

Tracking San Francisco Bay water quality using generalized additive models in an R Shiny framework

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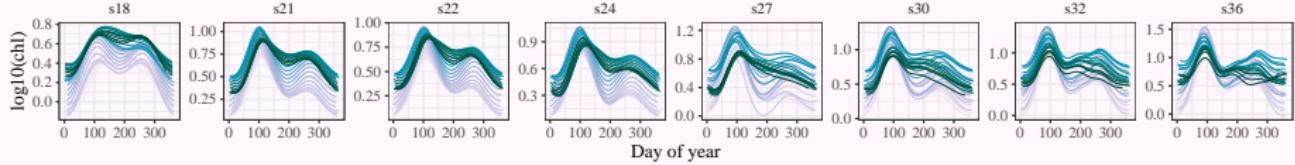
²San Francisco Baykeeper

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Why do we care about trends?



- Provide information on natural variation of water quality parameters
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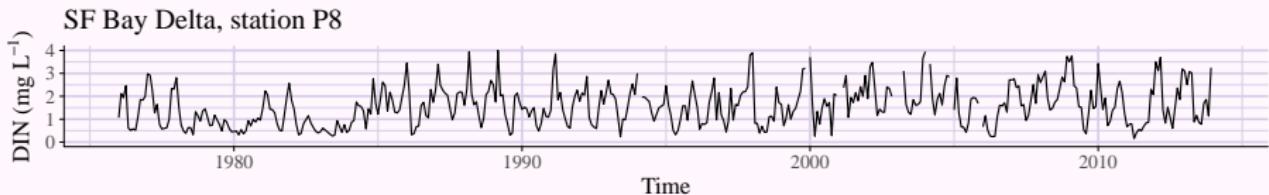


- Provide information on natural variation of water quality parameters
 - ▶ What are the 1st order principles that describe a system?
- Document historical changes in response to management actions
 - ▶ Did investments make a difference?
- Anticipate future changes with proposed restoration or management
 - ▶ Can we understand the past to predict the future?

Trends vary in space and time



Observed data represent effects of many processes



Climate

precipitation
temperature
wind events
ENSO effects

Local

light/turbidity
residence time
invasive species
trophic effects

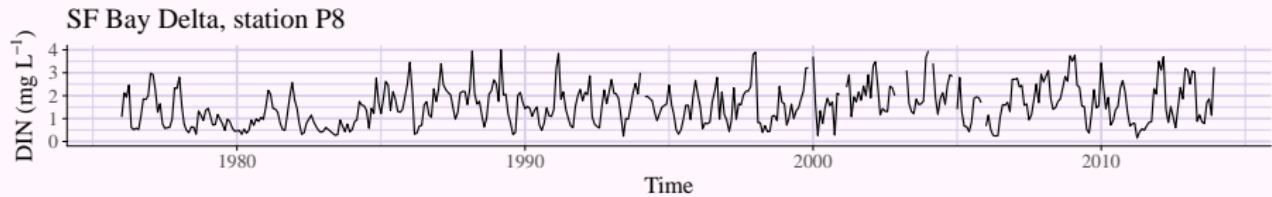
Regional/historical

watershed inputs
point sources
management actions
flow changes

Must translate data into information



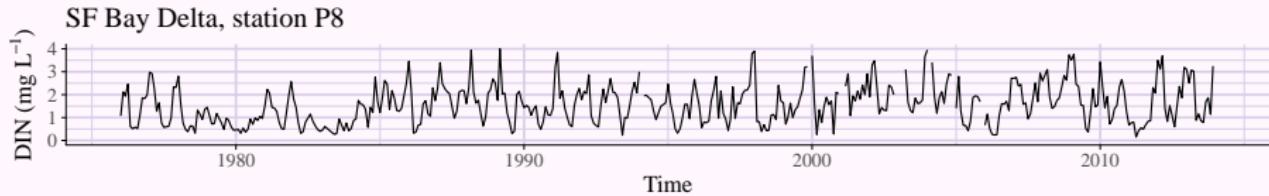
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Models should describe components to evaluate effects

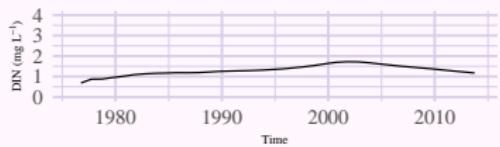
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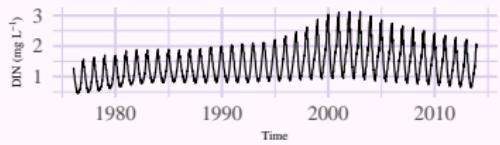


Models should describe components to evaluate effects

Annual



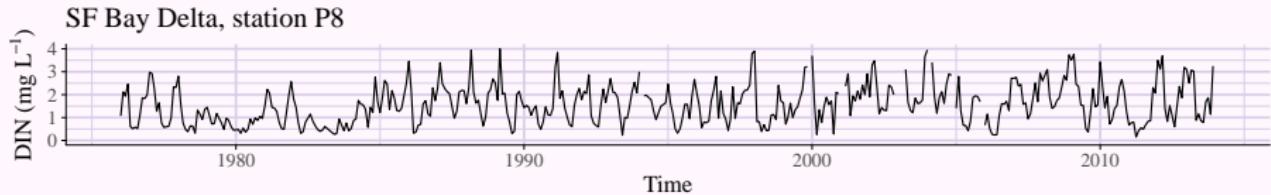
Seasonal



Must translate data into information

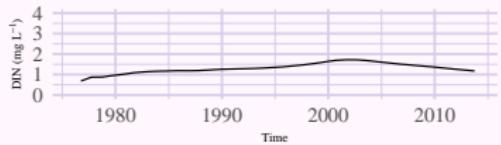


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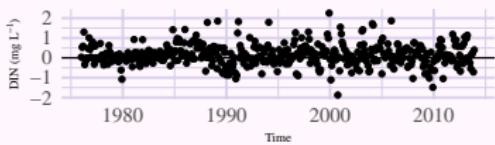


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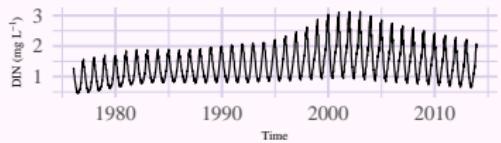
Annual



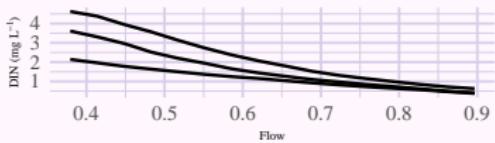
Residual



Seasonal



Flow effects



South San Francisco Bay

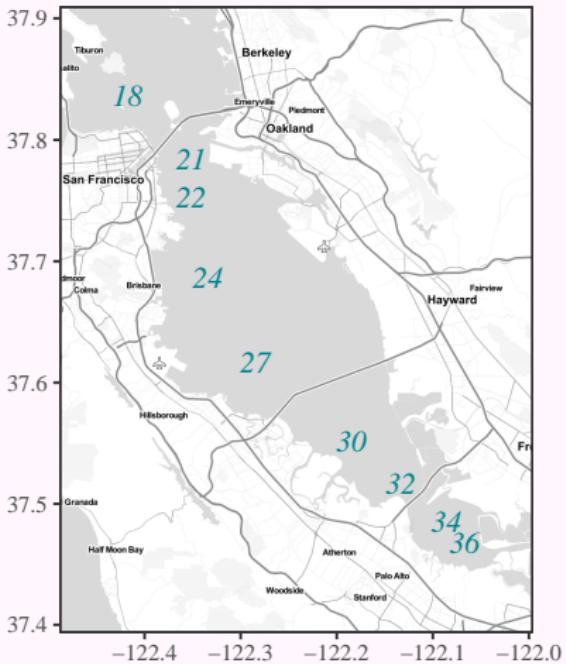


- A high-nutrient,
high-turbidity,
low-productivity system

[Cole and Cloern, 1984,

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South San Francisco Bay Long-term monitoring stations



South San Francisco Bay



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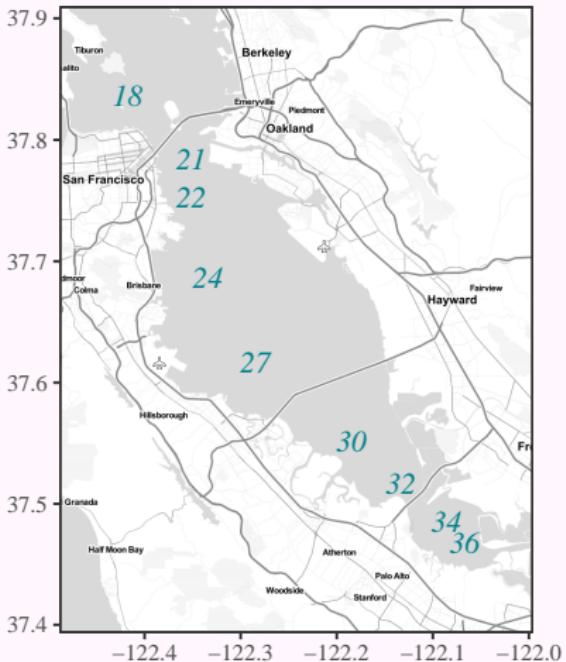
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- Recent increases observed in
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South San Francisco Bay
Long-term monitoring stations

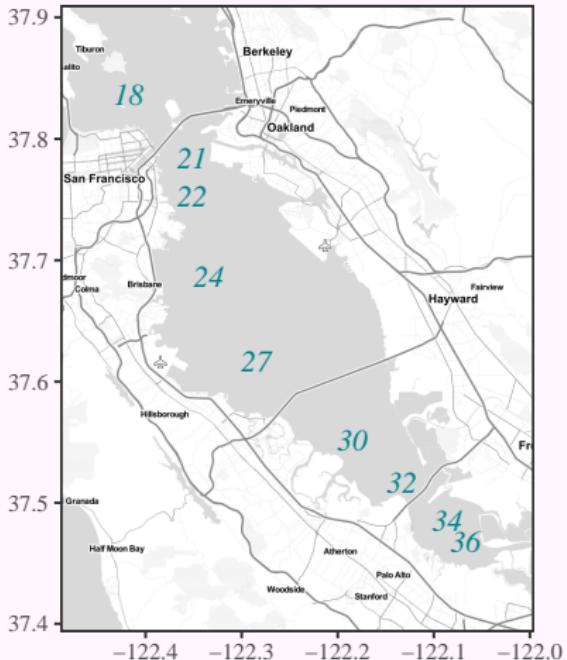


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[Cole and Cloern, 1984,
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- Recent increases observed in
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- Nutrient Management
Strategy (NMS) to
characterize status/trends and
management needs

South San Francisco Bay
Long-term monitoring stations

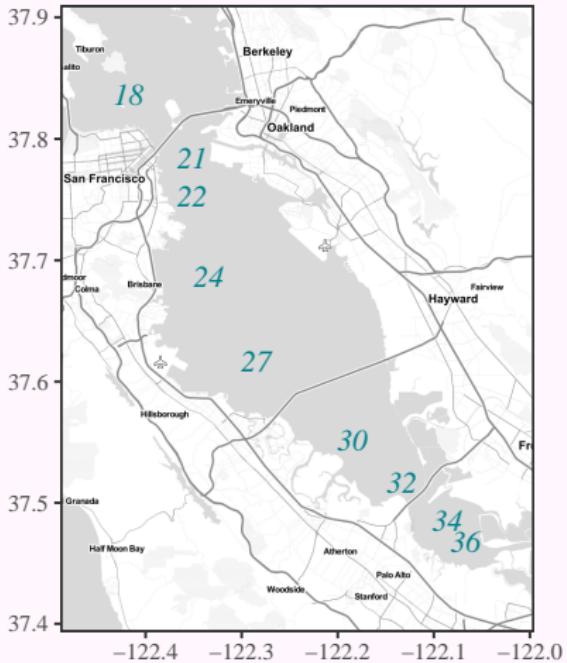


South San Francisco Bay



Questions of concern:

South San Francisco Bay
Long-term monitoring stations



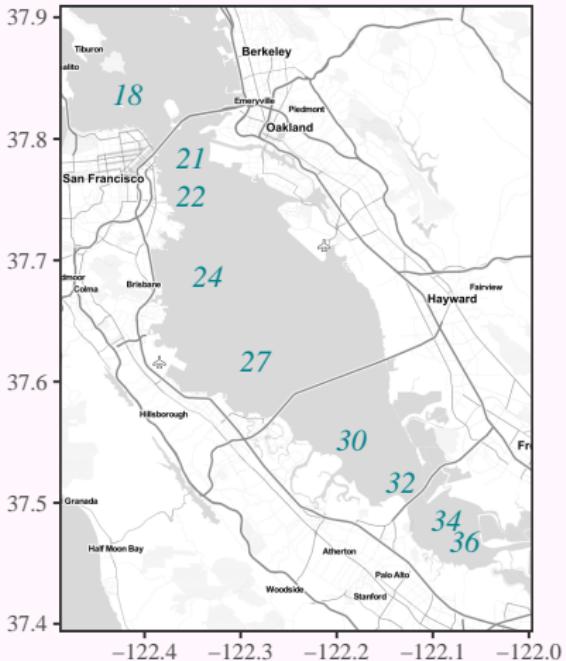
South San Francisco Bay



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- Since changes are visually apparent, which are significant?

South San Francisco Bay
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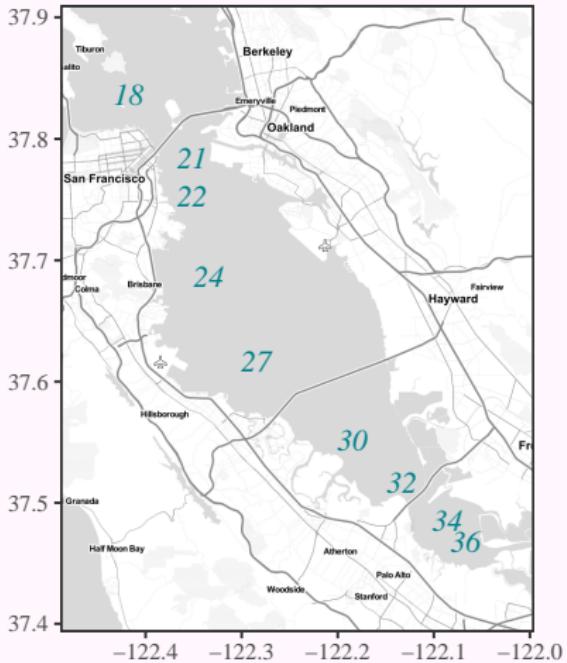


South San Francisco Bay

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- What has been the estimated rate and direction of any linear or non-monotonic change?

South San Francisco Bay
Long-term monitoring stations



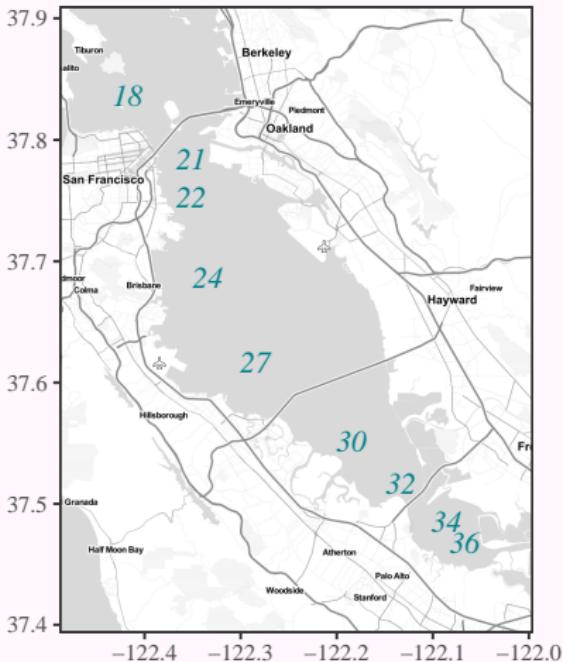
South San Francisco Bay



Questions of concern:

- Since changes are visually apparent, which are significant?
- What has been the estimated rate and direction of any linear or non-monotonic change?
- Do any of these changes coincide with changes in other water quality parameters?

South San Francisco Bay
Long-term monitoring stations



Application of additive models



- The Chesapeake Bay Program (CBP) has been wrestling with similar issues [Beck and Murphy, 2017, Murphy et al., 2019b]

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Application of additive models

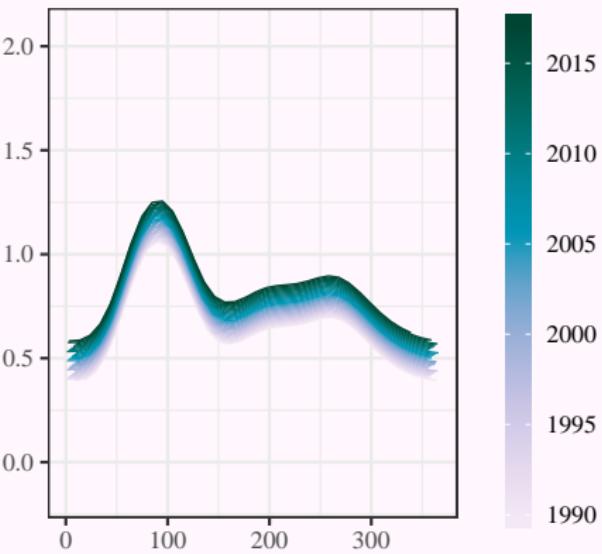
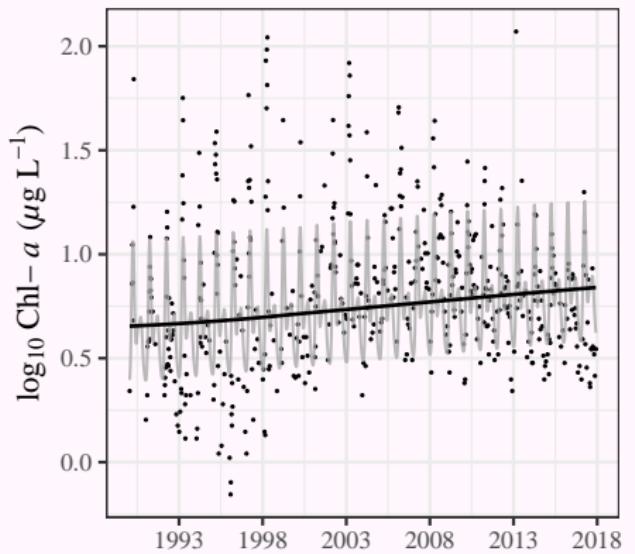


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 - ▶ `gam6: chl ~ year + s(doy) + s(year, k = large)`

Application of additive models

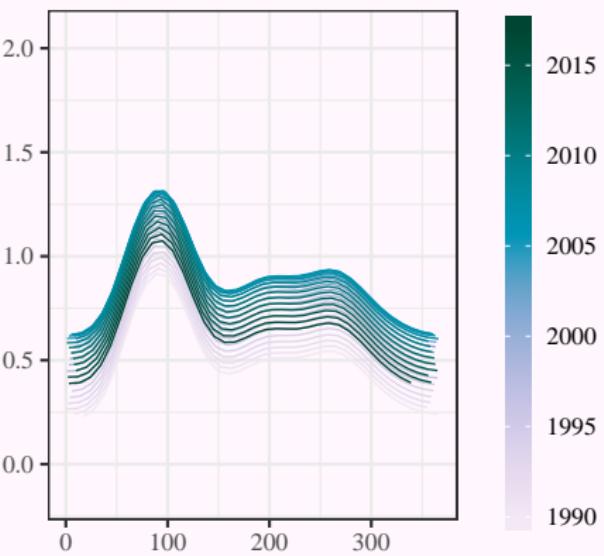
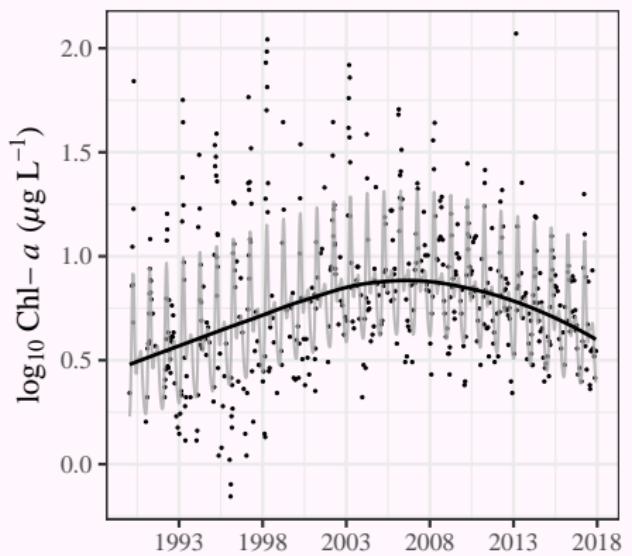


gam0: chl ~ year + s(doy)



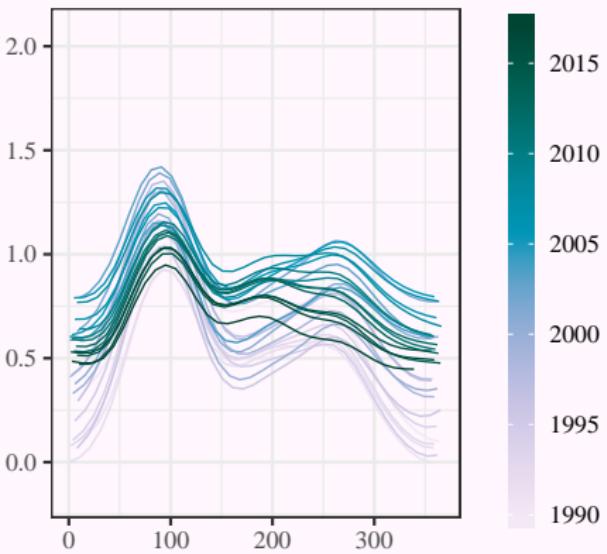
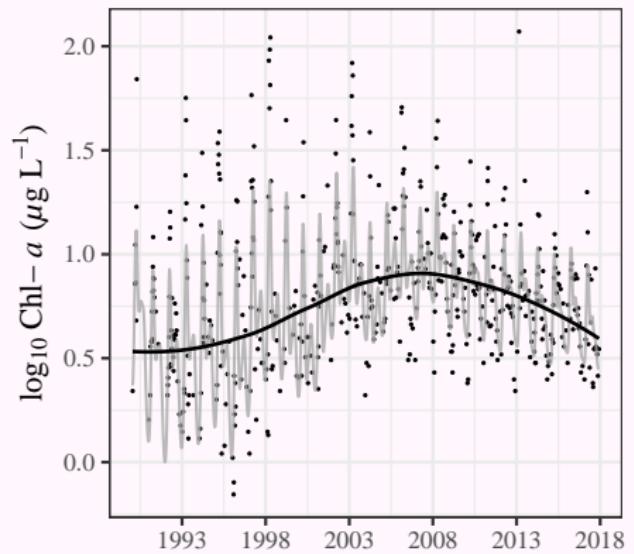
Application of additive models

gam1: $\text{chl} \sim \text{year} + s(\text{doy}) + s(\text{year})$



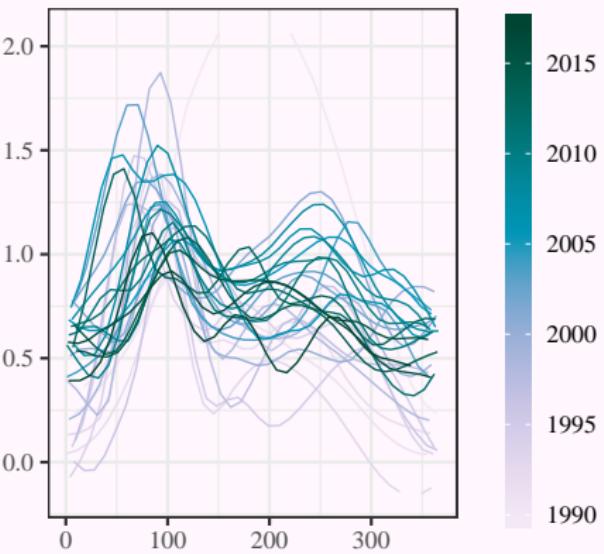
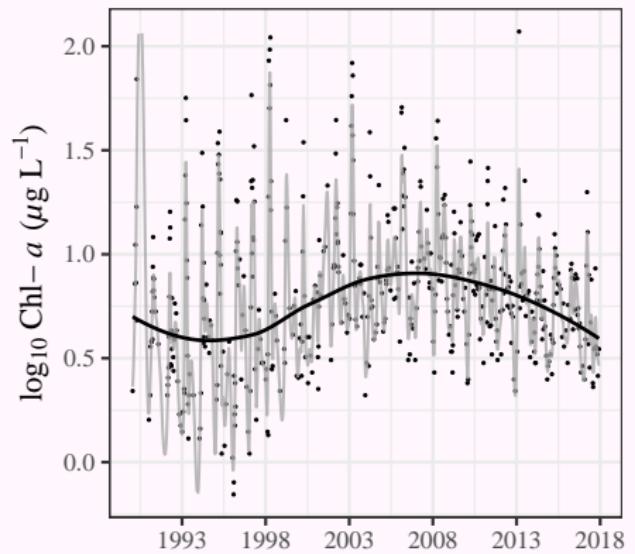
Application of additive models

gam2: $\text{chl} \sim \text{year} + s(\text{doy}) + s(\text{year}) + ti(\text{doy}, \text{year})$



Application of additive models

gam6: $\text{chl} \sim \text{year} + s(\text{doy}) + s(\text{year}, k = \text{large})$

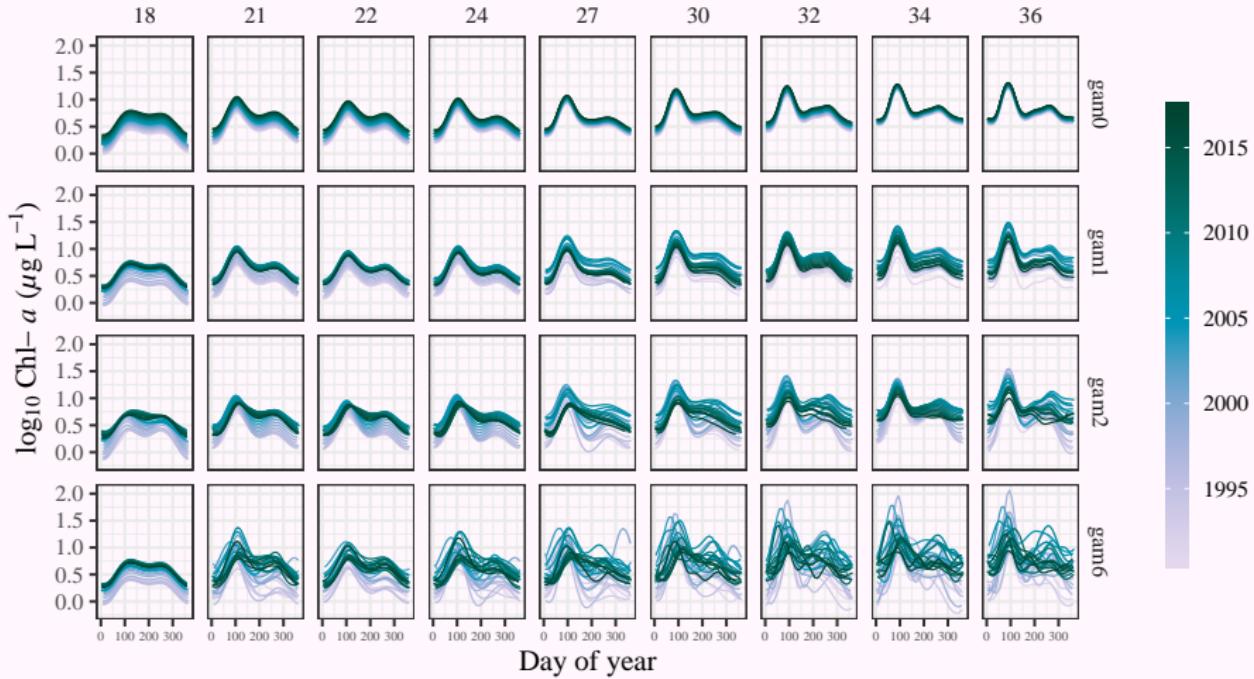


Application of additive models



Application of additive models

All years



Application of additive models



Table: Generalized cross-validation (GCV) summary statistics by station and model

Model	Stations (north to south)								
	18	21	22	24	27	30	32	34	36
gam0	-117.5	-30.6	-20.6	38.9	174.4	205.5	232.9	256.6	238.7
gam1	-138.8	-89.3	-70.3	-18.7	104.1	111.5	162.6	196	182
gam2	-141.8	-147.3	-116.4	-98.5	4	49.6	108.1	189.9	147.2
gam6	-139.5	-235.2	-116.3	-176.8	-92.1	-115.9	-149	-3.3	-65.5

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Table: R-squared summary statistics by station and model

Model	Stations (north to south)								
	18	21	22	24	27	30	32	34	36
gam0	0.47	0.41	0.37	0.37	0.33	0.36	0.32	0.31	0.32
gam1	0.51	0.48	0.43	0.44	0.43	0.48	0.41	0.41	0.43
gam2	0.53	0.54	0.48	0.53	0.54	0.54	0.49	0.41	0.48
gam6	0.51	0.68	0.54	0.66	0.68	0.72	0.75	0.69	0.75

Conclusions from additive models



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 - ▶ Non-monotonic trends were obvious
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How can this information support decision-making??

<https://sccwrc.shinyapps.io/sfbaytrends>

GAM evaluation - SF South Bay

Exploratory plots

The following plots show the raw data for all monitoring stations and parameters in South Bay, 1990 - 2017. Select the parameter, plot type (total time series, by year, or by month), and variable transformation. The year and month plots are aggregated boxplots of all observations at a station for each selected time period. The variable transformation can be used to show the observations in arithmetic or logarithmic space.

Choose station:

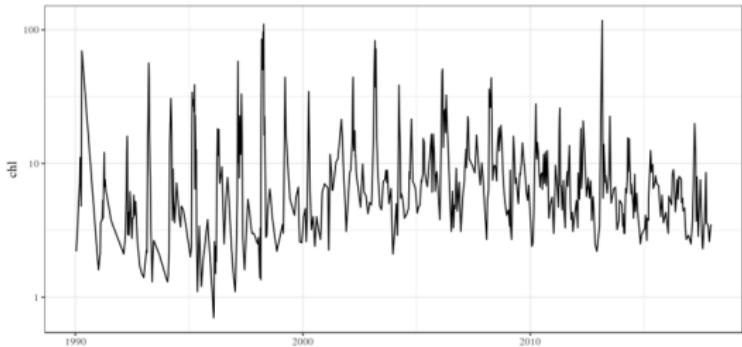
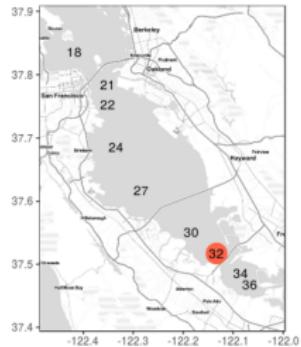
32

Choose plot type:

tot

Log-space:

TRUE



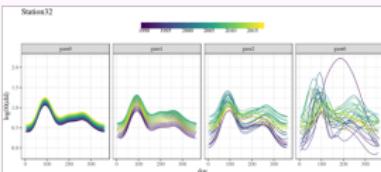
Shiny interactive web platform



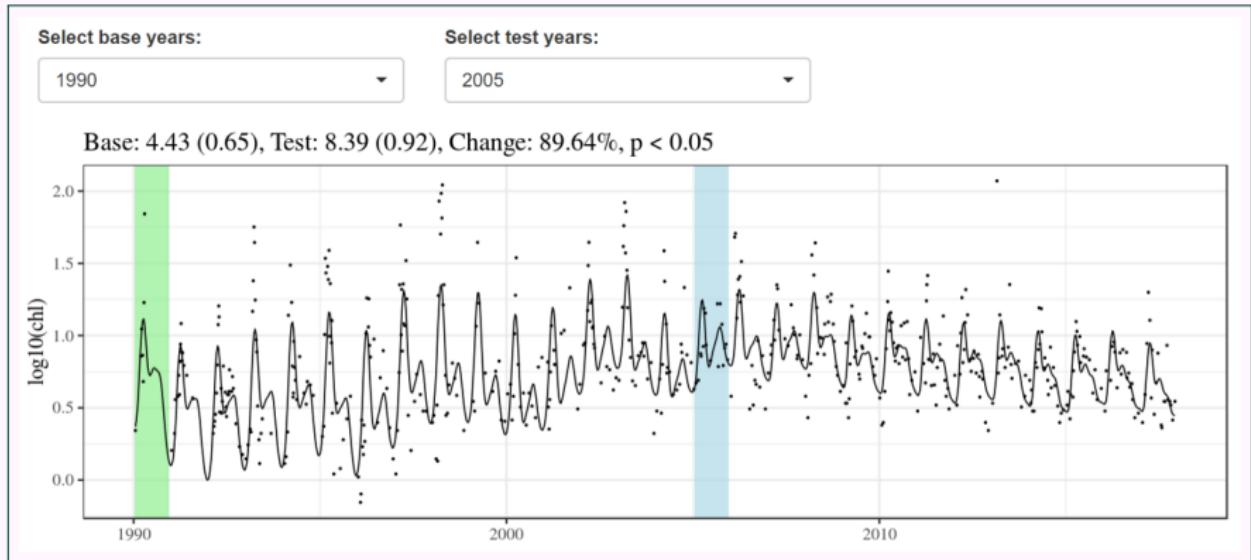
Explore results for each station, by model

model	smoother	edf	Ref.df	F	p.value
gam0	s(doy)	7.10	8.00	31.64	0.00
gam1	s(dec_time)	2.45	27.00	2.74	0.00
gam1	s(doy)	7.17	8.00	37.97	0.00
gam2	s(dec_time)	21.40	27.00	5.05	0.00
gam2	s(doy)	7.11	8.00	42.39	0.00
gam2	ti(dec_time,doy)	8.98	12.00	3.98	0.00
gam6	s(dec_time)	218.84	334.00	3.06	0.00
gam6	s(doy)	5.07	8.00	2.24	0.00

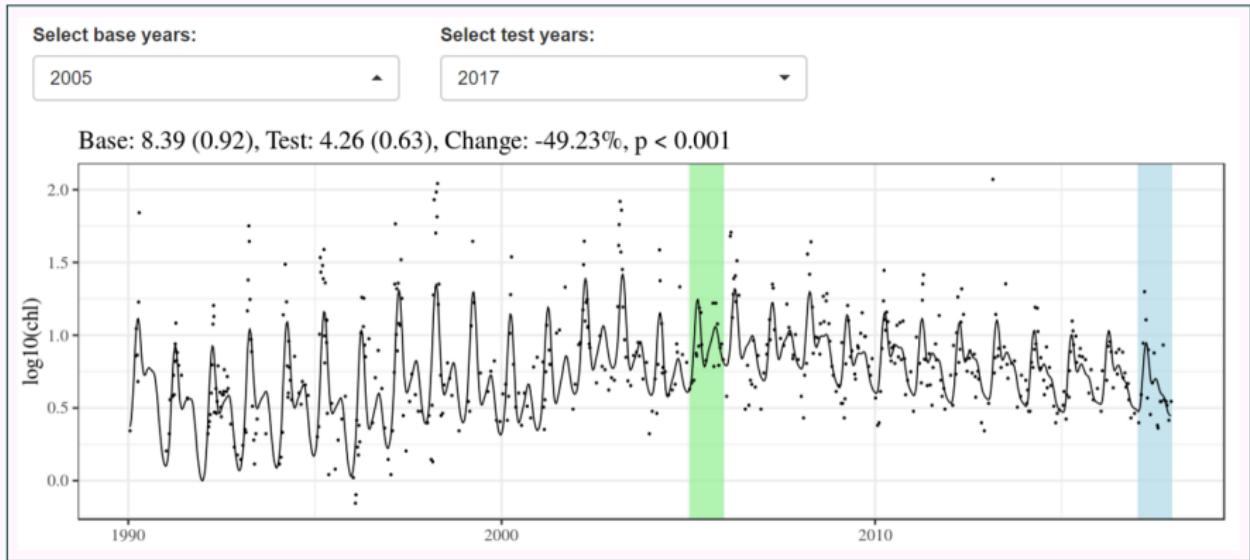
model	k	AIC	GCV	R2
gam0	NA	232.88	0.09	0.32
gam1	28	162.57	0.08	0.41
gam2	28	108.06	0.07	0.49
gam6	336	-148.96	0.06	0.75



Perform trend tests with selected years



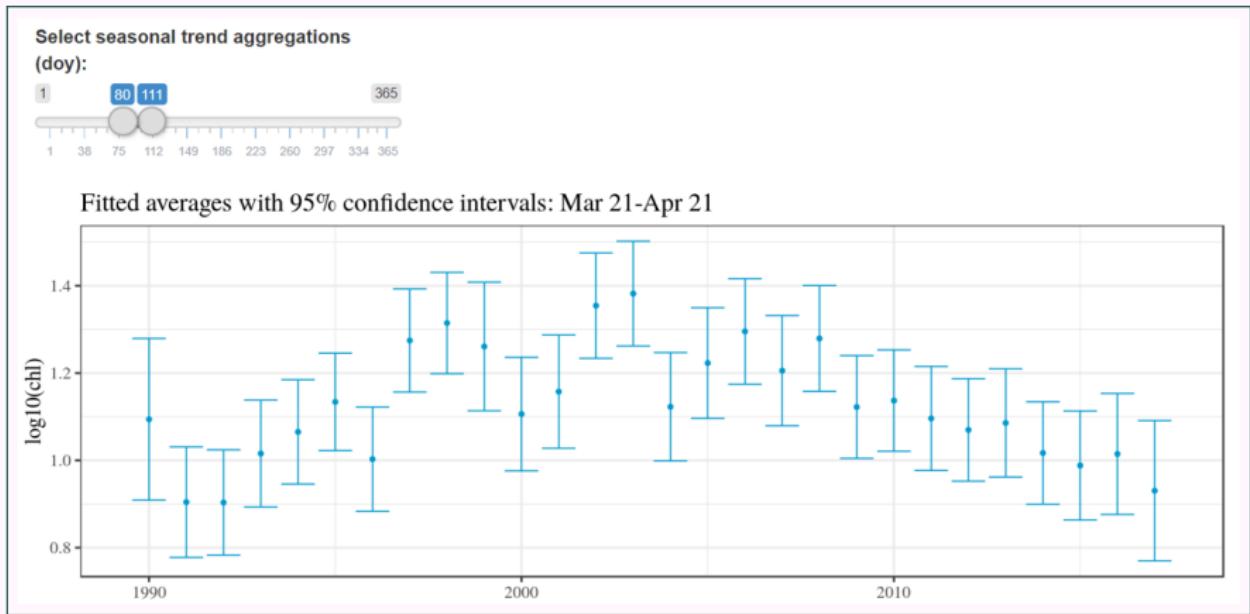
Perform trend tests with selected years



Shiny interactive web platform



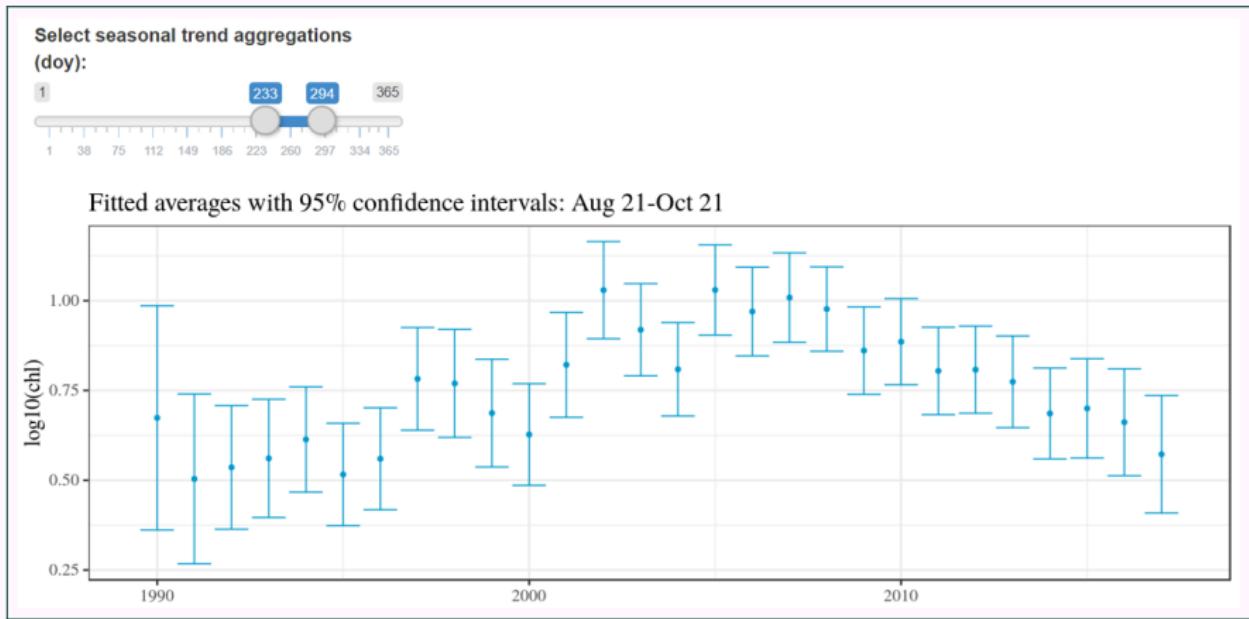
Evaluate trends between years, by season



Shiny interactive web platform



Evaluate trends between years, by season



Summary and next steps



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 - ▶ Does the GAM approach developed by the CBP transfer to SF Bay?
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- Shiny platform helps communicate results to stakeholder
 - ▶ Which station, model, and time period do I care about?
 - ▶ How can I understand limitations of the different models?
- Follow-up work:
 - ▶ Extend to other locations in the Bay
 - ▶ Explore trend analysis of aggregated stations
 - ▶ Incorporate additional variables - as response or as explanatory

Acknowledgments and contact info:

Research staff and employees at the San Francisco Estuary Institute, Delta Regional Monitoring Program, Southern California Coastal Water Research Project, and the Tampa Bay Estuary Program



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Links:

This presentation: https://github.com/fawda123/CERF_2019

Shiny app: <https://sccwrp.shinyapps.io/sfbaytrends/>

Detailed results: <http://fawda123.github.io/SFbaytrends/README>

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