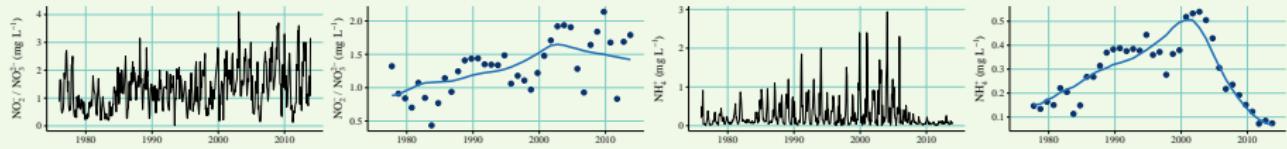


# Quantitative approaches to understanding nutrient pollution: Examples from the upper San Francisco Estuary

Marcus W. Beck, PhD

USEPA National Health and Environmental Effects Research Laboratory, Gulf Ecology Division, beck.marcus@epa.gov, Phone: 8509342480

Aug. 26, 2016



# Evaluating estuarine condition

How do we collect and use data?

The foundation of environmental management is a strong monitoring network [National Research Council, 1990]

Monitoring provides information for decision-making based on apparent trends...

*What are the changes in environmental condition over time?*

*Are these changes ‘good’ or ‘bad’ based on our management objectives?*

*What may have caused these changes?*

# Evaluating estuarine condition

How do we collect and use data?

***The good news:*** We are getting better at monitoring - standardized, automated, increased coverage, real-time/continuous

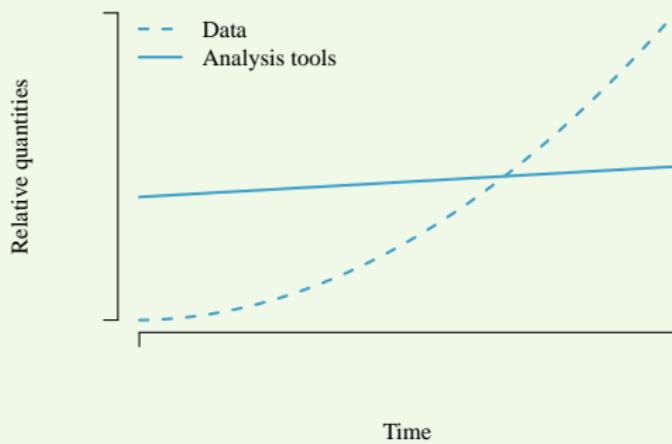
***The bad news:*** Our ability to use these data for decision-making has not kept pace with availability!

# Evaluating estuarine condition

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# Evaluating estuarine condition

## How do we collect and use data?

Most of my research career has focused on using monitoring data to understand effects of eutrophication in one form or another

*Eutrophication (noun) - an increase in the rate of supply of organic matter to an ecosystem*

– [Nixon, 1995]

Adapted from [Cloern, 2001]

# Evaluating estuarine condition

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### Nutrient Loading

Adapted from [Cloern, 2001]

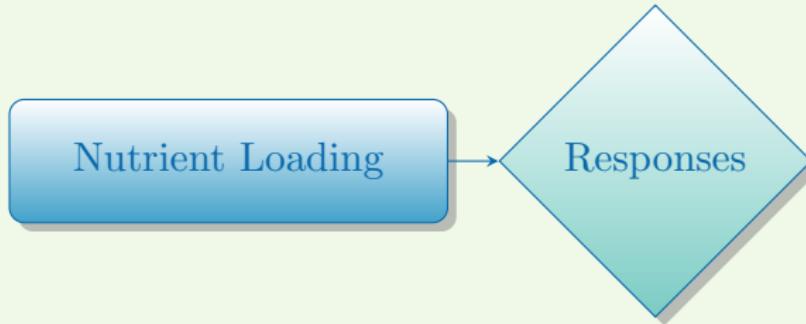
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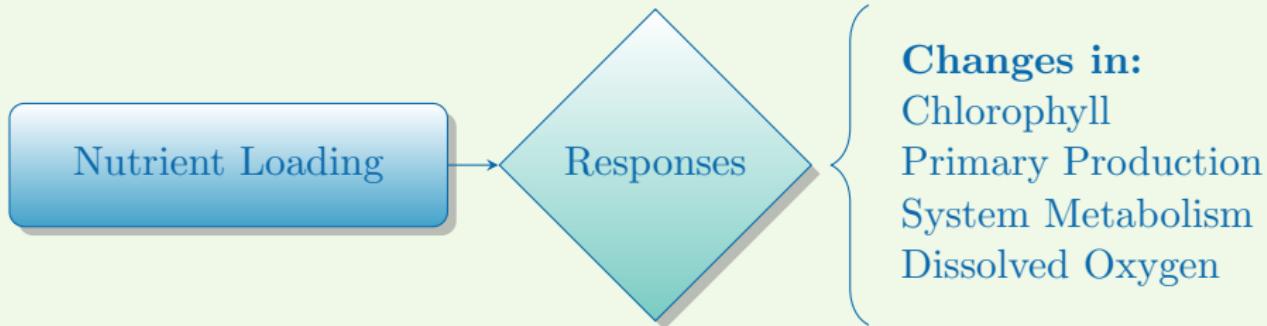
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# Evaluating estuarine condition

How do we collect and use data?

***Today's talk:*** My experience evaluating monitoring data to inform our understanding of the eutrophication paradigm

Water quality trends in the Delta:

- ***Example 1:*** Model theory and application
- ***Example 2:*** Trends over time
- ***Example 3:*** Selected case studies

# Model theory and background

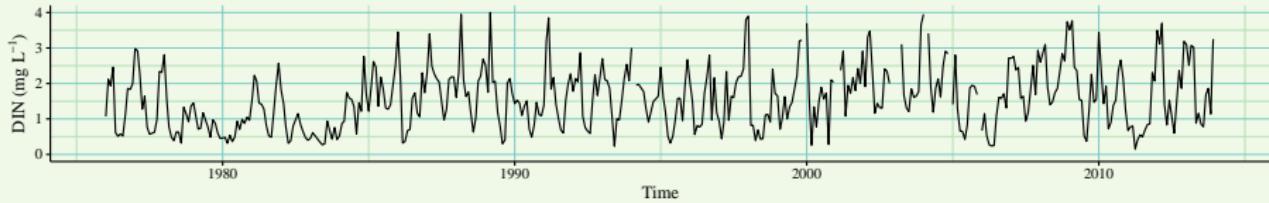
## WRTDS adaptation for tidal waters

Increasing availability of records describing *long-term changes*

Observed data can provide a means to an end, potentially *high power* with large sample size

Can we *develop* and *apply* tools that leverage the descriptive capabilities of these large datasets?

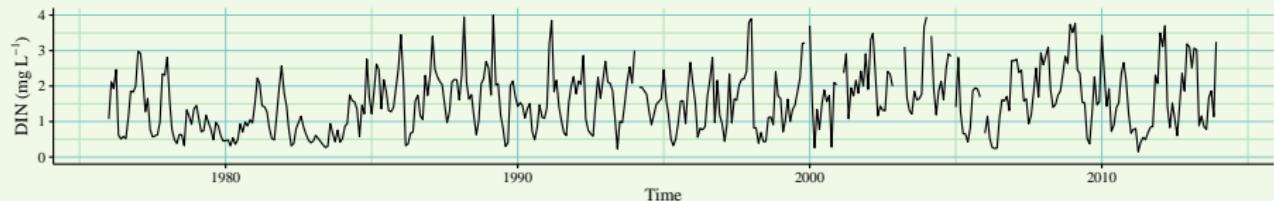
Can we *link descriptions* to *causal events* to inform management or understanding?



# Model theory and background

WRTDS adaptation for tidal waters

**Observed data represents effects of many processes**



## Climate

precipitation  
temperature  
wind events  
ENSO effects

## Local

light/turbidity  
residence time  
invasive species  
trophic effects

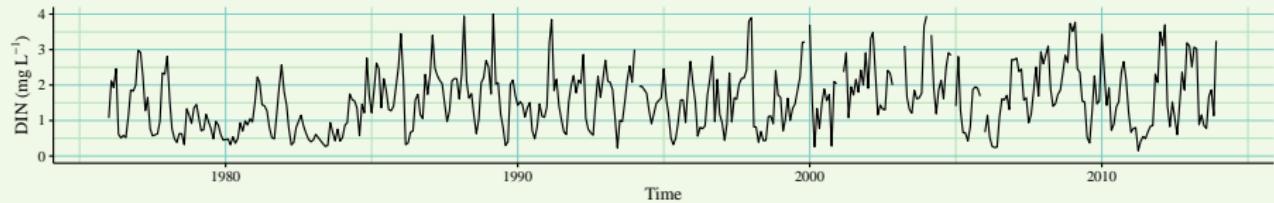
## Regional/historical

watershed inputs  
point sources  
management actions  
flow changes

# Model theory and background

WRTDS adaptation for tidal waters

Observed data represents effects of many processes

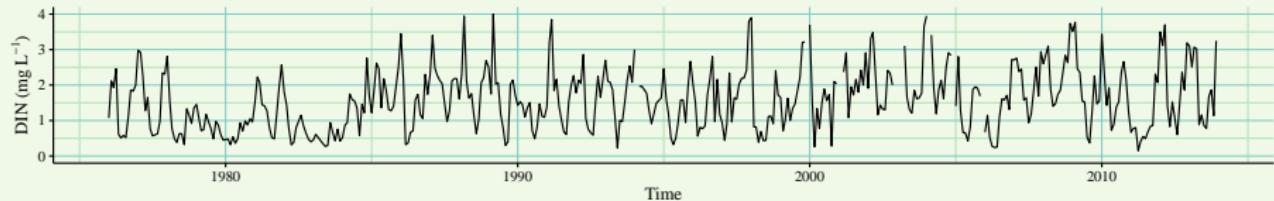


Models should describe components to evaluate effects

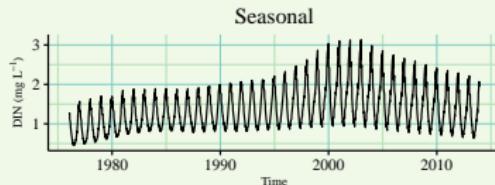
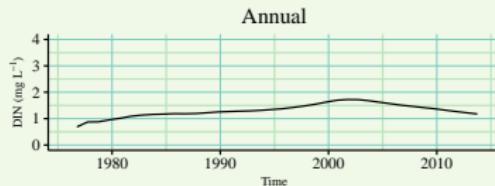
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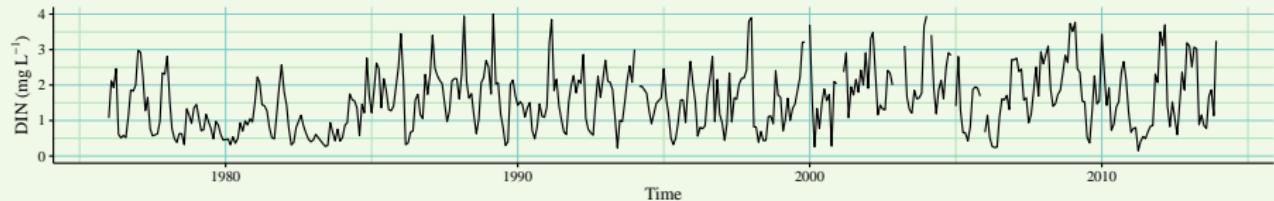
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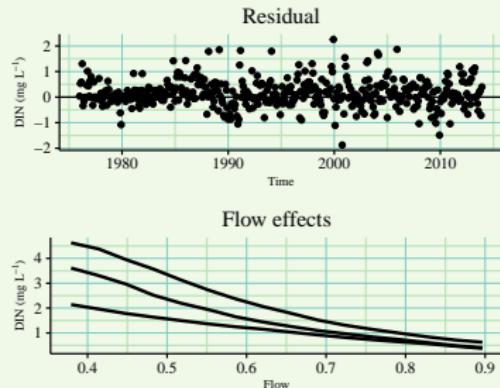
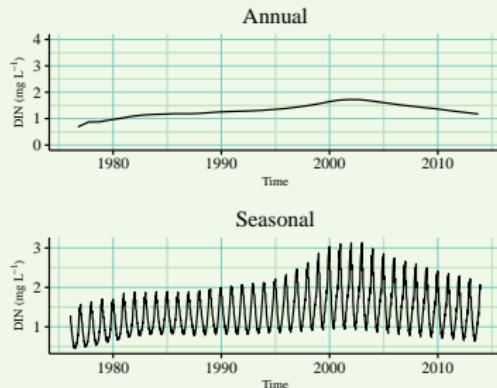
# Model theory and background

WRTDS adaptation for tidal waters

Observed data represents effects of many processes



Models should describe components to evaluate effects



# Model theory and background

## WRTDS adaptation for tidal waters

**Problem:** Response endpoints of eutrophication vary naturally over time and with discharge or tidal patterns

**Solution:** Develop a model that accounts for changes in relationships between drivers of pollution over time

The ***weighted regression (WRTDS)*** model is being developed by USGS for pollutant modelling in rivers [Hirsch et al., 2010]

Models pollution concentration as a function of ***time, discharge, and season***

**Adaptation:** Applied to Tampa Bay [Beck and Hagy III, 2015], further validated/compared in Patuxent Estuary [Beck and Murphy, In review]

# Model theory and background

## WRTDS adaptation for tidal waters

How does weighted regression work?

# Model theory and background

## WRTDS adaptation for tidal waters

### Application to Delta

- Nine stations (three Suisun, three middle, three delta)
- Three analytes (DIN, ammonium, nitrite/nitrate), two flow records
- Four decades of data, 1976-2013

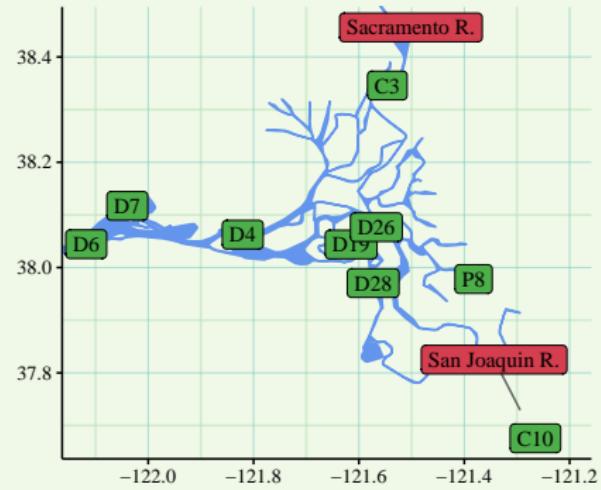


Figure : Stations (green) and flow estimates (red) modelled with WRTDS

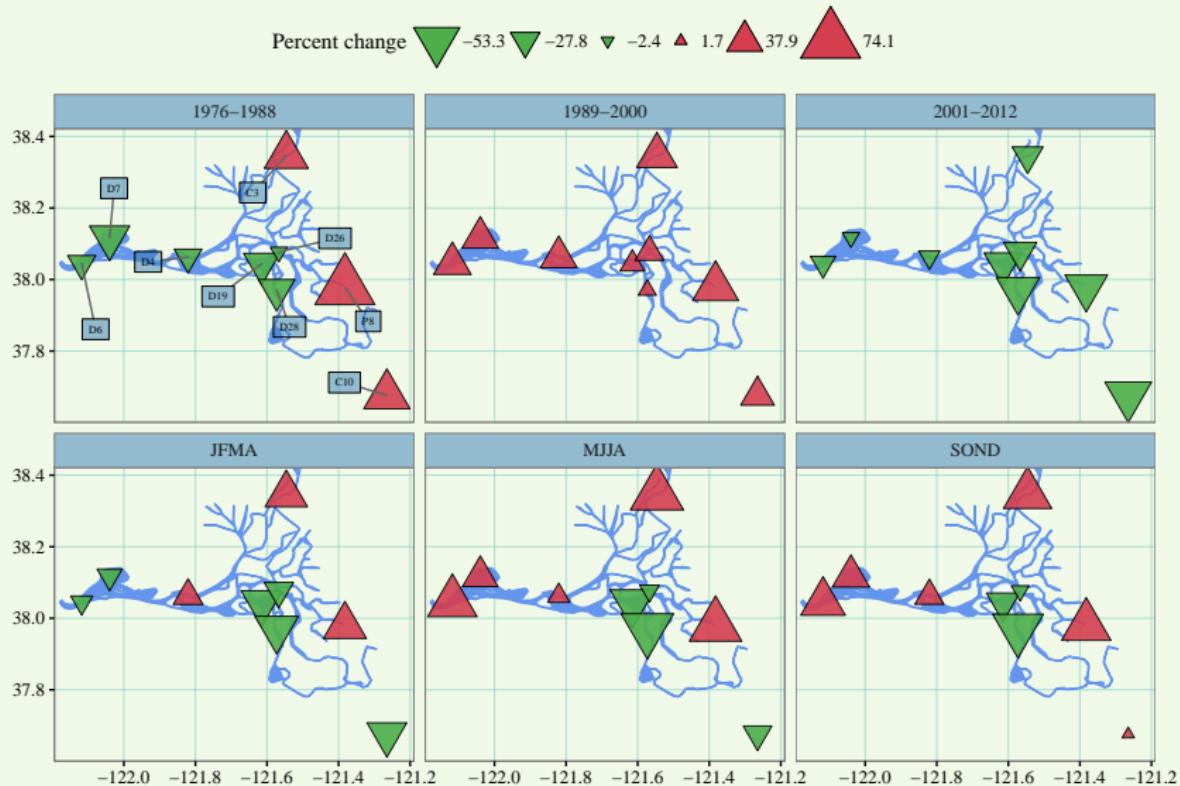
# Trends over time

## Nitrogen dynamics in the Delta

Predicted DIN trends, 1980-1990

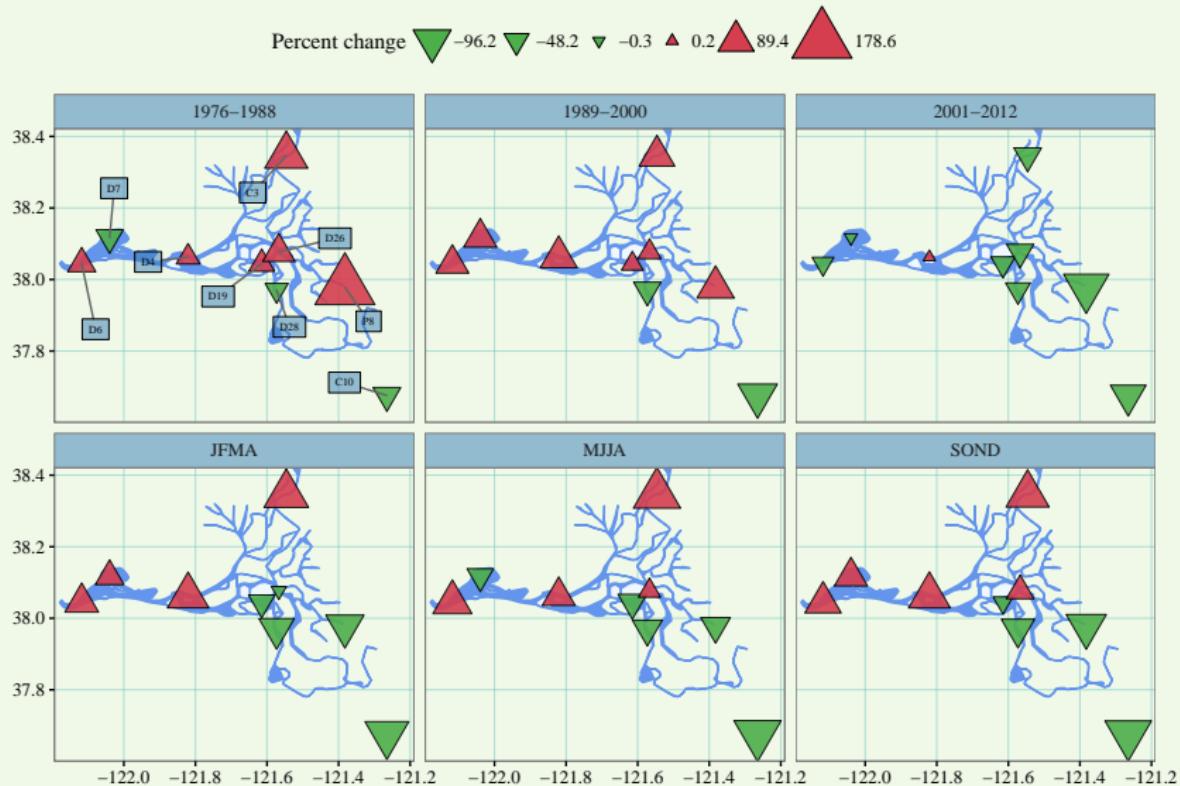
# Trends over time

## Nitrogen dynamics in the Delta - DIN



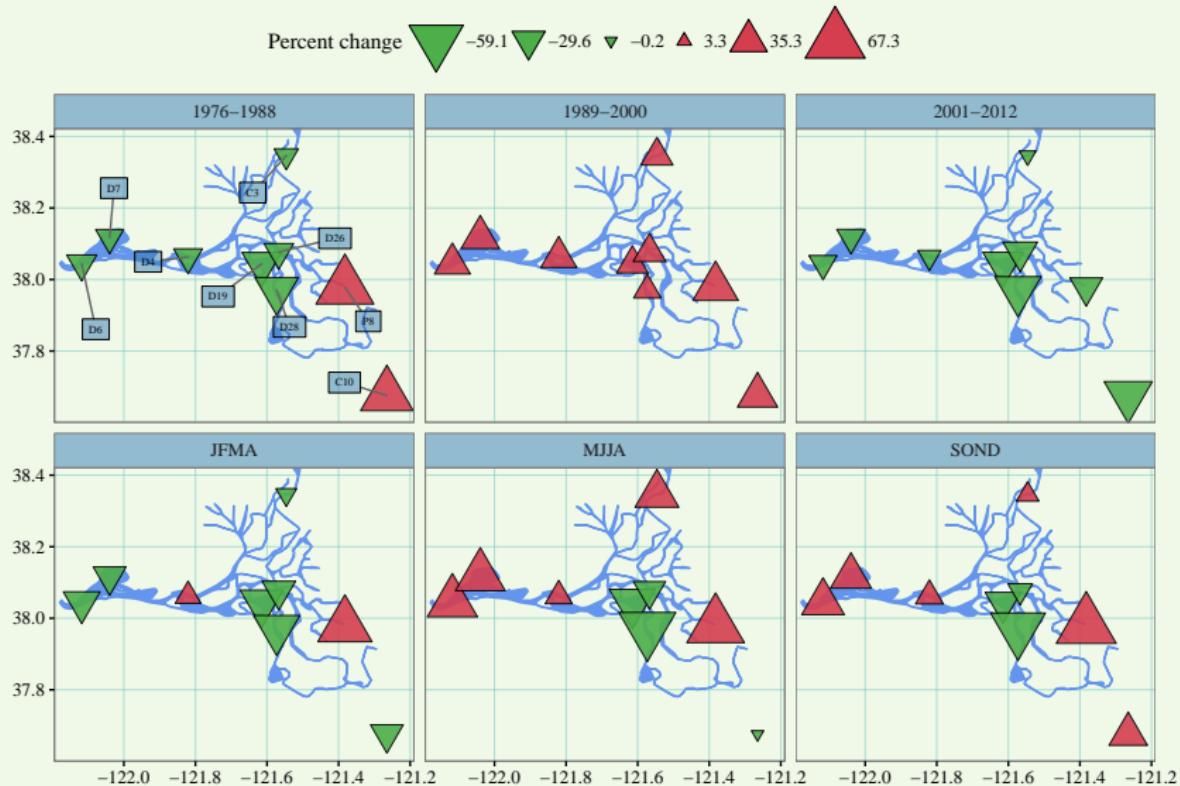
# Trends over time

## Nitrogen dynamics in the Delta - ammonium



# Trends over time

## Nitrogen dynamics in the Delta - nitrite/nitrate

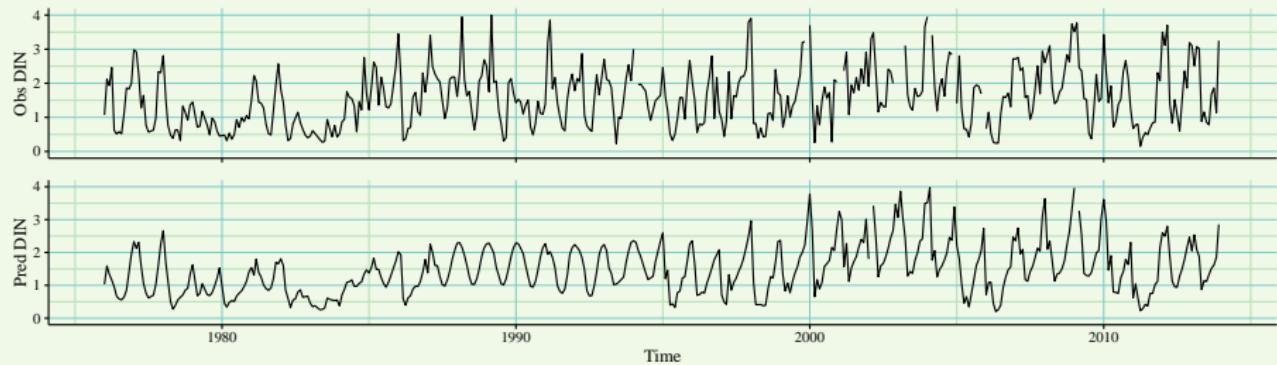


# Trends over time

## Nitrogen dynamics in the Delta - nitrite/nitrate

The **WRTDS** approach lets us model historical trends in relation to *time, discharge, and season*

Predicted trends follow observed... how can we leverage the results to better understand important processes?



# Selected case studies

Three examples were chosen to demonstrate the utility of WRTDS

- Disaggregating observed nitrogen time series
- Effects of wastewater treatment
- Effects of biological invasion

*Each example shows how model components describe processes*

# Selected case studies

## DIN trends at C10

**Hypothesis:** Because multiple factors influence nutrients at different times, WRTDS should describe non-linear complex relationships between nutrients, time, and flow

We should be able to *predict*:

- Annual trend independent of seasonal trend
- Changes in seasonal amplitudes and quantile trends over time
- Varying flow contributions

# Selected case studies

## DIN trends at C10

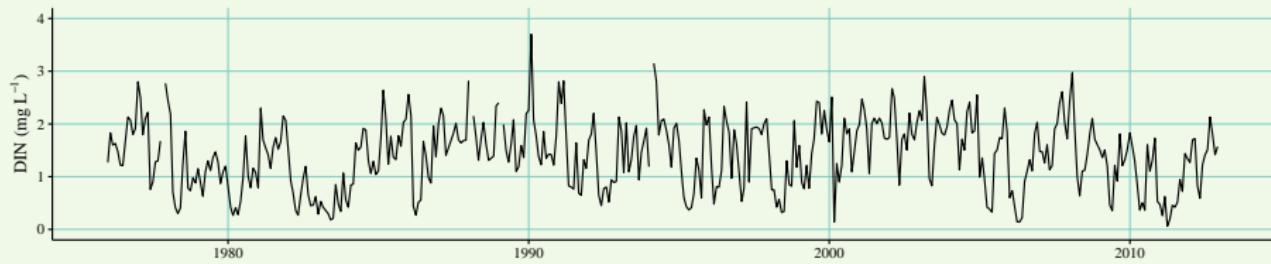


Figure : Observed DIN at C10, monthly samples.

# Selected case studies

## DIN trends at C10

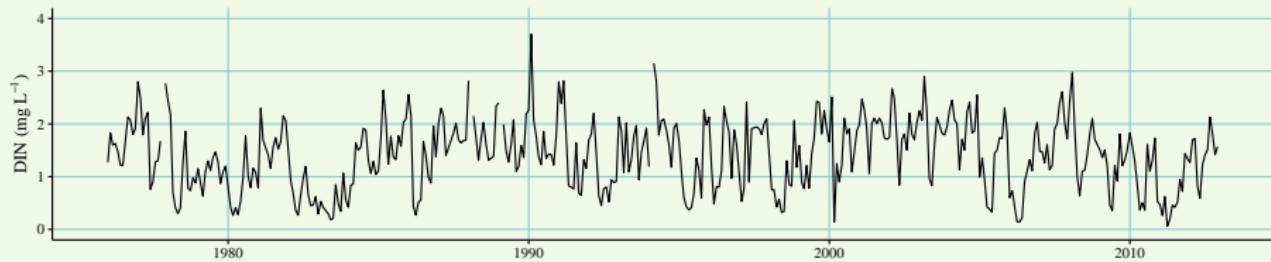


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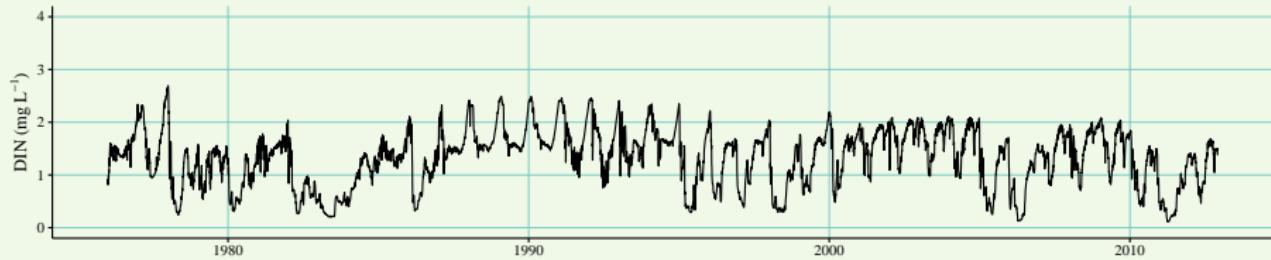


Figure : Predicted DIN at C10 using WRTDS and daily flow estimates.

# Selected case studies

## DIN trends at C10

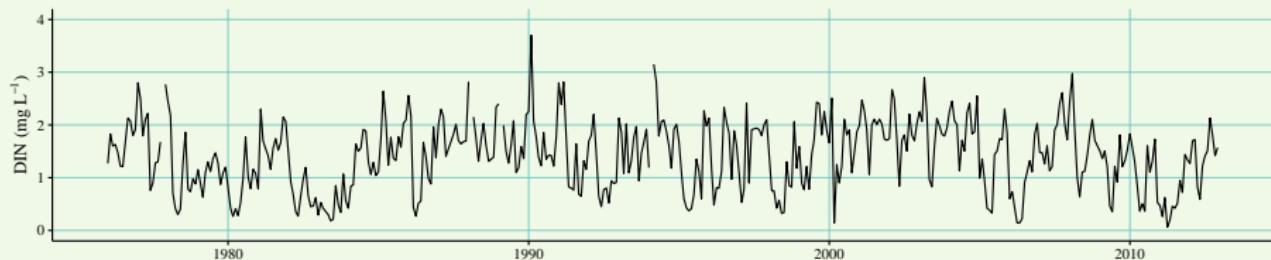


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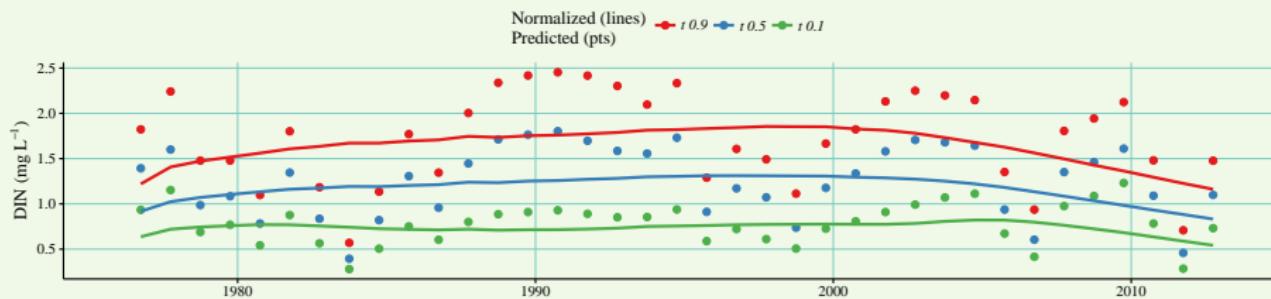


Figure : Annual trends by quantiles. Predicted and flow-normalized results are shown as points and lines.

# Selected case studies

## DIN trends at C10

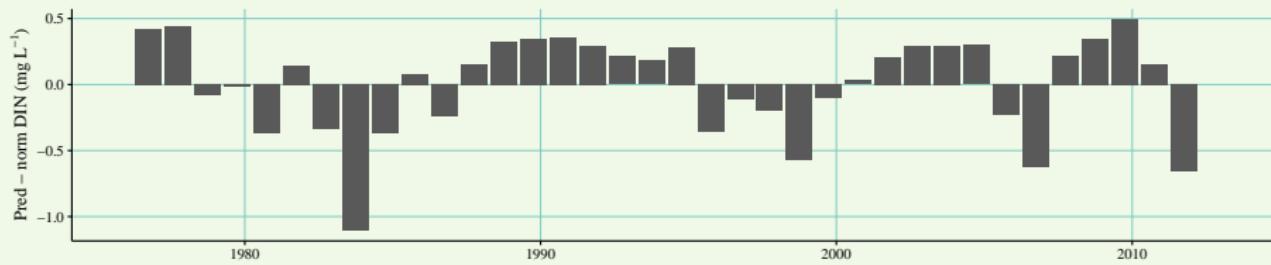


Figure : Difference between annual predicted and flow-normalized DIN, 50<sup>th</sup> percentile.

# Selected case studies

## DIN trends at C10

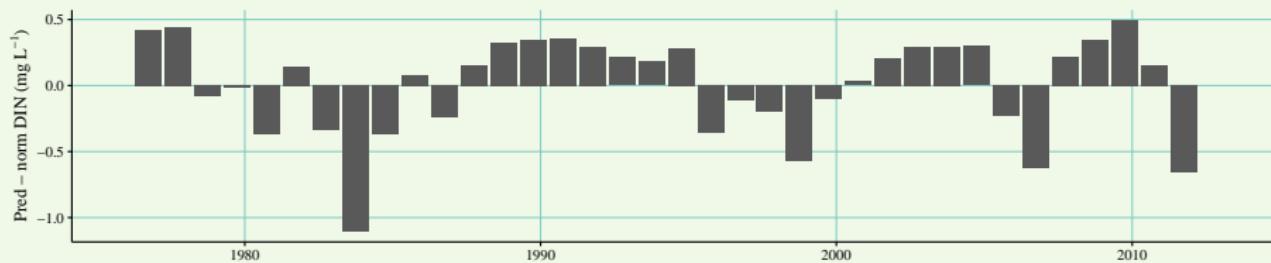


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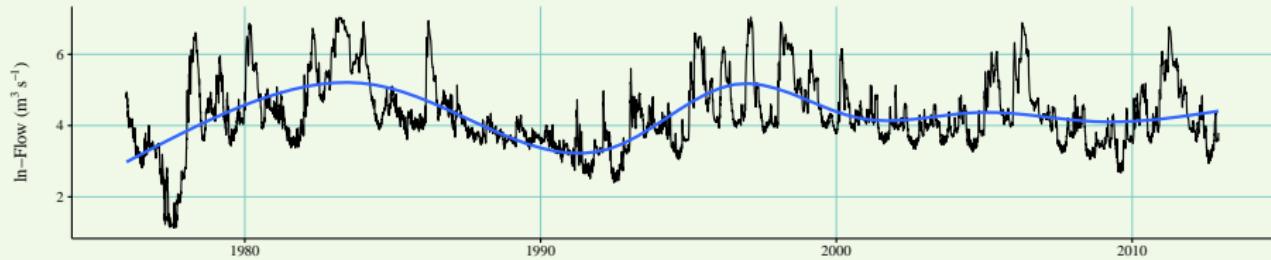


Figure : Daily flow at San Joaquin with locally-estimated smooth.

# Selected case studies

## DIN trends at C10

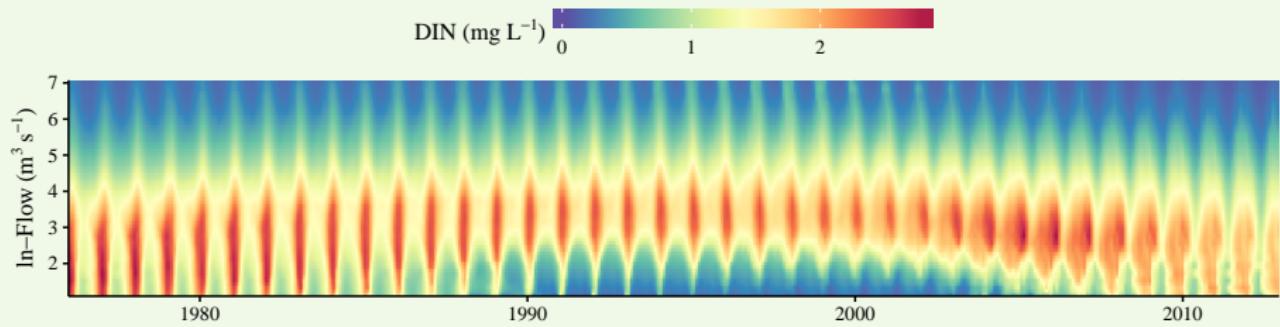


Figure : Modelled relationships between DIN, flow, and time.

# Selected case studies

## DIN trends at C10

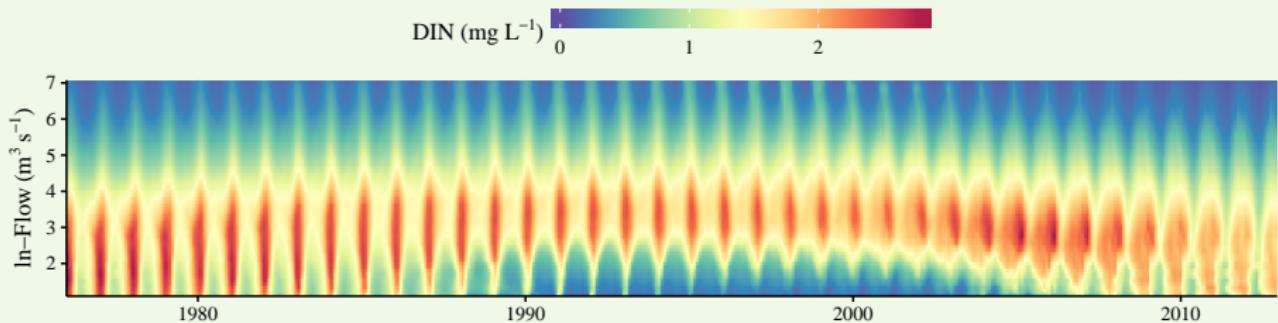


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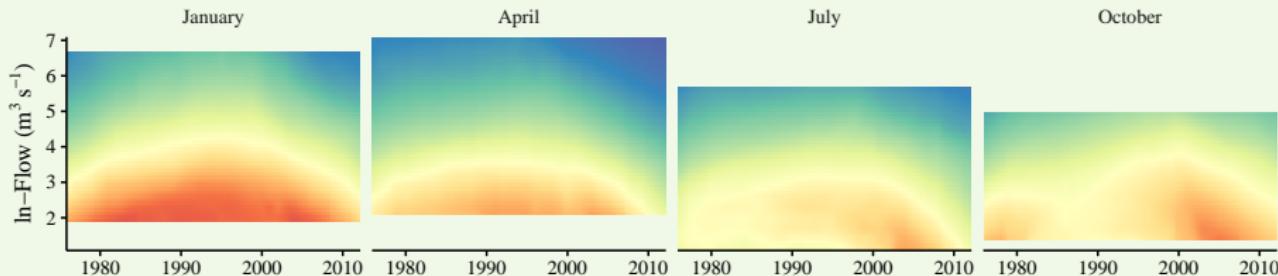


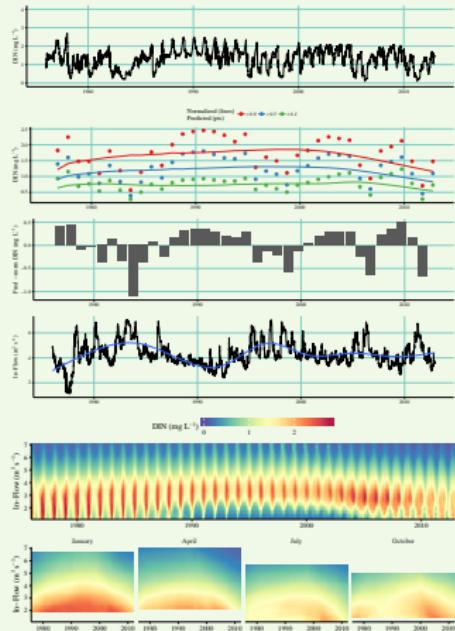
Figure : Annual variation of DIN for selected months.

# Selected case studies

## DIN trends at C10

Results at C10 showed the breadth of information provided by WRTDS

- Independent annual, seasonal trends
- Explicit flow effects in residuals
- Dynamic flow, season, time response



# Selected case studies

## Effects of wastewater treatment upgrades

Now... how can model information be linked to causation?

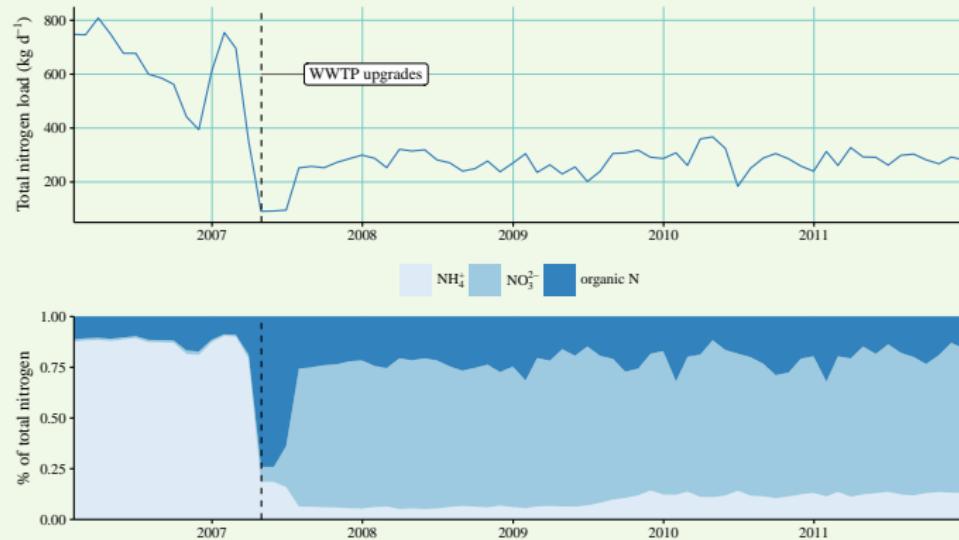


Figure : Nitrogen load measurements ( $\text{kg d}^{-1}$ ) at the Tracy Wastewater Treatment Plant. Wastewater discharge requirements were implemented in May, 2007.

# Selected case studies

## Effects of wastewater treatment upgrades

***Hypothesis:*** Response of nutrient concentrations at P8 is directly related to upstream WWTP upgrades

We should be able to ***predict:***

- A flow-normalized annual trend concurrent with WWTP upgrades
- Variation in nitrogen species response depending on change in load outputs

# Selected case studies

## Effects of wastewater treatment upgrades

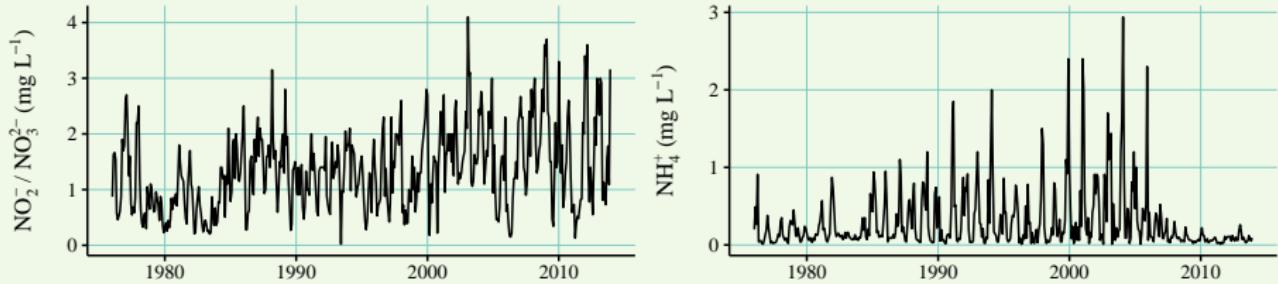


Figure : Observed nitrogen time series at P8

# Selected case studies

## Effects of wastewater treatment upgrades

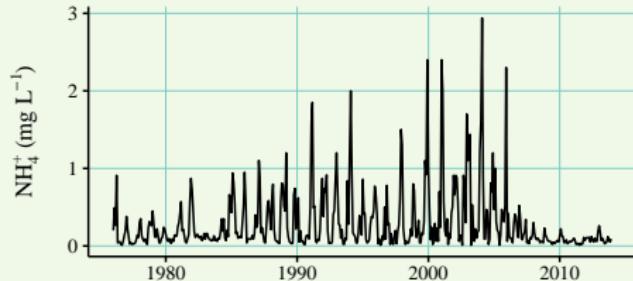
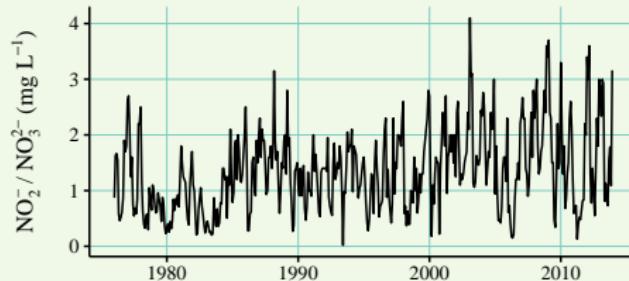


Figure : Observed nitrogen time series at P8

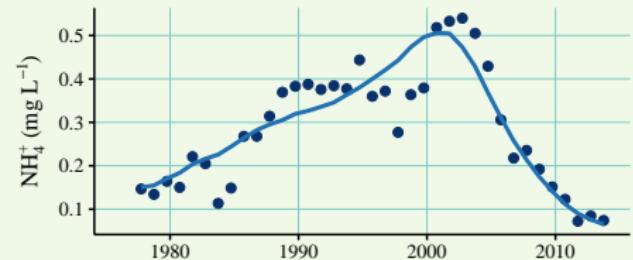
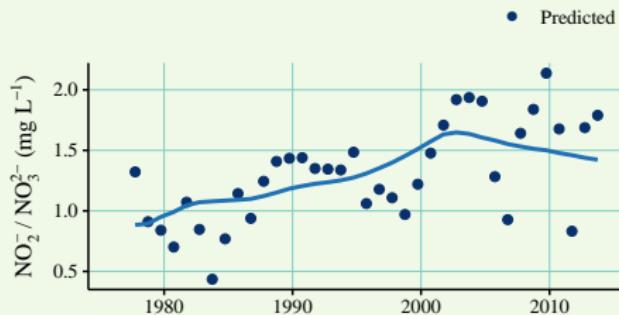


Figure : Annual predicted and flow-normalized nitrogen from WRTDS.

# Selected case studies

## Effects of wastewater treatment upgrades

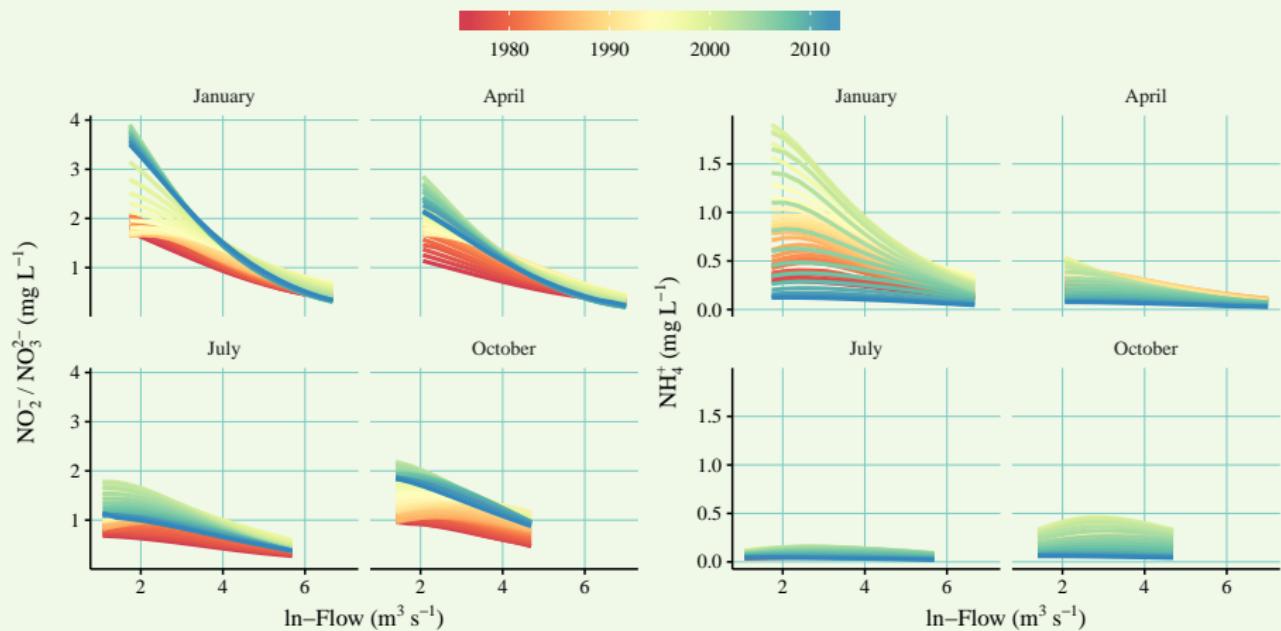


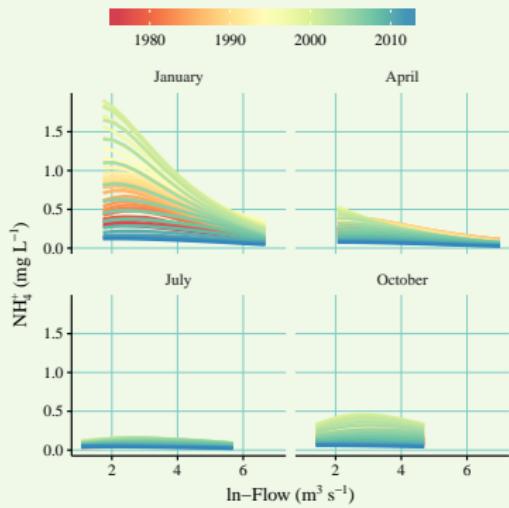
Figure : Nitrogen relationships with flow over time at P8.

# Selected case studies

## Effects of wastewater treatment upgrades

Results at P8 were linked to WWTP upgrades:

- Flow-normalized changes in ammonium, also nitrite/nitrate
- Ammonium reductions occurred in winter
- Largest response of ammonium at low flow... but not in summer



# Selected case studies

## Effects of biological invasion in Suisun Bay

**Hypothesis:** Biological invasions by benthic filter feeders have shifted abundance and composition of phytoplankton in Suisun Bay

We should be able to *predict*:

- A decline in annual, flow-normalized chlorophyll following increase in invaders
- Varying effects of flow given complex relationships between chlorophyll and invaders

# Selected case studies

## Effects of biological invasion in Suisun Bay

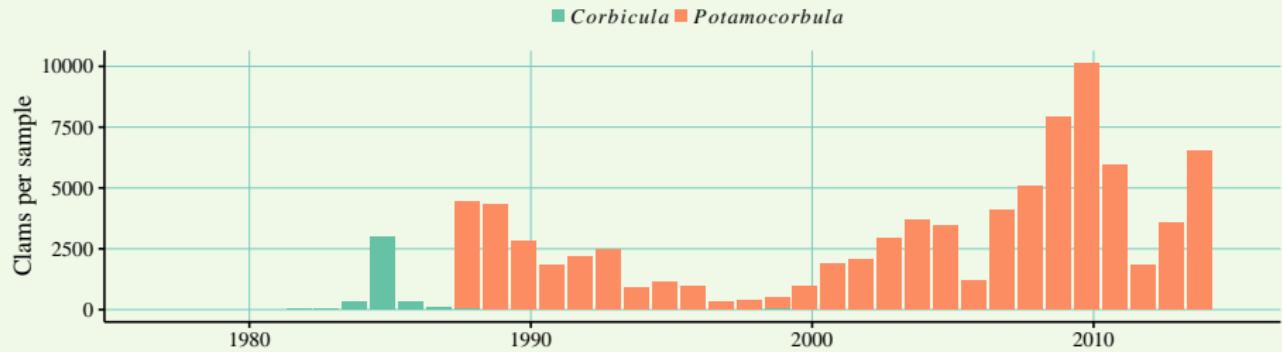


Figure : Clam density by year at D7, Suisun Bay [Crauder et al., 2016].

# Selected case studies

## Effects of biological invasion in Suisun Bay

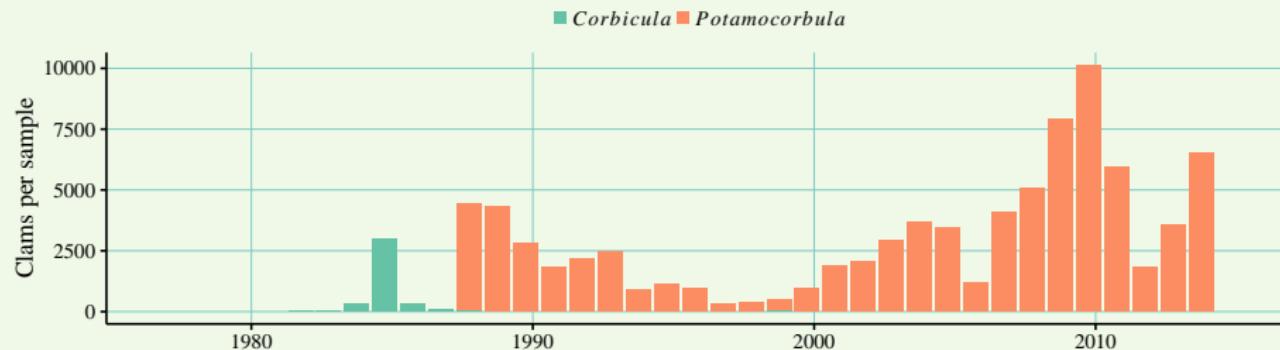


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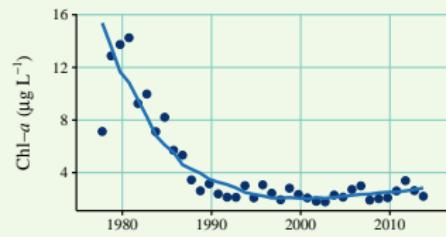


Figure : Annual predicted (points) and flow-normalized (lines) water quality data at D7.

# Selected case studies

## Effects of biological invasion in Suisun Bay

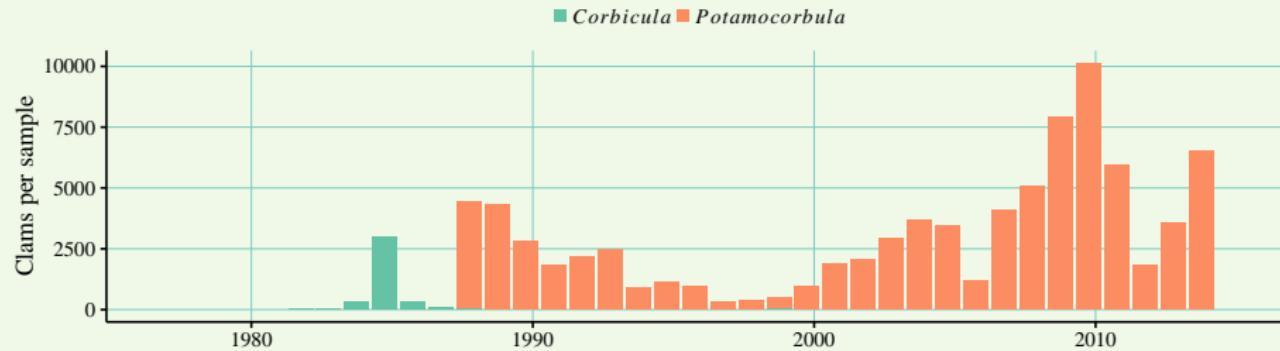


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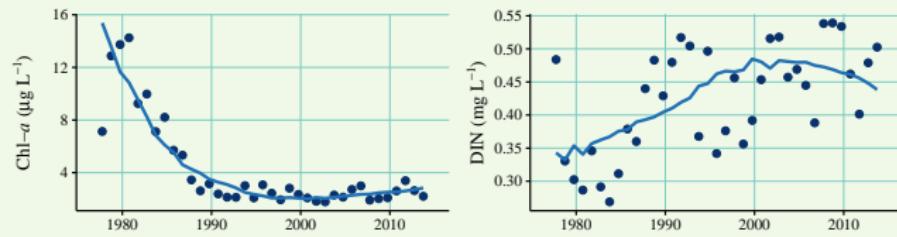


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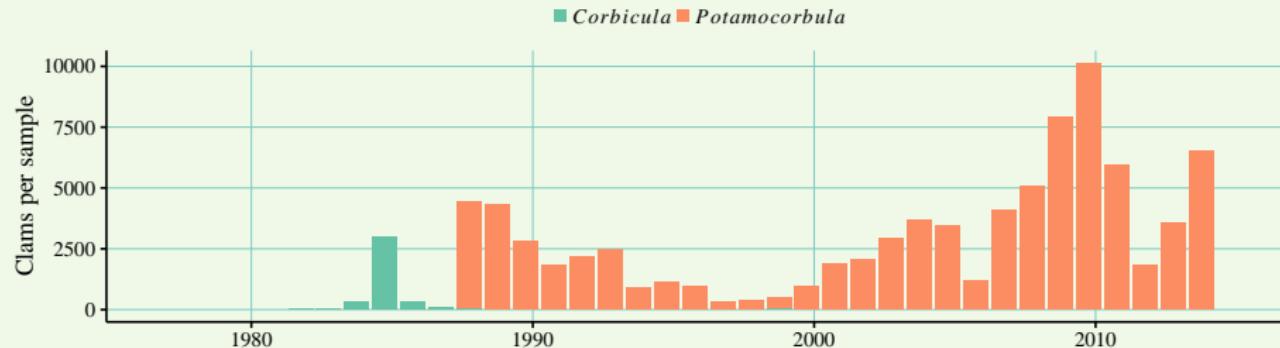


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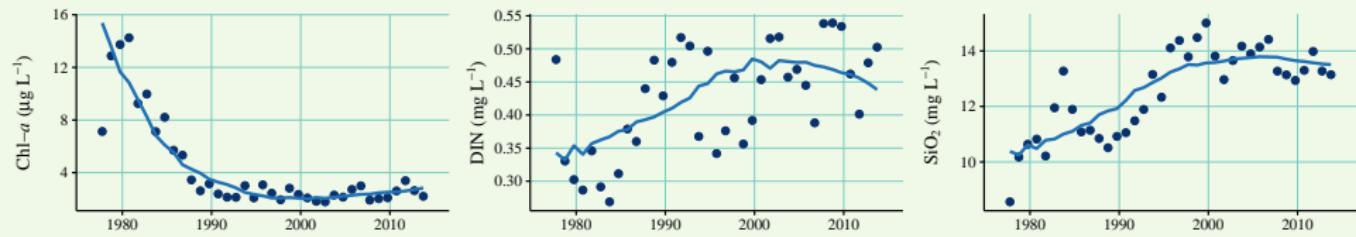
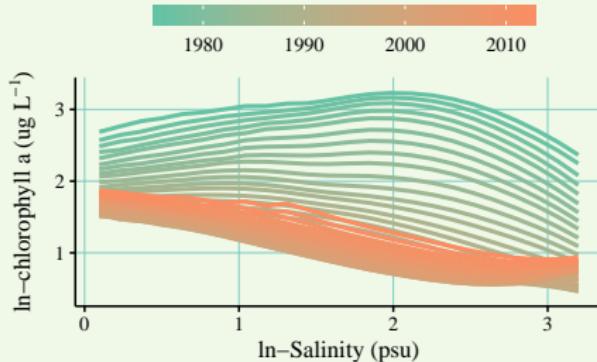


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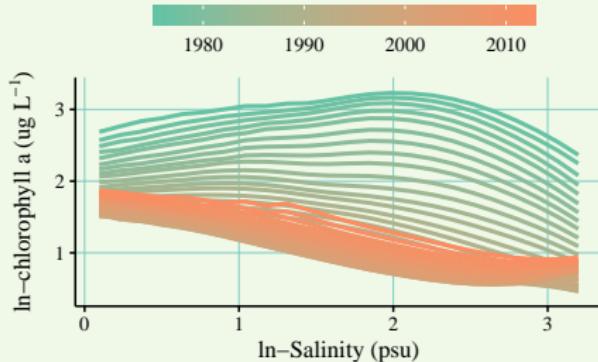
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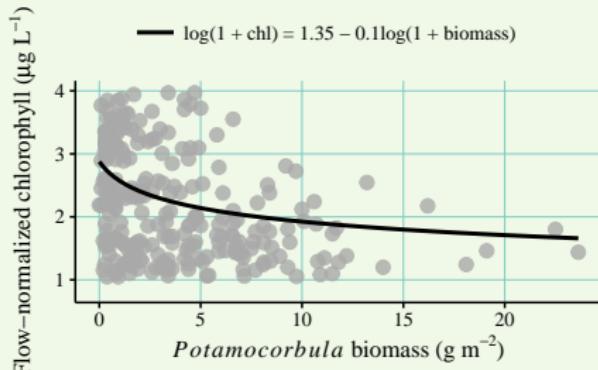
- Early: Flow-stimulation, then flushing
- Later: Flow-stimulation

# Selected case studies

## Effects of biological invasion in Suisun Bay

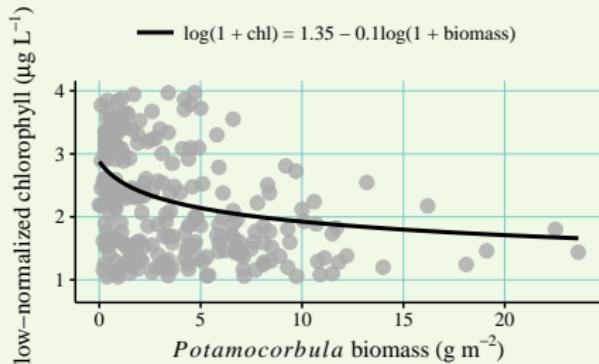
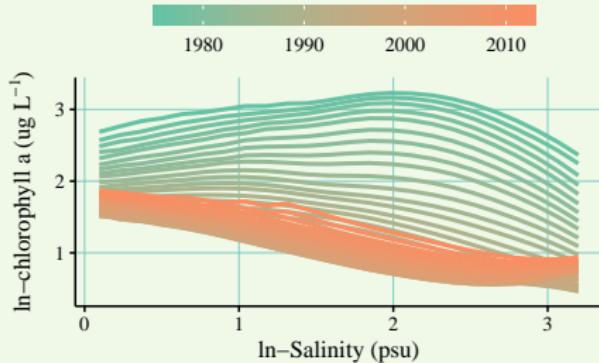


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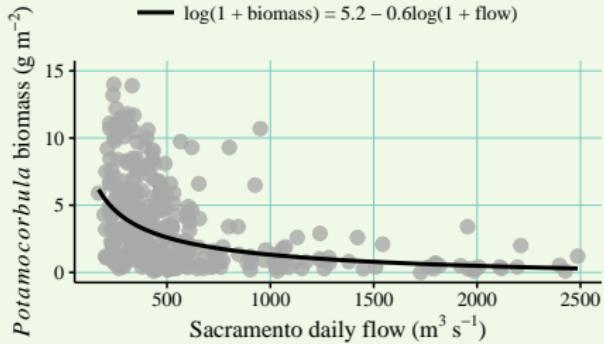


# Selected case studies

## Effects of biological invasion in Suisun Bay



- Early: Flow-stimulation, then flushing
- Later: Flow-stimulation

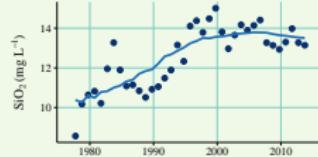
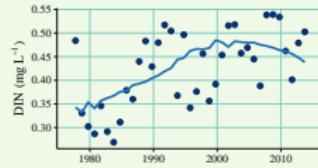
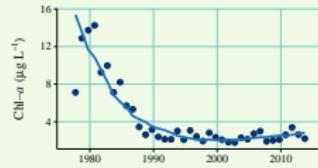


# Selected case studies

## Effects of biological invasion in Suisun Bay

Results at D7 show complex response of chlorophyll:

- Increase in clam abundance, decrease in chlorophyll
- Increase in DIN... but also decrease in SiO<sub>2</sub>

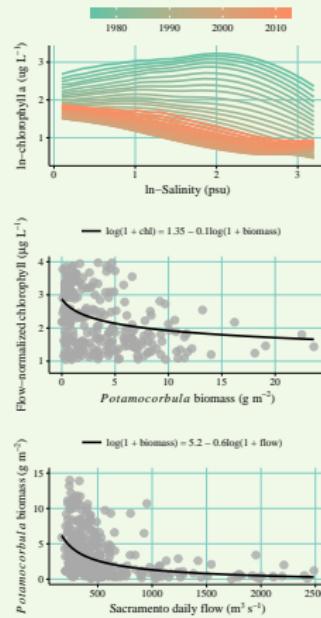


# Selected case studies

## Effects of biological invasion in Suisun Bay

Results at D7 show complex response of chlorophyll:

- Increase in clam abundance, decrease in chlorophyll
- Increase in DIN... but also decrease in SiO<sub>2</sub>
- Relationship with flow changed depending on physical or biological forcing



# Conclusions

## Lessons for monitoring and future work

Monitoring data are not particularly telling...

...so we use models or other methods to *decompose* the observations

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## Lessons for monitoring and future work

Monitoring data are not particularly telling...

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Chosen method depends on the question: WRTDS because water quality varies with time, season, and flow

# Conclusions

## Lessons for monitoring and future work

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- More complete description of trends
- Better link to causal events
- More comprehensive evaluation of site-specific issues
- Deconstruct the past to predict the future

# Conclusions

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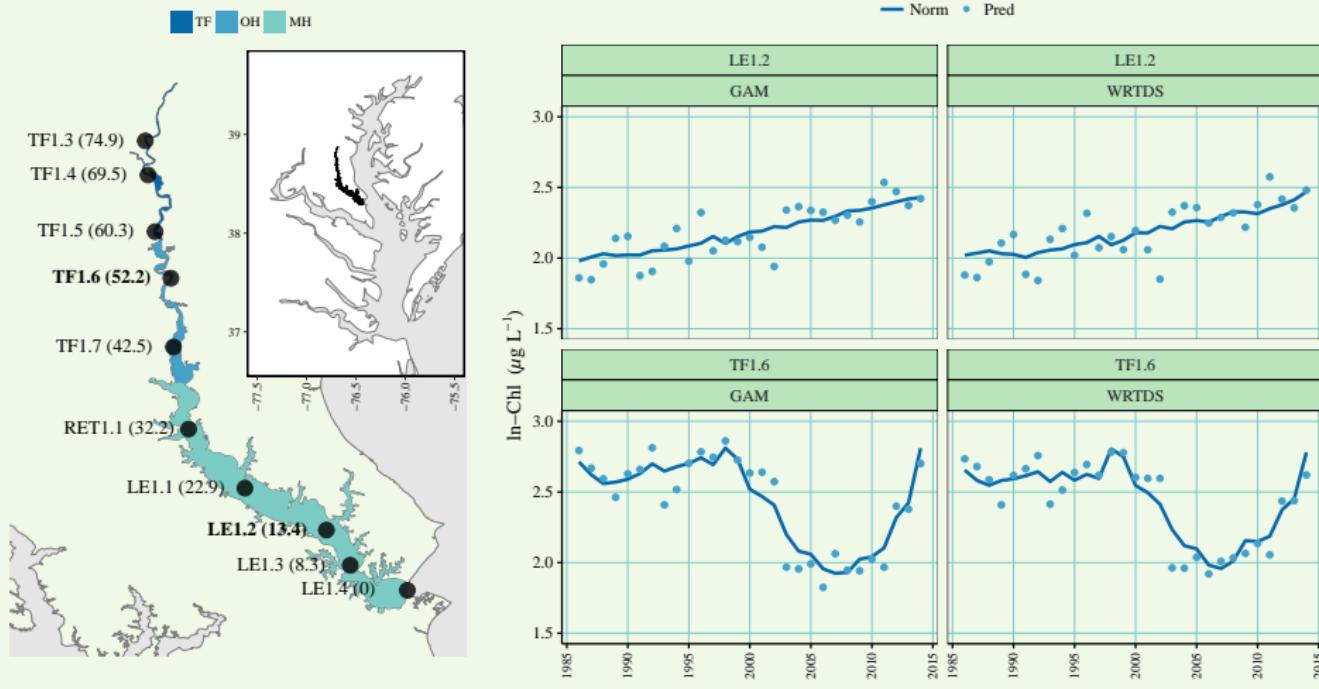
*WRTDStidal* package for R, active development

<https://github.com/fawda123/WRTDStidal>

# Conclusions

Lessons for monitoring and future work

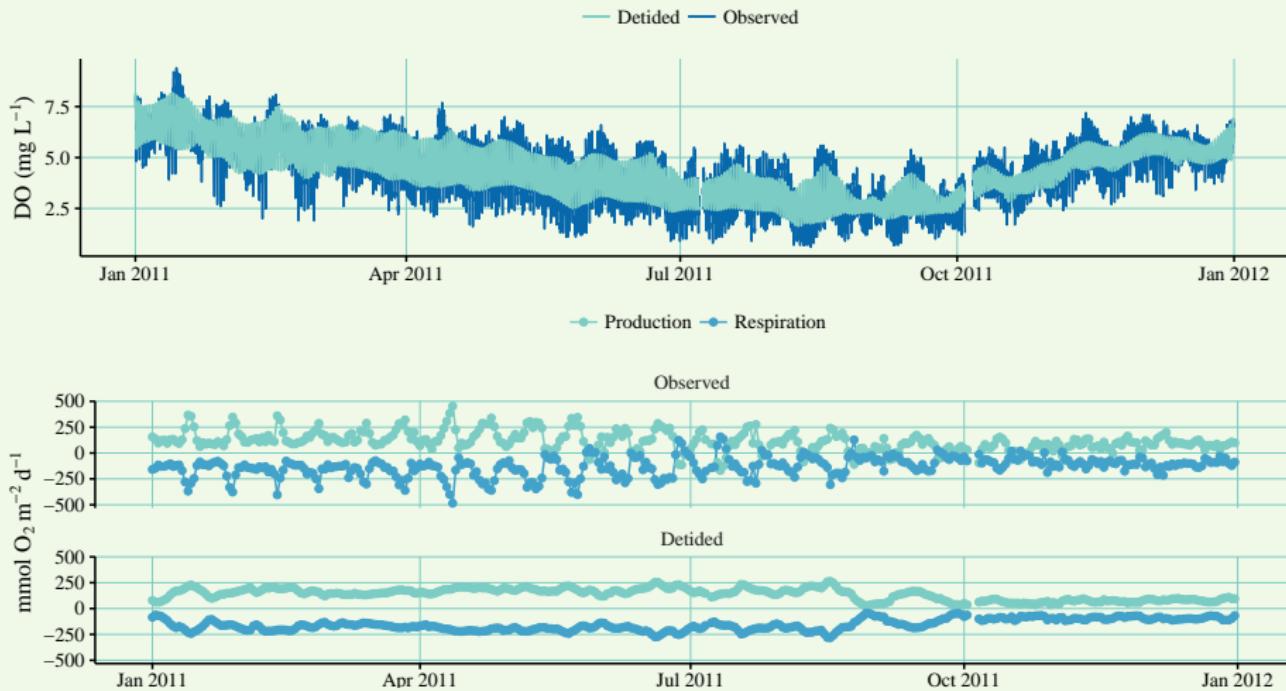
Comparing WRTDS and GAMs for trend evaluation



# Conclusions

## Lessons for monitoring and future work

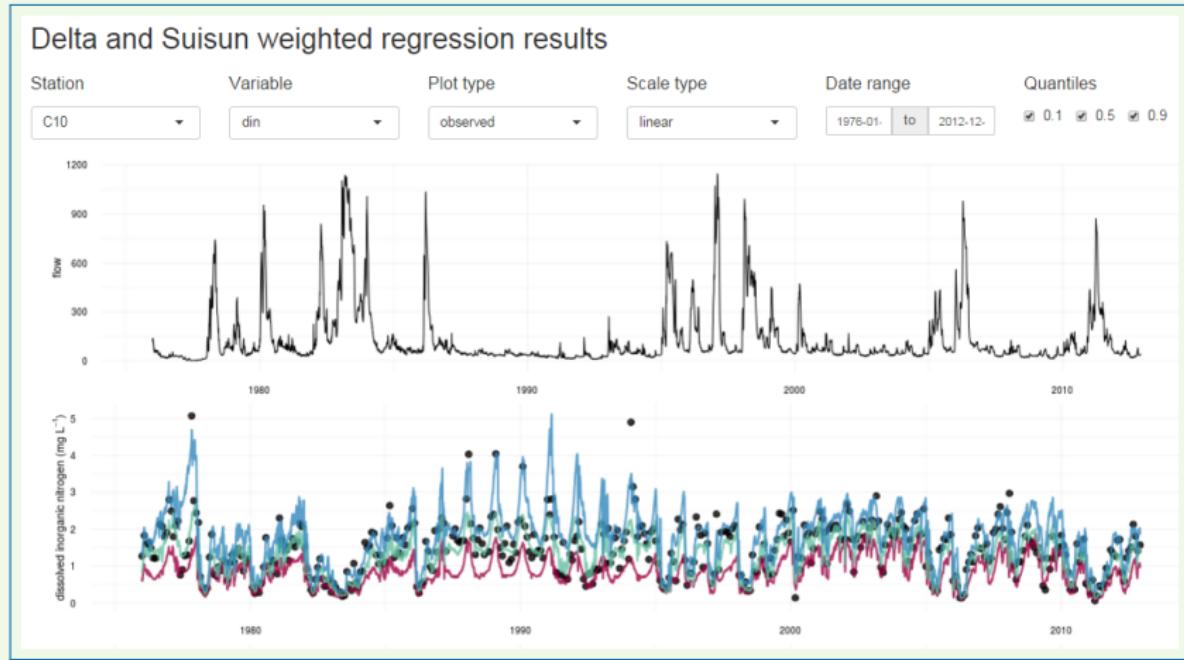
DO time series and ecosystem metabolism [Beck et al., 2015]



# Conclusions

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## Data management and analysis tools



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## Links:

This presentation: [https://github.com/fawda123/sfei\\_pres](https://github.com/fawda123/sfei_pres)

Shiny app: [https://beckmw.shinyapps.io/sf\\_trends/](https://beckmw.shinyapps.io/sf_trends/)

Detailed results: [http://fawda123.github.io/sf\\_trends/README](http://fawda123.github.io/sf_trends/README)

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