

# **Mis-identification of regime shift in the Bay of Quinte?**

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# Today

1. Bay of Quinte overview
2. Review of regime shifts in a simple ecosystem model
3. Data available in Bay of Quinte
4. Analyzing temporal trends using gams and breakpoint models
5. Quinte analysis
6. Work in progress: What to think about this analysis?

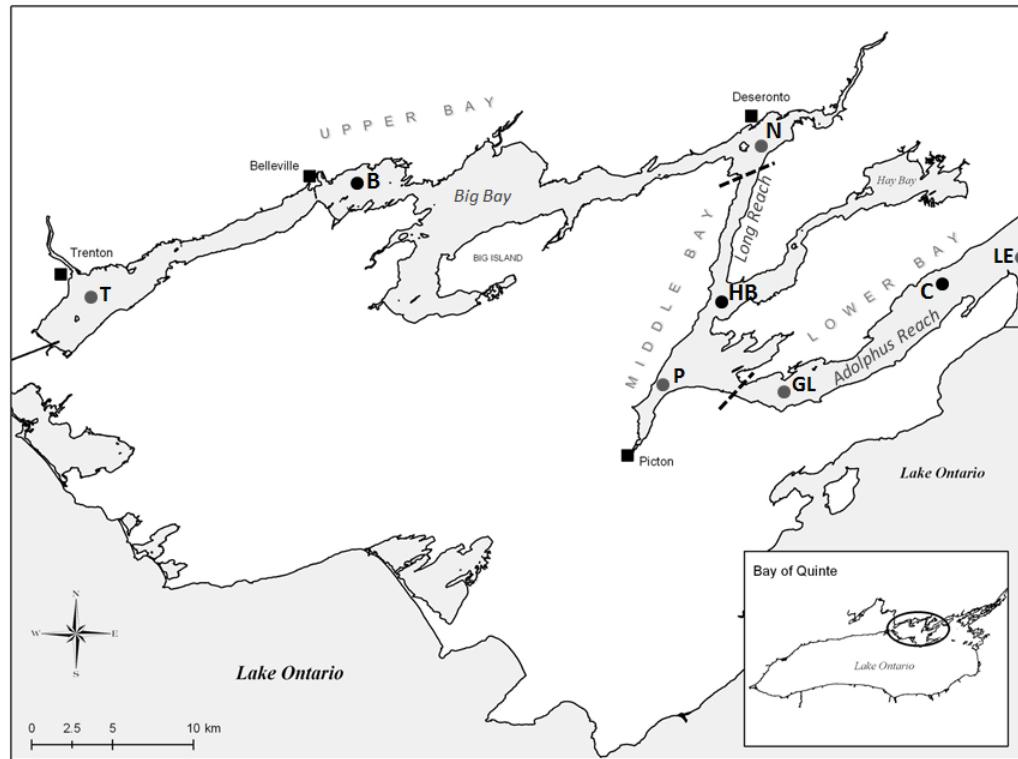


# **1. Bay of Quinte Overview**

# Bay of Quinte

Area of Concern: Eutrophic embayment of Lake Ontario

- 90 km long
- Several tributaries
- Ranges from 4-5m deep to 40-50m near the lake



- B = Belleville  
(upper Bay)
- HB = Hay Bay  
(mid Bay)
- C= Conway  
(lower Bay)

# Bay of Quinte

history of being increasingly eutrophic

- phosphorus controls implemented 1978
- invaded by zebra mussels in 1994
- meostrophic following this



Bay of Quinte before and after mussel invasion

## Standard explanation:

### Disturbance shift to new stable state

"In the mid-1990s, zebra and quagga mussels (*Dreissena* spp.) invaded the area, **dramatically changing the water clarity because of the filter-feeding capacity.**"

(Bay of Quinte remedial action plan 2017)

"**Dreissenid colonization induced precipitous decline of phytoplankton** and ultimately enabled macrophyte resurgence" (Nicholls and Carney, 2011)

"... filtering by the mussels.... **reduced chlorophyll concentrations and greatly increased water clarity.** Thus the hysteresis model of macrophytes is partially supported." (Minns et al 2004)

# Regime shifts in freshwater systems

frequently are cited as exemplars of regime shifts (Carpenter et al. 2011).

classic shift is in a shallow temperate lake moving between a clear-water, macrophyte-dominated state and a turbid, phytoplankton-dominated state (Scheffer et al. 1993)

Capon et al. (2015) reviewed 135 papers on regime shifts in freshwater systems and found 85% of lacked appropriate data or other supporting evidence for their claims.

however, Bay of Quinte described as having strong evidence of a regime shift  
(Capon et al 2015)

# Linear response to phosphorus in freshwater systems

recent analyses find sudden shifts between alternative stable states are a relatively rare phenomena

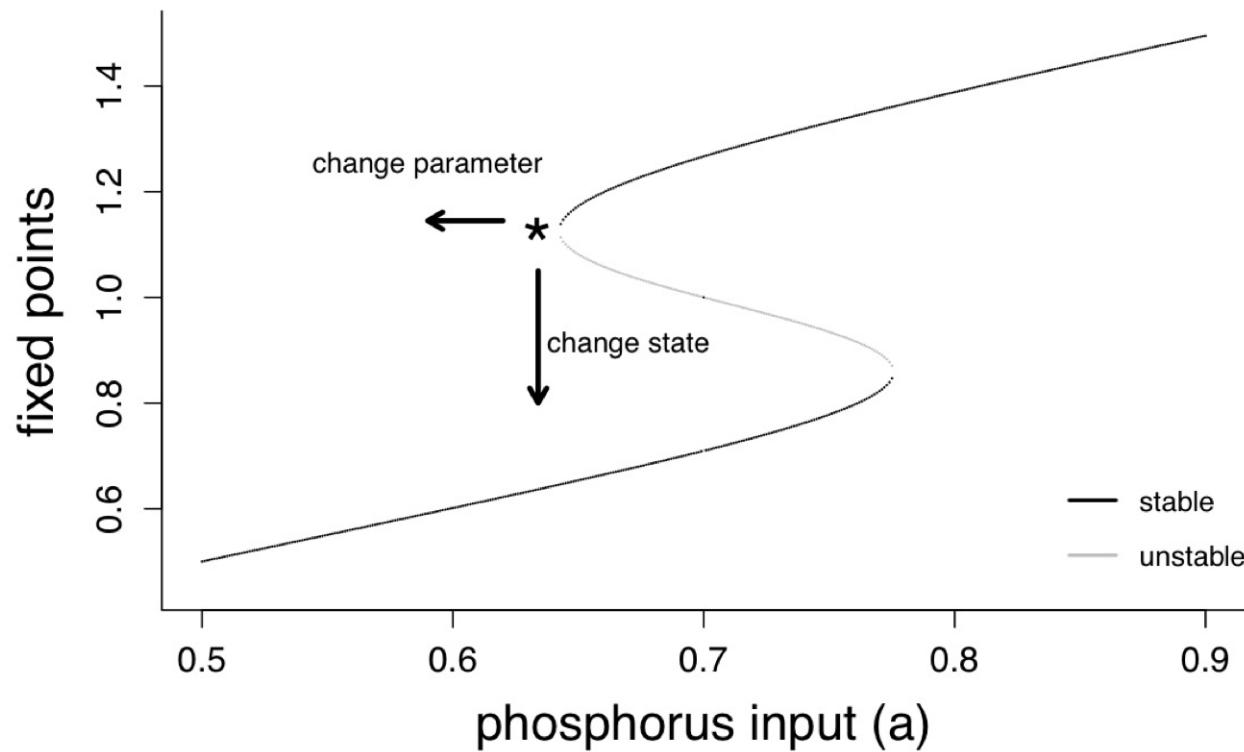
- no evidence of regime shifts in 902 shallow lakes
- instead, a strong linear relationship between total phosphorus (TP) and phytoplankton (Davidson et al. 2023)
- recommend a greater emphasis on nutrient reduction and a de-emphasis on regime shifts

## **2. Review of regime shifts in a simple ecosystem model**

# Regime shifts in bistable systems

a “sudden” change in state, e.g., Scheffer (2001)  $\frac{dx}{dt} = \frac{hx^\rho}{x^\rho + c} - bx + a$

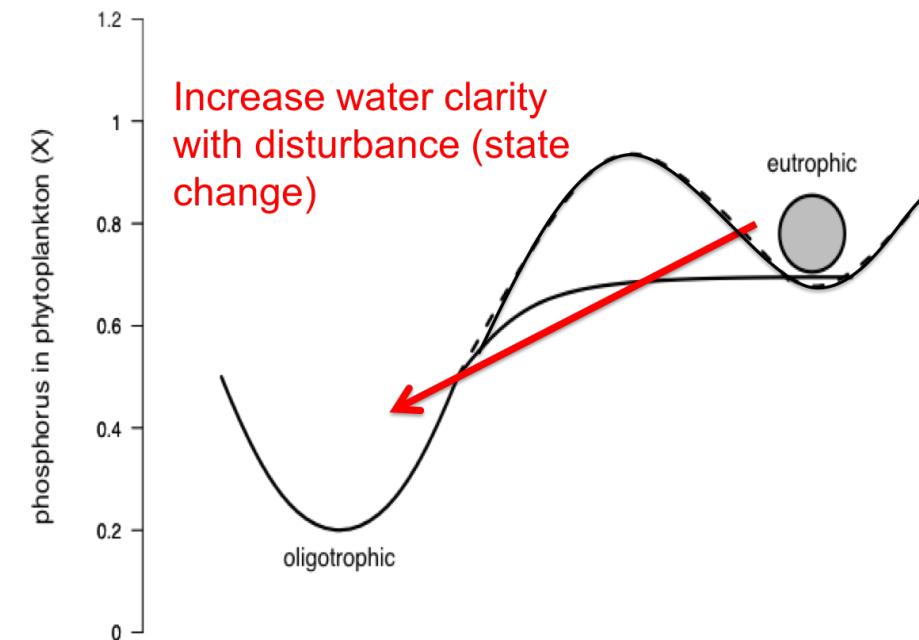
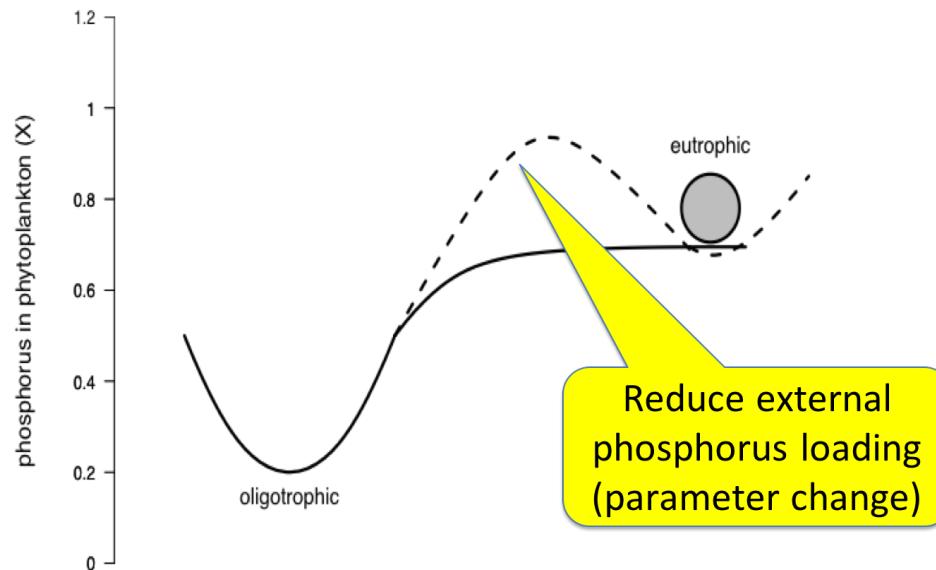
- lake system moves from phytoplankton-dominated, eutrophic green water state to macrophyte-dominated, oligotrophic state



[Francis et al. \(2021\)](#)

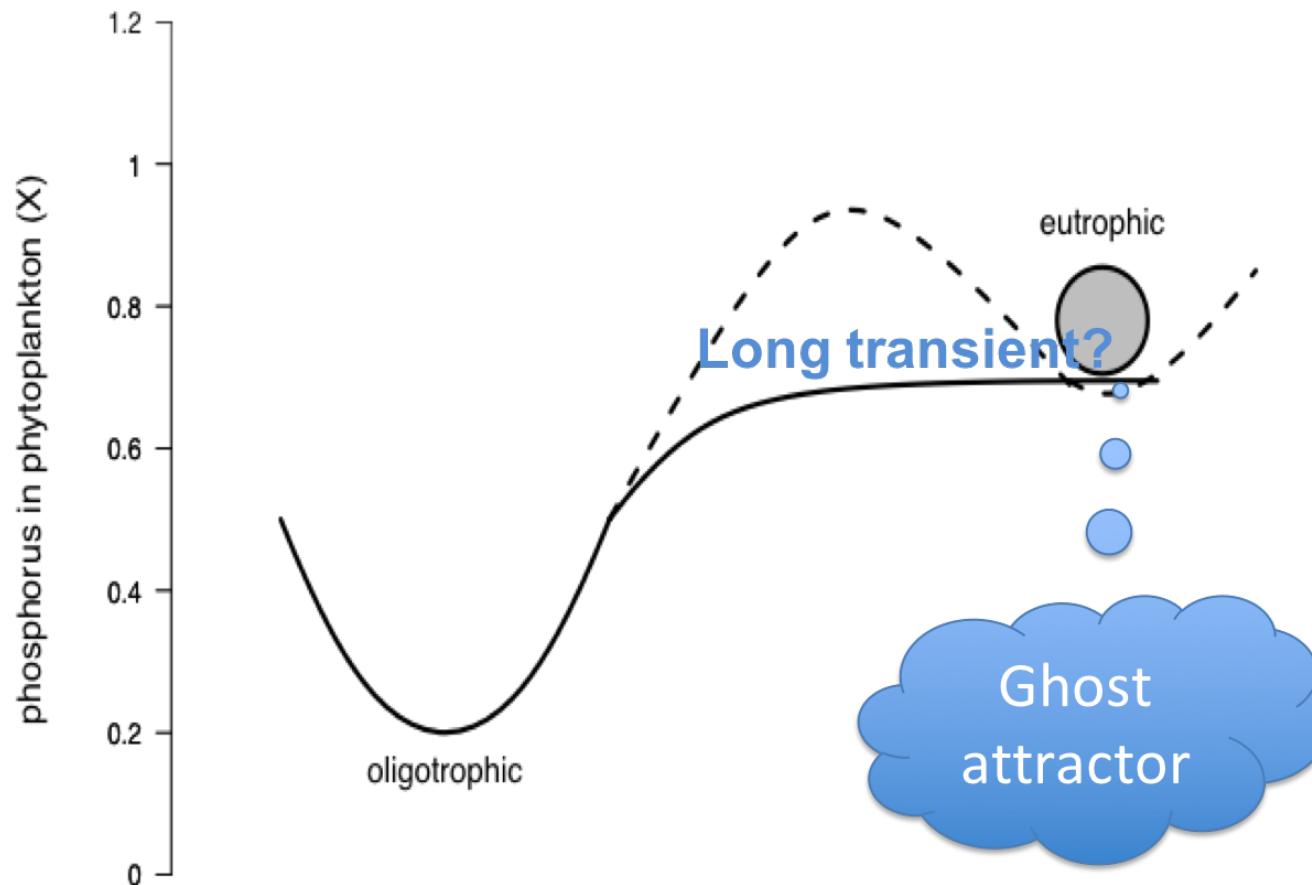
# Two ways to get a regime shift

1. Erode stability of current equilibrium, or
2. Push system to second stable basin with a disturbance



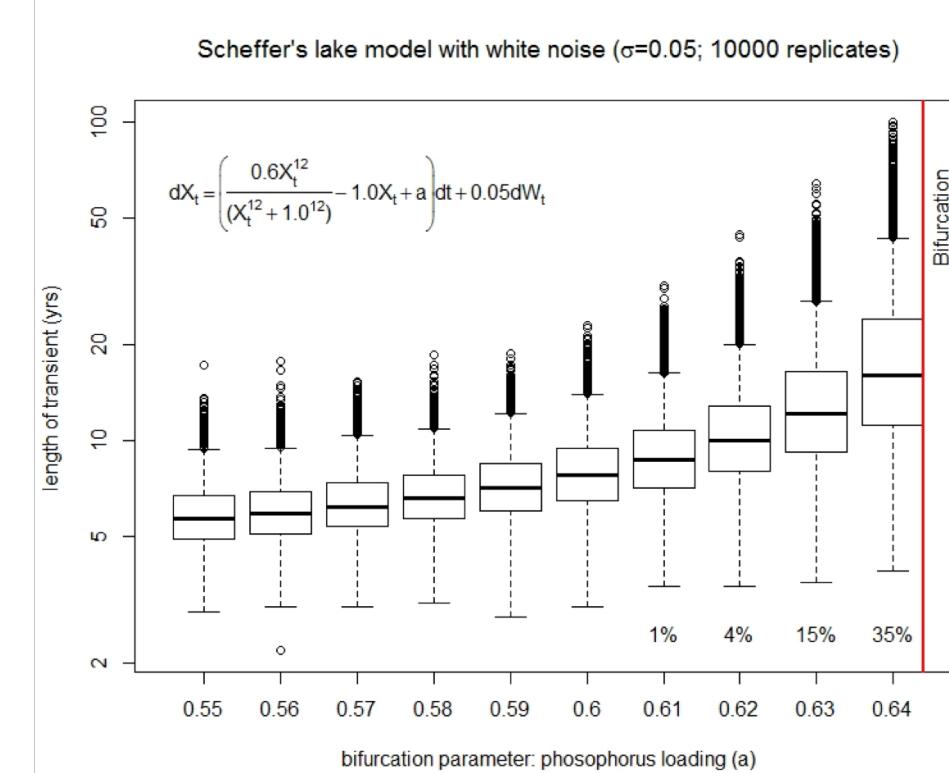
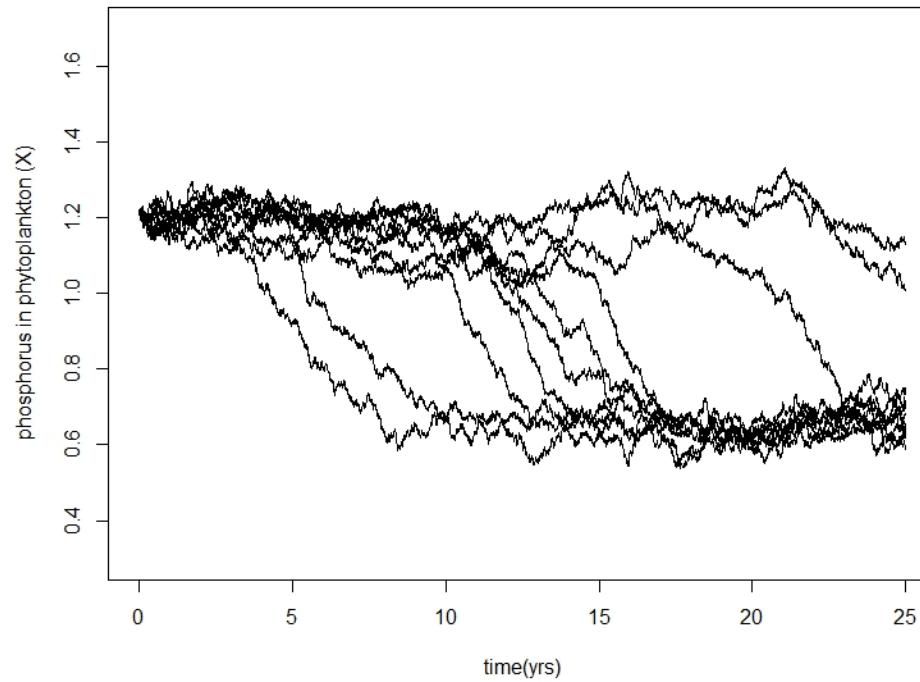
# Wait... is that all the mechanistic model predicts?

-asymptotic vs transient dynamics predicted by models



# Long transients in a regime shift model

-long transients can be a quite common prediction



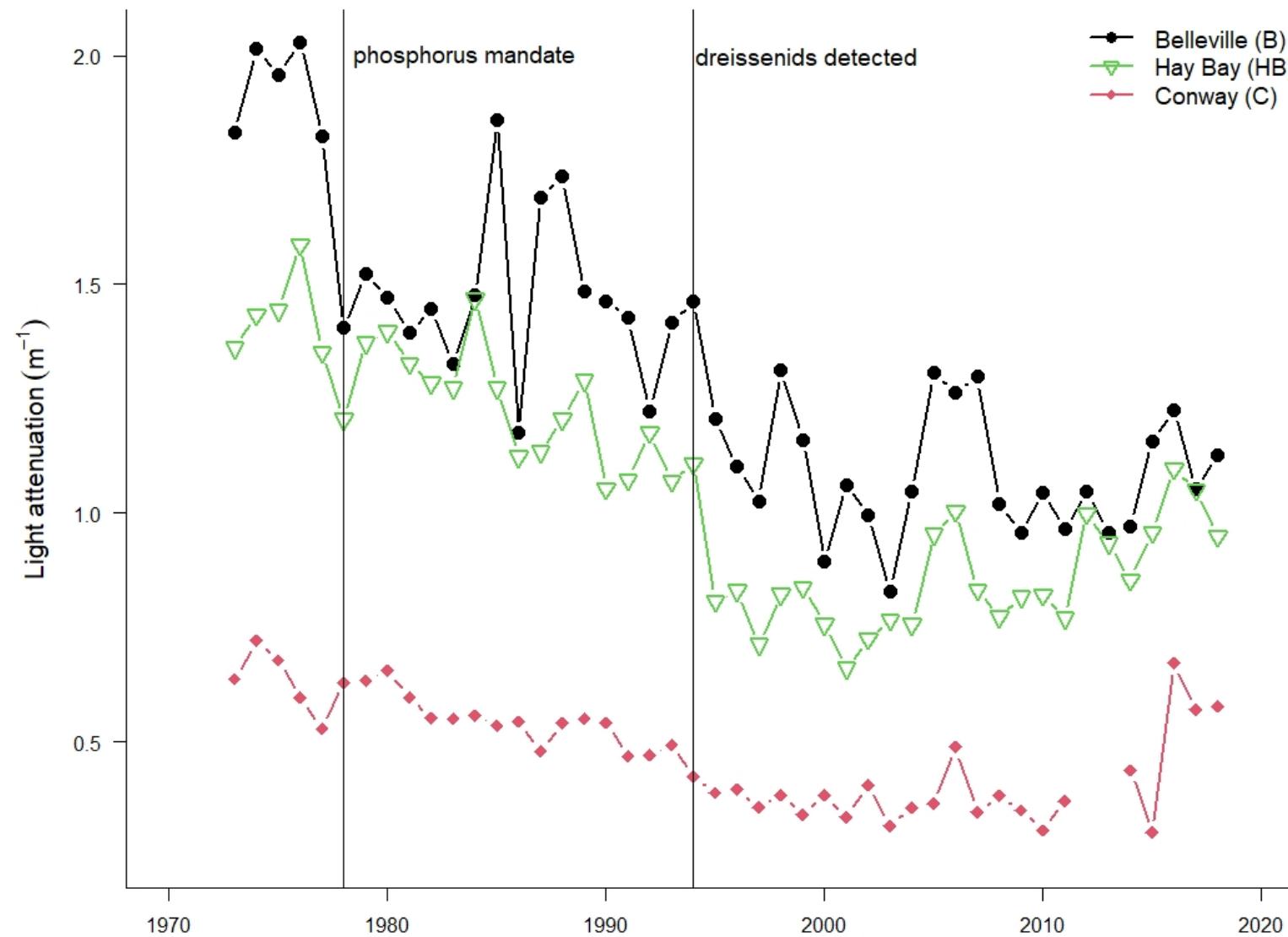
# Alternative explanations

- all of which arise from the SAME mechanistic model
  - 1. a regime shift to a 2nd stable state caused by the disturbance of the zebra mussel invasions
  - 2. a long transient of the unstable eutrophic state following phosphorus control
  - 3. slow change in phosphorus (i.e. the system does not have bistable dynamics)

Bio and Carbon DIC , DOC POC, PON Seston , AFDW Benthos density,  
biomass Macrophyte density, % cover Chl , Total Phyto Biomass,  
taxonomy Bacteria, APP, HNF, Ciliates Rotifers Zooplankton density,  
biomass, taxonomy Fish density, biomass Size-fractionated productivity  
Bacterial productivity Zooplankton production GeoChem Conductivity  
Dissolved Oxygen pH, Alkalinity , Hardness Cl - , Na + , SO4-, Mg 2+ , Ca  
2+ , K + Iron, Silica NO3 - , NO2 - , NH4 + ,TKN SRP , TP, TDP Physical  
Light Attenuation/Secchi Temperatures ( epi , hypo) Station Depth, Z  
mixing Euphotic Z (1% & 0.5 %) Weather, CFB Trenton PAR River  
discharge, water level

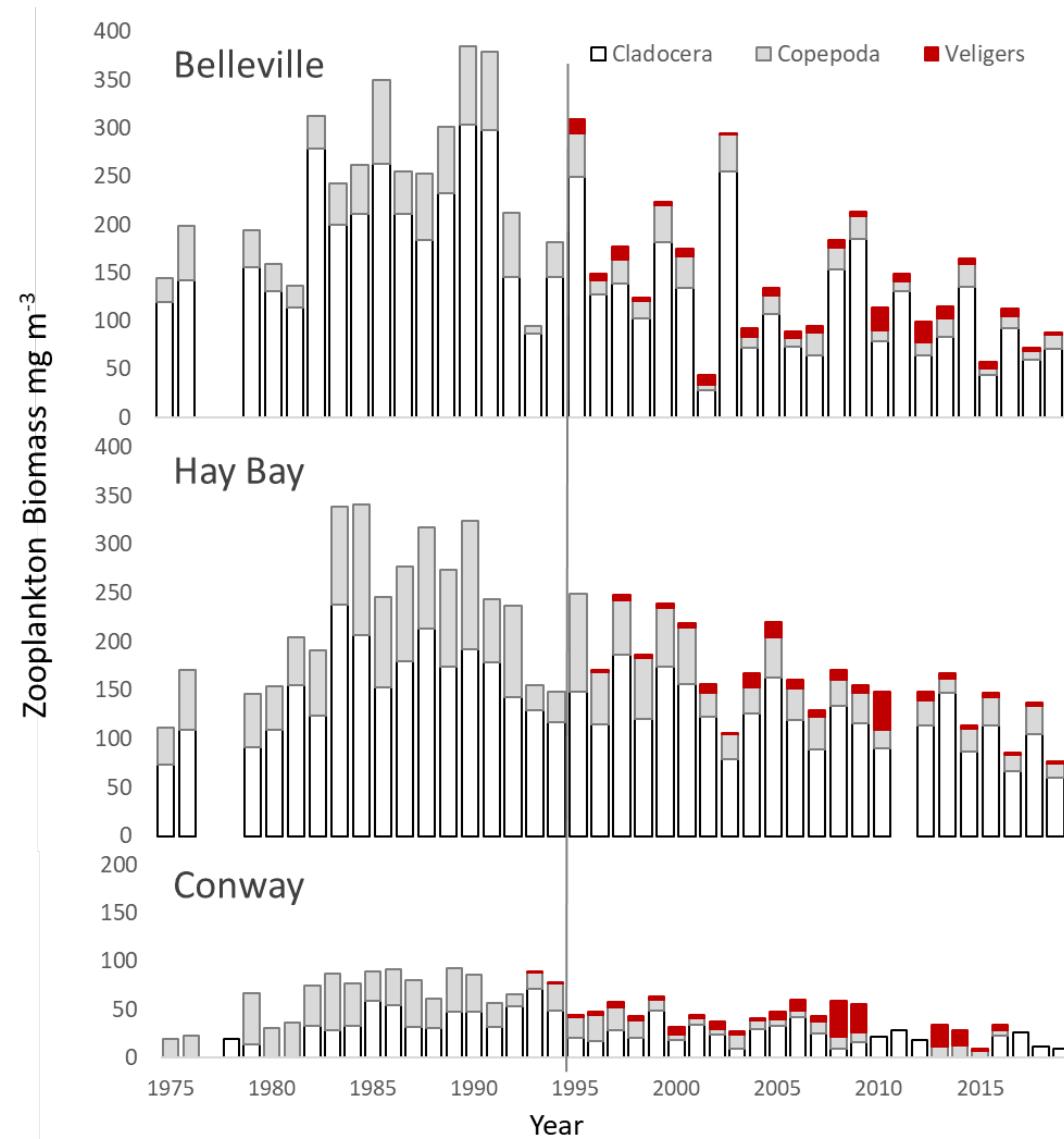
### **3. Quinte Selected Data: Sampling May-Oct 80+ Measures Weekly until 1980, then bi-weekly**

# Water clarity in Bay of Quinte



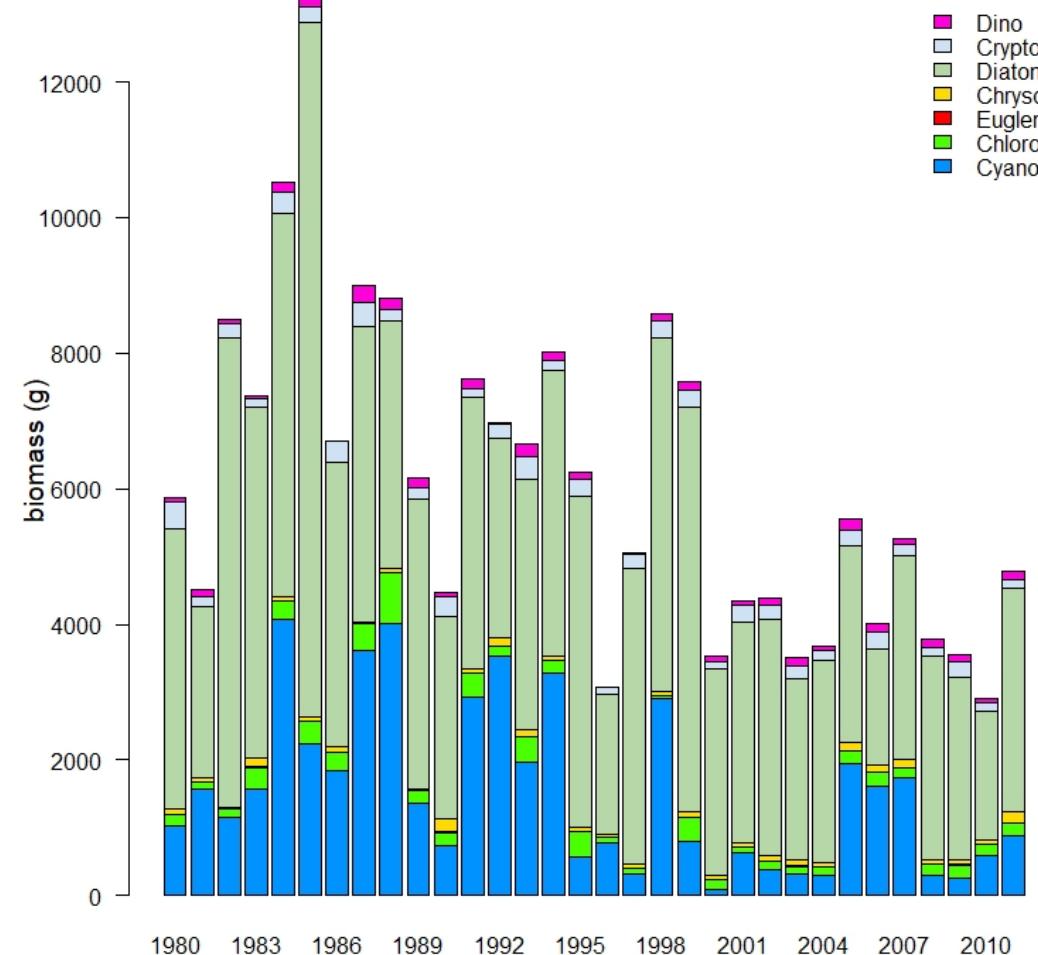
# Dressenids in Quinte

- mussel veligers first detected in 1994
- very low densities



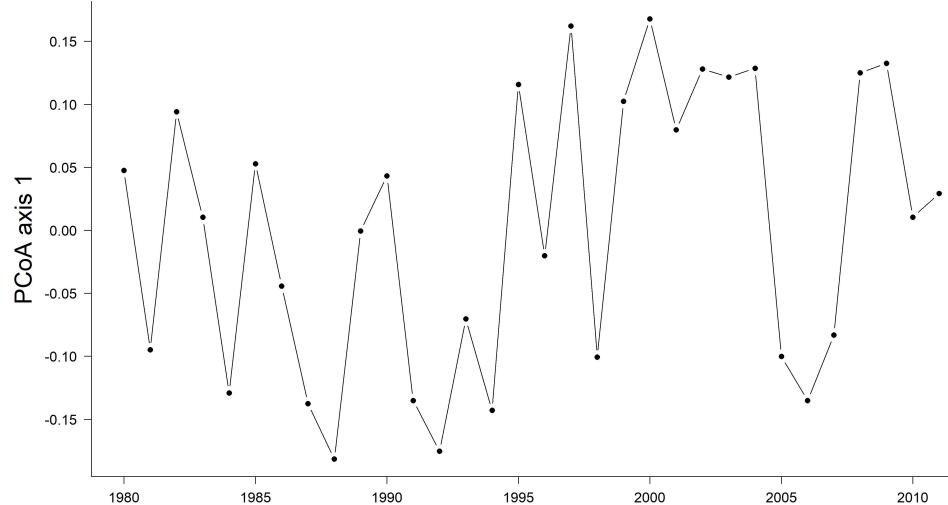
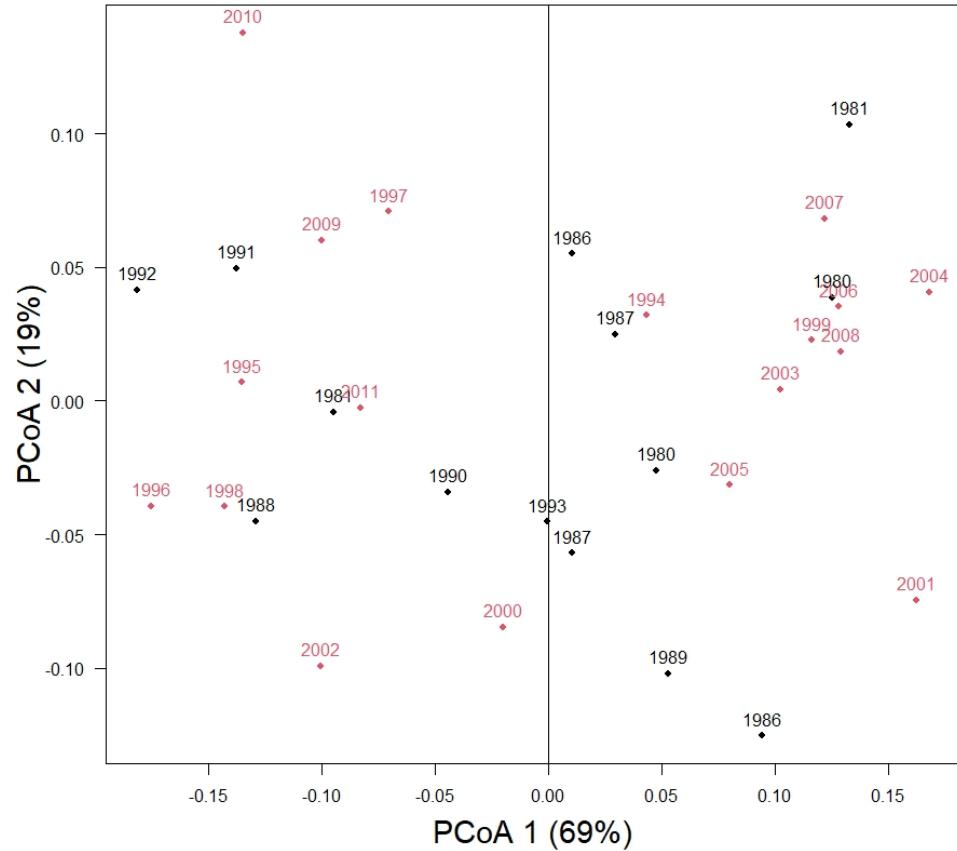
# Changes to phyto community: Belleville

- decline in biomass over time
- greater decline in Cyanobacteria

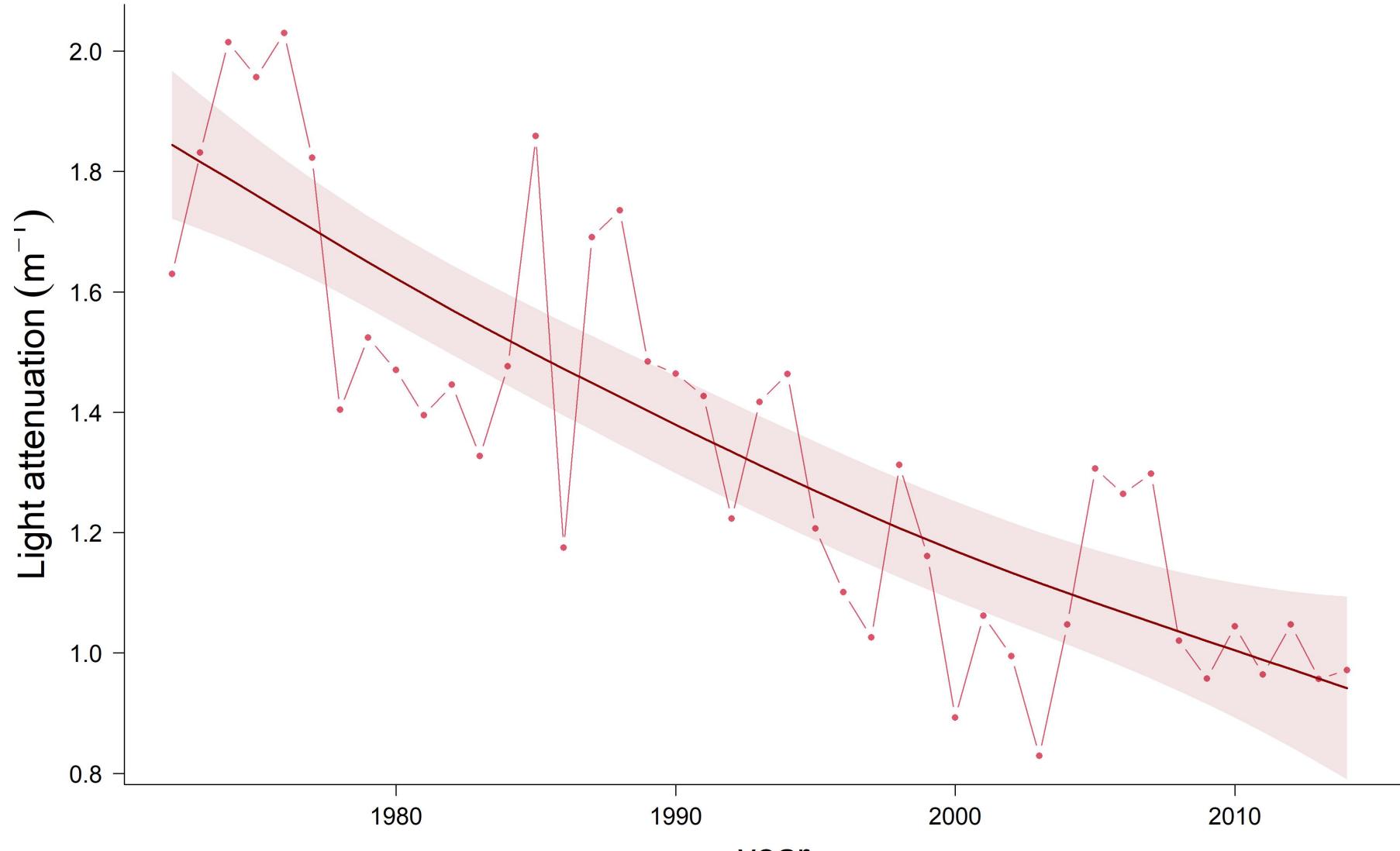


# Whole community metrics

- no very clear trends

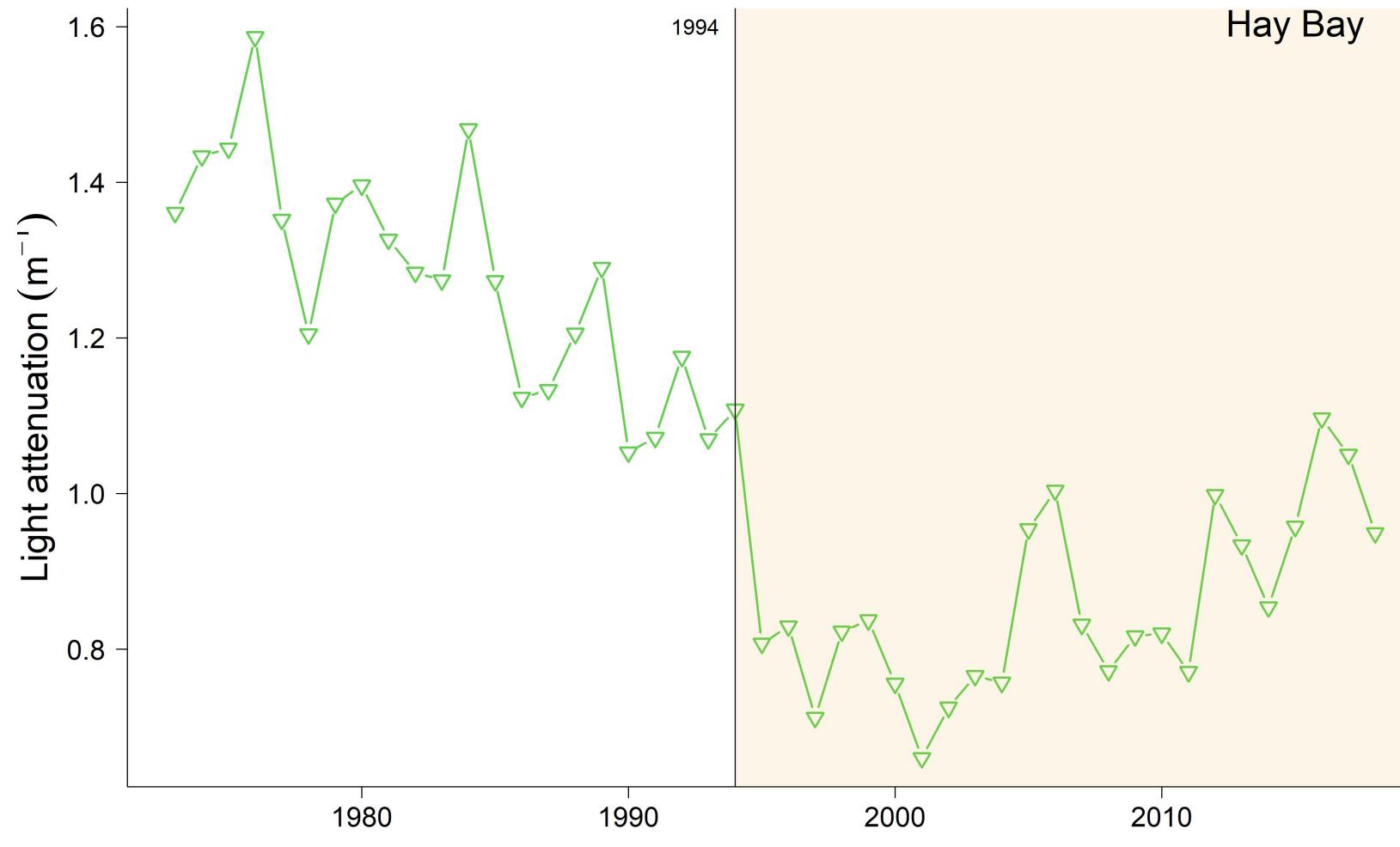


# Change in water clarity: Belleville



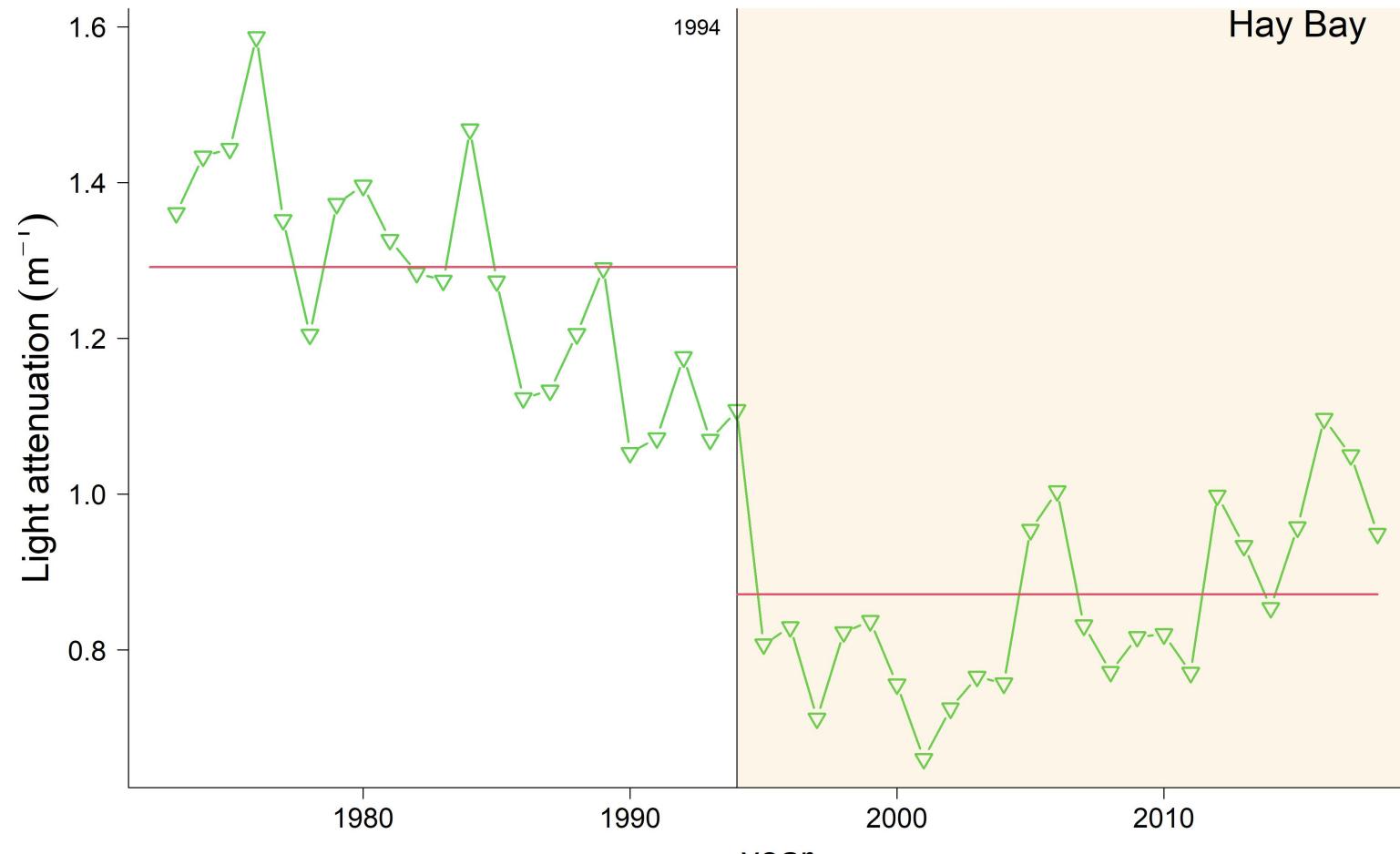
# Change in water clarity: Hay Bay (our best candidate)

- two regimes?



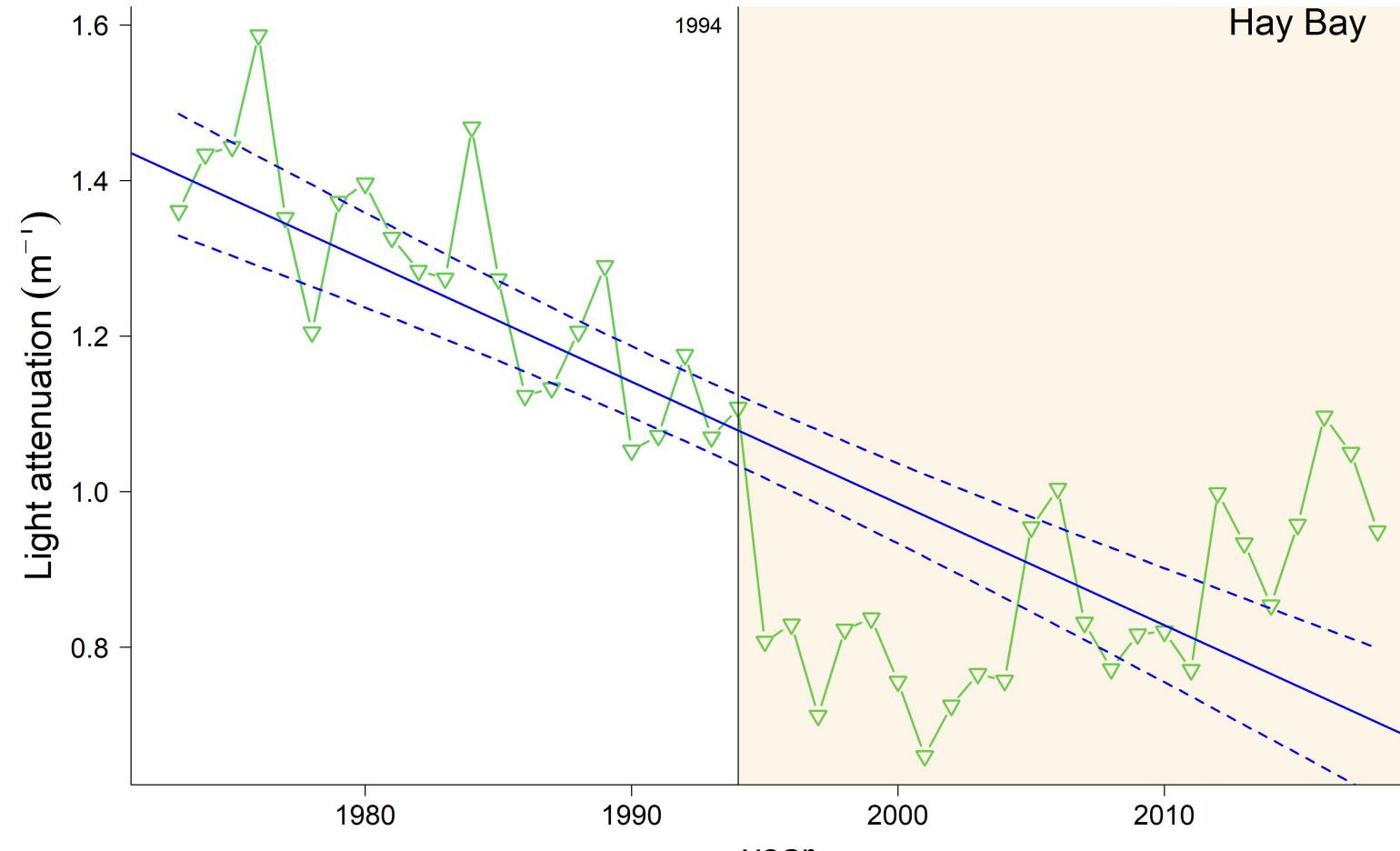
# Change in water clarity: Hay Bay (our best candidate)

- two regimes?
- compare means?

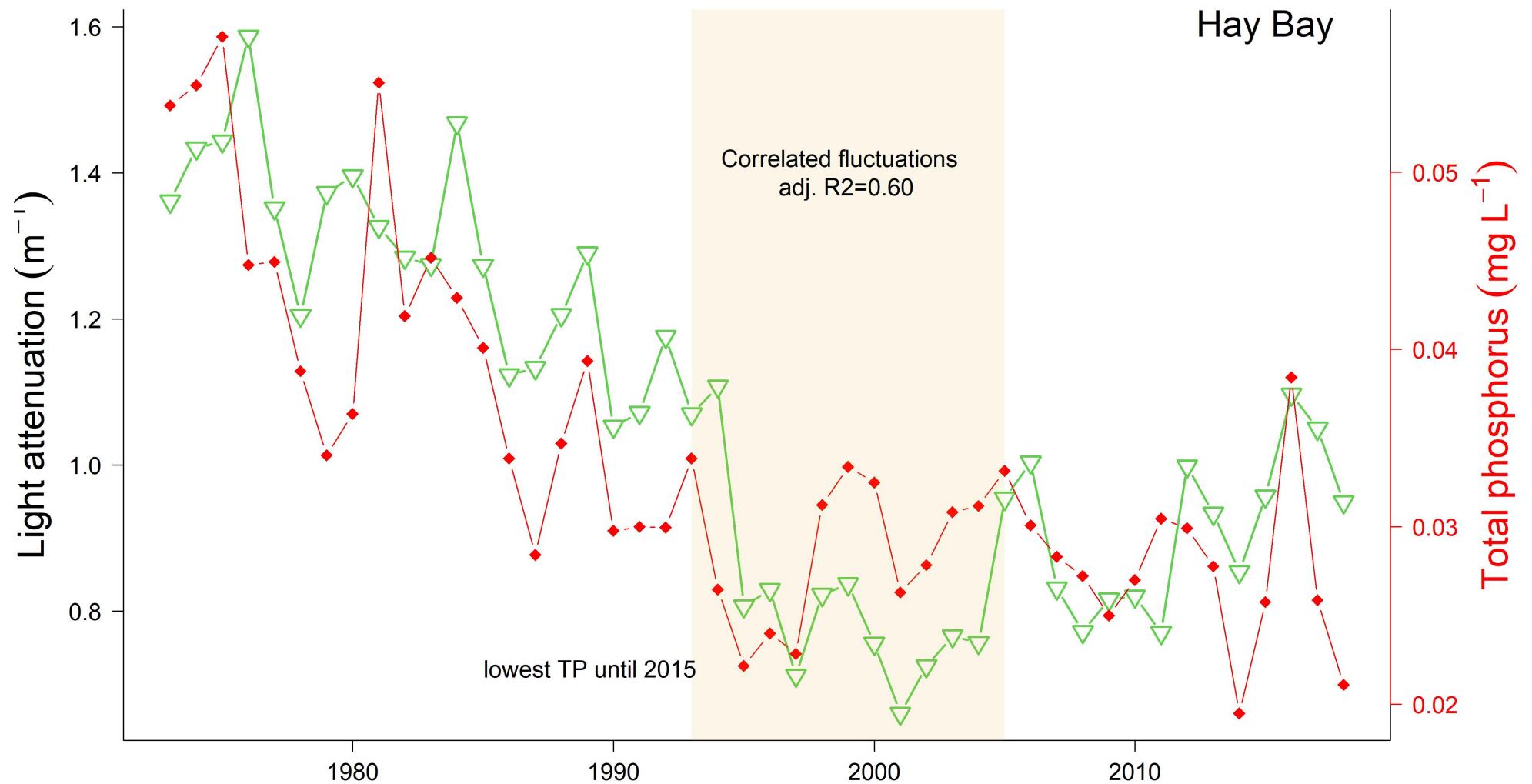


# Water clarity: Hay Bay (our best candidate)

- two regimes?
- linear change confounds mean comparison



# Water clarity & total phosphorus: Hay Bay

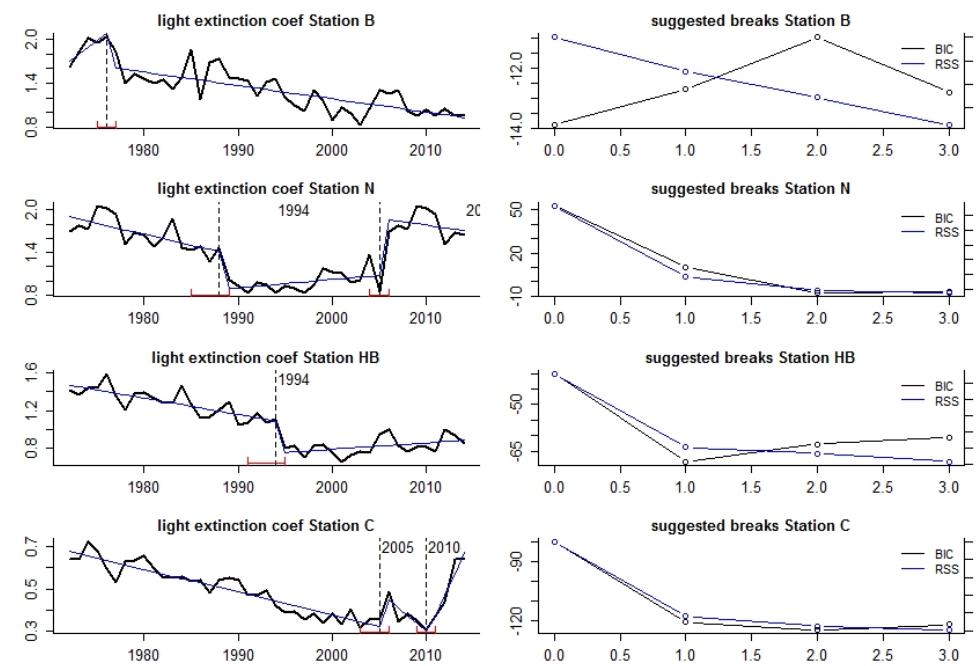


## **4. Analyzing temporal trends using GAMS and breakpoint models**

# Linear breakpoint models

$$y_{i,b} = \text{breakperiod}_b + \beta_b x_{i,b}$$

- breakpoint (piecewise) linear regressions to test if linear model with abrupt change in mean or slope fits best
- did not select breakpoint years *a priori*
- estimate the number and position of multiple breakpoints where the optimal number of breaks was selected using BIC (Bai and Perron 1998)



# Generalized Additive Models (GAMS) for regime shifts

$$y_i = \beta_0 + f(x_i)$$

- Thin plate regression splines fit using REML
- Simpson (2018), Pedersen et al (2019)

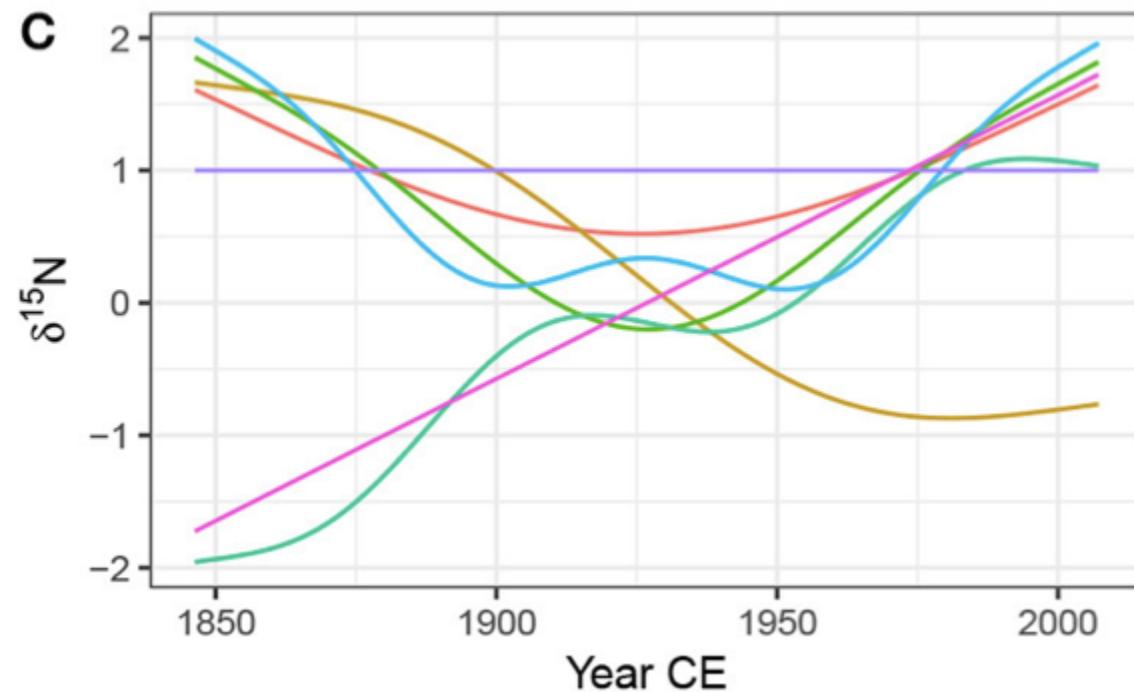
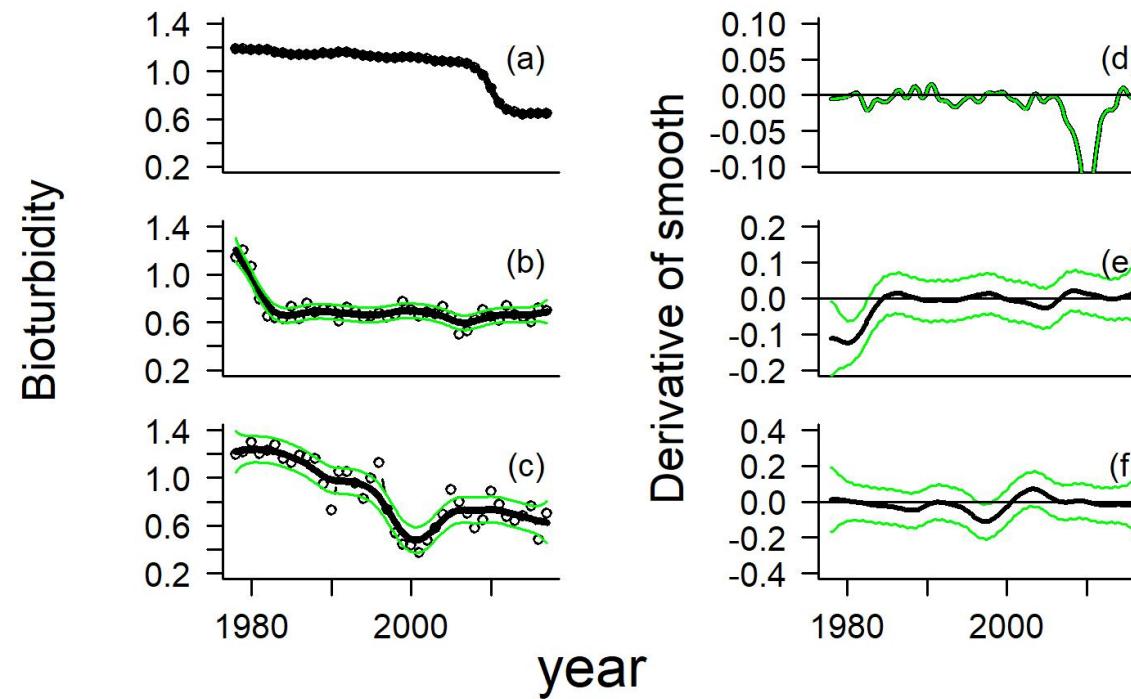


Image from Simpson (2018)

# Generalized additive models for Quinte (GAMs)

examine the first derivative of fitted smooth to find periods of rapid change

Simulated data from the Scheffer model (2001). The initial condition is previously stable high turbidity state

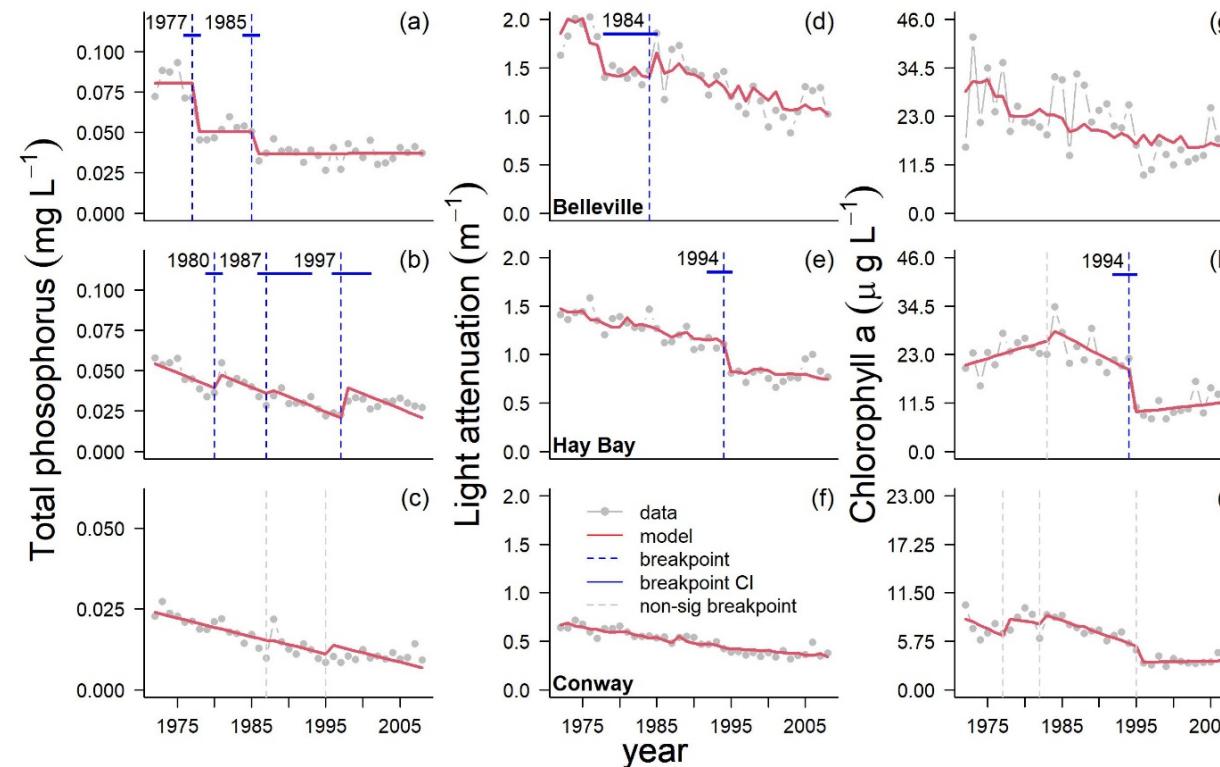


## **5. Quinte analysis**

# Linear breakpoint model: TP, water clarity and Chla

$$metric_{i,b} = breakperiod_b + \beta_{1,b}year_{i,b} + (\beta_{2,b}TP_{i,b})$$

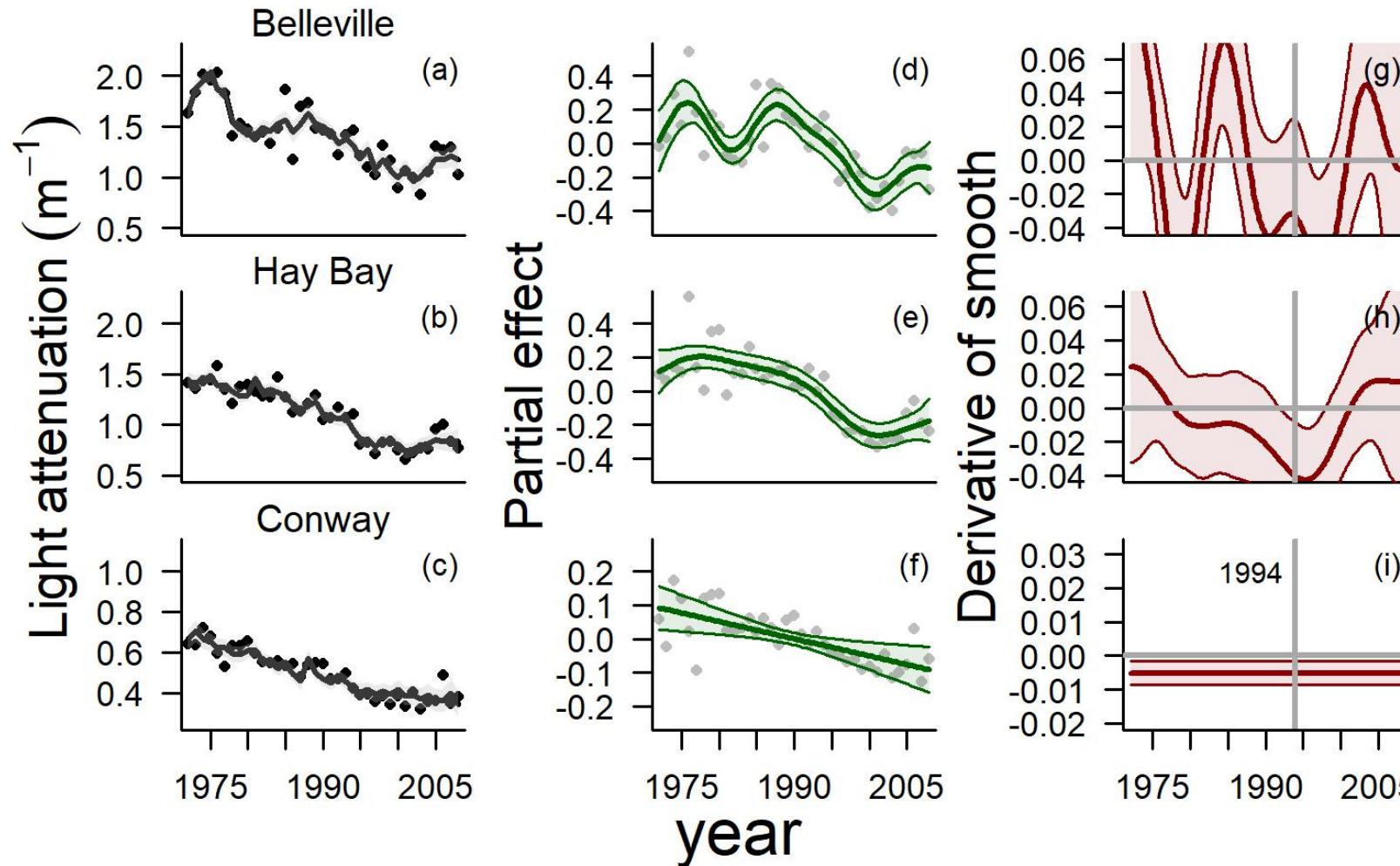
- Use total phosphorus as a covariate
- Belleville 1984 response to phosphorus controls in the 70s? (no break 1994)
- Hay Bay: maybe rapid change in 1994 after mussels at Hay Bay?
- Conway: no significant breaks (as expected)



# GAM analysis of water clarity

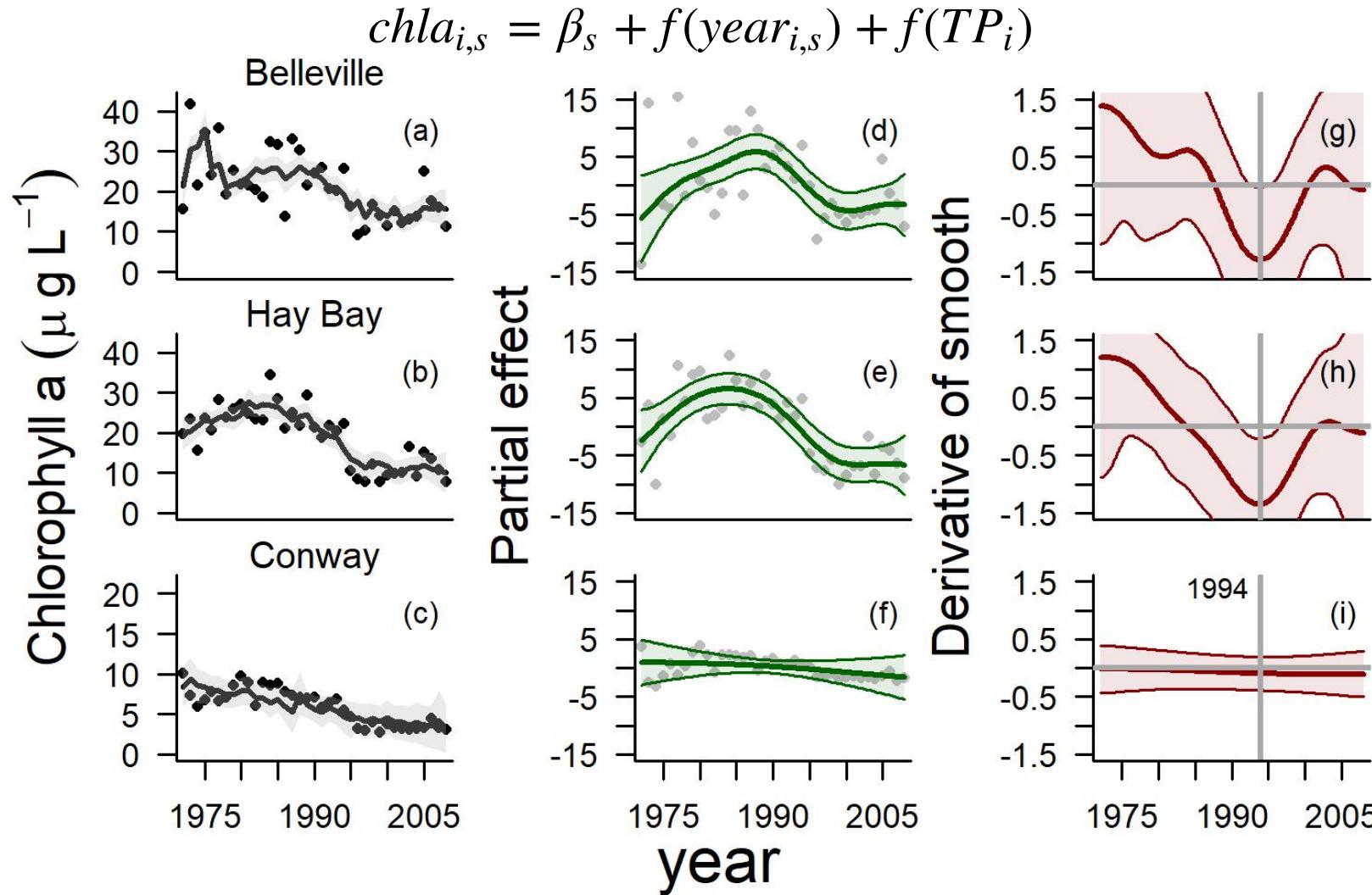
suggests rapid change at Belleville and Hay Bay

$$light_{i,s} = \beta_s + f(year_{i,s}) + f(TP_i)$$



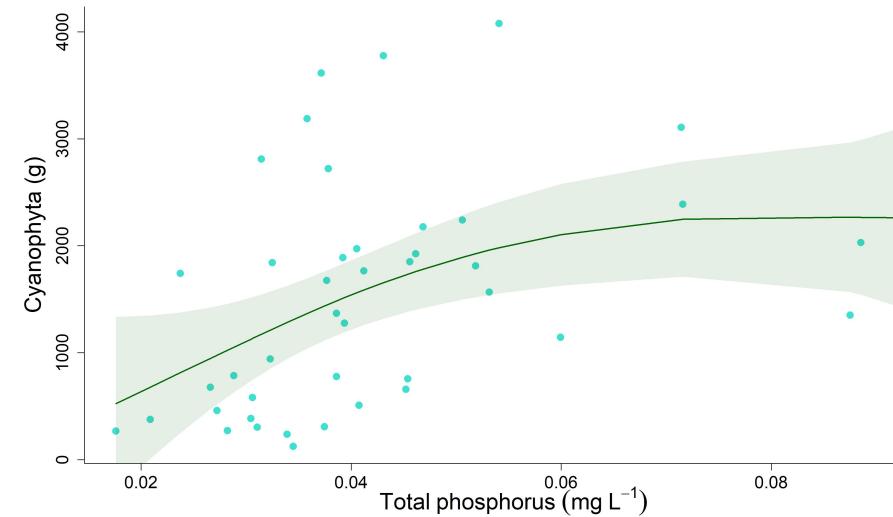
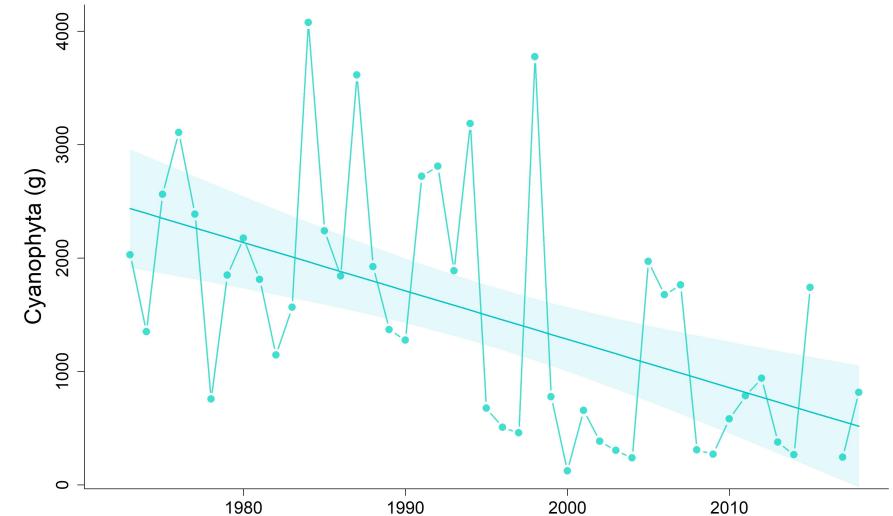
# GAM analysis of Chla

suggests rapid change at Belleville and Hay Bay



# Change in Cyanophyta: Belleville

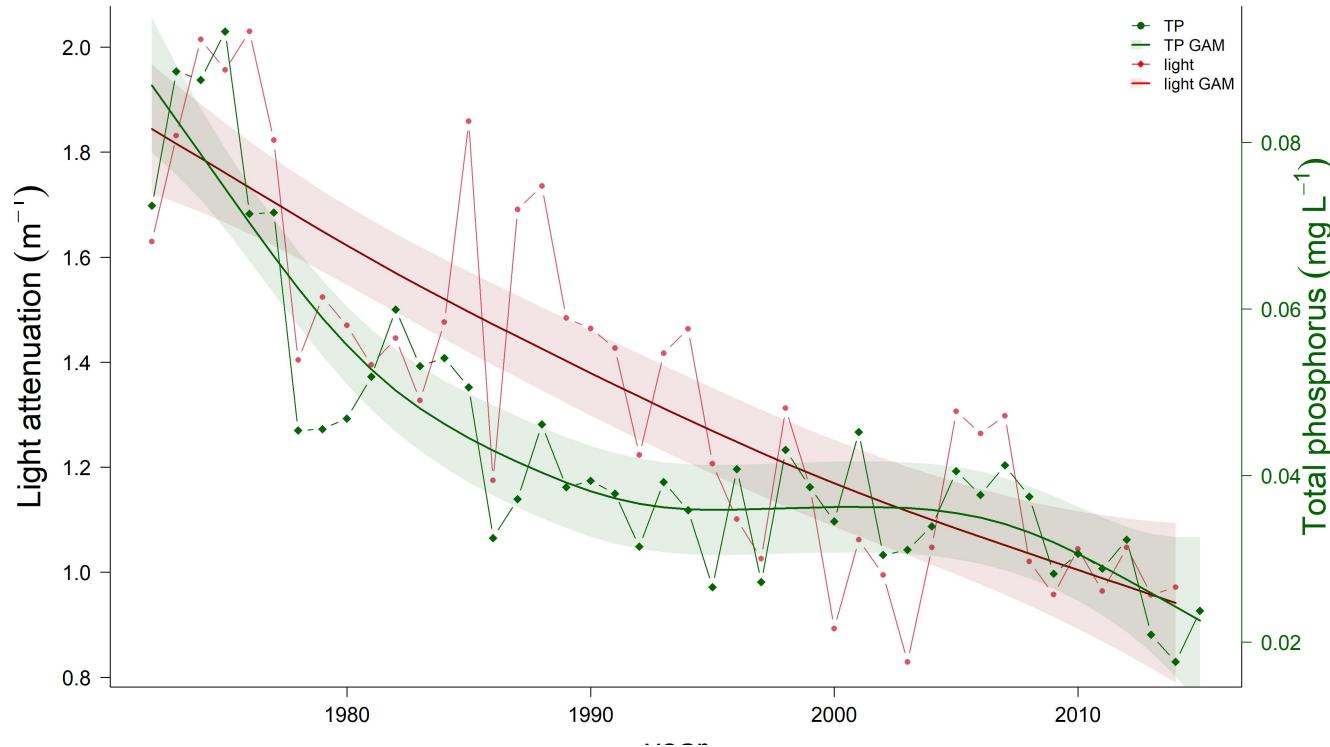
phyto	TP pvalue	TP Dev	Year pvalue	Year Dev
Cyano	0.02	0.22	0.02	0.40
Chloro	0.04	0.00	0.04	0.36
Chryso	0.71	0.33	0.71	0.03
Diatom	0.12	0.23	0.12	0.19
Crypto	0.11	0.01	0.11	0.08
Dino	0.29	0.01	0.29	0.04
Total	0.01	0.22	0.01	0.39



# Problem 1: Identifiability

## Concurvity between TP and year

- rapid response to management in the 70s
- slow change after that
- also collinearity

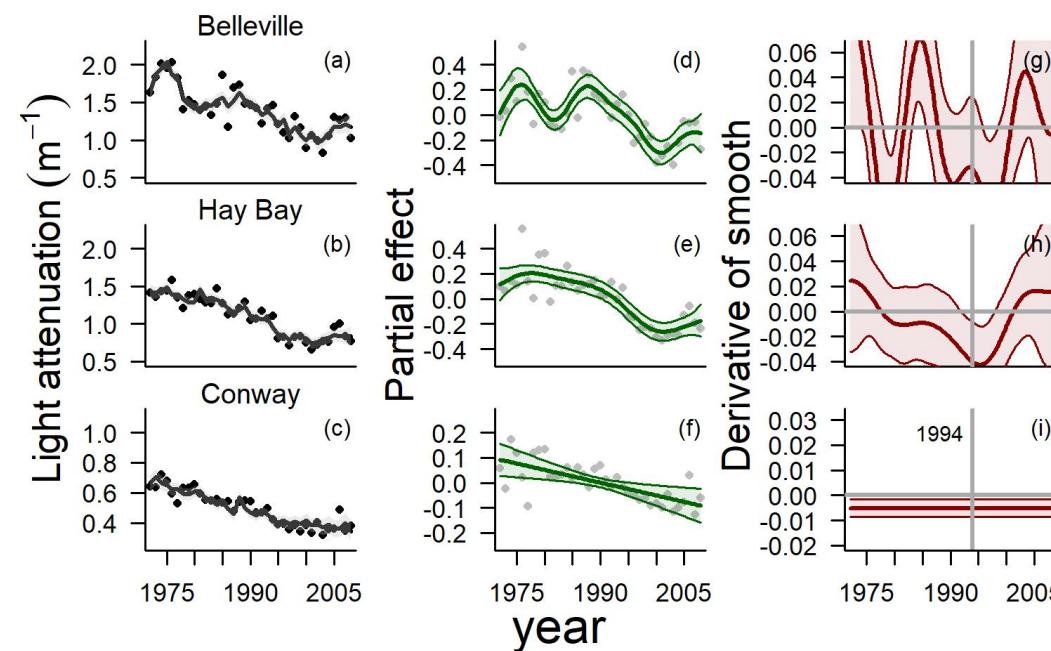


# Concurvity

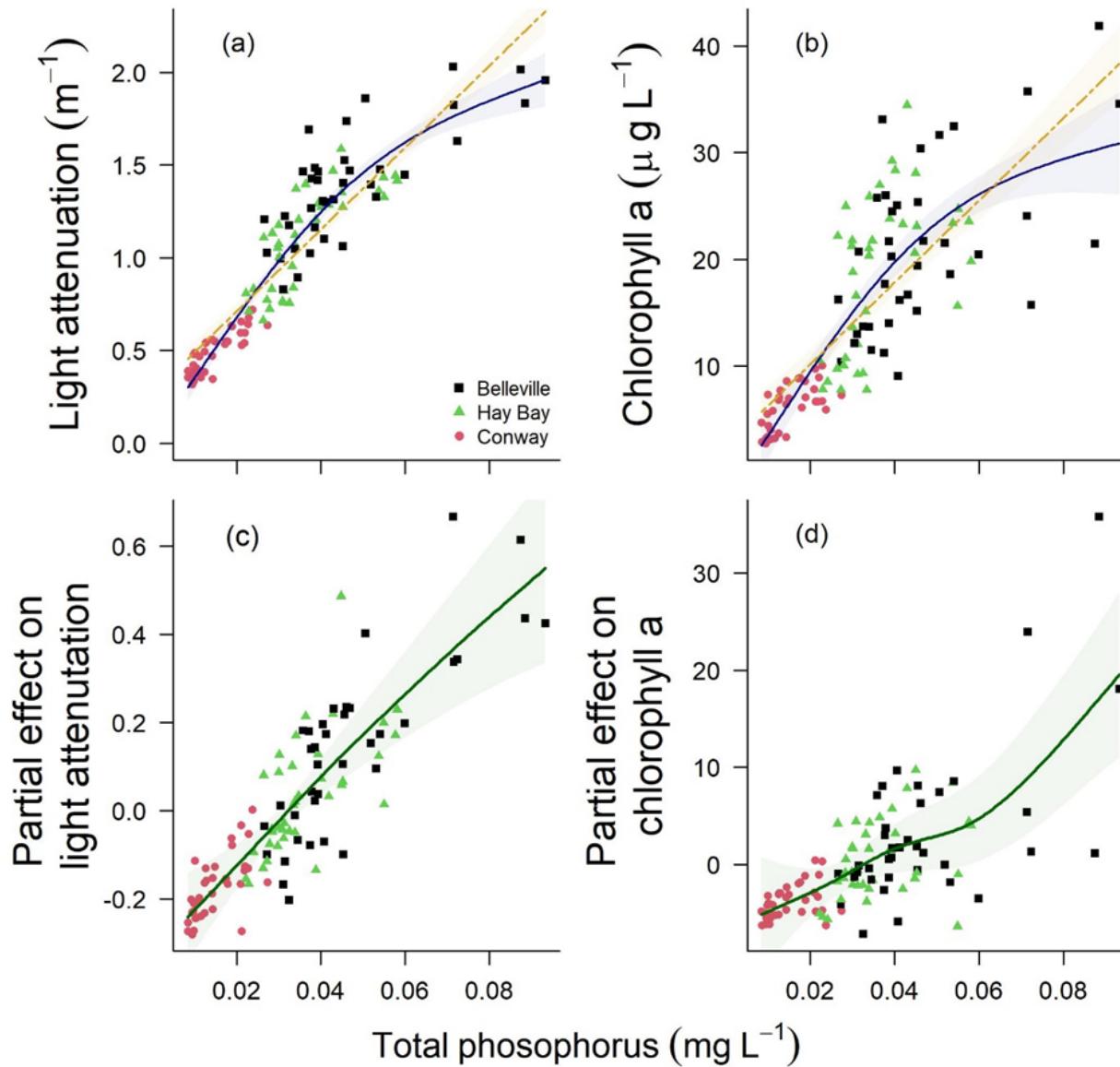
$$light_{i,s} = \beta_s + f(year_{i,s}) + f(TP_i)$$

	s(TP)	s(year)
worst	0.96	0.96
observed	0.84	0.21
estimate	0.80	0.69

- GAM purports to explain 97% of deviance!
- certainly inflated

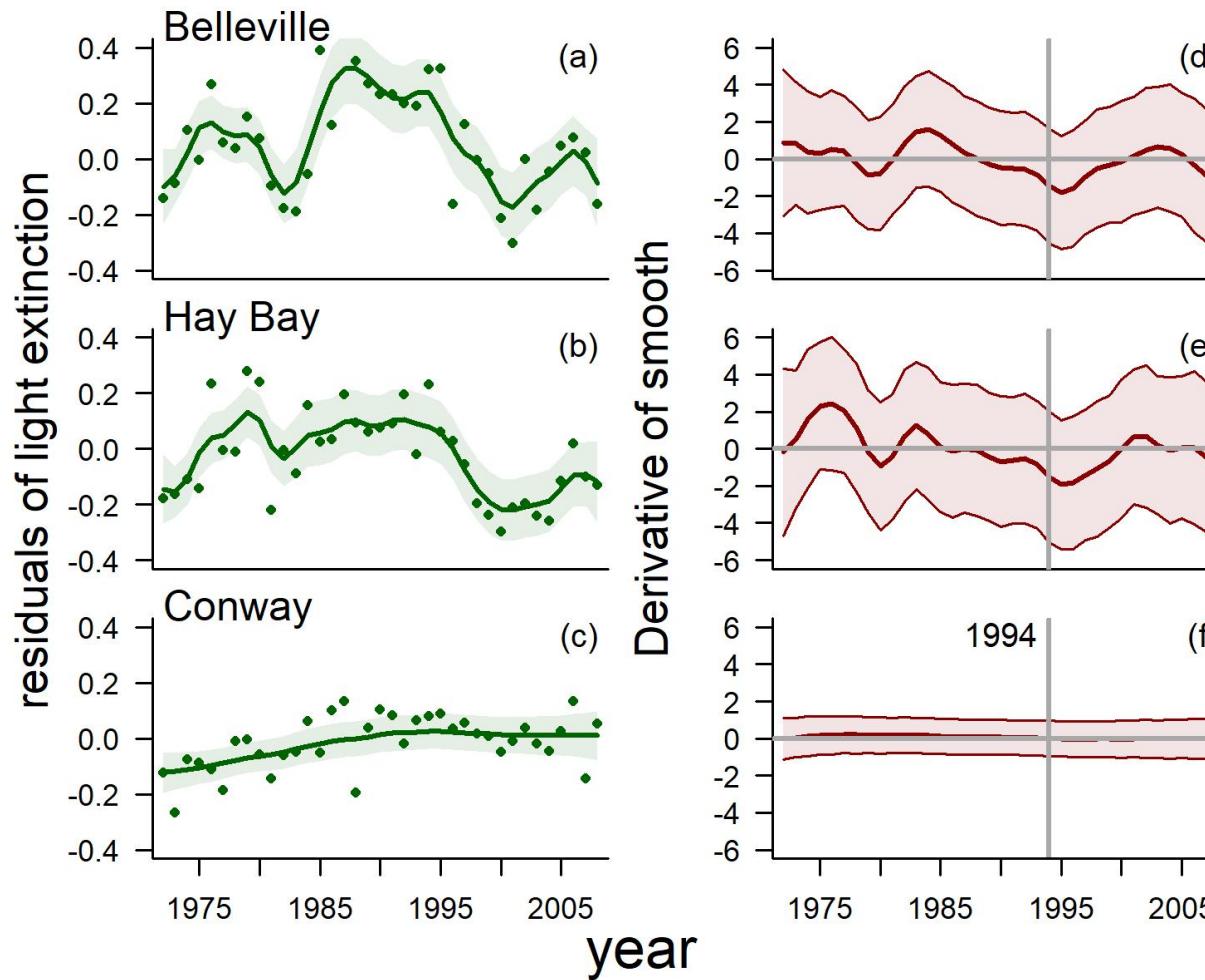


# Possible solution: Fit TP and use residuals?

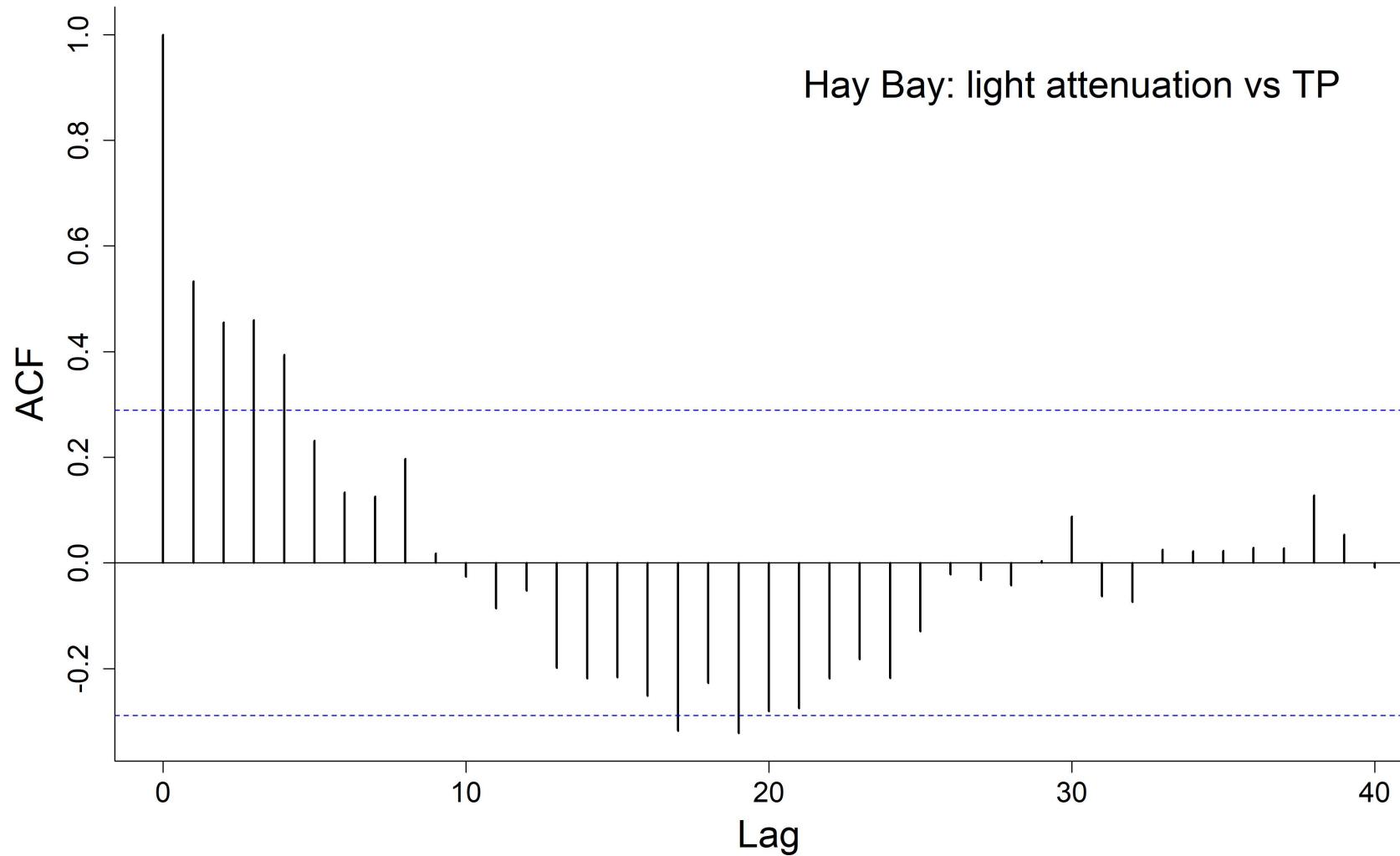


# Gam on residual from TP

rapid change magnitude becomes pretty small when we control for concurvity in phosphorus impacts



## Problem 2: Autocorrelation in residuals



## Solution: AR1 on errors

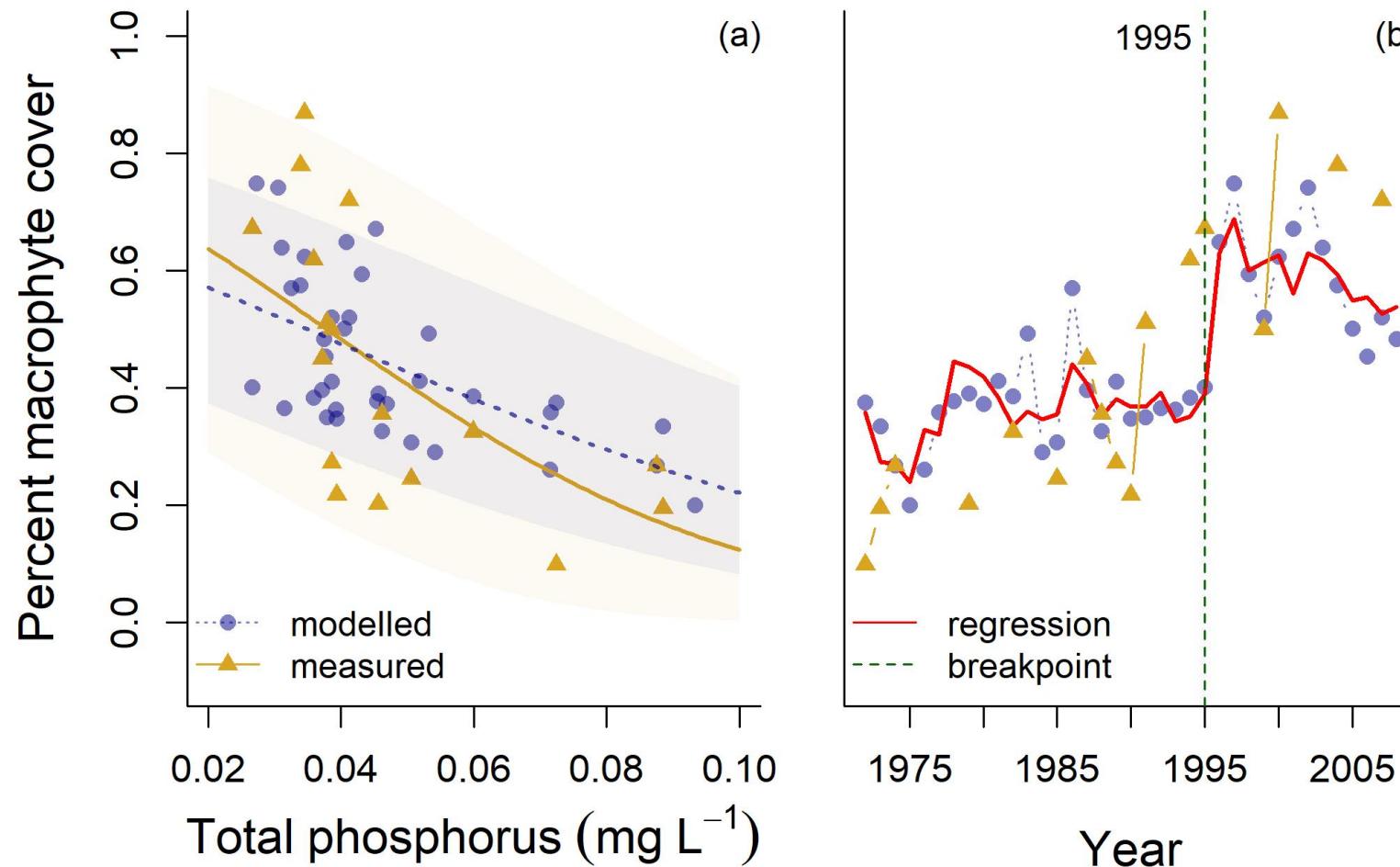
- haven't yet found AR1 or ARMA that actually reduces!
- analysis on first differences reassures me there is a relationship

## Problem 3: Missing data

- disastrous for breakpoint analysis
- use modelled data: Macrophytes
- shorten period of analysis: Phyoplankton
- rely on GAMs

# Macrophytes: Belleville

- both TP and year are significant predictors (breakpoint beta regression)
- modelled data suggests a regime shift, measured data not so much



# Conclusion: What is the correct interpretation of TP effects?

1. **TP:** Slow change from 1977 with very low concentrations in 1994 (Belleville & Hay Bay)
2. **Water clarity:** Breakpoint or GAM at Belleville: Concomitant slow change in light; but Hay Bay abrupt change?
3. **Water clarity with TP as covariate or on residuals GAM:** some indication of rapid change at Belleville as well
4. **Cyanos:** Slow change from 1977 (TP is best predictor tho, and no indication of rapid change with covariate)
5. **Macrophytes:** More rapid change in modelled Belleville macrophyte data, no rapid change in fragmentary measured data

# Transient or Zebra mussels?

- “**Zebra mussels only**” mechanism requires effects on clarity as early as 1984 at Belleville
  - Also requires large effect at undetectable density, but no further effect at larger density
- Rates of change ARE consistent with a “**phosphorus only**” mechanism if we allow for moderately long transients in water clarity and chla

# Overall

- pretty good evidence of small magnitude disturbance in Hay Bay, but if so, probably did affect TP too (although no statistical evidence for this claim)
- how to interpret the decoupling of TP and light/chla/cyanos that produces “rapid change” at Belleville? Is this evidence of a transient?
- identifiability is a huge issue

## Next:

Make reviewers happy

- “bombarded with statistics”

Perhaps there is no clarity to be had

# Funding

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BIOLOGY



**Fisheries and Oceans  
Canada**

**Pêches et Océans  
Canada**

**Canada**

# Thanks!

- Project Quinte: The long line of ecologists that collected this data....
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- BIRS Workshop 19w5108 New Mathematical Methods for Complex Systems in Ecology



Questions?

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