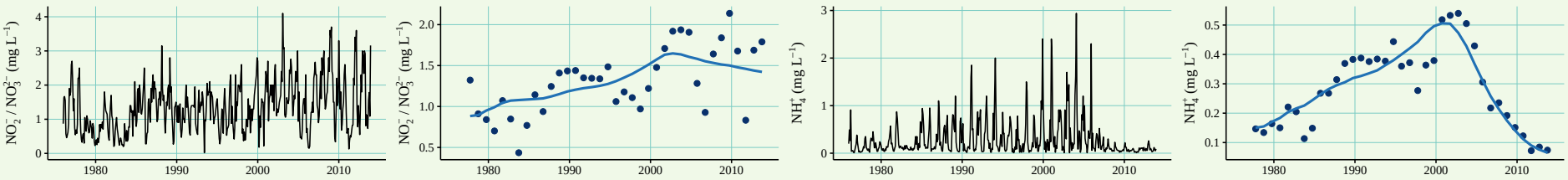
Quantitative approaches to understanding nitrogen pollution: Examples from the upper San Francisco Estuary

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?

How can we leverage monitoring data to develop our conceptual model of eutrophication?

> *Eutrophication (noun) - an* ***increase*** *in the rate of supply of* ***organic matter*** *to an ecosystem*
>
> *– [Nixon, 1995]*

Adapted from [Cloern, 2001]

Evaluating estuarine condition

How do we collect and use data?

How can we leverage monitoring data to develop our conceptual model of eutrophication?

> *Eutrophication (noun) - an* ***increase*** *in the rate of supply of* ***organic matter*** *to an ecosystem*
>
> *– [Nixon, 1995]*

Nutrient Loading

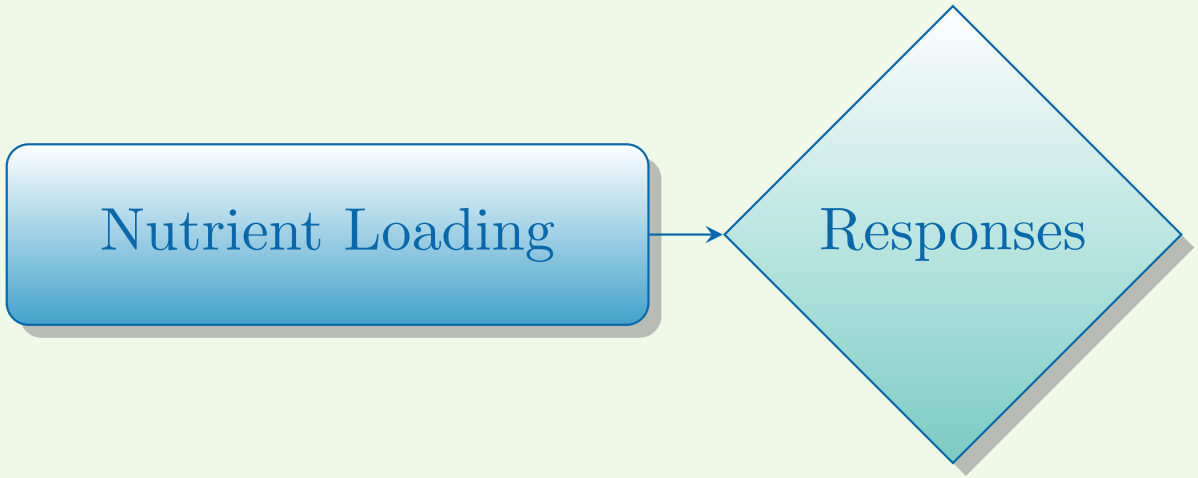
Adapted from [Cloern, 2001]

Evaluating estuarine condition

How do we collect and use data?

How can we leverage monitoring data to develop our conceptual model of eutrophication?

> *Eutrophication (noun) - an* ***increase*** *in the rate of supply of* ***organic matter*** *to an ecosystem*
>
> *– [Nixon, 1995]*



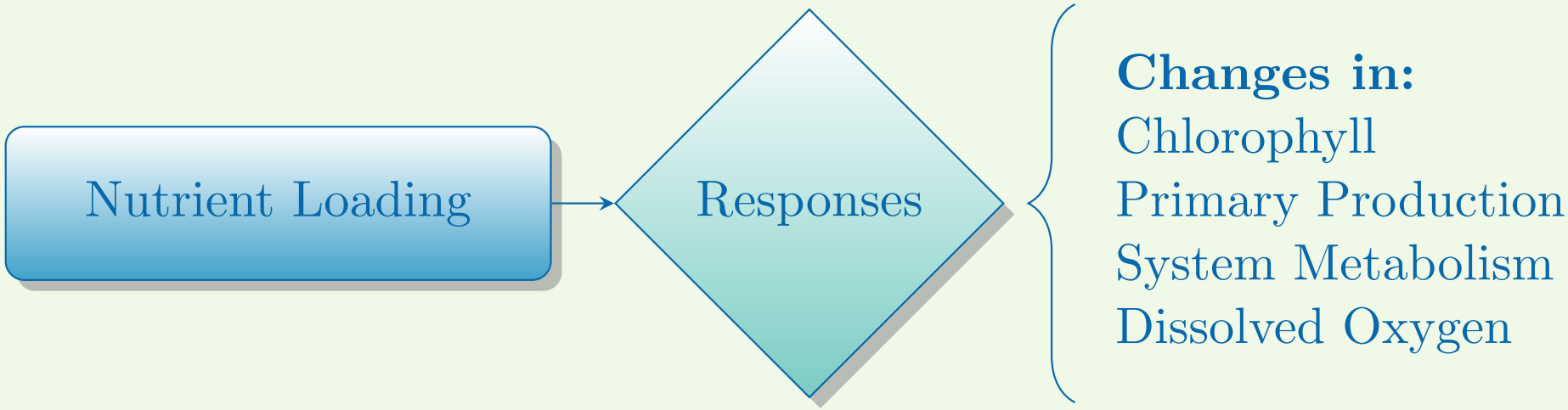
Adapted from [Cloern, 2001]

Evaluating estuarine condition

How do we collect and use data?

How can we leverage monitoring data to develop our conceptual model of eutrophication?

> *Eutrophication (noun) - an* ***increase*** *in the rate of supply of* ***organic matter*** *to an ecosystem*
>
> *– [Nixon, 1995]*



Adapted from [Cloern, 2001]

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

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

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:

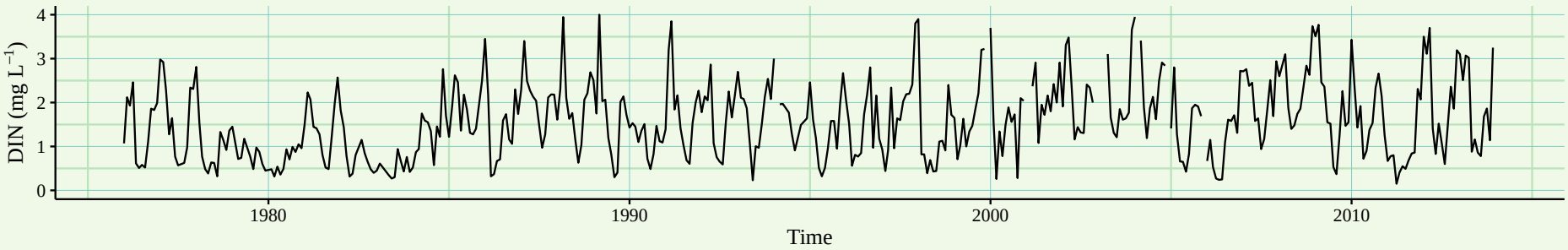
- ***Example 1***: Model theory and application
- ***Example 2***: Trends over time
- ***Example 3***: Selected case studies

Can we ***develop*** and ***apply*** methods that ***link trends*** with ***causal events***?

Model theory and background

WRTDS adaptation for tidal waters

Observed data represents effects of many processes

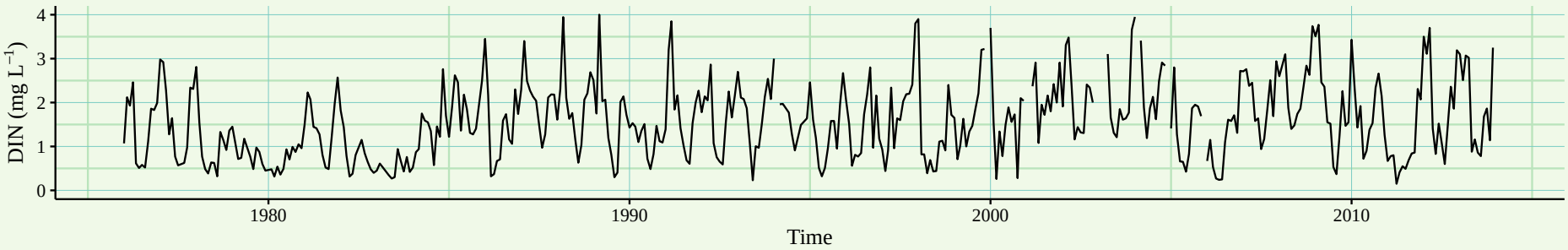


Climate	***Local***	***Regional/historical***
precipitation	light/turbidity	watershed inputs
temperature	residence time	point sources
wind events	invasive species	management actions
ENSO effects	trophic effects	flow changes

Model theory and background

WRTDS adaptation for tidal waters

Observed data represents effects of many processes

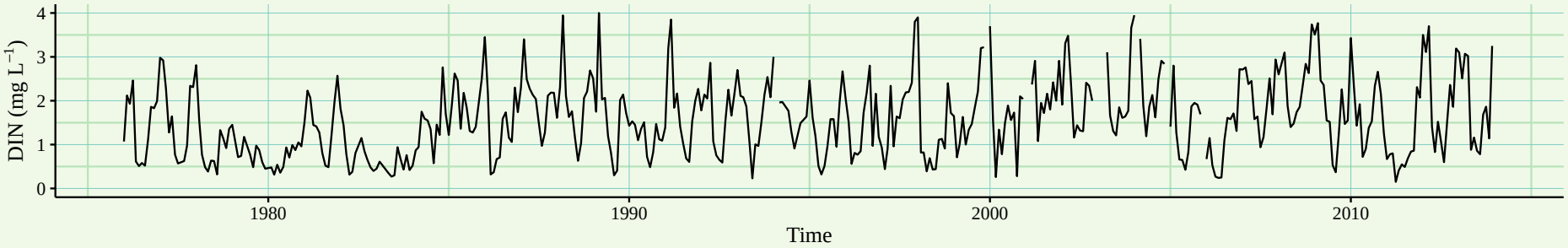


Models should describe components to evaluate effects

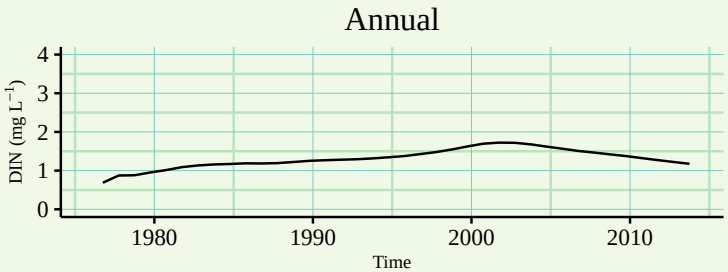
Model theory and background

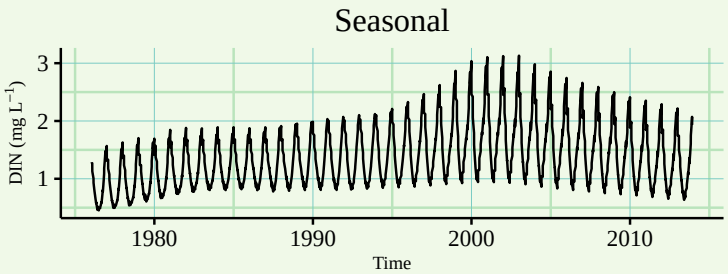
WRTDS adaptation for tidal waters

Observed data represents effects of many processes



Models should describe components to evaluate effects

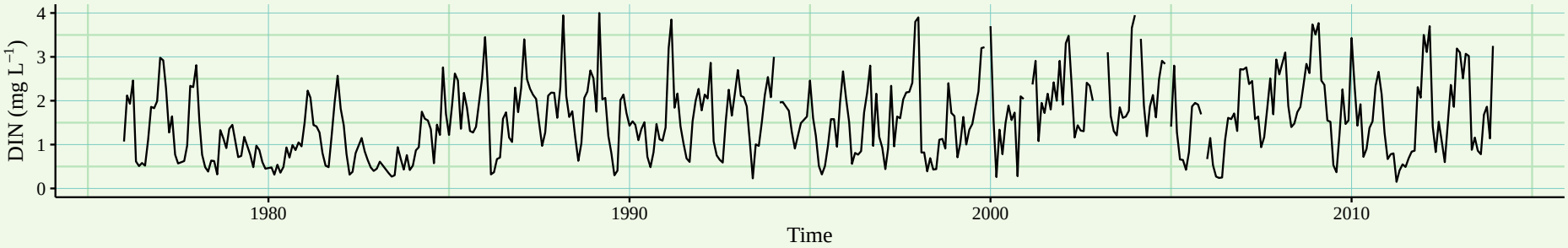




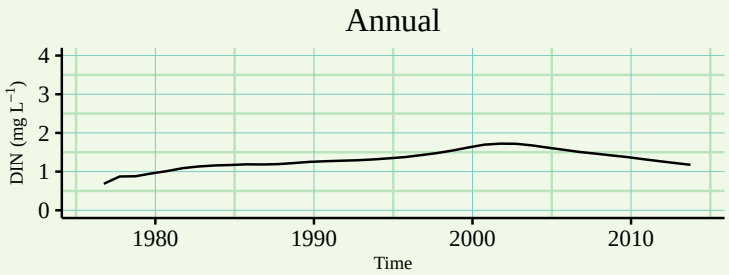
Model theory and background

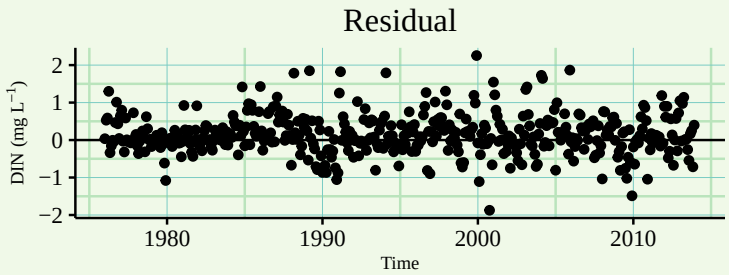
WRTDS adaptation for tidal waters

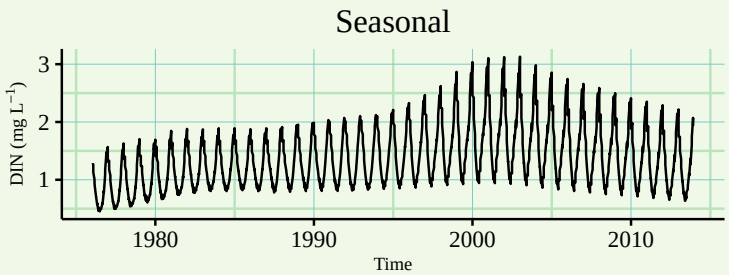
Observed data represents effects of many processes

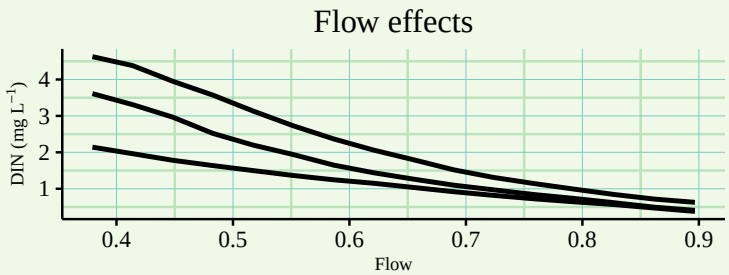


Models should describe components to evaluate effects









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

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)*** approach models pollutants in rivers as a function of ***time***, ***discharge***, and ***season***
[Hirsch et al., 2010]

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

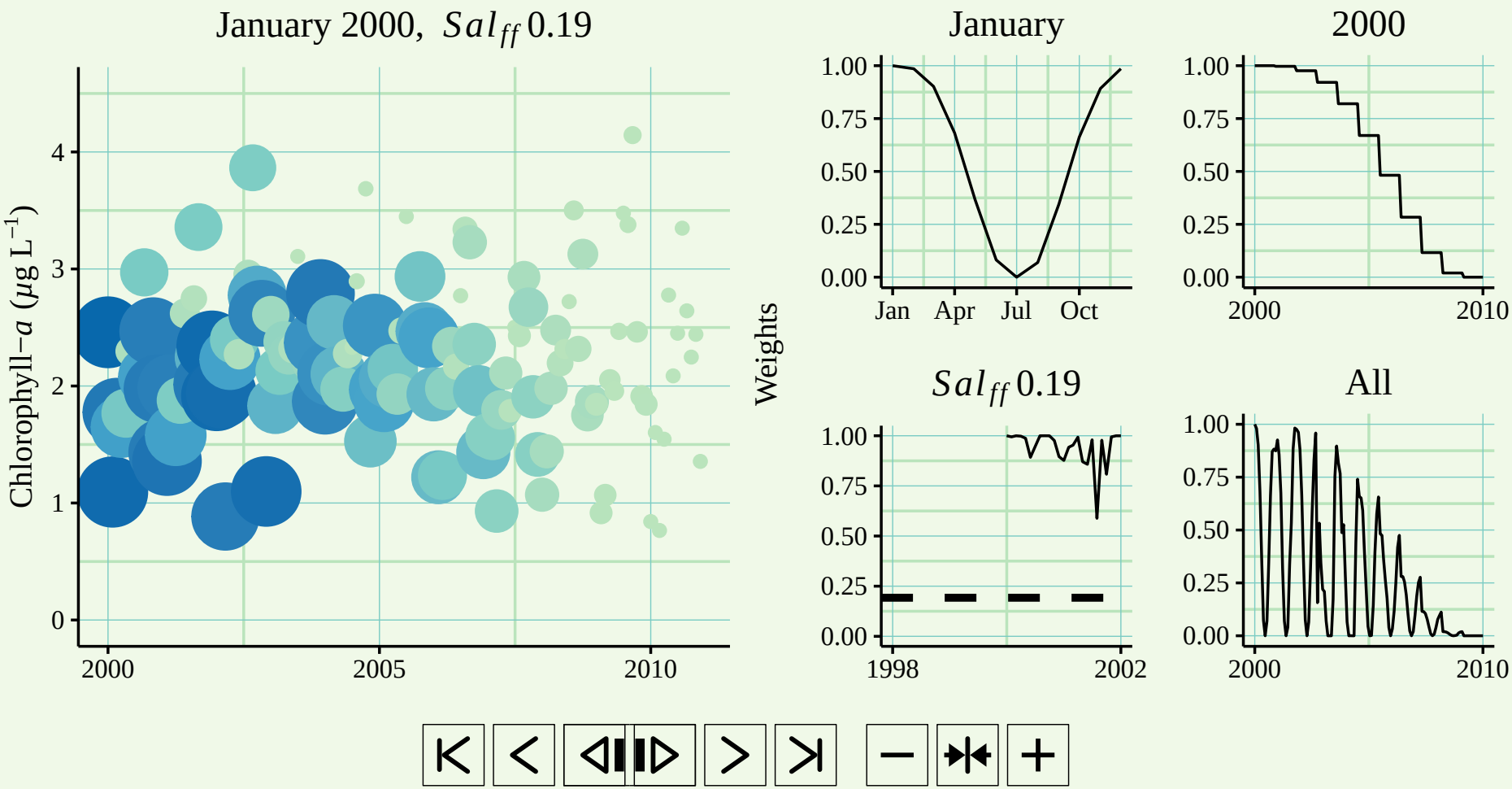
The ***weighted regression (WRTDS)*** approach models pollutants in rivers as a function of ***time***, ***discharge***, and ***season***
[Hirsch et al., 2010]

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

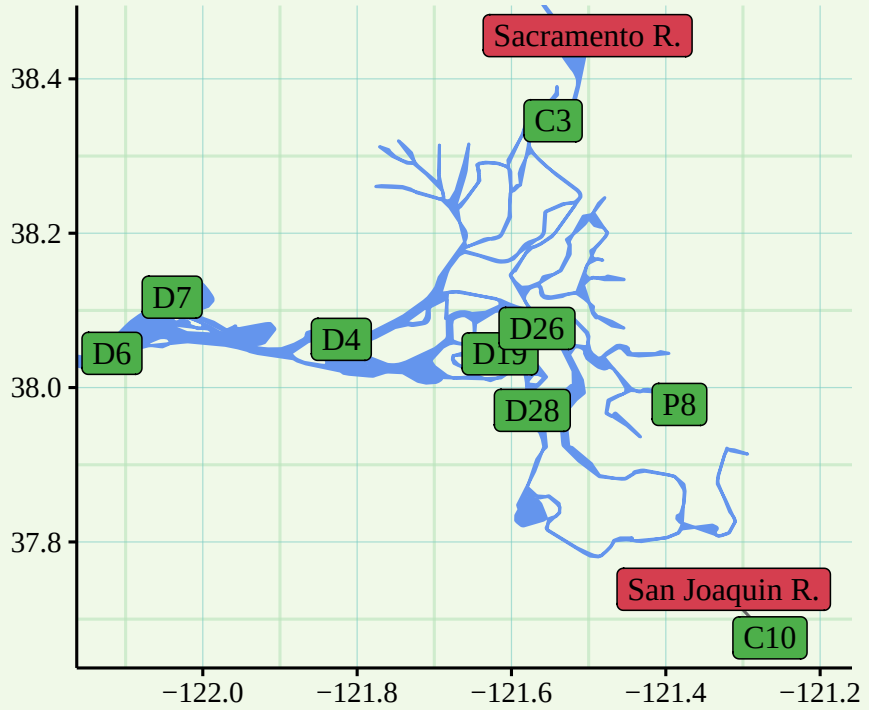
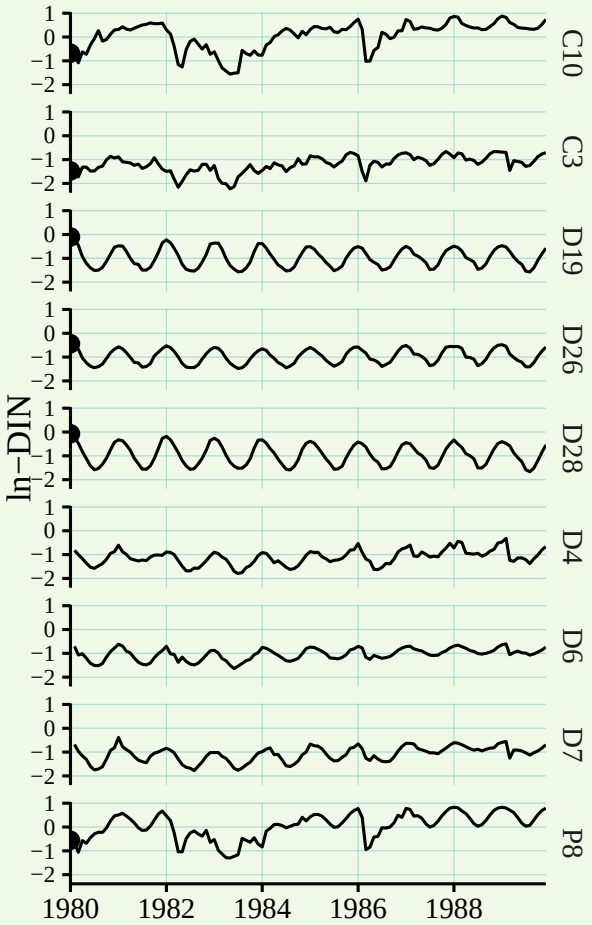


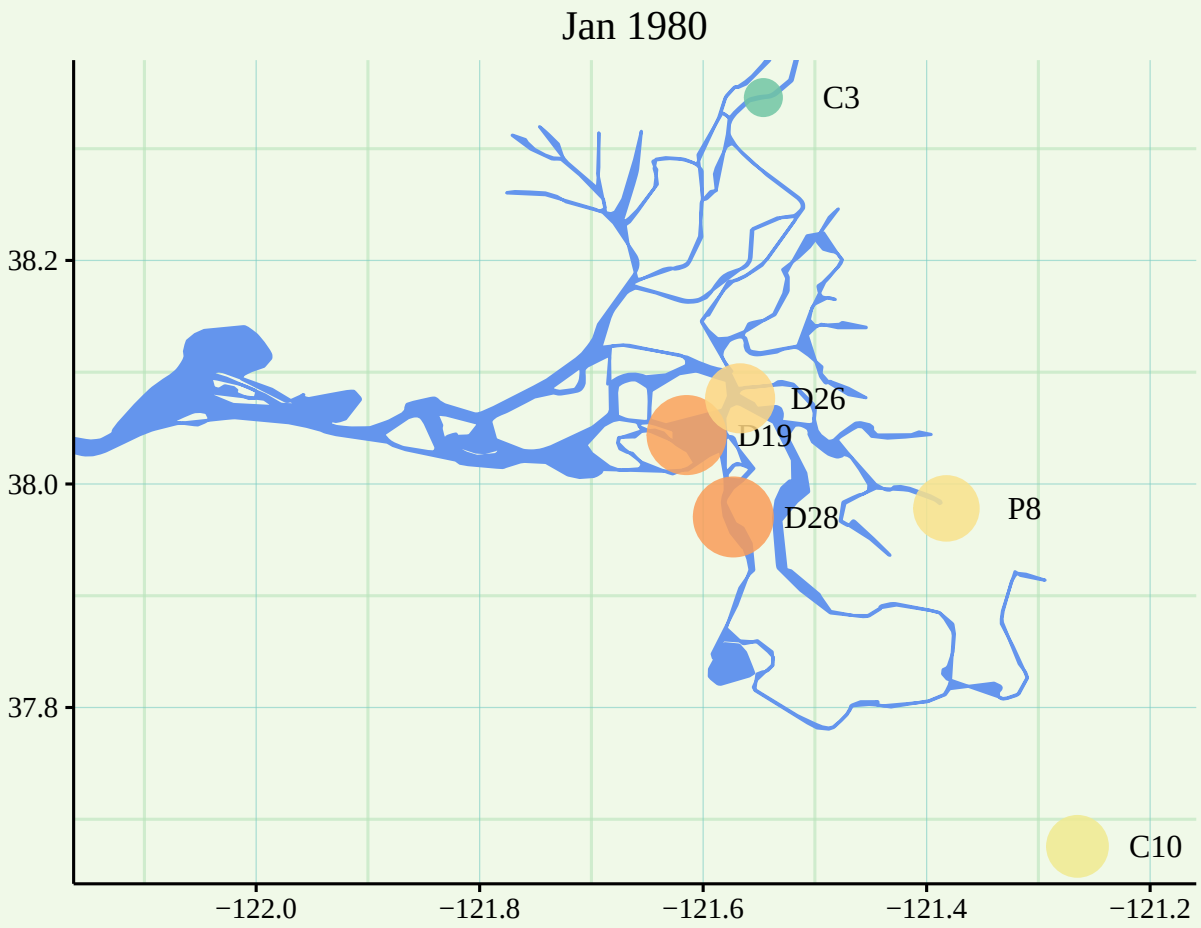
Figure: Stations (green) and flow estimates (red) modelled with WRTDS

Trends over time

Nitrogen dynamics in the Delta

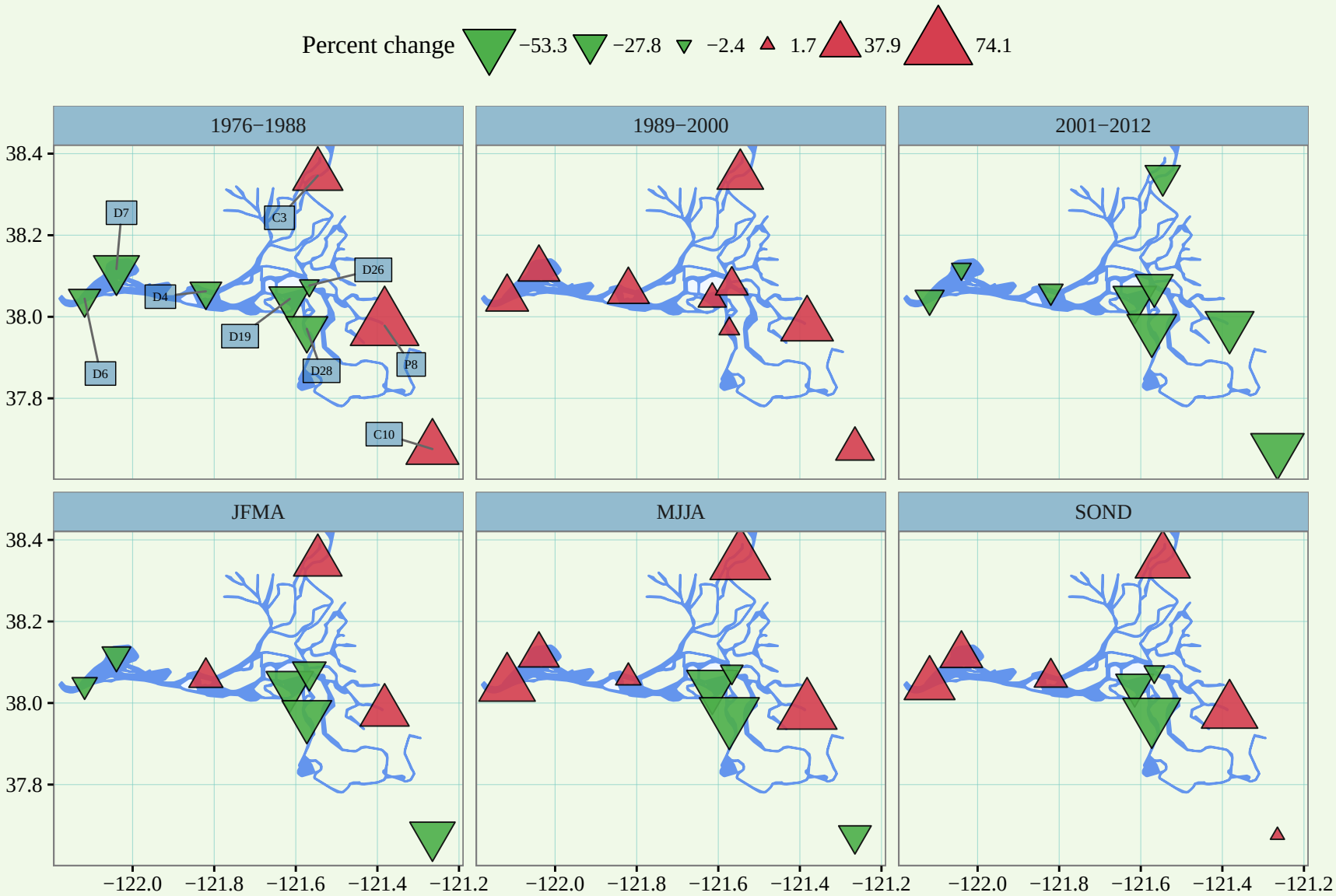
Predicted DIN trends, 1980-1990





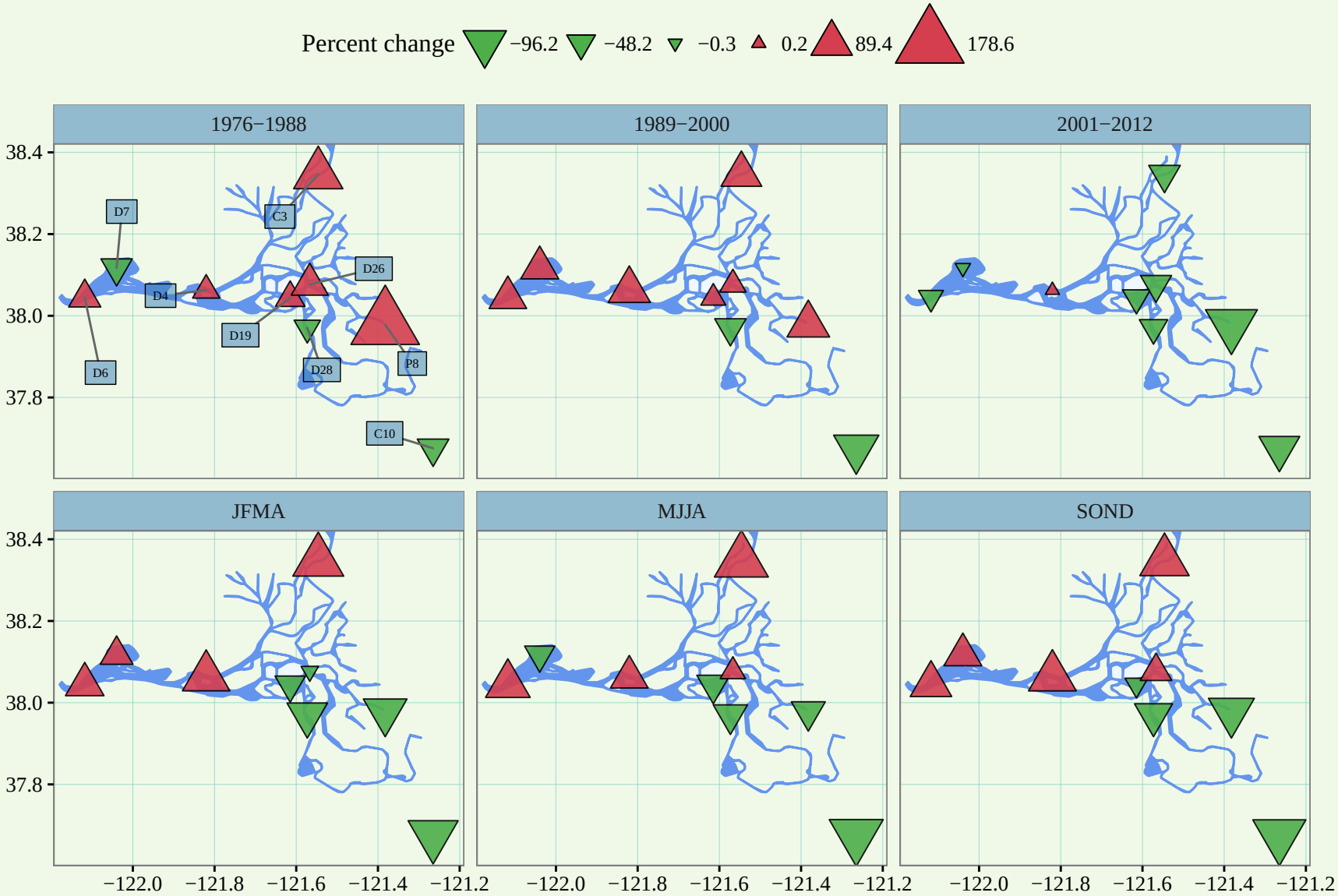
Trends over time

Nitrogen dynamics in the Delta - DIN



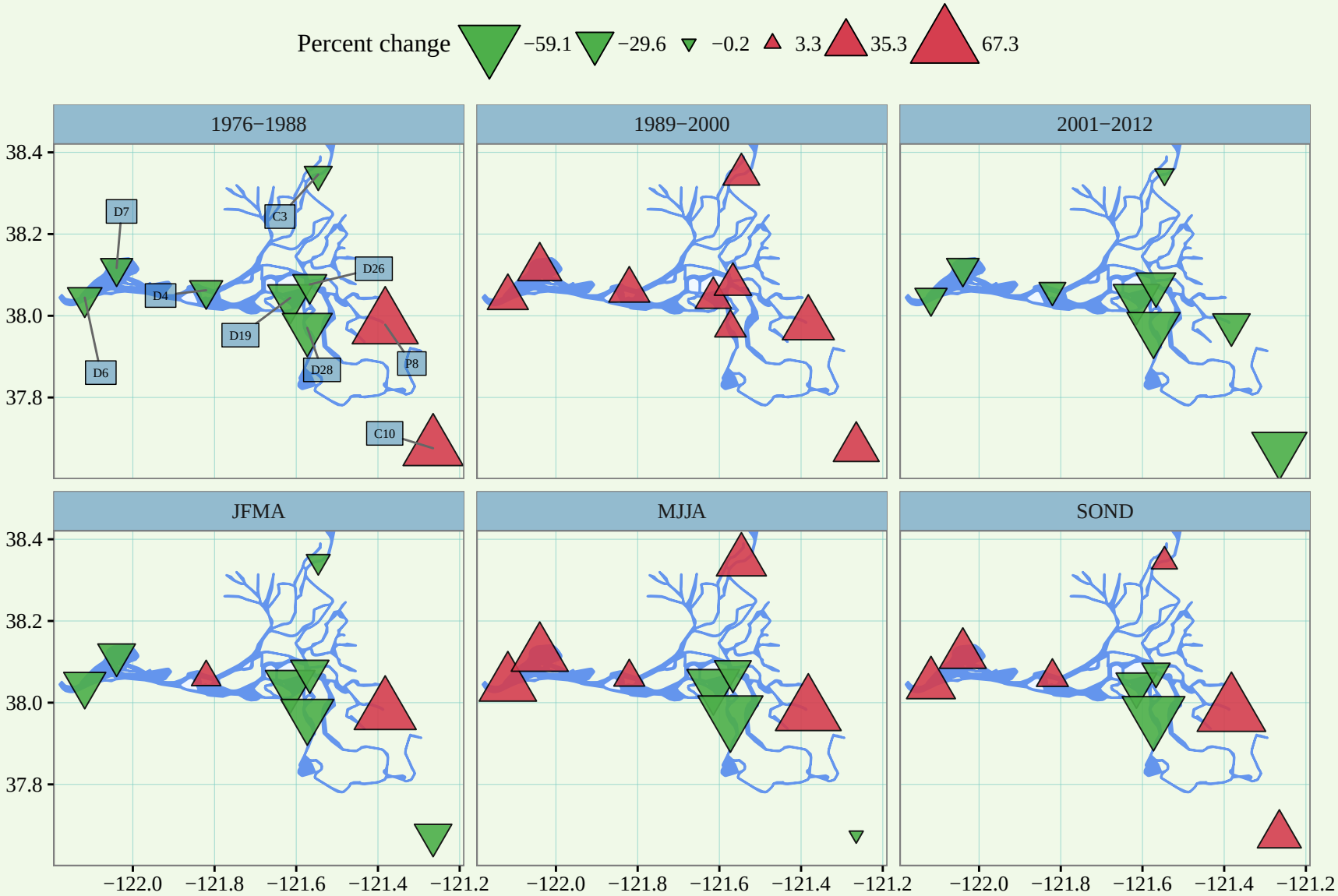
Trends over time

Nitrogen dynamics in the Delta - ammonium



Trends over time

Nitrogen dynamics in the Delta - nitrite/nitate

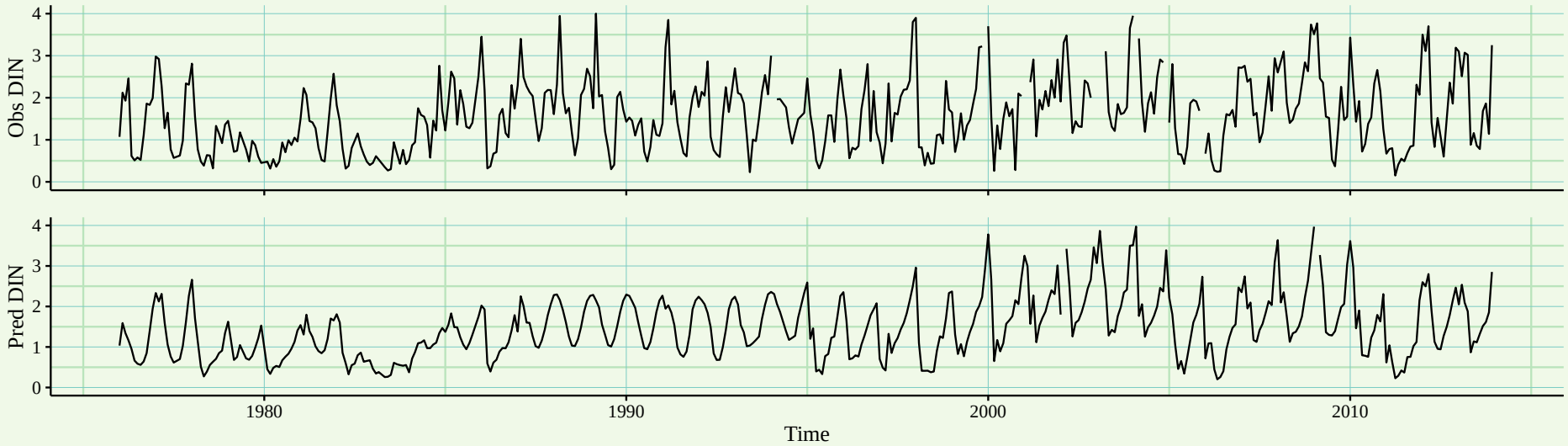


Trends over time

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

Two examples demonstrate the utility of WRTDS adaptation to tidal waters:

- Effects of wastewater treatment at P8
- Effects of biological invasion in Suisun Bay

Selected case studies

Two examples demonstrate the utility of WRTDS adaptation to tidal waters:

- Effects of wastewater treatment at P8
- Effects of biological invasion in Suisun Bay

Each shows how ***model components*** describe ***processes***

Selected case studies

Effects of wastewater treatment upgrades

How can model information be linked to causation?

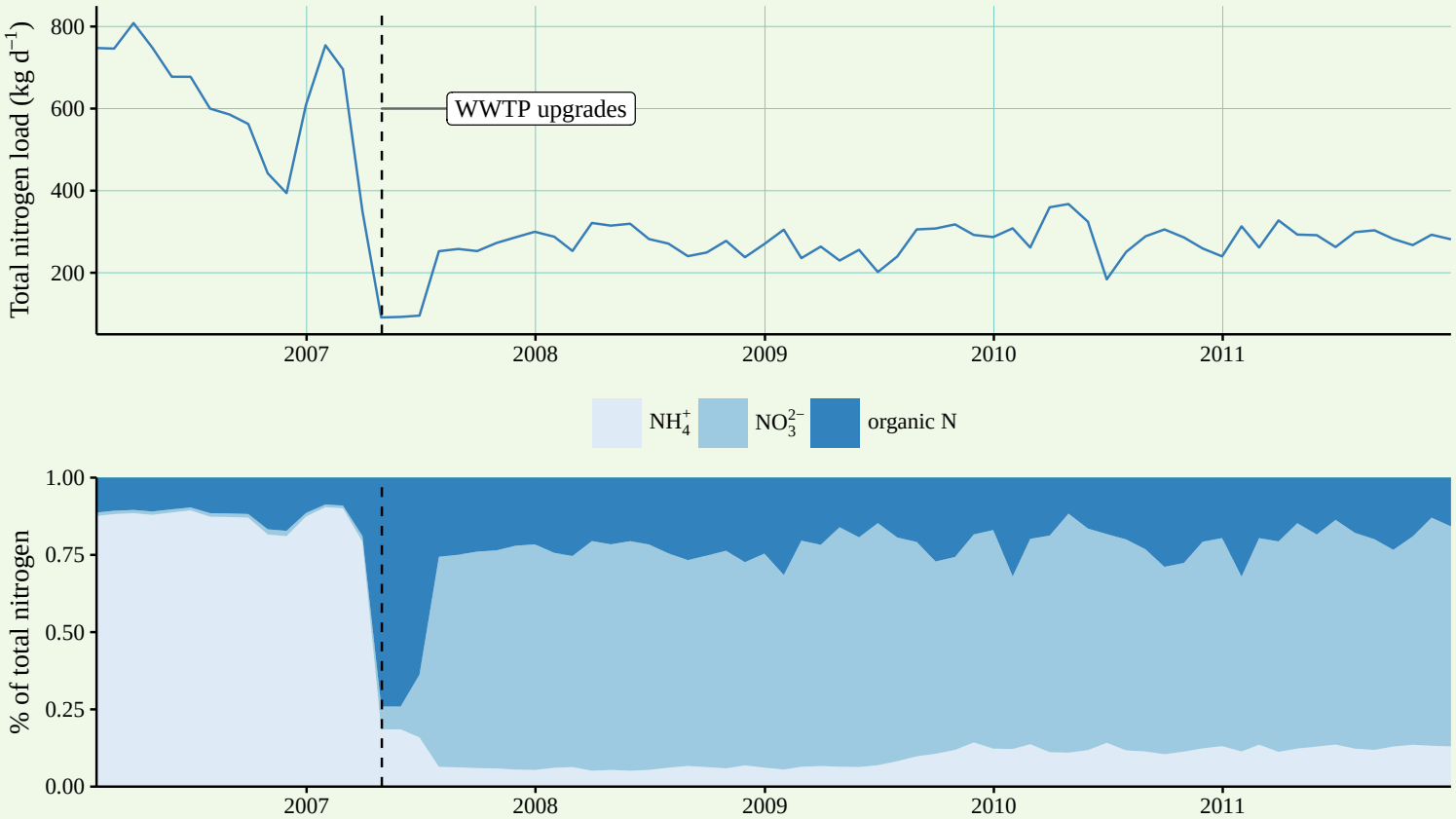


Figure: Nitrogen load measurements (kg d^{-1}) at the Tracy Wastewater Treatment Plant. Wastewater discharge requirements were implemented in May, 2007.

Selected case studies

Effects of wastewater treatment upgrades

Hypothesis: Response of nutrient concentrations at P8 is linked 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

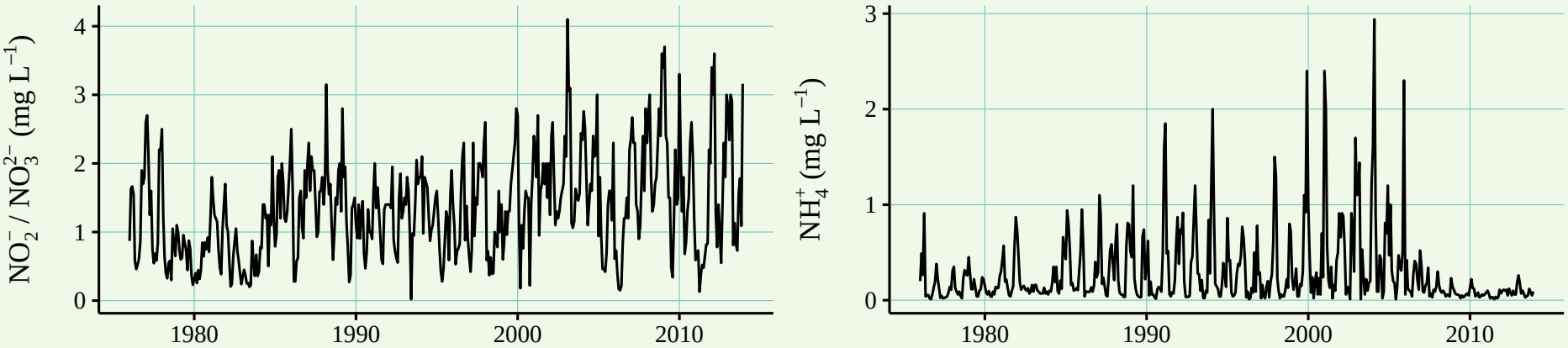


Figure: Observed nitrogen time series at P8

Selected case studies

Effects of wastewater treatment upgrades

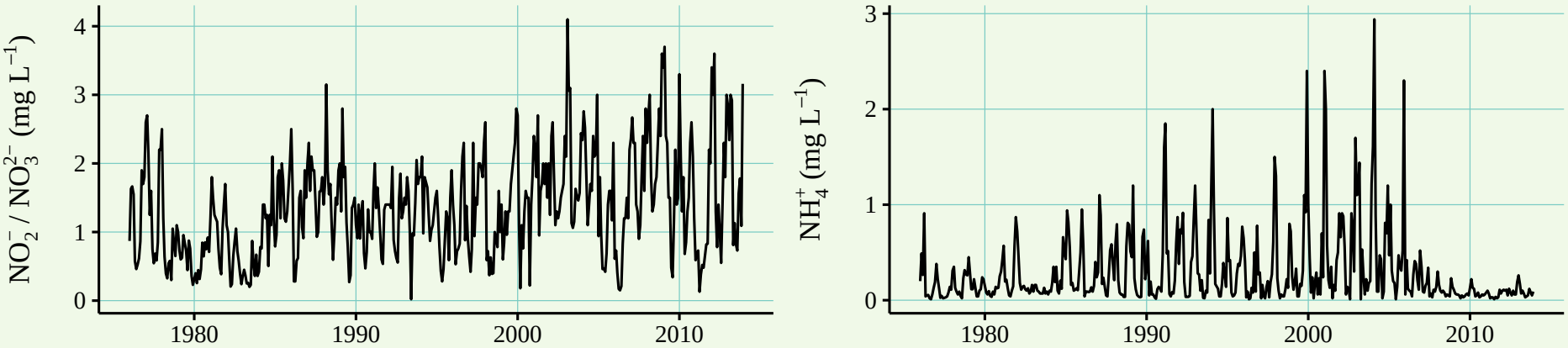


Figure: Observed nitrogen time series at P8

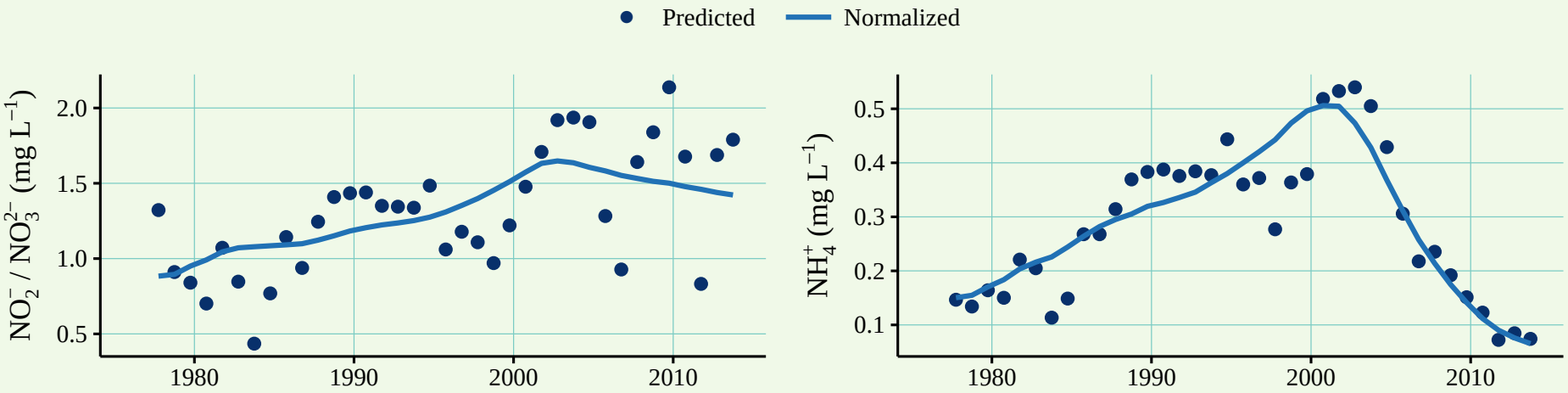


Figure: Annual predicted and flow-normalized nitrogen from WRTDS.

Selected case studies

Effects of wastewater treatment upgrades

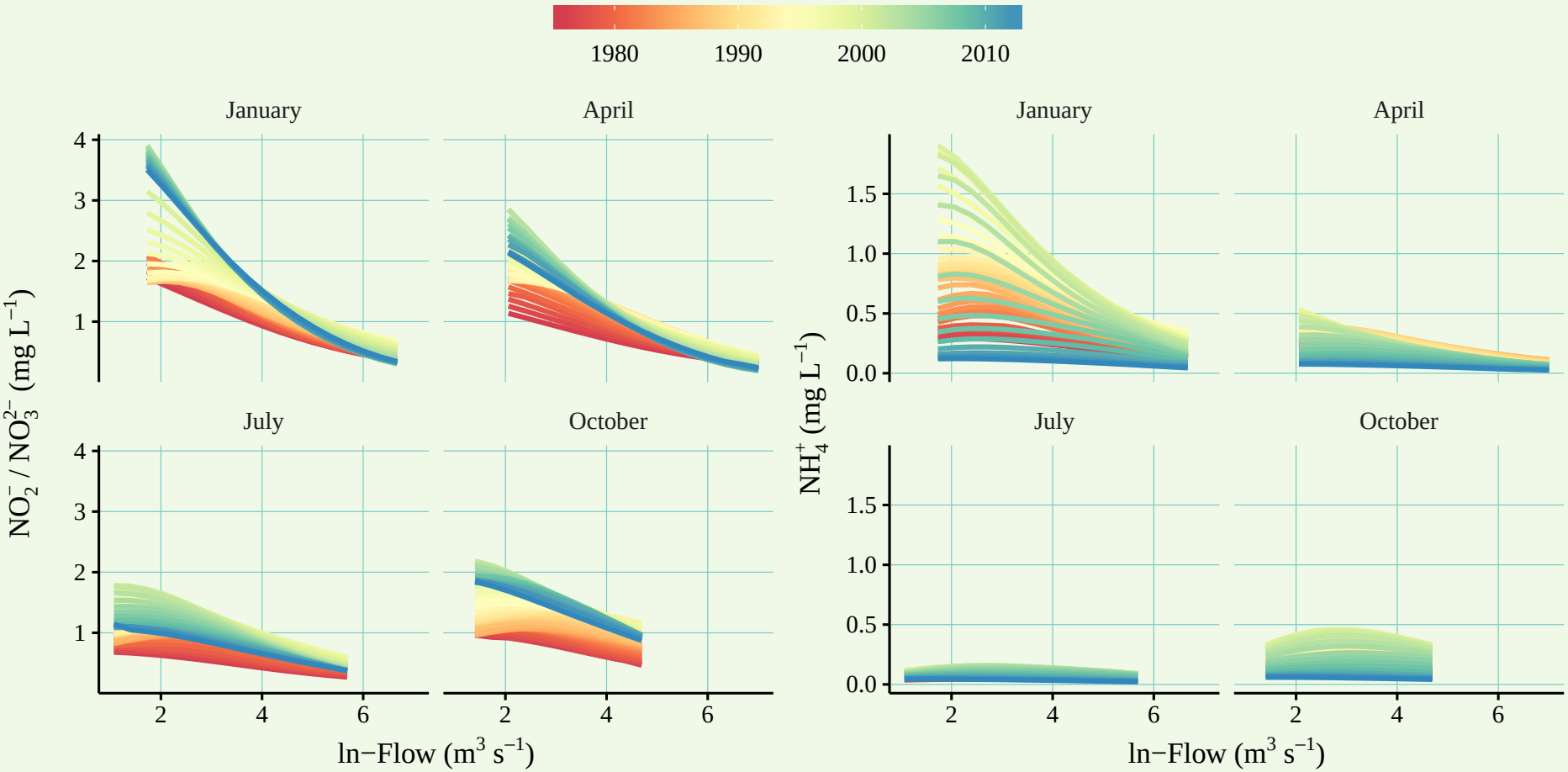


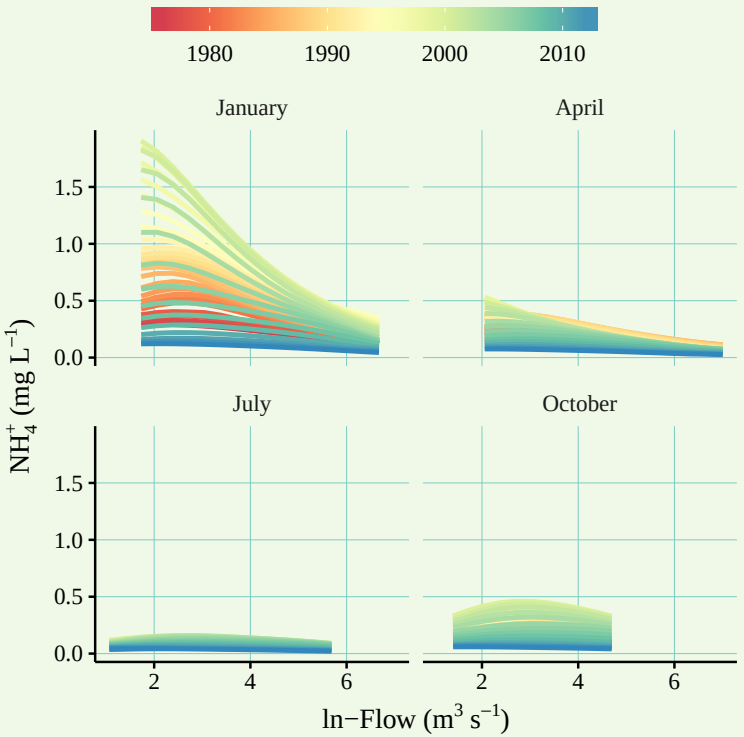
Figure: Nitrogen relationships with flow over time at P8.

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

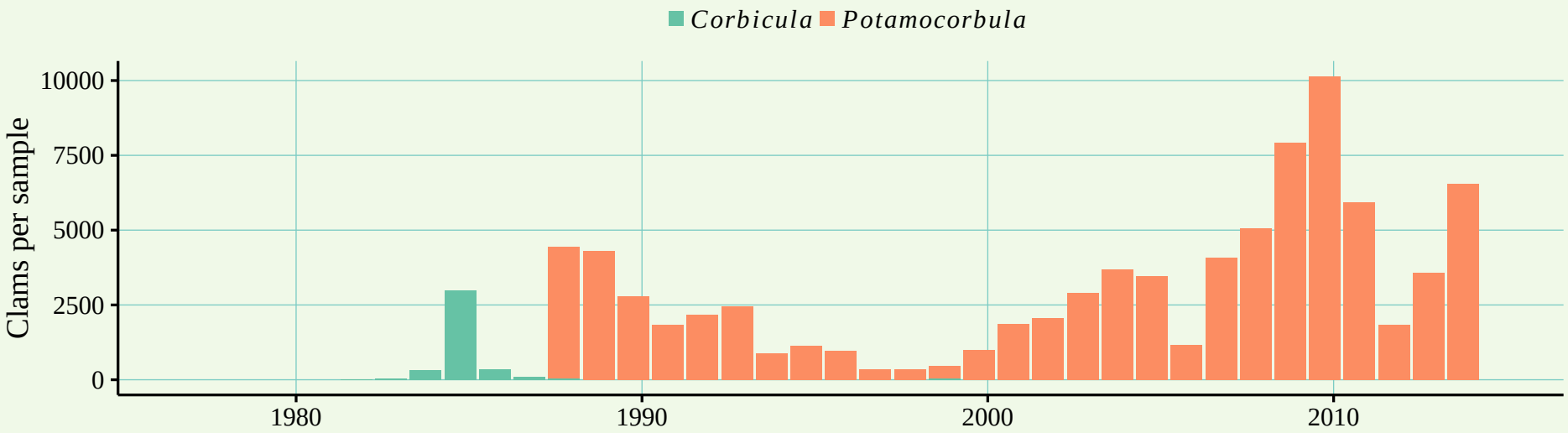


Figure: Clam density by year at D7, Suisun Bay [Crauder et al., 2016].

Selected case studies

Effects of biological invasion in Suisun Bay

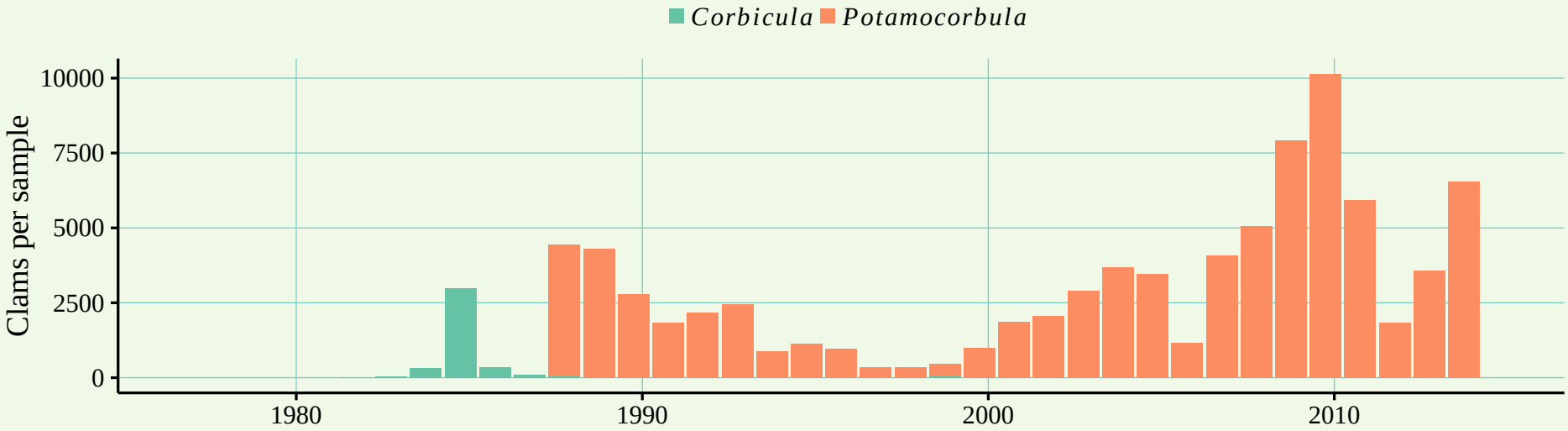


Figure: Clam density by year at D7, Suisun Bay [Crauder et al., 2016].

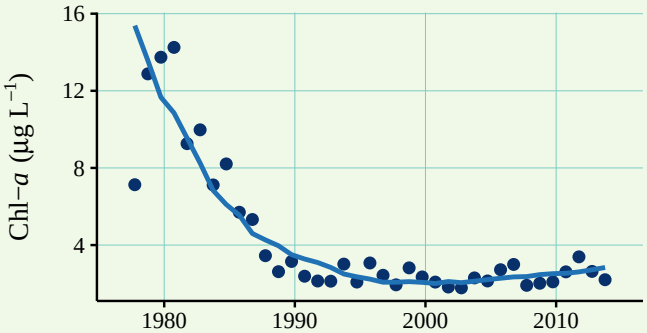


Figure: Annual predicted (points) and flow-normalized (lines) water quality data at D7.

Selected case studies

Effects of biological invasion in Suisun Bay

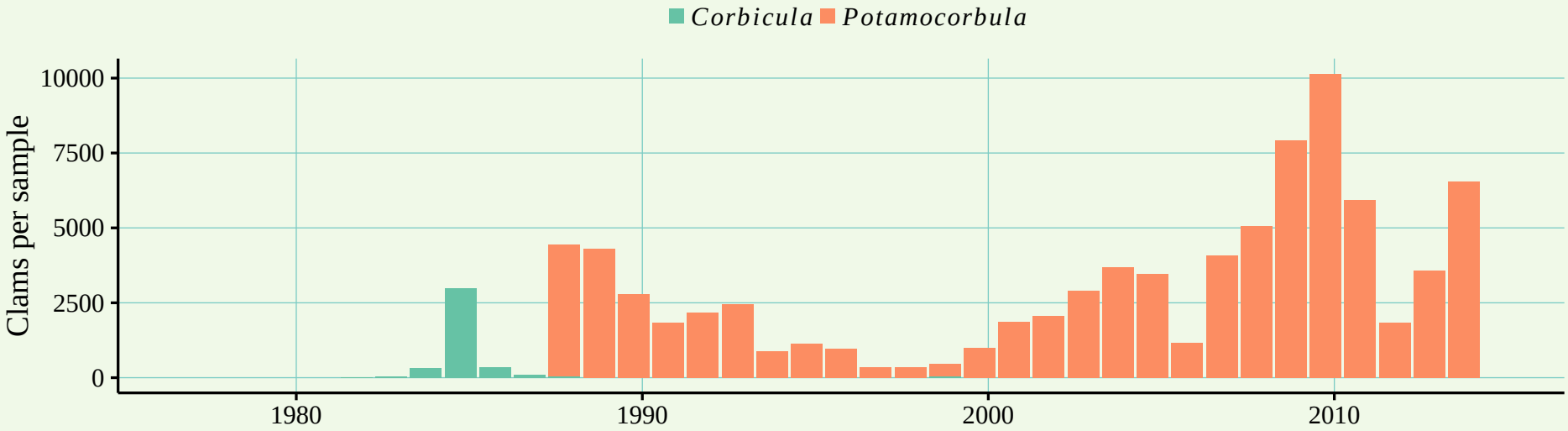


Figure: Clam density by year at D7, Suisun Bay [Crauder et al., 2016].

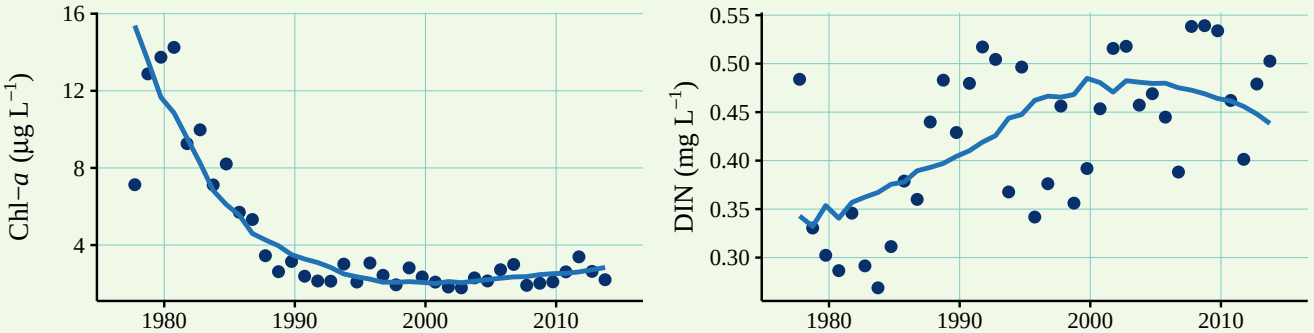


Figure: Annual predicted (points) and flow-normalized (lines) water quality data at D7.

Selected case studies

Effects of biological invasion in Suisun Bay

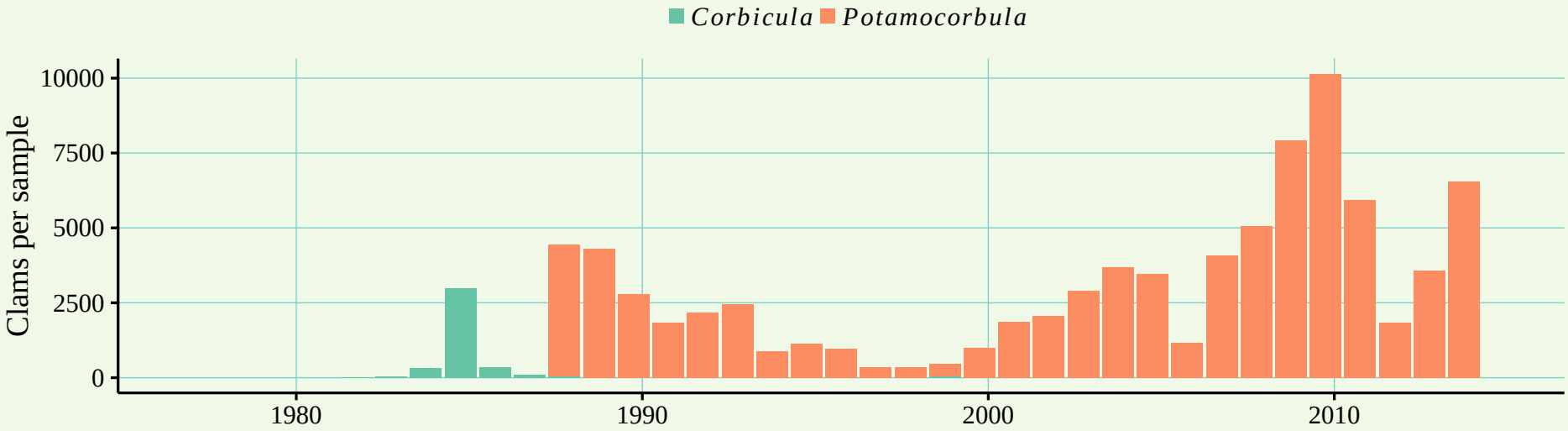


Figure: Clam density by year at D7, Suisun Bay [Crauder et al., 2016].

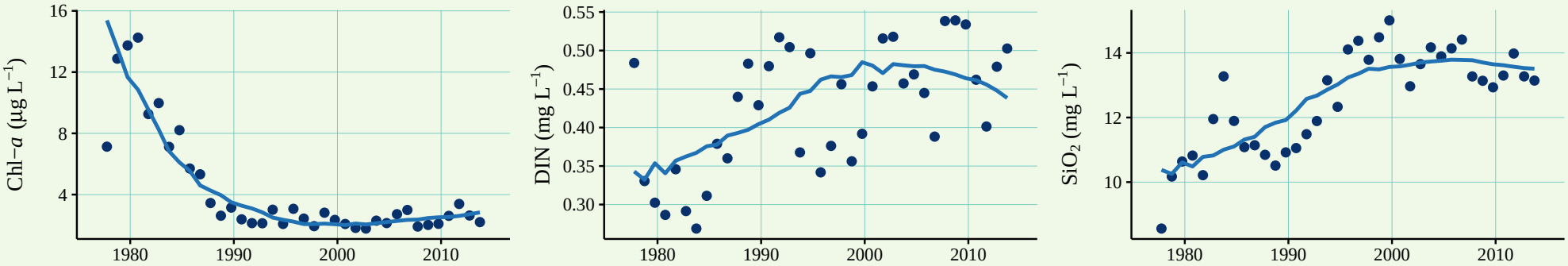
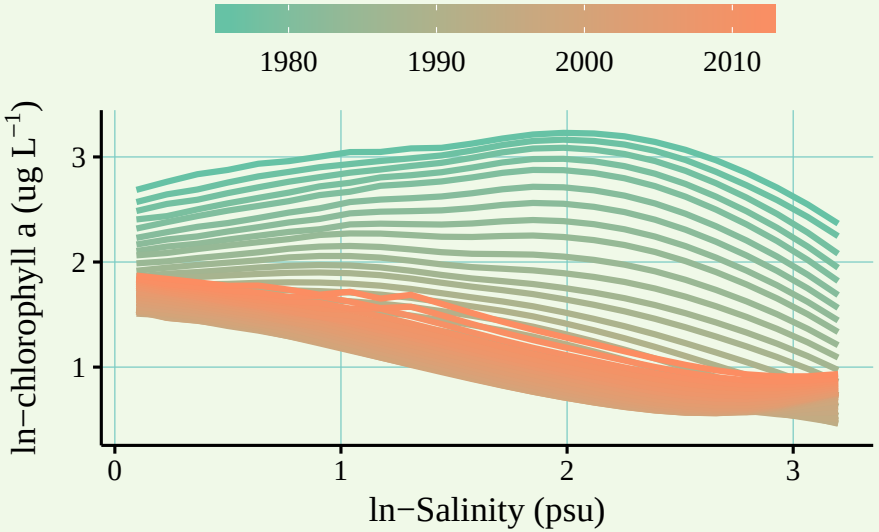


Figure: Annual predicted (points) and flow-normalized (lines) water quality data at D7.

Selected case studies

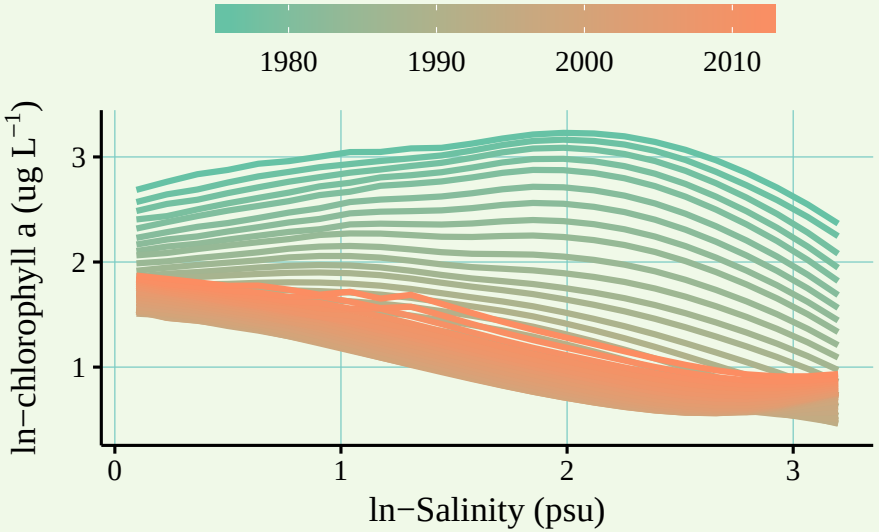
Effects of biological invasion in Suisun Bay

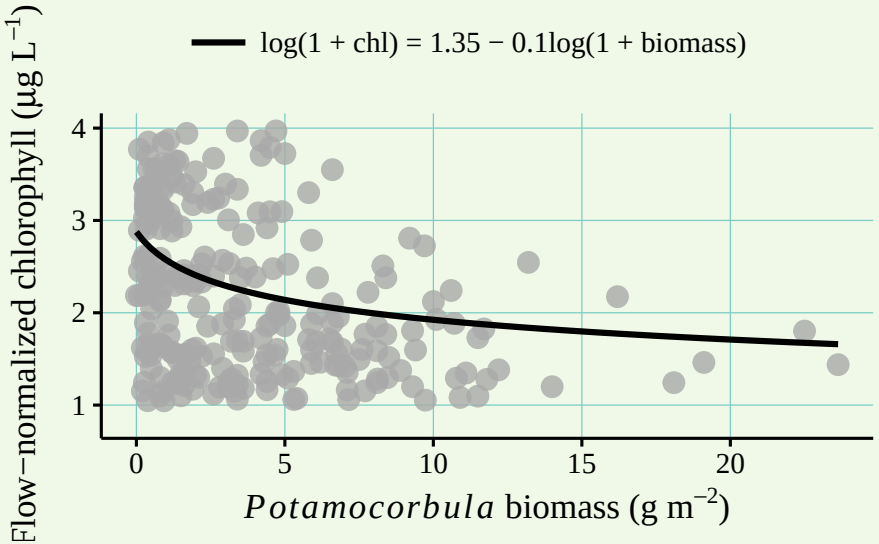


- Early: Flushing
- Later: Flow-stimulation

Selected case studies

Effects of biological invasion in Suisun Bay

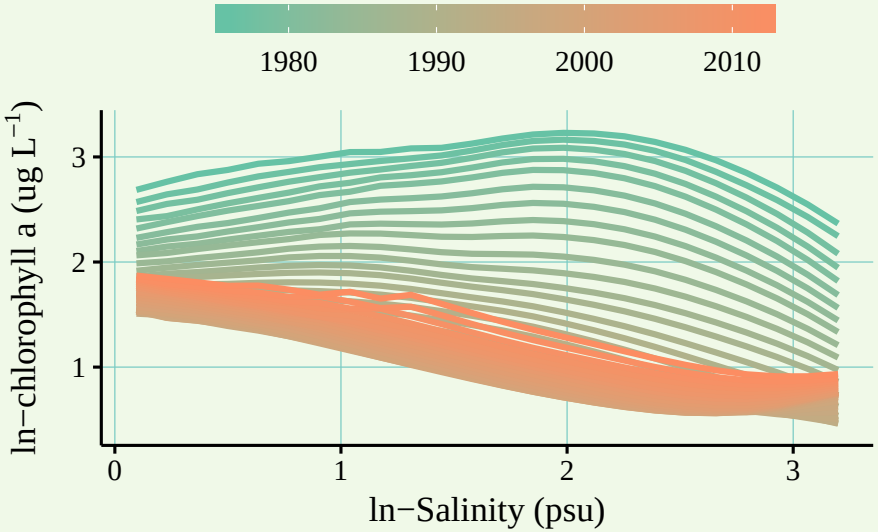




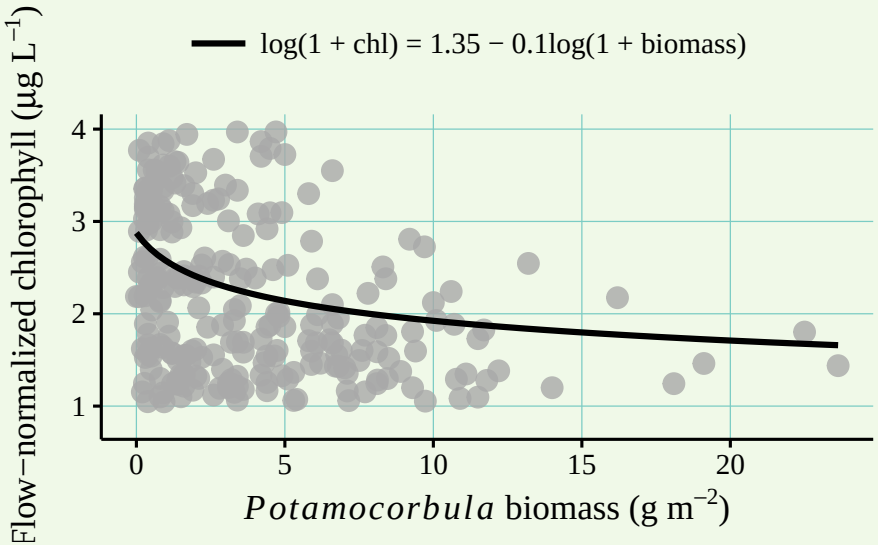
- Early: Flushing
- Later: Flow-stimulation

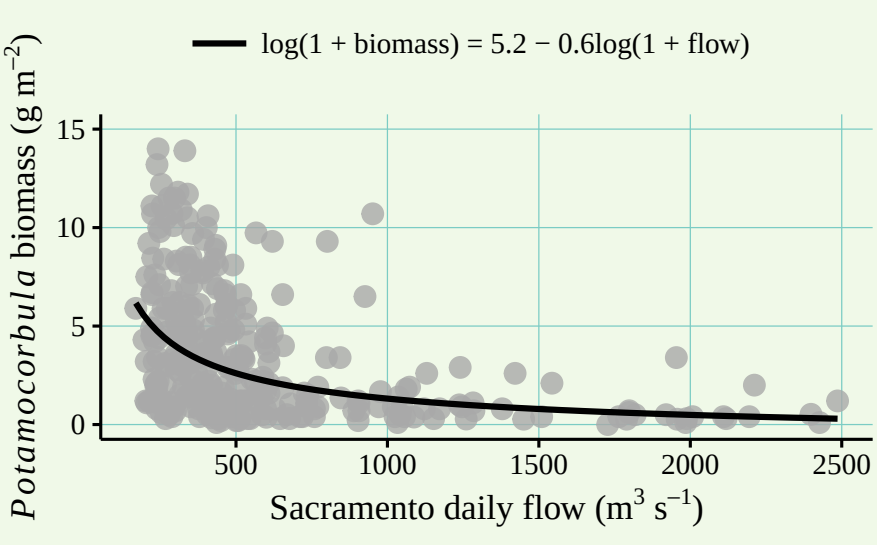
Selected case studies

Effects of biological invasion in Suisun Bay



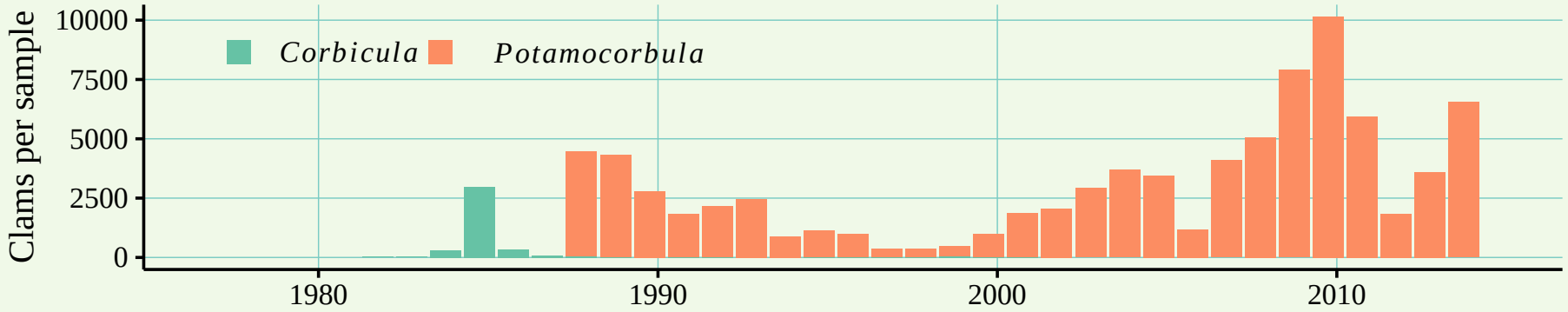
- Early: Flushing
- Later: Flow-stimulation





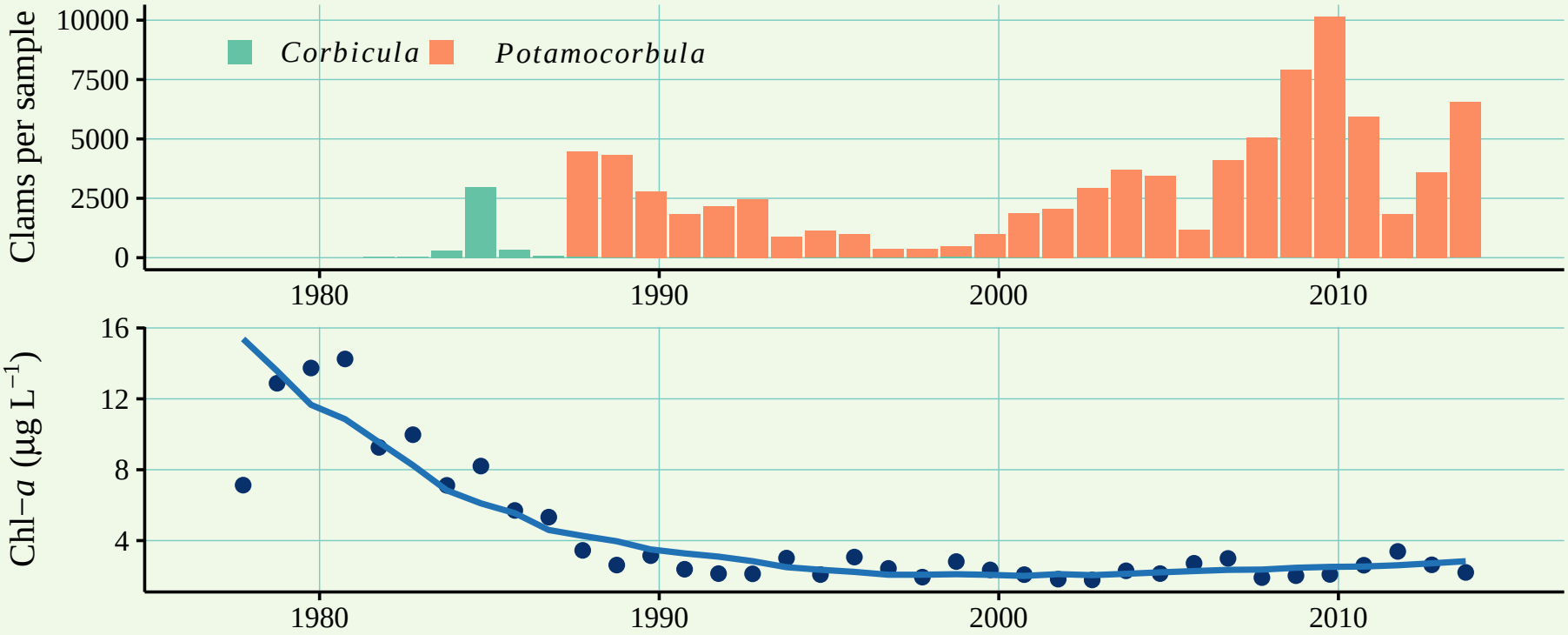
Selected case studies

Effects of biological invasion in Suisun Bay



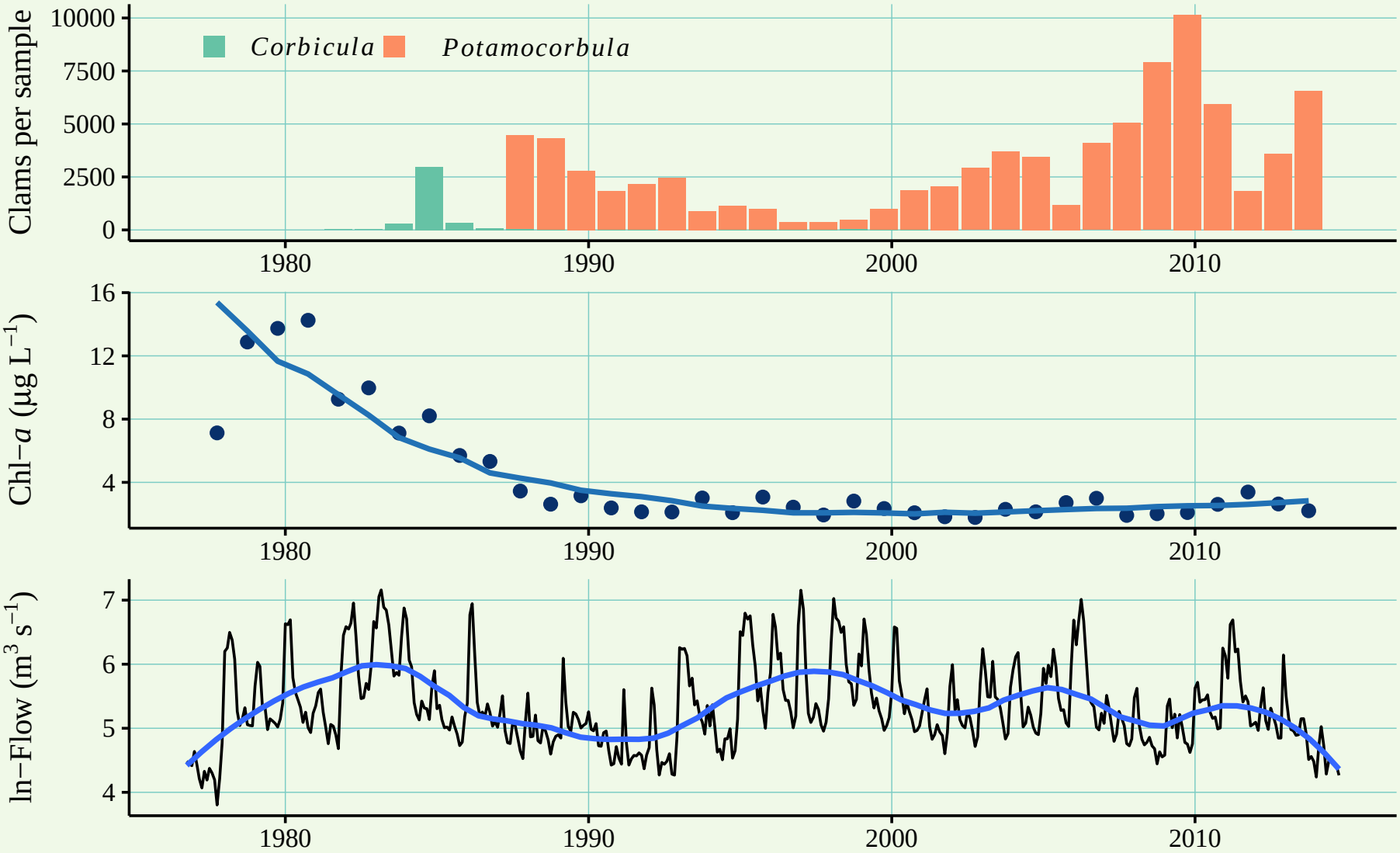
Selected case studies

Effects of biological invasion in Suisun Bay



Selected case studies

Effects of biological invasion in Suisun Bay

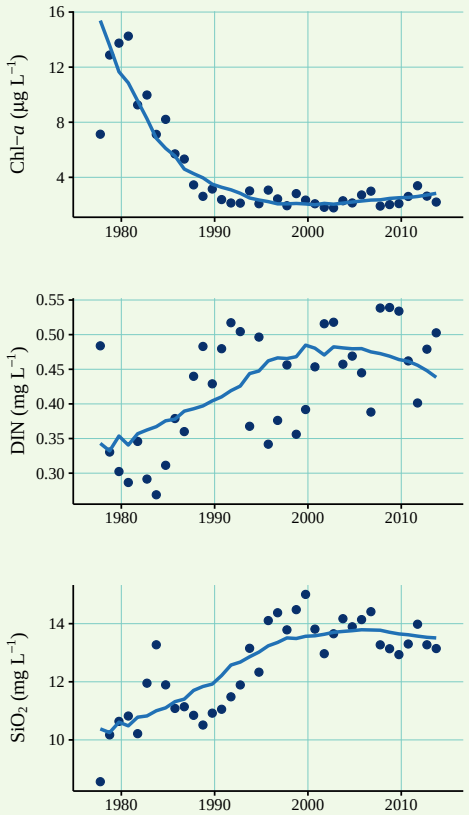


Selected case studies

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 increase in SiO_2

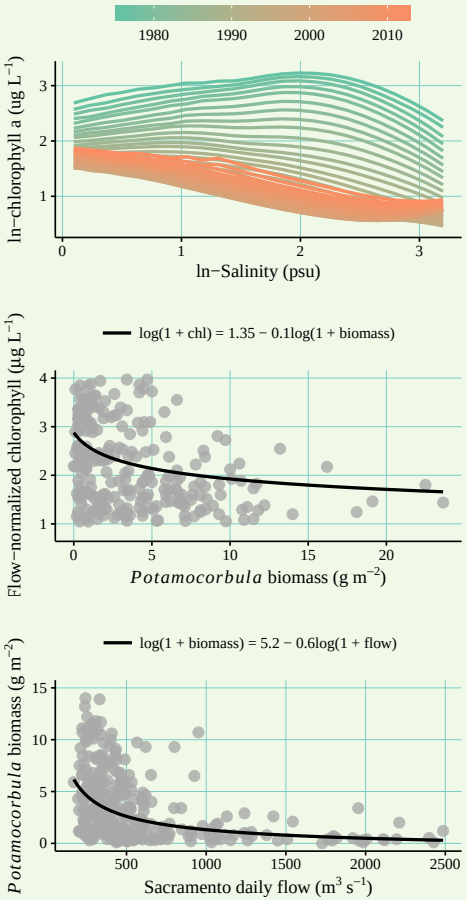


Selected case studies

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 increase in SiO_2
- 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

Conclusions

Lessons for monitoring and future work

Monitoring data are not particularly telling...
...so we use models or other methods to ***decompose*** the observations

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

Conclusions

Lessons for monitoring and future work

Monitoring data are not particularly telling...
...so we use models or other methods to ***decompose*** the observations

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

- 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

Lessons for monitoring and future work

Monitoring data are not particularly telling...
...so we use models or other methods to ***decompose*** the observations

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

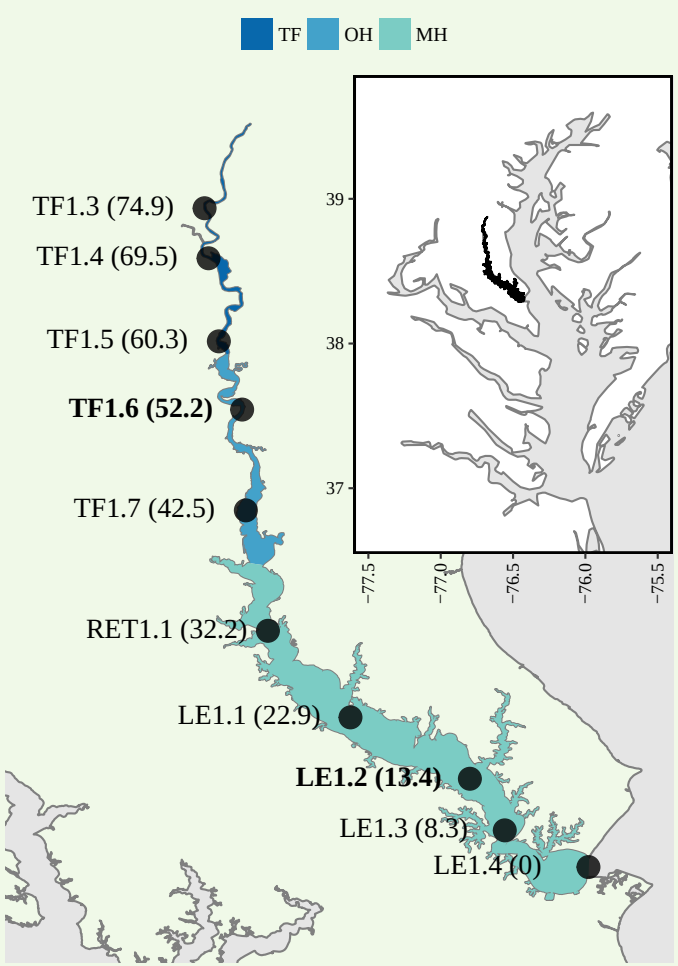
- More complete description of trends
- Better link to causal events
- More comprehensive evaluation of site-specific issues
- Deconstruct the past to predict the future

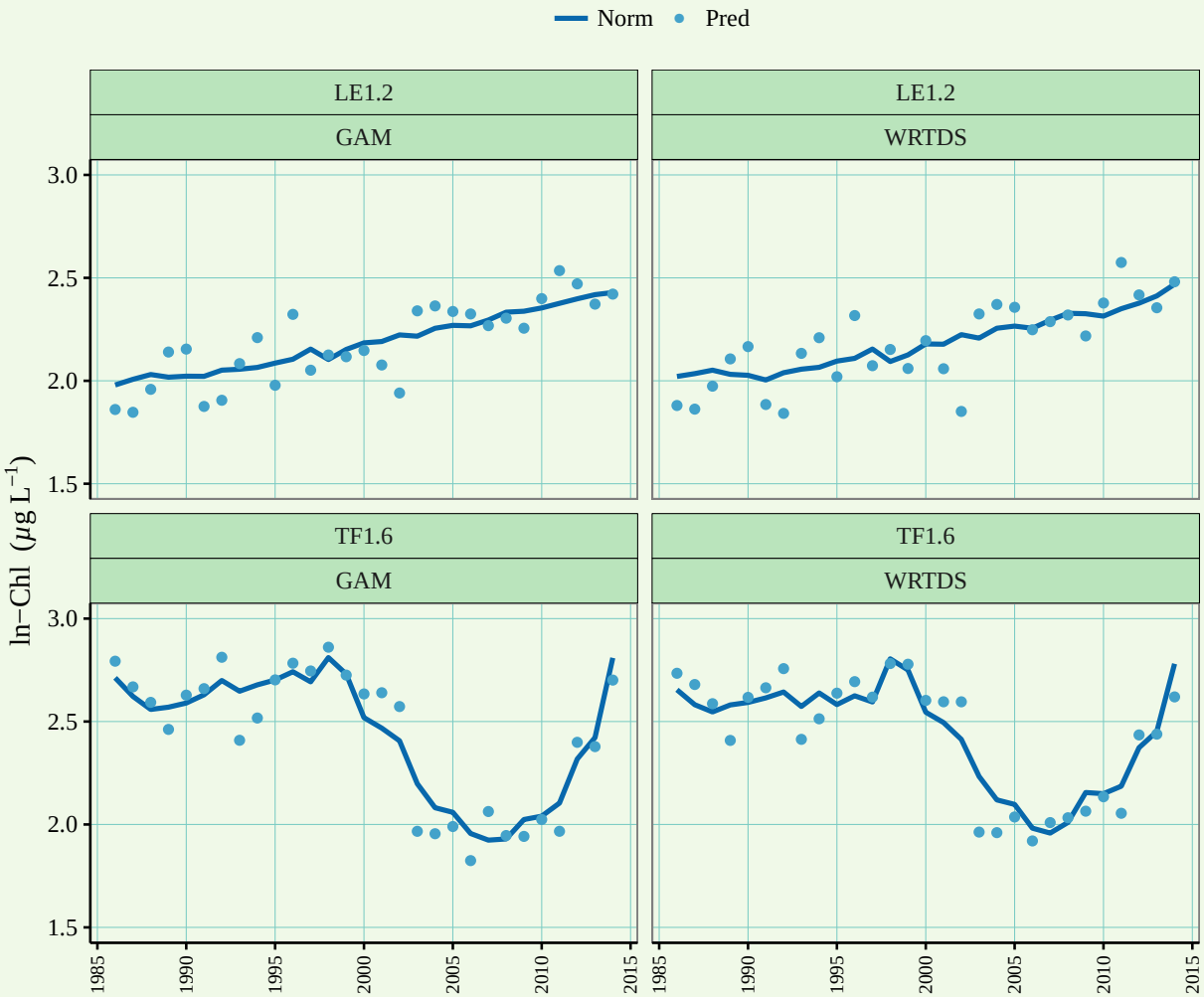
WRTDStidal package for R, active development
`https://github.com/fawda123/WRTDStidal`

Conclusions

Lessons for monitoring and future work

Comparing WRTDS and GAMs for trend evaluation

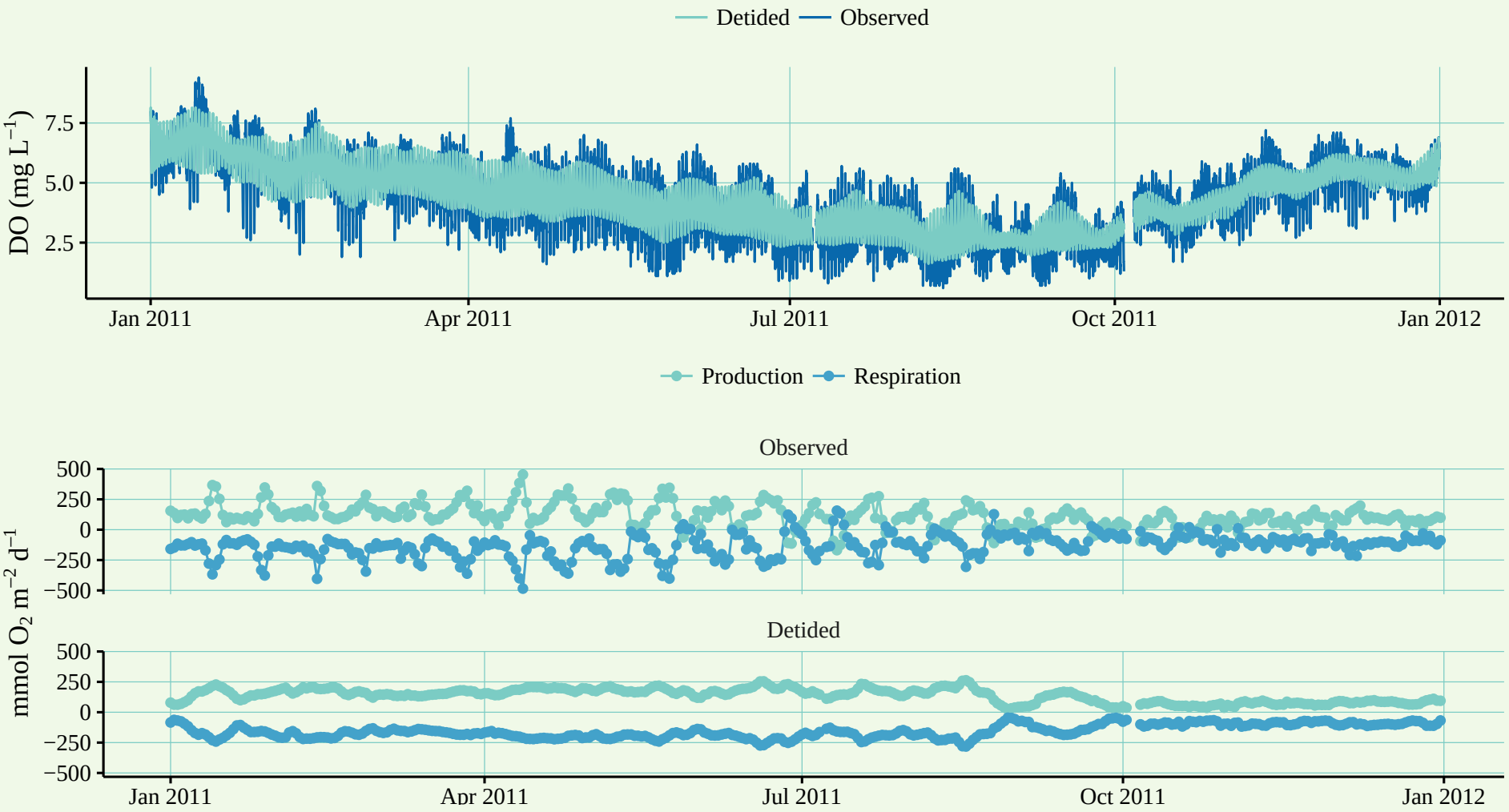




Conclusions

Lessons for monitoring and future work

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



Conclusions

Lessons for monitoring and future work

Data management and analysis tools

Acknowledgments and contact info:

Research staff and employees at USEPA Gulf Ecology Division, San Francisco Estuary Institute

David Senn, Phil Bresnahan, Emily Novick, James D. Hagy III, Thomas Jabusch

beck.marcus@epa.gov

Github @fawda123

Phone: 8509342480

Links:

This presentation: `https://github.com/fawda123/sfei_pres`
Shiny app: `https://beckmw.shinyapps.io/sf_trends/`
Detailed results: `http://fawda123.github.io/sf_trends/README`

References

Beck MW, Hagy III JD. 2015.
Adaptation of a weighted regression approach to evaluate water quality trends in an estuary.
Environmental Modelling and Assessment, 20(6):637–655.

Beck MW, Hagy III JD, Murrell MC. 2015.
Improving estimates of ecosystem metabolism by reducing effects of tidal advection on dissolved oxygen time series.
Limnology and Oceanography: Methods, 13(12):731–745.

Cloern JE. 2001.
Our evolving conceptual model of the coastal eutrophication problem.
Marine Ecology Progress Series, 210:223–253.

Crauder JS, Thompson JK, Parchaso F, Anduaga RI, Pearson SA, Gehrts K, Fuller H, Wells E. 2016.
Bivalve effects on the food web supporting delta smelt - a long-term study of bivalve recruitment, biomass, and grazing rate patterns with varying freshwater outflow.
Technical Report Open-File Report 2016-1005, US Geological Survey, Reston, Virginia.

Hirsch RM, Moyer DL, Archfield SA. 2010.
Weighted regressions on time, discharge, and season (WRTDS), with an application to Chesapeake Bay river inputs.
Journal of the American Water Resources Association, 46(5):857–880.

Nixon SW. 1995.
Coastal marine eutrophication: A definition, social causes, and future concerns.
Ophelia, 41:199–219.