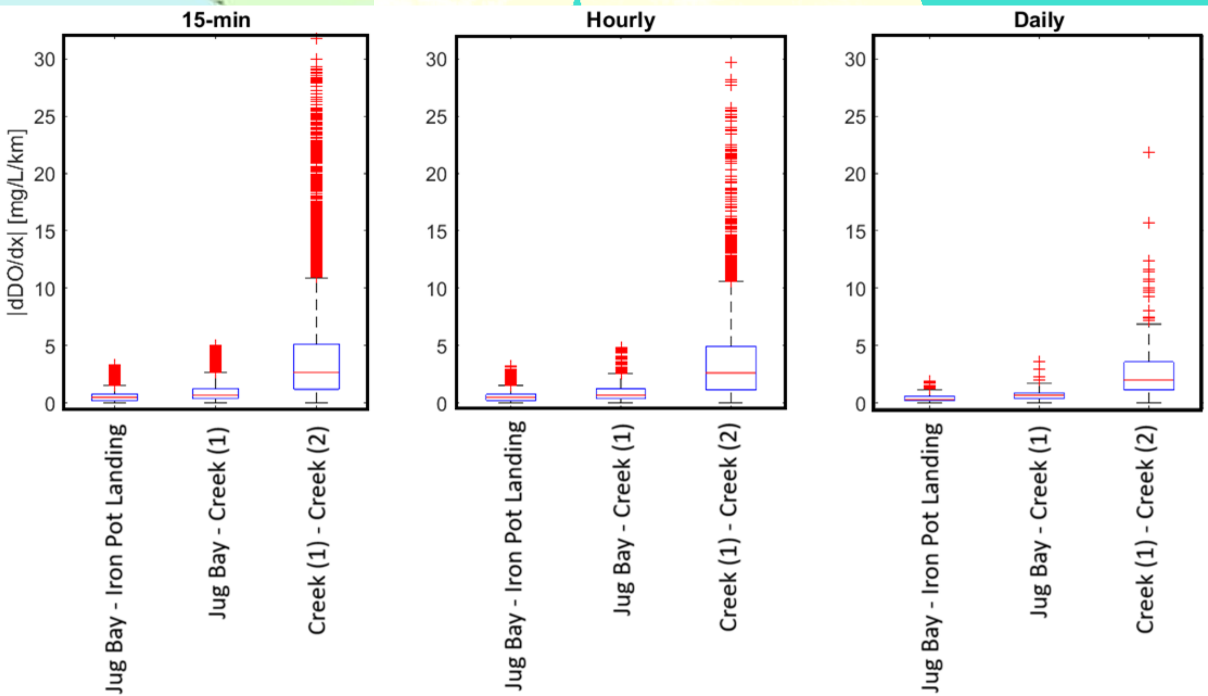


- Median dDO/dx
  - across main-stem reaches:
    ~0.34 mg/L/km (Iron Pot Landing → Jug Bay; ~2.15 km)
    ~0.67 mg/L/km (Jug Bay → Marsh Creek #1; ~1.5 km)

- Much larger gradients occurred over short distances near marsh–estuary interfaces:
  - ~2.0 mg/L/km median across ~0.275 km between two marsh creeks
  - Short-term maxima >20 mg/L/km



Synthesis and Implications

- Long-term changes: reduced diel DO variability upstream with nutrient controls (local) and increased diel DO variability mid-estuary driven by rising flow and nitrogen loads under Climate Change.
- Hotspots: shallow, productive areas (e.g., Mataponi Creek) exhibit the largest diel swings and highest sensitivity to habitat change.
- Flow regimes: high flow dampens diel variability in the upper estuary but amplifies it in the mid-estuary.
- Multi-scale insight: DO variability is driven by multiple factors and differs sharply by location; changes emerge from decadal to hourly scales, and models need to capture this full range.

Acknowledgements

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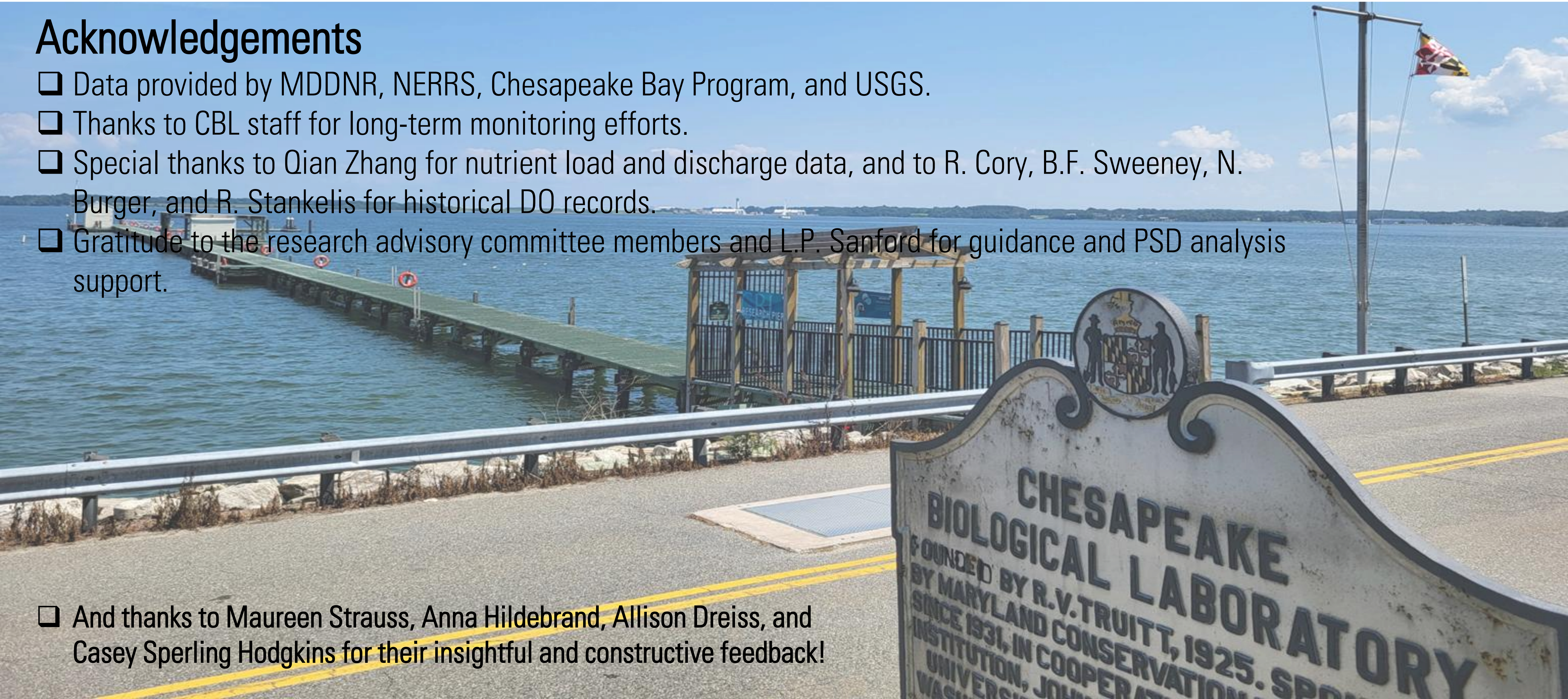
- Gratitude to the research advisory committee members and L.P. Sanford for guidance and PSD analysis support.



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