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

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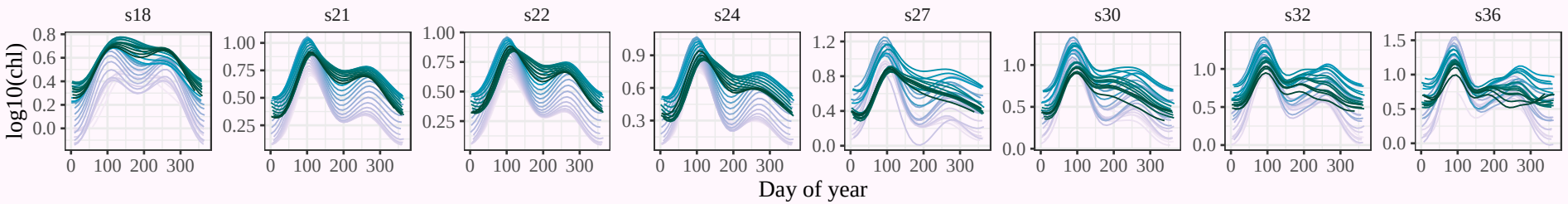
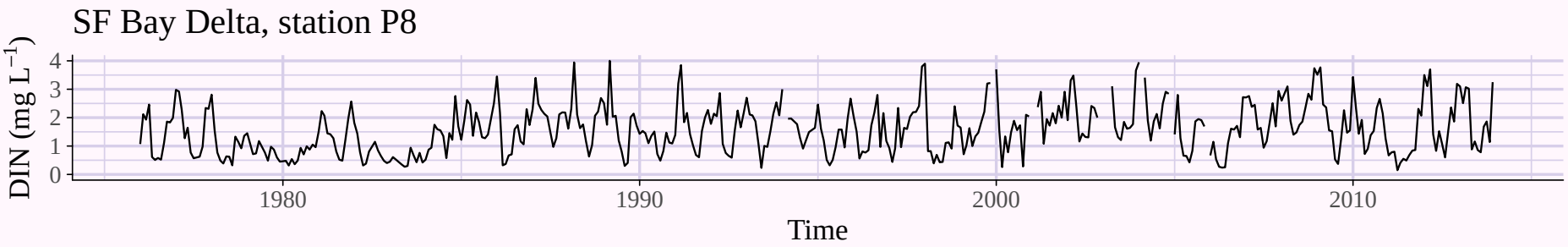


Why do we care about trends?

- Provide information on natural variation of water quality parameters - identify 1st order principles to understand a system
- Document historical changes in response to management actions - did investments make a difference?
- Anticipate future changes with proposed restoration or management - understand the past to predict the future

Trends vary in space and time

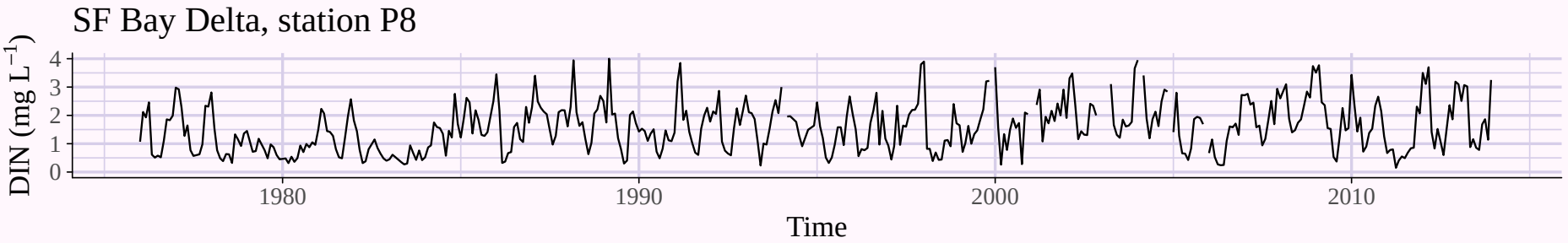
Observed data represent effects from many processes



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

Must translate data into information

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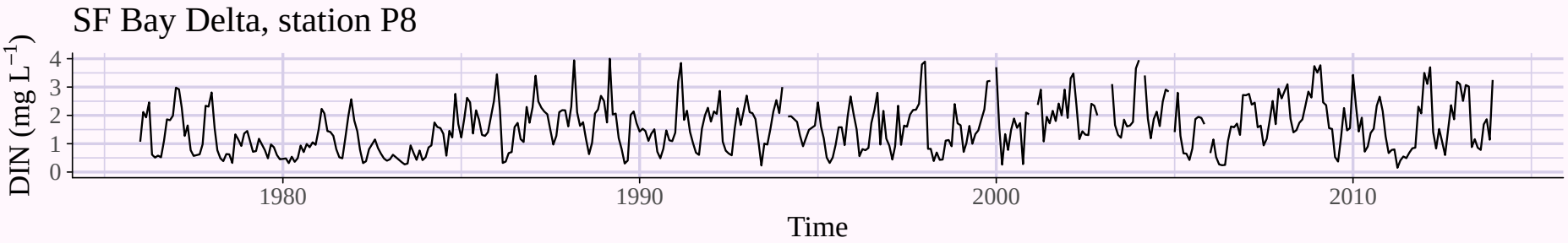

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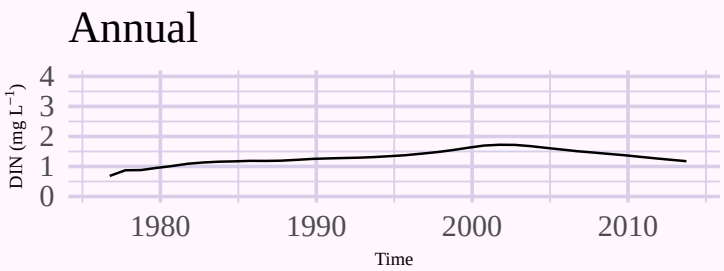

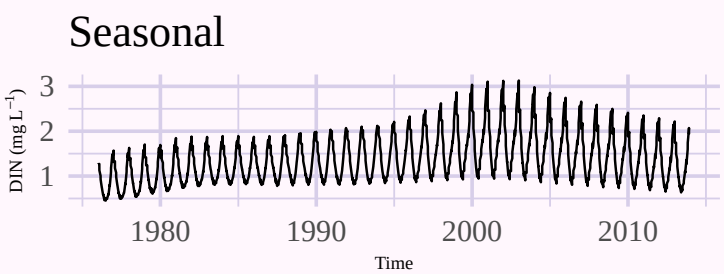

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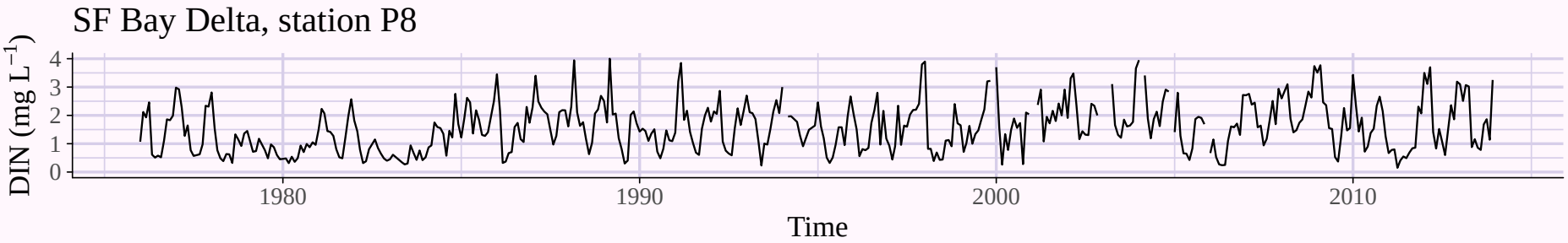
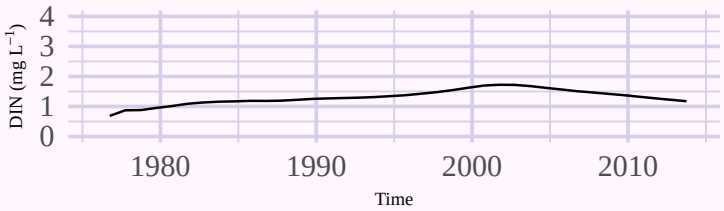
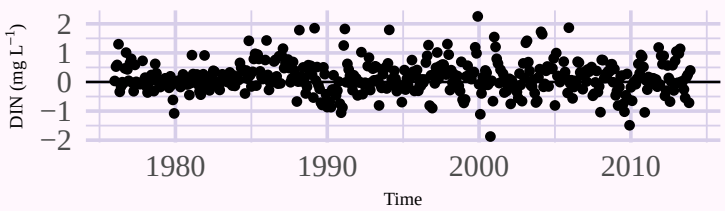


Models should describe components to evaluate effects

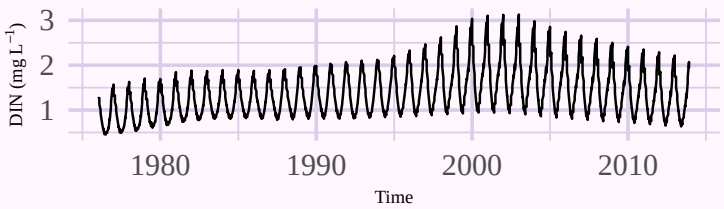
Annual



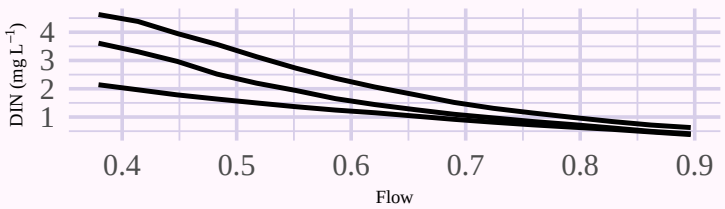
Residual



Seasonal



Flow effects



South San Francisco Bay

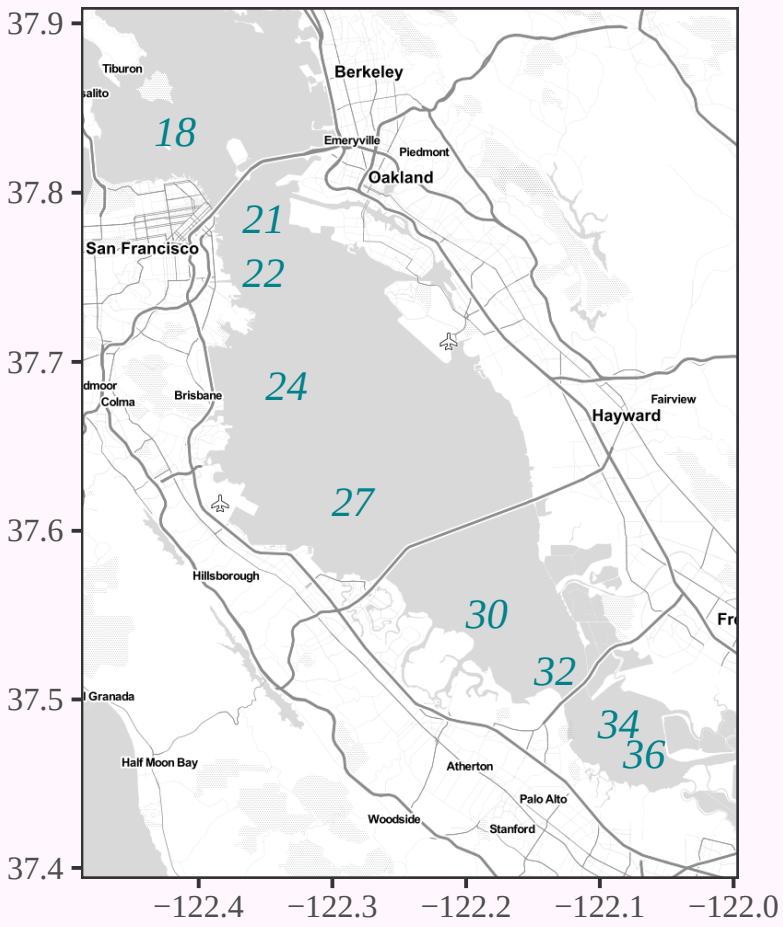
- Historically a high-nutrients, high-turbidity, low-productivity system

  [Cole and Cloern, 1984,

  Alpine and Cloern, 1988]

South San Francisco Bay

Long−term monitoring stations



South San Francisco Bay

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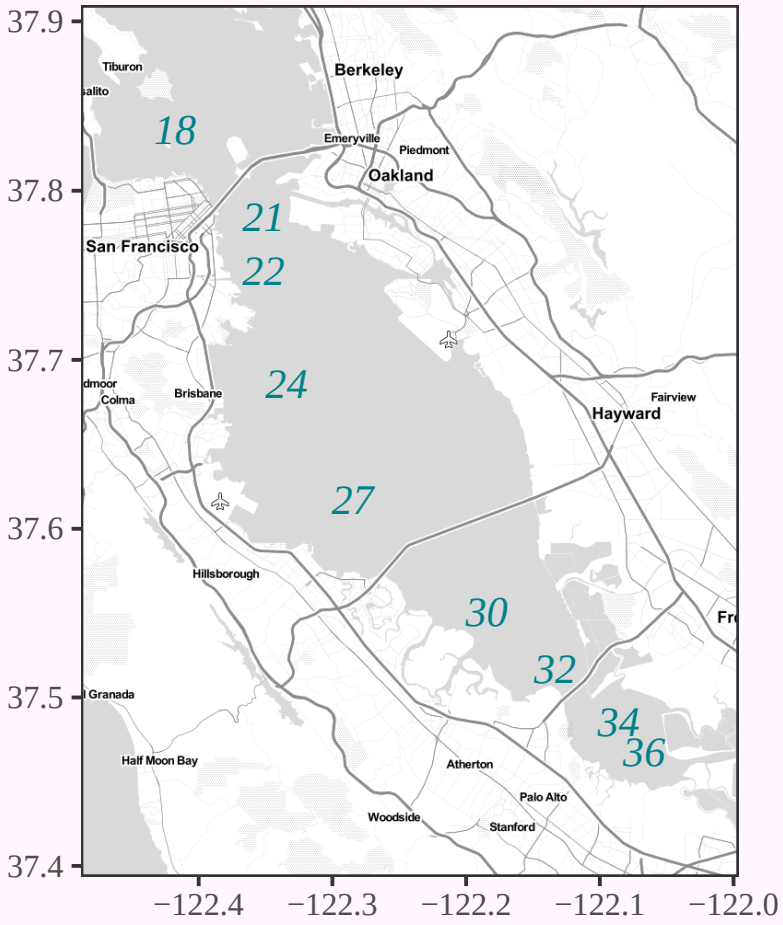
- Recent increases observed in summer-fall chl-a concentrations

  [Cloern et al., 2007, Cloern and Jassby, 2012]

South San Francisco Bay

Long−term monitoring stations



South San Francisco Bay

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- Recent increases observed in summer-fall chl-a concentrations

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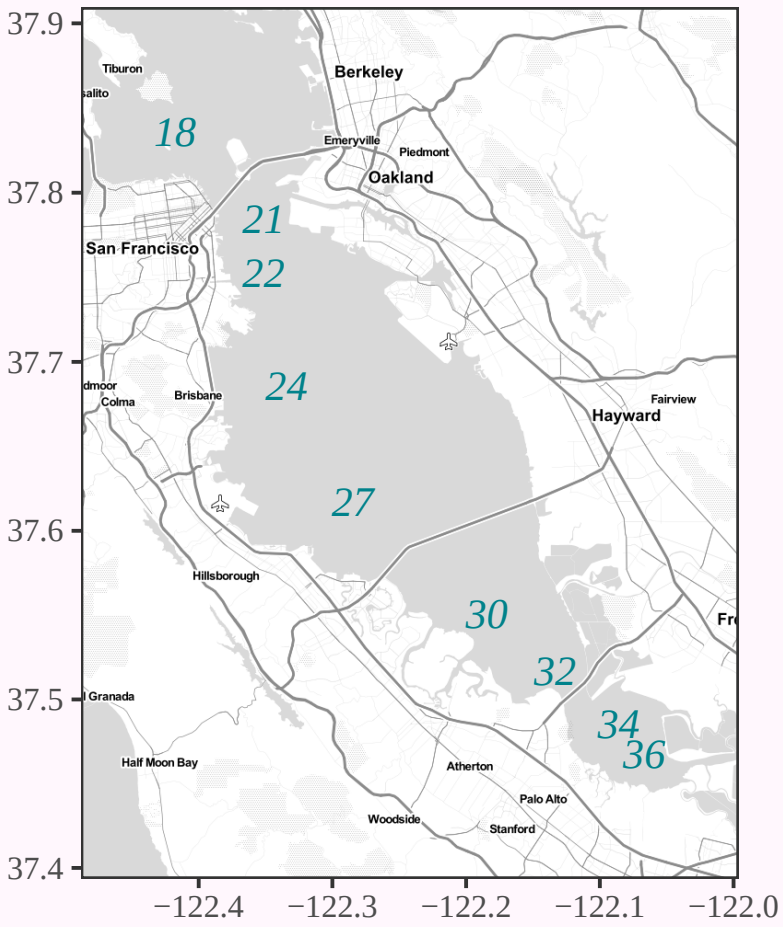
- Lead to creation of a Nutrient Management Strategy (NMS) to characterize status/trends and management needs

South San Francisco Bay

Long−term monitoring stations

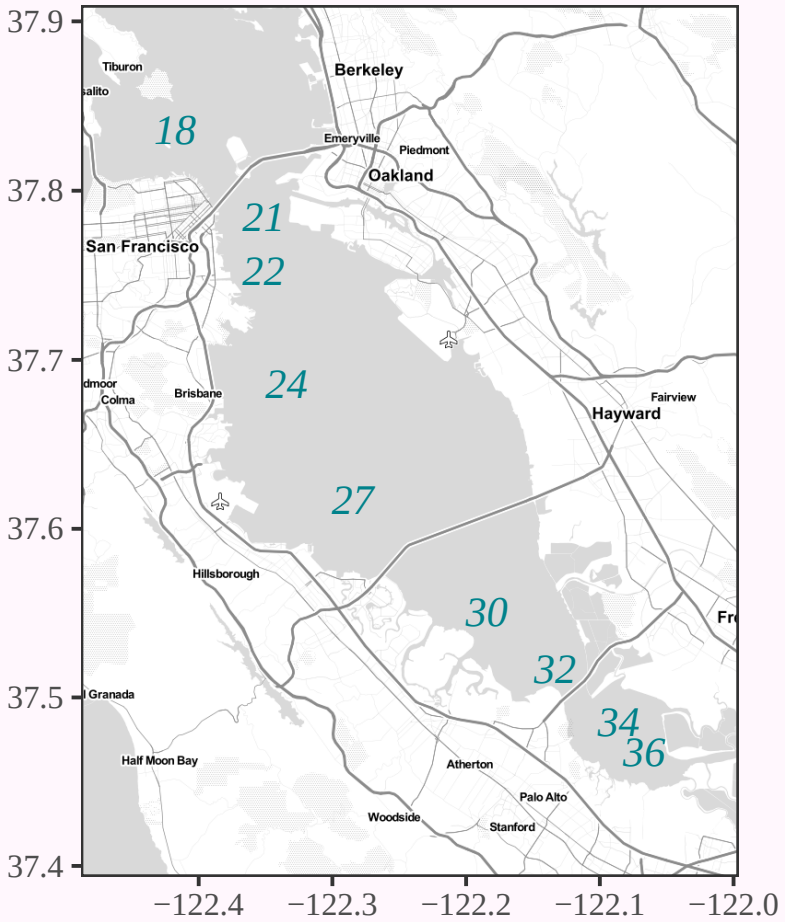


South San Francisco Bay

Questions of concern:

South San Francisco Bay

Long−term monitoring stations



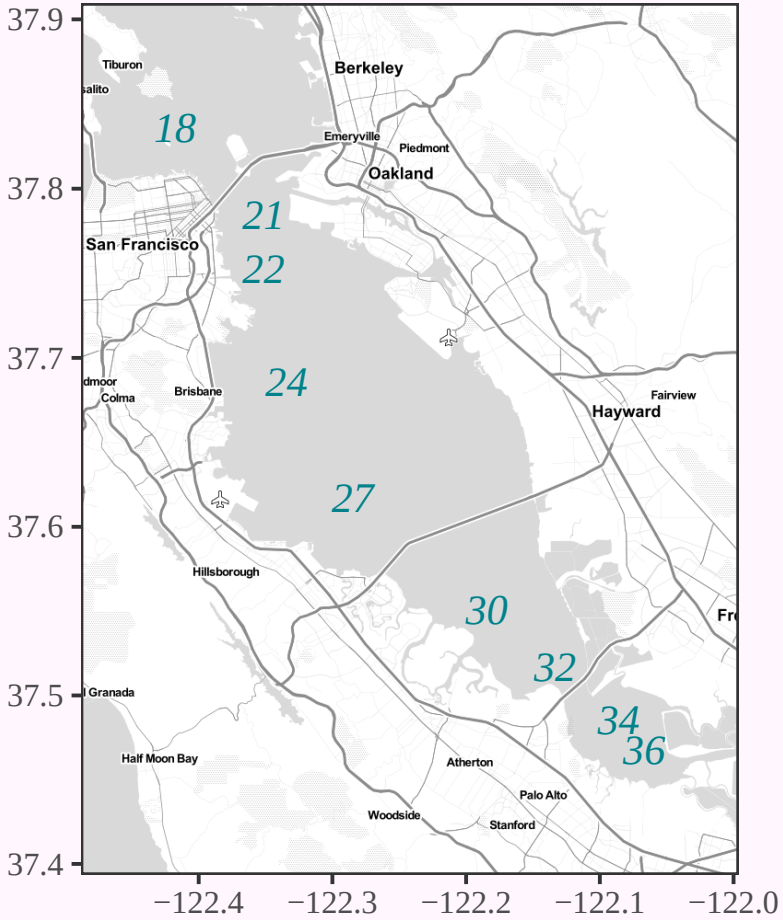
South San Francisco Bay

Questions of concern:

- Since changes are visually apparent, which are significant?

South San Francisco Bay

Long−term monitoring stations



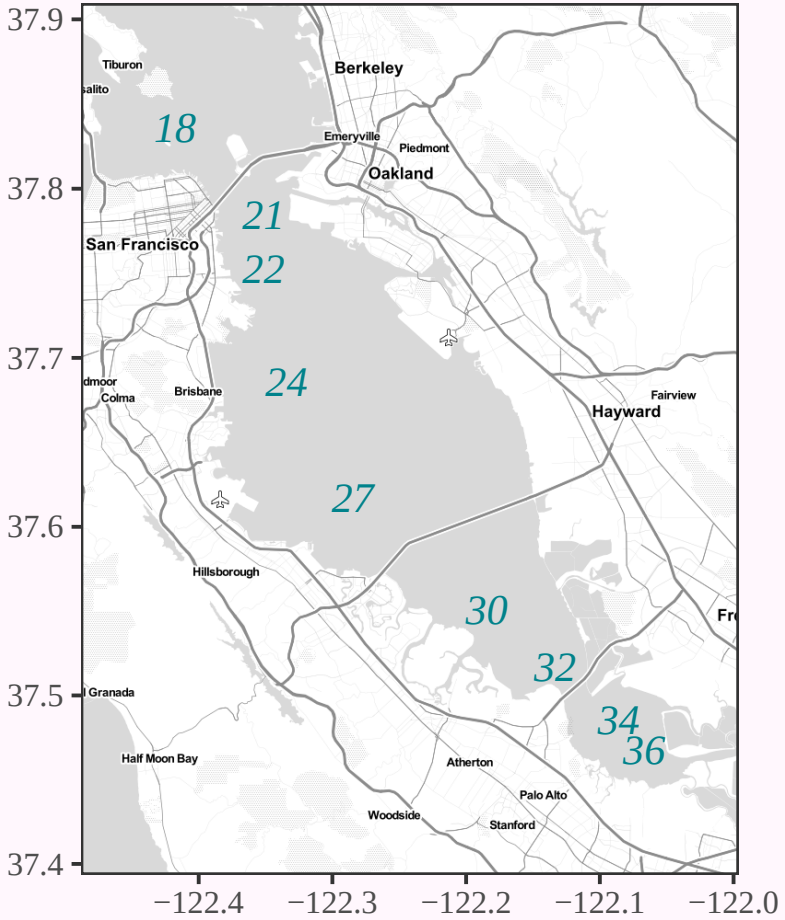
South San Francisco Bay

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?

South San Francisco Bay

Long−term monitoring stations



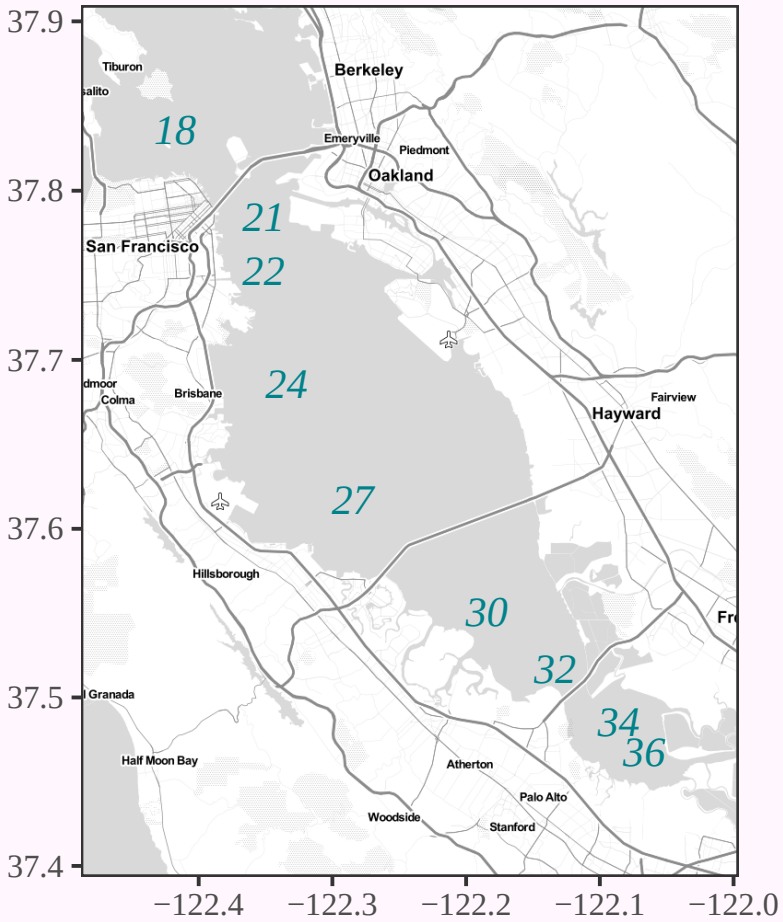
South San Francisco Bay

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, i.e., can a flexible statistical analysis method be applied to evaluate significant, non-linear changes in water quality parameters? [Beck and Murphy, 2017, Murphy et al., 2019b]

- We applied Generalized Additive Models (GAMs) developed by CBP to characterize long-term trends at nine stations over thirty years in South SF Bay

- An interactive website was also developed using R Shiny to explore trends and communicate results with stakeholders

Application of additive models

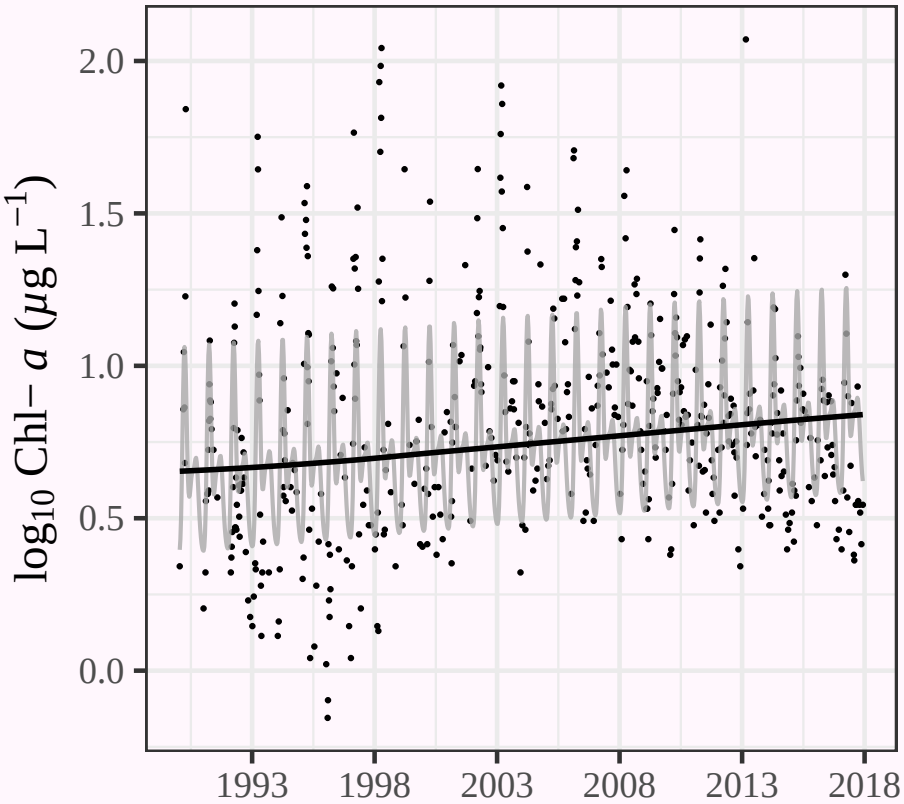
For each station, chlorophyll was modelled as a function of annual and seasonal changes over time baytrends R package, [Murphy et al., 2019a]

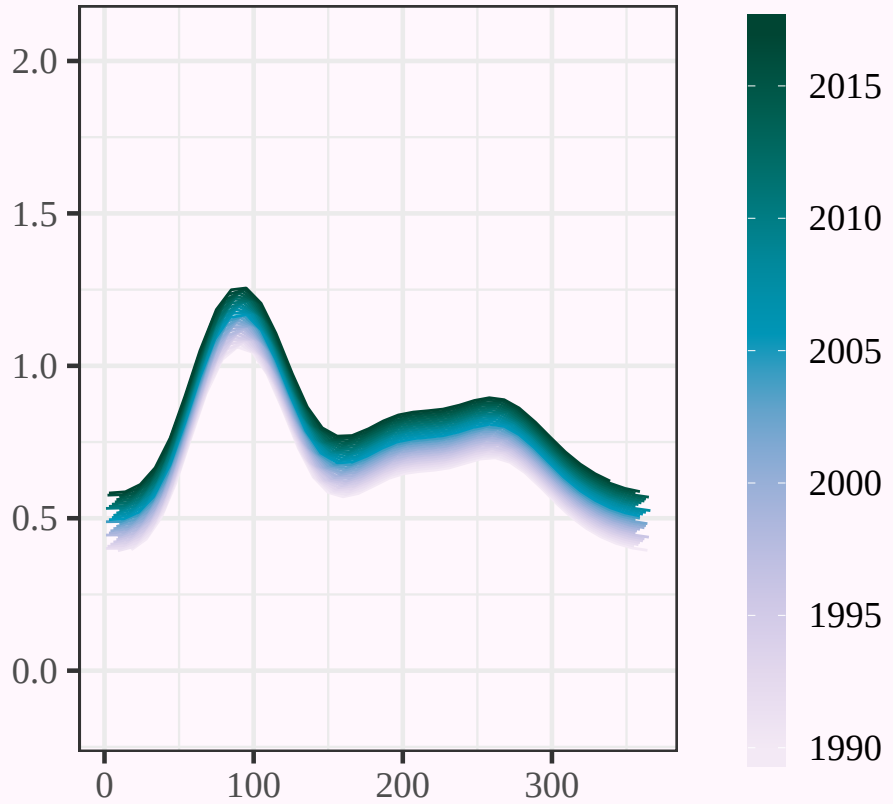
Four GAMs were evaluated and compared using standard methods for model comparison (AIC, R^2, GCV)

- `gam0`: chl $\sim$ year + s(doy)
- `gam1`: chl $\sim$ year + s(doy) + s(year)
- `gam2`: chl $\sim$ year + s(doy) + s(year) + ti(doy, year)
- `gam6`: chl $\sim$ year + s(doy) + s(year, k = large)

Application of additive models

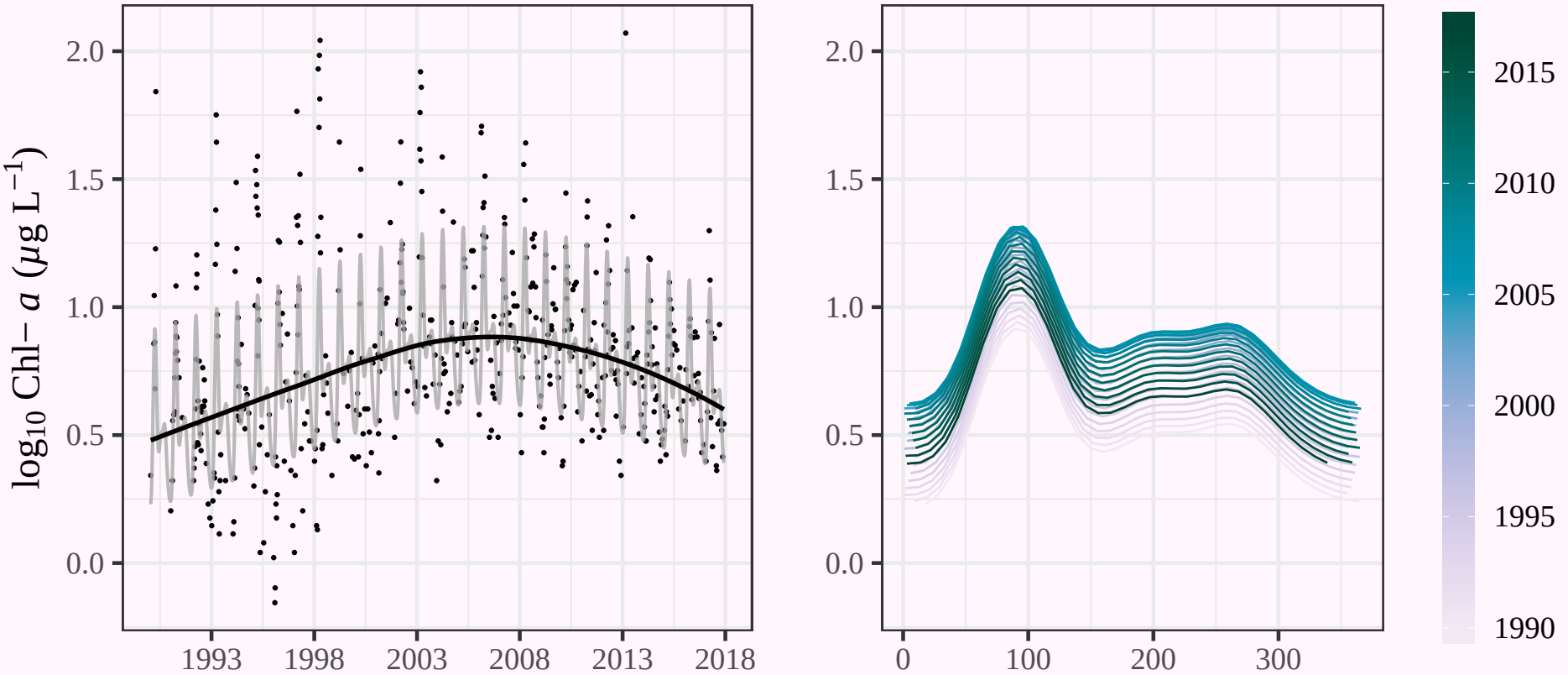
gam0: chl ~ year + s(doy)





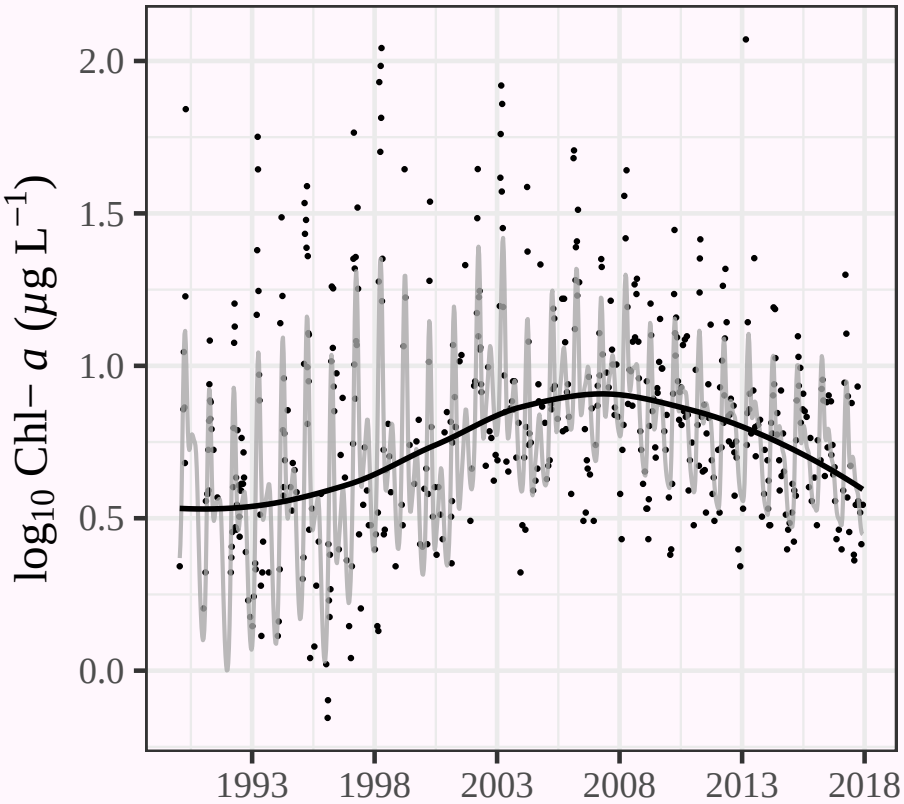
Application of additive models

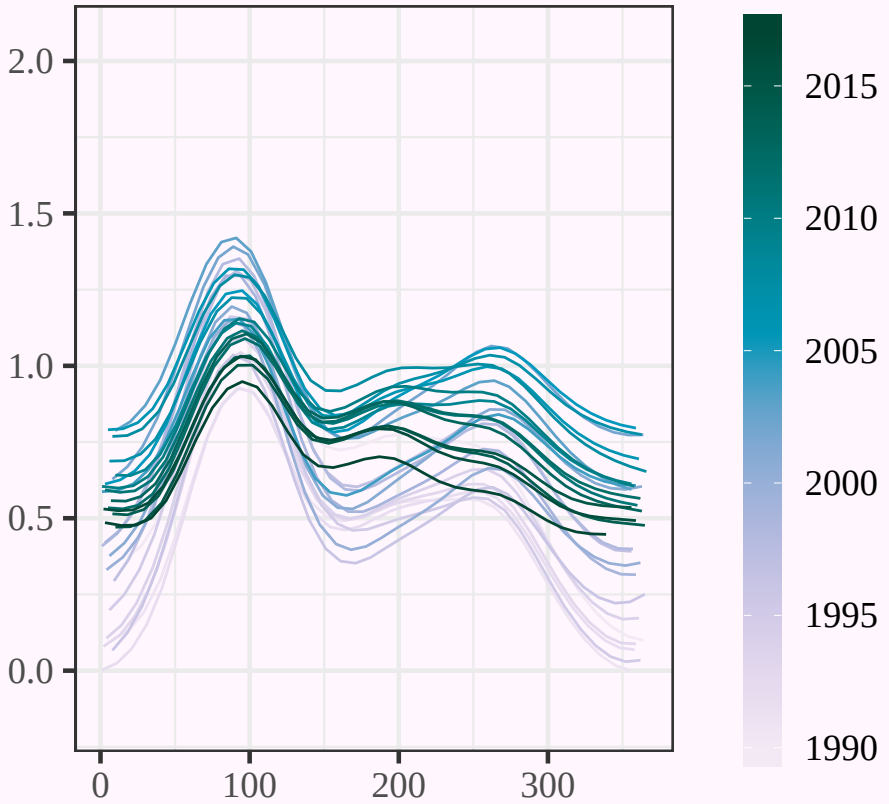
`gam1`: chl $\sim$ year + s(doy) + s(year)



Application of additive models

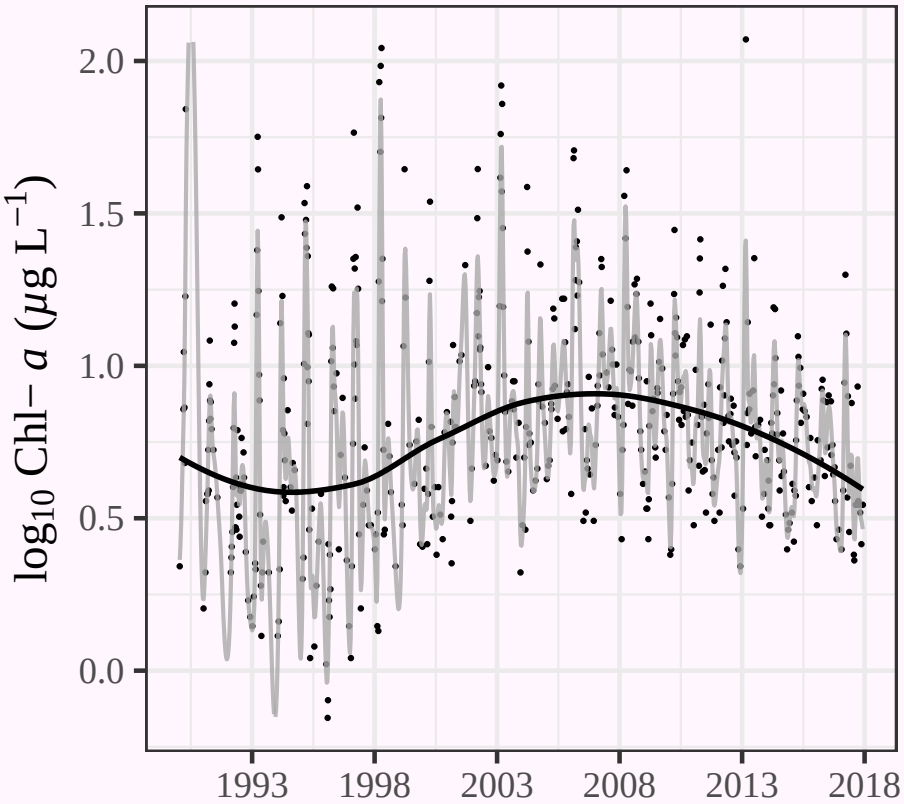
gam2: chl ~ year + s(doy) + s(year) + ti(doy, year)

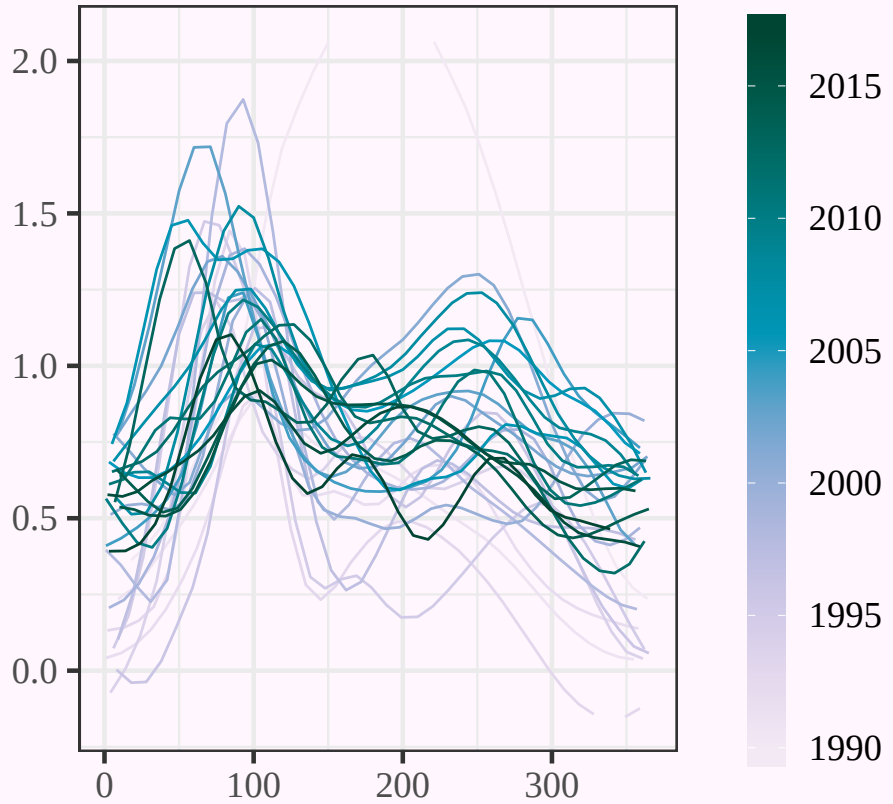




Application of additive models

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





Descriptive results of additive models

Station 32 example

Descriptive results of additive models

Overall comparisons of model structure across stations

Descriptive results of additive models

Extension to other response endpoints

Shiny interactive web platform

Why do we need this? Synthesis of results in a communicable format Answer to specific questions Understand implications and limitations of different methods

Shiny interactive web platform

Example 1

Shiny interactive web platform

Example 2

Shiny interactive web platform

Example 3

Summary and next steps

References

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