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Extracting Signal from the Noisy Environment of an Ecosystem

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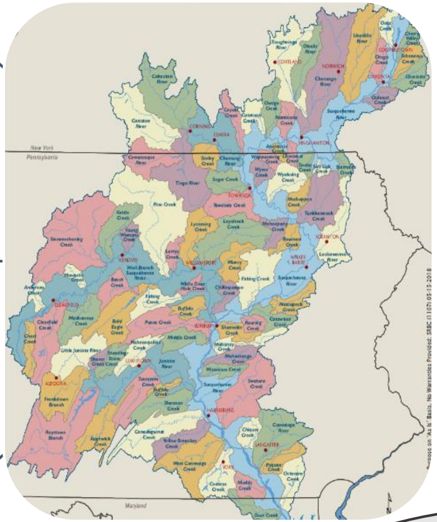
River Basin Management: Signal Vs Noise

River basins are complex systems.

Geological
- Rock- Soil
- Terrain
- Flow

Weather
- Precipitation
- Evaporation
- Snow

People
- Mining
- Withdrawal
- Effluents



SRBC
SUSQUEHANNA RIVER BASIN COMMISSION
NY ▪ PA ▪ MD ▪ USA

Stakeholder
- MD
- PA
- NY

Consumers
- Residents
- Farming Community
- Natural Gas Industry
- Other

Objectives
- Support Growth
- Sustain Environment

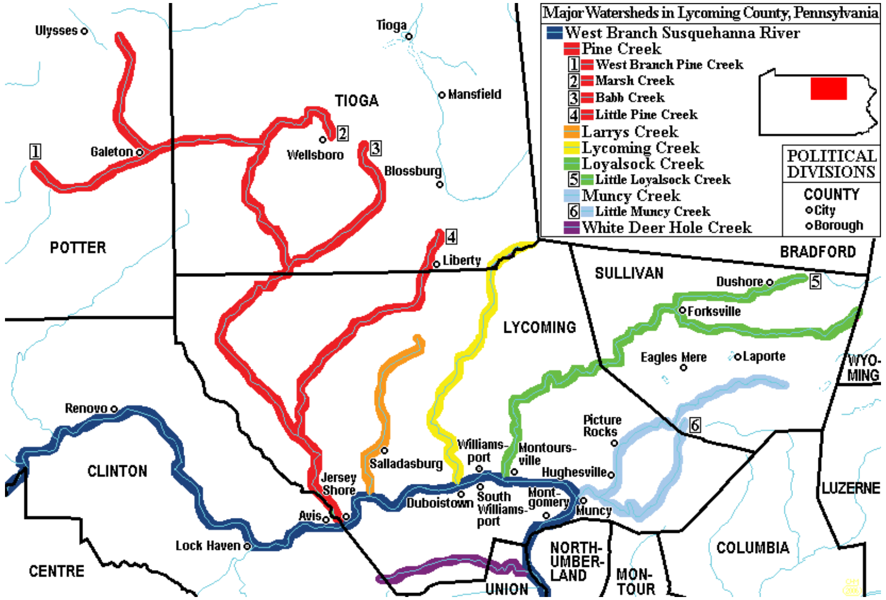
What “signal” should SRBC focus on in achieving the objectives?

Regulators need to identify “Signal” from noisy data

Signal Extraction and Definition

- Volume and variety of data
- Data scientist was sought
- How to systematically define and extract signal from noise
  - Lack of guiding framework
  - Limited tool set
- Explored available tools and literature
- Signal desired attributes
  - Clearly definable
  - Must be able to detect
  - Ability to explain movement in response variable with help of explanatory variables.
  - Has an effect on environment or is an indicator of change in environment
- Rational approach to variable selection
  - Maximize the information obtained from the analysis of variable
    - Linked to a large set of spatial, temporal environmental variables.

Available Data



Initial scope limited to “Pine Creek”

- Largest tributary of the West Branch Susquehanna River
- 87.2 miles (140.3 km) long
- Largest watershed of all the West Branch’s tributaries

File	*n*	Parameters	Start	End	Missing Data	Frequency/Periodicity
Water Quality	195,142	6	6/23/2011 12:00	12/31/2017 23:45	<0.15%	4 hours until 10/9/2014; 15 minutes since then
Chemistry	754	51	8/10/1983 00:00	3/5/2018 08:45	~70%	No noticeable pattern; 1983, 1994, 2002, & 2008 – 2018
Fish	52	59	9/09/2008 12:00	8/03/2017 09:45	~0%	No noticeable pattern
Macroinvertebrates	134	223	8/10/1983 00:00	10/17/2017 14:00	<0.001%	No noticeable pattern; 1983 – 2002 & 2008 – 2017
Biotic integrity community data	59	95	No dates given	Seems to be averages	~22%	n/a

Community Metrics

- Community metrics (Diversity) from observed species count
  - For fish and macroinvertebrates
  - Available for numerous sites
- Community (Diversity) metrics advantages
  - Good overall metrics of environmental quality
  - Environmental quality is a core standard by which SRBC has to accomplish its mission
- Multiple response variables computed for diversity

Metric	Formula	Remark
Margalef's species Richness	$S_{Marg,y} = \frac{S_y - 1}{\log F_y}$	Where S_y is species count and F_y is the total count of all individual fish caught
Pielou evenness	$J_y = \frac{-\sum_{s=1}^{S_y} N_{y,s}/N_y \log(N_{y,s}/N_y)}{\log S_y}$	Where N_y is abundance and $N_{y,s}$ is average density of species 's' (individuals km^{-2})
Hill's N1 Diversity	$N1_y = \exp\left(-\sum_{s=1}^{S_y} \frac{N_{y,s}}{N_y} \log \frac{N_{y,s}}{N_y}\right)$	N_y and $N_{y,s}$ defined as above
Hill's N2 dominance	$N2_y = \frac{1}{\sum_{s=1}^{S_y} (N_{y,s}/N_y)}$	S_y,N_y and $N_{y,s}$ defined as above

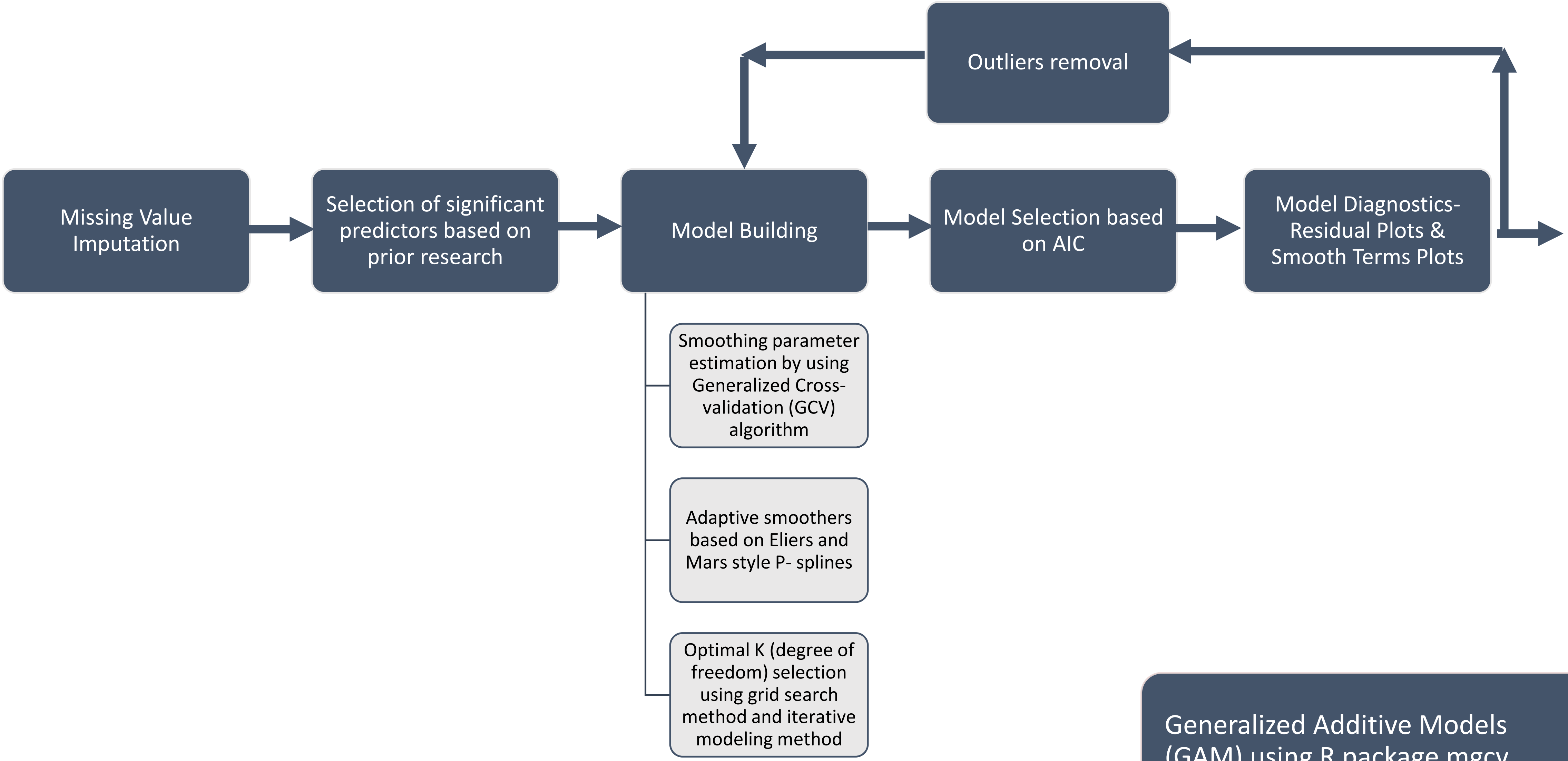
Metrics of composition, structure, and functioning of North Sea demersal fish community doi:10.1093/icesjms/fsr188 Greenstreet et al. 2012

Model Selection: Generalized Additive Model (GAM)

- More powerful than linear model due to inclusion of non-linear smoothers
- Parametric and non-parametric functions to explore linear and non-linear patterns
- Addition of smooth functions of covariates
- Smooth/basis function estimated from the data
- Mostly used when
  - Non-linear relationships
  - Distribution other than normal (response)
  - Need regularization(to avoid overfitting)
- Applications: air quality, ecology, medicine, genetics, molecular biology, etc.

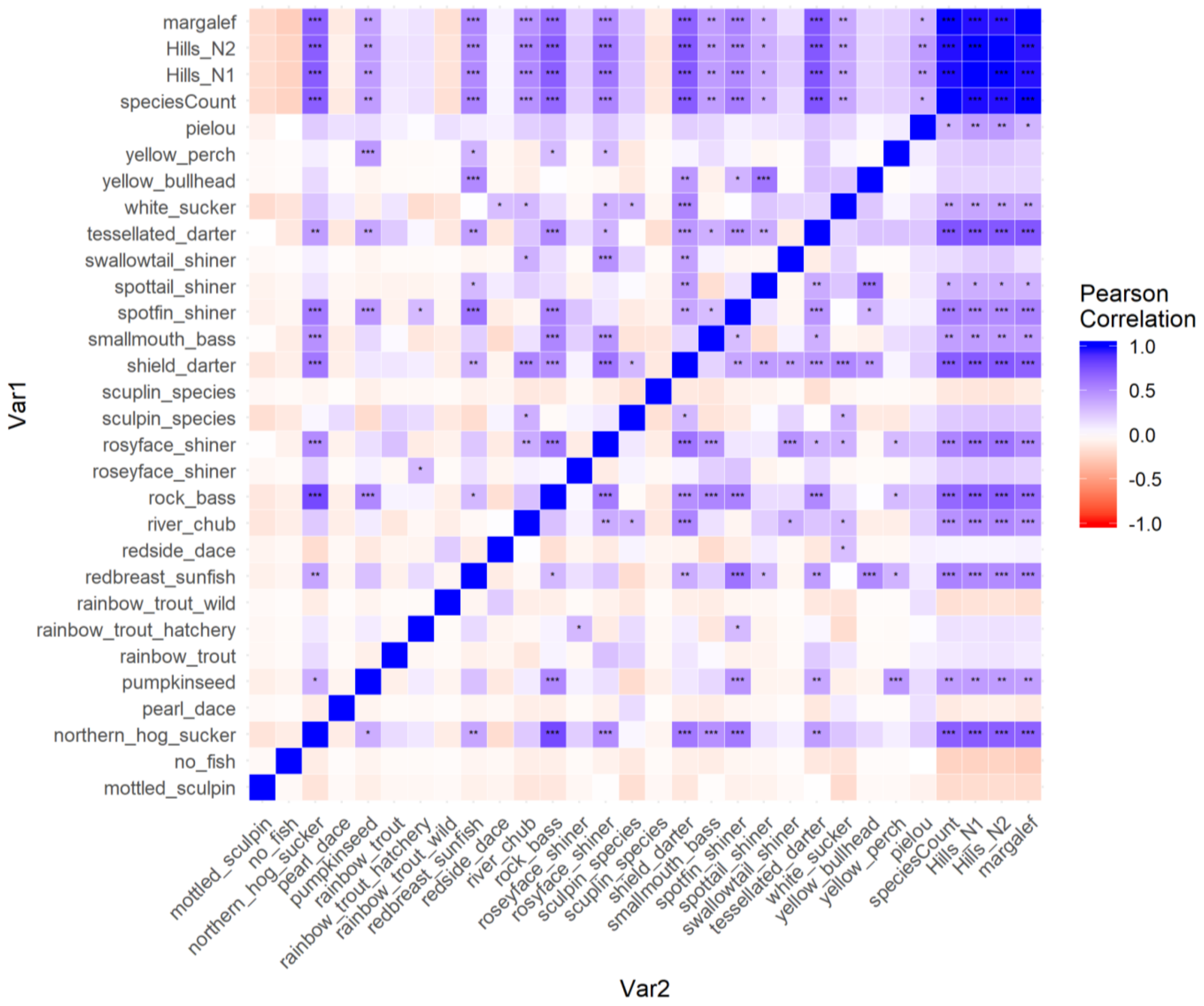
These factors made us chose GAM over other models

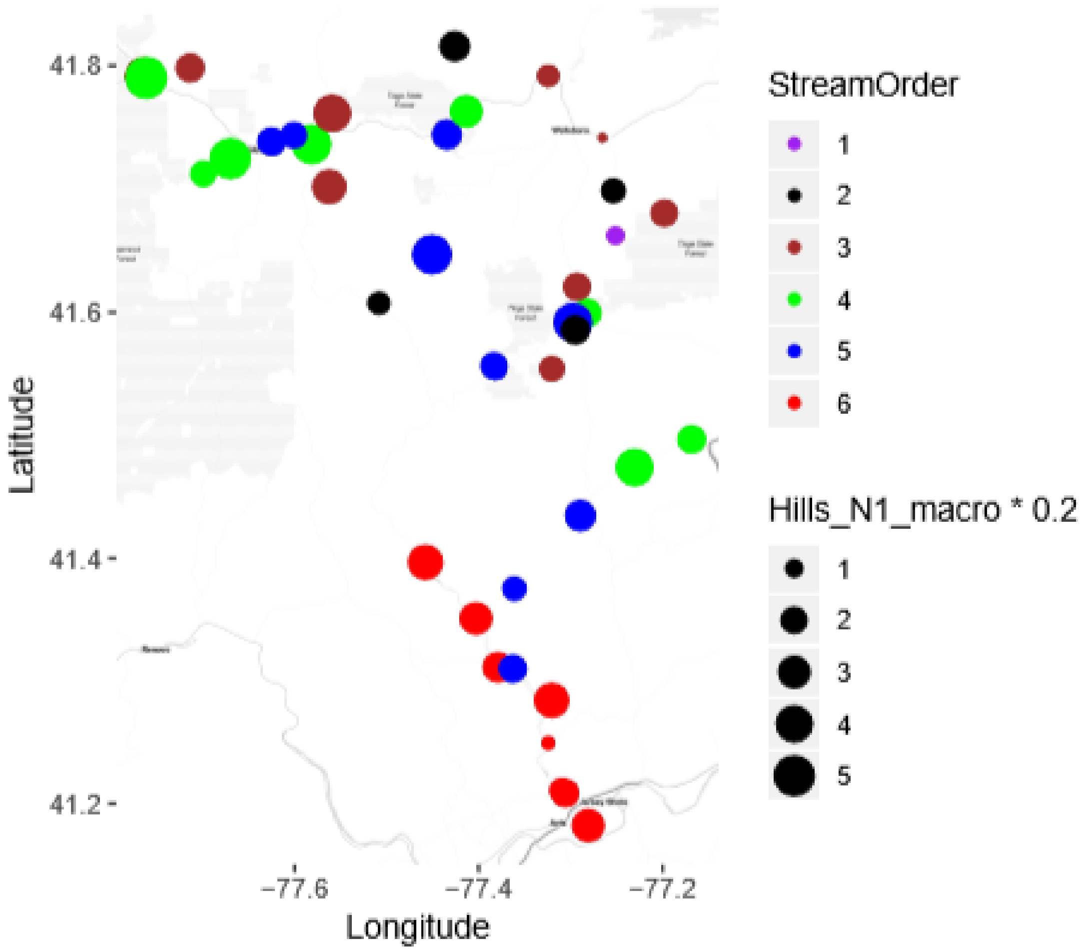
Modeling Steps



Generalized Additive Models (GAM) using R package mgcv

Model Inputs Selection

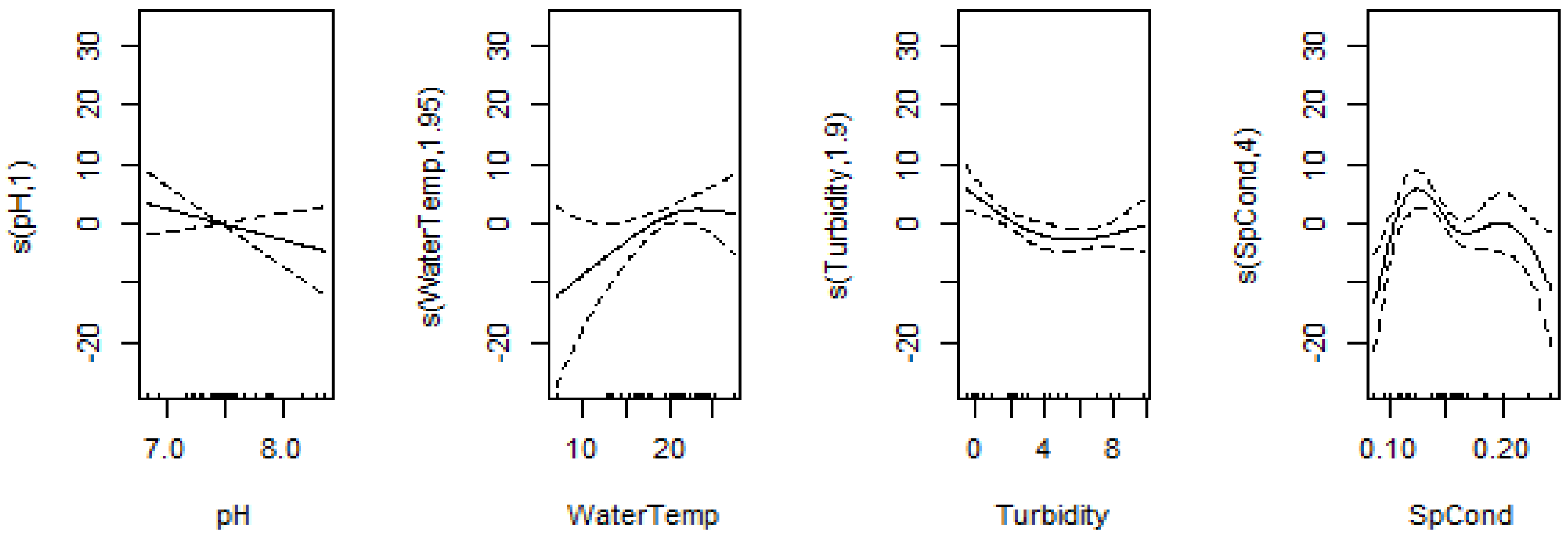




Hill’s N1 GAM Model: Fish

- Data
  - 50 observations
  - Repeated measurement at few stations
- Grid search for degrees of freedom (3 to 8)
- Best AIC: 288.94
- Deviance Explained:**74%**
- Outliers removed

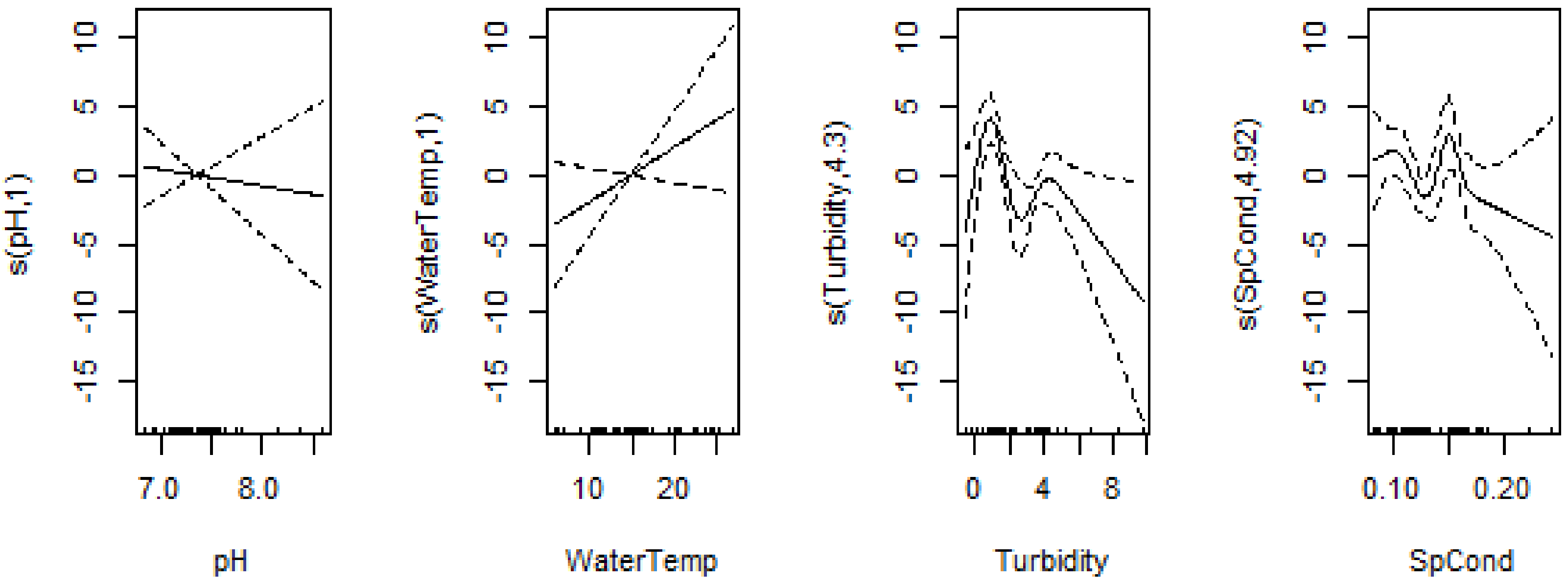
Model Smooth Functions Plots



Hill's N1 GAM Model: Macroinvertebrates

- Data
  - 115 observations
  - Repeated measurement at few stations
- Iterative modeling method for degrees of freedom
- Best AIC: 640.61
- Adaptive Smoothing Parameter
- Deviance Explained:**61.9%**
- Outliers removed

Model Smooth Function Plots



GAM Models Summary

- Extract significant information from noisy dataset
- Explained significant % of variance in Hill’s N1, Hill’s N2, and Margalef diversity metrics

Fish GAM Model

- 72% to 75% variance explained

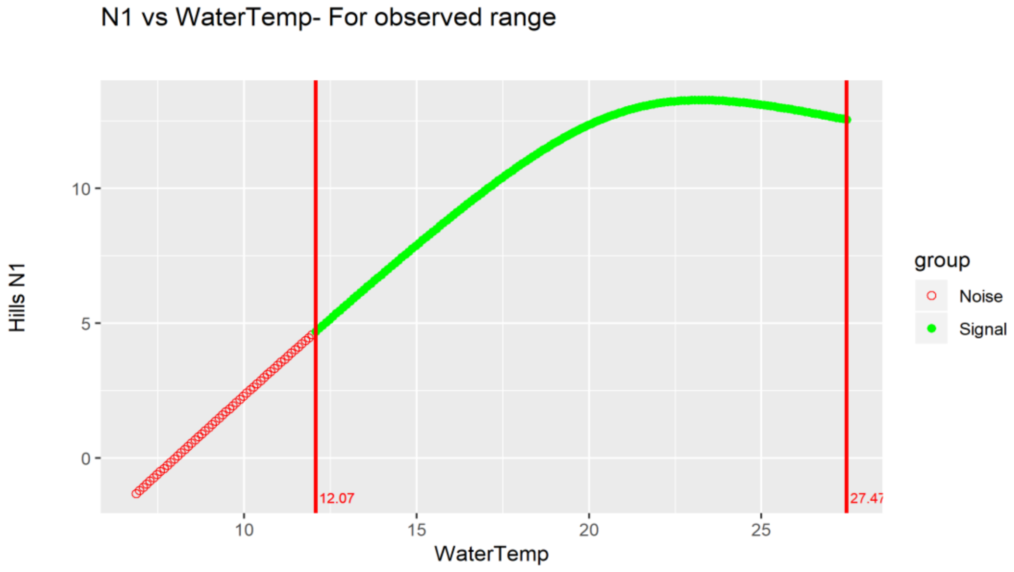
Diversity Metric	% Variance Explained	AIC
Hill’s N1	73.8	289
Hill’s N2	72.4	283
Pielou	54	-156
Margalef	74.9	111

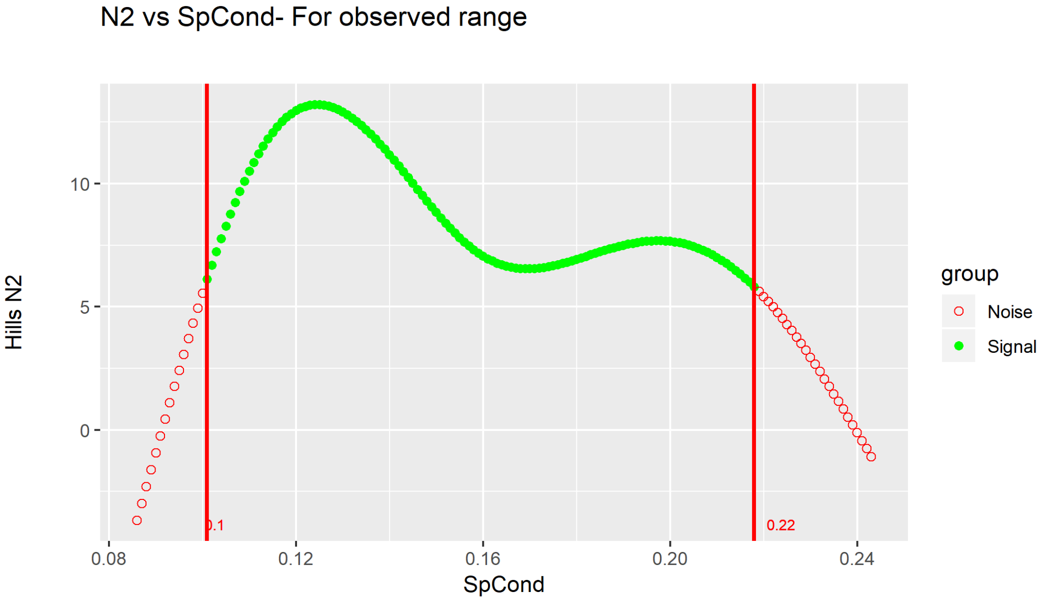
Macroinvertebrate GAM Models

- 54% to 66% variance explained

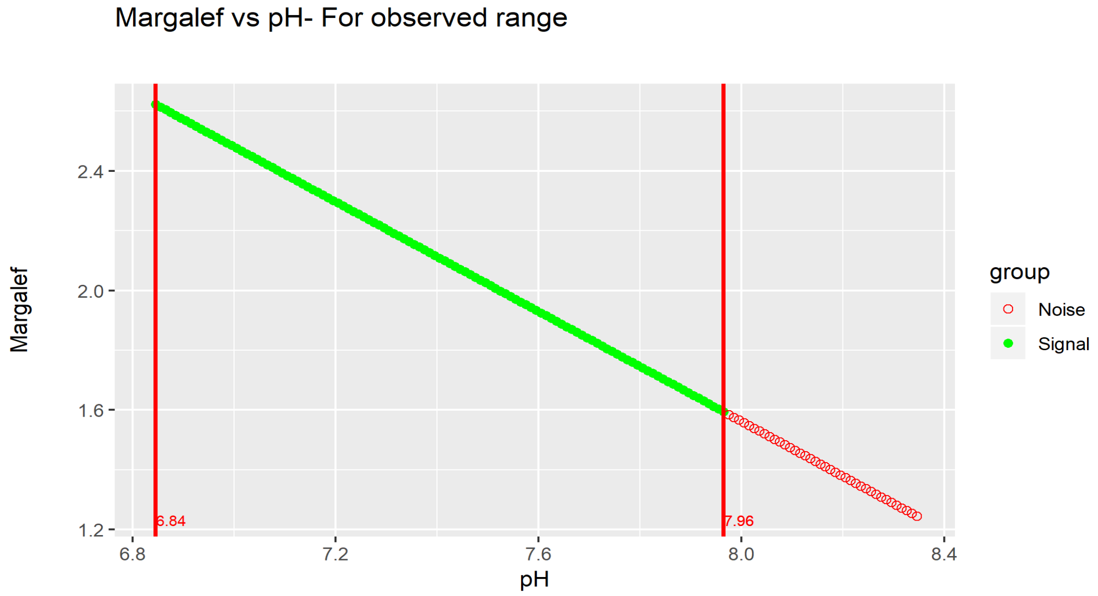
Diversity Metric	% Variance Explained	AIC
Hill's N1	61.9	641
Hill's N2	54.2	598
Pielou	45.5	-251
Margalef	65.9	296

Signal Prediction Analysis: Fish Diversity



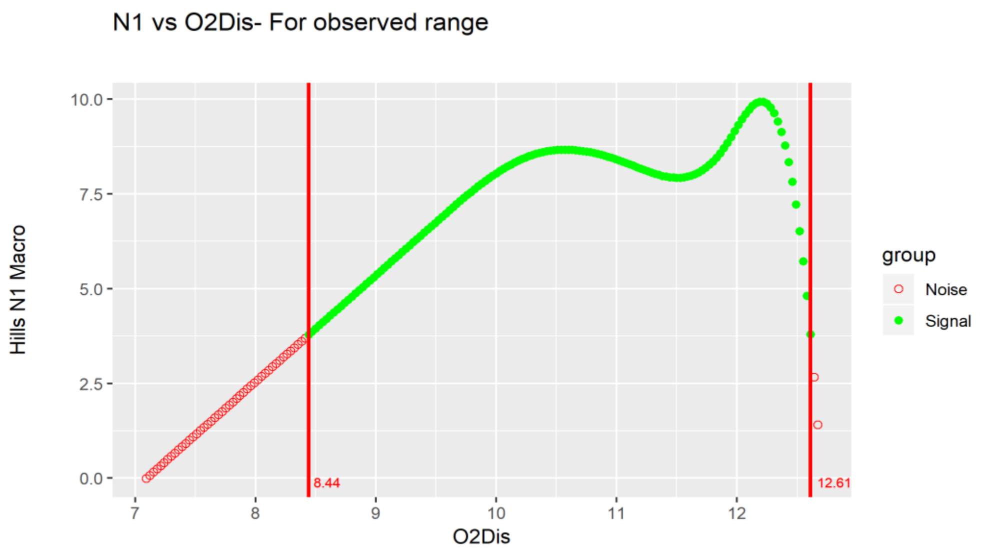


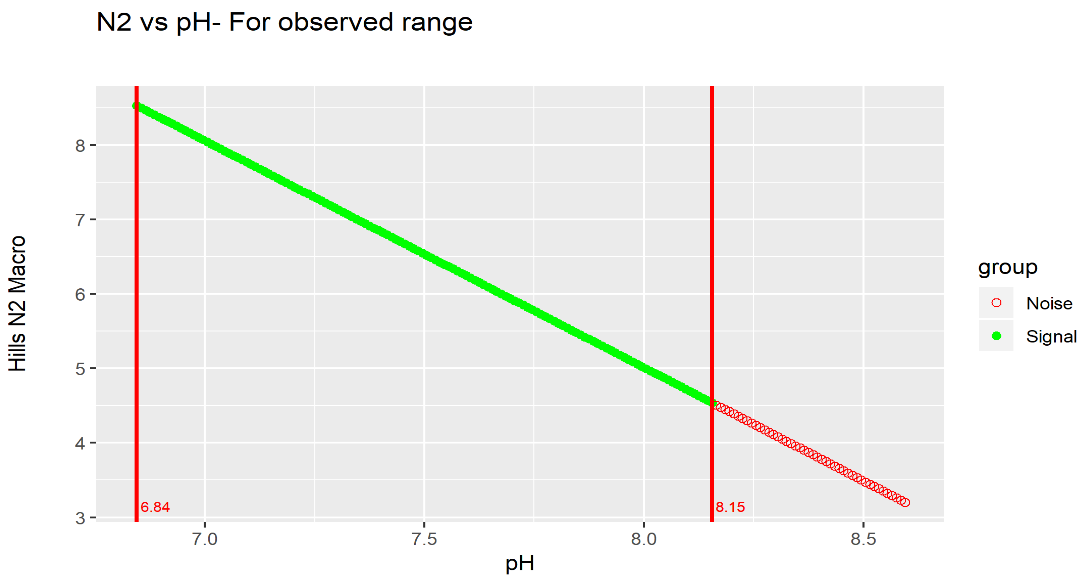
- Posterior simulations
- Change one environmental variable while keeping other variables constant
- Threshold calculations based on quantile method

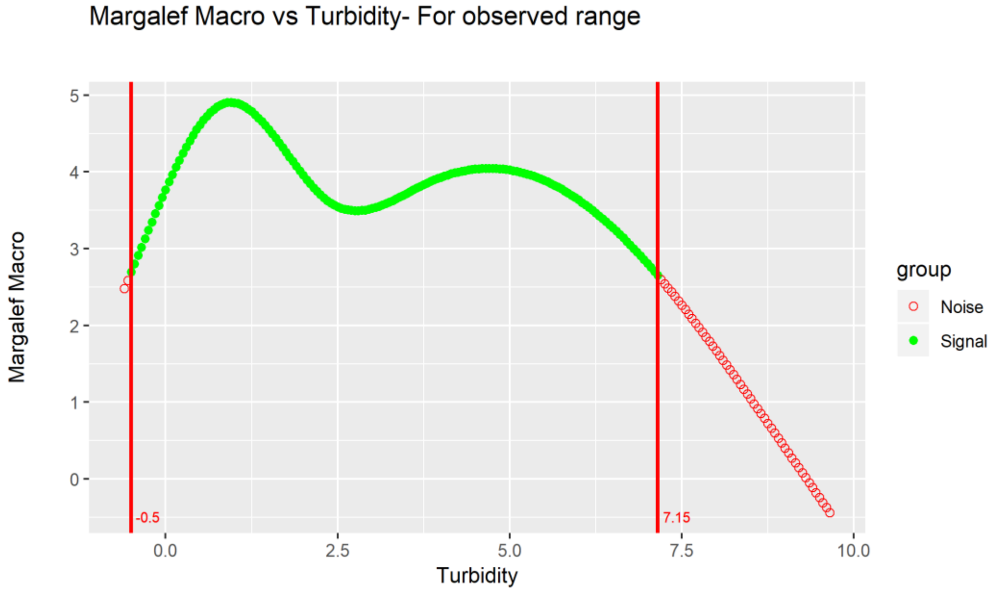


- Fish diversity deteriorates when
  - Dissolved oxygen < 8
  - Specific conductivity > 0.2

Signal Prediction Analysis: Macroinvertebrate Diversity







- Macroinvertebrate diversity deteriorates when
  - Dissolved oxygen < 8.5
  - Turbidity > 7

Our Findings

River basin monitoring

- A framework to synthesize multiple datasets
  - Enables regulators to prioritize and communicate
  - Can help stakeholder in understanding the impact of their actions
- Flexible: diversity metric can be replaced with another metric
- Dynamic dashboard application to monitor biotic response

Next Steps

Refine synthesis in collaboration with SRBC

Action Threshold Identification

Incorporate Variable Interactions

Adding More Information

Questions?

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