Quantitative approaches to understand nutrient pollution in estuaries: An example for the upper San Francisco Estuary

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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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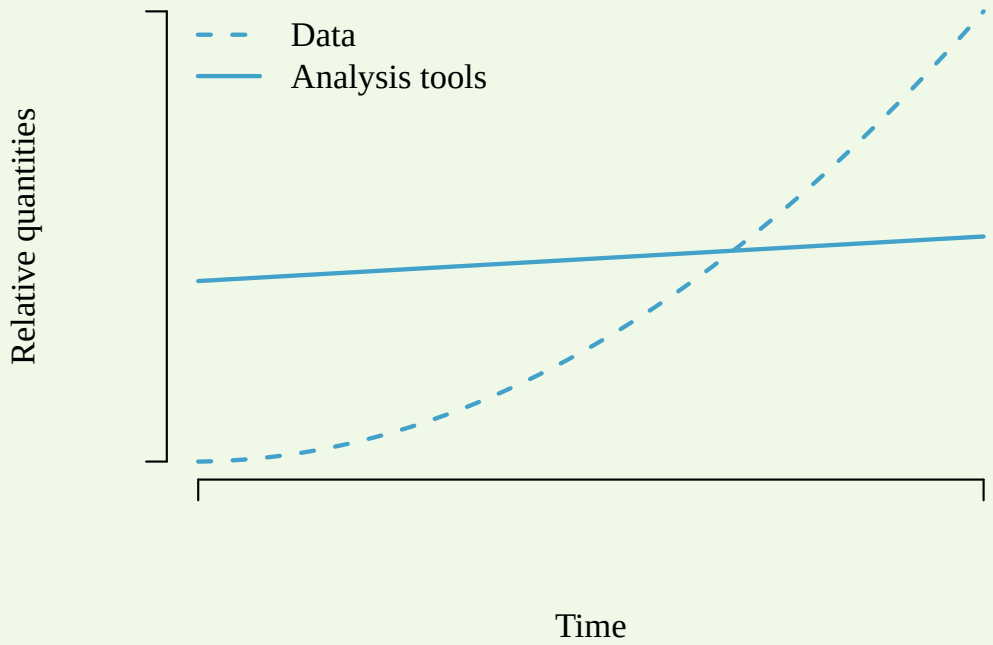

Evaluating estuarine condition

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*
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> *– [Nixon, 1995]*

Adapted from [Cloern, 2001]

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Nutrient Loading

Adapted from [Cloern, 2001]

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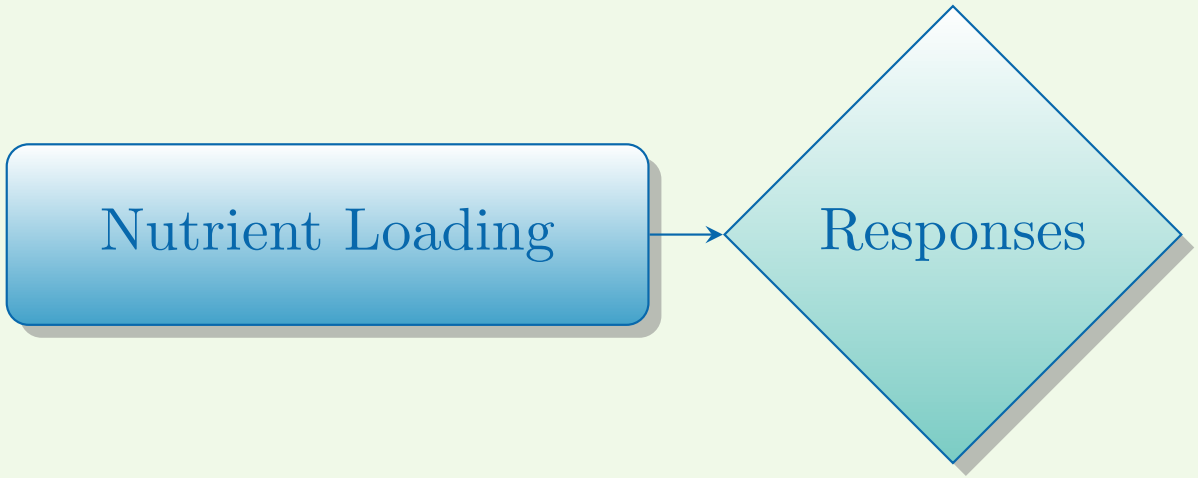

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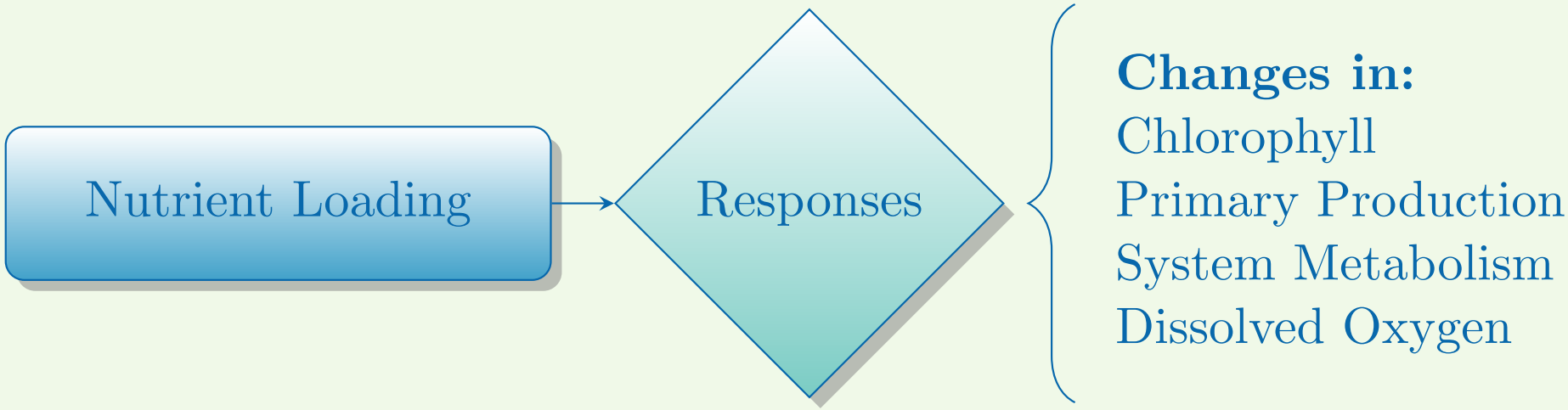

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Evaluating estuarine condition

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

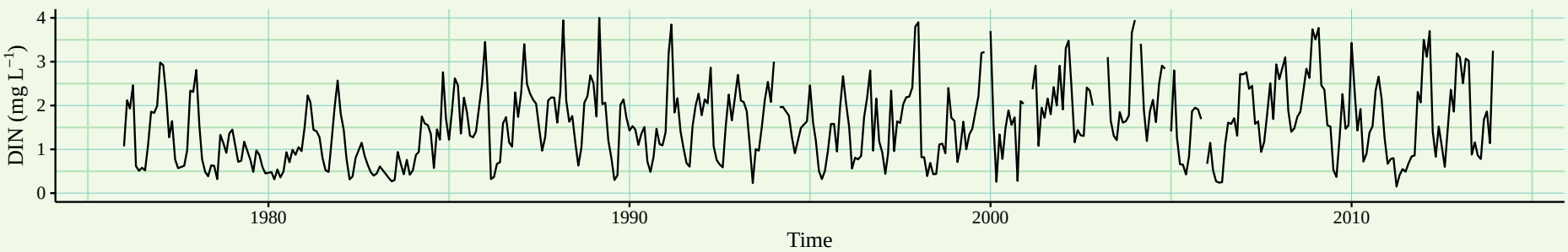
WRTDS adaptation for tidal waters

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?

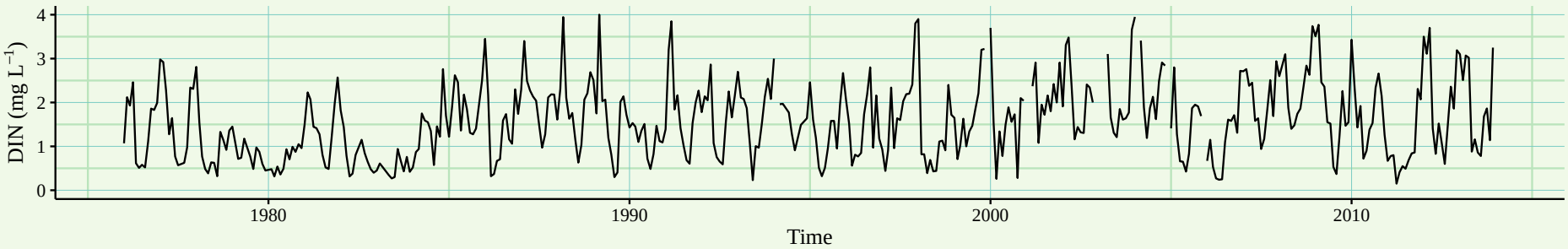
Can we ***link descriptions*** to ***causal events*** to inform management or understanding?



Model theory and background

WRTDS adaptation for tidal waters

Observed data represents effects of many processes



Climate	***Local***	***Regional/historical***
precipitation	light/turbidity	watershed inputs
temperature	residence time	point sources
wind events	invasive species	management actions
ENSO effects	trophic effects	flow changes

Model theory and background

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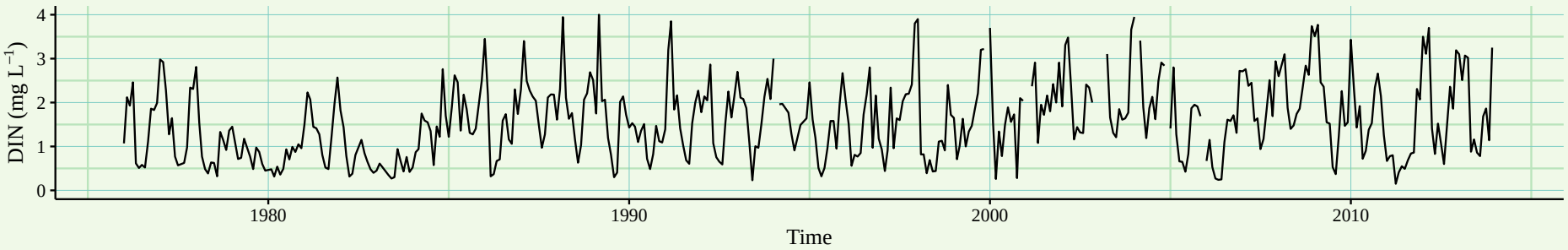
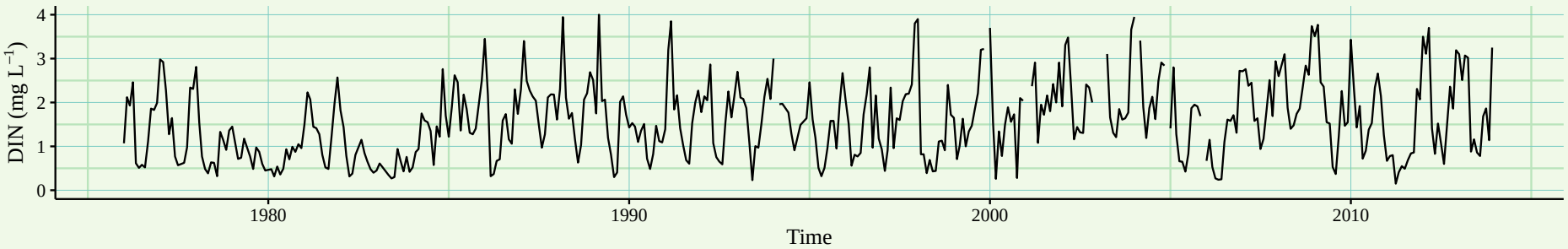


Models should describe components to evaluate effects

Observed data represents effects of many processes



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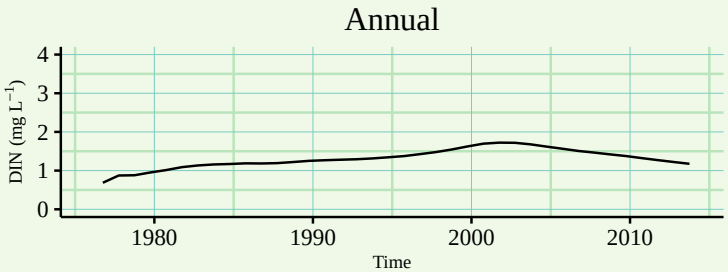

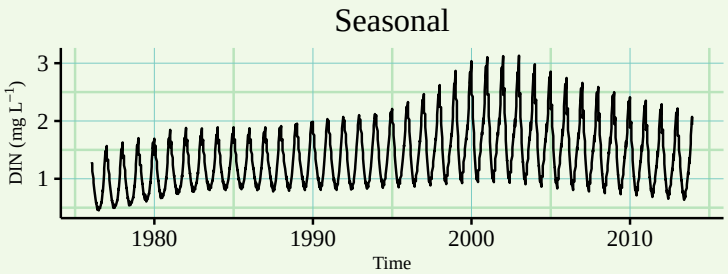

Model theory and background

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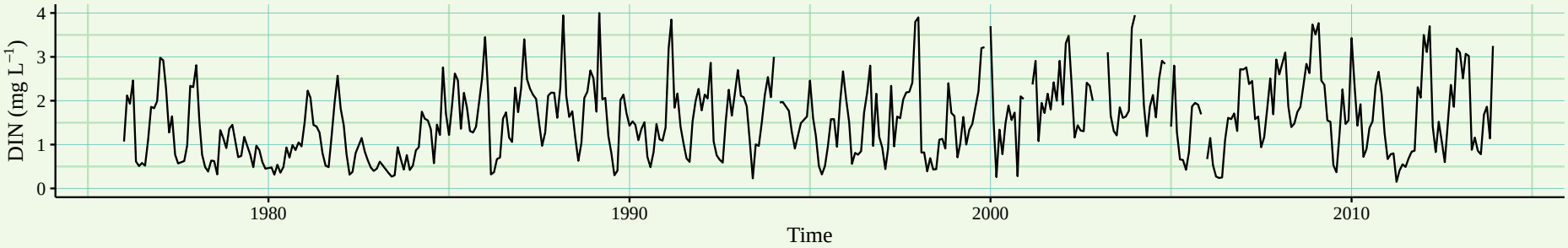

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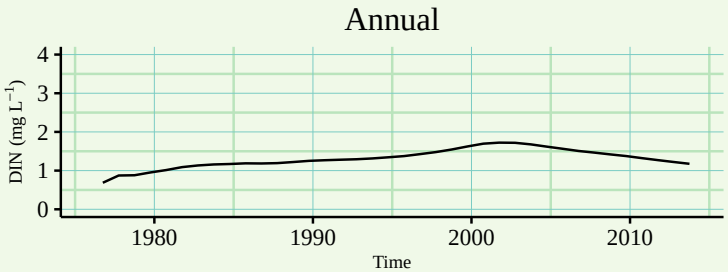
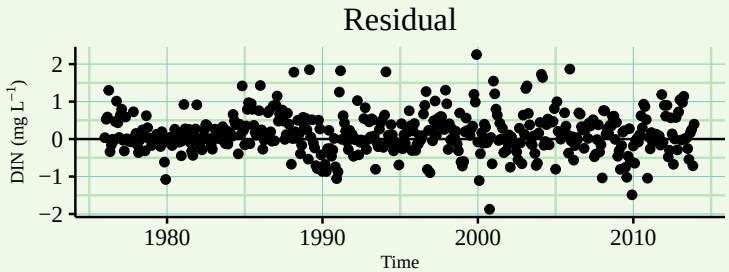
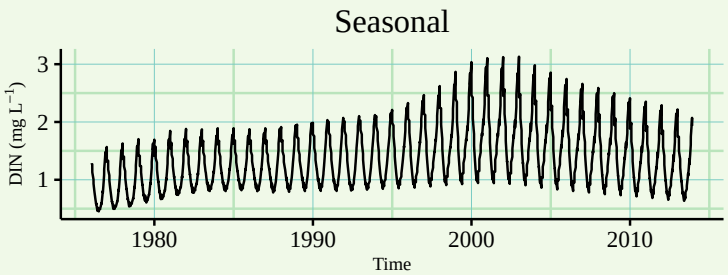
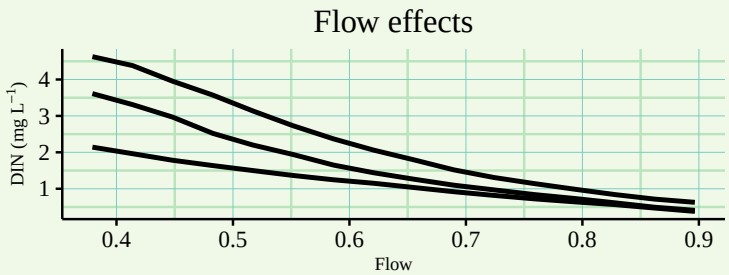








Model theory and background

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]

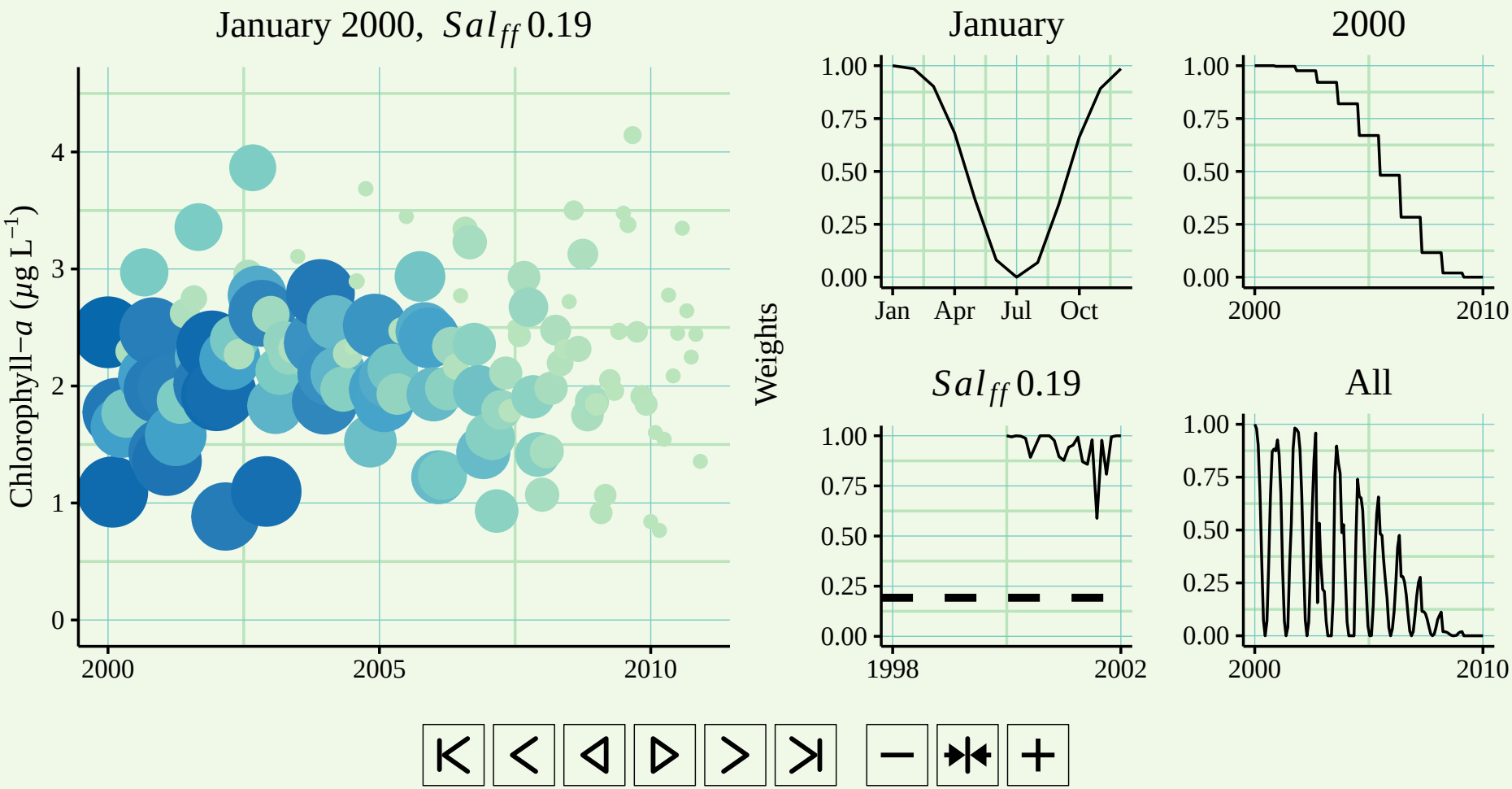
Models pollution concentration as a function of ***time***, ***discharge***, and ***season***

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?



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

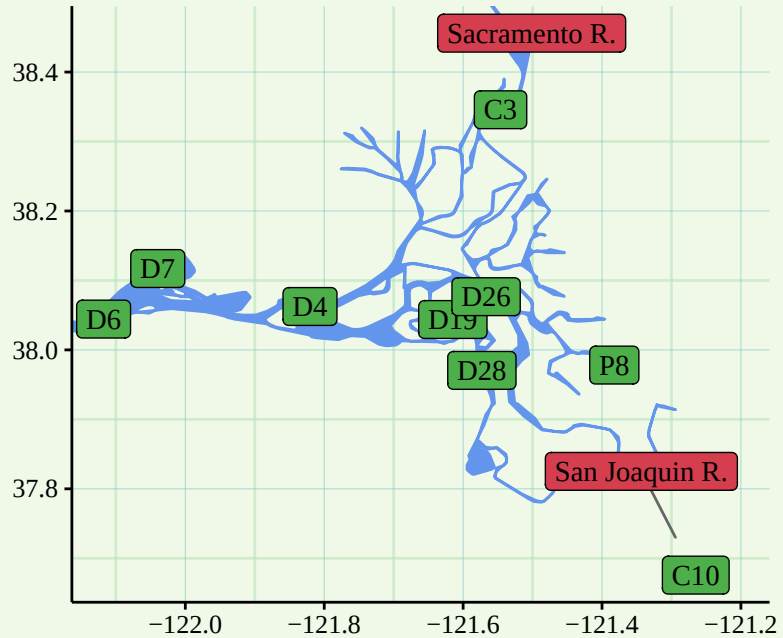
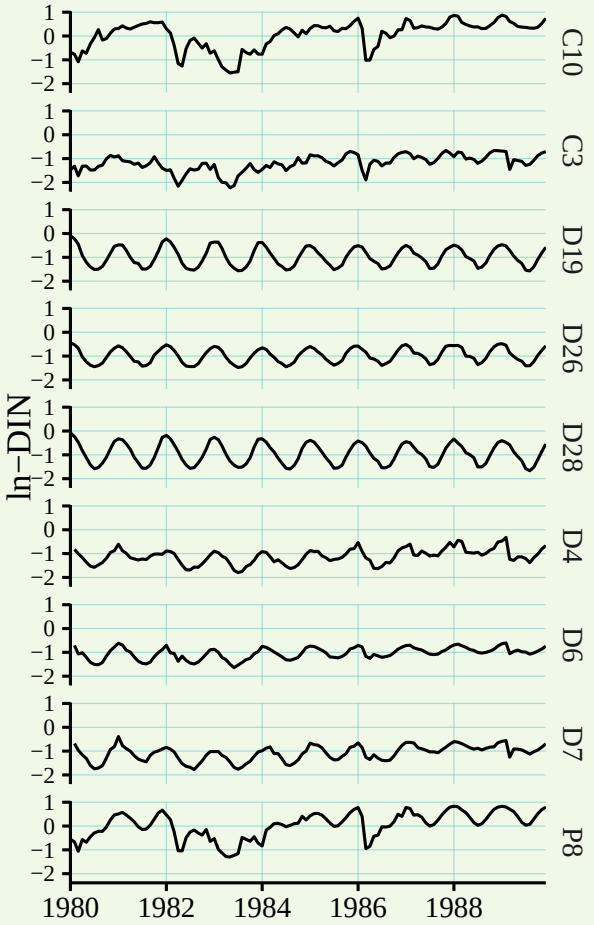


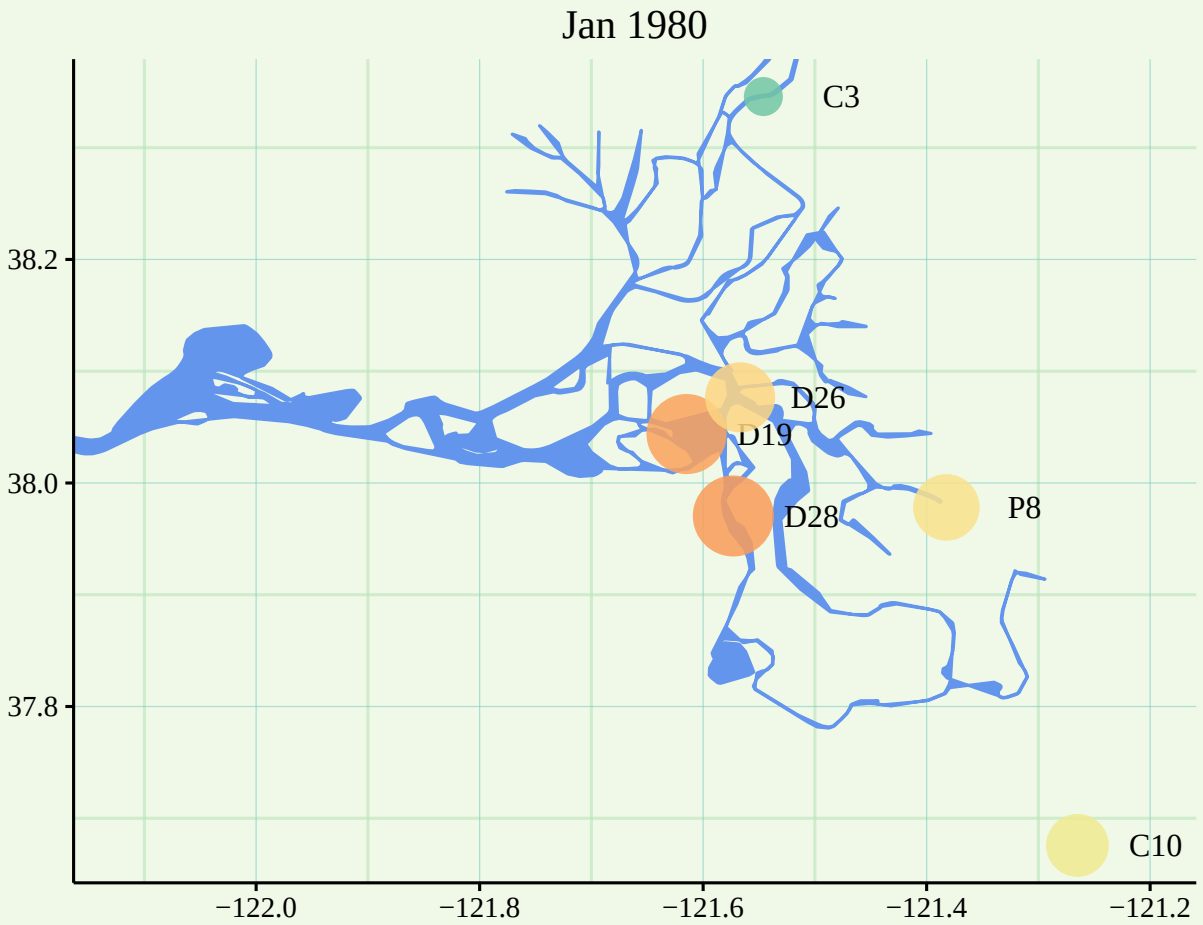
Figure : Stations (green) and flow estimates (red) modelled with WRTDS

Trends over time

Nitrogen dynamics in the Delta

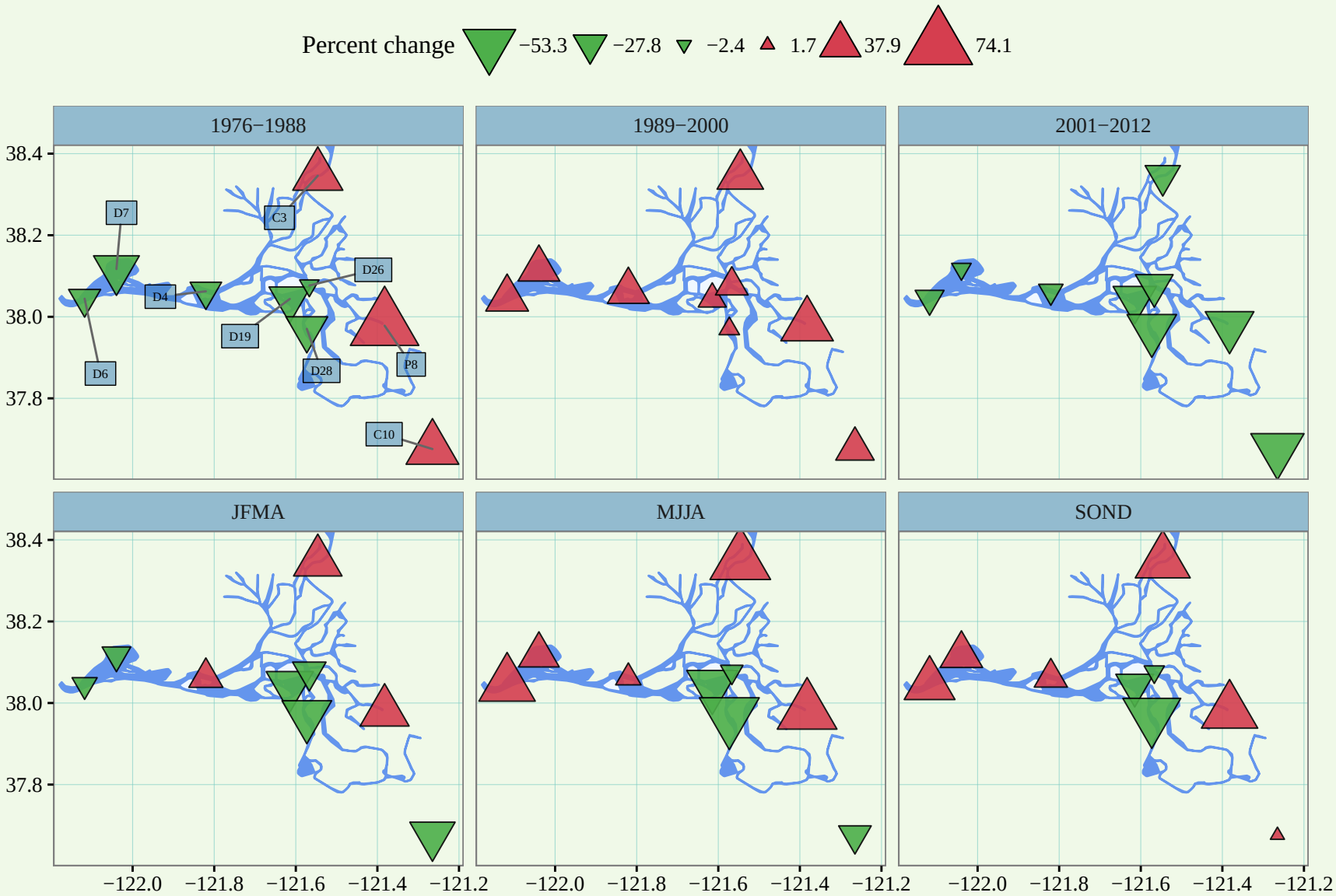
Predicted DIN trends, 1980-1990





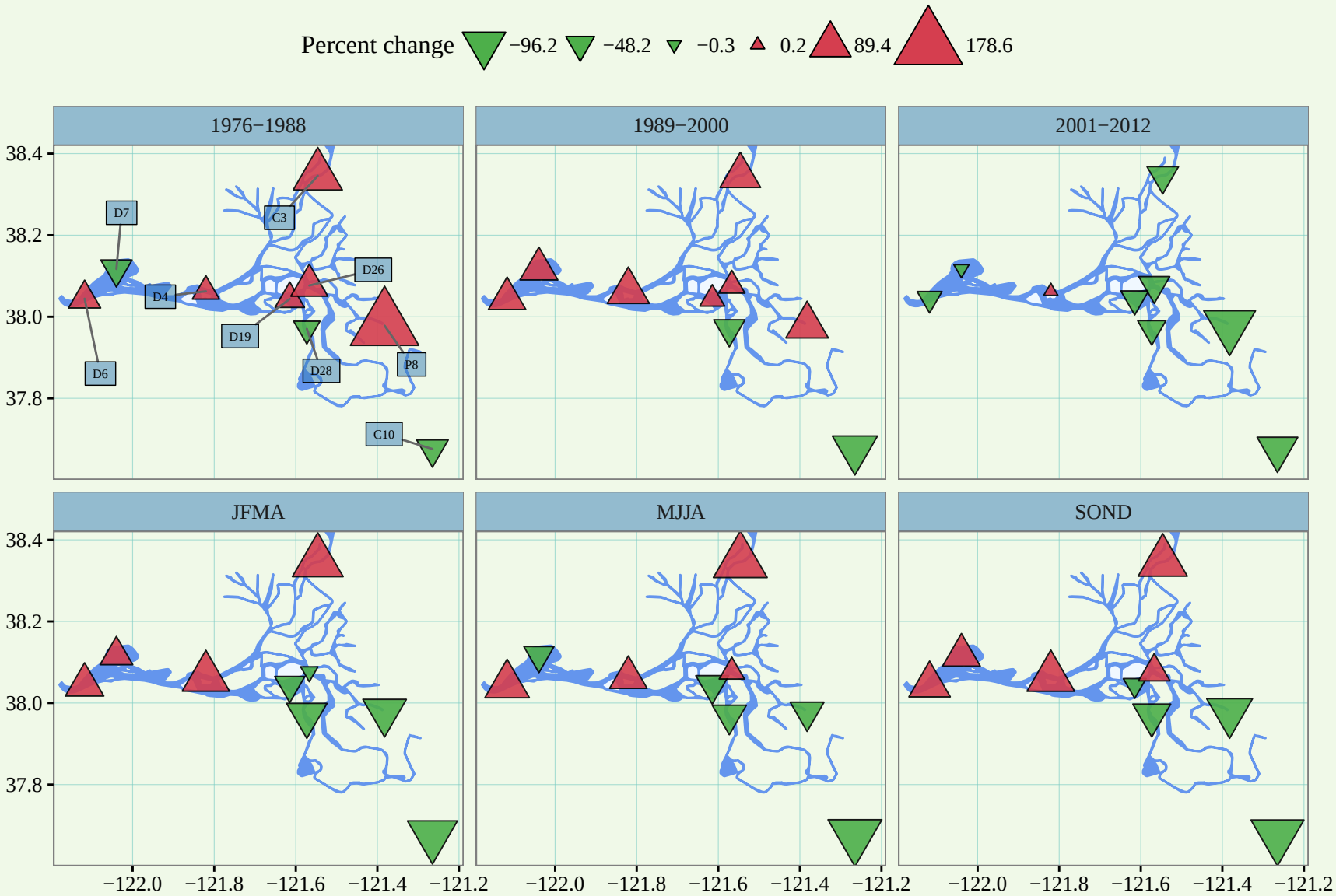
Trends over time

Nitrogen dynamics in the Delta - DIN



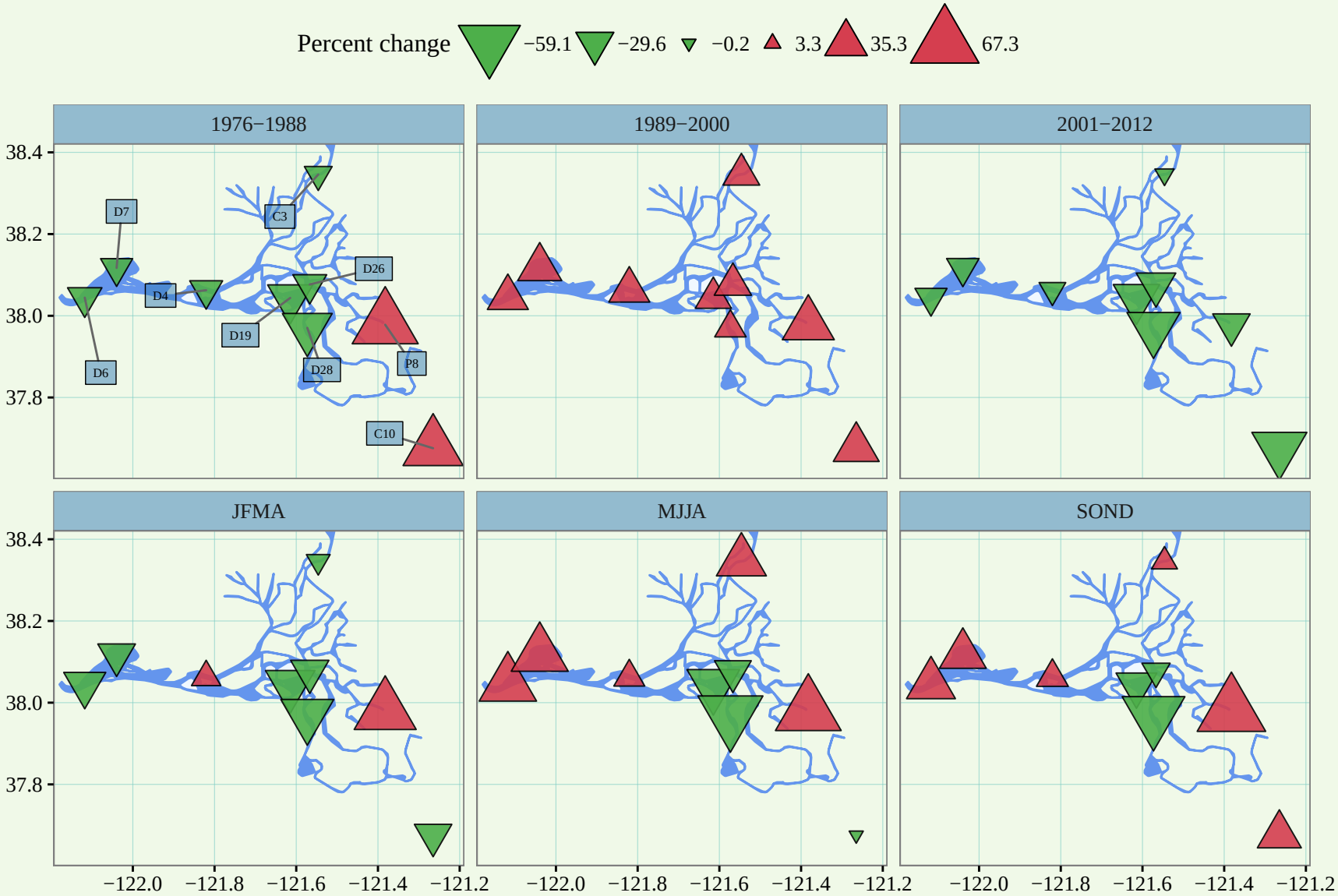
Trends over time

Nitrogen dynamics in the Delta - ammonium



Trends over time

Nitrogen dynamics in the Delta - nitrite/nitate

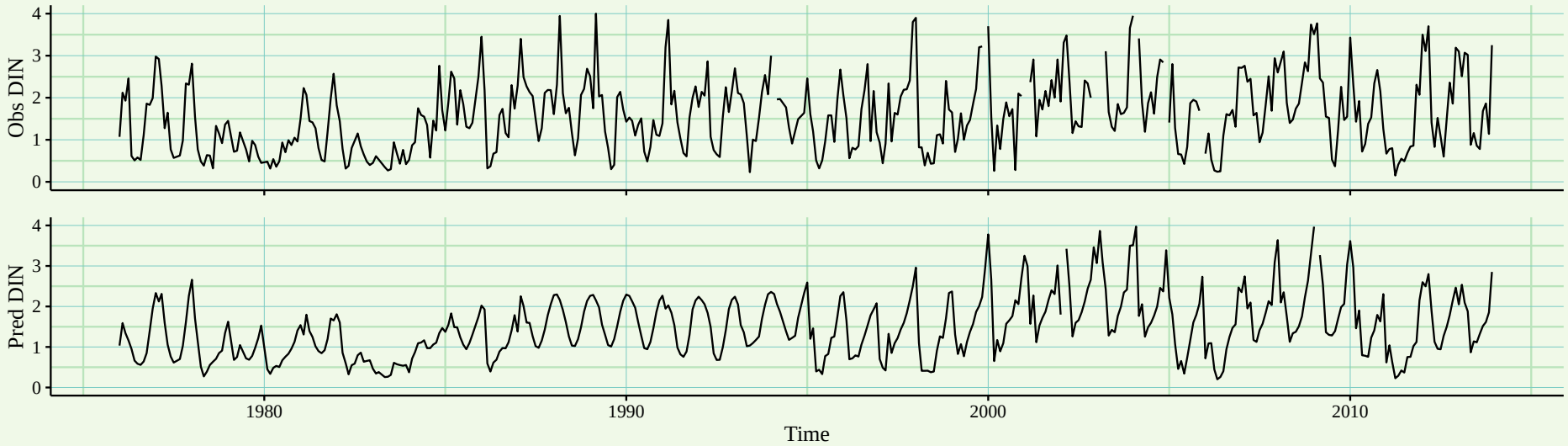


Trends over time

Nitrogen dynamics in the Delta - nitrite/nitate

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

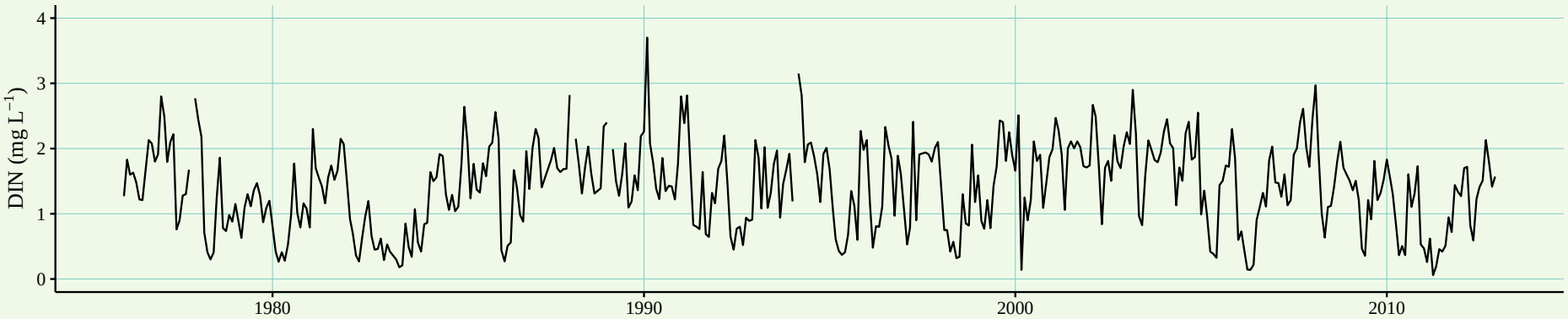
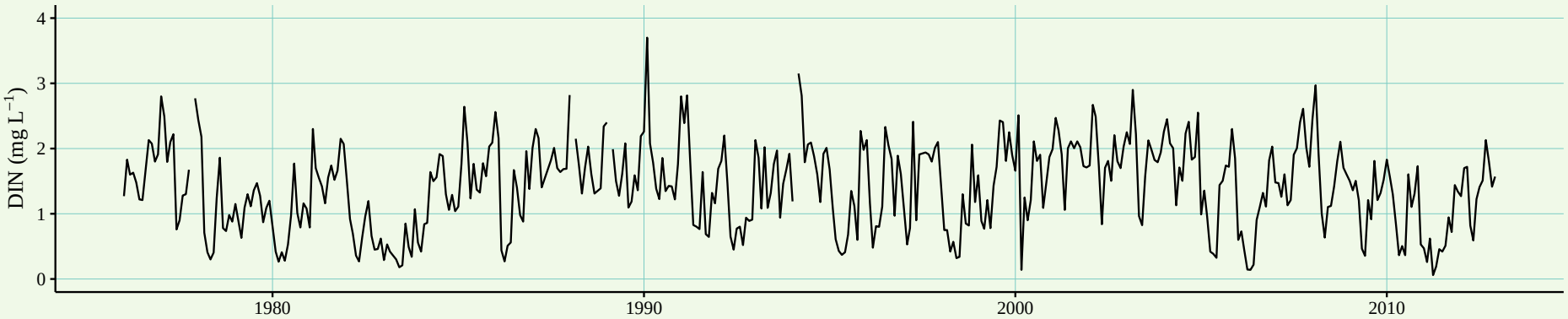


Figure : Observed DIN at C10, monthly samples.

Selected case studies

DIN trends at C10



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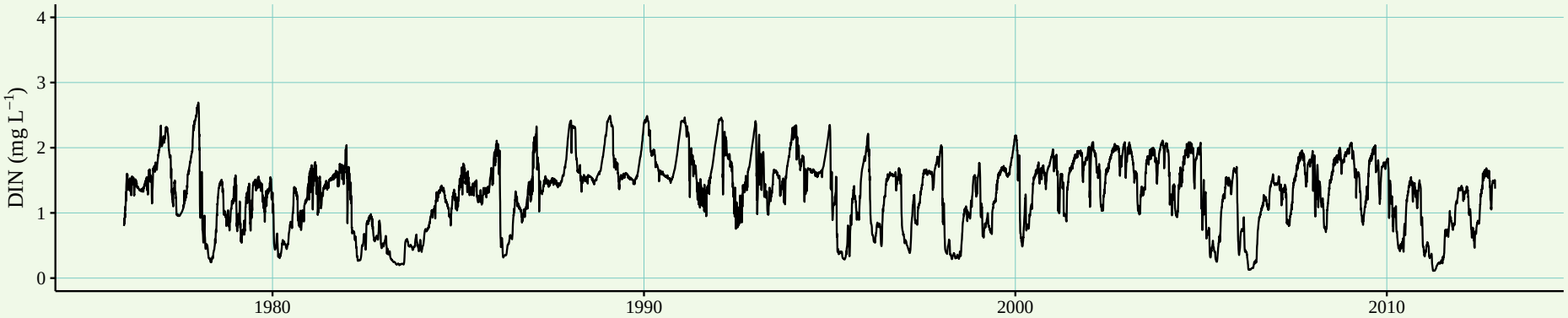
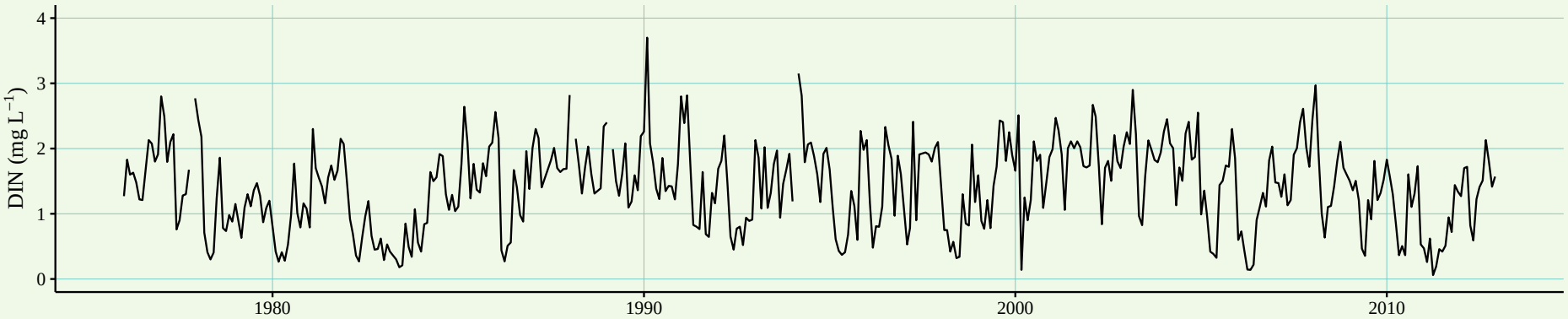


Figure : Predicted DIN at C10 using WRTDS and daily flow estimates.

Selected case studies

DIN trends at C10



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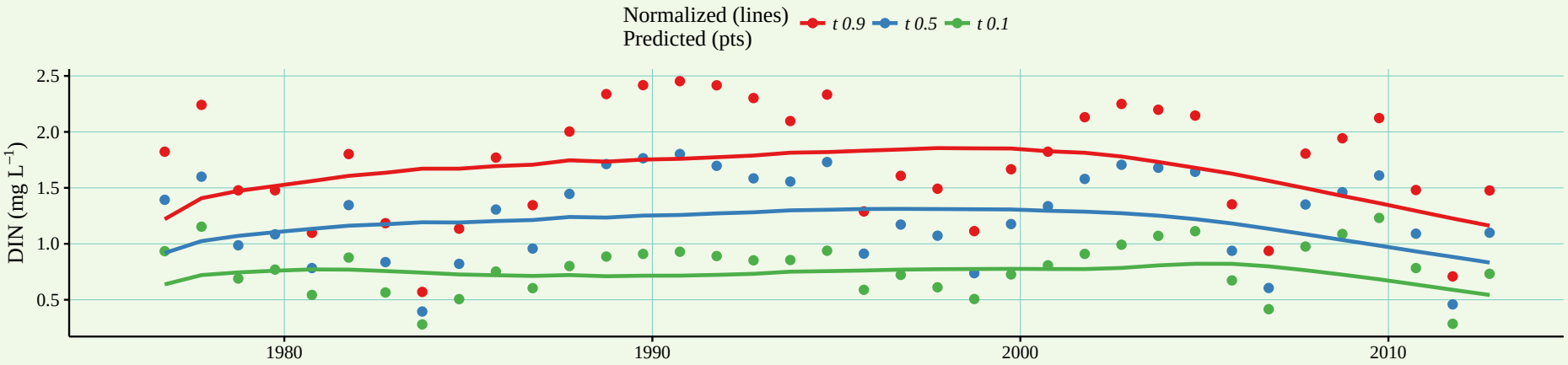


Figure : Annual trends by quantiles. Predicted and flow-normalized results are shown as points and lines.

Selected case studies

DIN trends at C10

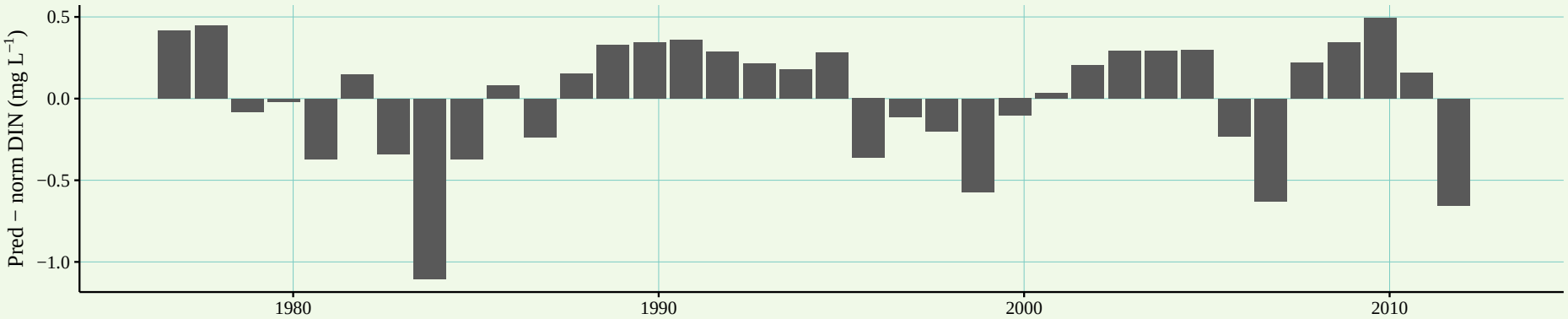
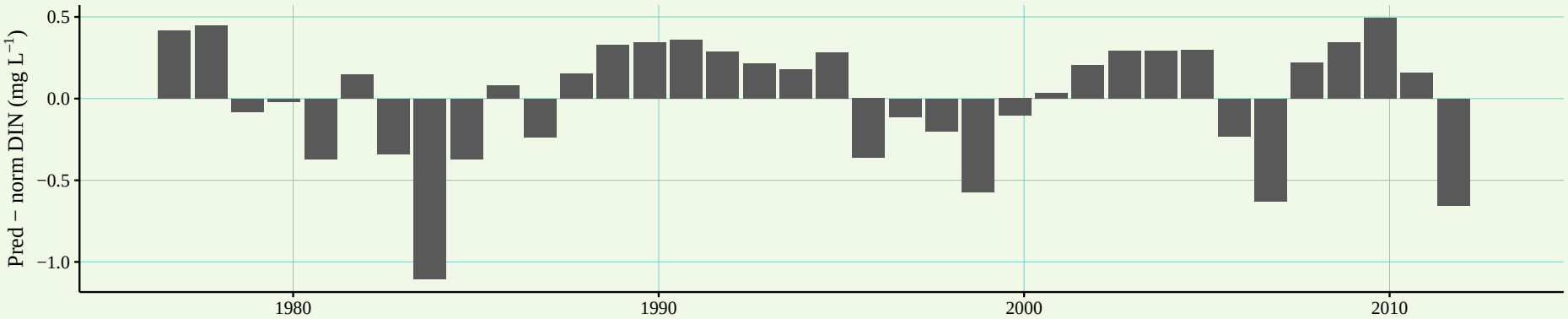


Figure : Difference between annual predicted and flow-normalized DIN, 50th percentile.

Selected case studies

DIN trends at C10



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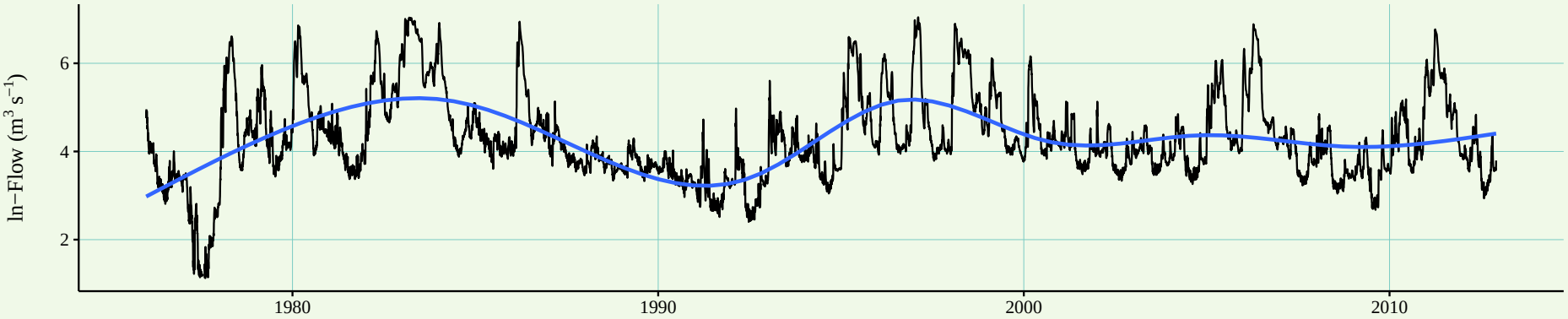


Figure : Daily flow at San Joaquin with locally-estimated smooth.

Selected case studies

DIN trends at C10

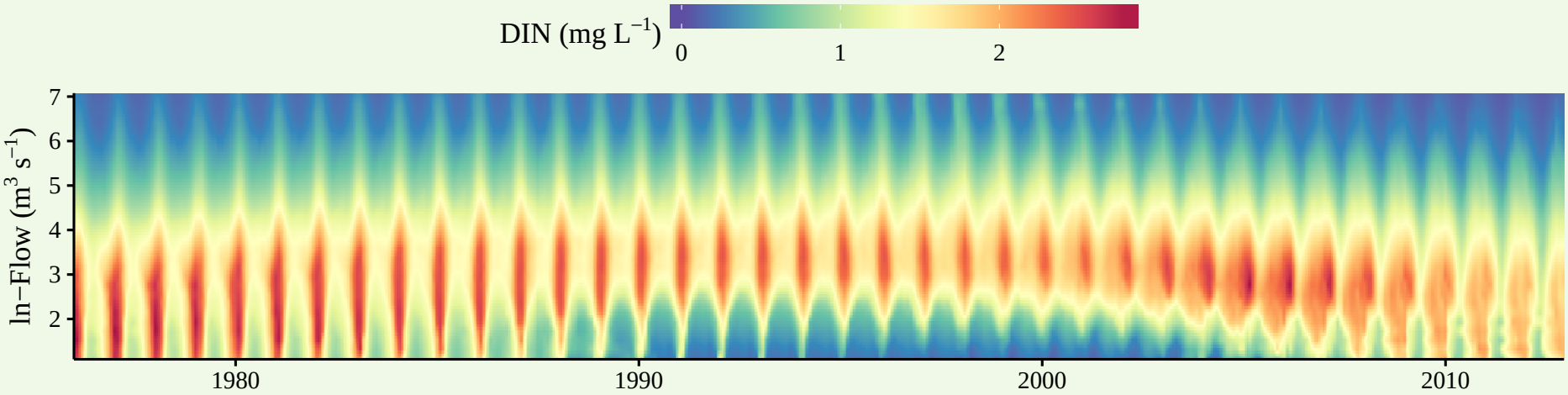
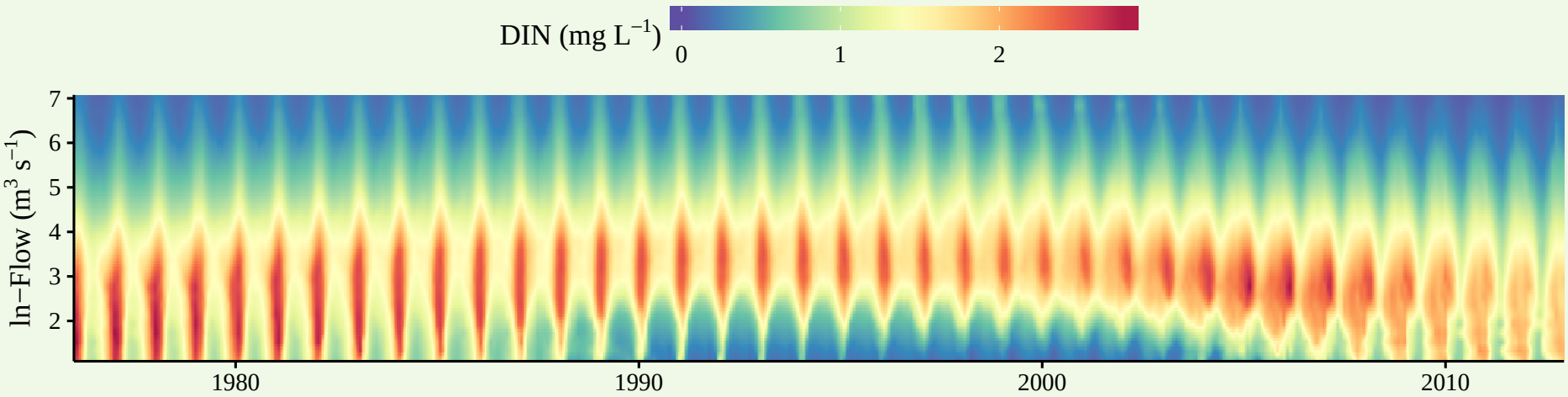


Figure : Modelled relationships between DIN, flow, and time.

Selected case studies

DIN trends at C10



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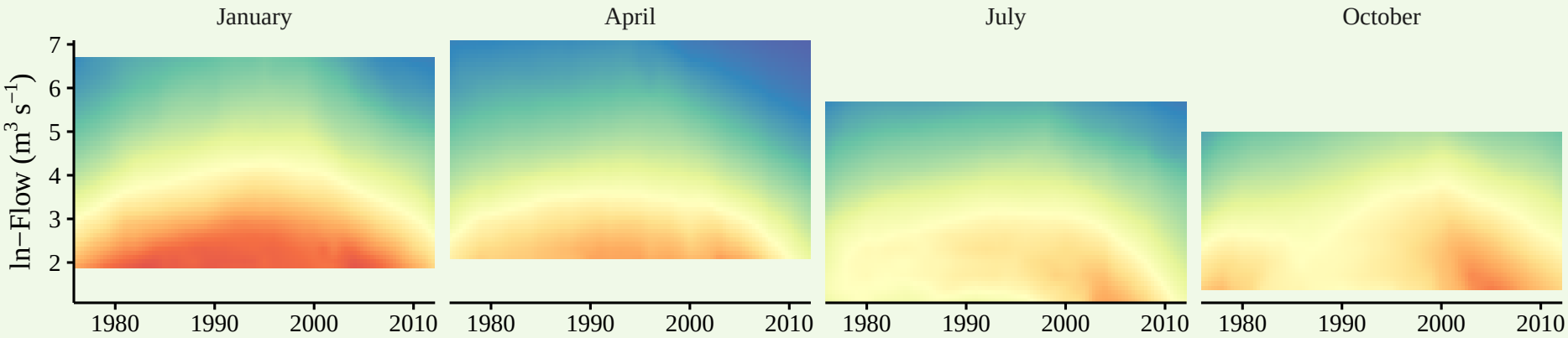


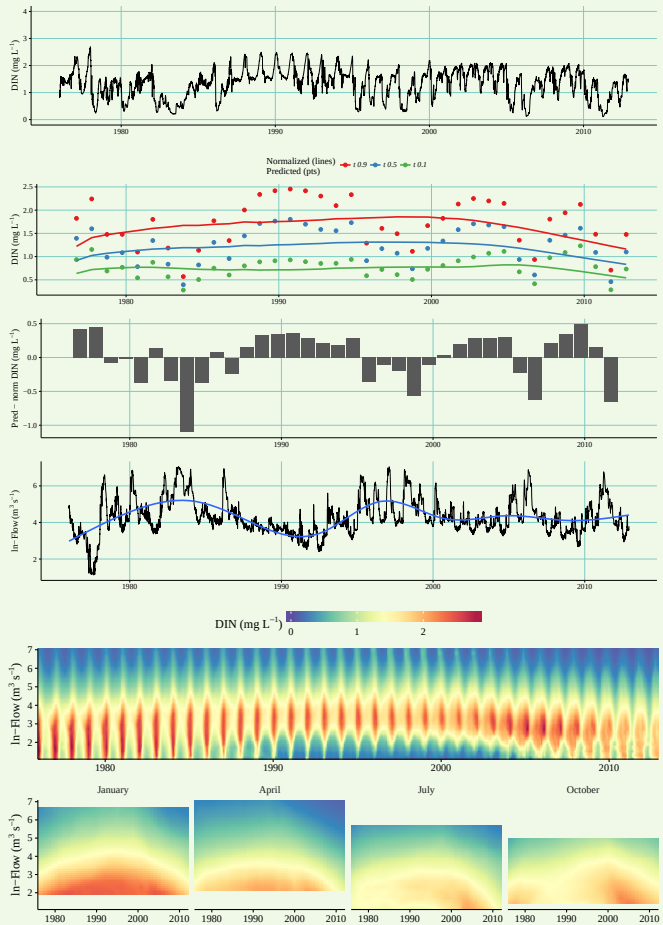
Figure : Annual variation of DIN for selected months.

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?

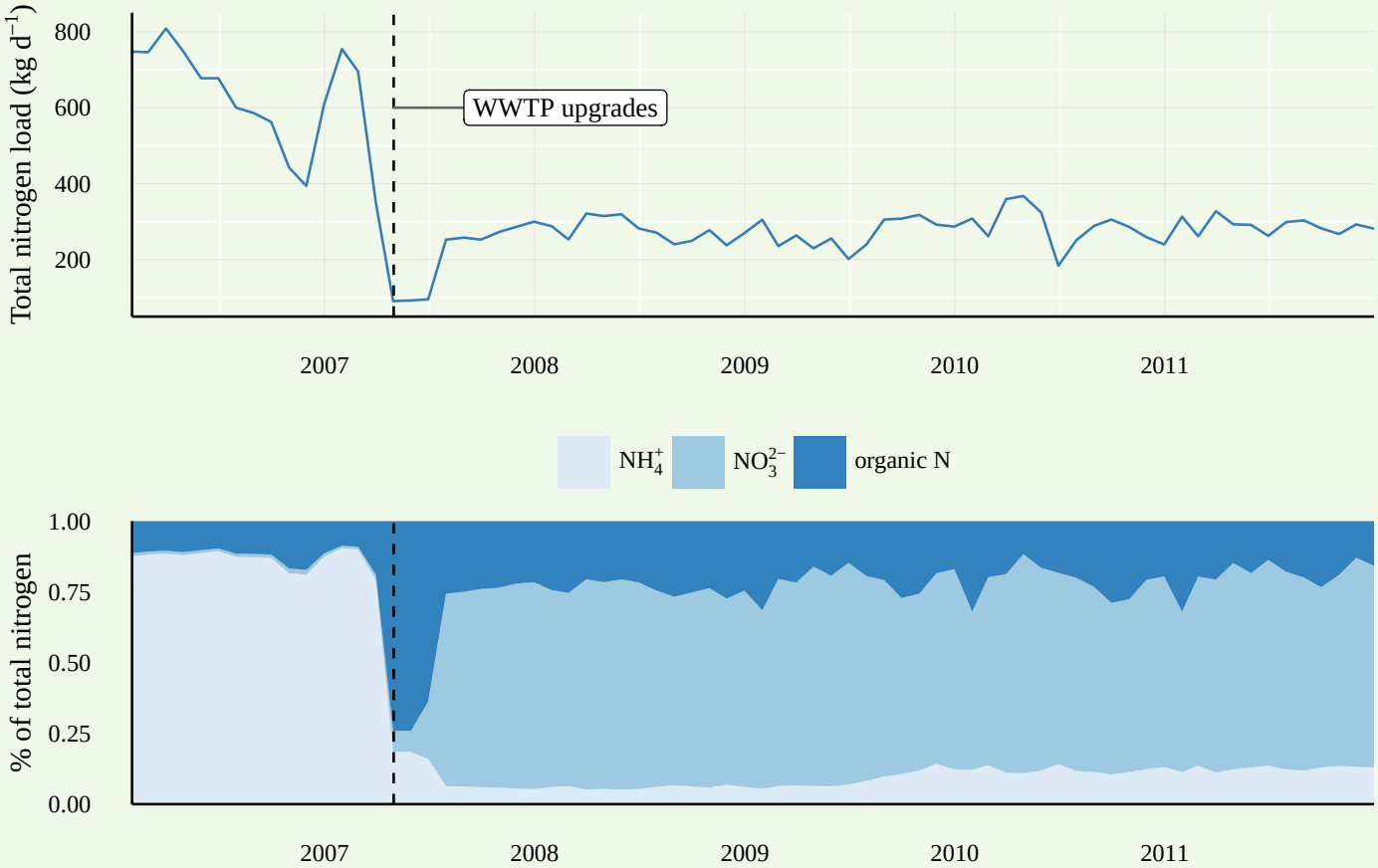


Figure : Nitrogen load measurements (kg d^{-1}) at the Tracy Wastewater Treatment Plant. Wastewater discharge requirements were implemented in May, 2007.

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

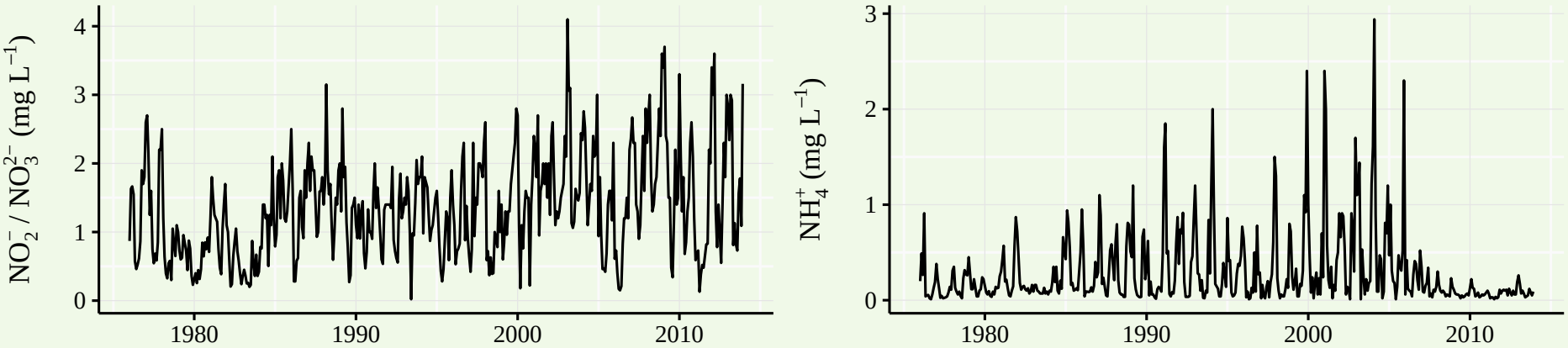
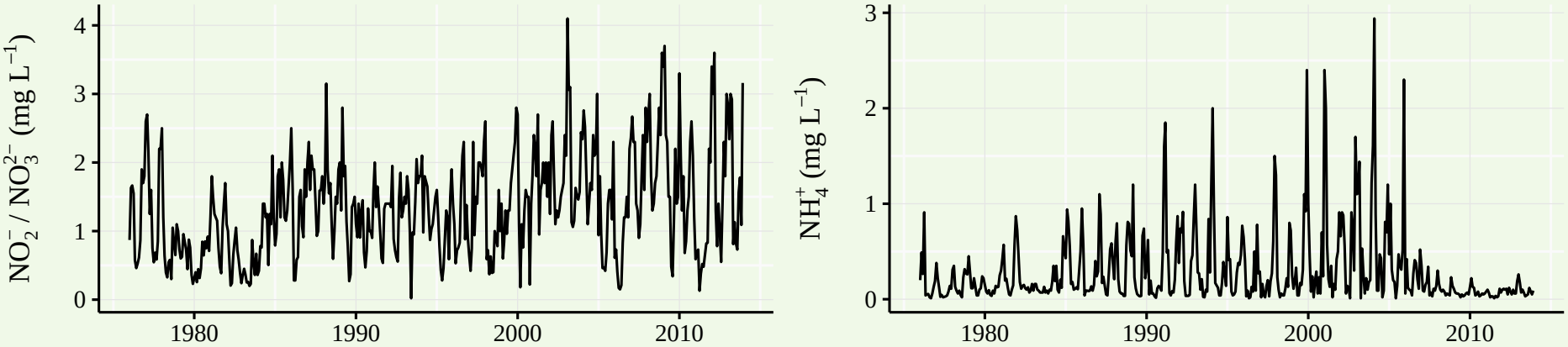


Figure : Observed nitrogen time series at P8

Selected case studies

Effects of wastewater treatment upgrades



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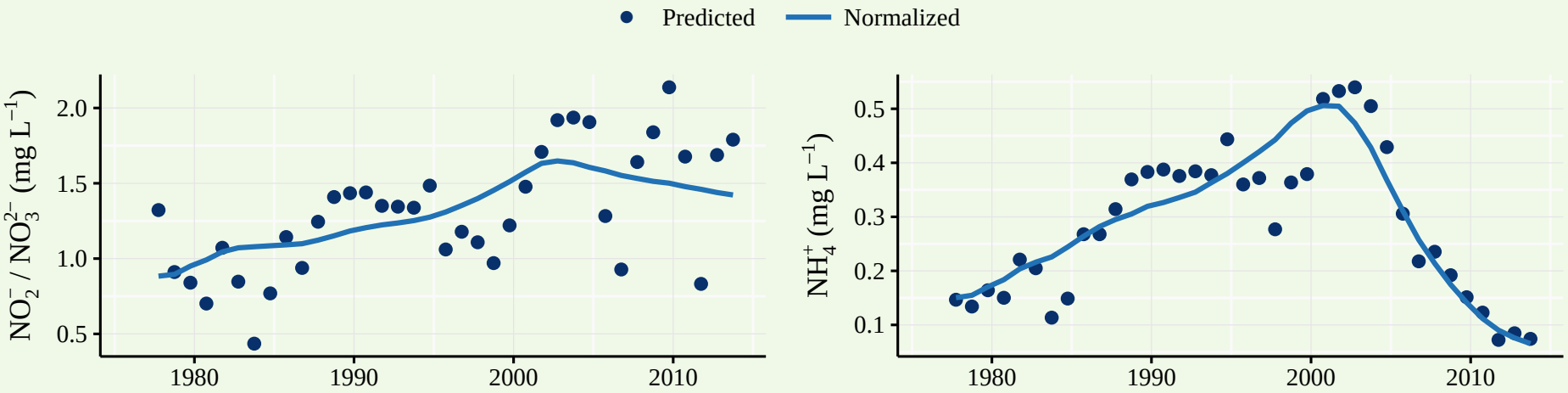


Figure : Annual predicted and flow-normalized nitrogen from WRTDS.

Selected case studies

Effects of wastewater treatment upgrades

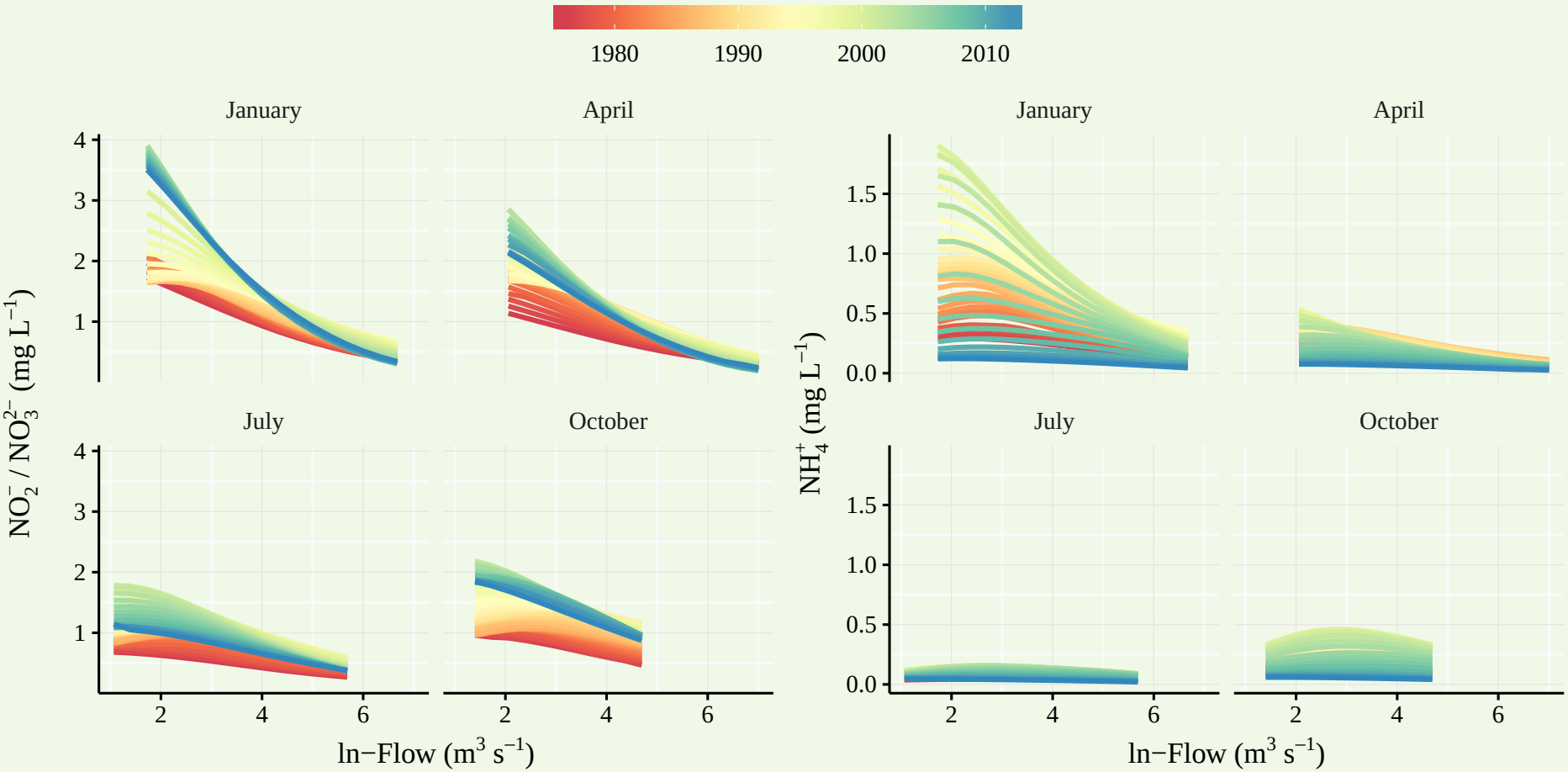


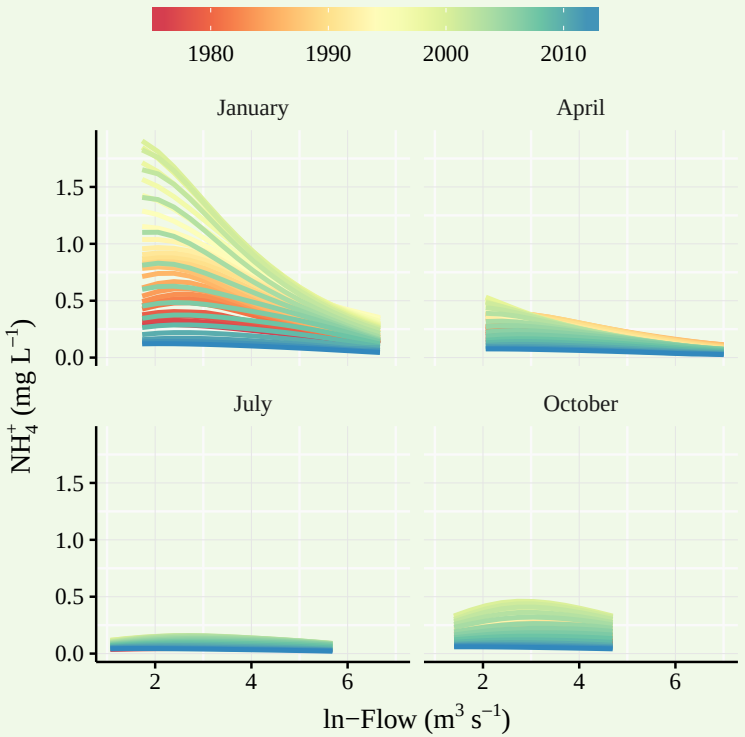
Figure : Nitrogen relationships with flow over time at P8.

Selected case studies

Effects of wastewater treatment upgrades

Results at P8 were linked to WWTP upgrades:

- Flow-normalized changes at P8, 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 phtyoplankton 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

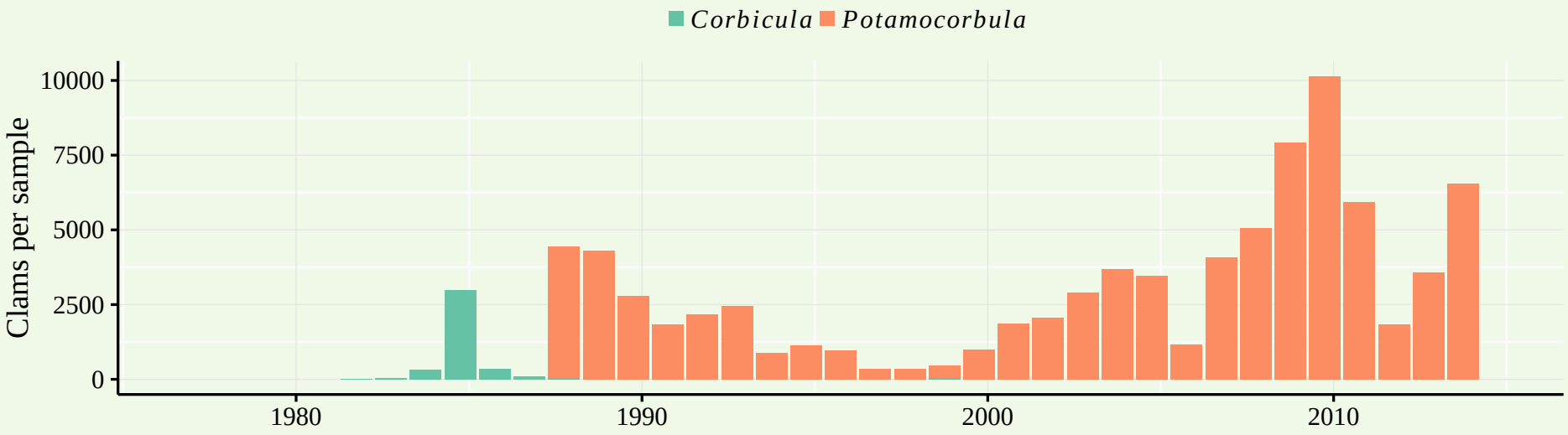
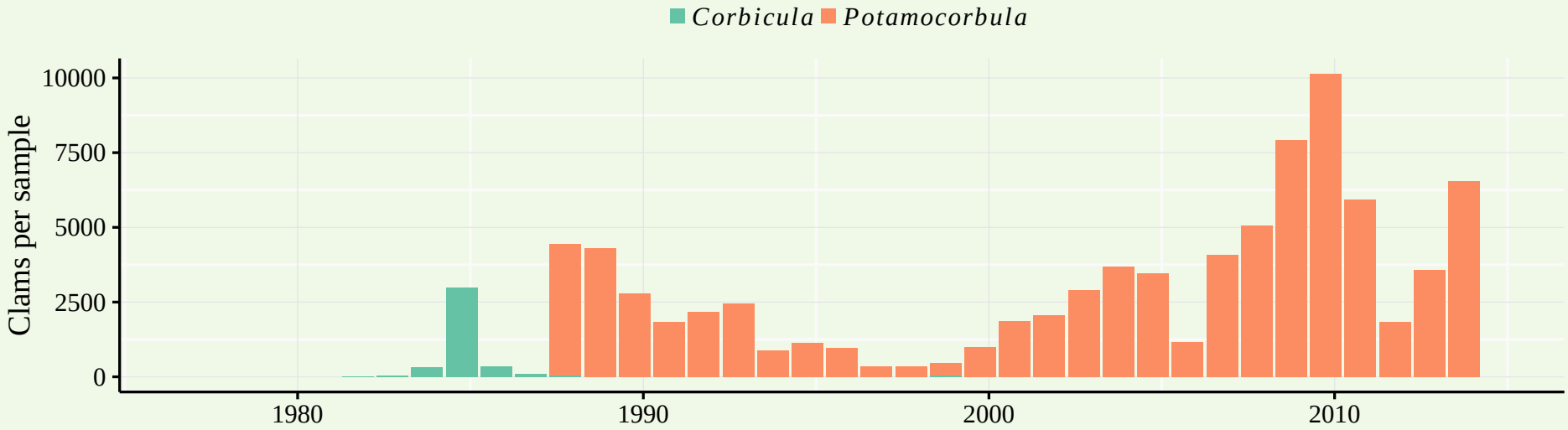


Figure : Clam density by year at D7, Suisun Bay.

Selected case studies

Effects of biological invasion in Suisun Bay



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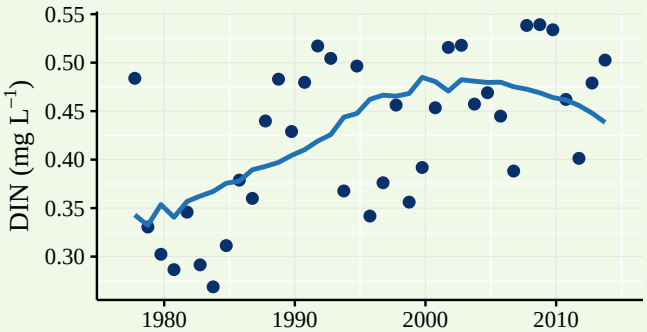

Figure : Annual predicted (points) and flow-normalized (lines) water quality data at D7.

Selected case studies

Effects of biological invasion in Suisun Bay

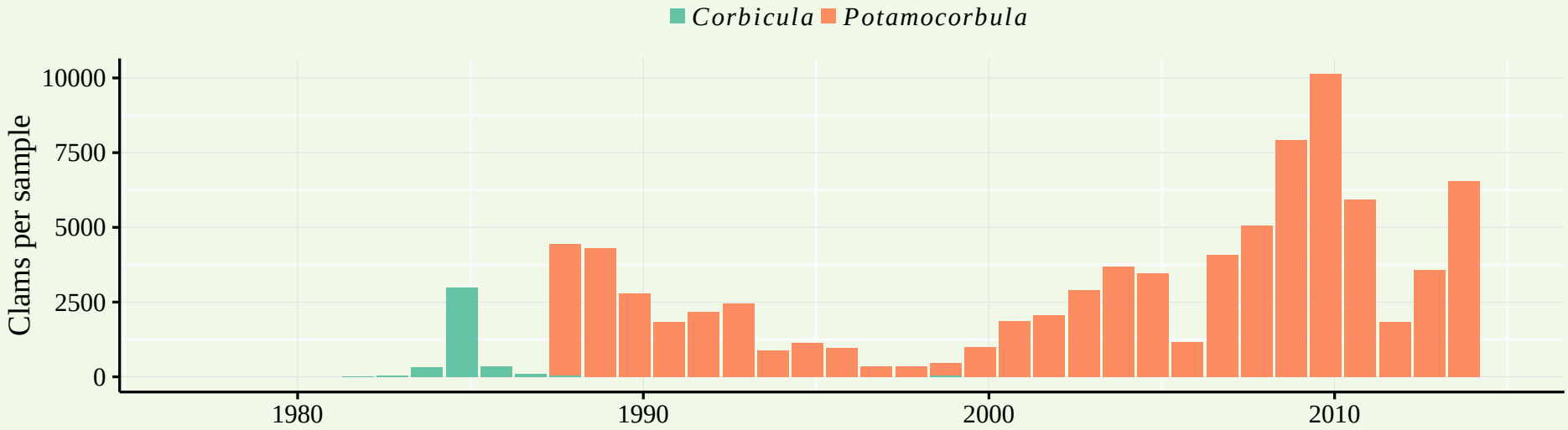

Figure : Clam density by year at D7, Suisun Bay.

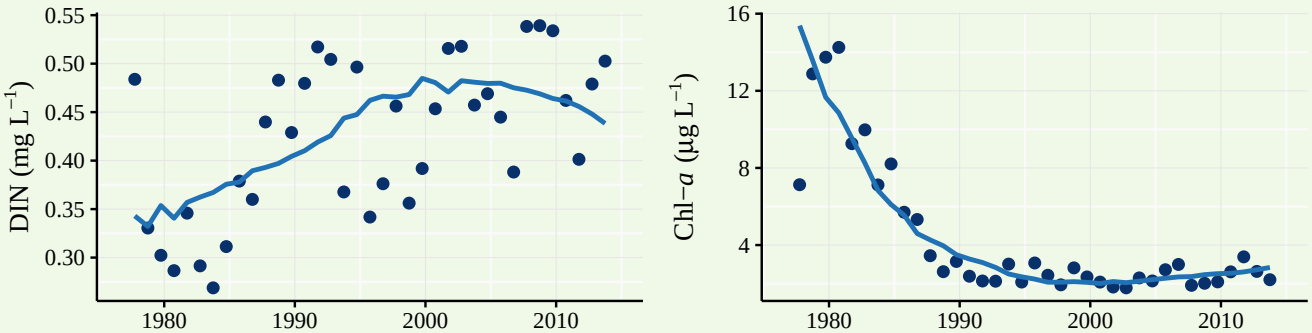

Figure : Annual predicted (points) and flow-normalized (lines) water quality data at D7.

Selected case studies

Effects of biological invasion in Suisun Bay

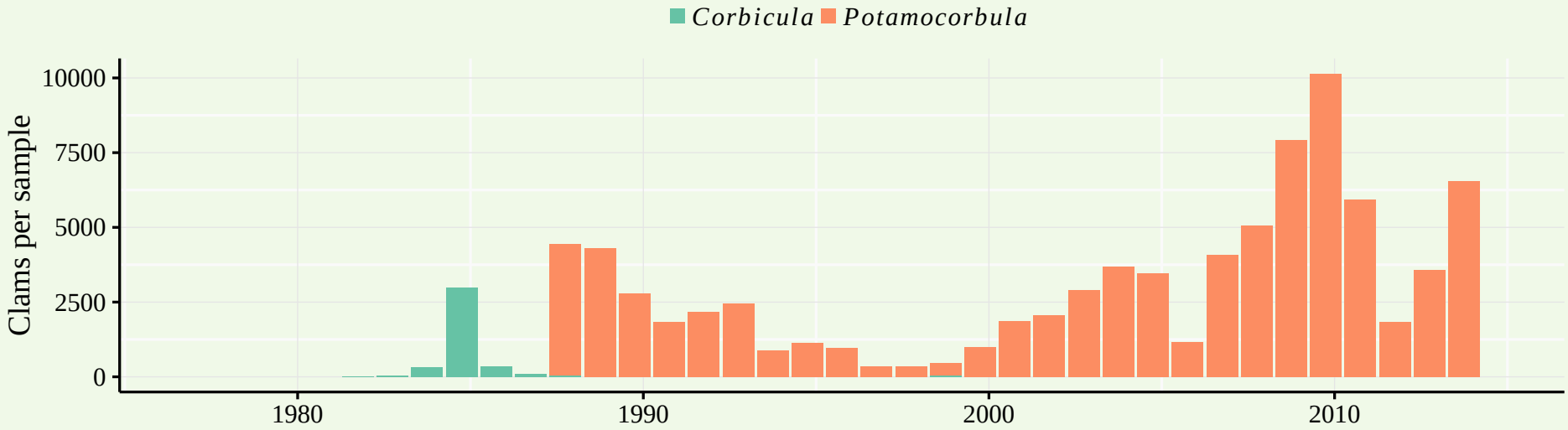

Figure : Clam density by year at D7, Suisun Bay.

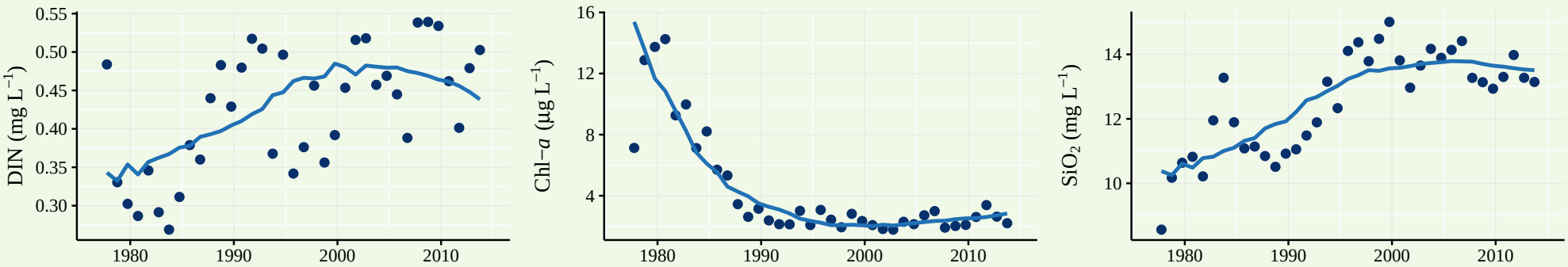

Figure : Annual predicted (points) and flow-normalized (lines) water quality data at D7.

Conclusions

Model predictions are not inherently interesting But predictions based on time-varying parameters A means to an end

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