Exploring Water Quality in the Neuse River Watershed and Estuary through Hybrid Modeling

Neuse River, New Bern, N.C. by Phillip Parrott

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LNBA

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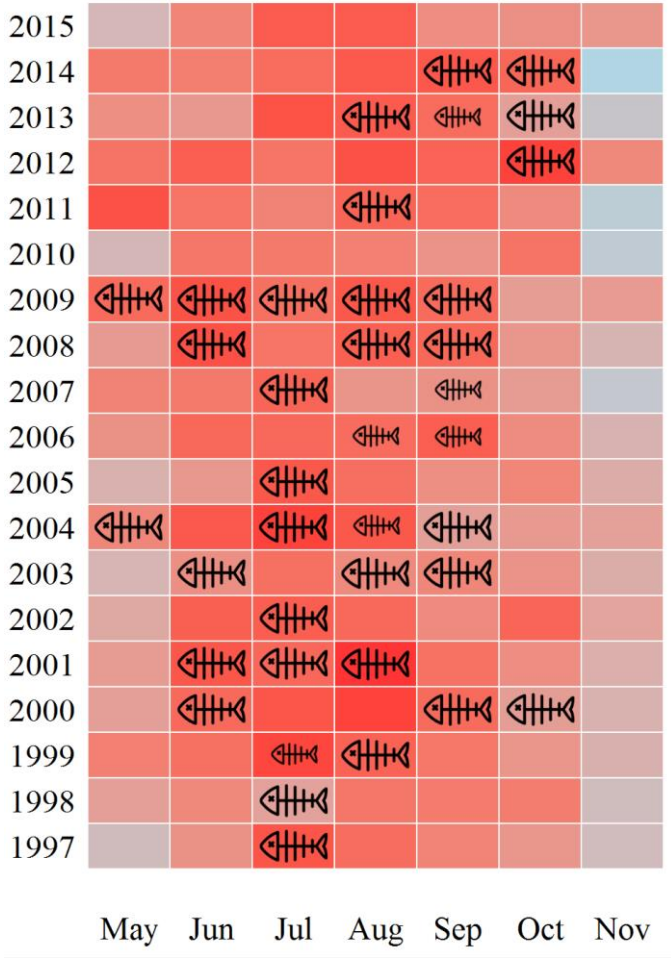
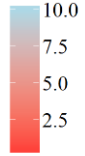
Background

https://floodofextremes.wordpress.com/2014/09/04/tens-of-thousands-of-dead-fish-wash-ashore-in-north-carolina/

http://www.newbernsj.com/20121017/massive-fish-kill-continues-in-the-neuse-river/310179836



Dissolved oxygen (mg/l)



Fishkill event

https://ncseagrant.ncsu.edu/currents/2016/10/forecasting-hypoxia-algal-blooms-for-the-neuse-river-estuary/

The hybrid modeling approach

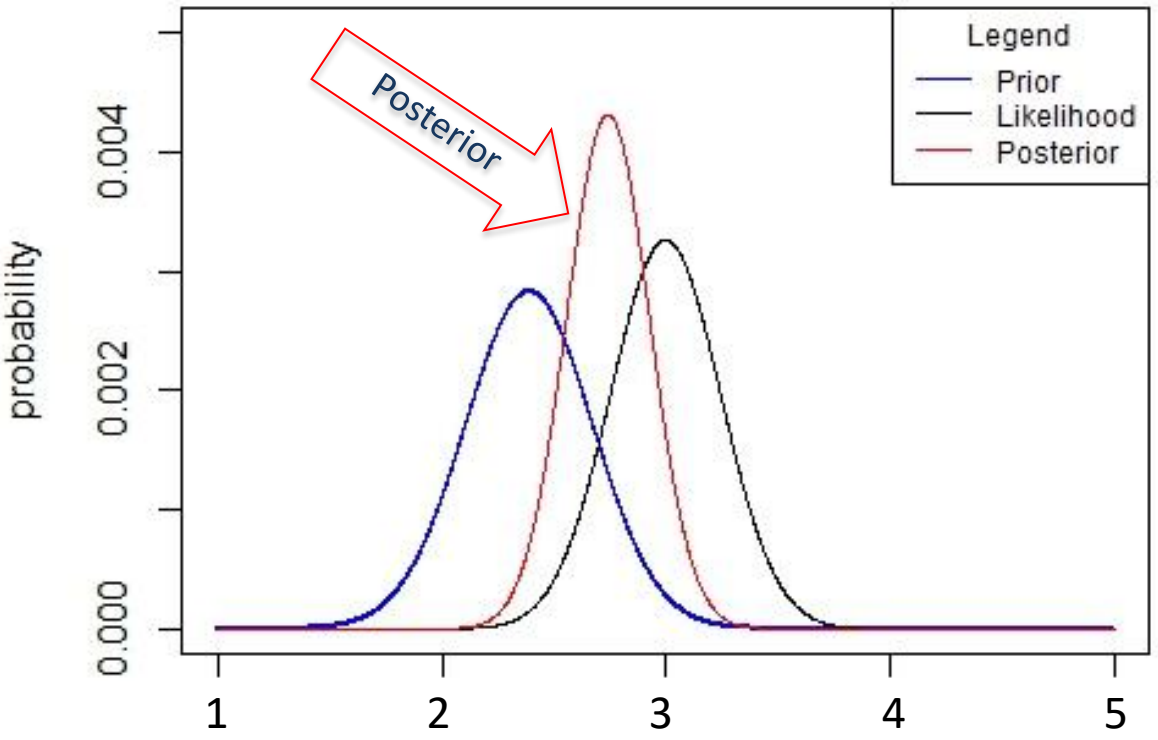
Mechanistic modeling:

1. Process-based model formulation (e.g., mass balance).
2. Parameters (i.e., rates) based on experimental studies.

Statistical modeling:

1. Parameter calibration using observed data.
2. Rigorous hypothesis testing.
3. Quantification of forecast uncertainty

Bayesian hybrid modeling



Outline

1. The Estuary
2. The Watershed

1. Estuary Study objectives

- assess how changes in **nutrient loading** will affect bottom layer dissolved oxygen (**BLDO**) concentrations
- **forecast BLDO in advance** of the hypoxic season

Approach:

- Process-based formulation considering hydro-meteorologic and anthropogenic drivers
- Bayesian framework for parameter updating and uncertainty quantification, using 19-year data record

Previous modeling studies focused on chlorophyll, but did not develop a strong link between nutrients and hypoxia.

Study site and Data

- USGS (flow)
- NCDEQ (nutrients)
- ModMon (Neuse monitoring program)

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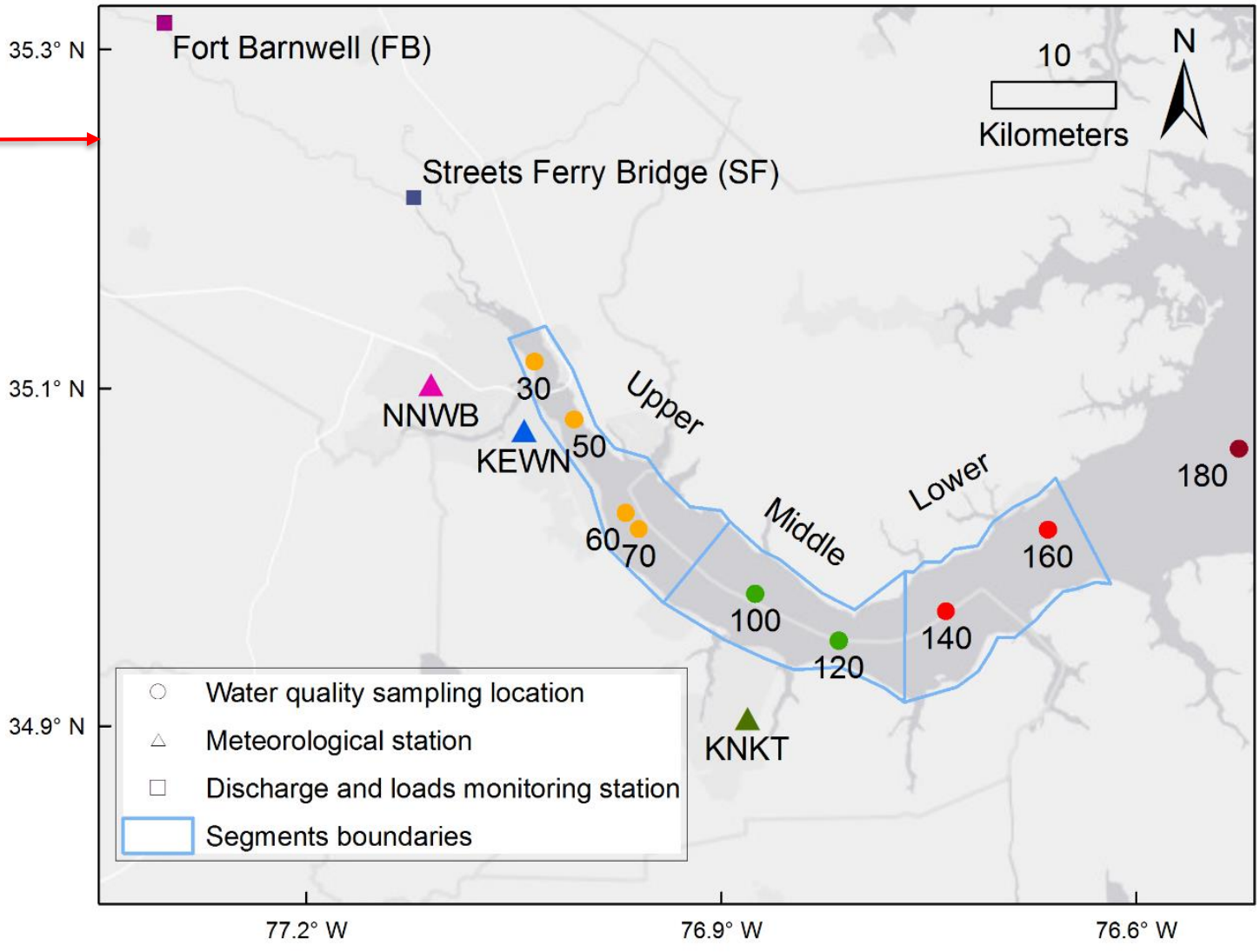
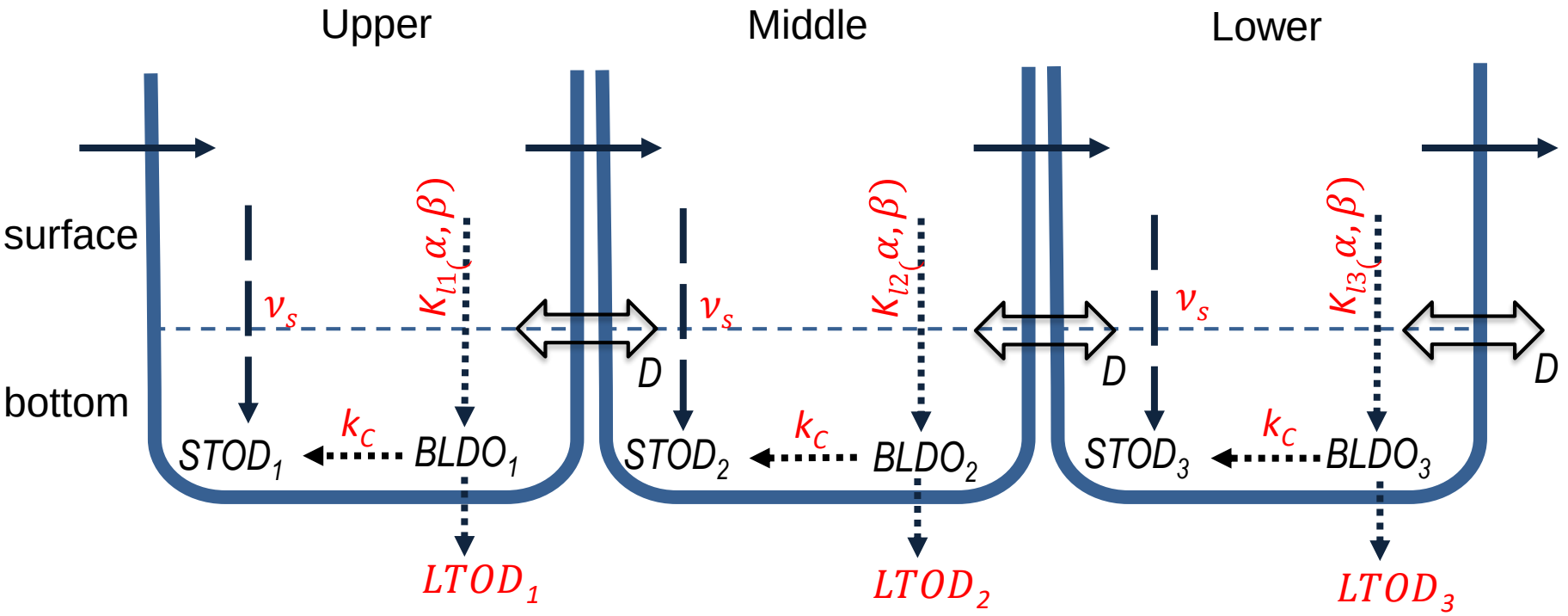


Mechanistic model



Flow and nutrient loadings

Longitudinal dispersion

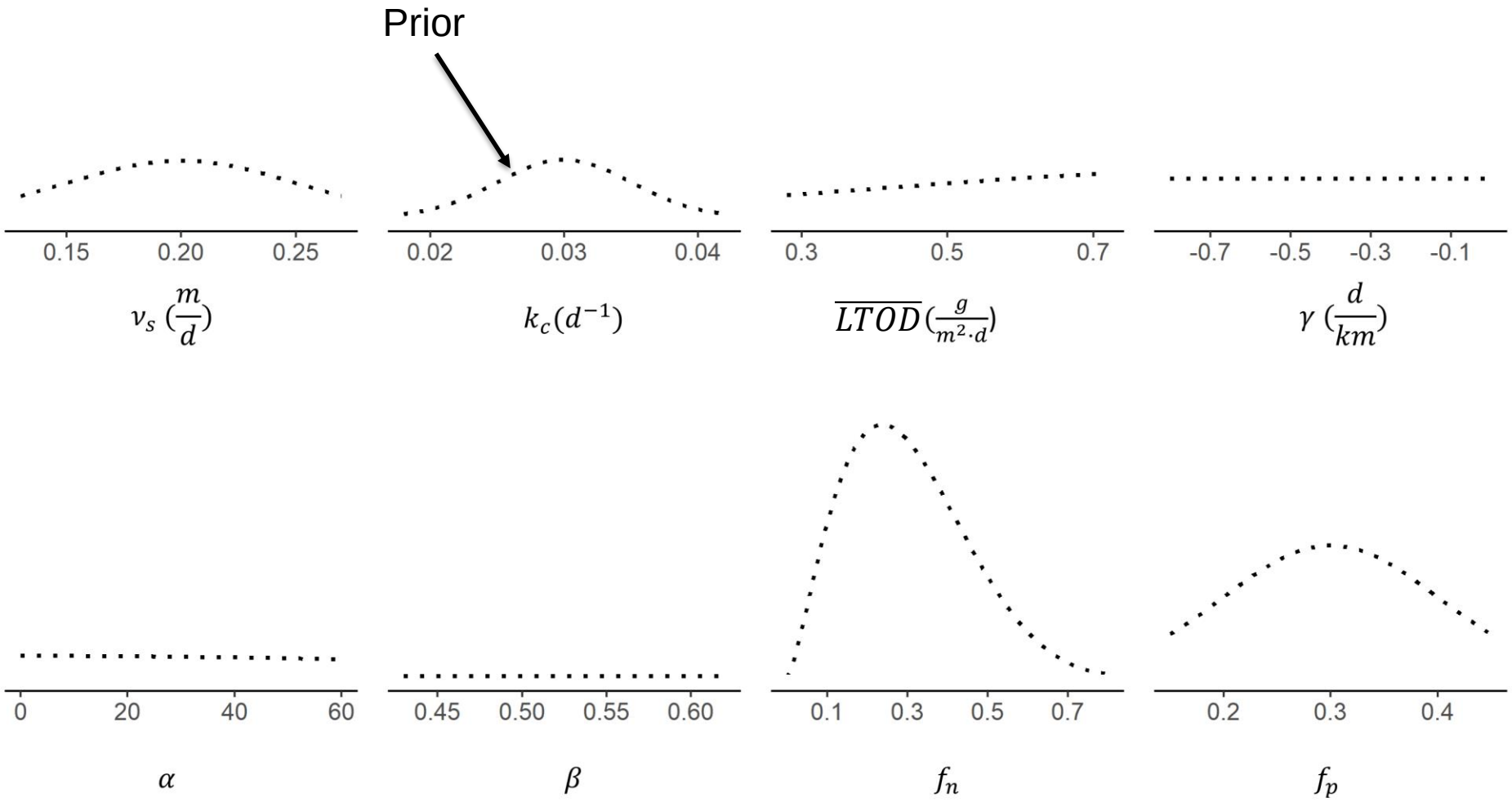
Nutrients to OM conversion and settling

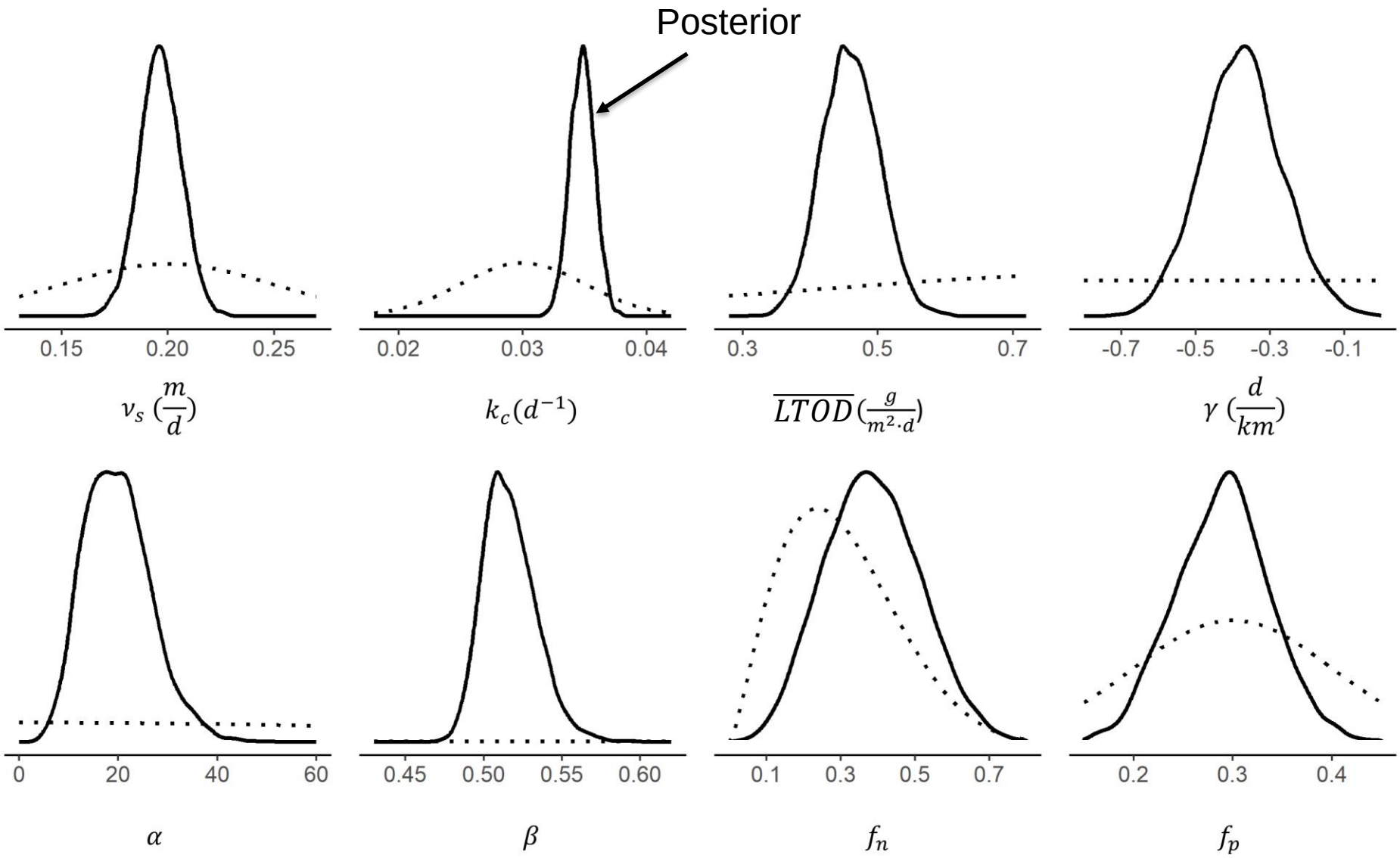
Oxygen exchange

$LTOD$ — long-term oxygen demand due to processes in sediments (g/m^2/d)

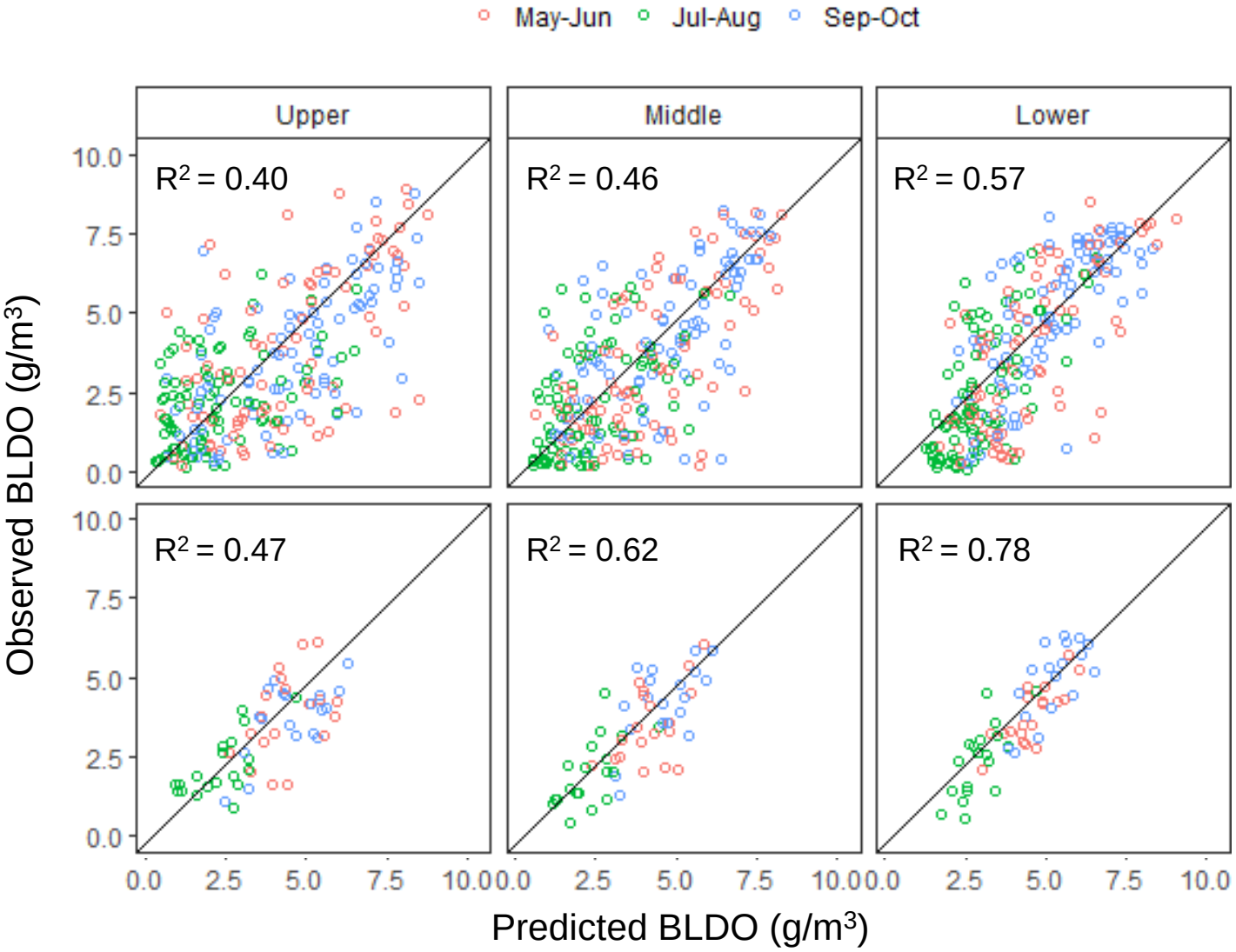
$STOD$ — short-term oxygen demand due to seasonal primary production (g/m^2/d)

Model parameters calibration




Posterior
0.15
0.20
0.25
ν_s $(\frac{m}{d})$
0.02
0.03
0.04
$k_c(d^{-1})$
0.3
0.5
0.7
$\overline{LTOD}$ $(\frac{g}{m^2 \cdot d})$
-0.7
-0.5
-0.3
-0.1
γ $(\frac{d}{km})$
0
20
40
60
α
0.45
0.50
0.55
0.60
β
0.1
0.3
0.5
0.7
f_n
0.2
0.3
0.4
f_p

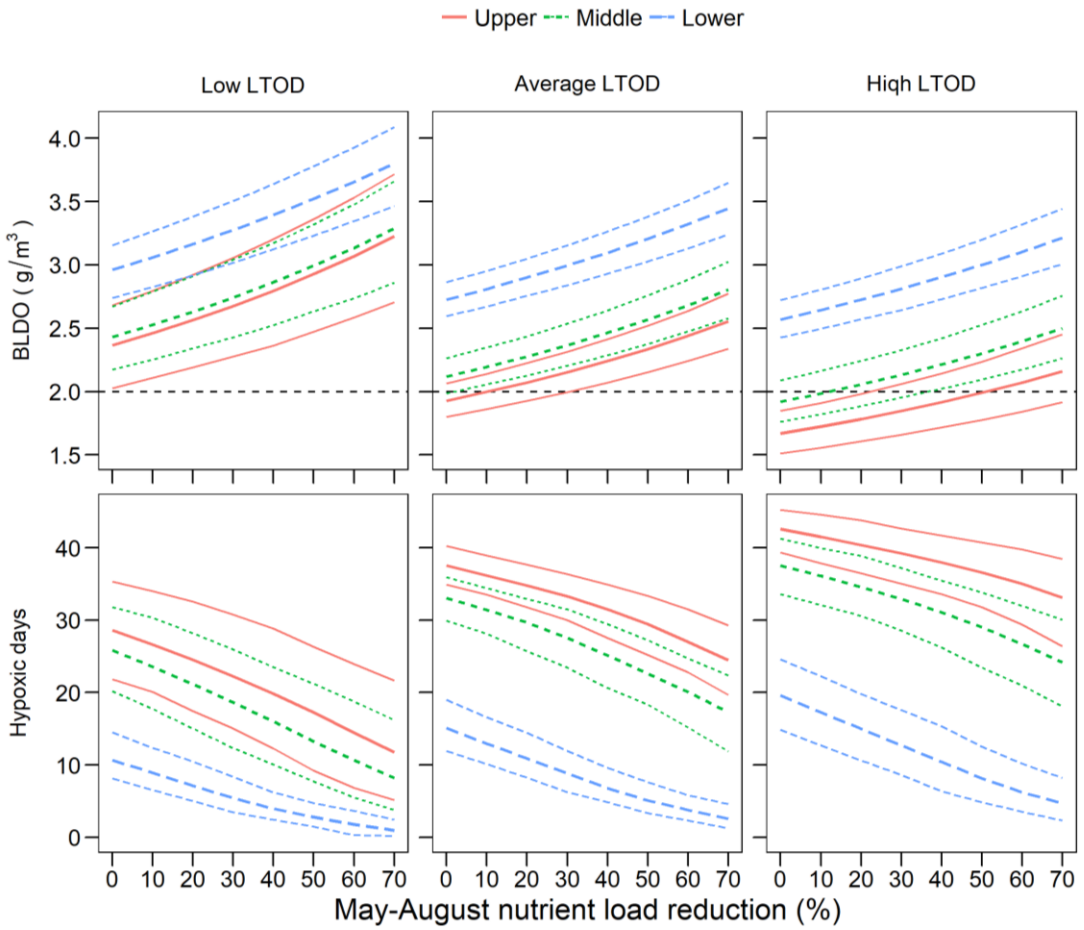
Model skill



Biweekly

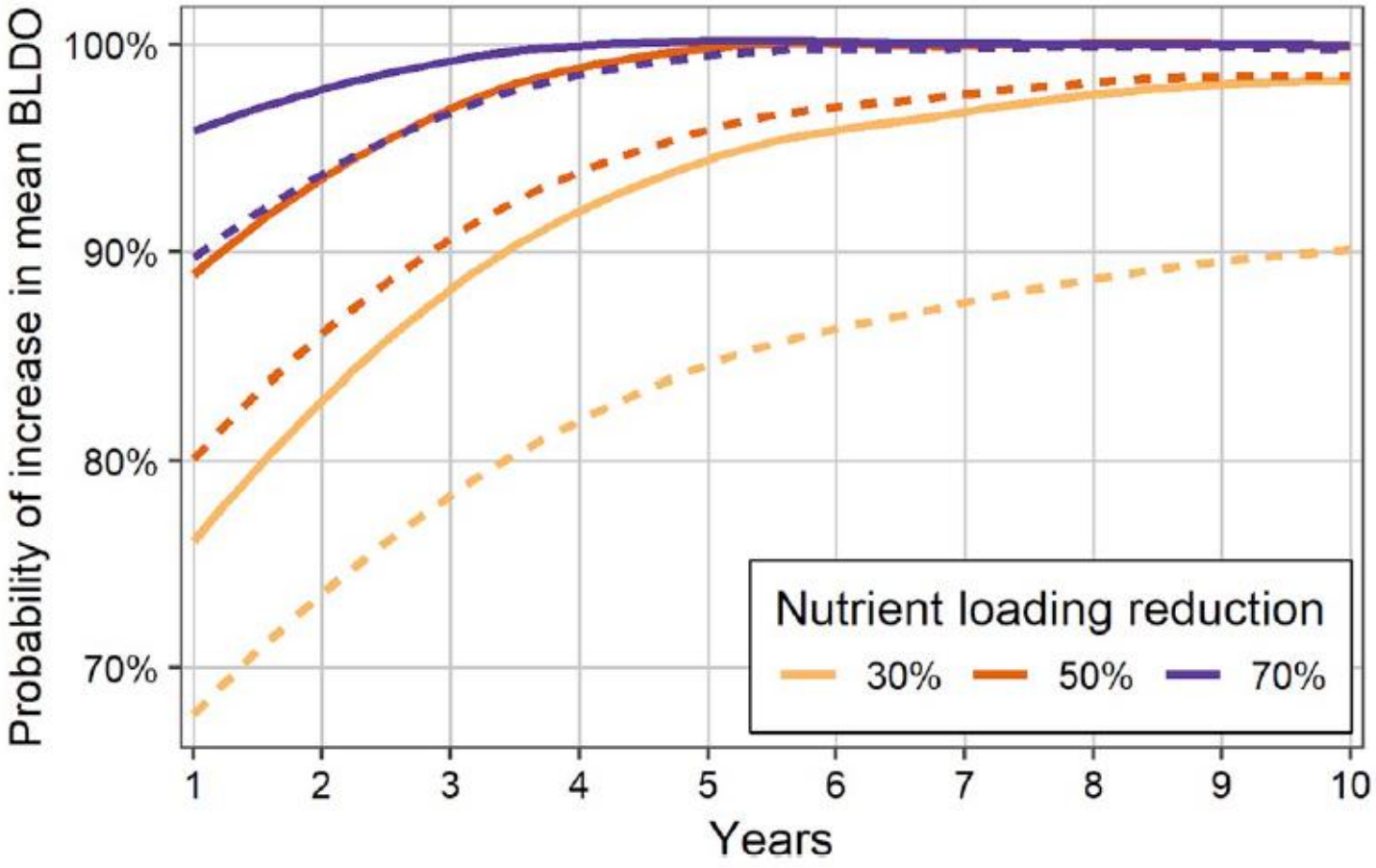
Bimonthly mean

Nutrient reduction scenarios



- 30% nitrogen and phosphorus loading reduction would:
  - increase the average July-August BLDO concentration by 11%
  - decrease the amount of hypoxic days by 25%

Probabilistic Projections



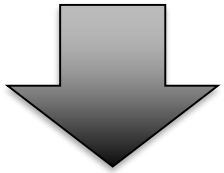
Annual Forecasts

- Raise public awareness of hypoxia and its causes.
- Rigorously assess modeling assumptions and skill.
- Provide heads up to fisheries and water quality managers.

- Forecasts currently developed in early June to predict July-August conditions.

2018 Forecast

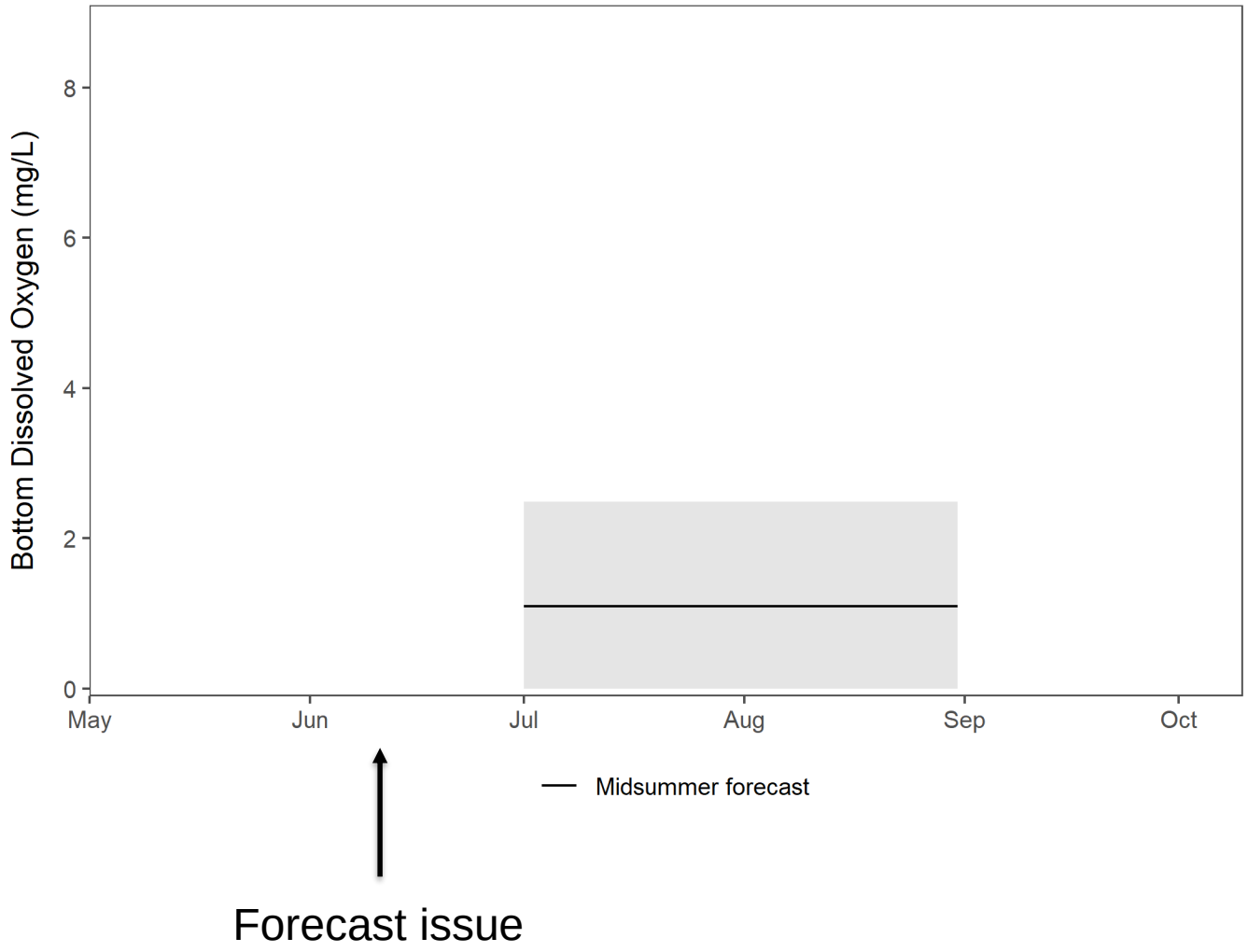
- Low flows in winter (30% below mean flow)
  → **increased LTOD**
- High spring flows (60% above mean flow)
  → **increased STOD**
  → **increased stratification**



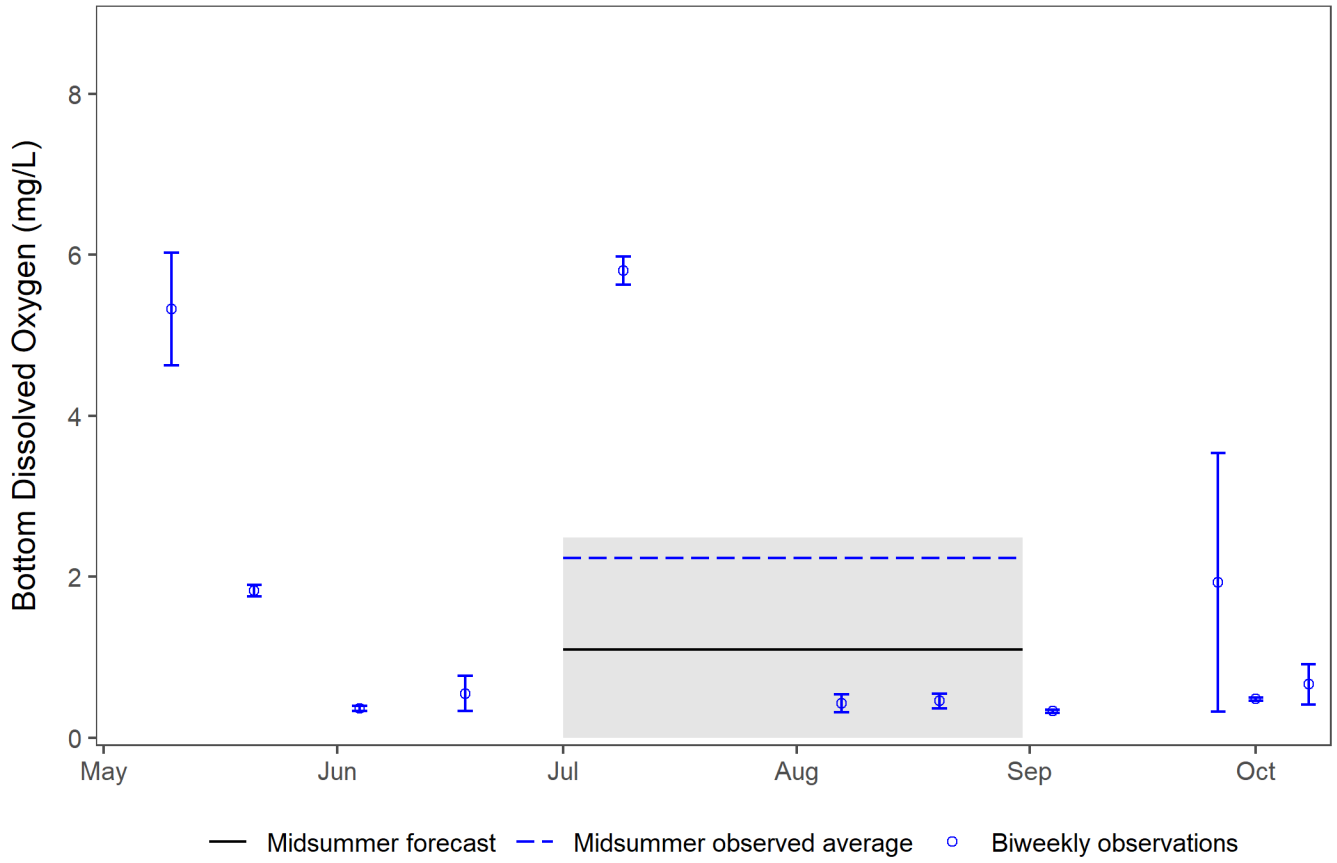
Predicted mean midsummer BLDO
36% below the long-term average

https://ncseagrant.ncsu.edu/news/2018/07/model-forecasts-severe-hypoxia-through-august-in-neuse-estuary/

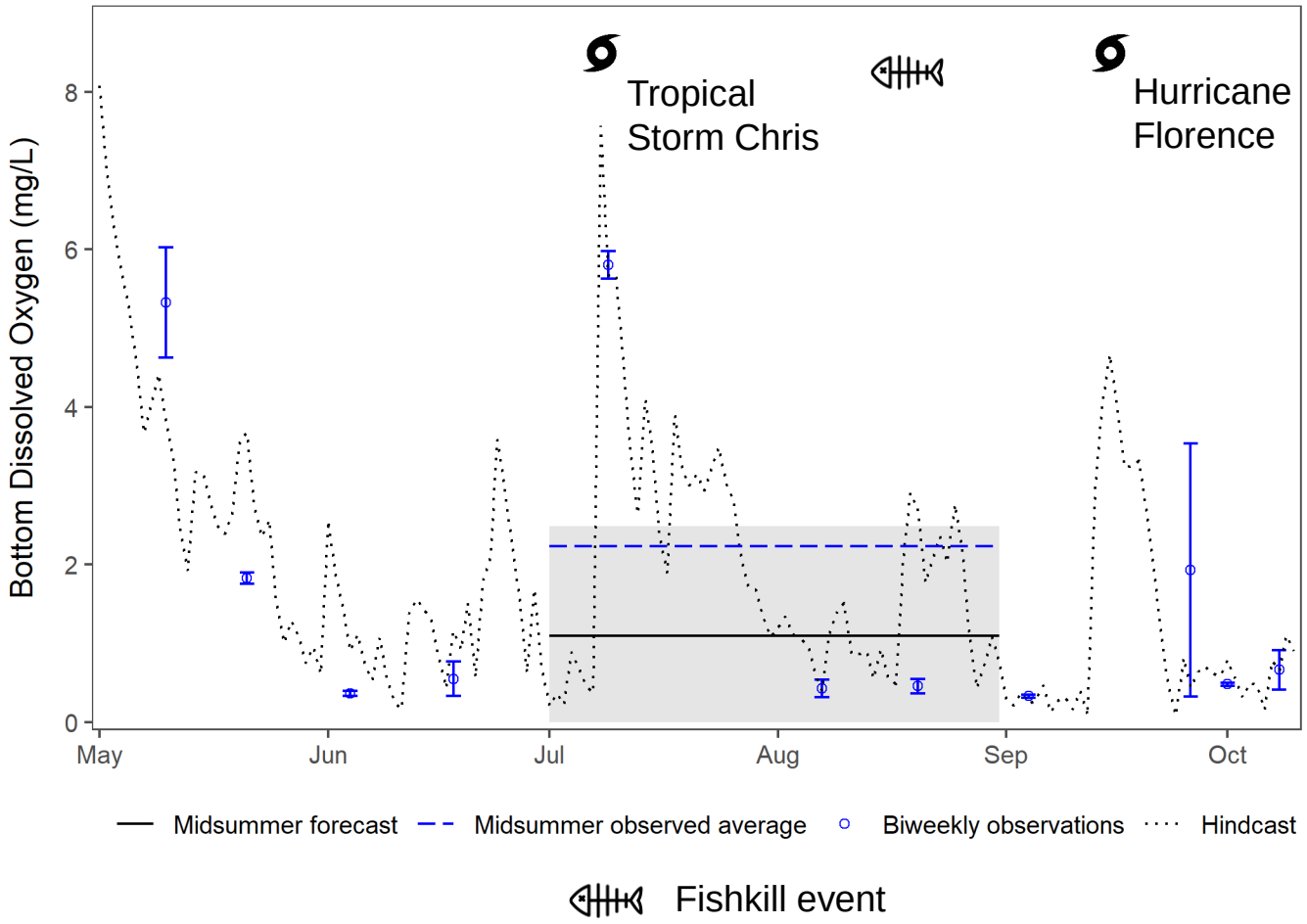
2018 Forecast



2018 Forecast + Observed



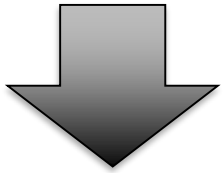
2018 Forecast + Observed + Hindcast



https://ncseagrant.ncsu.edu/currents/2019/01/tropical-systems-disrupt-neuse-river-oxygen-levels/

2019 Forecast

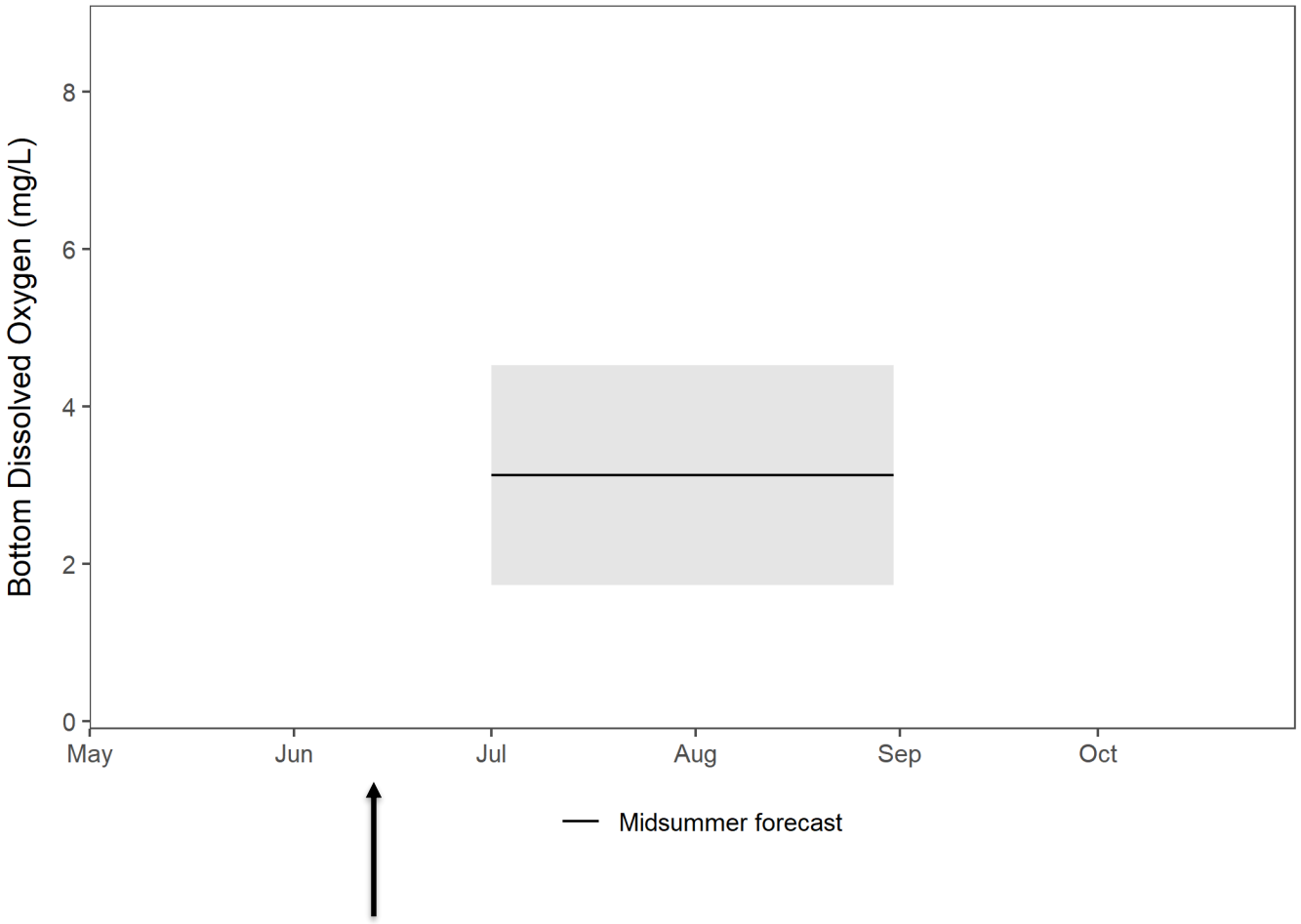
- High flows in winter (almost double mean flow)
  → **decreased LTOD**
- Low spring flows (12% below mean flow)
  → **slightly decreased STOD**
  → **slightly decreased stratification**



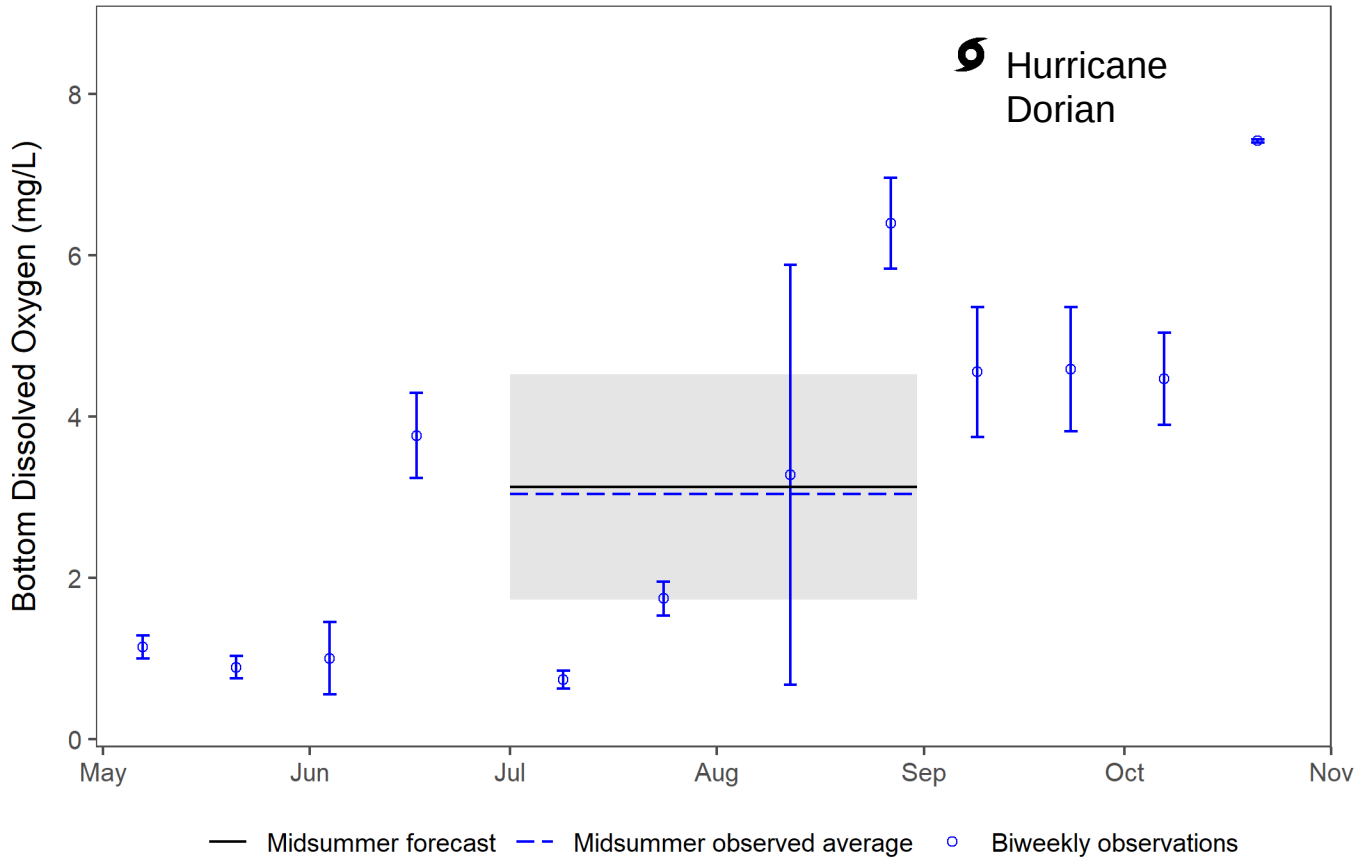
Predicted mean midsummer BLDO
50% above the long-term average

https://ncseagrant.ncsu.edu/news/2019/06/researchers-forecast-healthier-neuse-river-oxygen-levels/

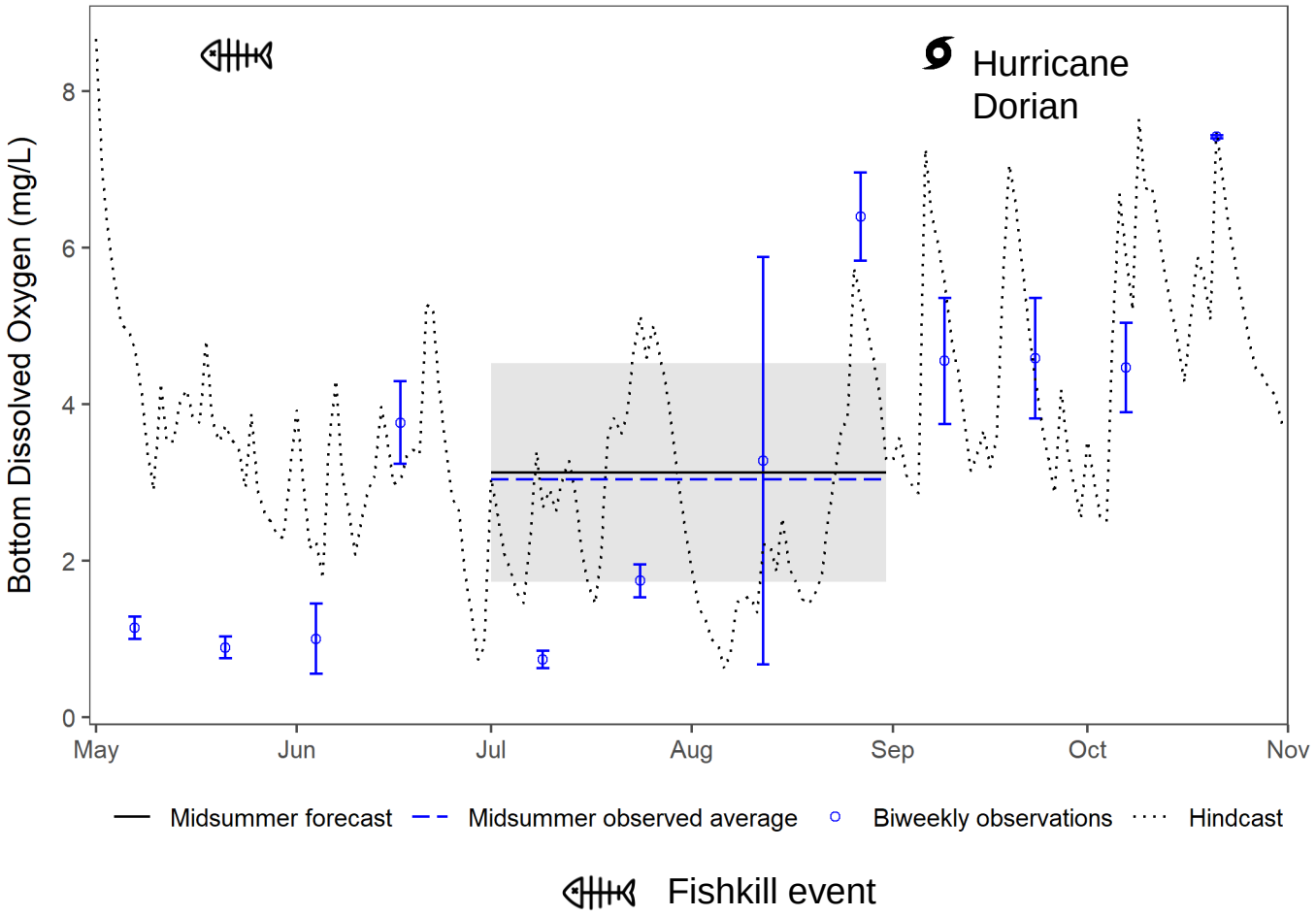
2019 Forecast



2019 Forecast + Observed



2019 Forecast + Observed + Hindcast



Summary

- Model hindcasts explains the majority of the variability in monthly BLDO concentrations across the estuary.
- Model establishes a quantitative linkage between hypoxia and seasonal nutrient loading.
- Forecasts provide a useful verification of model mechanisms and performance.
- Seasonal forecasts have substantial uncertainty due to meteorological fluctuations – could potentially benefit from weekly updating.

Katin, A., Del Giudice, D., & Obenour, D. R. (2019). Modeling biophysical controls on hypoxia in a shallow estuary using a Bayesian mechanistic approach. *Environmental Modelling & Software*, *120*, 104491.

2. Watershed Study objectives

- Characterize **nitrogen export rates** from major source types in the Neuse and surrounding watersheds
- Estimate how nitrogen export responds to changes in **climate and watershed development**

Approach:

- Process-based formulation considering hydro-meteorologic and anthropogenic drivers
- Bayesian framework for parameter updating and uncertainty quantification, using 19-year data record

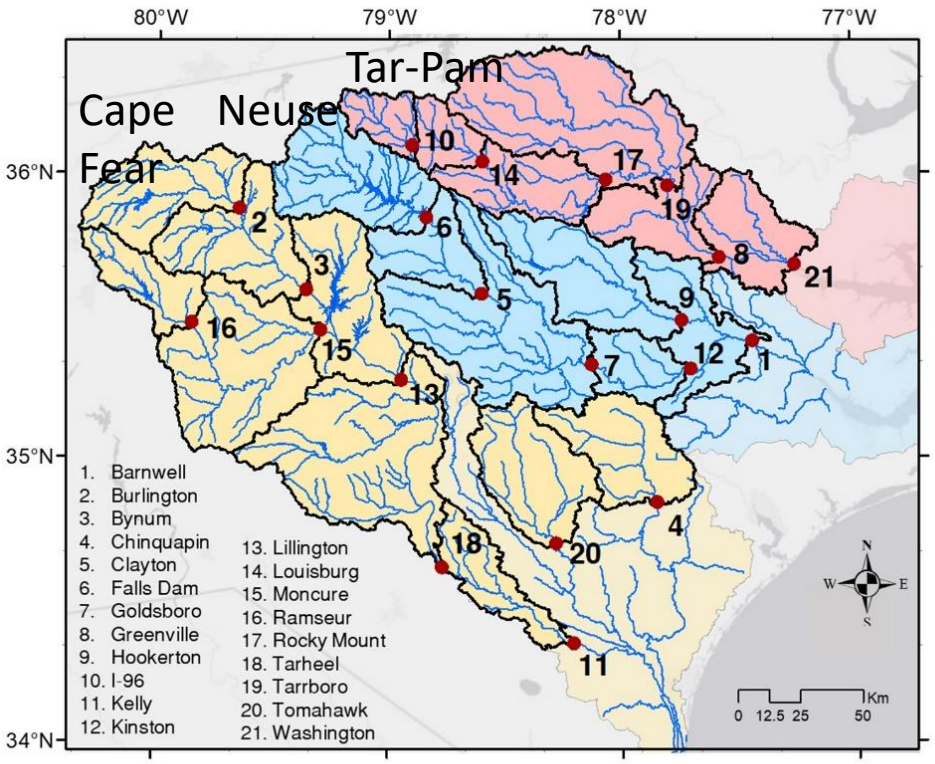
Previous hybrid modeling studies focused on estimating nitrogen export rates, but with limited source specificity and no temporal variability.

Note what this study does not do:

- Assess (small) changes in land-use export rates due to watershed management (e.g., new BMPs, fertilizer application rates, etc.)

Future/ongoing research

Study area and data

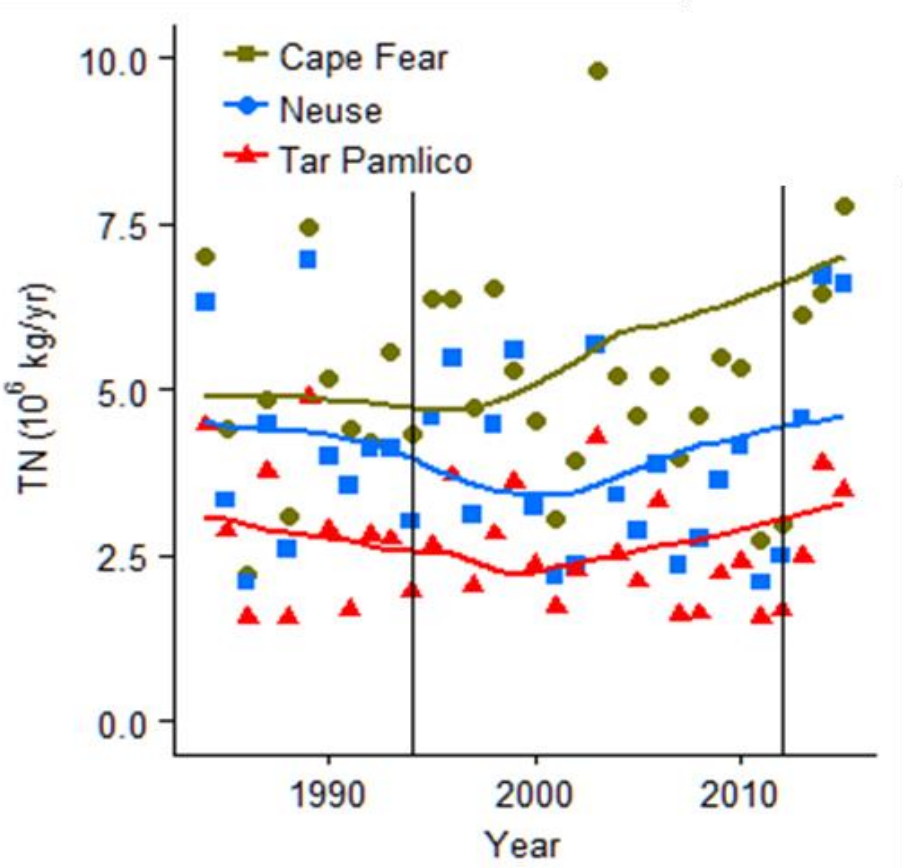


Data:

- USGS (flow, land cover)
- USDA (livestock)
- NC DEQ (river water quality, dischargers)
- NCSCO (weather)

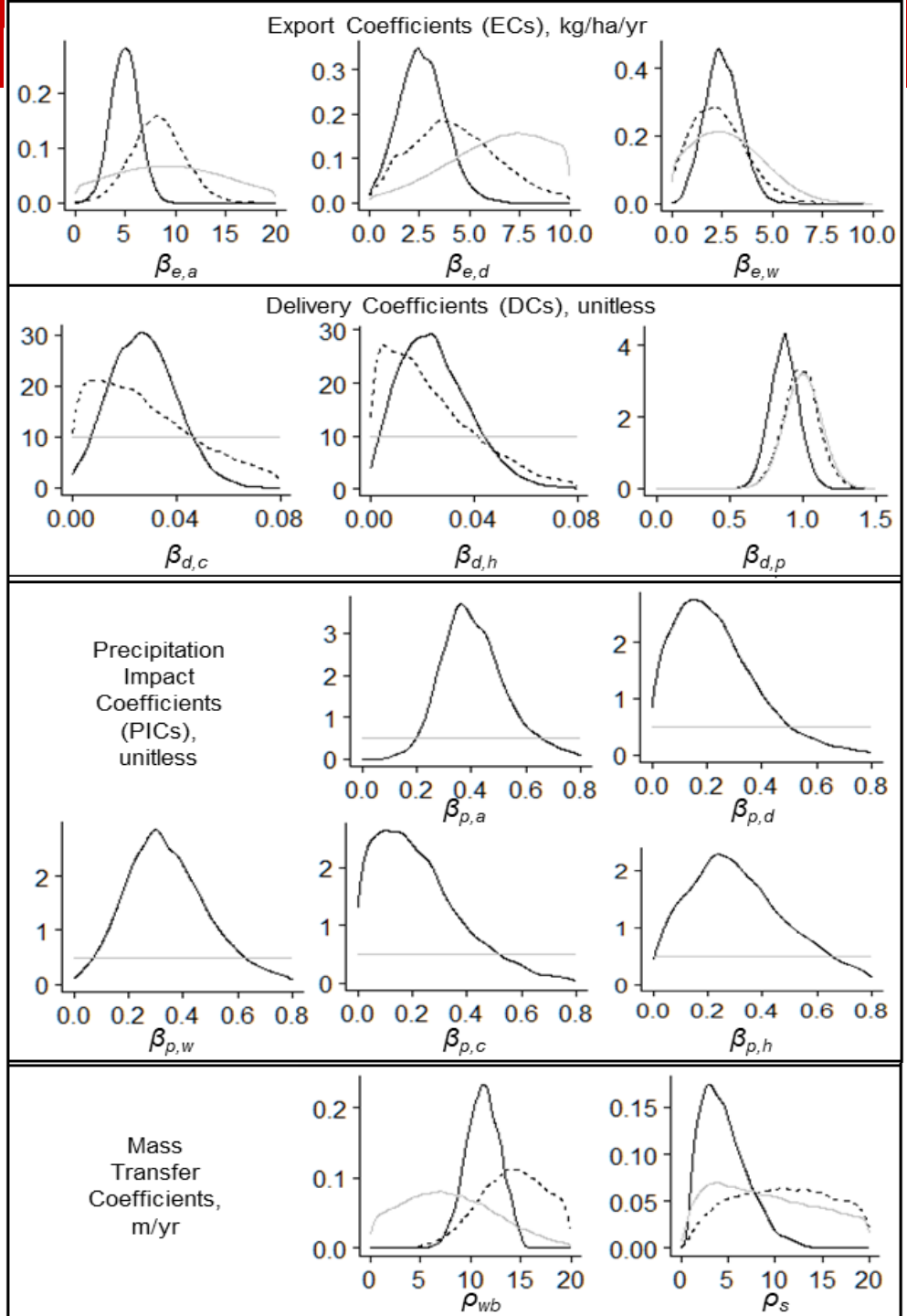
WRTDS loading results

- Estimates reflect loadings at downstream stations
- Points are annual estimates
- Lines are Flow-Normalized (FN) trend lines

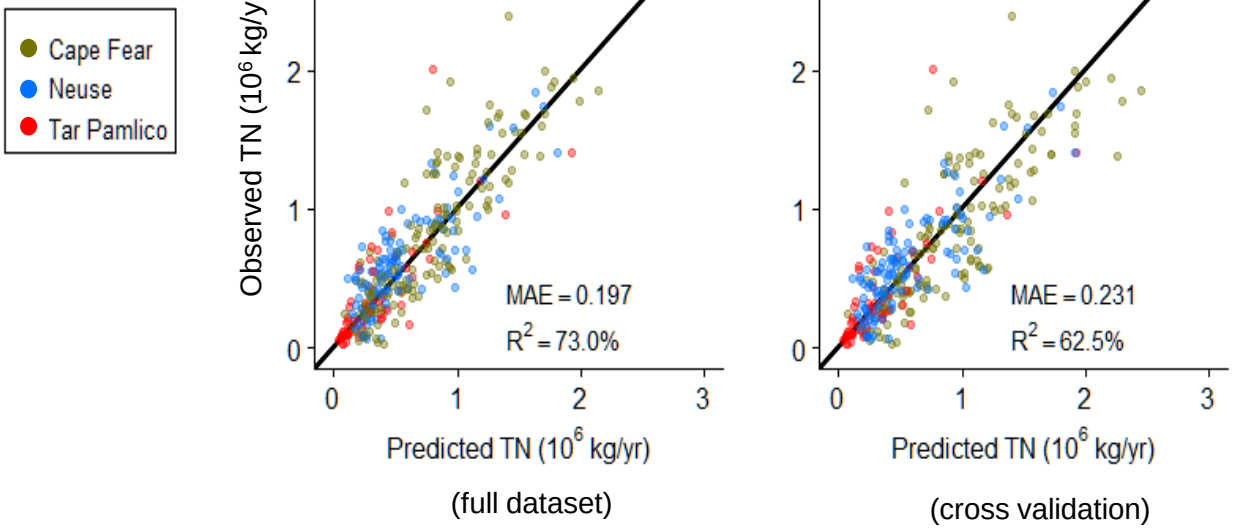


Model Calibration

- prior
- Posterior without temporal variability)
- Posterior (including temporal variability)



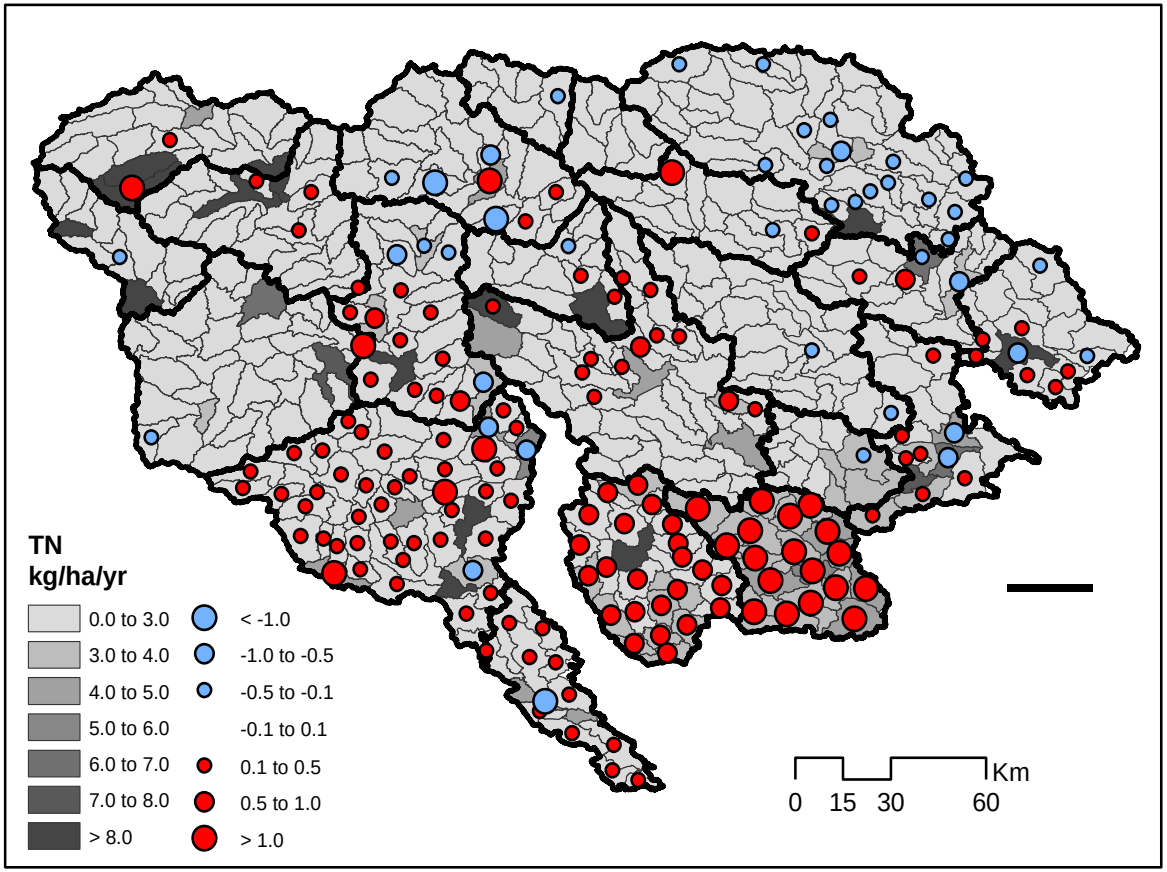
Model performance



1994-2012 loading (dry)

Export Rates:
Ag: 1.1 kg/ha/yr
Dev: 1.5 kg/ha/yr
Wild: 0.87 kg/ha/yr

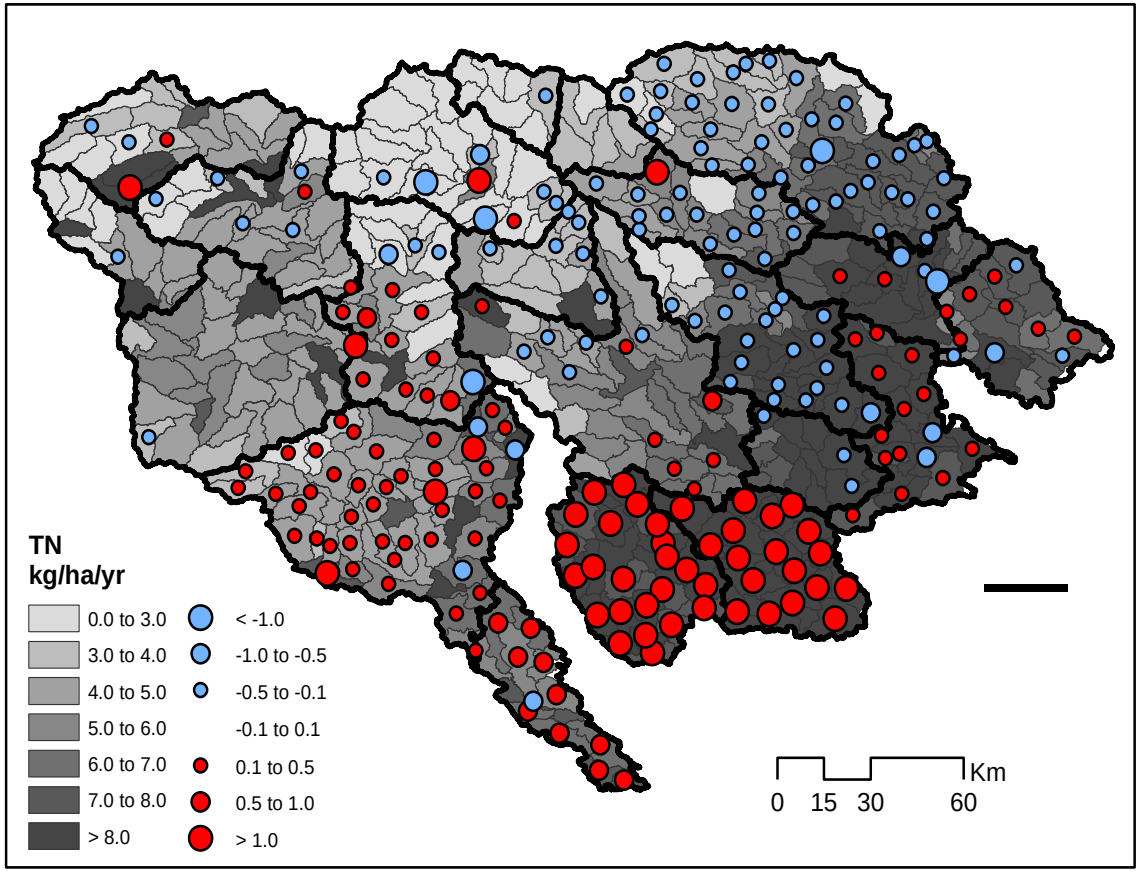
Chicken: 1.6%
Hog: 0.96%



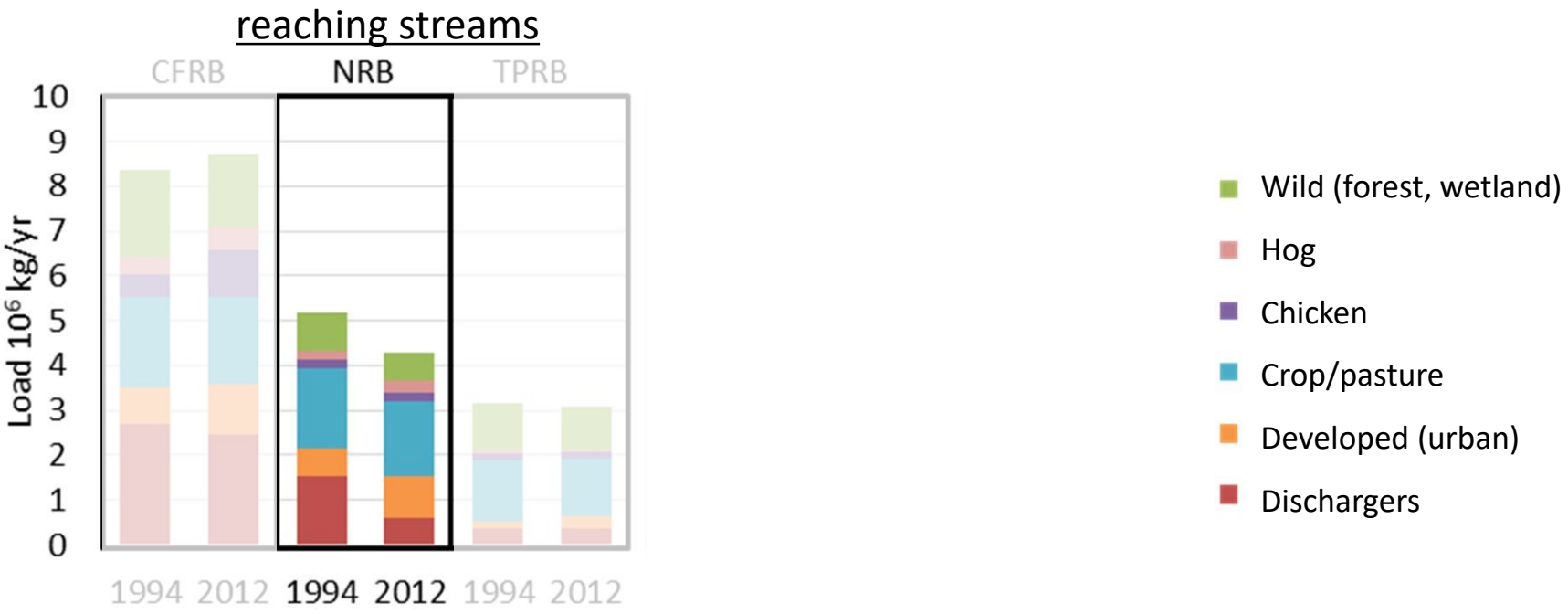
1994-2012 loading (wet)

Export Rates:
Ag: 8.8 kg/ha/yr
Dev: 3.8 kg/ha/yr
Wild: 4.2 kg/ha/yr

Chicken: 3.9%
Hog: 4.0%



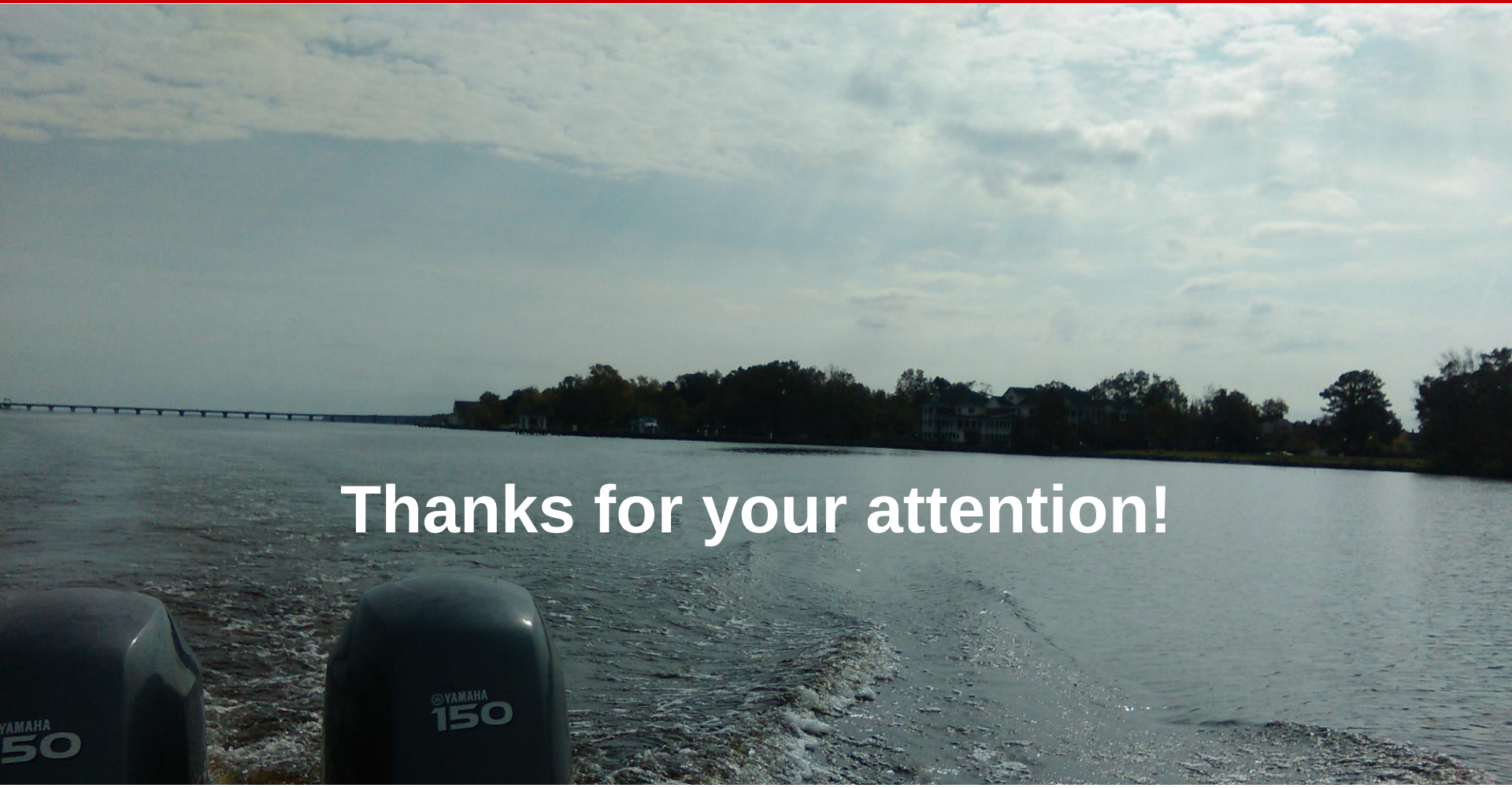
Results (average weather)



Summary

- Agriculture is now the largest source of nutrient export in the NRB overall, and particularly in wet years.
- Agricultural areas with high livestock densities export more nitrogen.
- Urban land export is the fastest growing nitrogen source, and is particularly relevant in dry years.
- Point sources have declined substantially in the NRB.
- Future work could focus on refining the model with more detailed tributary loading and land use data.

Strickling, H. L., & Obenour, D. R. (2018). Leveraging Spatial and Temporal Variability to Probabilistically Characterize Nutrient Sources and Export Rates in a Developing Watershed. *Water Resources Research*, 54(7), 5143-5162.



Thanks for your attention!

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http://paerllab.web.unc.edu/projects/modmon/

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North Carolina