Effects of Phosphorus control on fisheries in the Bay of Quinte Area of Concern

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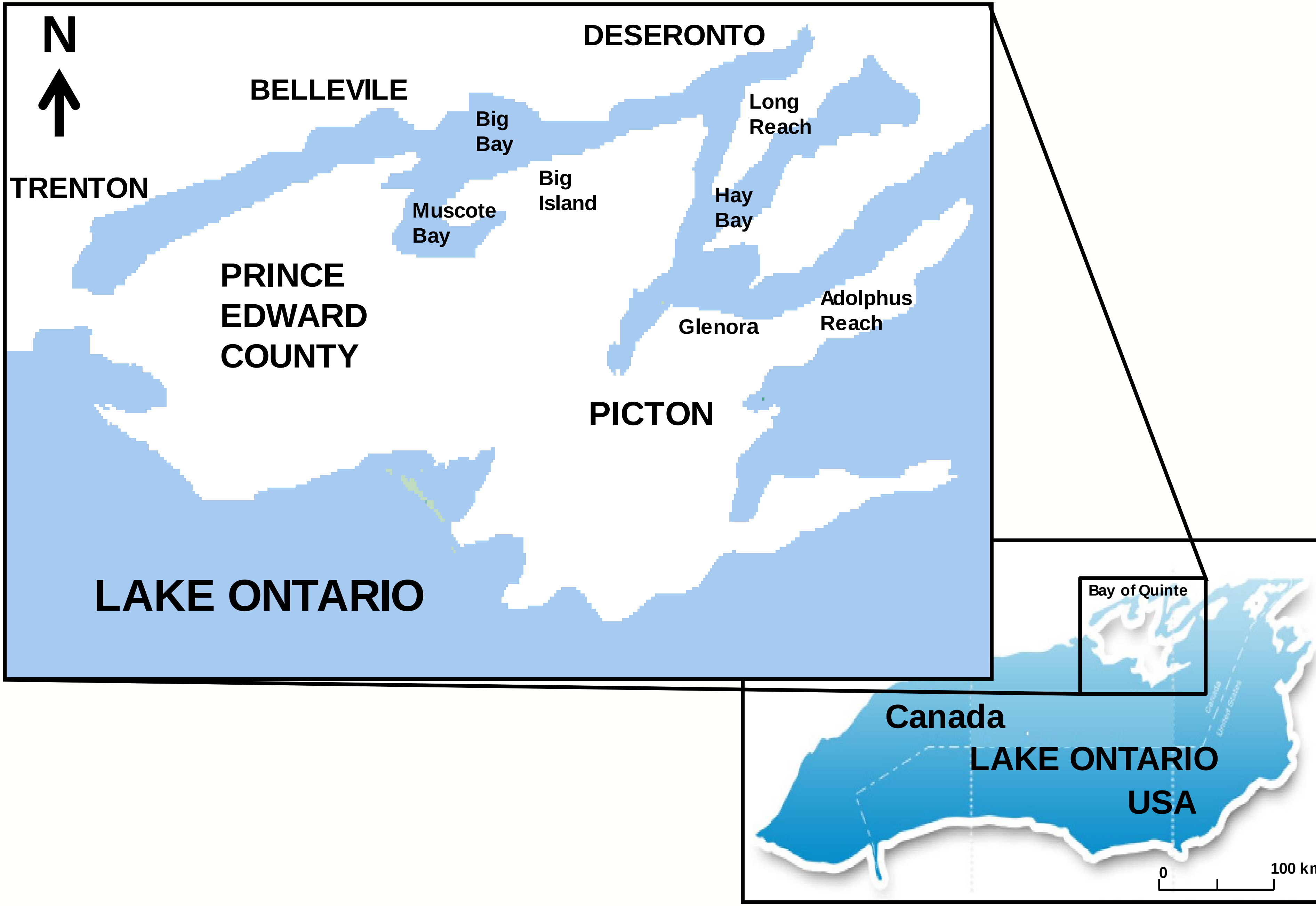
Objective

Delineate the signature of Total Phosphorus (TP) on the fish biomass variability in the Bay of Quinte.

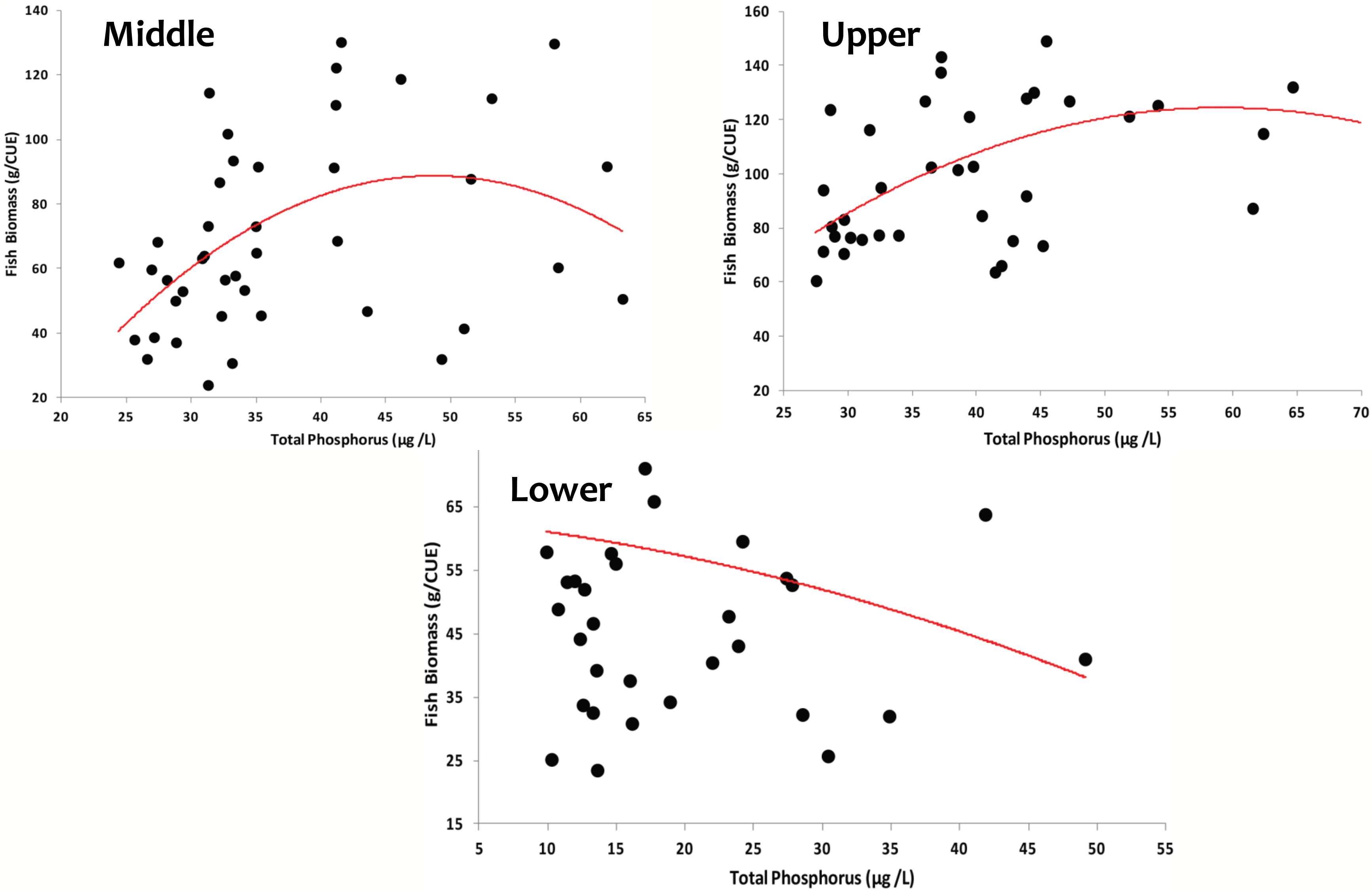
Method and Materials

- A **combination of Bayesian statistical techniques** [(1)dynamic linear modelling, (2)Bayesian Hierarchical modelling, (3) Piecewise Regression modelling and (4)Multiple linear regression modelling)].

- **Data:** Intensive study of **fish** (Gill net and trawl survey,OMNRF) and **water quality parameters** in Bay of Quinte in Lake Ontario (1972–2013).


N
DESERONTO
BELLEVILE
Big
Bay
Long
Reach
TRENTON
Big
Island
Hay
Bay
Muscote
Bay
PRINCE
EDWARD
COUNTY
Adolphus
Reach
Glenora
PICTON
LAKE ONTARIO
Bay of Quinte
Canada
LAKE ONTARIO
USA
0
100 km

Fish biomass vs Total Phosphorus



Dynamic Linear Model

Observation Equation:

$\text{Ln}[\textit{Fish Biomass}]_{ti} = \text{level}_t + \beta_t \ln[\textit{Total Phosphorus}]_{ti} + \varepsilon_{ti},$

$\varepsilon_{ti} \sim N[0, \psi_t]$

System Equations:

$\text{level}_t = \text{level}_{t-1} + \text{rate}_t + \omega_{t1},\ \omega_{t1} \sim N[0, \Omega_{t1}]$

$\text{rate}_t = \text{rate}_{t-1} + \omega_{t2},\ \omega_{t2} \sim N[0, \Omega_{t2}]$

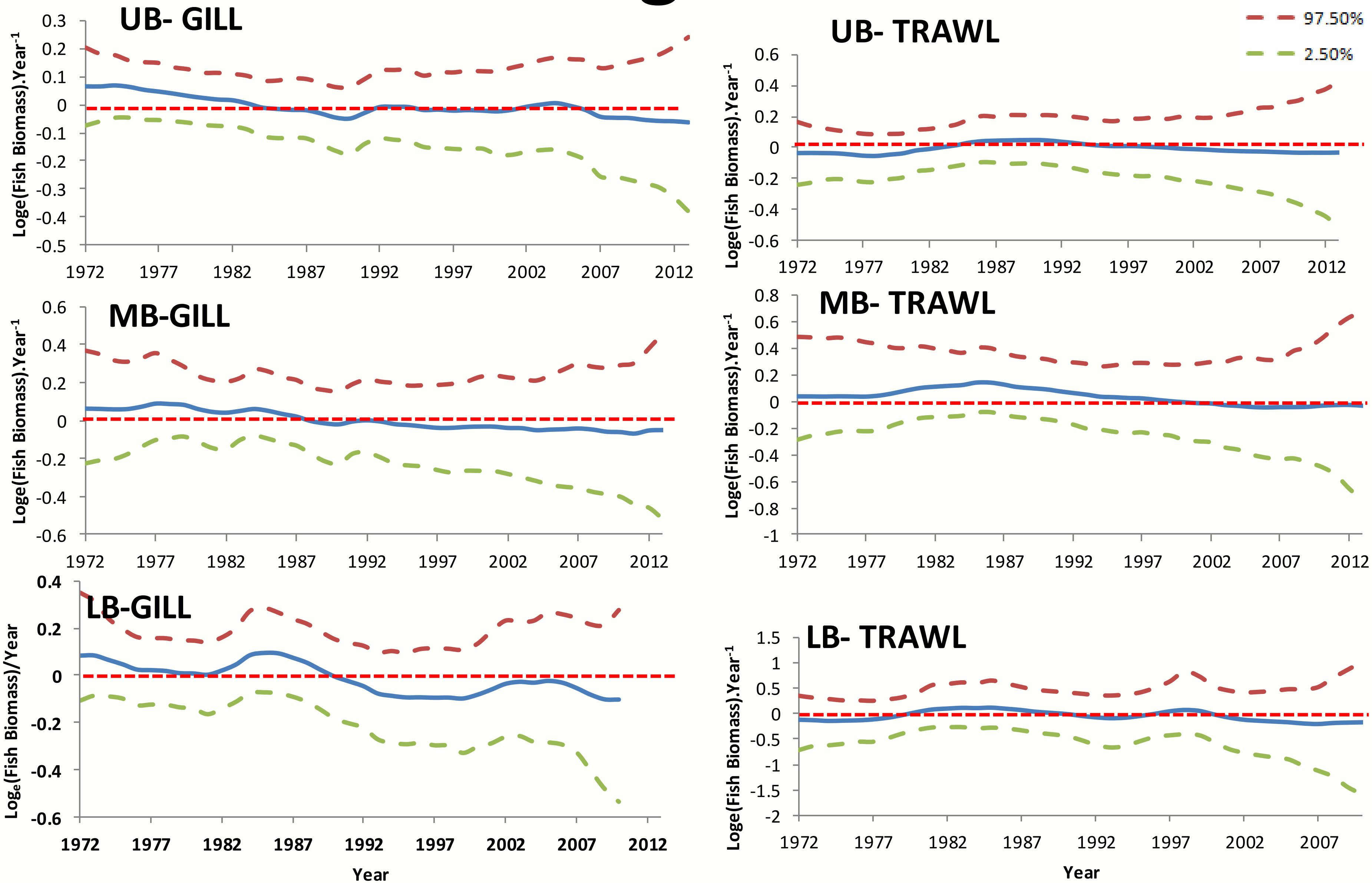
$\beta_t = \beta_{t-1} + \omega_{t3},\ \omega_{t3} \sim N[0, \Omega_{t3}]$

$1/\Omega_{tj}^2 = \zeta^{t-1}\, 1/\Omega_{tj}^2,\ 1/\psi_t^2 = \zeta^{t-1}\, 1/\psi_t^2$ $t>1$ and $j = 1 \ldots 3$

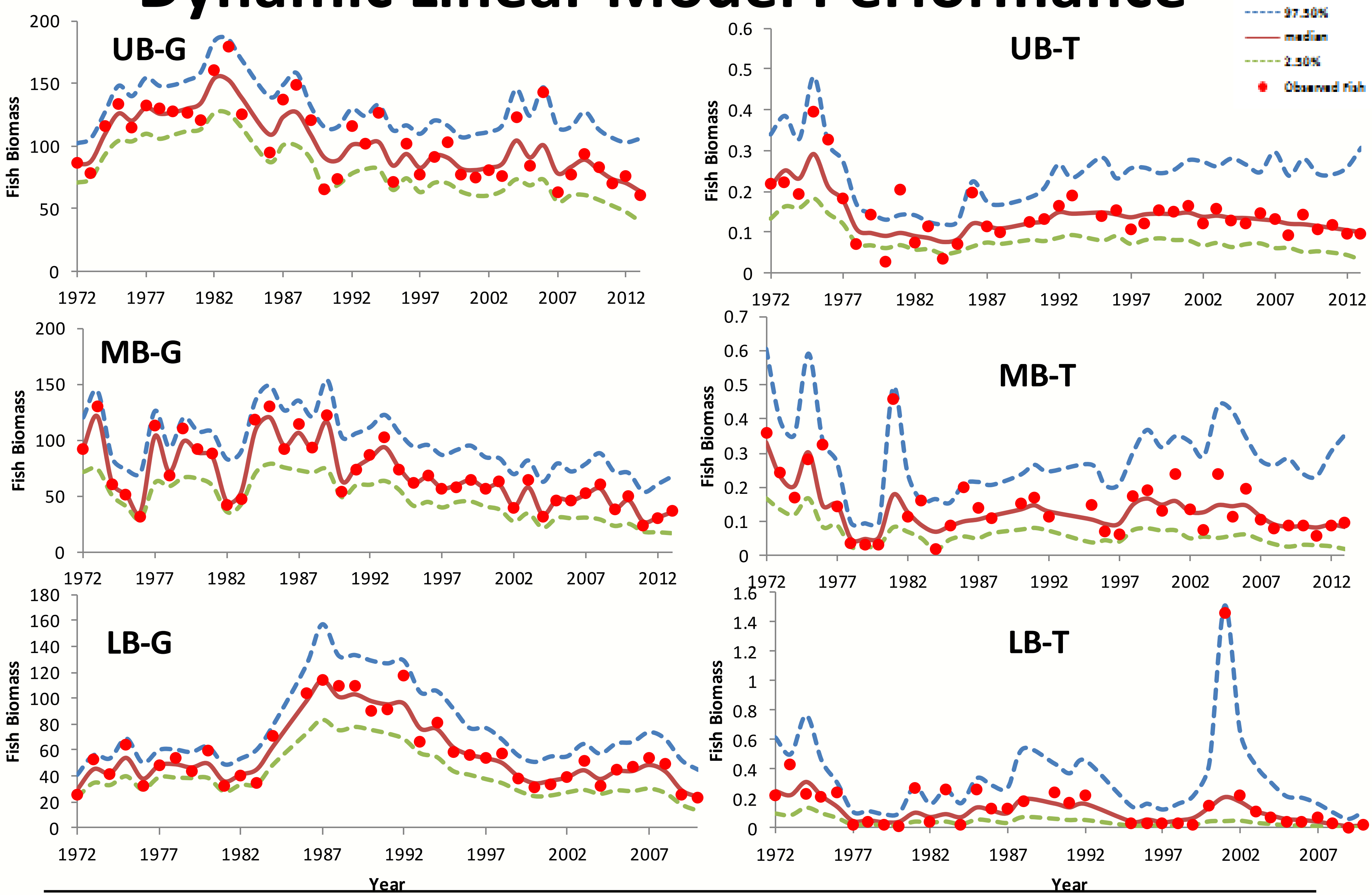
$\text{level}_1, \text{rate}_1, \beta_1 \sim N(0, 10000)$ $t=1$

$1/\Omega_{1j}^2,\ 1/\psi_1^2 \sim \text{gamma}(0.001, 0.001)$

Rate of Change: Fish Biomass



Dynamic Linear Model Performance



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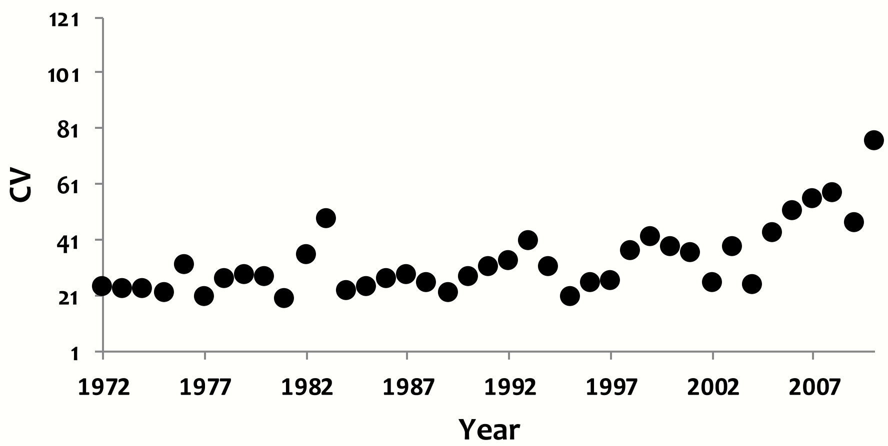
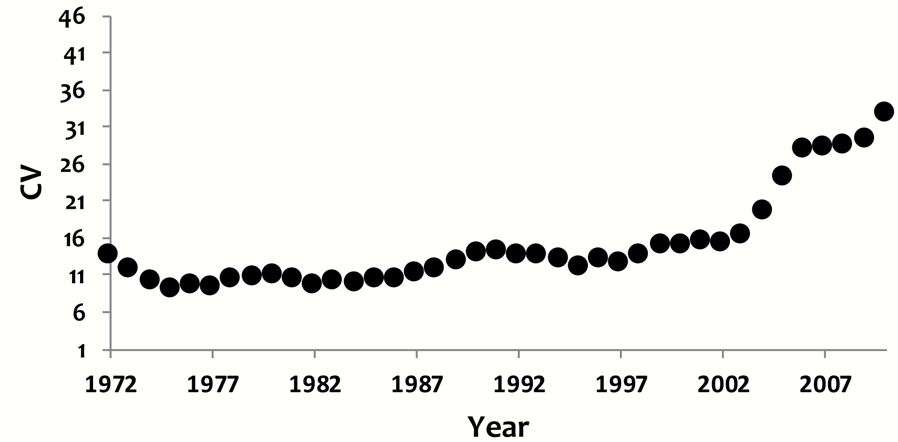
Freshwater Ecosystem Research

Coefficient of variation: Gillnet(DLM)

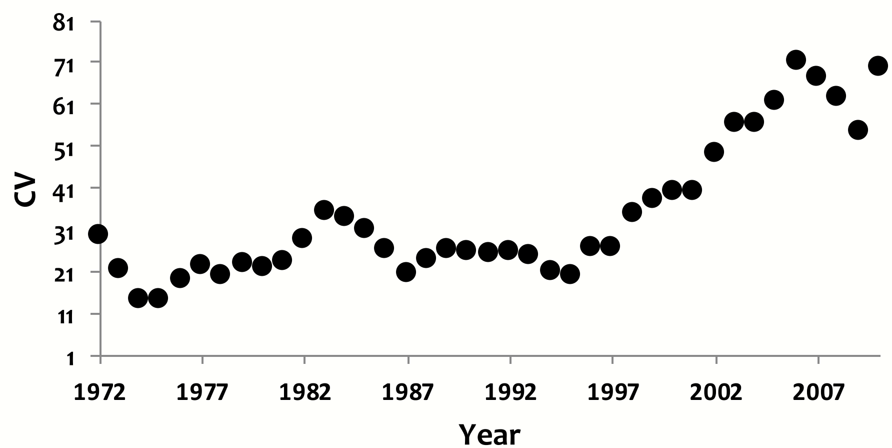
Middle



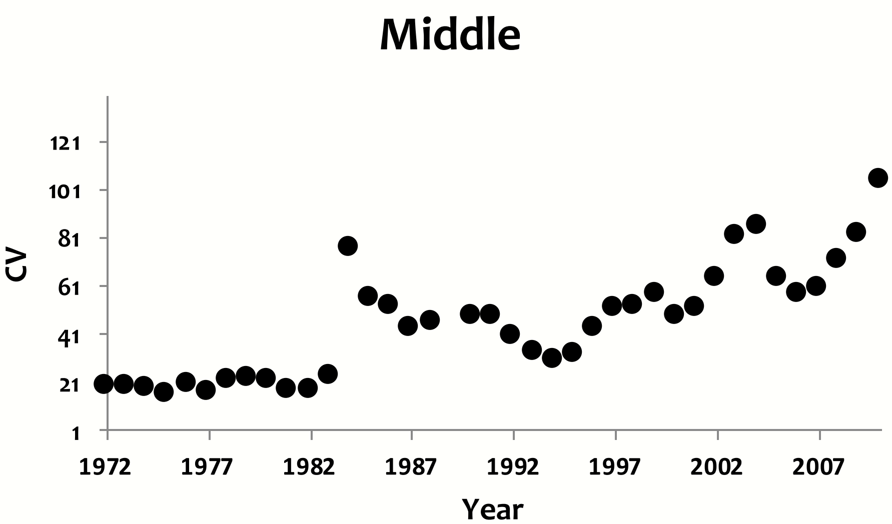
Upper

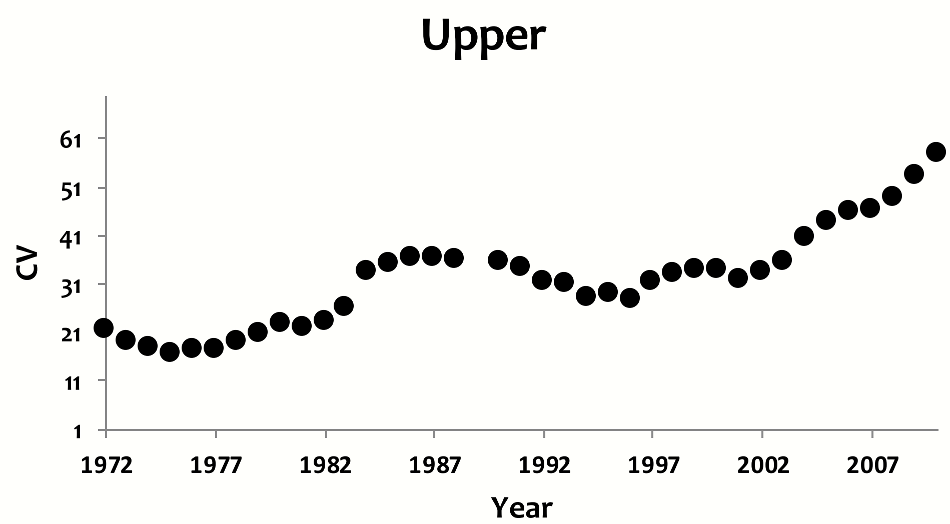


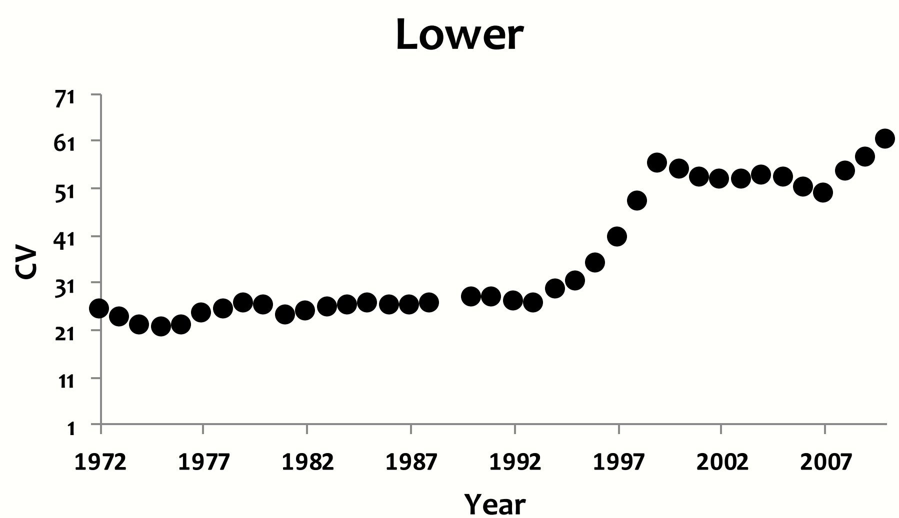
Lower



Coefficient of variation (CV):Trawl (DLM)







Bayesian Hierarchical Model

$$Ln[Fish\ Biomass]_{ti} = \beta_{0i} + \beta_{1i} ln[Total\ Phosphorus]_{ti} + \varepsilon_{ti},\ \varepsilon_{ti} \sim N[0, \sigma^2]$$

$$\beta_{0i} \sim N(\beta_{0g},\ \tau_{0i}^2)\ \beta_{1i} \sim N(\beta_{1g},\ \tau_{1i}^2)$$

$$\beta_{0g} \sim N(\mu_0,\ \sigma_0^2)\ \beta_{1g} \sim N(\mu_1,\ \sigma_1^2)$$

$$\mu_0 \sim N(0,\ 1000)\ \mu_1 \sim N(0,\ 1000)$$

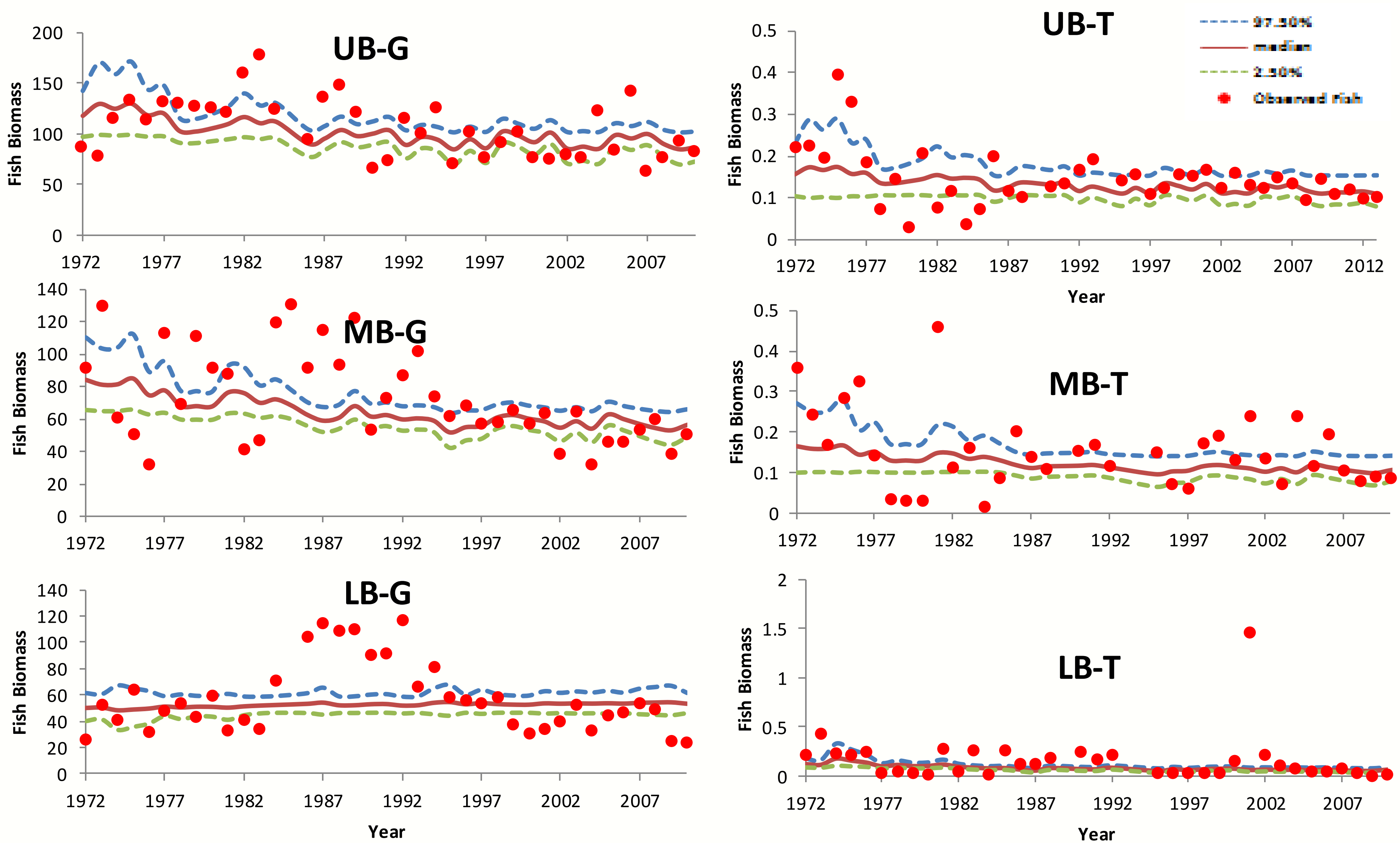
$$\tau_{0i}^2 \sim IG(0.001,\ 0.001)\ \tau_{1i}^2 \sim IG(0.001,\ 0.001)$$

$$\sigma_0^2 \sim IG(0.001,\ 0.001)\ \ \sigma_1^2 \sim IG(0.001,\ 0.001)$$

$$\sigma^2 \sim IG(0.001,\ 0.001)$$

i=1….3 (lower/middle/upper)

Predictions with parametric error



Regression coefficients (BHM)

Parameter	Gill net		Trawl	
	mean	sd	mean	sd
Slope[Upper]	0.2082	0.0977	0.2194	0.1739
Slope[Middle]	0.2579	0.1094	0.2878	0.1952
Slope[Lower]	-0.0396	0.0796	0.3919	0.1386

Piecewise Regression Model

$$\text{Ln}[\textit{Fish Biomass}]_i = \alpha_0 + \alpha_1(\ln[\textit{Total Phosphorus}]_i$$
$$+\alpha_2\,[Step(1978\text{-}Year[i]*(Year[i]\ \text{-}1972)]$$
$$+\alpha_3\,[Step(Year[i]\ \text{-}1979*Step\ (1994\text{-}Year[i]*(Year[i]\ \text{-}1978)]$$
$$+\alpha_4\,[Step(Year[i]\text{-}1995)*(Year[i]\ \text{-}1994)]$$
$$\alpha_i \sim N(0,\ 0.0001)\ i = 0\ldots.4$$
$$\sigma^2 \sim IG(0.0,\ 0.001)$$

Piecewise Regression coefficients

Group Name	Measures	Intercept	Slope(TP)	Slope(Pre-TP-Ctrl)	Slope(Post-TP-Ctrl)	Slope(Post-Mussels)	Sigma
All Fish	Mean	3.615	0.326	0.115	0.030	-0.032	0.317
	Stdev	1.011	0.265	0.042	0.013	0.012	0.038
Planktivore	Mean	-12.260	3.973	0.308	0.029	-0.072	0.962
	Stdev	3.062	0.803	0.127	0.039	0.038	0.114
Benthivore	Mean	4.534	-0.150	0.058	0.020	-0.021	0.231
	Stdev	0.736	0.193	0.031	0.009	0.009	0.027
Piscivore	Mean	4.743	-0.414	-0.077	0.086	-0.019	0.630
	Stdev	2.006	0.526	0.083	0.025	0.025	0.075
Sun Fishes	Mean	5.259	-2.009	0.046	-0.044	0.086	0.973
	Stdev	3.107	0.821	0.136	0.043	0.039	0.125
Percid	Mean	8.059	-1.151	-0.114	0.040	-0.073	0.519
	Stdev	1.652	0.433	0.069	0.021	0.020	0.061

Piecewise Regression coefficients

Group Name	Measures	Intercept	Slope(TP)	Slope(Pre-TP-Ctrl)	Slope(Post-TP-Ctrl)	Slope(Post-Mussels)	Sigma
Walleye	Mean	7.861	-1.347	-0.287	0.092	-0.073	0.782
	Stdev	2.489	0.653	0.103	0.031	0.031	0.092
Yellow P	Mean	9.000	-1.587	0.023	-0.026	-0.084	0.472
	Stdev	1.504	0.394	0.062	0.019	0.019	0.056
White P	Mean	-2.721	1.468	0.065	0.065	0.044	0.611
	Stdev	1.945	0.510	0.081	0.025	0.024	0.072
B Bullhead	Mean	5.815	-1.446	0.251	0.018	-0.110	0.625
	Stdev	1.992	0.523	0.084	0.025	0.025	0.076
F Drum	Mean	11.550	-2.793	-0.282	0.065	-0.030	0.687
	Stdev	2.186	0.573	0.091	0.028	0.027	0.081

Multiple Regression Model

$$\mathrm{Ln}[\mathit{Fish\ Biomass}]_i = \alpha_0 + \alpha_1 \ln[\mathit{Zooplankton}]_i + \alpha_2 \ln[\mathit{Total\ Phosphorus}]_i + \alpha_3 [\mathit{Surface\ Water\ Temperature}]_i$$

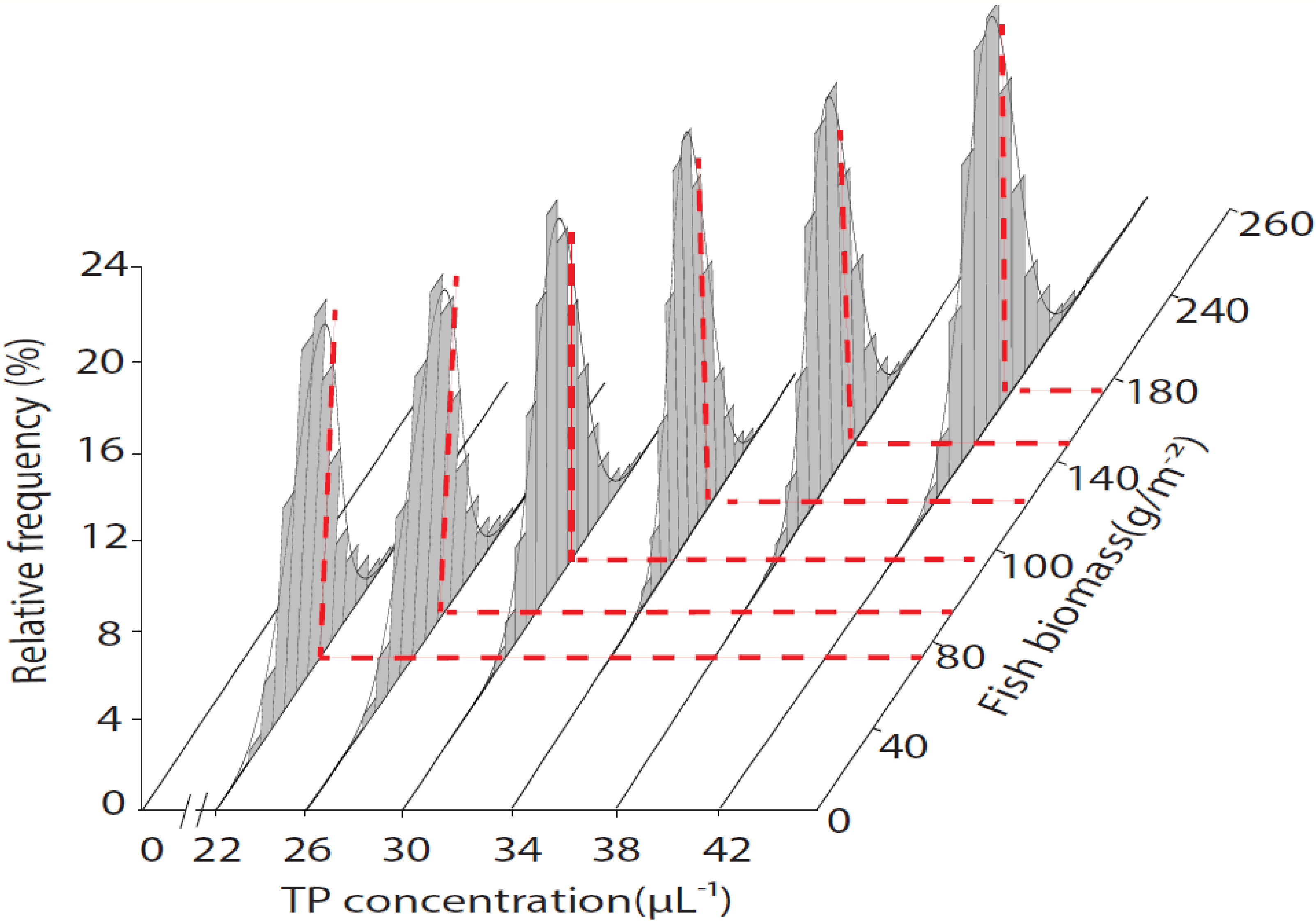
$$\alpha_i \sim N(0,\ 0.0001)\ i = 0 \ldots 3$$

$$\sigma^2 \sim IG(0.0,\ 0.001)$$

Importance of the variables

Groups	Variables: Total Phosphorus	Variables: Zooplankton	Variables: Surface Water Temperature	Intercept
All Fish	↑	↑	↓	↓
Planktivores	↑	↑	↓	↓
Benthivores	↑	↑	↓	↑
Piscivores	↑	↑	↓	↓
Percid	↑	↑	↓	↓
Sun Fishes	↓	↑	↑	↓
Walleye	↑	↑	↓	↓
Yellow P.	↑	↑	↓	↑
White P.	↑	↑	↓	↑
B. Bullhead	↑	↑	↓	↑
F. Drum	↓	↑	↓	↑

All Fishes



24
20
16
12
8
4
0
Relative frequency (%)
0
22
26
30
34
38
42
TP concentration(μL⁻¹)
0
40
80
100
140
180
240
260
Fish biomass(g/m⁻²)

Conclusions

- The relationship between fish and TP was quite strong when the system was eutrophic (early 1970s), but became distinctly weaker during recent years.
- The effect of TP on fish biomass is in good agreement in Upper and Middle bays between sampling gears, but differs in the lower bay with a relatively stronger effect in the trawl data.
- Following the invasion of dreissenids the Fish-TP relationship has changed and the biomass of fish is lower.

Conclusions

- TP variability shows a strong signature on biomass of fish, even when we explicitly account for the role of zooplankton and surface water temperature.
- There are other interactions that have not been included in these analyses which we expect may be influencing the biomass of the fish community.
- Understanding the effects of P reduction on the fish community is important when setting water quality standards.

Future Work

- Additional analysis of the Bay of Quinte data set to examine the responses of different groups of fishes within the fish community.
- Compilation and analysis of data from other freshwater ecosystems for similar analyses to put the Bay of Quinte into a broader context.

Thank you!