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

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Perry de Valpine[4] David Senn[5]

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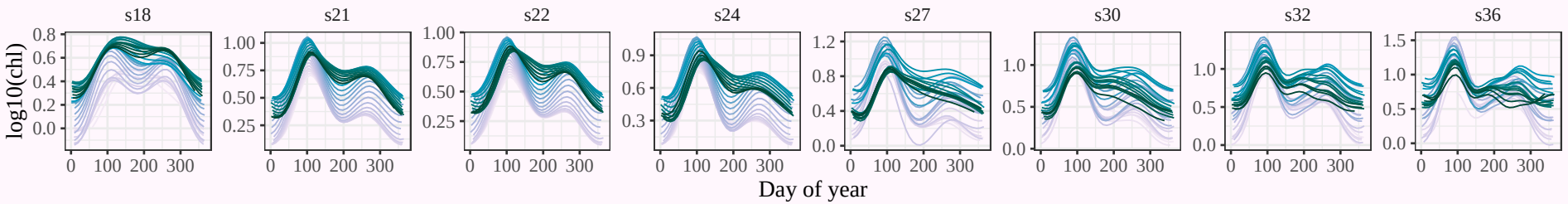
[3]University of Maryland at Cheseapeake Bay Program
[4]University of California Berkeley
[5]San Francisco Estuary Institute

Nov. 4, 2019



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- Provide information on natural variation of water quality parameters
  - What are the 1^{st} order principles that describe a system?

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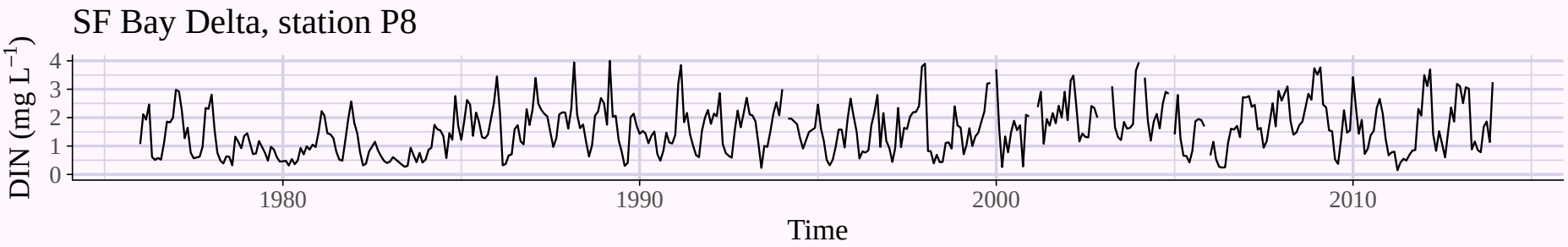
- Document historical changes in response to management actions
  - Did investments make a difference?
- Anticipate future changes with proposed restoration or management
  - Can we understand the past to predict the future?

Trends vary in space and time

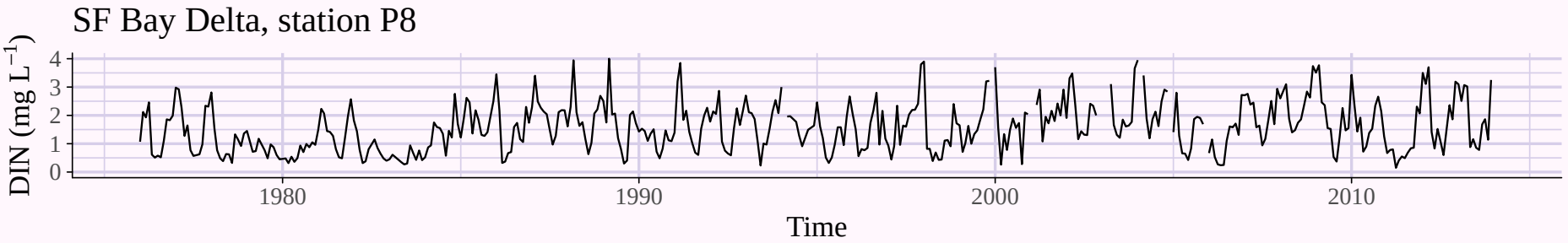
Observed data represent effects of many processes



Climate	***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

Must translate data into information

Observed data represents effects of many processes



Models should describe components to evaluate effects

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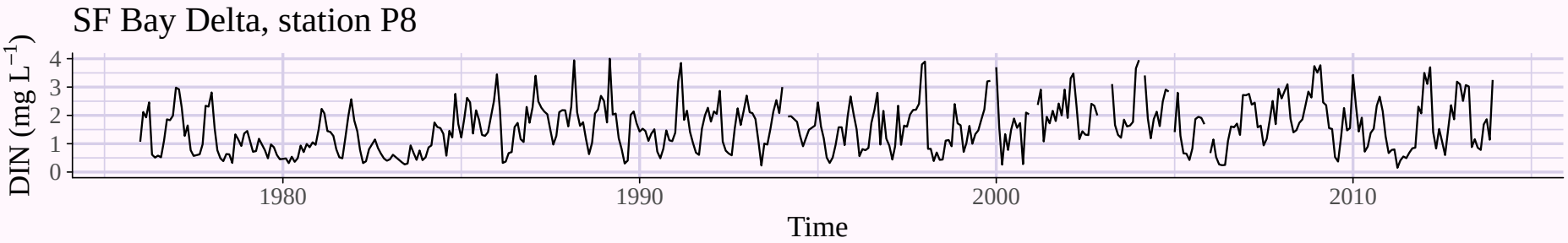
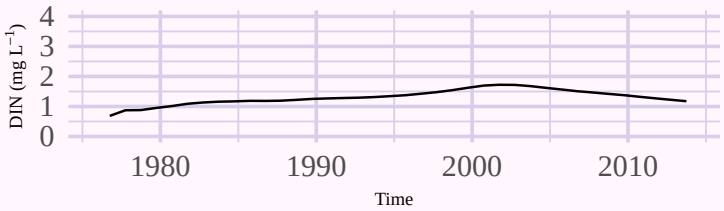
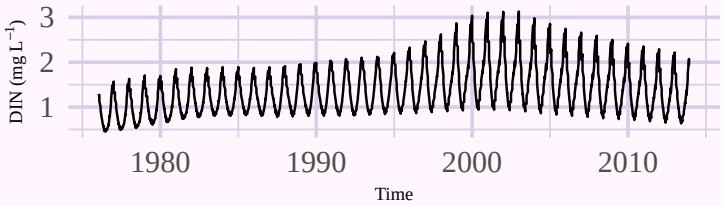


Models should describe components to evaluate effects

Annual



Seasonal



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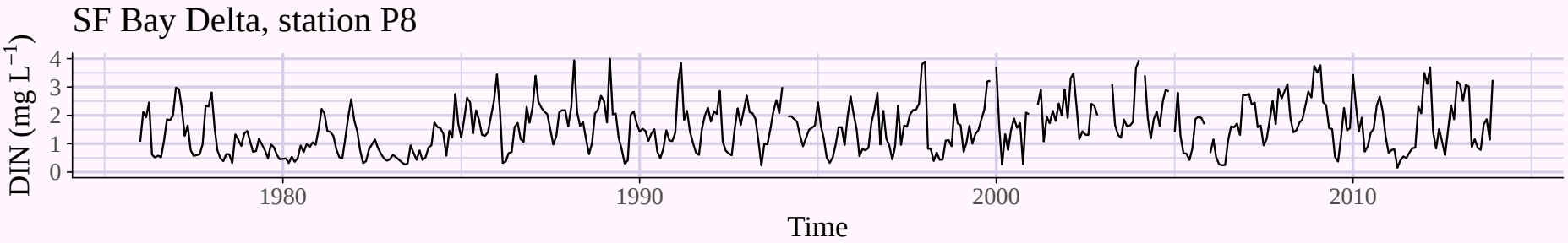

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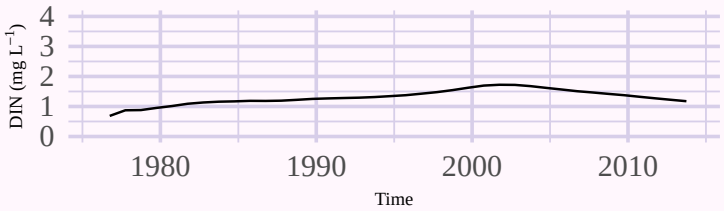
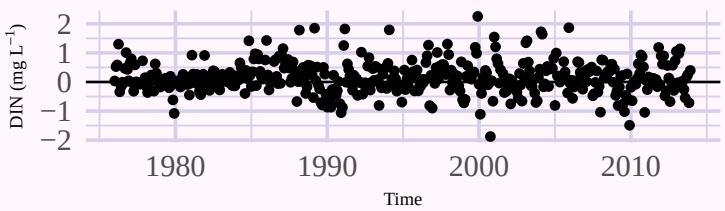


Residual



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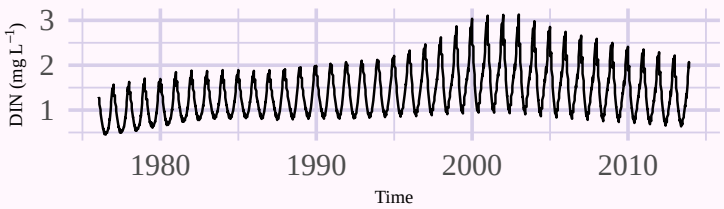
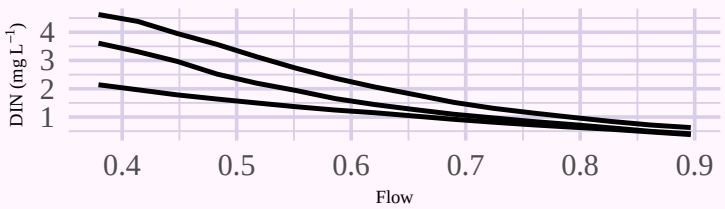


Flow effects



South San Francisco Bay

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

  [Cole and Cloern, 1984,

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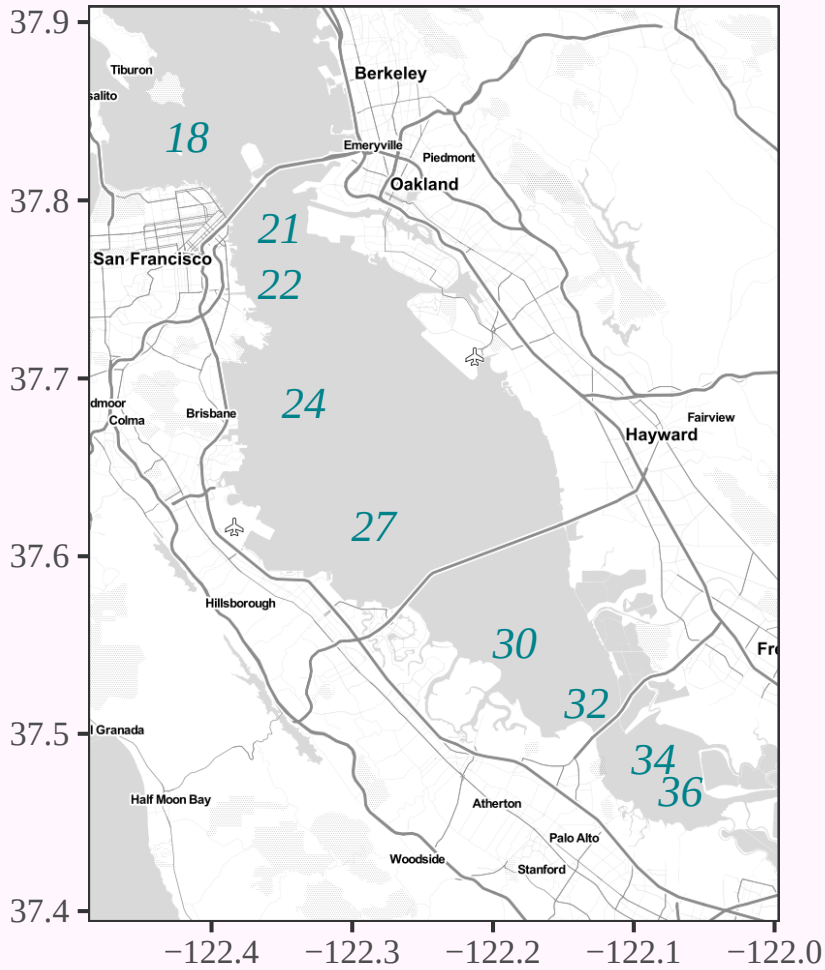
South San Francisco Bay

Long−term monitoring stations



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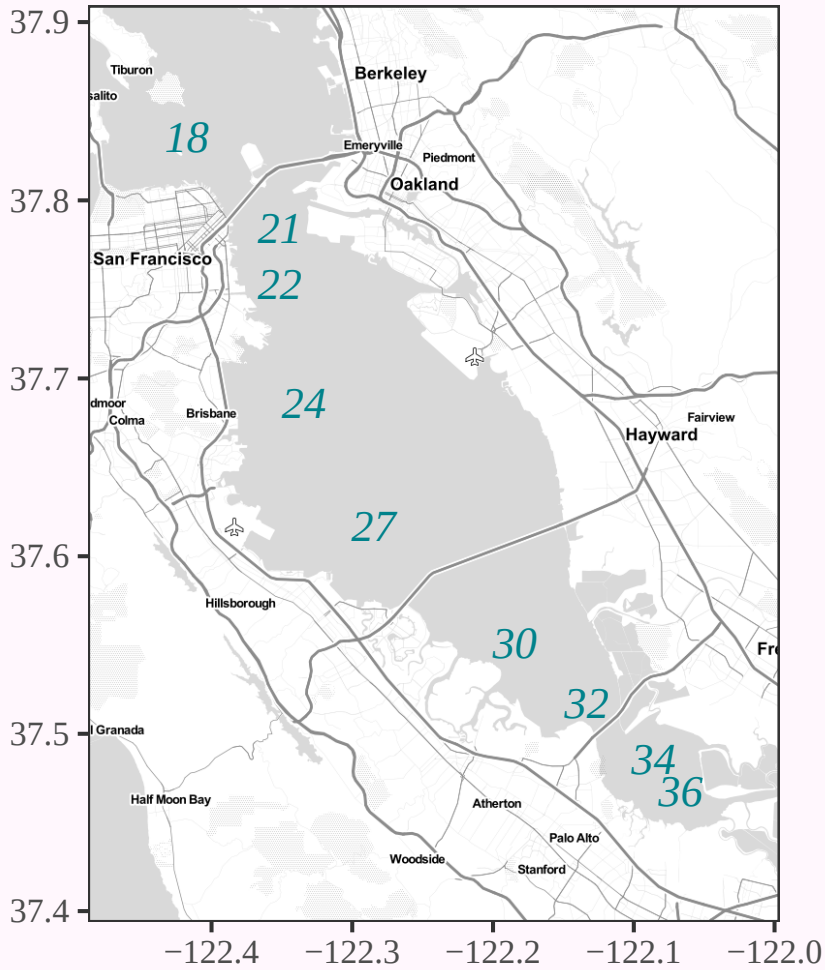

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- Nutrient Management Strategy (NMS) to characterize status/trends and management needs

South San Francisco Bay

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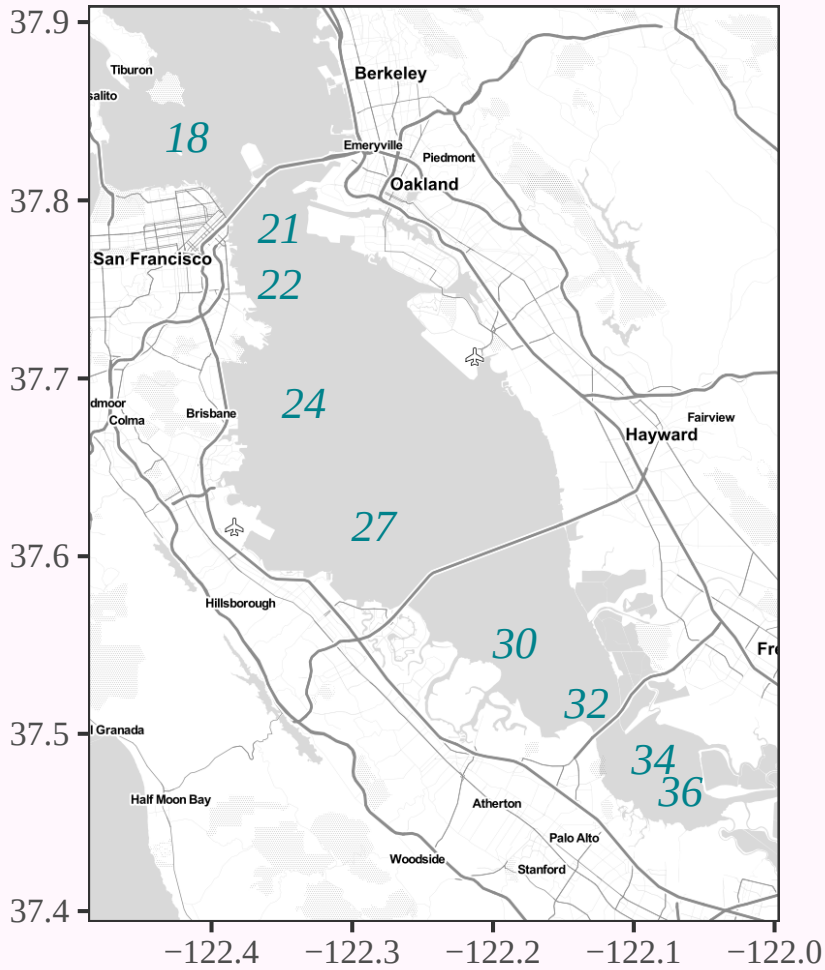
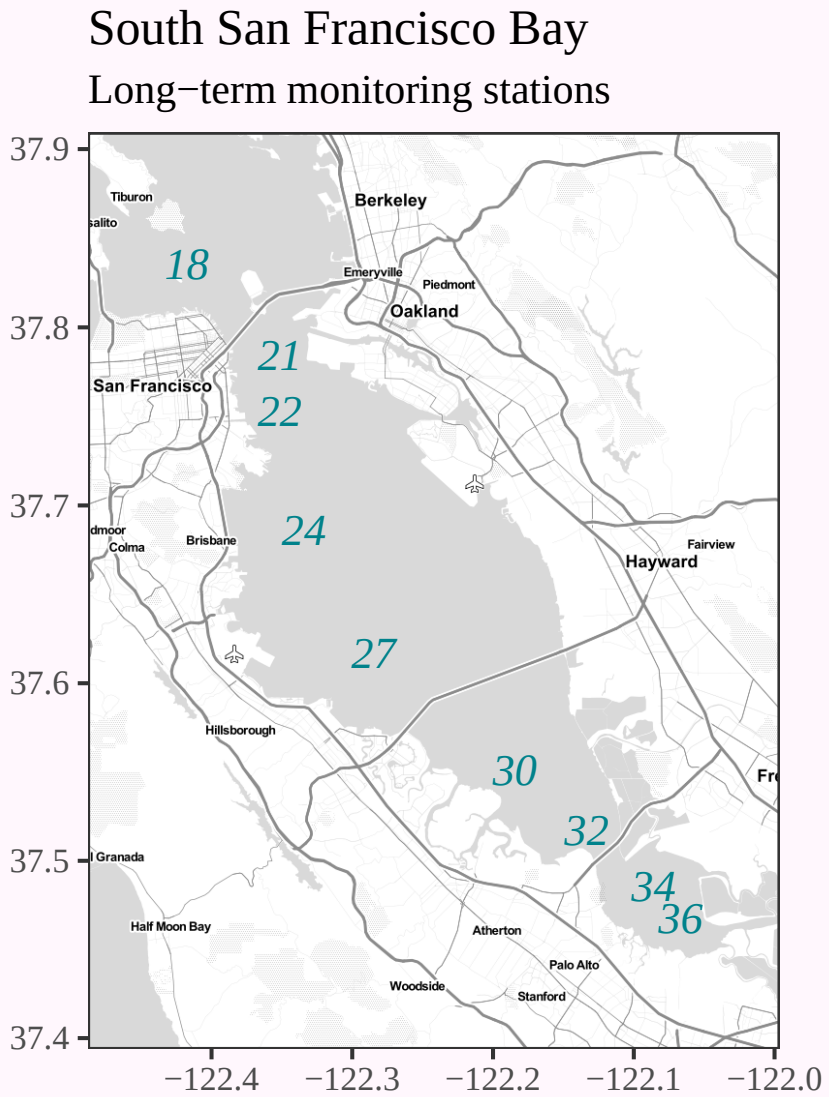


South San Francisco Bay

Questions of concern:



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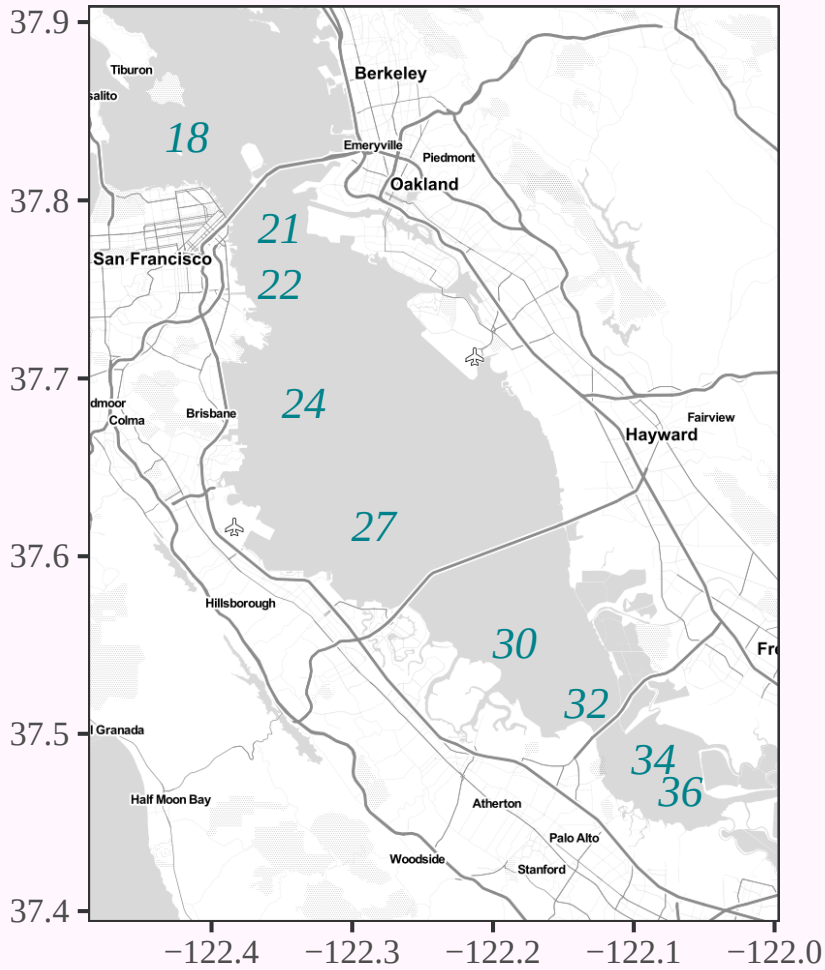
South San Francisco Bay

Long−term monitoring stations



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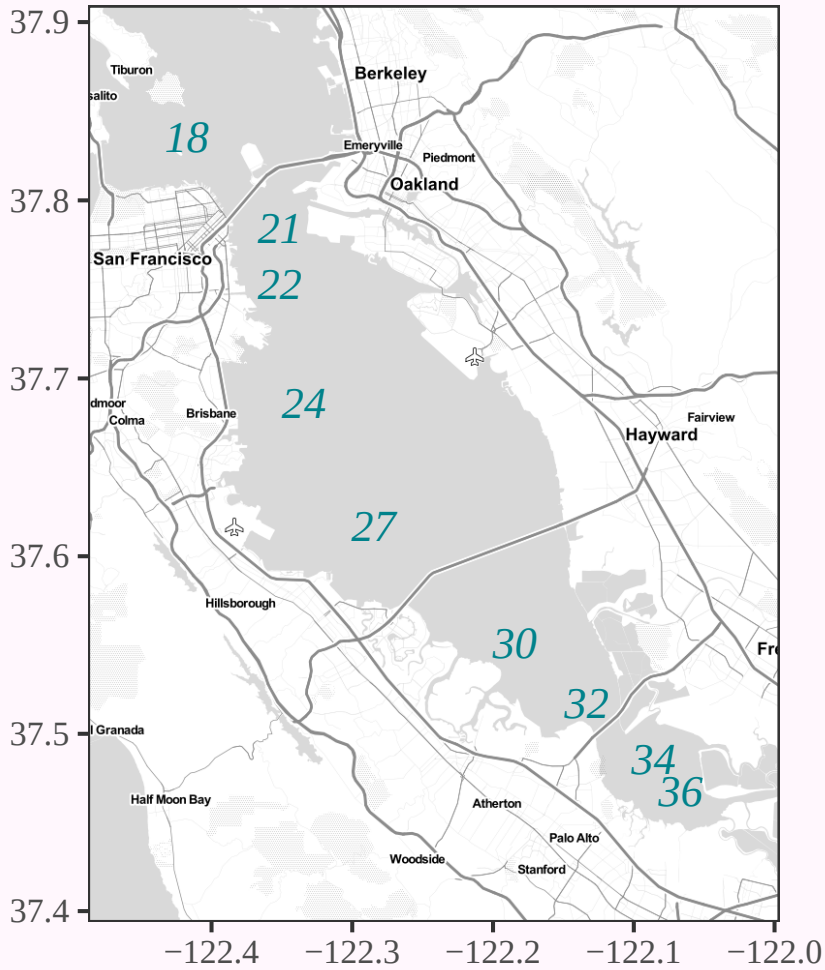

South San Francisco Bay

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?

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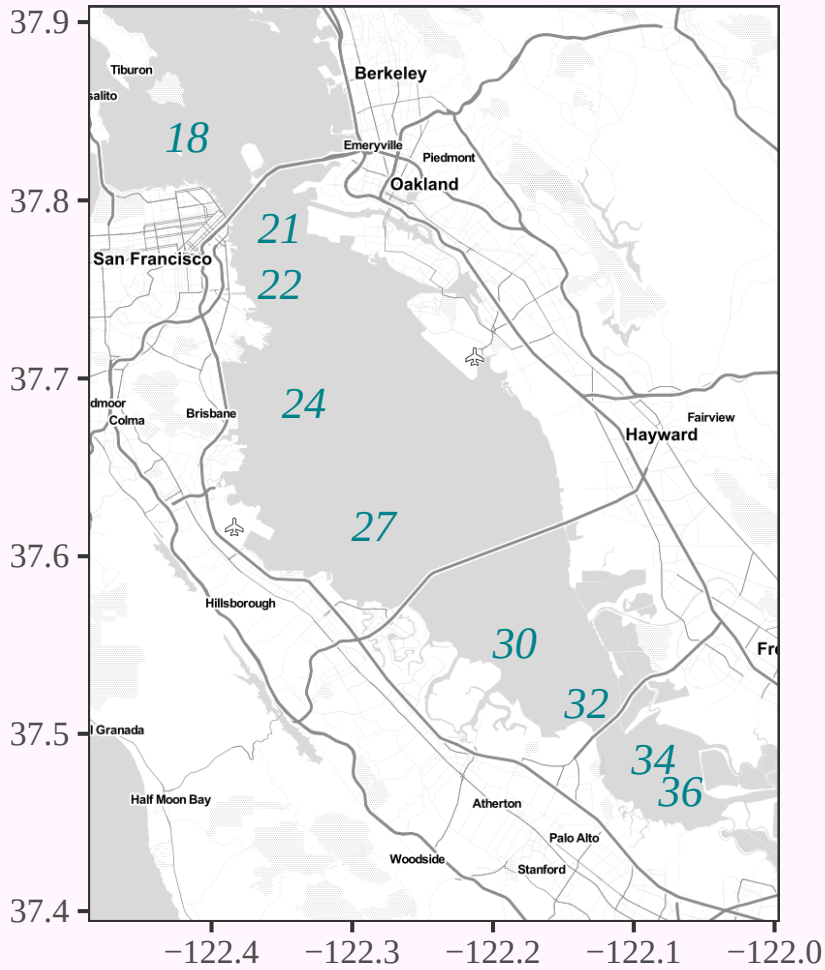

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  - `gam6`: chl $\sim$ year + s(doy) + s(year, k = large)

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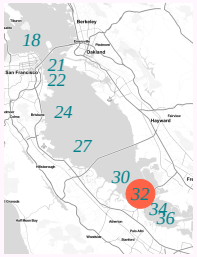

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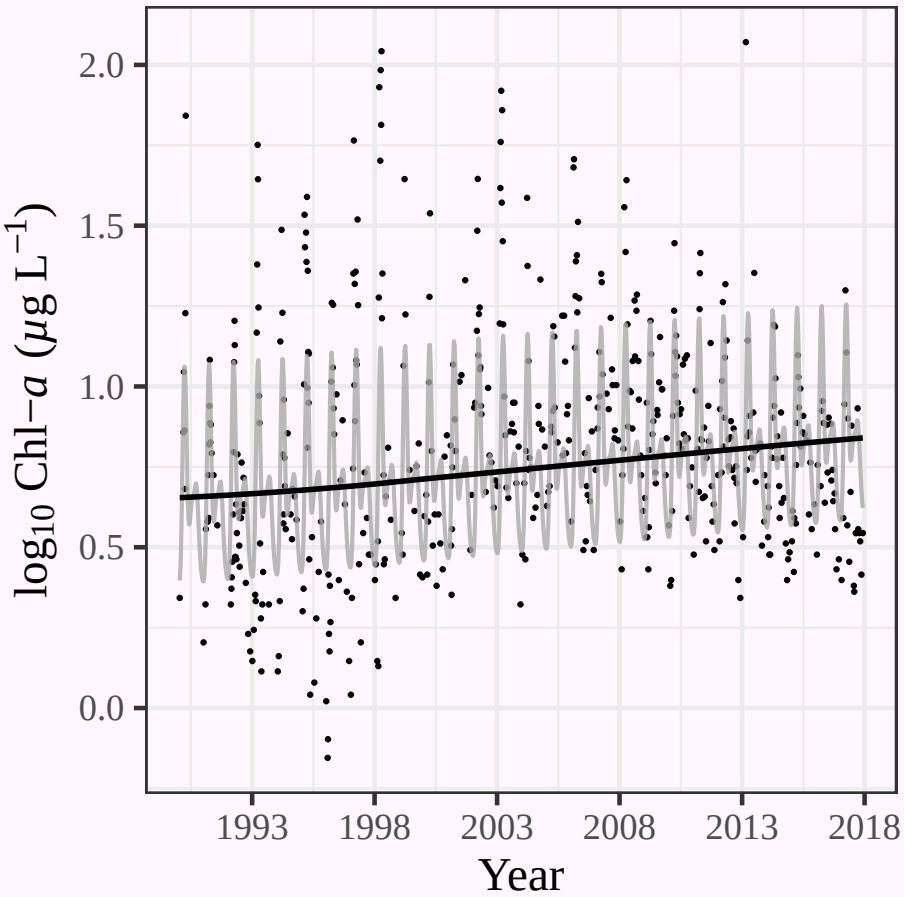

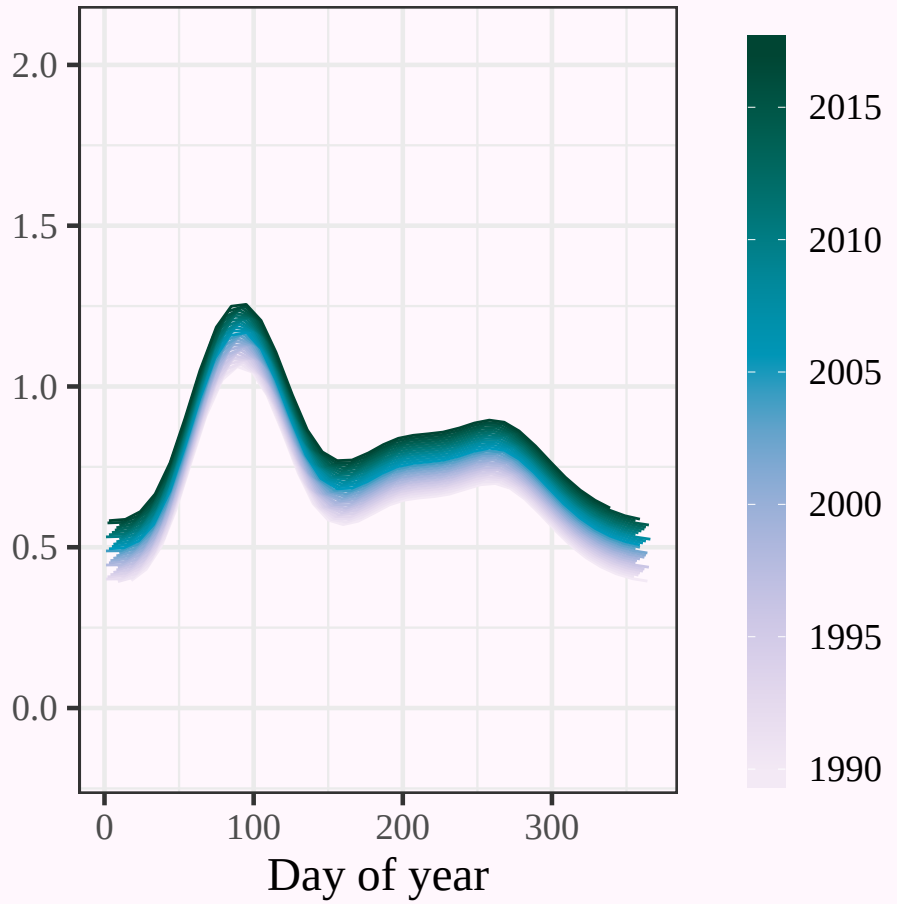

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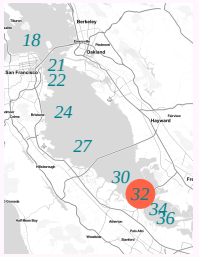
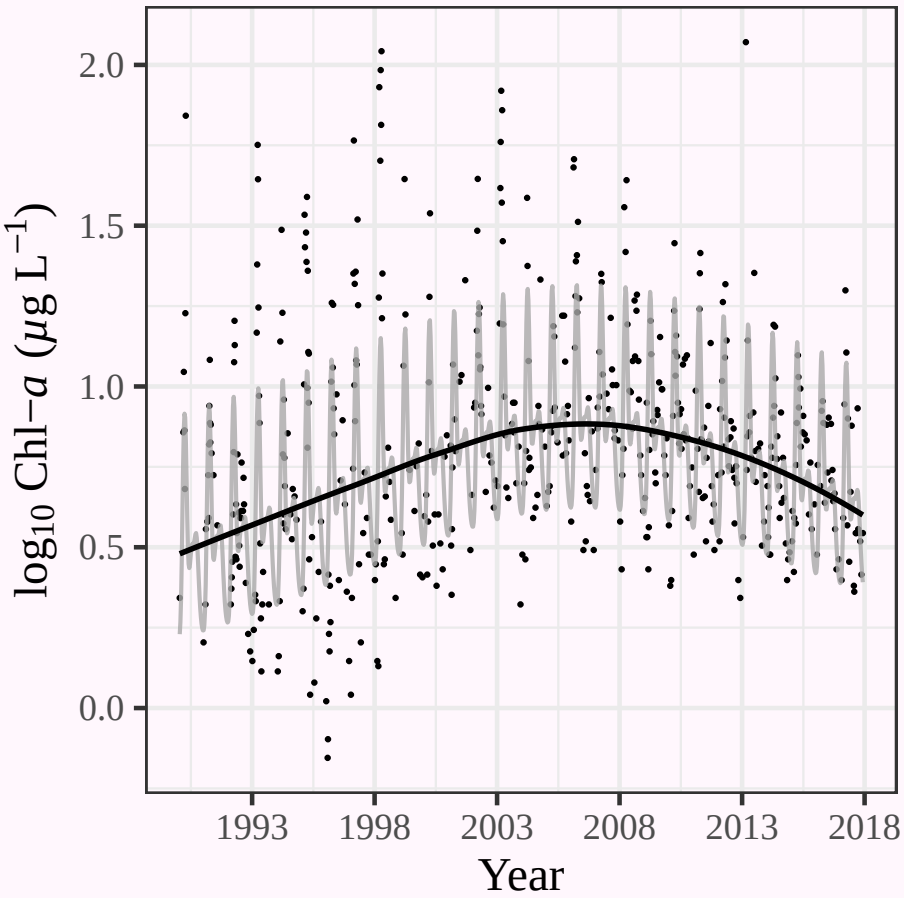
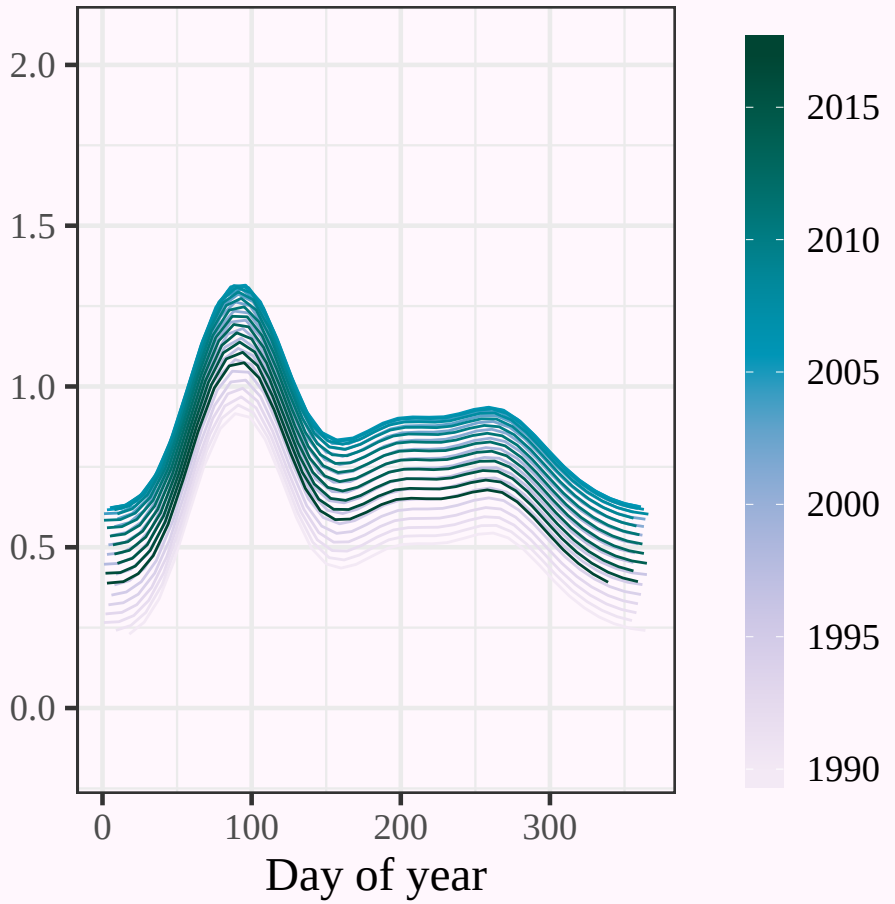


gam1: chl ~ year + s(doy) + s(year)





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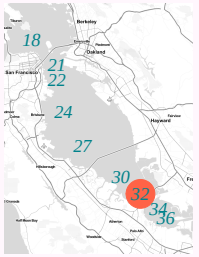
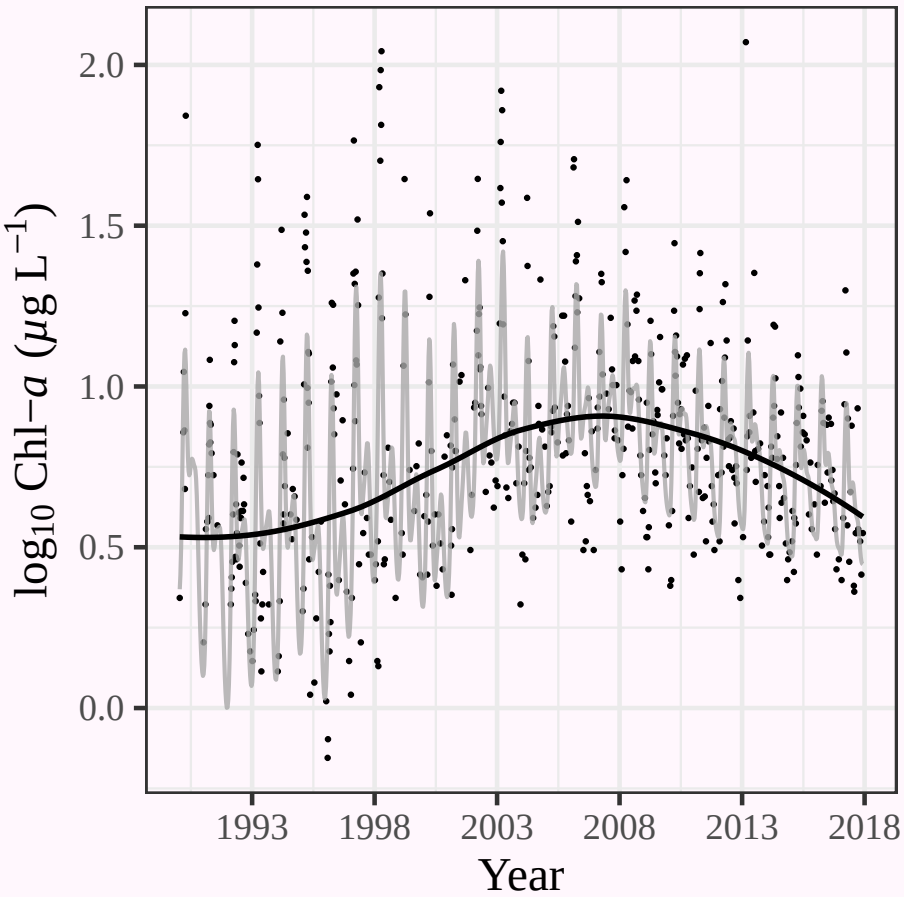
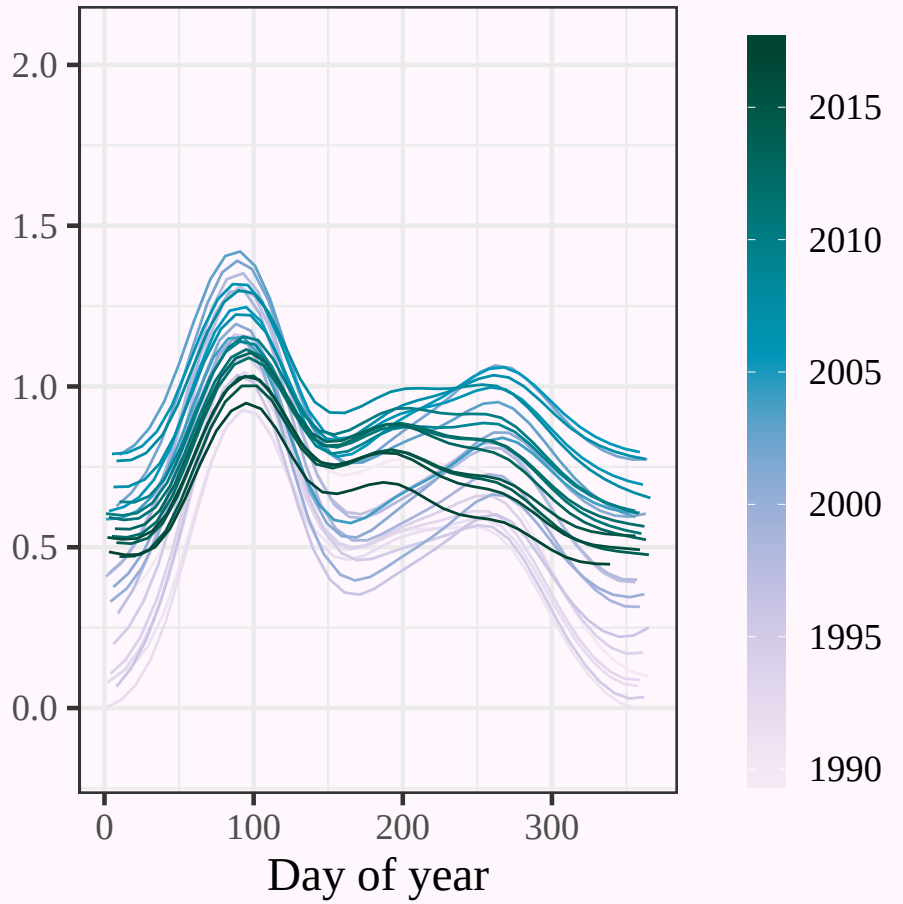


gam2: chl ~ year + s(doy) + s(year) + ti(doy, year)





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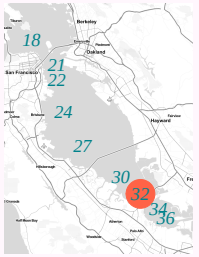

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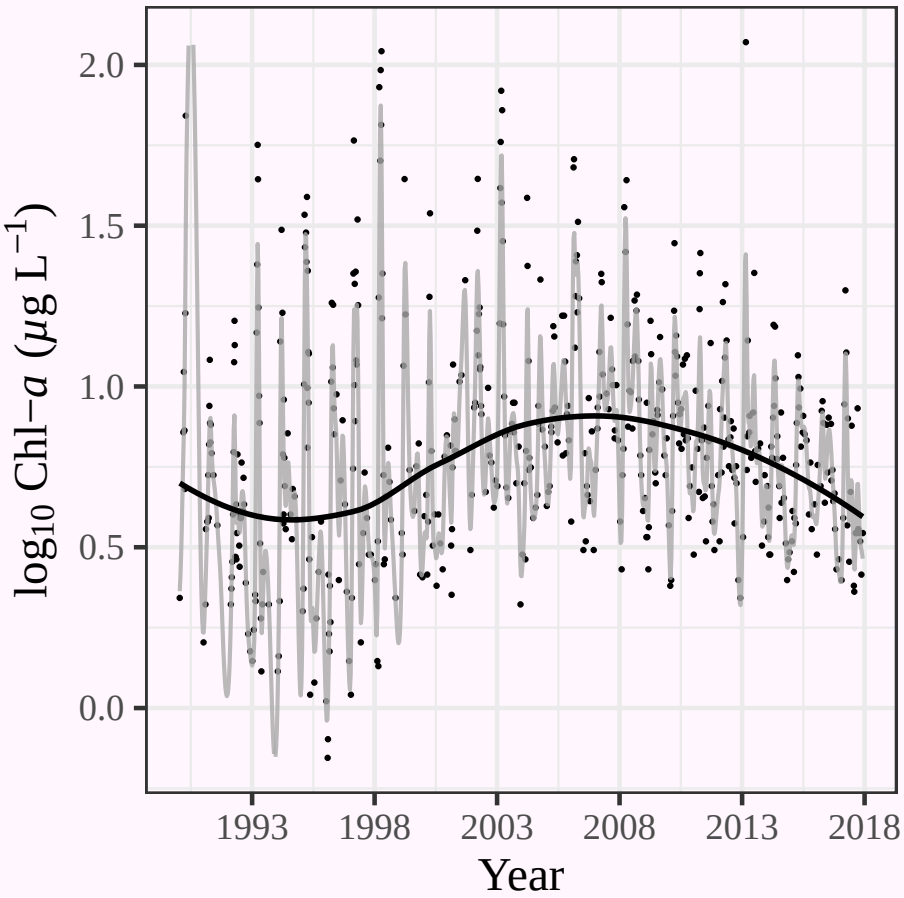

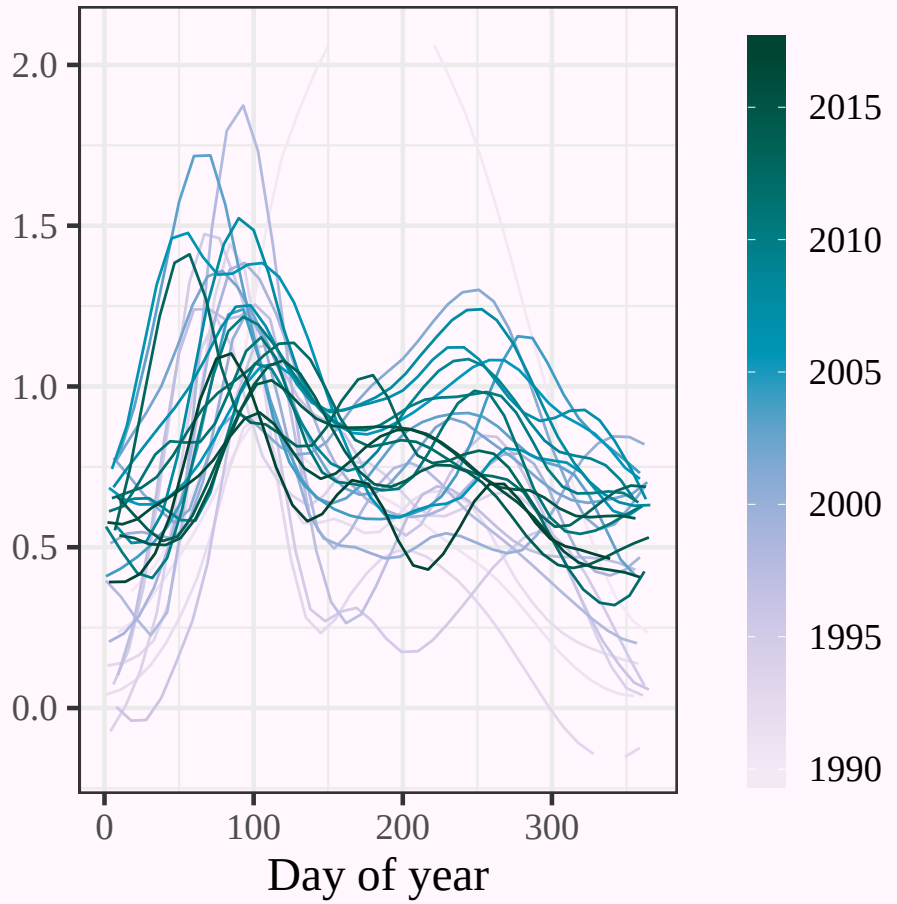

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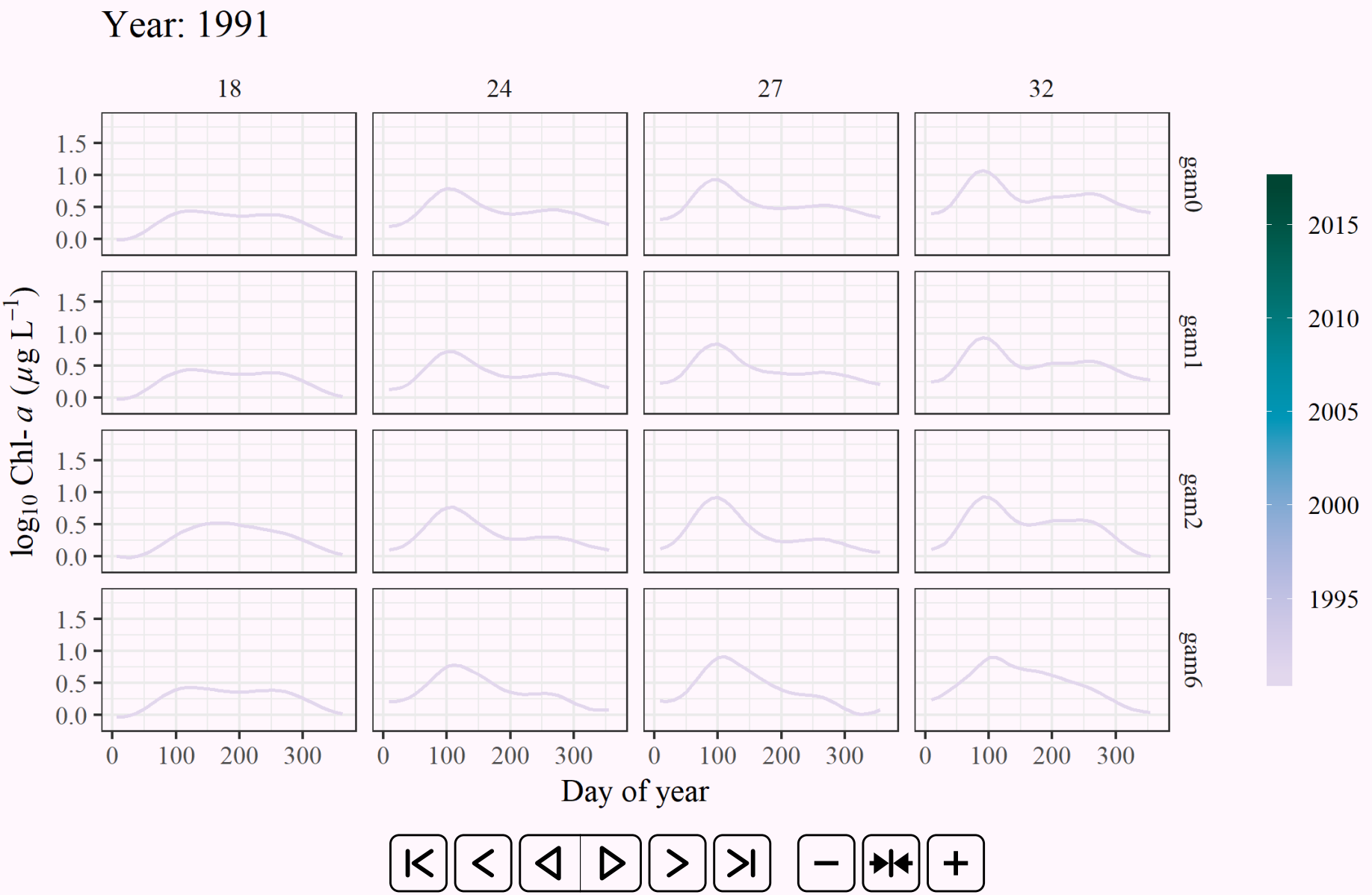

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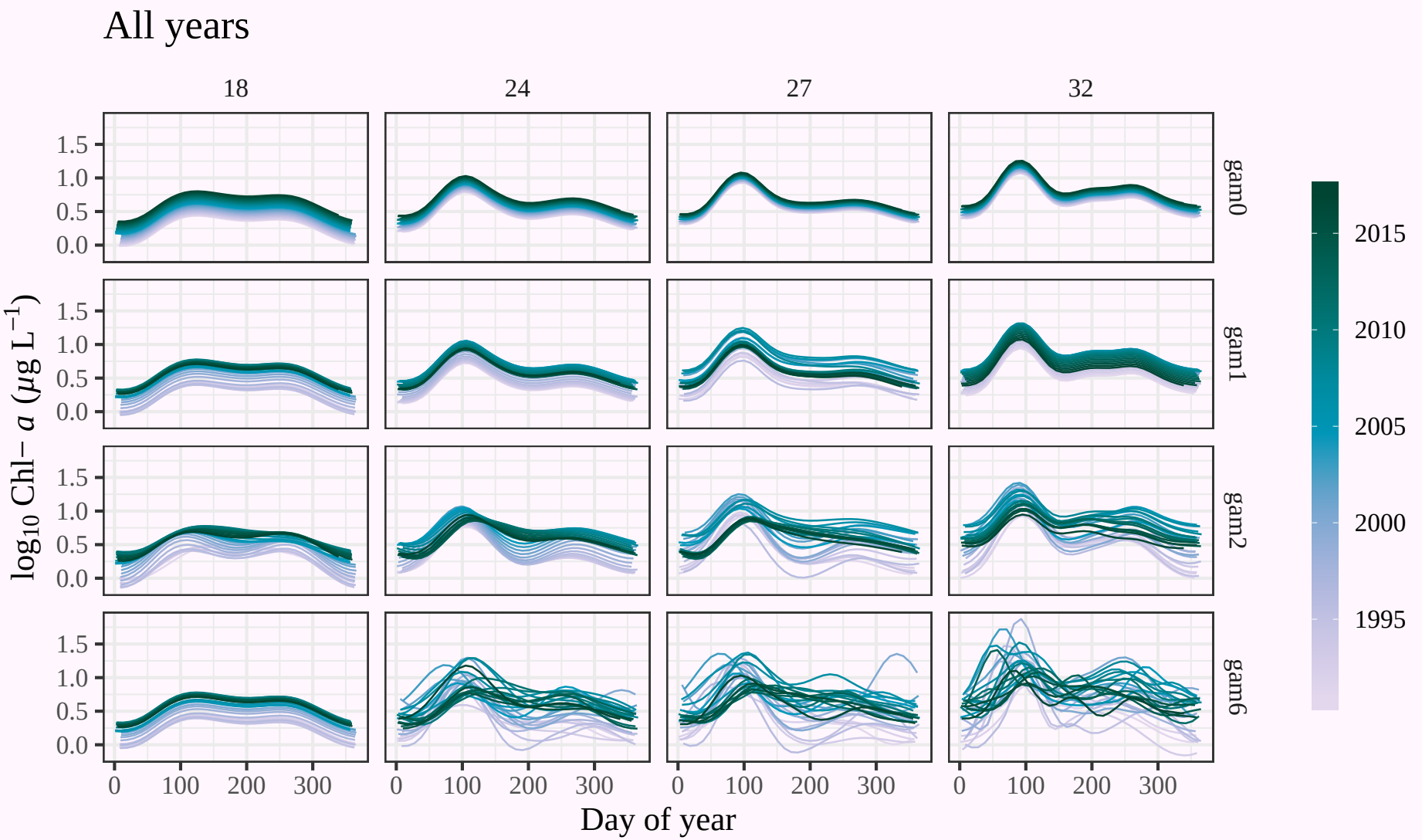

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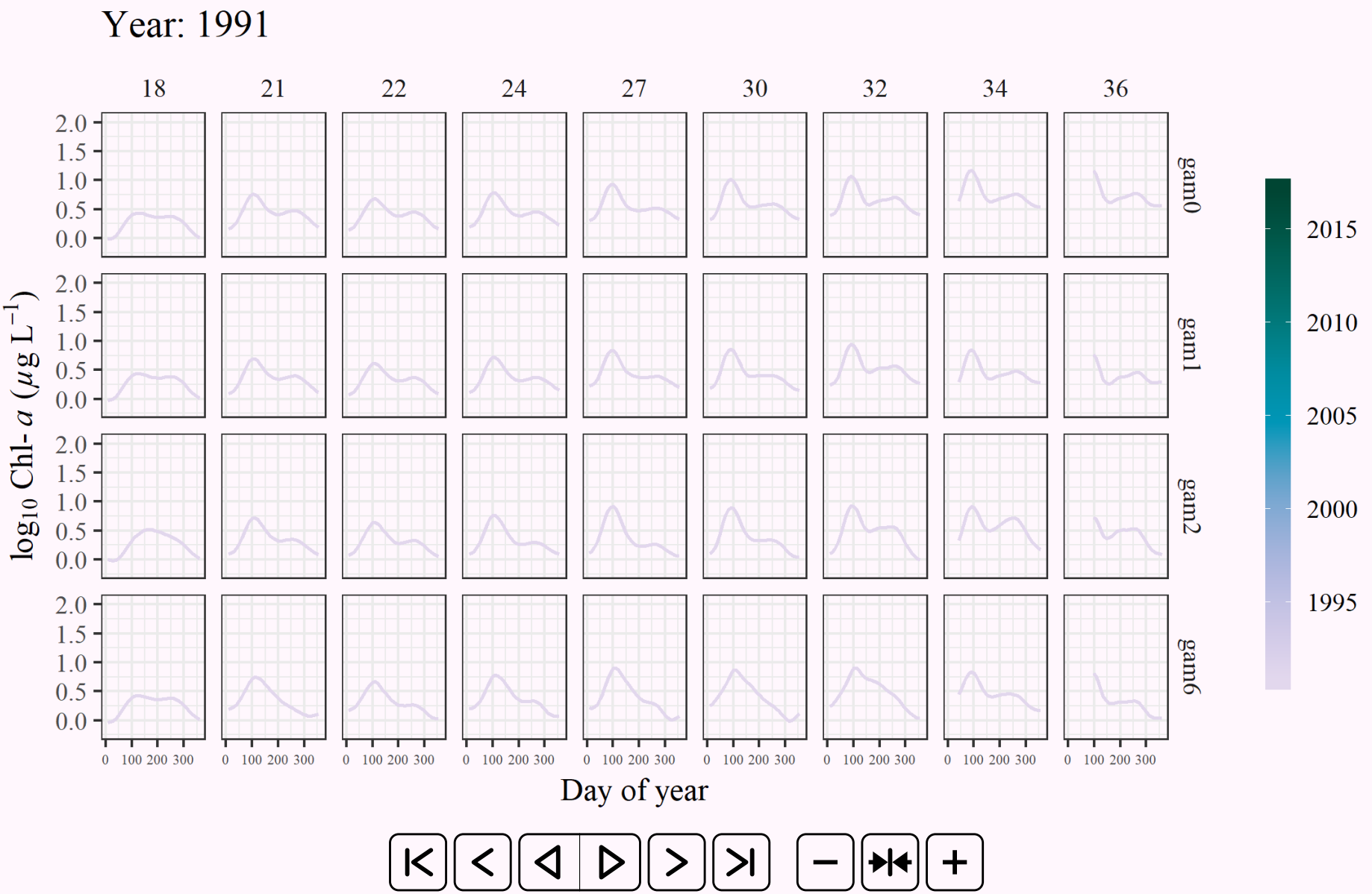

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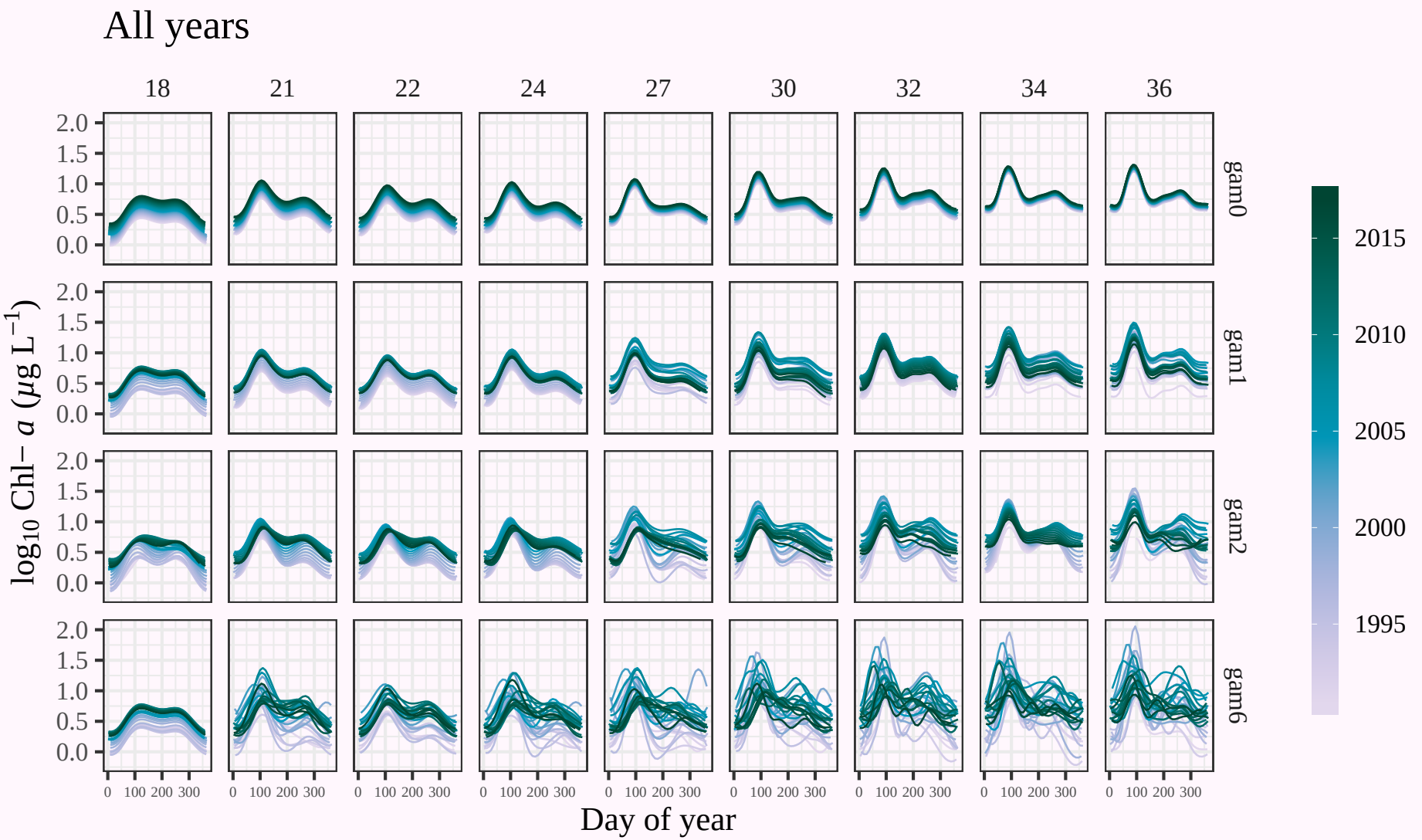

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Table: Generalized cross-validation (GCV) summary statistics by station and model

	Stations (north to south)								
Model	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

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Model	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

- More complex models provided more “parsimonious” fit
  - Non-monotonic trends were obvious
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How can this information support decision-making??

Shiny interactive web platform

https://sccwrp.shinyapps.io/sfbaytrends

GAM evaluation - SF South Bay

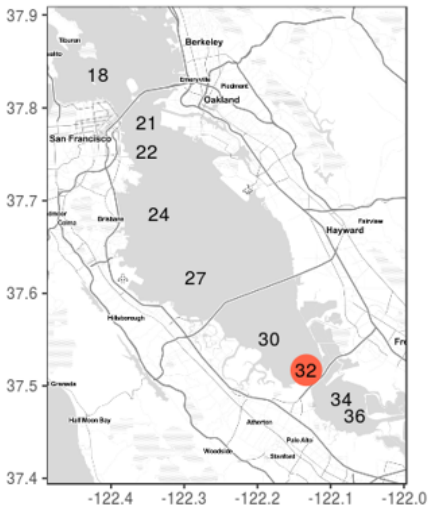
Exploratory plots

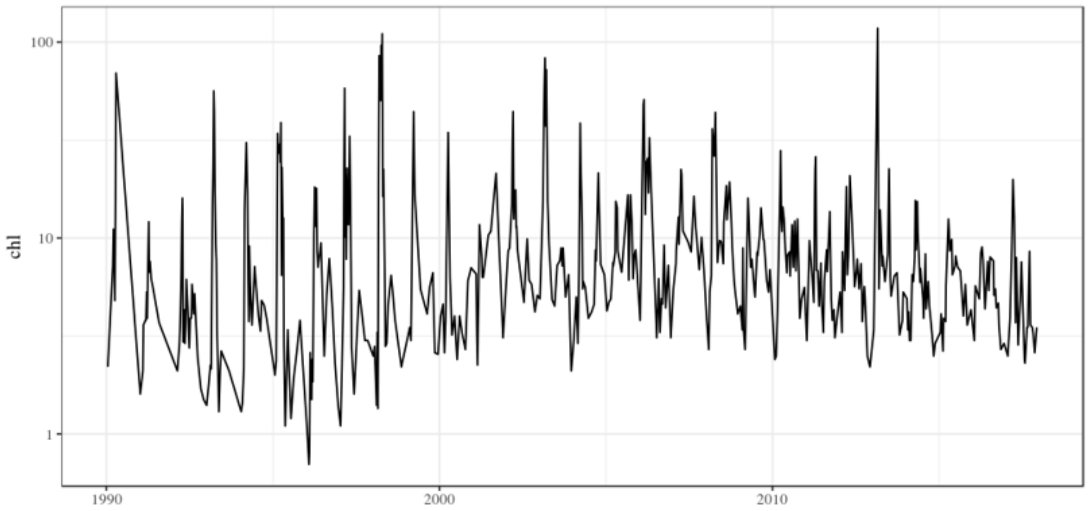
The following plots show the raw data for all monitoring stations and parameters in South Bay, 1990 - 2017. Select the parameter, plot type (total time series, by year, or by month), and variable transformation. The year and month plots are aggregated boxplots of all observations at a station for each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



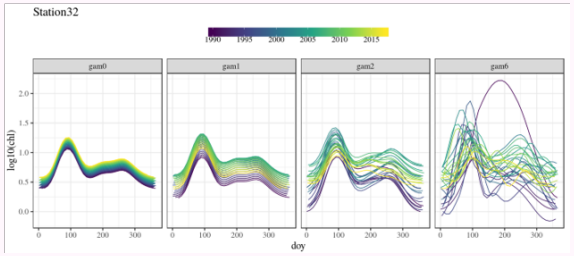


Shiny interactive web platform

Explore results for each station, by model

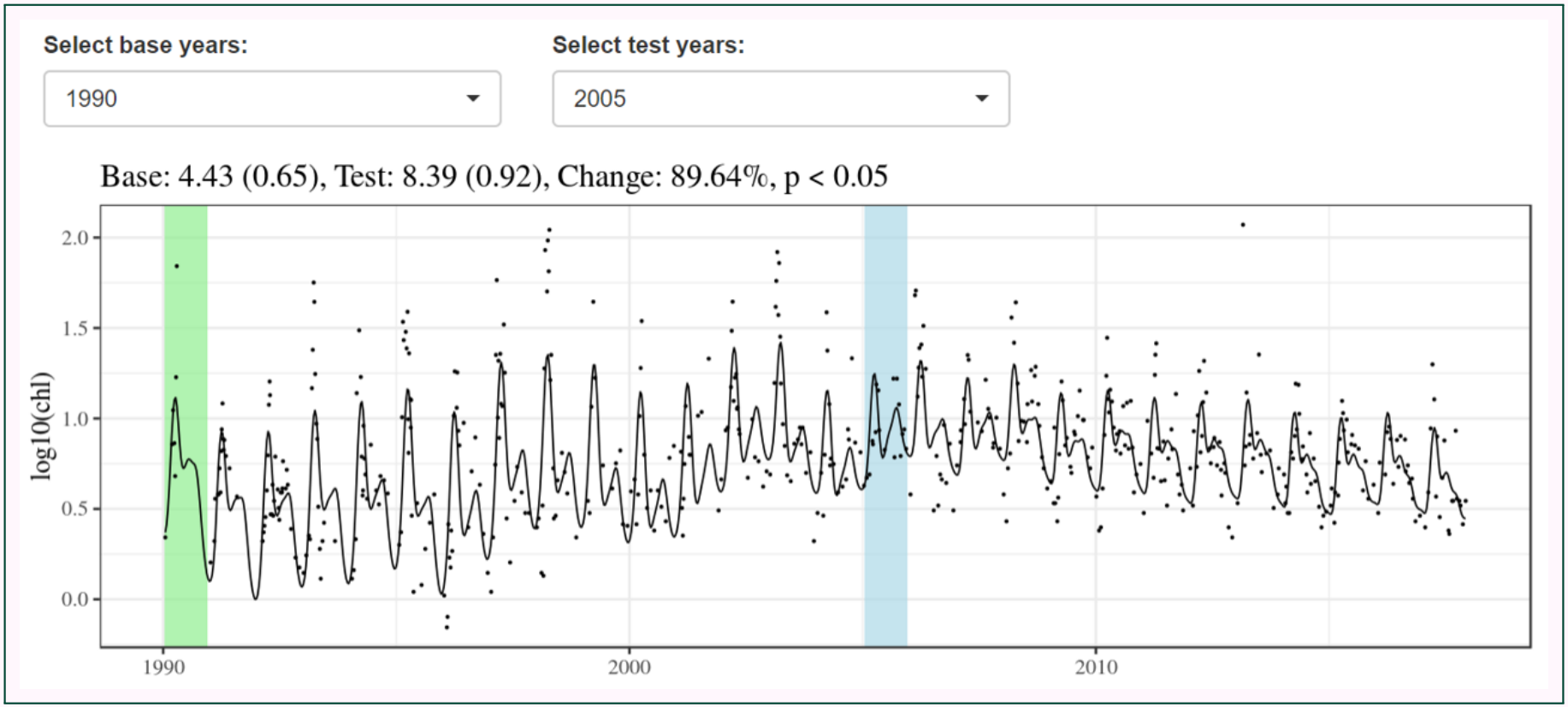
model	smoother	edf	Ref.df	F	p.value
gam0	s(doy)	7.10	8.00	31.64	0.00
gam1	s(dec_time)	2.45	27.00	2.74	0.00
gam1	s(doy)	7.17	8.00	37.97	0.00
gam2	s(dec_time)	21.40	27.00	5.05	0.00
gam2	s(doy)	7.11	8.00	42.39	0.00
gam2	ti(dec_time,doy)	8.98	12.00	3.98	0.00
gam6	s(dec_time)	218.84	334.00	3.06	0.00
gam6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



Shiny interactive web platform

Perform trend tests with selected years



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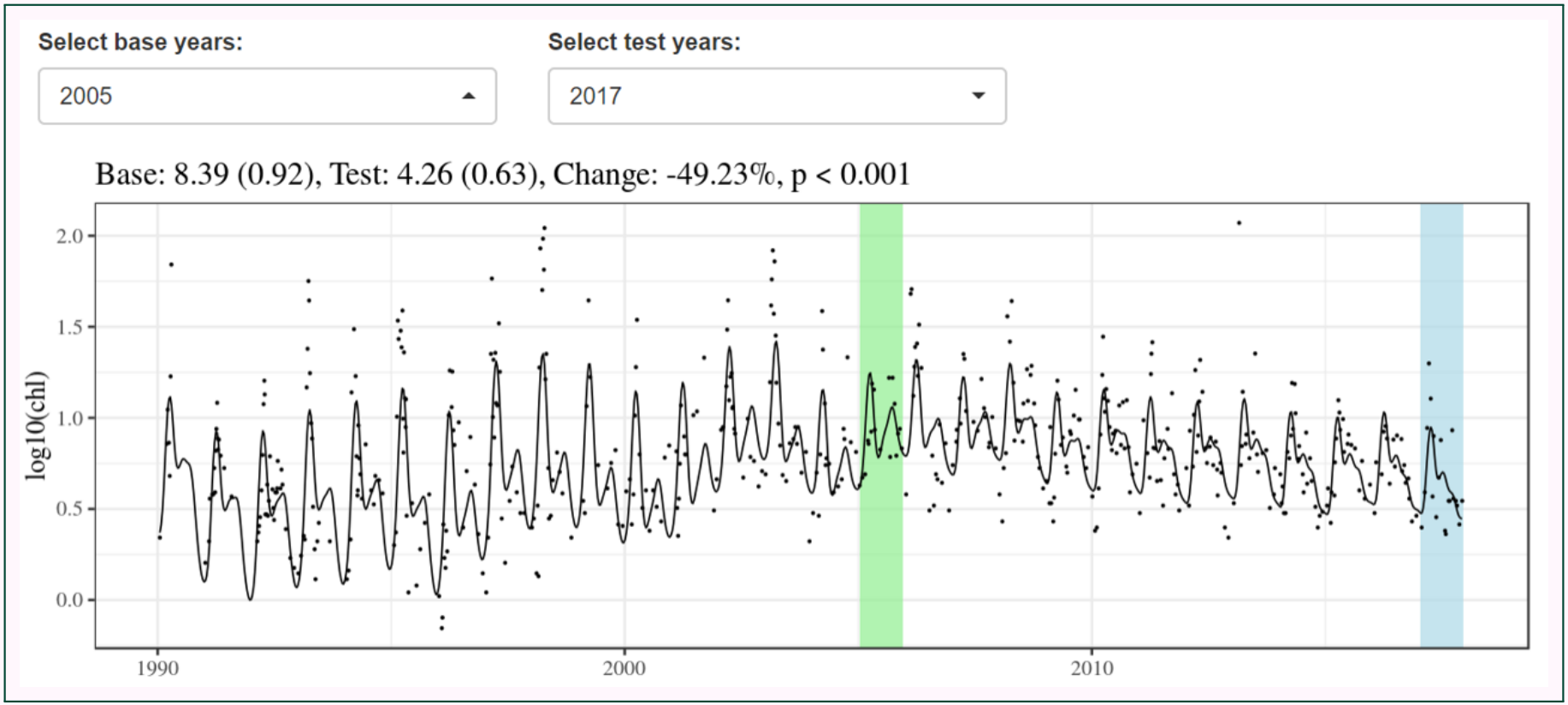
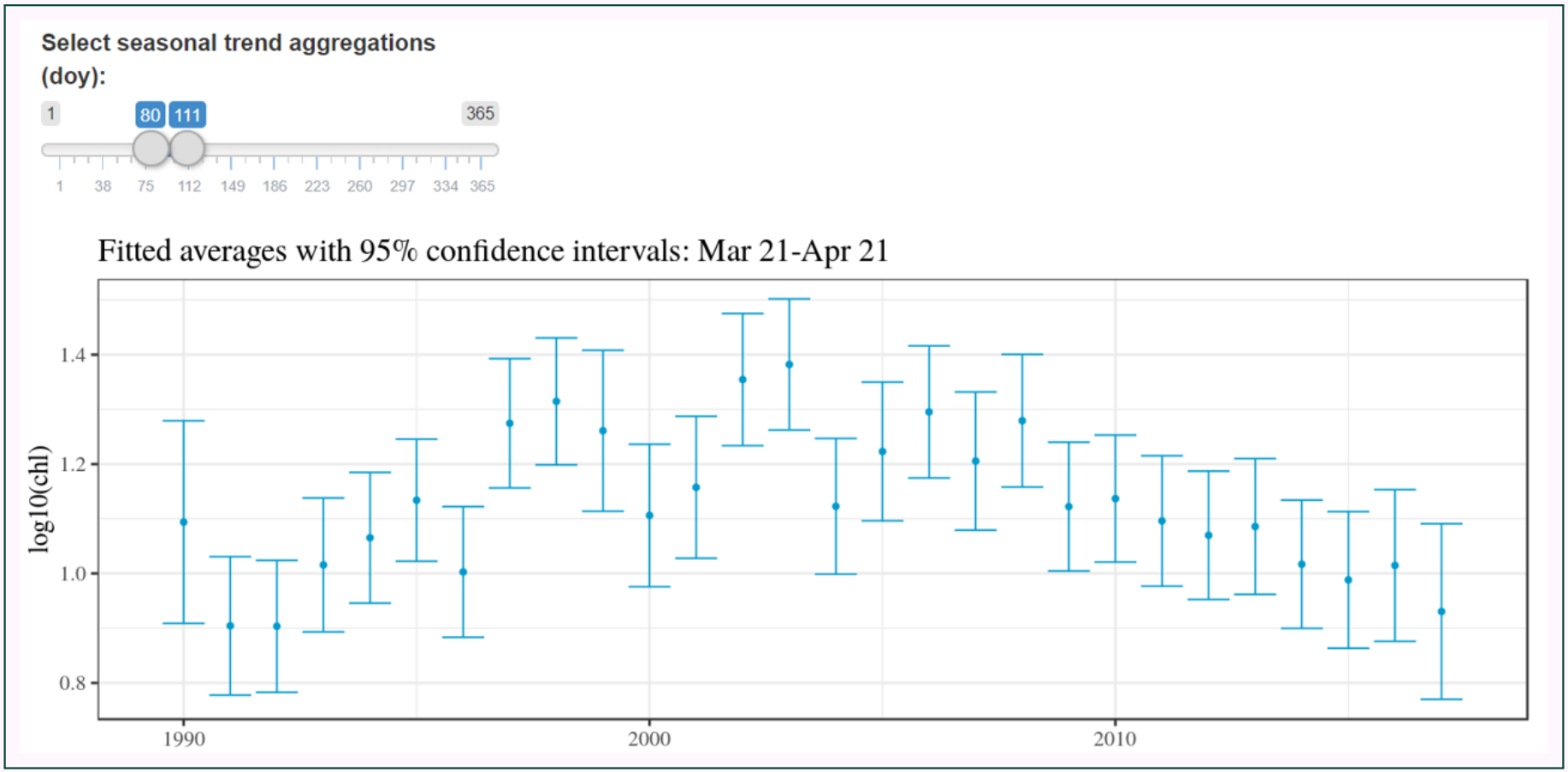


Shiny interactive web platform

Evaluate trends between years, by season



Shiny interactive web platform

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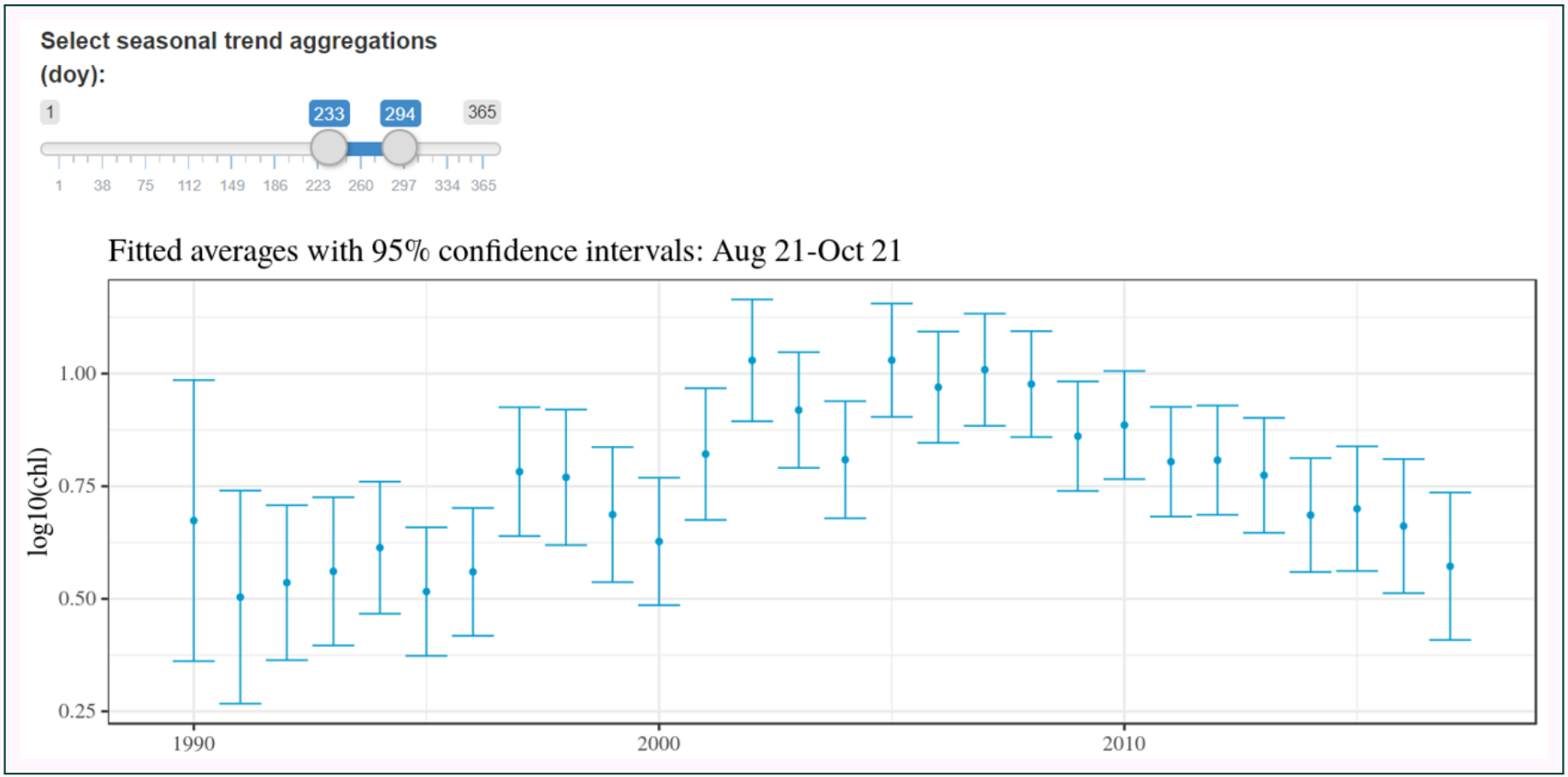

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  - Which station, model, and time period do I care about?
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- Follow-up work:
  - Extend to other locations in the Bay
  - Explore trend analysis of aggregated stations
  - Incorporate additional 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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