Assessing the impacts of endocrine disrupting compounds (EDCs) on fish population dynamics: a case study of smallmouth bass in Chesapeake Bay

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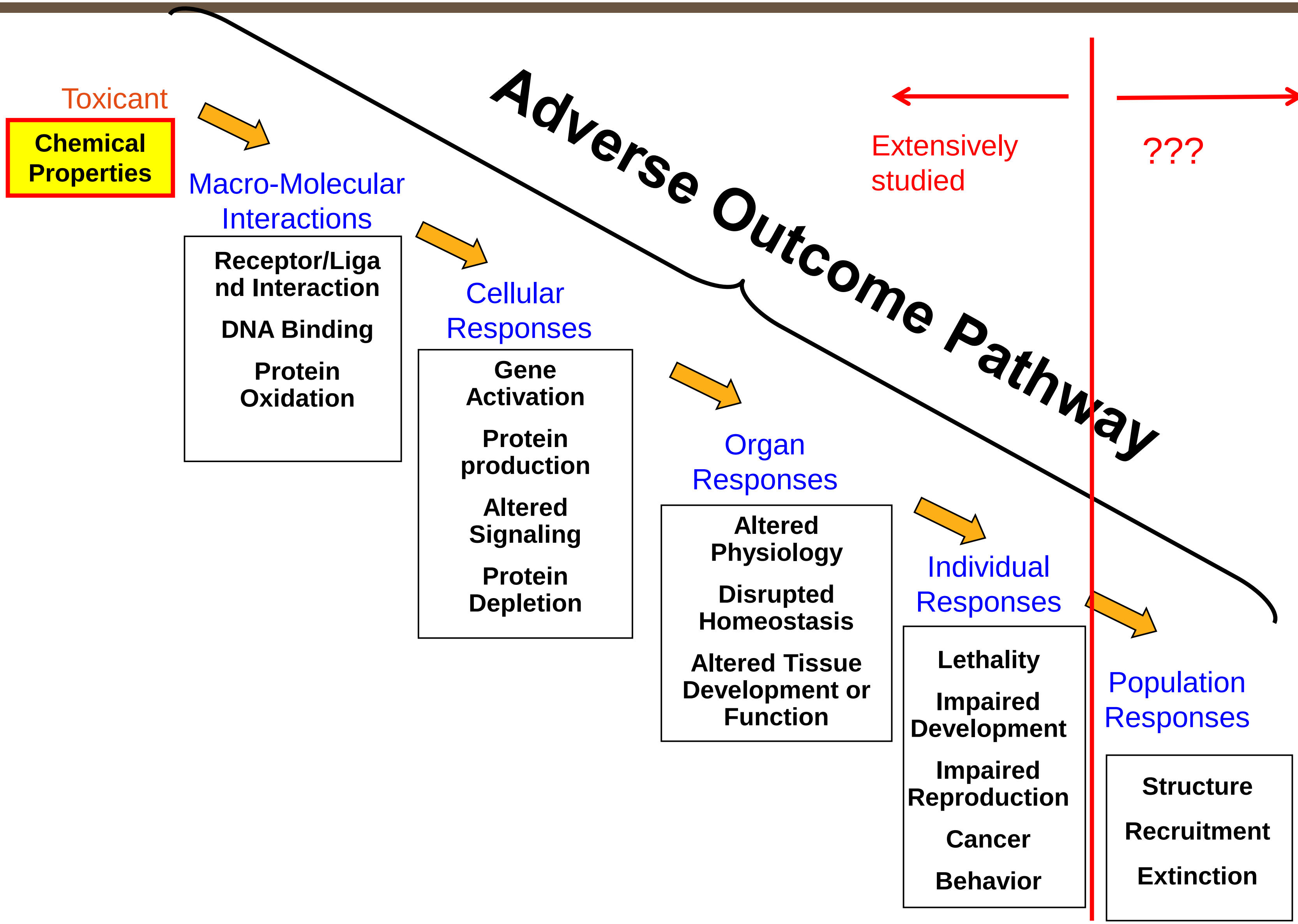
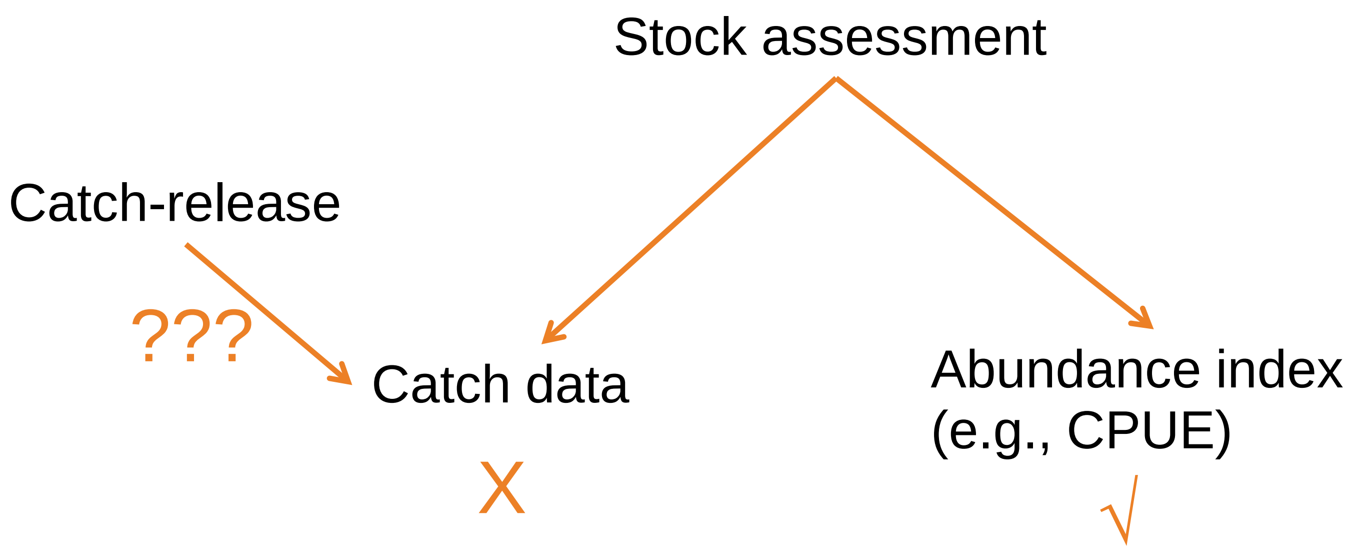
EDC:



Toxicant
Chemical Properties
Macro-Molecular Interactions
Receptor/Ligand Interaction
DNA Binding
Protein Oxidation
Cellular Responses
Gene Activation
Protein production
Altered Signaling
Protein Depletion
Organ Responses
Altered Physiology
Disrupted Homeostasis
Altered Tissue Development or Function
Individual Responses
Lethality
Impaired Development
Impaired Reproduction
Cancer
Behavior
Population Responses
Structure
Recruitment
Extinction
Adverse Outcome Pathway
Extensively studied
???

Challenges for EDC risk assessment at population level



- Integrated analysis
  - Growth data
  - Length/age composition
  - Recruitment
  - …

Smallmouth bass (*Micropterus dolomieu*)

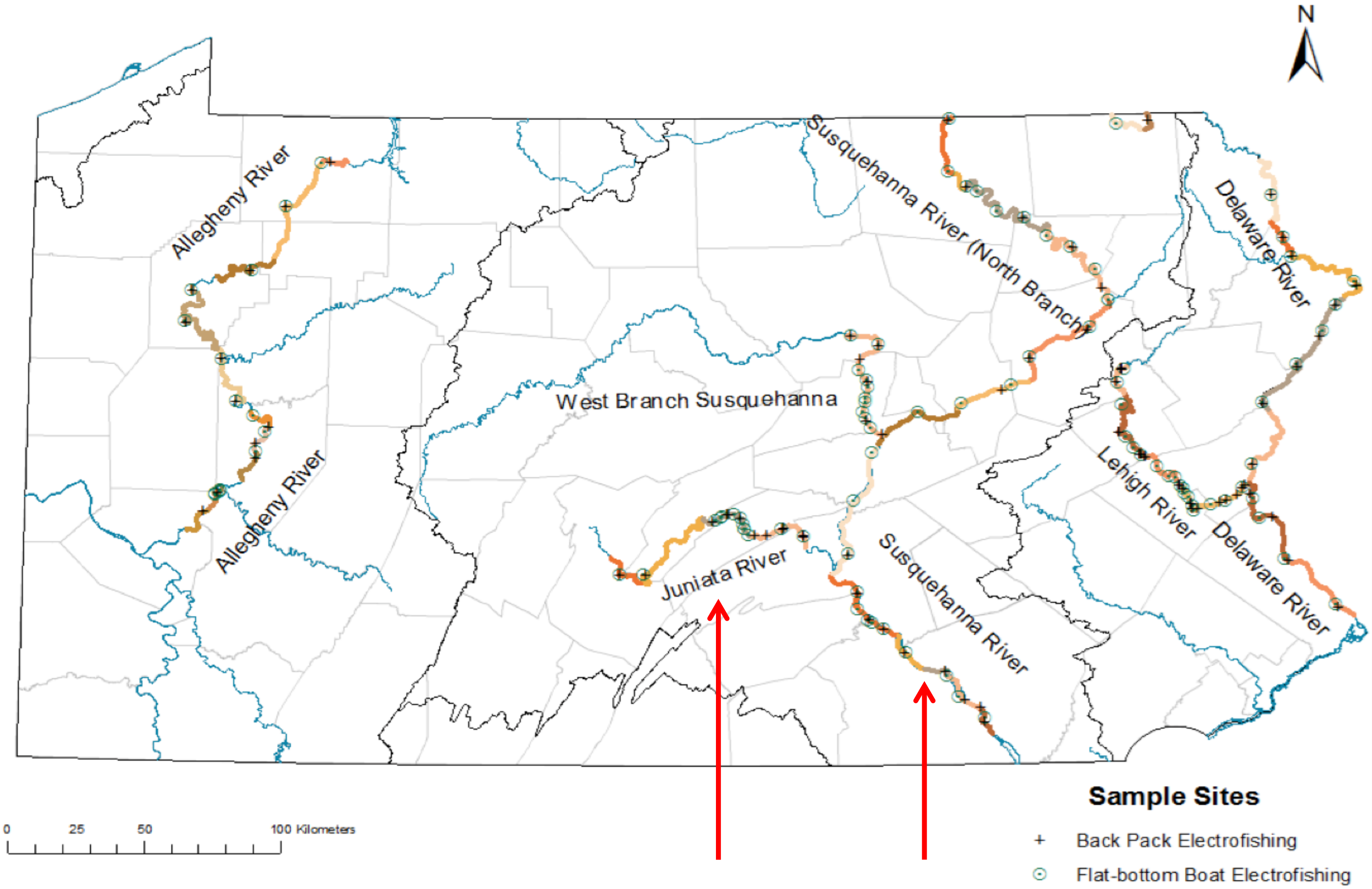
- Life history traits
  - Inhabit freshwater lakes and rivers throughout North America
  - Survival and spawning sensitive to environmental stresses
- Important freshwater recreational fisheries but no catch data
- EDC impacts on smallmouth bass
  - Intersex: feminization of male fish (Blazer et al. 2007)
  - Disease outbreak in 2005 → large die-off of young fish → adult abundance decline

Objectives

Using smallmouth bass as a case study:

- Develop an integrated analysis to estimate growth, natural mortality and recruitment in the catch-at-length analysis framework
- Explore the spatial and temporal variation in growth and mortalities
- Explore the hypothetical EDC impacts on fish population through a simulation
- Provide a modeling framework for population-level EDC risk assessment for Chesapeake Bay watershed

Study sites: 7 rivers in PA



Provided by Robert Lorantas
Pennsylvania Fish and Boat Commission

Data

- Provided by the Pennsylvania Fish and Boat Commission
  - Length-age data, 1980-2012
  - Catch-per-unit-effort (CPUE) data, 1990-2013
  - Young-of-year (age 0) CPUE data, 1987-2010

Modeling framework

Growth analysis

$$L_{i,j} = \left(L_{\infty,j}\left(1-\exp\left(-K_j\left(t_{i,j}-t_{0,j}\right)\right)\right)\right)\exp\left(\varepsilon_{L,i,j}\right);\ \varepsilon_{L,i,j} \sim N\left(0, \sigma^2_{L,j}\right)$$ ⟺ Fit length-age data

↓

$$\Delta L_{l,j} = \left(L_{\infty,j} - L_{l,j}\right)\left(1-\exp\left(-K_j\right)\right)$$

↓

Length-based analysis

$$P_{l,l',j} = \int_{l'_{low}}^{l'_{up}} f_{l,j}(x)\,dx$$

↓

$$N_{l',y+1,j} = \left(\sum_l \left(P_{l,l',j} N_{l,y,j} \exp\left(-Z_{l,y,j}\right)\right) + R_{l',y+1,j}\right)\exp\left(\varepsilon_{N,l',y+1,j}\right);\ \varepsilon_{N,l',y+1,j} \sim N\left(0, \sigma^2_{N,j}\right)$$

$$I_{l,y,j} = \left(q_{l,j} N_{l,y,j}\right)\exp\left(\varepsilon_{I,l,y,j}\right),\ \varepsilon_{I,l,y,j} \sim N\left(0, \sigma^2_{I,j}\right)$$

⇕

Fit length-based CPE data

$$SSN_{y,j} = \sum_l N_{l,y,j} g_l$$

↓

$$R_{y,j} = \left(a_j \times SSN_{y,j} \exp\left(-b_j \times SSN_{y,j}\right)\right)\exp\left(\varepsilon_{R,y,j}\right);\ \varepsilon_{R,y,j} \sim N\left(0, \sigma^2_{R,j}\right)$$

$$R_{l,y,j} = R_{y,j}\ P'_{l,j}$$

↓

Fit young-of-year CPE data ⟺ $I'_{y,j} = \left(q_j' R_{y,j}\right)\exp\left(\varepsilon_{I',y,j}\right);\ \varepsilon_{I',y,j} \sim$

- Size 1: 25 – 175 mm
  young-of-year
- Size 2: 175.1 – 225 mm
- Size 3: 225.1 – 300 mm
  mature
- Size 4: 300.1 – 375 mm
  harvestable
- Size 5: 375.1 – 550 mm

Bayesian estimator

- Posterior probability

$$\ln Pr(\theta \mid \text{Data}) \propto LL(\text{Data} \mid \theta) + \ln Pr(\theta)$$

	Growth analysis	Length-based analysis
Prior (θ) probability	$L_{\infty,j}$, K_j, $t_{0,j}$ $\sigma_{L,j}$	initial length-structured abundance $N_{l,y=1,j}$ mortalities $M_{YOY,j}$, $M_{JUV,j}$ and $Z_{ADU,j}$ spawner-recruitment parameters a_j and b_j catchability coefficient $q_{I,j}$ and $q'_{I,j}$ standard deviation $\sigma_{N,j}$, $\sigma_{R,j}$, $\sigma_{I,j}$ and $\sigma_{I',j}$
Data likelihood	$LL(\text{Data} \mid \theta) = LL_i$	$LL(\text{Data} \mid \theta) = LL_N + LL_R + LL_I + LL_{I'}$

Modeling growth and mortalities: hierarchical priors

Growth analysis

Length-based analysis

- Constant

Spatial variation

$$\begin{bmatrix} \ln L_{\infty, j} \\ \ln K_j \end{bmatrix} \sim MVN\left(\begin{bmatrix} \ln \bar{L}_{\infty} \\ \ln \bar{K} \end{bmatrix}, \Sigma \right)$$

$$M_{YOY, j} \sim \log normal(\bar{M}_{YOY}, \sigma^2_{MYOY})$$

$$M_{JUV, j} \sim \log normal(\bar{M}_{JUV}, \sigma^2_{MJUV})$$

$$Z_{ADU, j} \sim \log normal(\bar{Z}_{ADU}, \sigma^2_{ZADU}),$$

- Random walk

Temporal variation

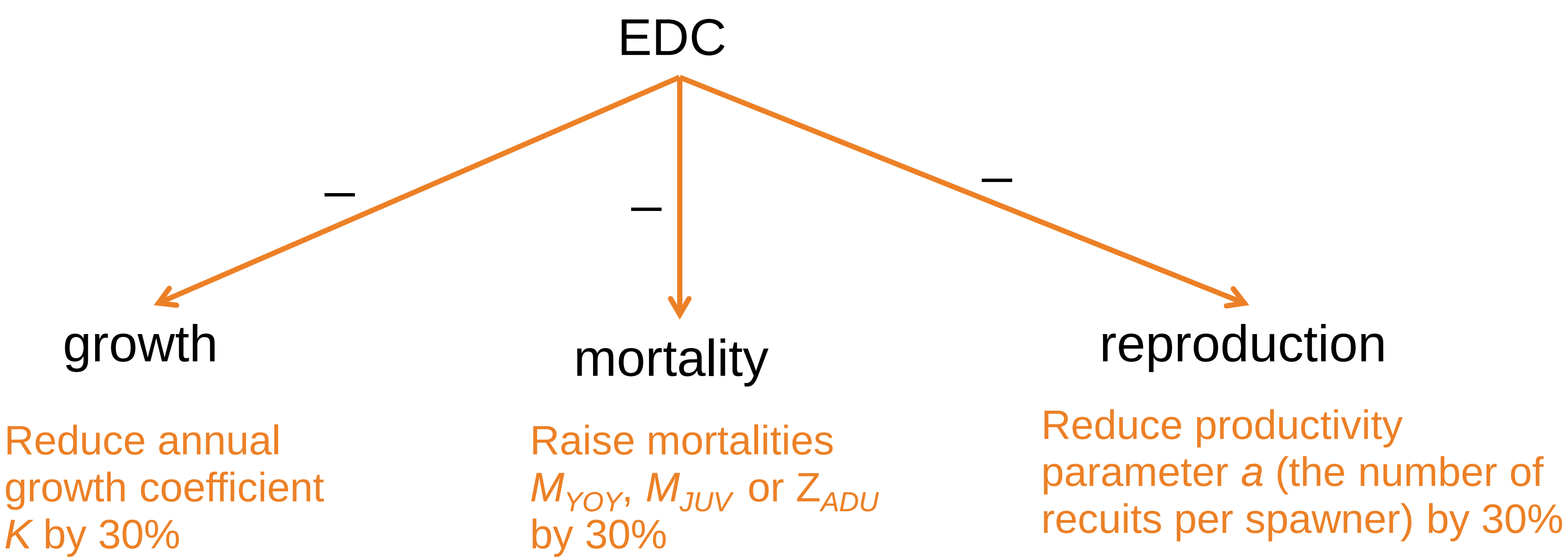
$$M_{YOY, y+1, j} \sim \log normal(M_{YOY, y, j}, \sigma'^2_{MYOY})$$

$$M_{JUV, y+1, j} \sim \log normal(M_{JUV, y, j}, \sigma'^2_{MJUV})$$

$$Z_{ADU, y+1, j} \sim \log normal(Z_{ADU, y, j}, \sigma'^2_{ZADU})$$

$$M_{YOY, y=1, j} \sim \log normal(\bar{M}_{YOY}, \sigma^2_{MYOY})$$

Simulation on EDC impacts

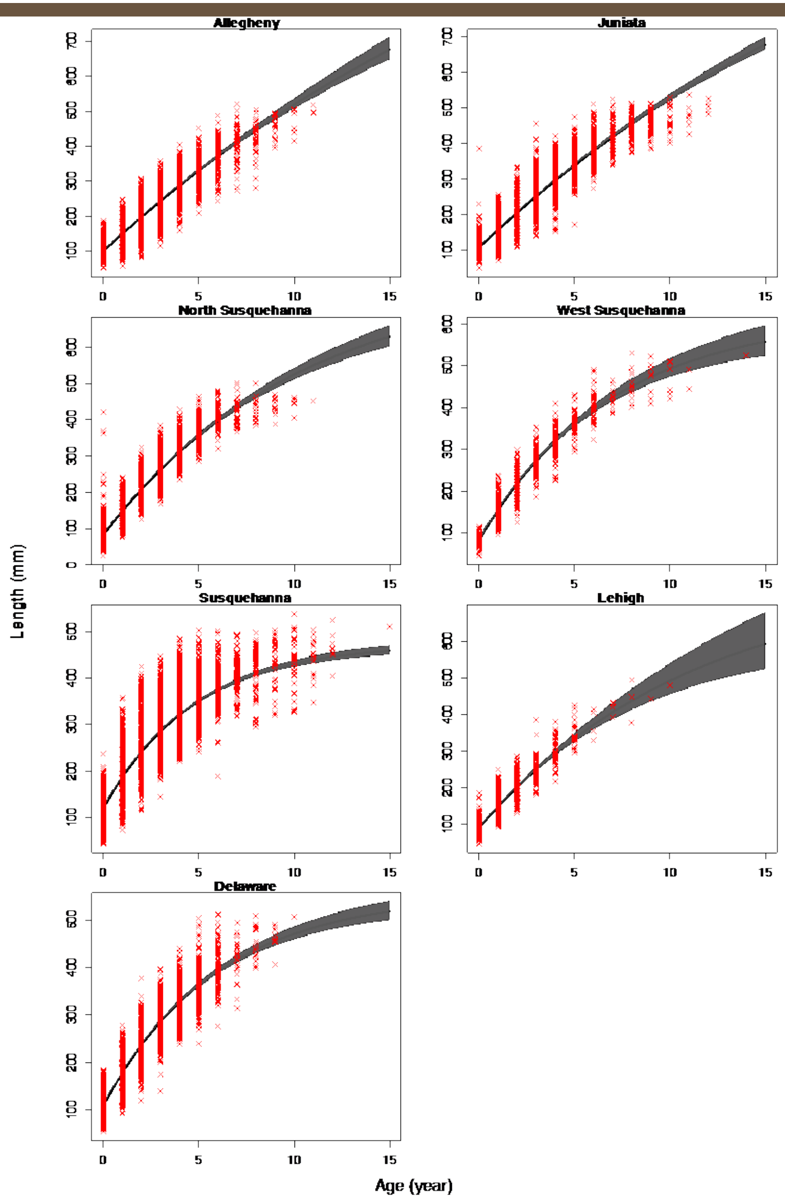


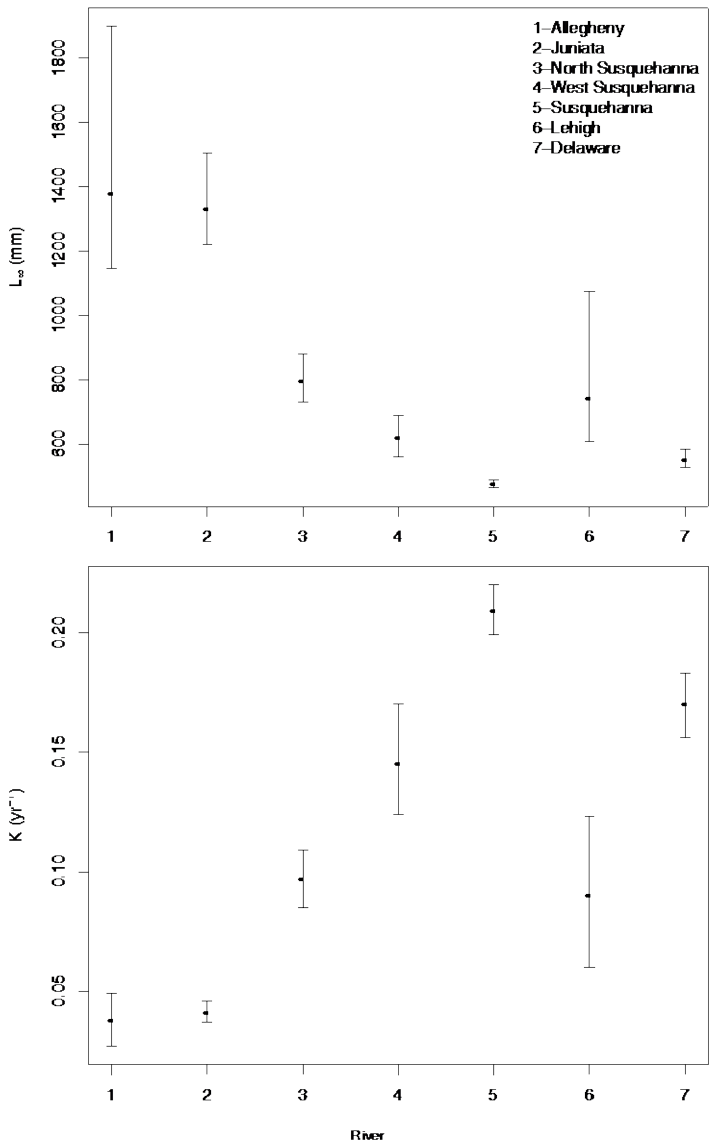
- Forecast population for 100 years (Juniata & Susquehanna)
  - Initialized with estimated 2013 population
  - Proportional stock density (PSD) → lower, better

$$PSD(\%) = \frac{\text{number of fish} > 300 \text{ mm, i.e., in the last two length groups}}{\text{number of fish} > 175 \text{ mm, i.e., in the last four length groups}} \times 100$$

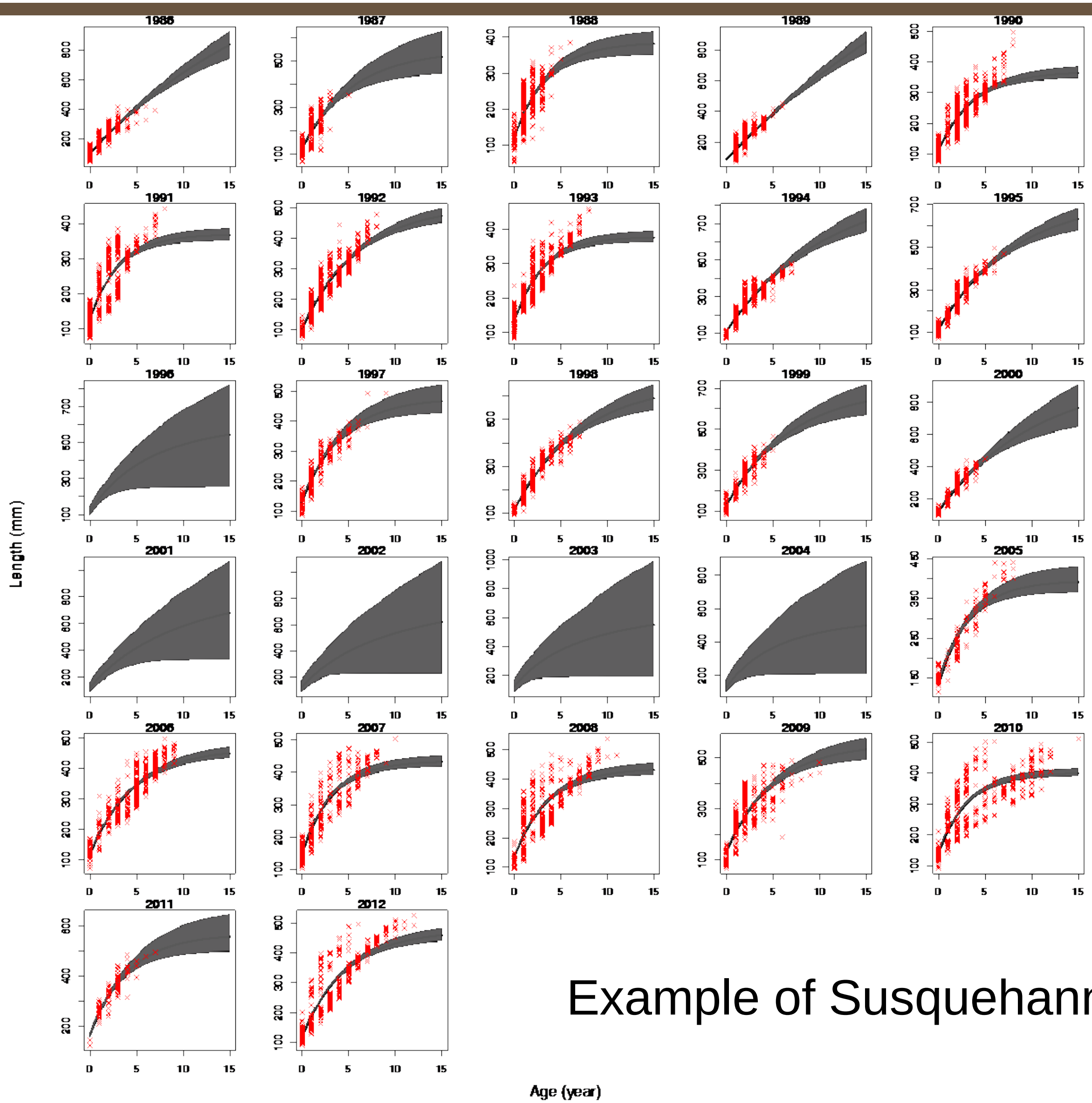
  - Probability that PSD = 40-70% → balanced population

Estimated growth: spatial variation



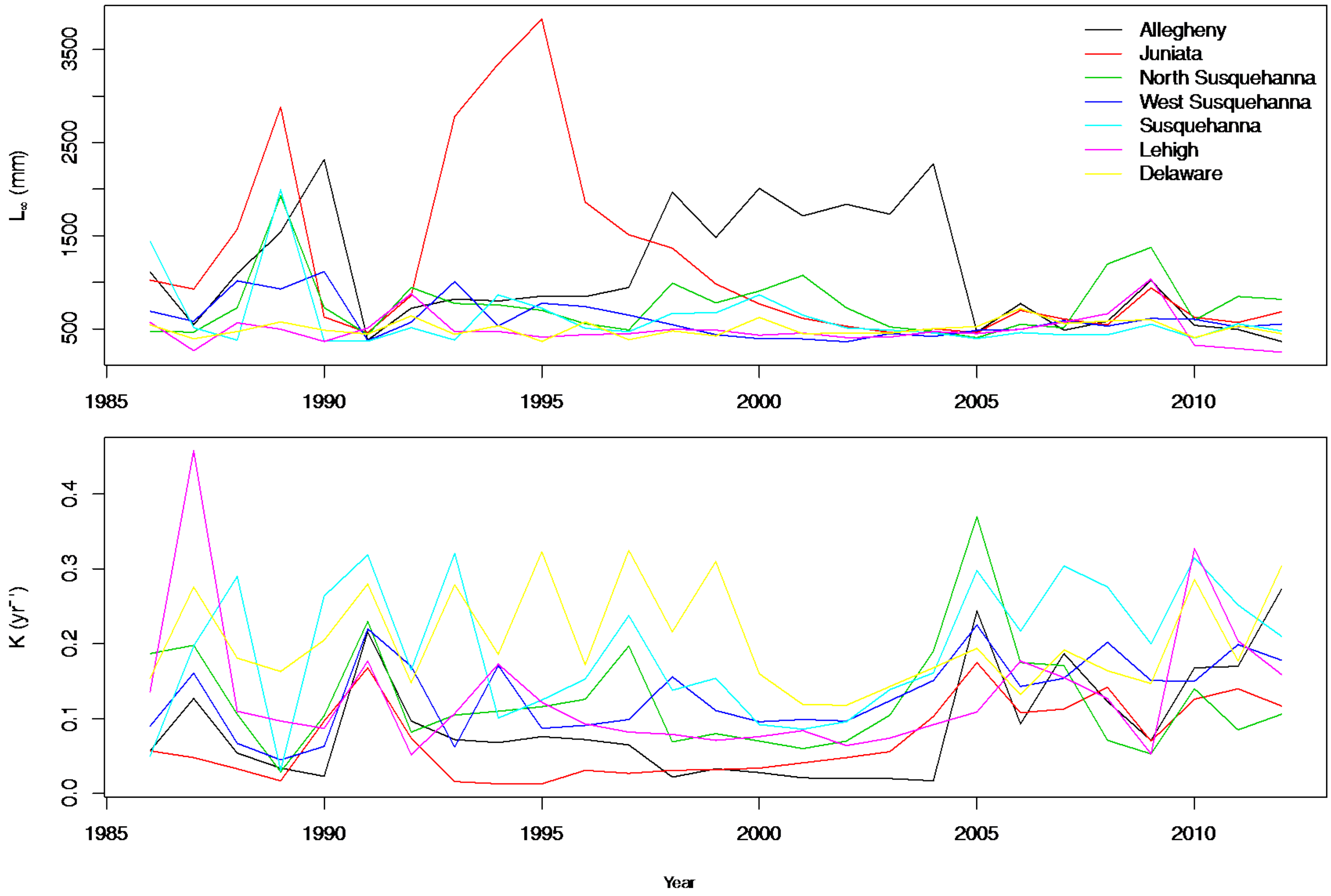


Estimated growth: temporal variation

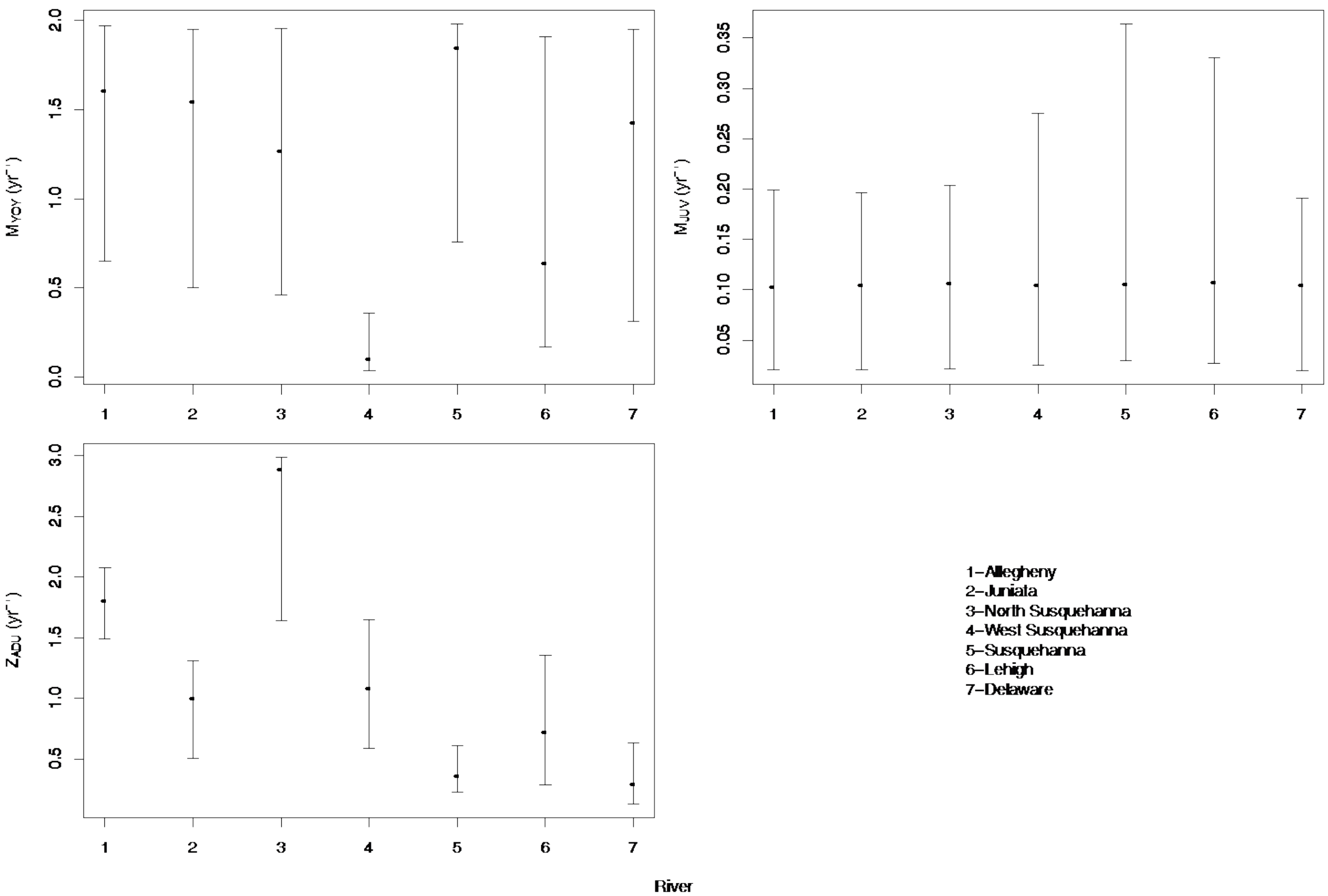


Example of Susquehanna River

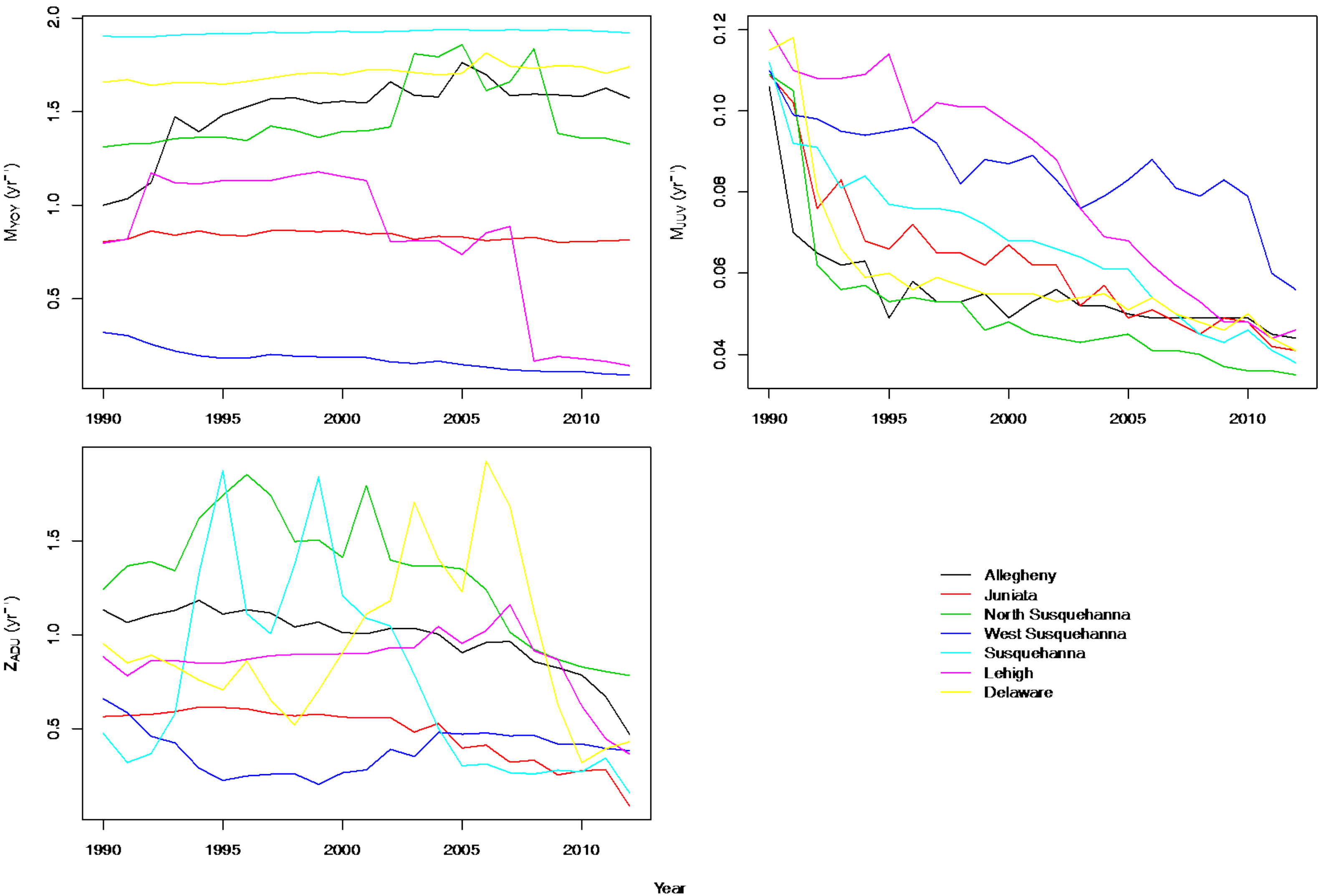
Estimated growth: temporal variation



Estimated mortalities: spatial variation



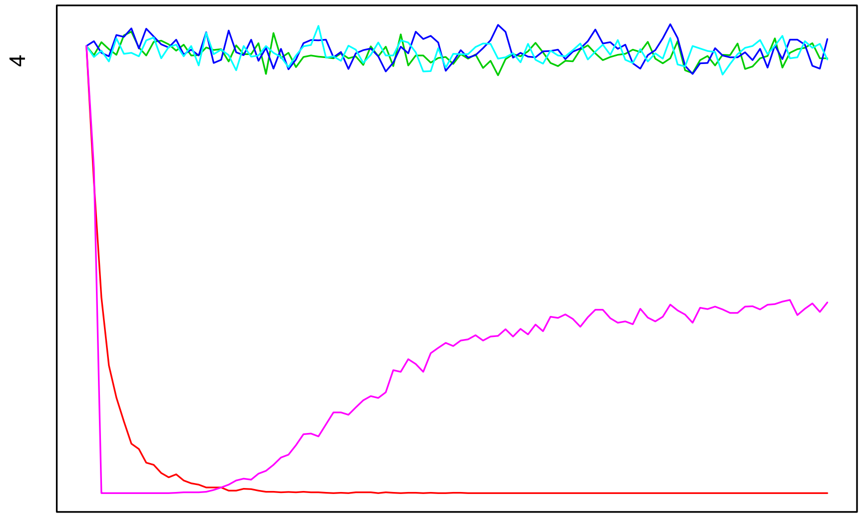
Estimated mortalities: temporal variation



EDC impacts: simulation

Juniata River

Susquehanna River



Conclusions

- Smallmouth bass
  - Growth and mortalities vary spatially and temporally
  - EDC impacts through growth and reproduction could be more dramatic than through natural mortality in our simulated population
  - Rivers could respond to EDC impacts differently
- A modeling framework
  - Stock assessment for data-poor freshwater fisheries
  - EDC impacts at population level for Chesapeake Bay watershed

Linkage to EDC risk assessment

Growth analysis

$$L_{i,j} = \left(L_{\infty,j}\left(1-\exp\left(-K_j\left(t_{i,j}-t_{0,j}\right)\right)\right)\right)\exp\left(\varepsilon_{L,i,j}\right);\ \varepsilon_{L,i,j} \sim N\left(0, \sigma^2_{L,j}\right) \Longleftrightarrow \text{Fit length-age data}$$

$$\Delta L_{l,j} = \left(L_{\infty,j} - L_{l,j}\right)\left(1-\exp\left(-K_j\right)\right)$$

Length-based analysis

$$P_{l,l',j} = \int_{l'_{low}}^{l'_{up}} f_{l,j}(x)\,dx$$

$$N_{l',y+1,j} = \left(\sum_l \left(P_{l,l',j}N_{l,y,j}\exp\left(-Z_{l,j}\right)\right) + R_{l',y+1,j}\right)\exp\left(\varepsilon_{N,l',y+1,j}\right);\ \varepsilon_{N,l',y+1,j} \sim N\left(0, \sigma^2_{N,j}\right)$$

$$I_{l,y,j} = \left(q_{l,j}N_{l,y,j}\right)\exp\left(\varepsilon_{I,l,y,j}\right),\ \varepsilon_{I,l,y,j} \sim N\left(0, \sigma^2_{I,j}\right)$$

$\Updownarrow$ Fit length-based CPE data

$$SSN_{y,j} = \sum_l N_{l,y,j}\,g_l$$

$$R_{y,j} = \left(a_j \times SSN_{y,j}\exp\left(-b_j \times SSN_{y,j}\right)\right)\exp\left(\varepsilon_{R,y,j}\right);\ \varepsilon_{R,y,j} \sim N\left(0, \sigma^2_{R,j}\right)$$

$$R_{l,y,j} = R_{y,j}\,P'_{l,j}$$

$$\text{Fit young-of-year CPE data} \Longleftrightarrow I'_{y,j} = \left(q_j' R_{y,j}\right)\exp\left(\varepsilon_{I',y,j}\right);\ \varepsilon_{I',y,j} \sim N\left(0, \sigma^2_{I',j}\right)$$

K = *f* (EDC type, concentration, …)

Z = *f* (EDC type, concentration, …)

a = *f* (EDC type, concentration, …)

…

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