The impact of P reduction on the sustainability of fish populations in the Bay of Quinte

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Contents

Objective

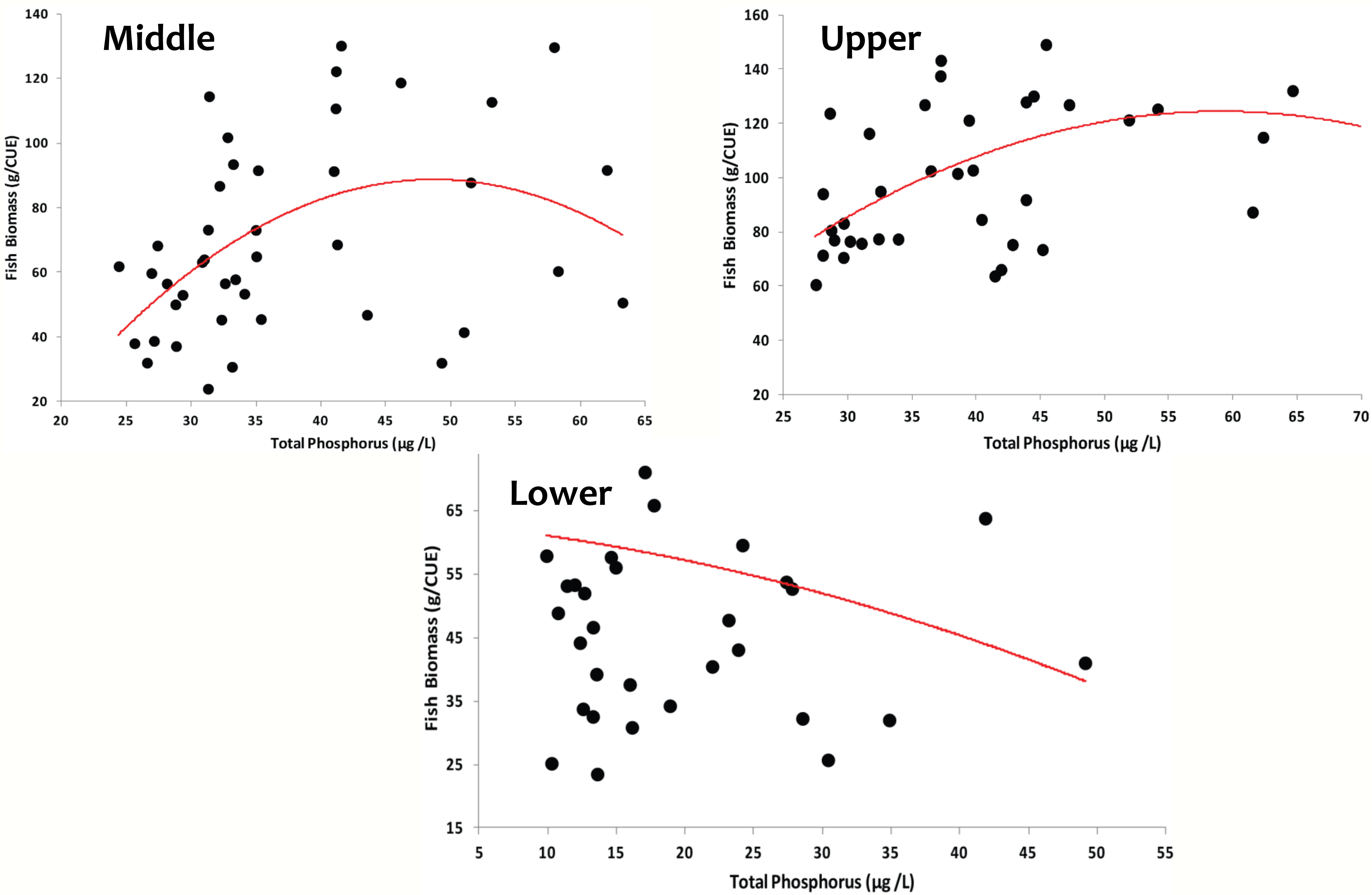
Delineate the signature of Total Phosphorus (TP) on the fish biomass variability in the Bay of Quinte.

Method and Materials

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

Fish biomass vs Total Phosphorus



Dynamic Linear Model

Observation Equation:

$\mathrm{Ln}[\mathit{Fish\ Biomass}]_{ti} = \mathrm{level}_t + \beta_t \ln[\mathit{Total\ Phosphorus}]_{ti} + \psi_{ti},$

$\psi_{ti} \sim N[0, \Psi_t]$

System Equations:

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

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

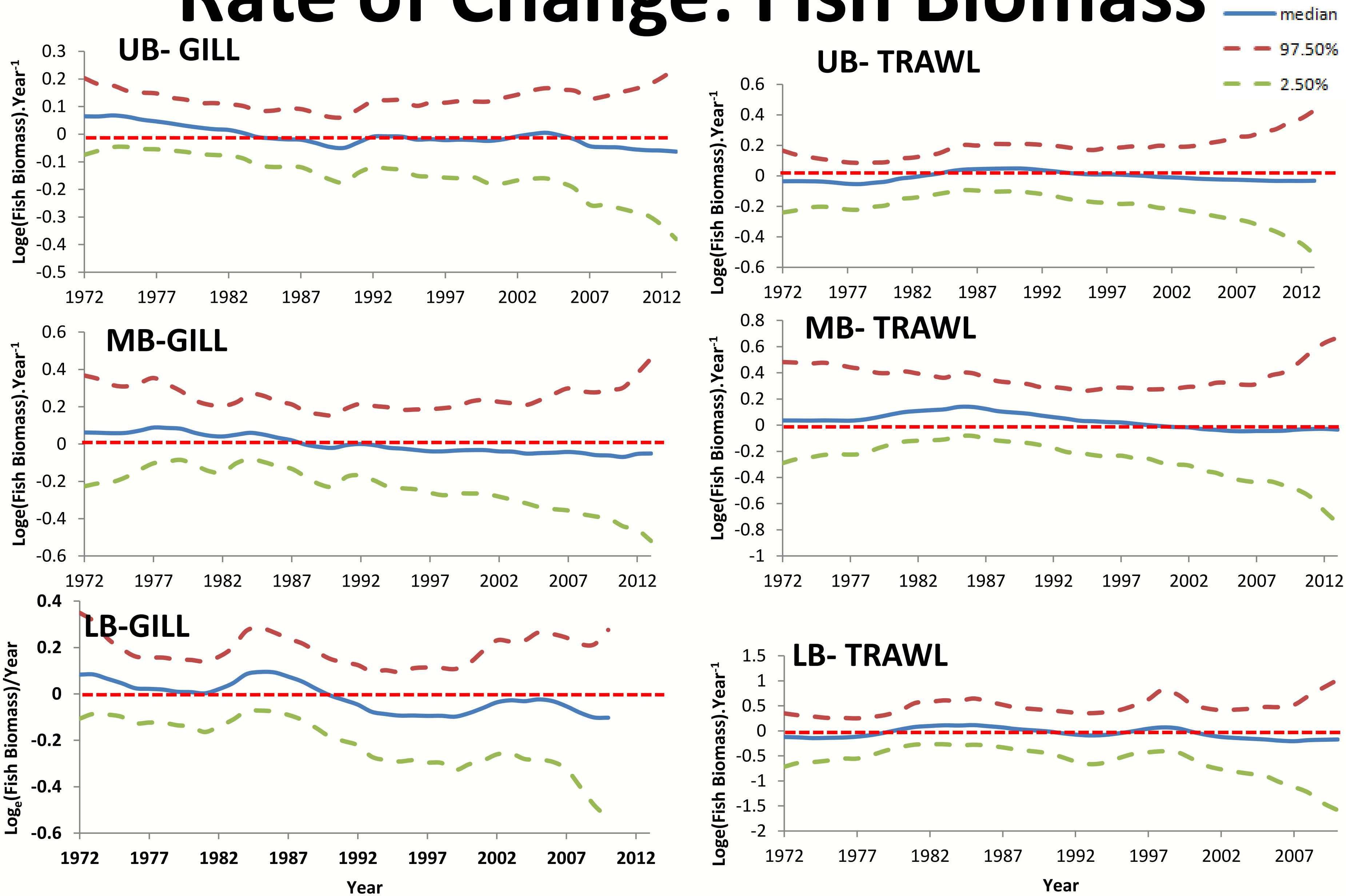
$\beta_t = \beta_{t-1} + \omega_{t3},\ \omega_{t3} \sim N[0, \Omega_{t3}]$

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

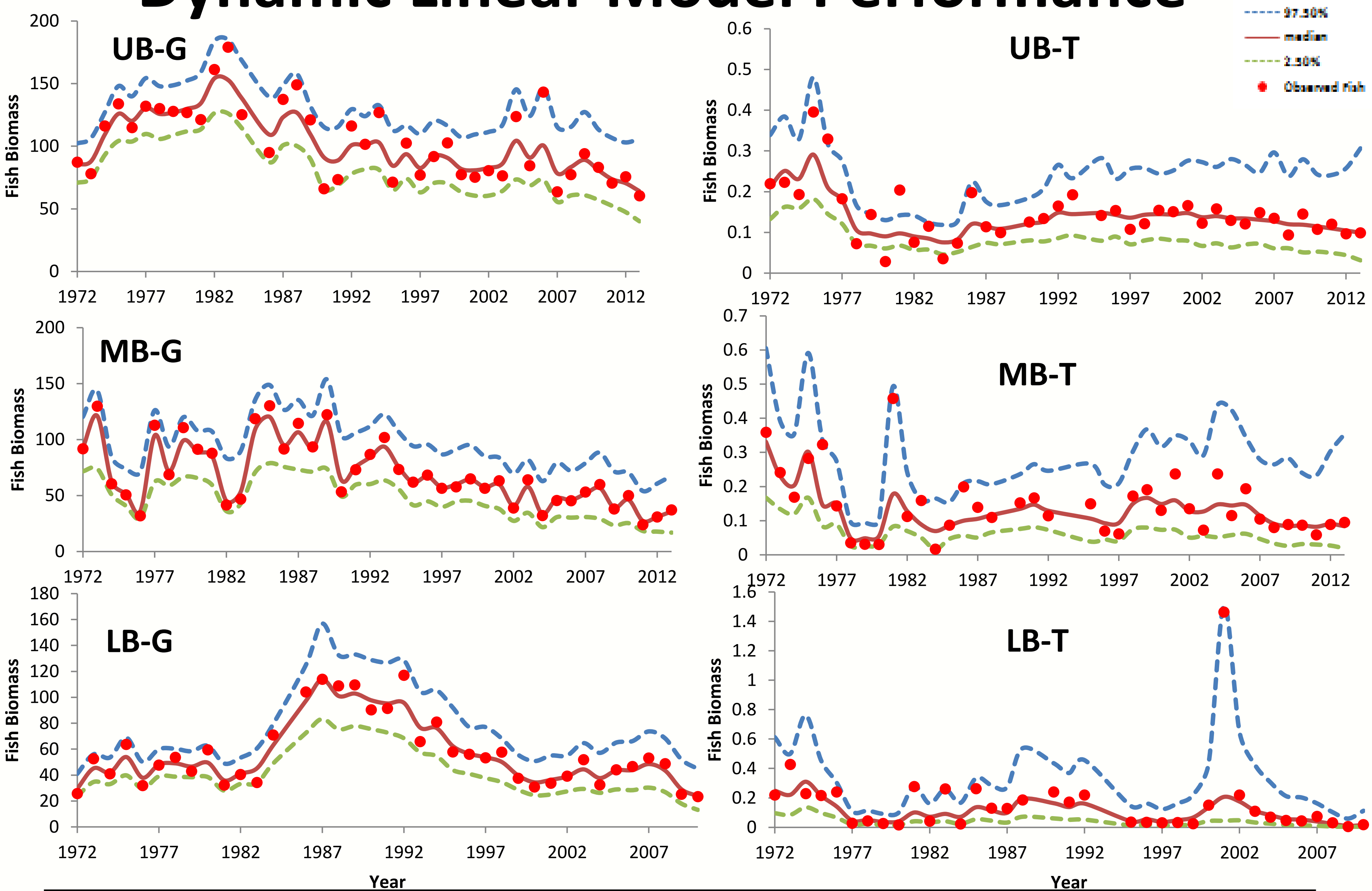
$\mathrm{level}_1, \mathrm{rate}_1, \beta_1 \sim N(0, 10000)$ $t=1$

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

Rate of Change: Fish Biomass

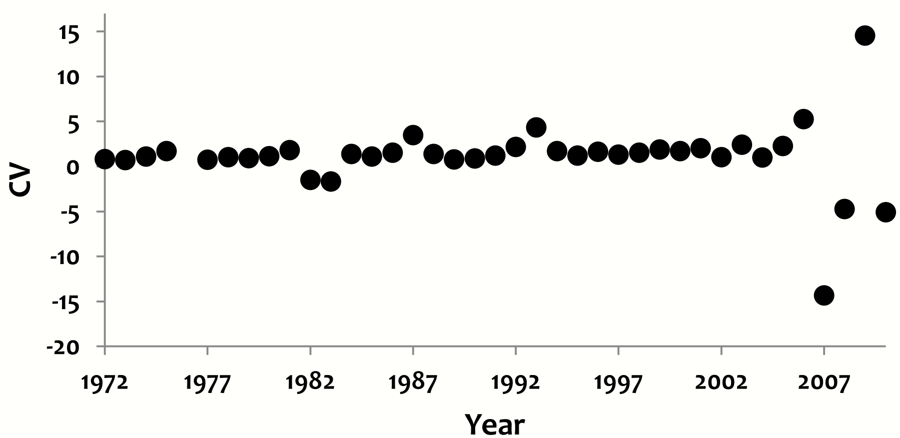


Dynamic Linear Model Performance

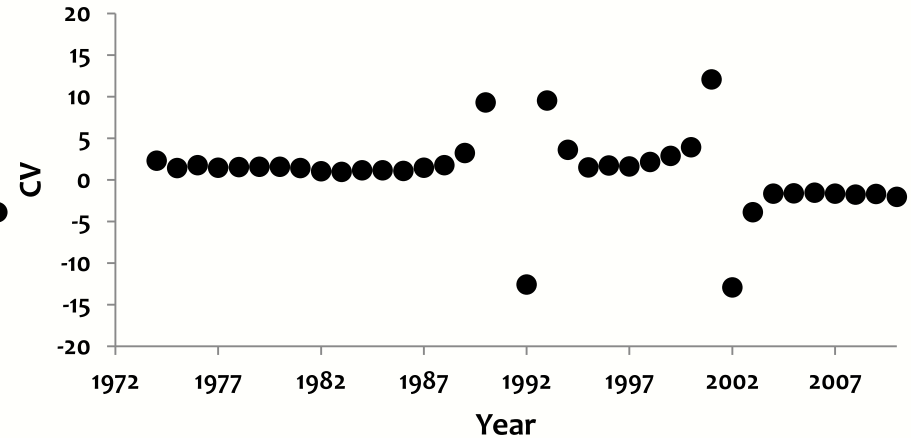


Coefficient of variation: Gillnet(DLM)

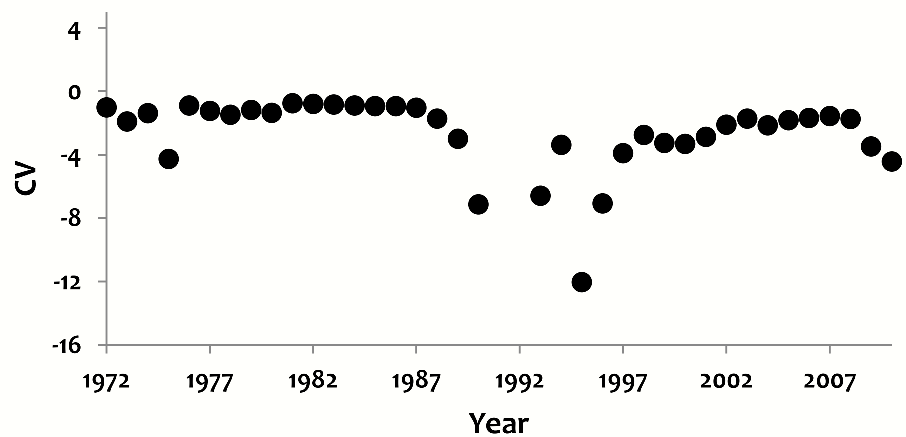
Middle



Upper

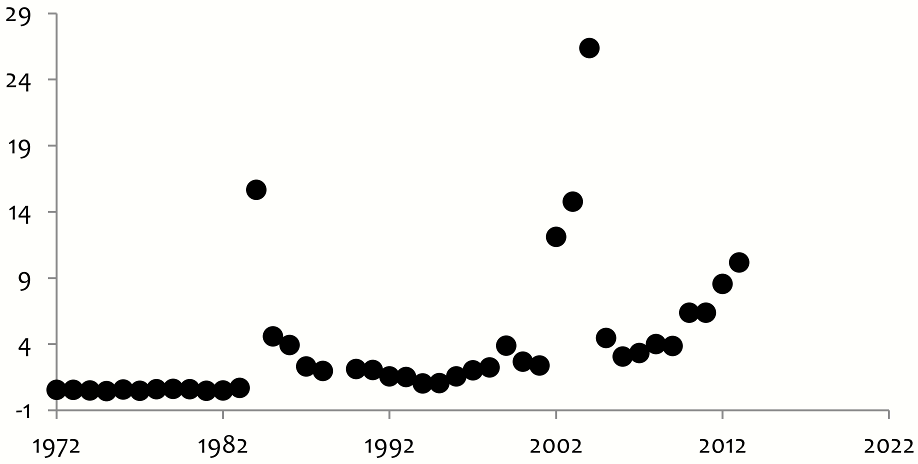


Lower

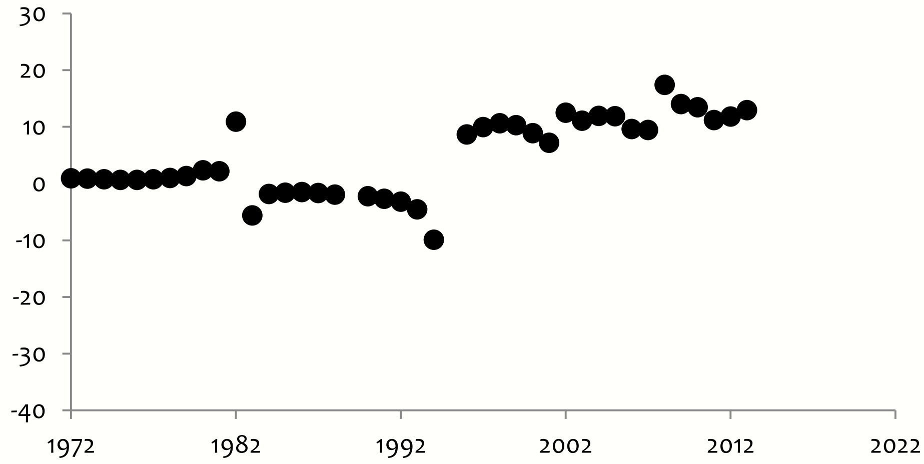


Coefficient of variation (CV):Trawl (DLM)

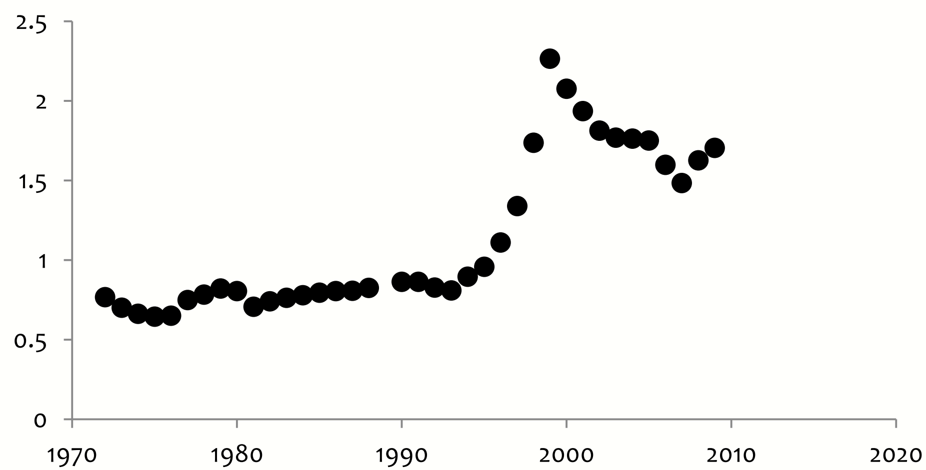
Middle Bay



Upper Bay



Lower Bay



Bayesian Hierarchical Model

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

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

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

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

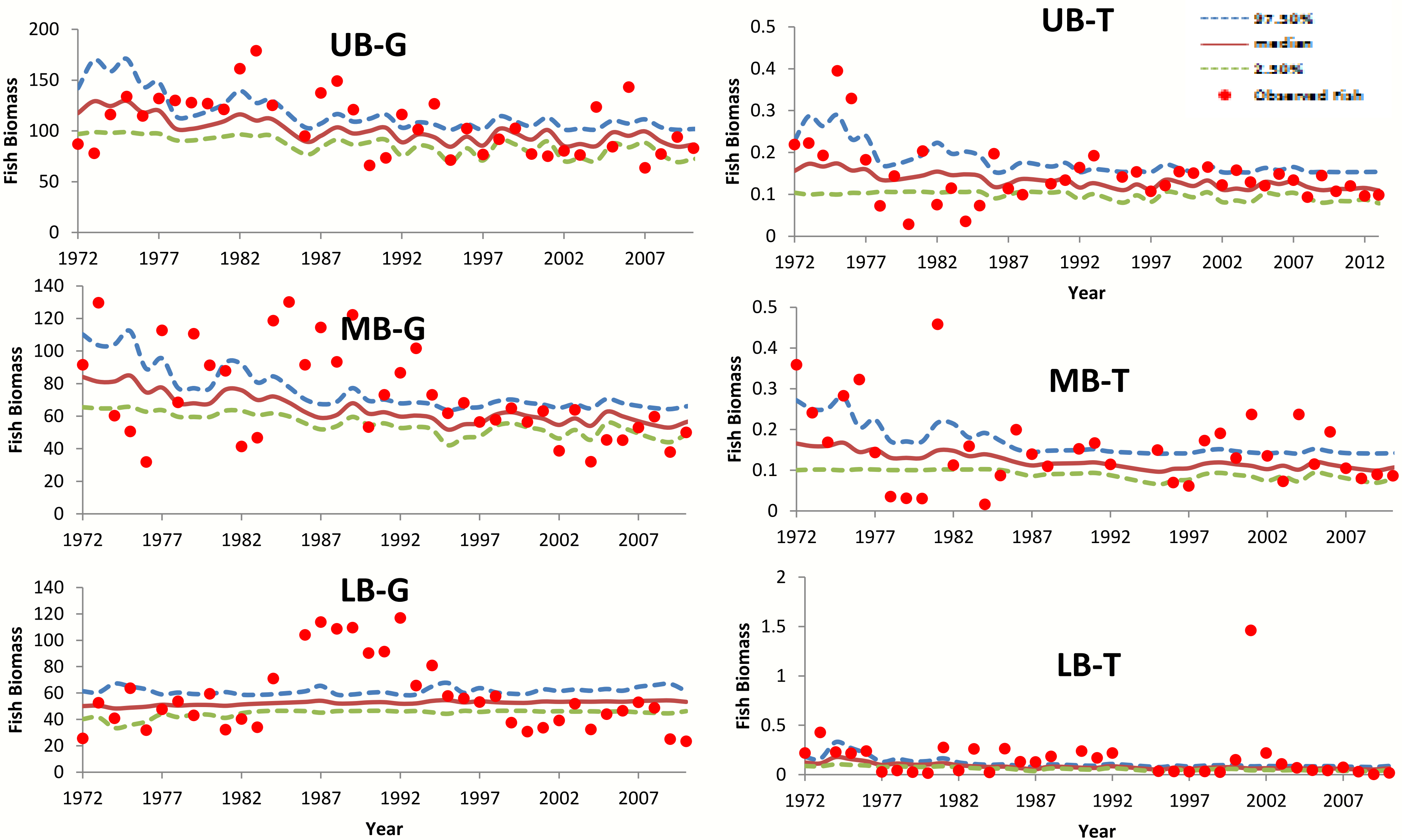
$$\tau_{0i}^2 \sim IG(0.001, 0.001)\ \tau_{1i}^2 \sim IG(0.001, 0.001)$$

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

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

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

Multiple Regression Model

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

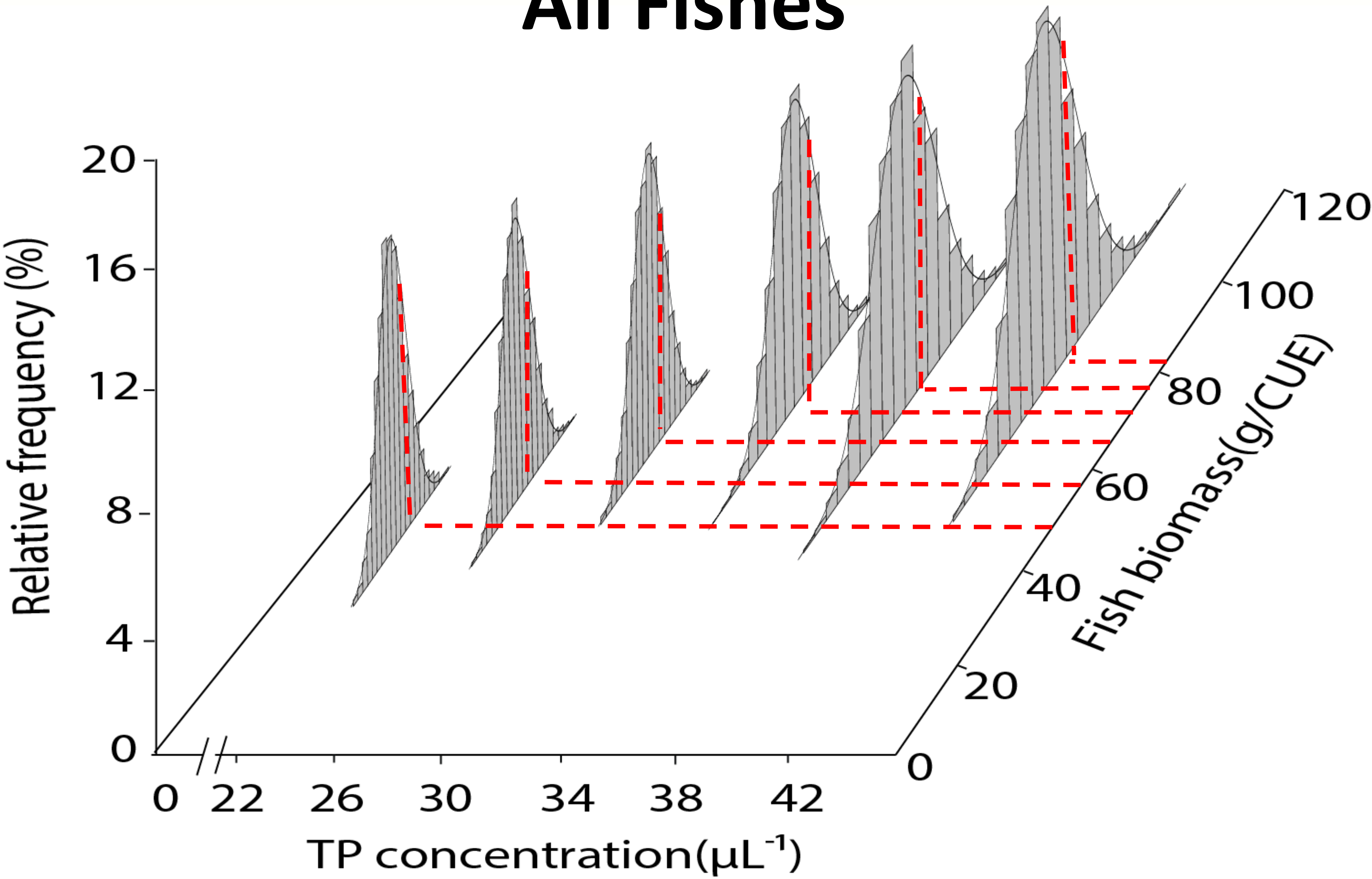
$$\alpha_i \sim N(0,\ 0.0001)\ i = 0....3$$

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

Multiple Regression coefficients

Parameter	mean	sd	median
alpha[intercept]	5.05	1.04	5.04
alpha[Zooplankton]	0.31	0.12	0.31
alpha[TP]	0.75	0.27	0.76
alpha[SWT]	-0.22	0.05	-0.22
sigma	0.22	0.03	0.22

All Fishes



Relative frequency (%)
20
16
12
8
4
0
0
22
26
30
34
38
42
TP concentration(μL-1)
Fish biomass(g/CUE)
0
20
40
60
80
100
120

All Fishes
Piecewise Regression Model

$$\mathrm{Ln}[\textit{Fish Biomass}]_i = \alpha_0 + \alpha_1(\ln[\textit{Zooplankton}]_i + \alpha_2(\ln[\textit{Total Phosphorus}]_i + \alpha_3[\textit{Surface Water Temperature}]_i + \alpha_4[\textit{Step}(1994-\textit{Year}[i])*\textit{Year}[i]] + \alpha_5[\textit{Step}(\textit{Year}[i]-1995)*(\textit{Year}[i]-1994)]$$

$$\alpha_i \sim N(0, 0.0001)\ i = 0....4$$

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

Piecewise Regression coefficients

Group Name	Measures	alpha[Intercept]	Alpha[Zoop]	Alpha[TP]	Alpha[STemp]	Alpha[step-1994]	Alpha[step-1995]	sigma
Bass-centrarchid	Mean	-5.395	-0.134	3.923	-0.236	**-0.00012**	**-0.04667**	0.465
	Stdev	2.367	0.307	0.803	0.137	**0.00021**	**0.02271**	0.072
Planktivore	Mean	-1.041	-0.069	0.613	0.131	**0.00036**	**-0.06479**	0.590
	Stdev	3.006	0.390	1.020	0.173	**0.00026**	**0.02884**	0.092
Benthivore	Mean	4.615	0.085	0.042	-0.062	**0.00013**	**-0.03249**	0.204
	Stdev	1.041	0.135	0.353	0.060	**0.00009**	**0.00998**	0.032
All_Fish	Mean	4.925	0.1141	0.02911	-0.05808	**0.00012**	**-0.02590**	0.16
	Stdev	0.8377	0.1086	0.2841	0.0483	**0.00007**	**0.00803**	0.03
Piscivore	Mean	6.066	0.214	-0.088	-0.077	**0.00007**	**-0.01923**	0.236
	Stdev	1.203	0.156	0.408	0.069	**0.00010**	**0.01154**	0.037
PERCID	Mean	6.725	0.439	-0.156	-0.063	**-0.00016**	**-0.03094**	0.208
	Stdev	1.057	0.137	0.359	0.061	**0.00009**	**0.01014**	0.032
Walleye	Mean	7.516	0.491	-0.186	-0.072	**-0.00019**	**-0.03297**	0.232
	Stdev	1.182	0.153	0.401	0.068	**0.00010**	**0.01134**	0.036

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.
- TP variability shows a strong signature on biomass of fish, even when we explicitly account for the role of zooplankton and surface water temperature.

Conclusions

- **Following the invasion of dreissenids the Fish-TP relationship has changed and the biomass of fish is lower.**
- **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!