The statistical power to detect regional temporal trends in riverine contaminants in the Chesapeake Bay Watershed, USA

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Project motivations and objectives - in a nutshell 🐿️

- BMPs are at the core for achieving TMDL milestones in the Chesapeake Bay Watershed (CBW)

- As BMPs are implemented to reduce nutrients and sediments entering streams in the CBW, there is the potential for chemical contaminant concentrations to also be reduced

- The ability (i.e., statistical power) to detect **regional** declines in chemical contaminant concentrations in streams and rivers is currently unknown

Primary research question

What is the statistical power to detect **regional** temporal trends in river contaminant concentrations within the Chesapeake Bay Watershed as a result of BMPs?

Regional vs. site-specific temporal trends 📉

- Although quantifying temporal change at a specific site or sub-watershed may be of interest in some cases, depending on management goals and objectives, developing expectations for detecting regional trends is critically important when management actions are focused across broad spatial scales

Objectives

1. Quantify *existing* temporal trends in concentrations of select contaminants and estimate components of spatio-temporal variation

2. Using estimated parameters from objective 1, perform power analyses simulations to determine the statistical power to detect regional temporal trends under different monitoring scenarios

Contaminants 👩‍🔬

- The contaminants we focused on are:

1. **Atrazine**

2. **Metolachlor**

3. **Total estrogenicity**

4. **Total PCBs in river sediments**

Data:

- **Atrazine, metolachlor, and PCBs**: National Water Quality Monitoring Council (NWQMC), Water Quality Portal (WQP) queries

- **Estrogenicity**: USGS data releases (Barber et al., 2019; Iwanowicz et al., 2017; Williams et al., 2019) and PA DEP

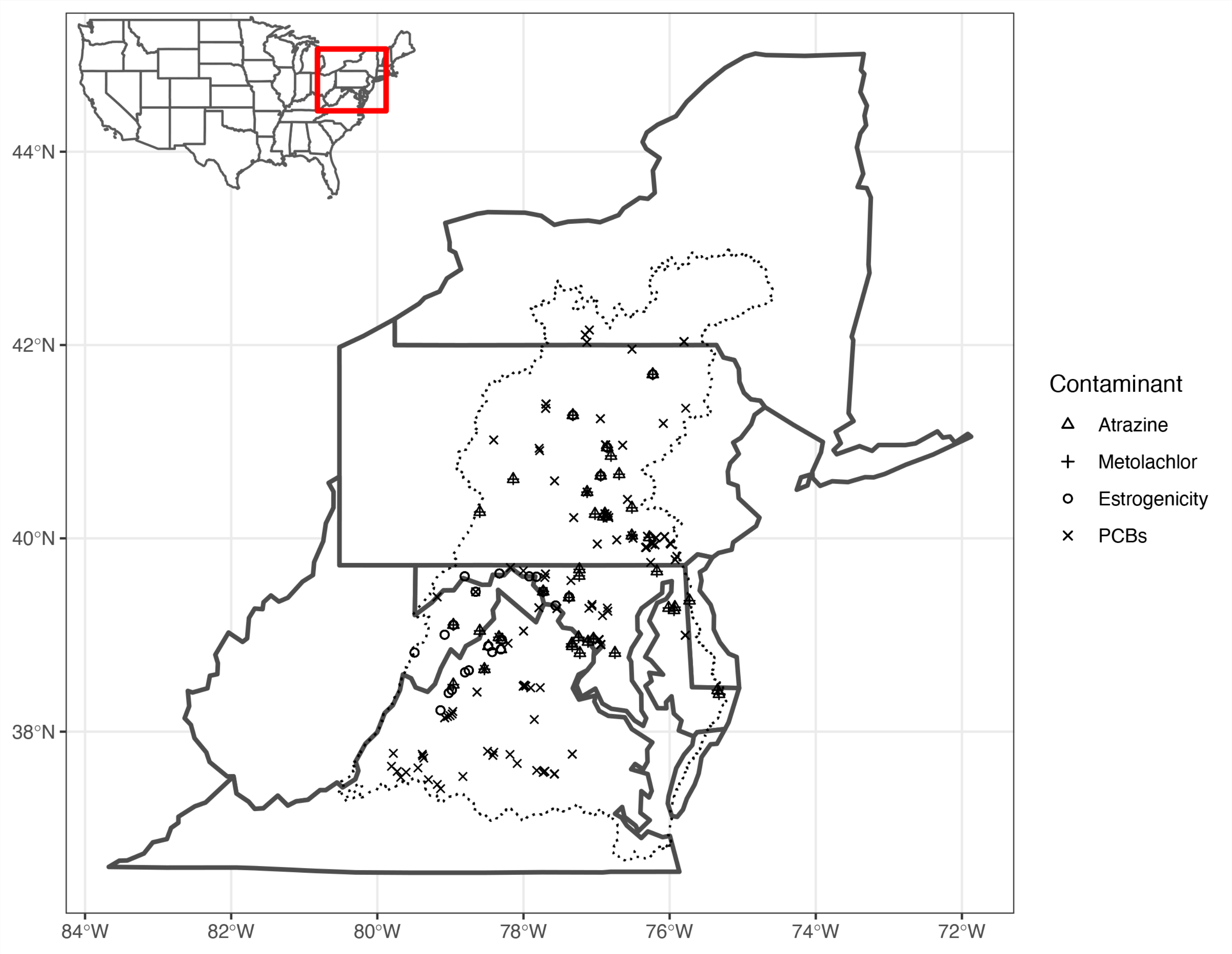
- non-flow-adjusted trends

Data:

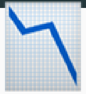
Contaminant	Number of observations	Number of sites	Concentration range	Years	Percentage censored
Atrazine	1,885	42	0.002 – 38.0	1990 - 2020	11
Metolachlor	1,780	39	0.001 – 26.0	1990 - 2020	12
Total Estrogenicity	478	25	0.100 – 12.6	2008 - 2018	55
Total PCBs	194	102	0.0 – 1200	1972 - 2019	NA

*Concentration: Atrazine and metolachlor = μg/L, estrogenicity = ng/L, PCBs = μg/kg dry weight

Study site locations 🗺️



Model - Bayesian hierarchical censored regression



$y_i \sim N(\mu_i, \sigma_\epsilon^2) I(, C_i)$

$\mu_i = \alpha + \beta_{j(i)} \times year_i + \gamma_{j(i)} + \nu_{k(i)} + \delta_{jk(i)}$

overall intercept: α (year predictor is centered so α = average log_e concentration at the start of the time-series)

residual variance: σ_ϵ^2

random **site** effect: $\gamma_j \sim N(0, \sigma_{site}^2)$

random **trend** effect: $\beta_j \sim N(\lambda, \sigma_{trend}^2)$ ➔ λ = **population-average trend**

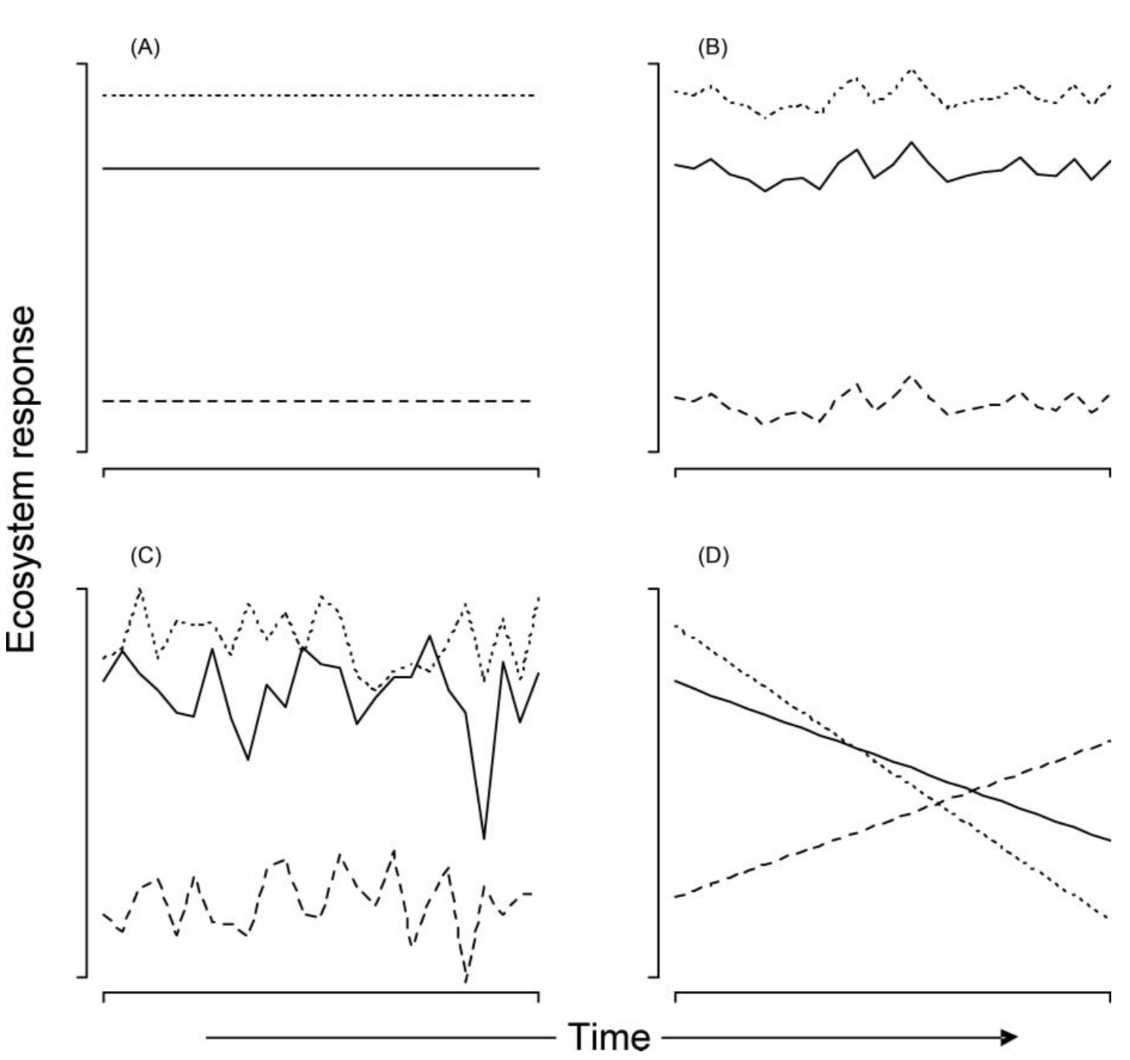
random **year** effect (coherent temporal variation): $\nu_k \sim N(0, \sigma_{coherent}^2)$

random **site** $\times$ **year** effect (ephemeral temporal variation): $\delta_{jk} \sim N(0, \sigma_{emphemral}^2)$

C_i: log_e detection limit for observation i

Used Bayesian estimation with diffuse priors: $\sigma_x \sim U(0, 5)$; α and $\lambda \sim N(0, 1000)$

Variance components 📊



Power analysis - a simulation approach ⚡

Steps:

1. Fit aforementioned model to obtain posterior distributions of estimated parameters

2. Set reality: **number of sites to sample**, **number of years to sample**, **trend magnitude** (λ), and **annual sample frequency**

3. Simulate data with known reality

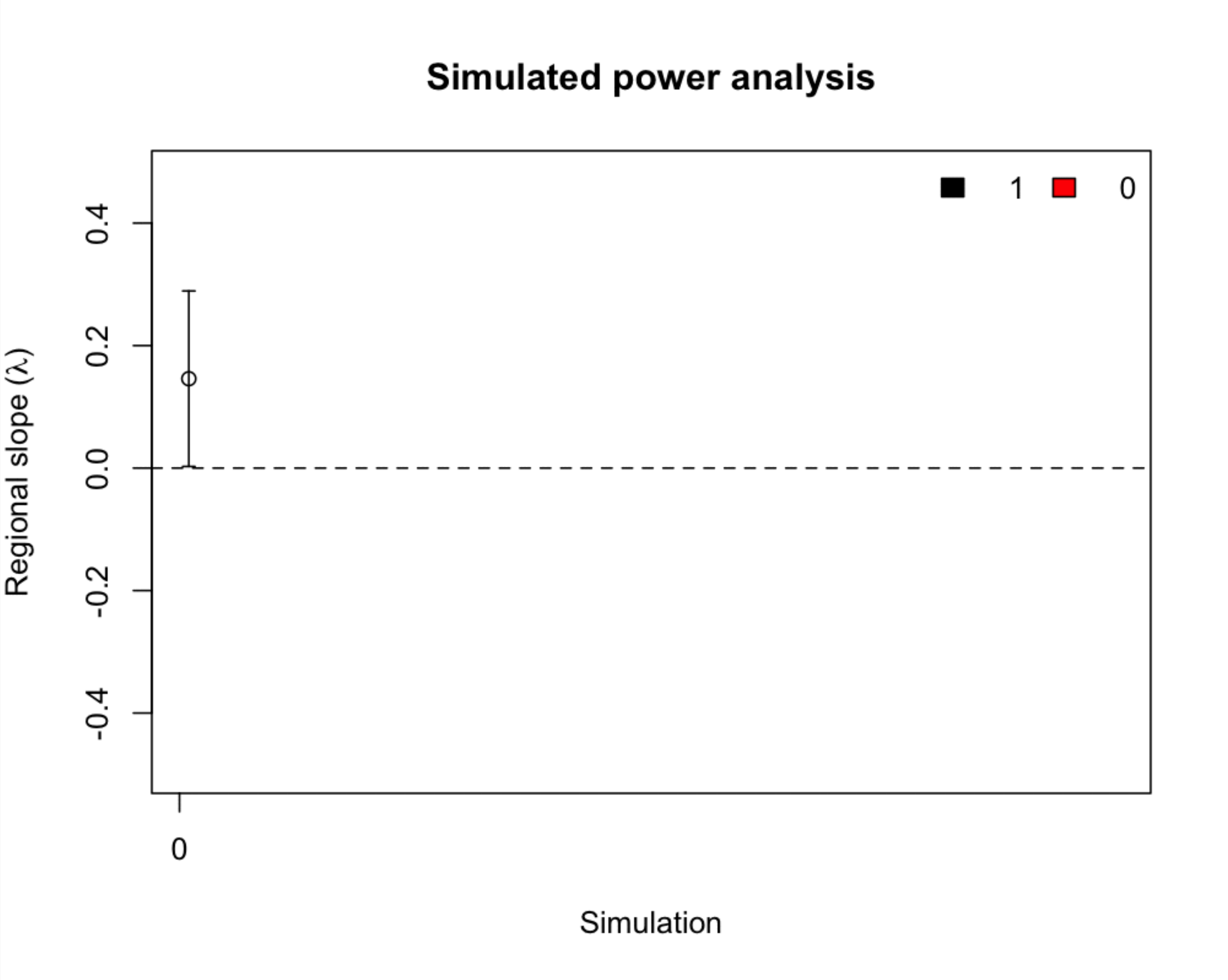
Power analysis - a simulation approach ⚡

Steps con't:

4. Fit aforementioned model to simulated data and see if λ differs from zero

5. Repeat steps 3-4 100 times: proportion of simulations where λ is different than zero (based on 95% CI overlapping zero) = power

Visualize simulated power 👀



Monitoring scenarios 📚

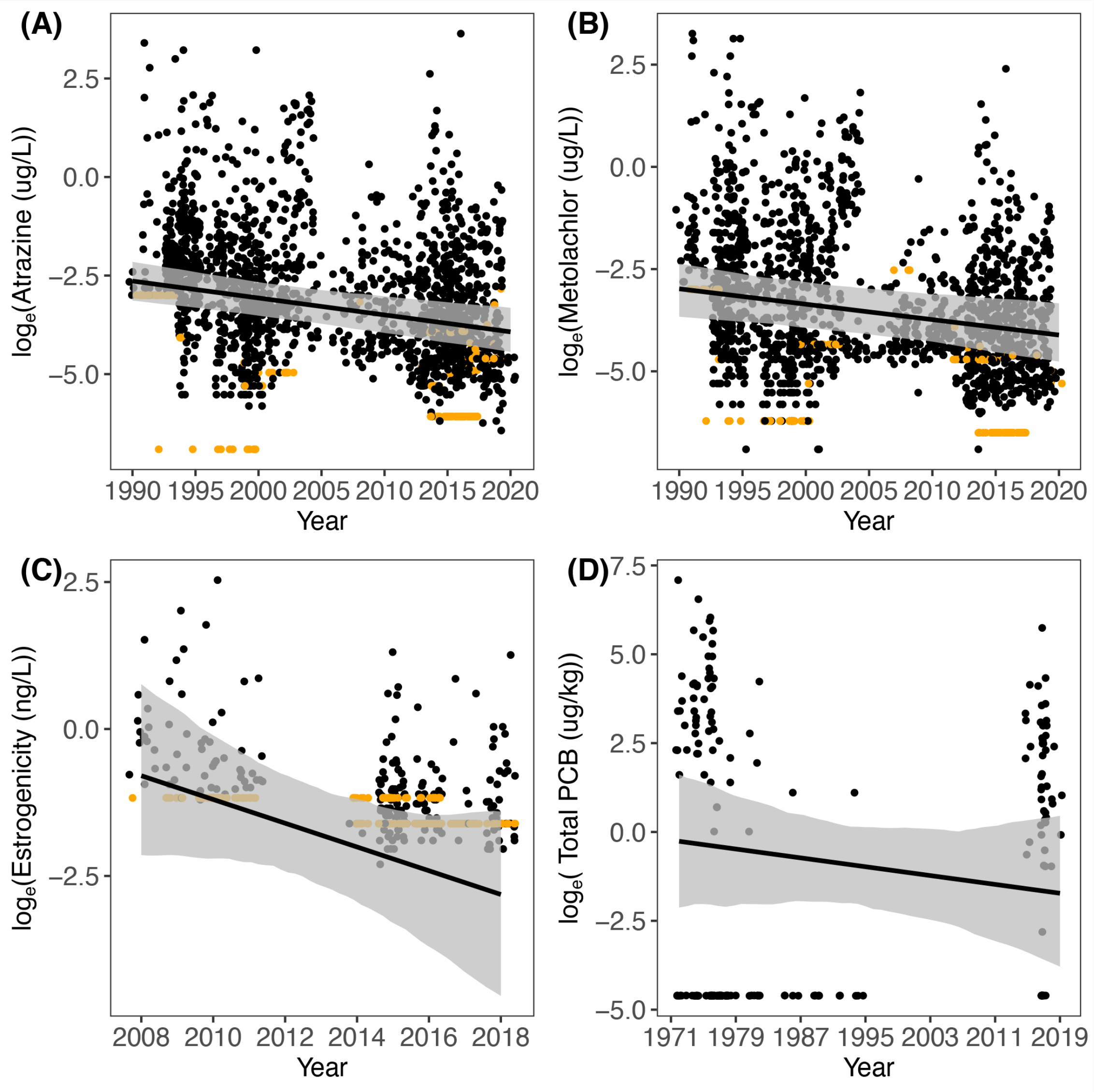
- Duration: 5, 10, 20 years

- Number of sites sampled each year: 10, 20, 30, 50, 80, 100

- Percent decline/year (effect size; λ): -5, -7, -10, -15, -20

- Annual sampling frequency: every year, every 2^{nd} or 4^{th} year

Results: temporal trends 📉



Trend summary - declining trends 📉

- **Atrazine**: -4 %/year (95% CI = -6%/year, -2%/year)

- **Metolachlor**: -4%/year (95% CI = -7%/year, -1%/year)

- **Total estrogenicity**:-25%/year (95% CI = -57%/year, 2.0%/year)

*Posterior probability of a decline = 0.97

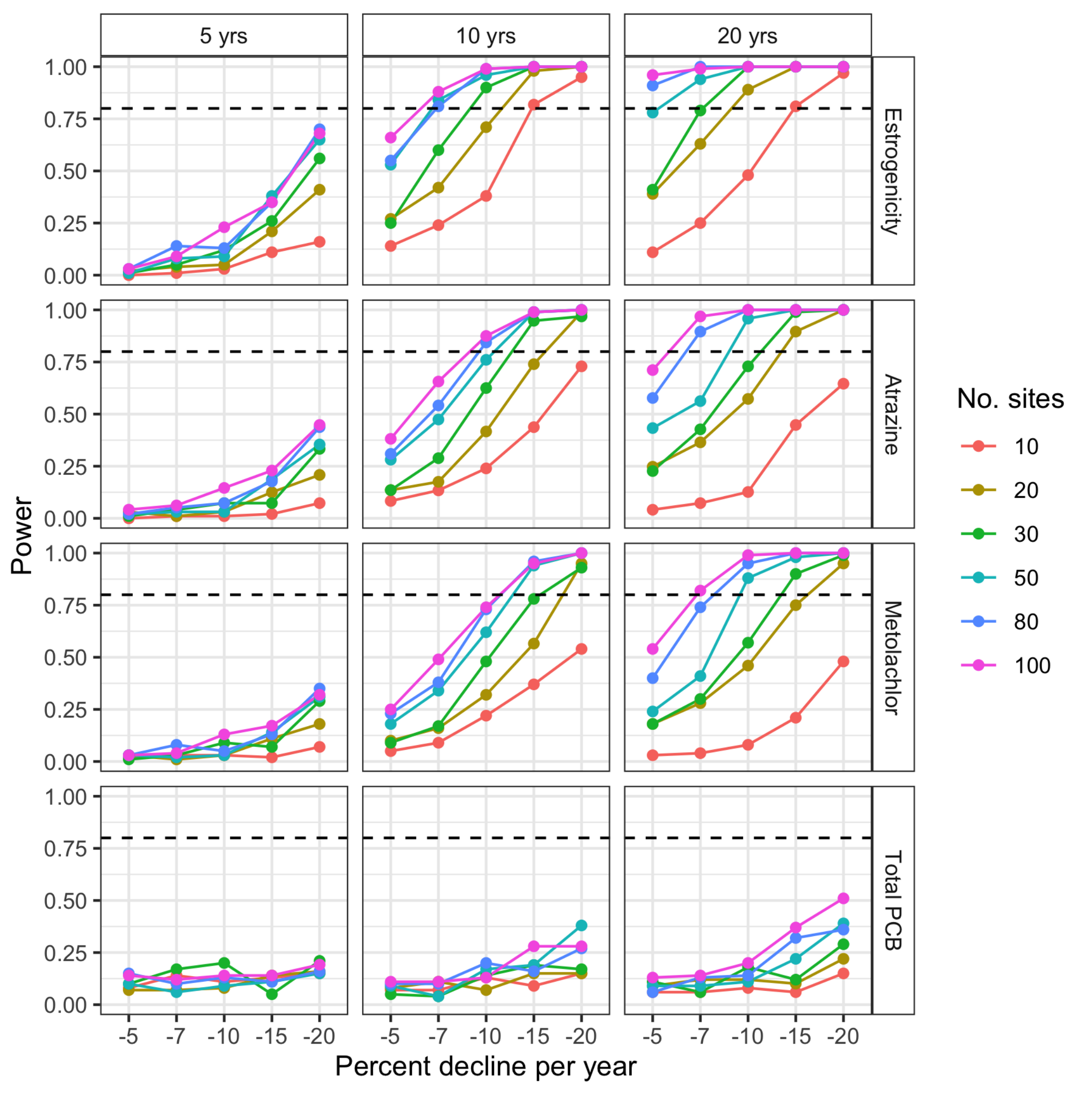
- **PCBs**:-7%/year (95% CI = -21%/year, 9%/year)

Variance components summary

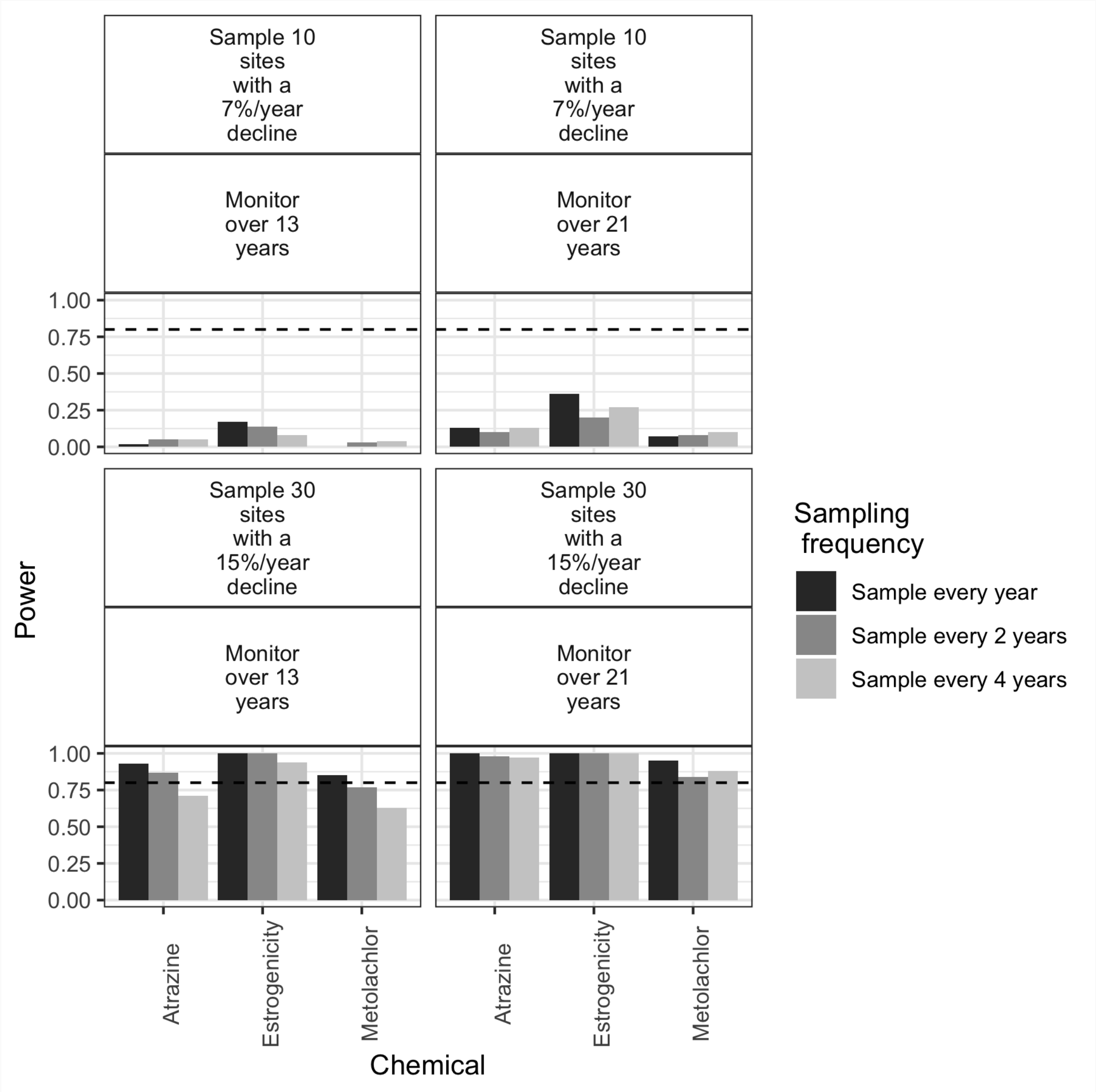
- Spatial and residual > emphemeral and coherent temporal

- Spatial variability > temporal variability is consistent with past work in lakes and fisheries (e.g., lake nutrients, fish relative abundance)

Power curves



Sampling every n^{th}-year



Major findings

- For herbicides atrazine and metolachlor, that have had 30 years of regular sampling across the Chesapeake watershed, there were significant declining regional temporal trends in river concentrations of approximately 4% per year. Temporal trends for total estrogenicity and total PCBs were also negative, but not statistically significant

- Monitoring programs aimed at detecting small annual declines (< 5 to 7 % declines per year) are underpowered and unlikely to detect these small rates of decreasing contaminant concentrations, unless sampling has occurred at roughly 100 or more sites for at least 20 years

Major findings

- Monitoring for short time periods (e.g., 5 years) is inadequate for detecting regional temporal trends, regardless of the number of sites sampled or the magnitude of the annual declines

- Annual sampling frequency had little impact on the ability to detect regional trends for any monitoring scenario. This suggests that sampling all sites every year is not necessary

- Overall, the ability to detect temporal trends was greatest for total estrogenicity, suggesting that this aggregate measure of estrogenic activity may be a useful indicator

Management implications

- Expectations should be set to detect regional trends over decadal time periods for determining the response of contaminant concentrations to BMPs

- This study provides information that can be used to help (1) guide the development of future monitoring programs aimed at detecting regional declines in riverine chemical contaminant concentrations in response to land management actions, and (2) set expectations for the ability to detect changes over time

Questions

Wagner, T., McLaughlin, P., Smalling, K., Breitmeyer, S., Gordon, S., and Noe, G.B., 2021. The statistical power to detect regional temporal trends in riverine contaminants in the Chesapeake Bay Watershed, USA. Science of the Total Environment 812:152435.