Climate change, hydrology, and aquatic species distributions

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Outline

1) Efforts to relate climate and biodiversity

2) Flow variability and freshwater biodiversity

3) Freshwater biodiversity in the Mobile River basin

4) Flow-morphology relationships in Midwestern fishes

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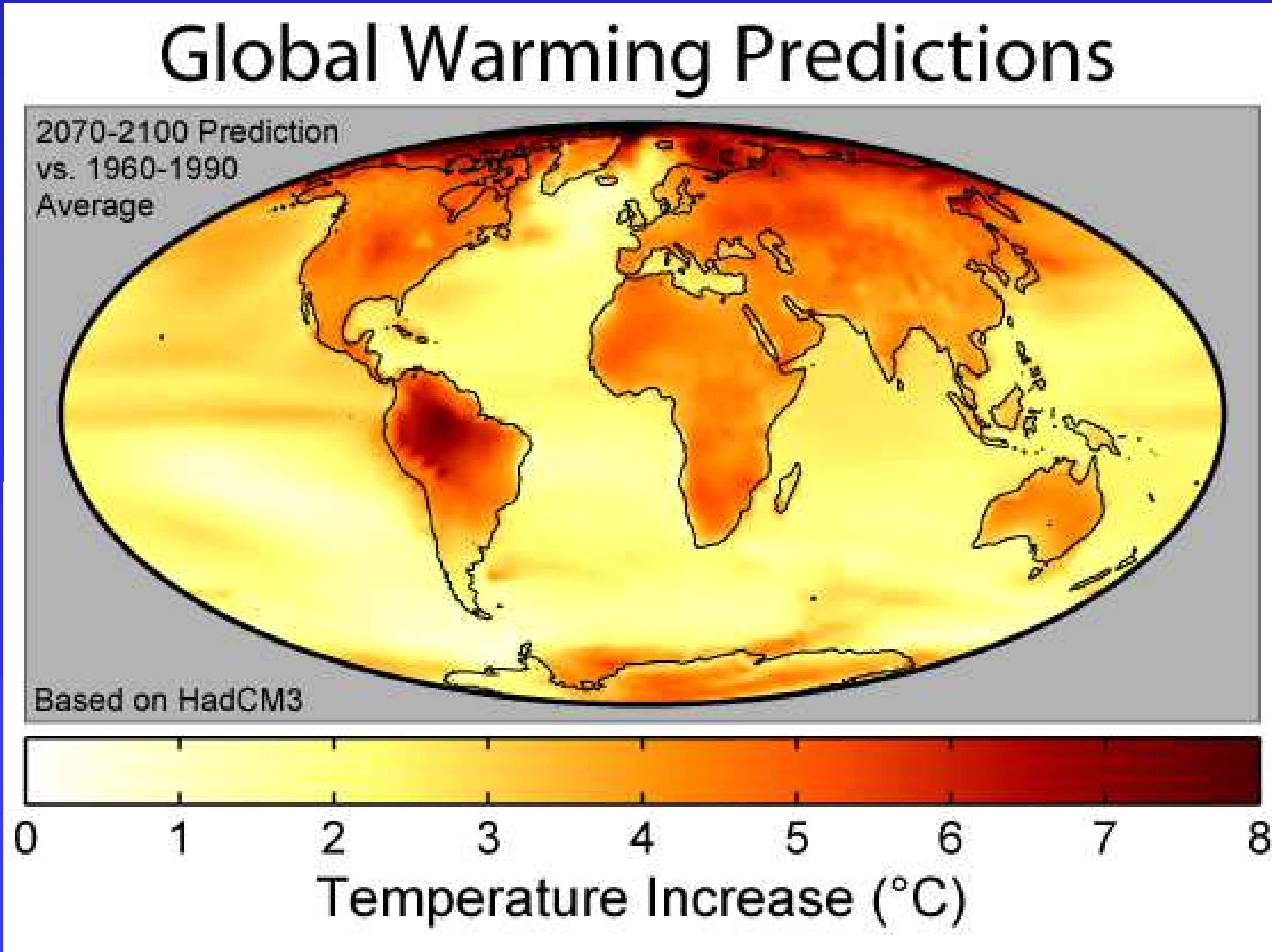
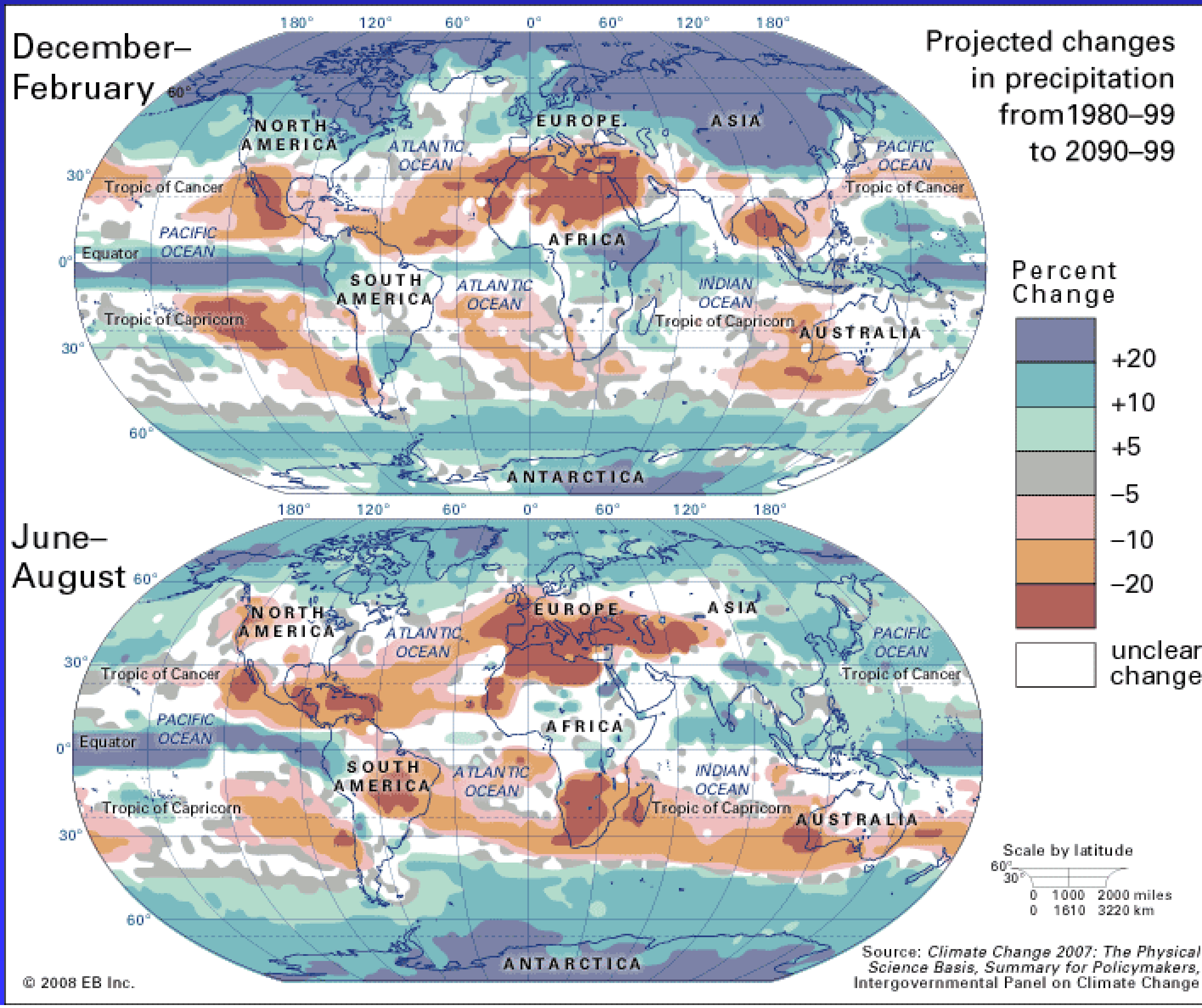
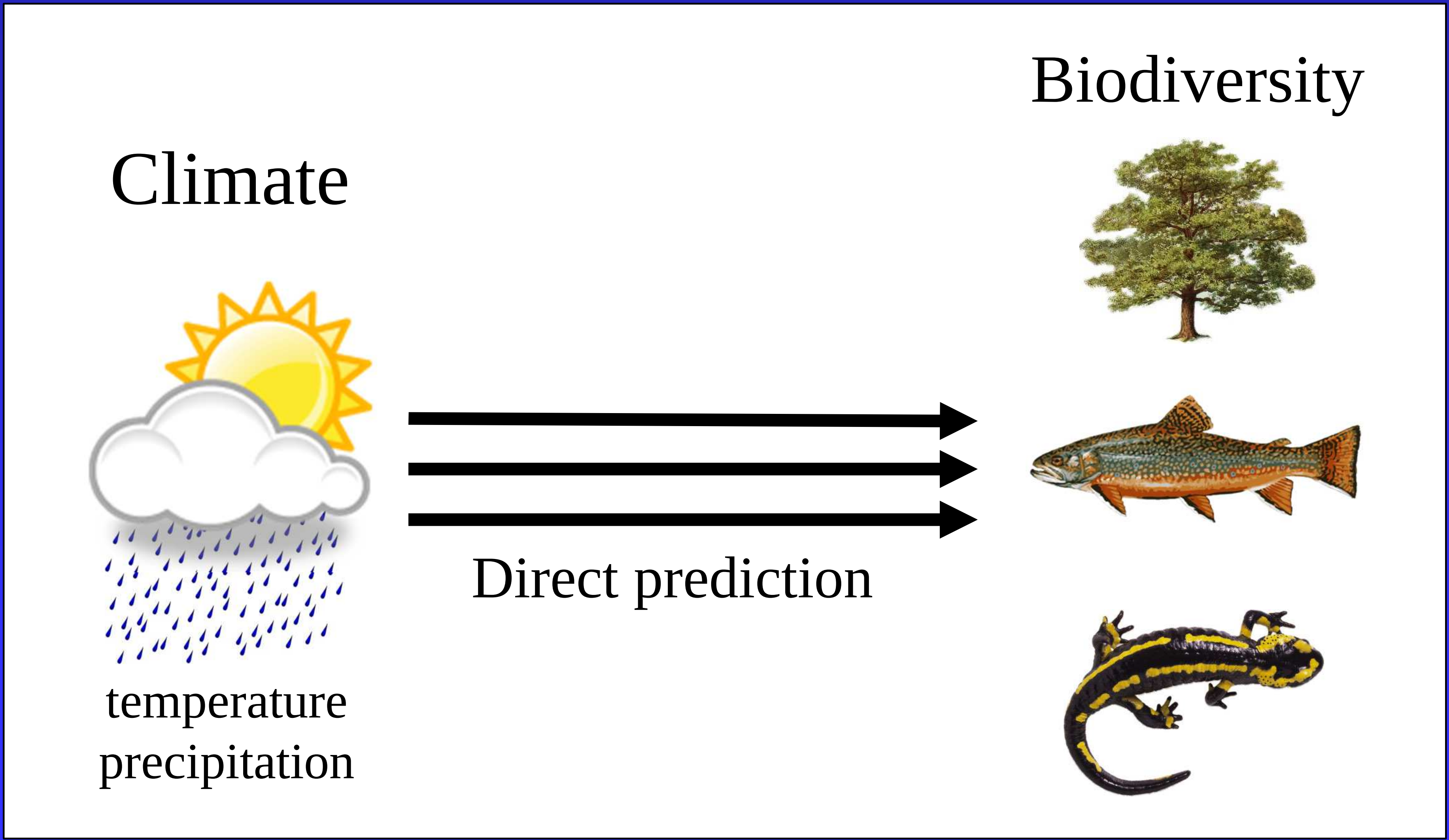
Global temperature change



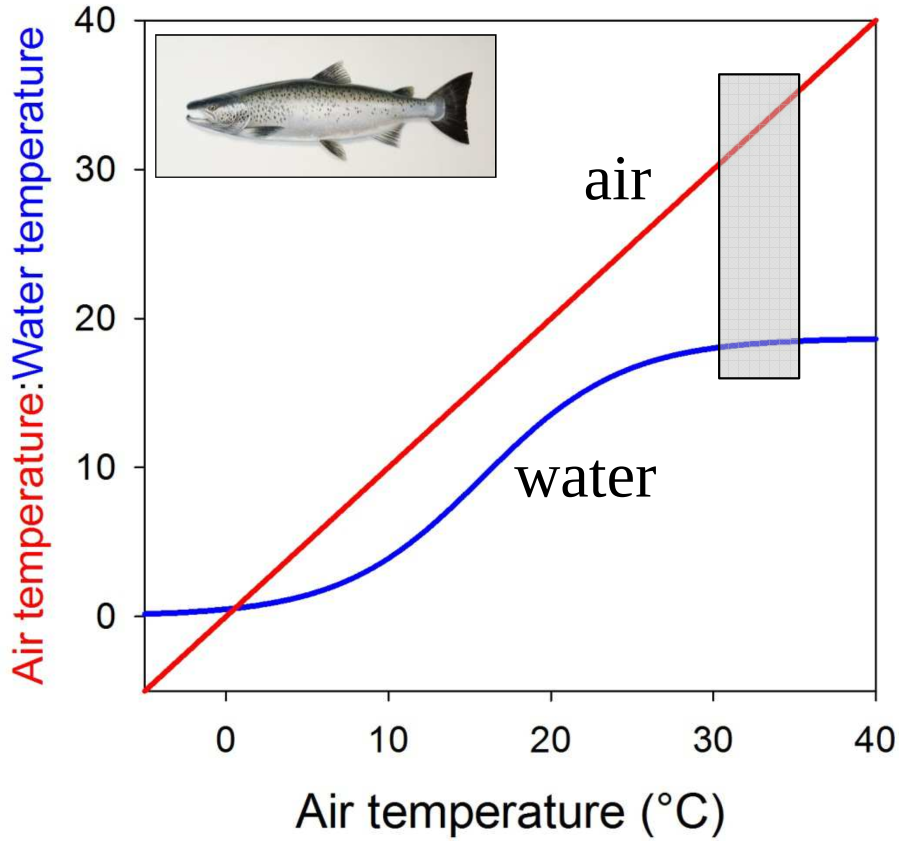
Global precipitation change



Predicting species responses to climate across broad spatial scales



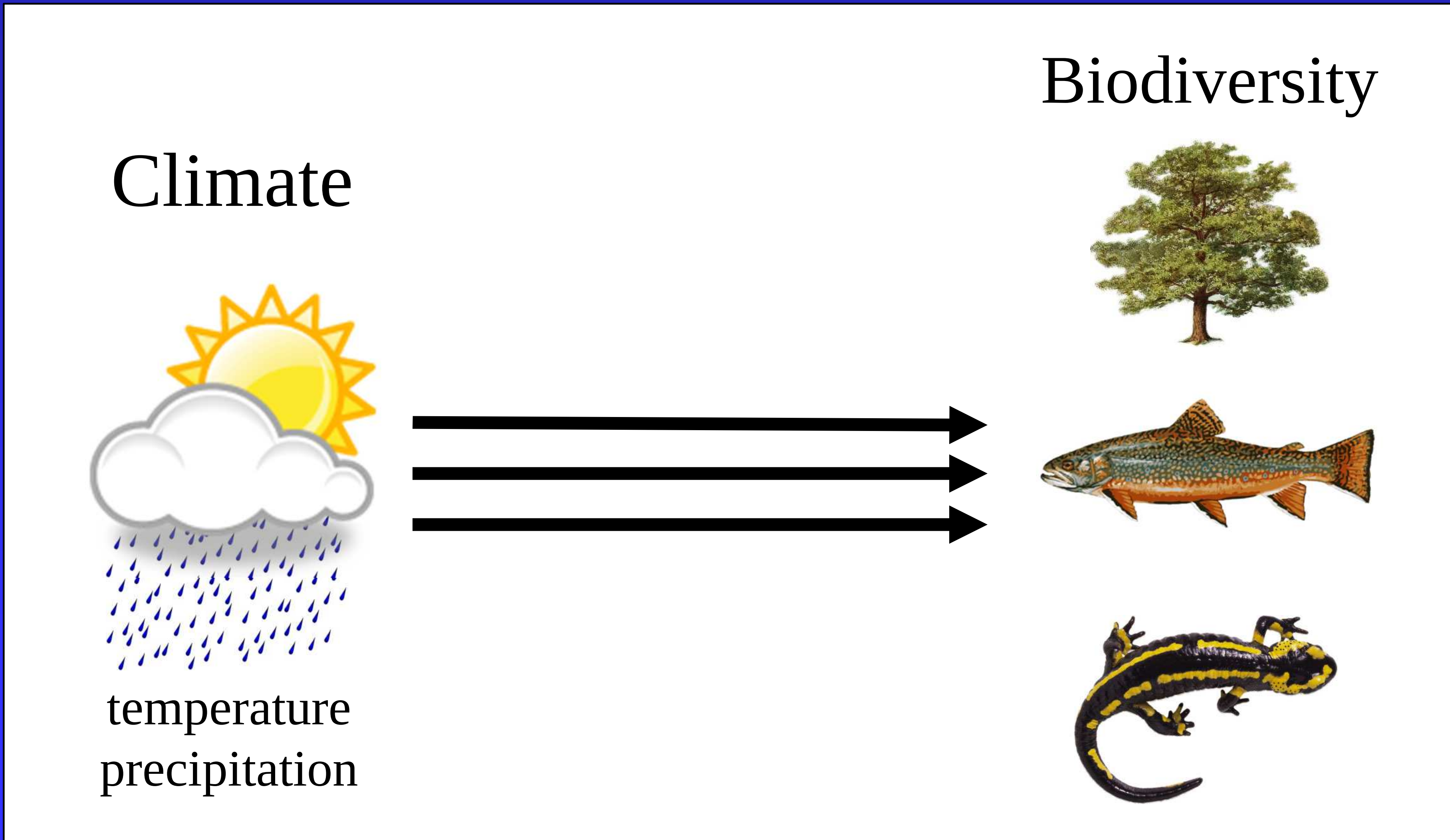
Air temperature and water temperature



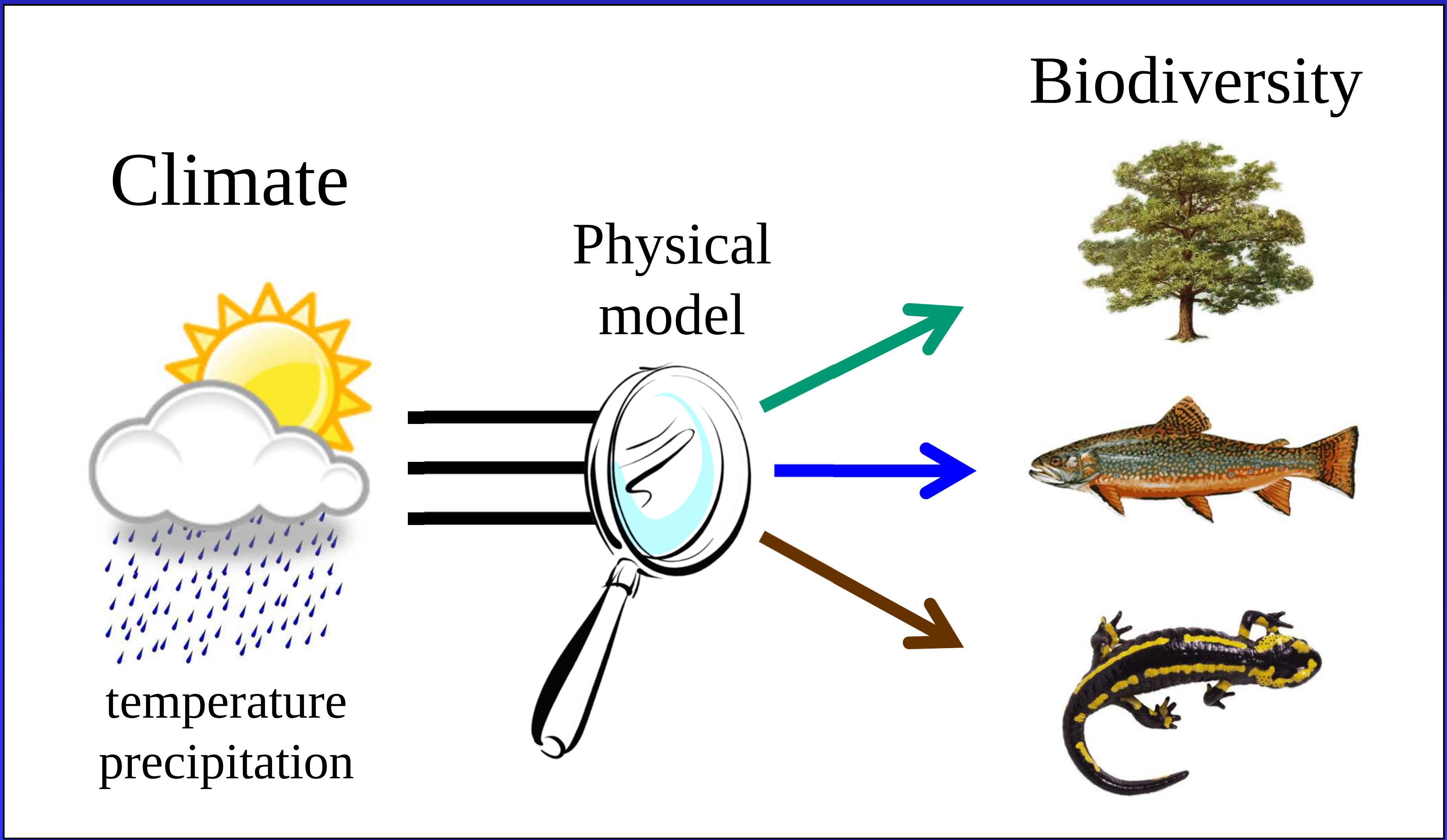
- 4°C increase in air temperature at 30°C (30°C to 34°C)
- Results in 0.4°C increase in water temperature (18.0°C to 18.4°C)

Caissie (2001), Journal of Hydrology

Predicting species responses to climate across broad spatial scales



Predicting species responses to climate across broad spatial scales



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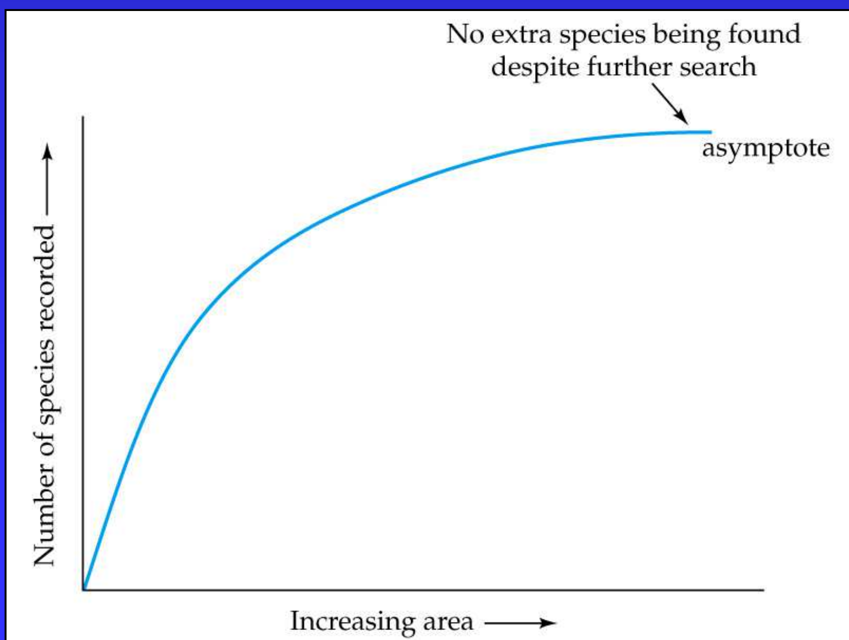
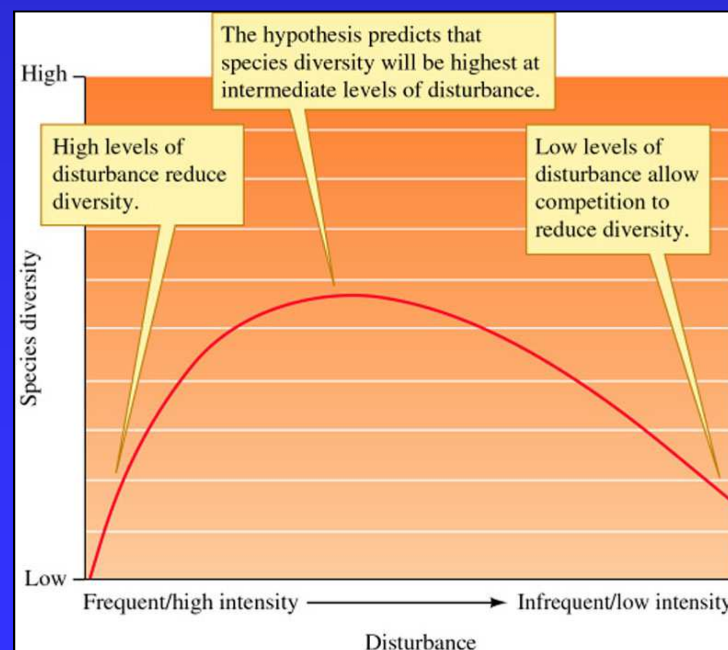
Hydrological variability and freshwater biodiversity

- Flow volume and variability regulate patterns of biodiversity
- Species are adapted to particular flow regimes



Species-area relationship



Intermediate Disturbance Hypothesis

Hydrological variability, climate change, and freshwater biodiversity

- Flow volume and variability regulate patterns of biodiversity
- How will flow regimes change with predicted changes in temperature and precipitation in the coming century?
- How do we take advantage of biodiversity collections to predict the potential impacts of climate change on biodiversity?

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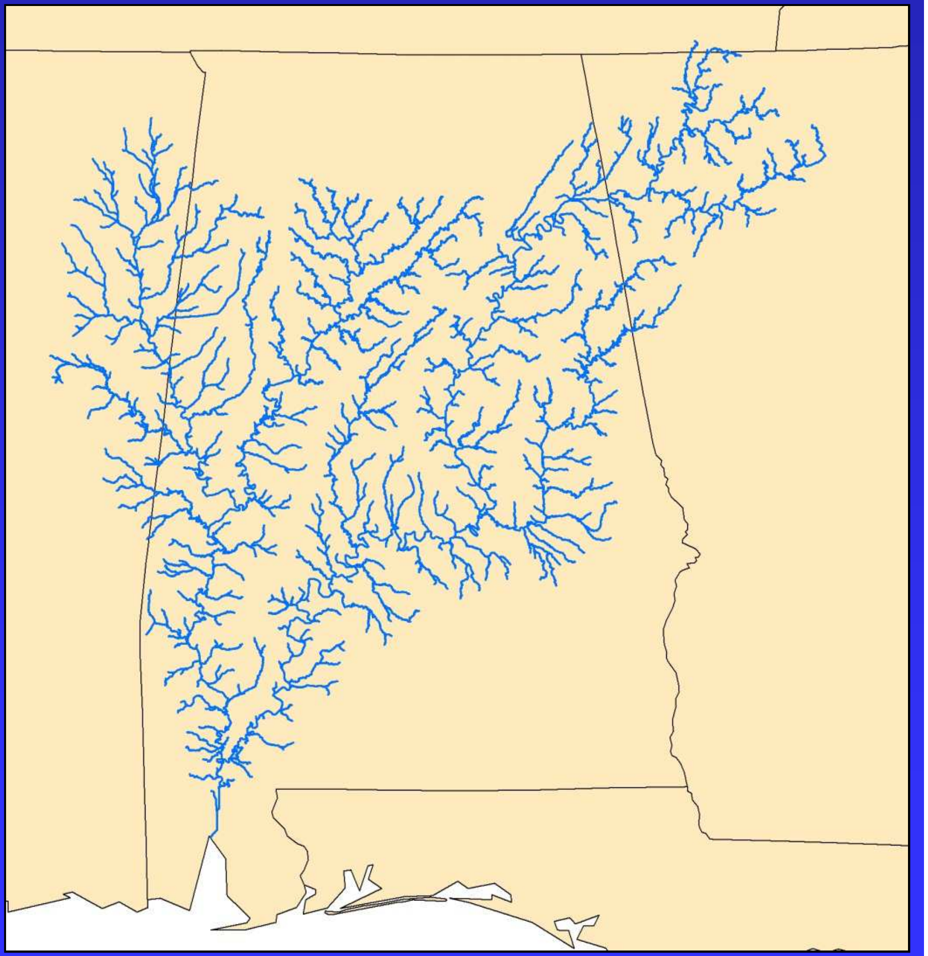
Mobile River watershed

- Drains 110,000 km^2

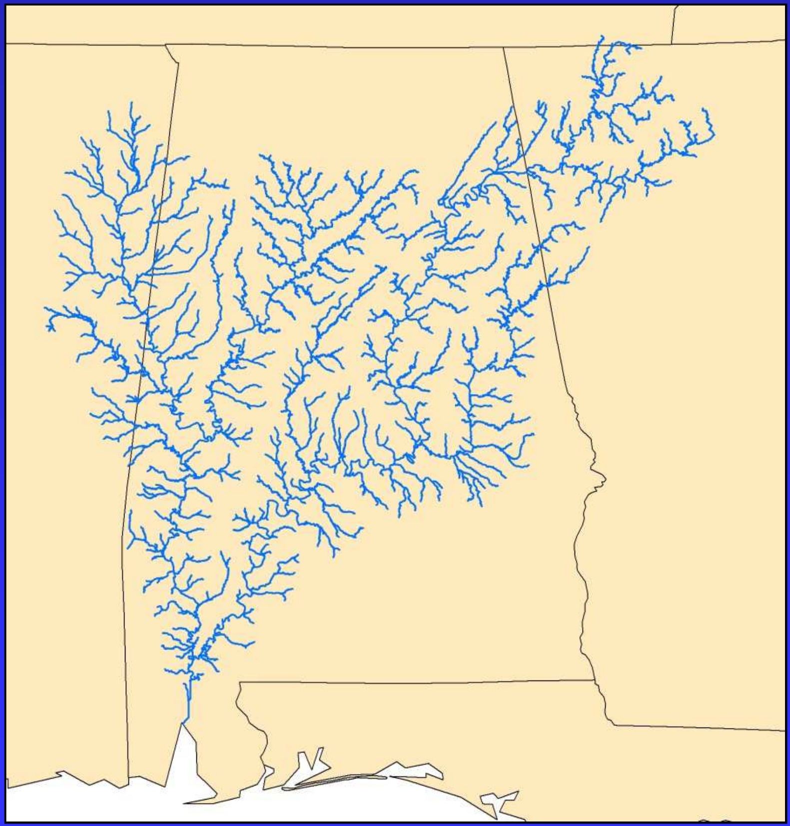
- Rich aquatic biodiversity



Soil and Water Assessment Tool (SWAT)

- Watershed-scale distributed hydrological model

- Generates streamflow predictions using contemporary temperature, precipitation, landcover, soil, and elevation data



Chien, Yeh, and Knouft (2013) *Journal of Hydrology*

Soil and Water Assessment Tool (SWAT)

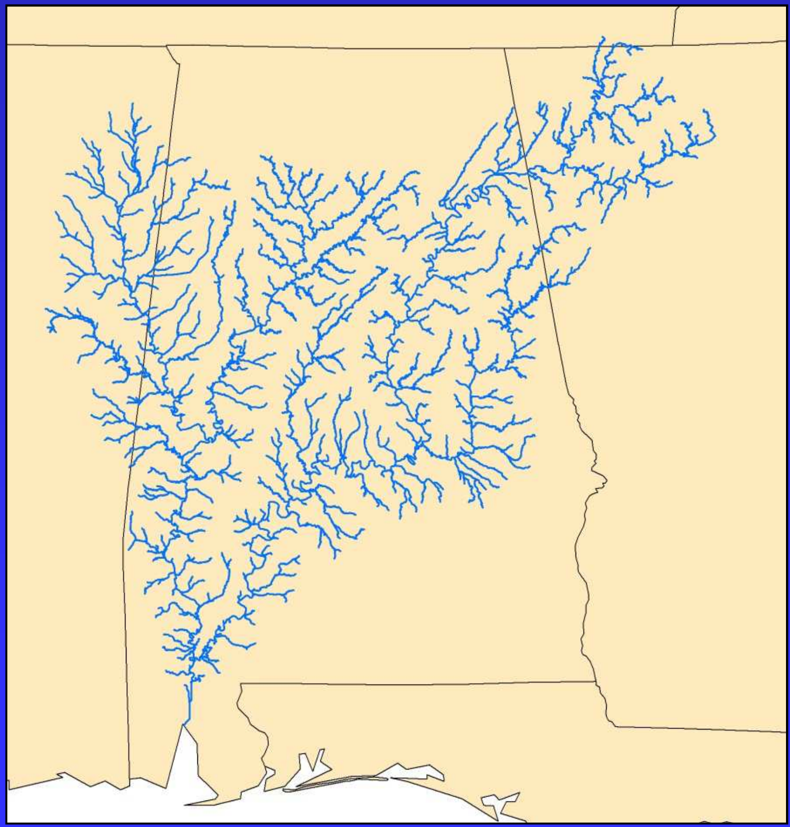
- SWAT is a distributed watershed-scale hydrological model
- SWAT predicts the impact of changes in climate, land use and land cover, and agricultural management on water, sediment, and agricultural chemical yields
- Readily available input (weather, soils, land use, and topographic data)
- Incorporate projected future climate model predictions into SWAT to produce streamflow estimates in 2051-2060

Predicting future streamflows from 2051-2060 using SWAT

- Future flows predicted across the Mobile River watershed based on climate projections from 26 downscaled Global Climate Models

  - nine climate models (CGCM3.1, CNRM-CM3, GFDL-CM2.0, GFDL-CM2.1, IPSL-CM4, MIROC3.2, ECHO-G, ECHAM5/MPI-OM, MRI-CGCM2.3.2)

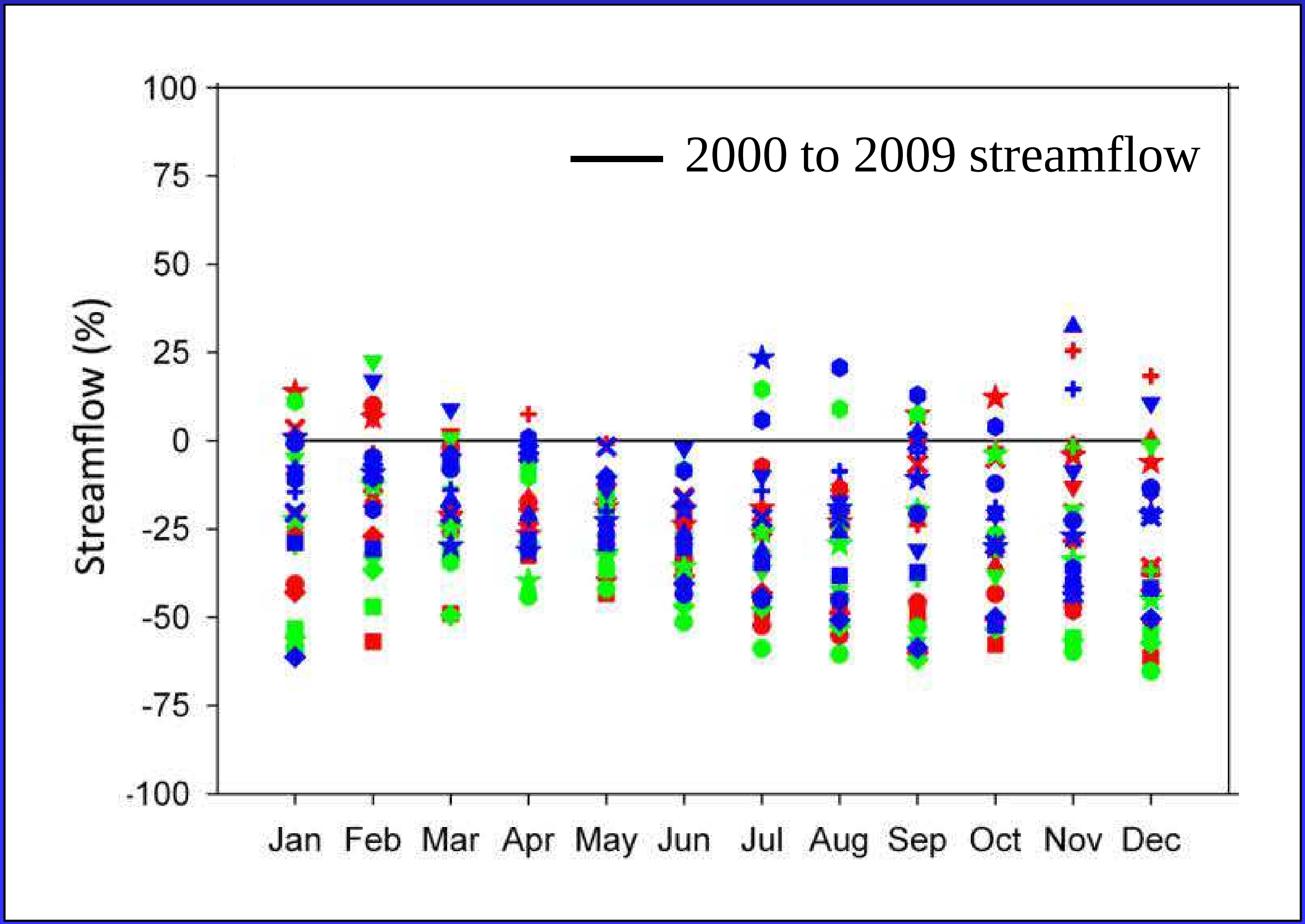
  - three emissions scenarios (A2, A1B, B1)



Streamflow in the Mobile River watershed (2051-2060)

Flow volume decreases

Flow variability increases



Predicting current and future hydrological habitat availability

- Integrate current species distribution data and current flow variables to estimate preferred habitat for each species
- Predict the distribution of future habitat based on future streamflow data generated using SWAT models
- Ecological niche modeling with Maxent

Future flow data

- 26 different flow scenarios
  Highest flow scenario - CNRM-CM3 (France)
  Median flow scenario - CGCM3.1 (Canada)
  Lowest flow scenario - IPSL-CM4 (France)

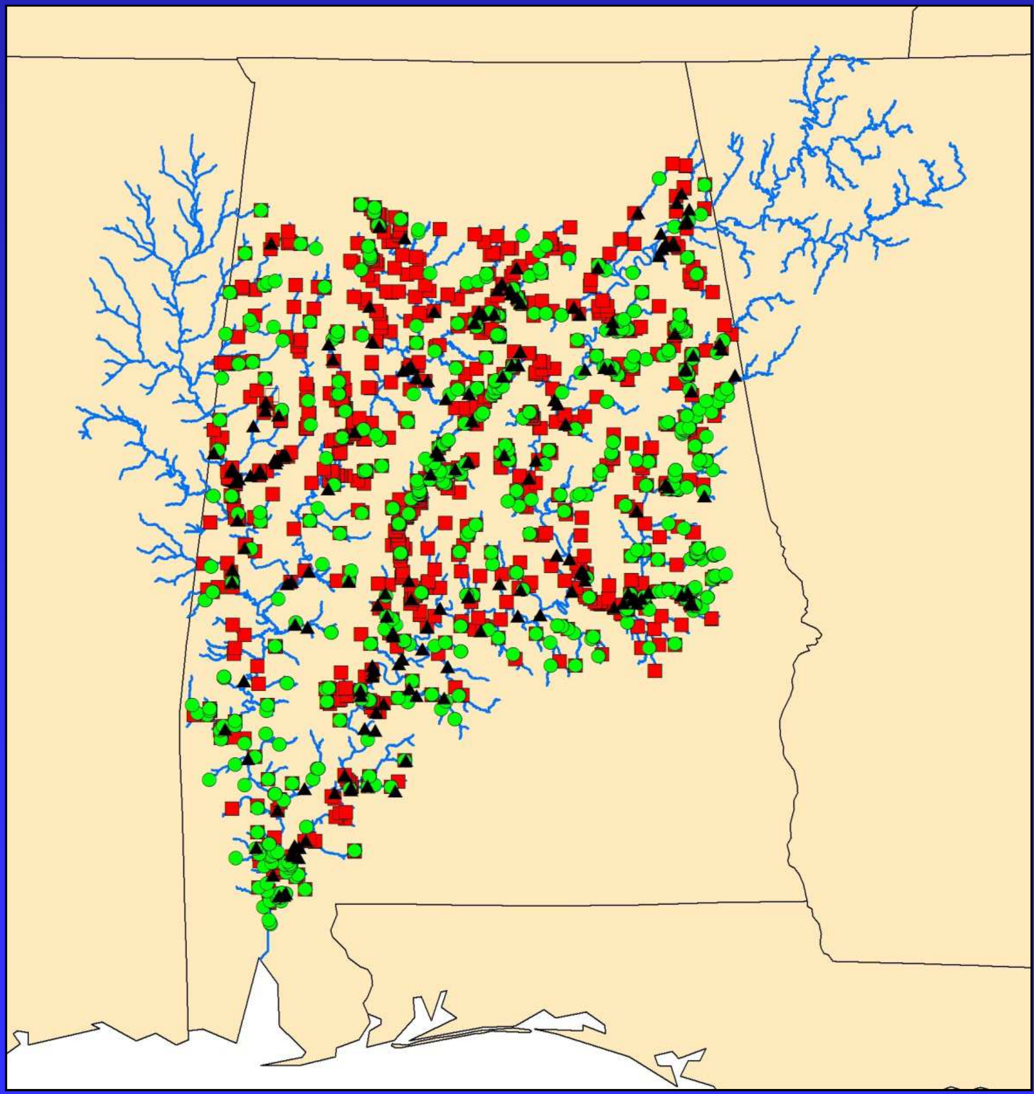
- Flow and topographic variables
  - Annual maximum, minimum, mean, CV, slope

Museum-based species locality data

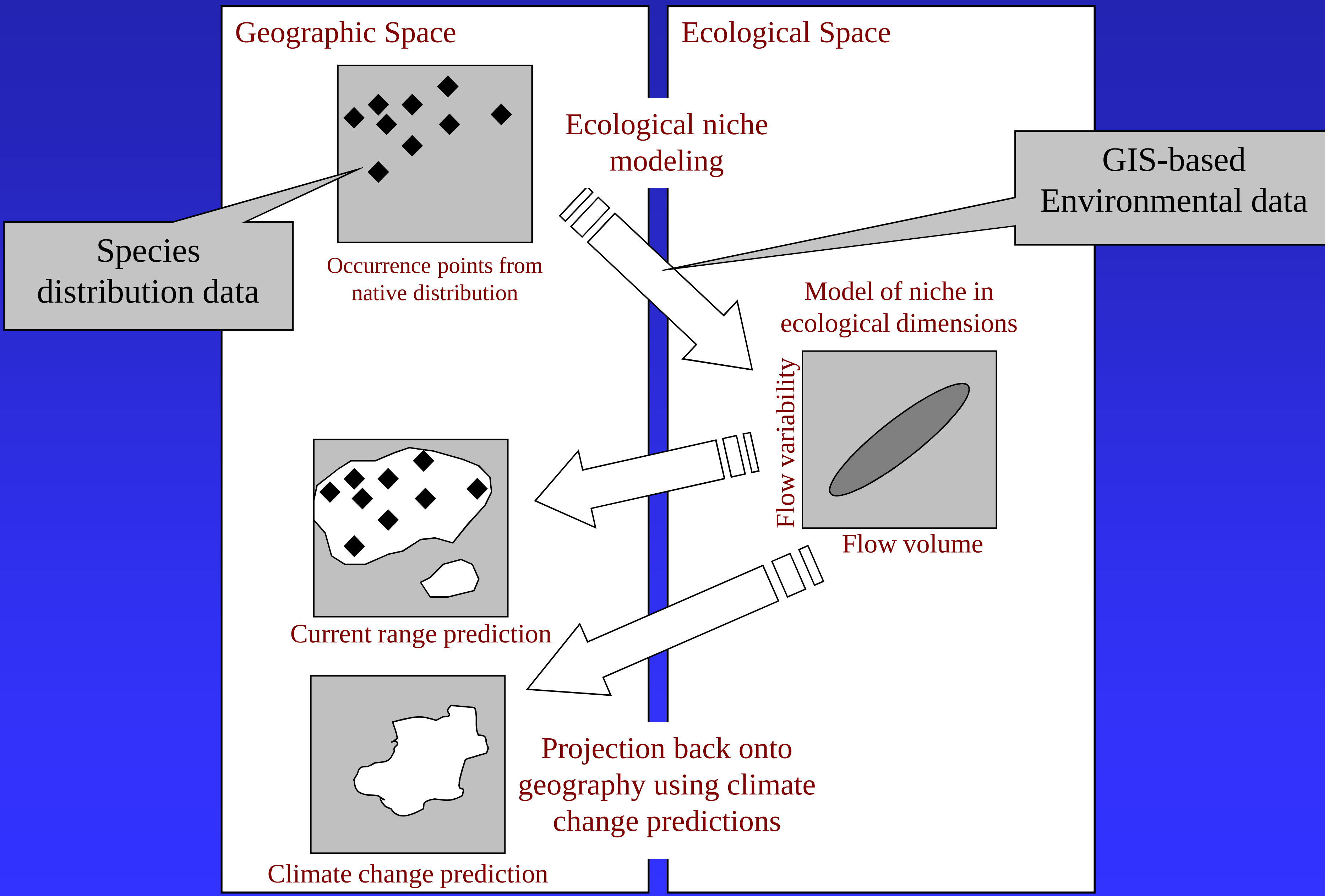
Fishes
103 species
(20,200 localities)

Crayfishes
12 species
(1,142 localities)

Mussels
16 species
(2,004 localities)

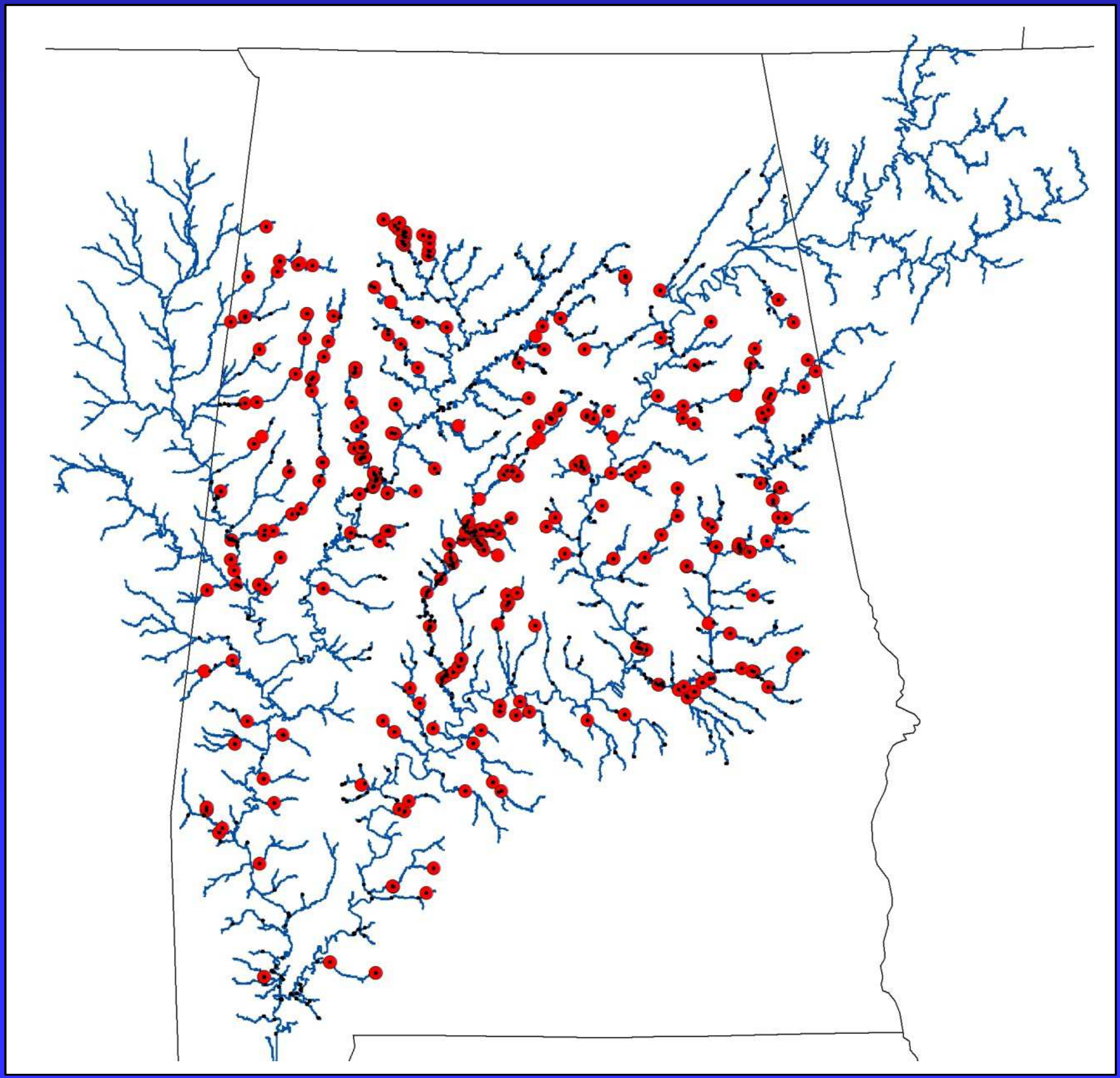


Climate Change and Ecological Niche Modeling



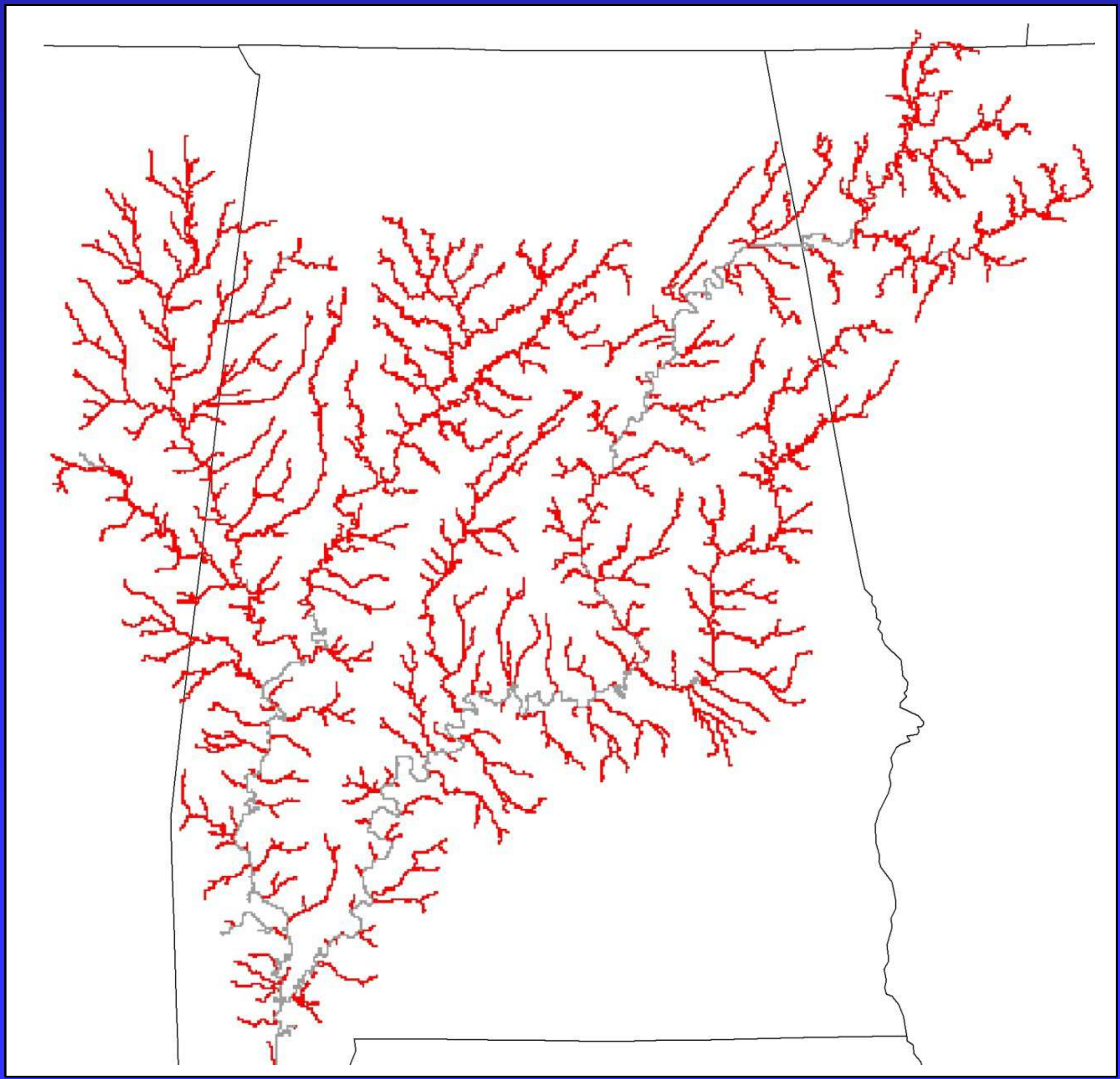
Current and future habitat availability

Etheostoma stigmaeum



Current and future habitat availability

Etheostoma stigmaeum



Current Flow

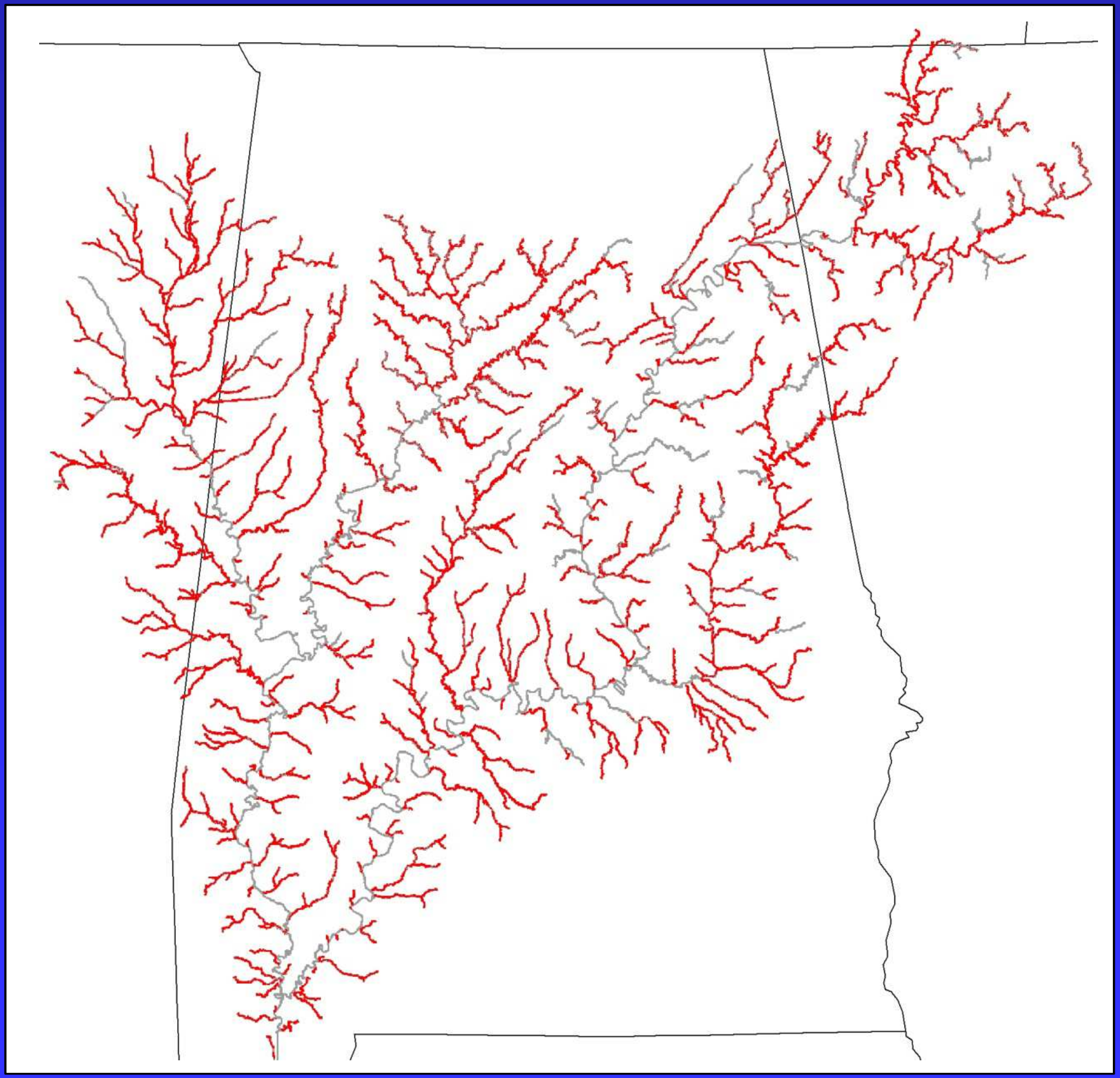
AUC = 0.626

P < 0.0001

CV flow

Current and future habitat availability

Etheostoma stigmaeum



Future High Flow

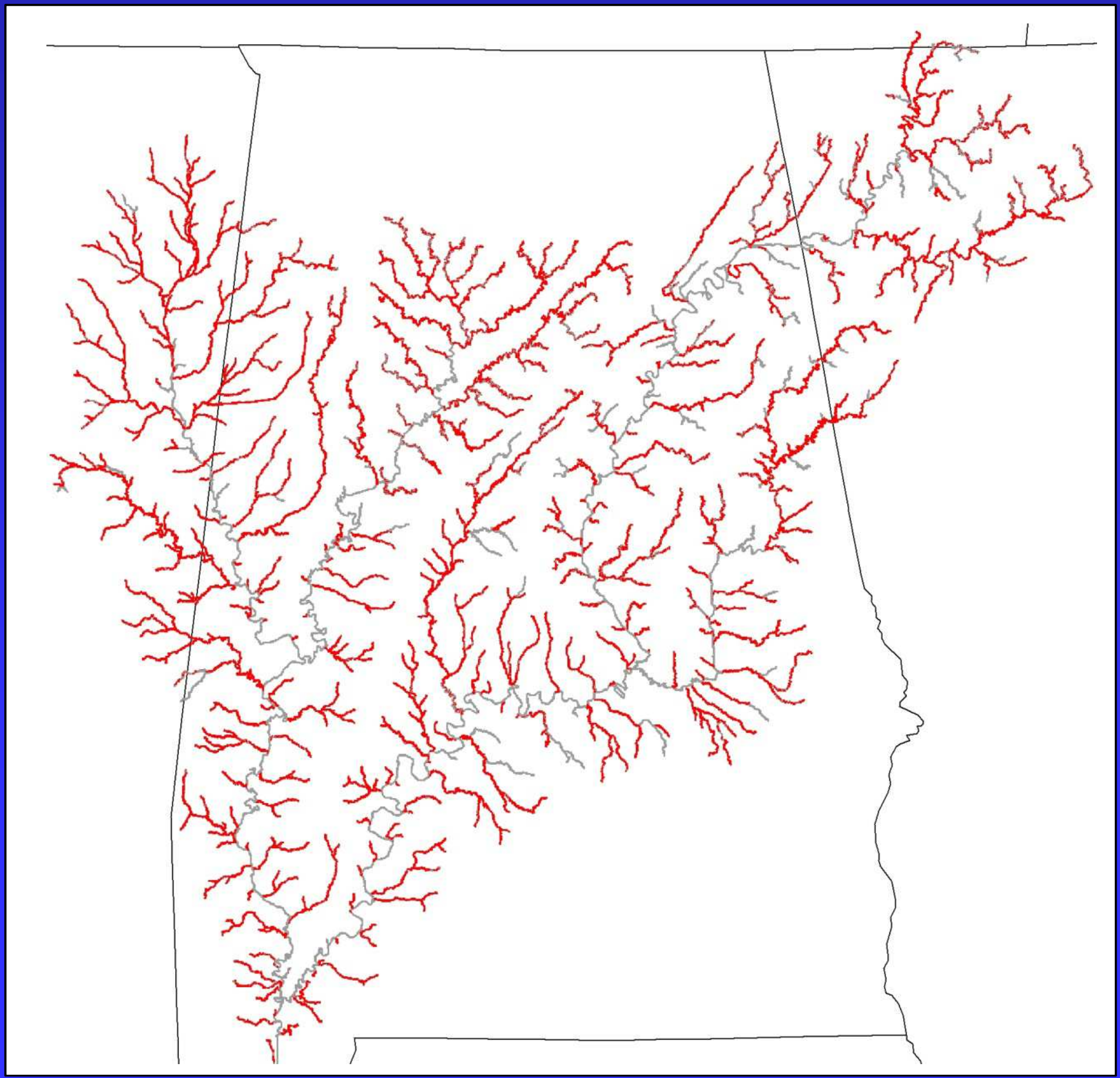
-17.2%

Current and future habitat availability

Etheostoma stigmaeum

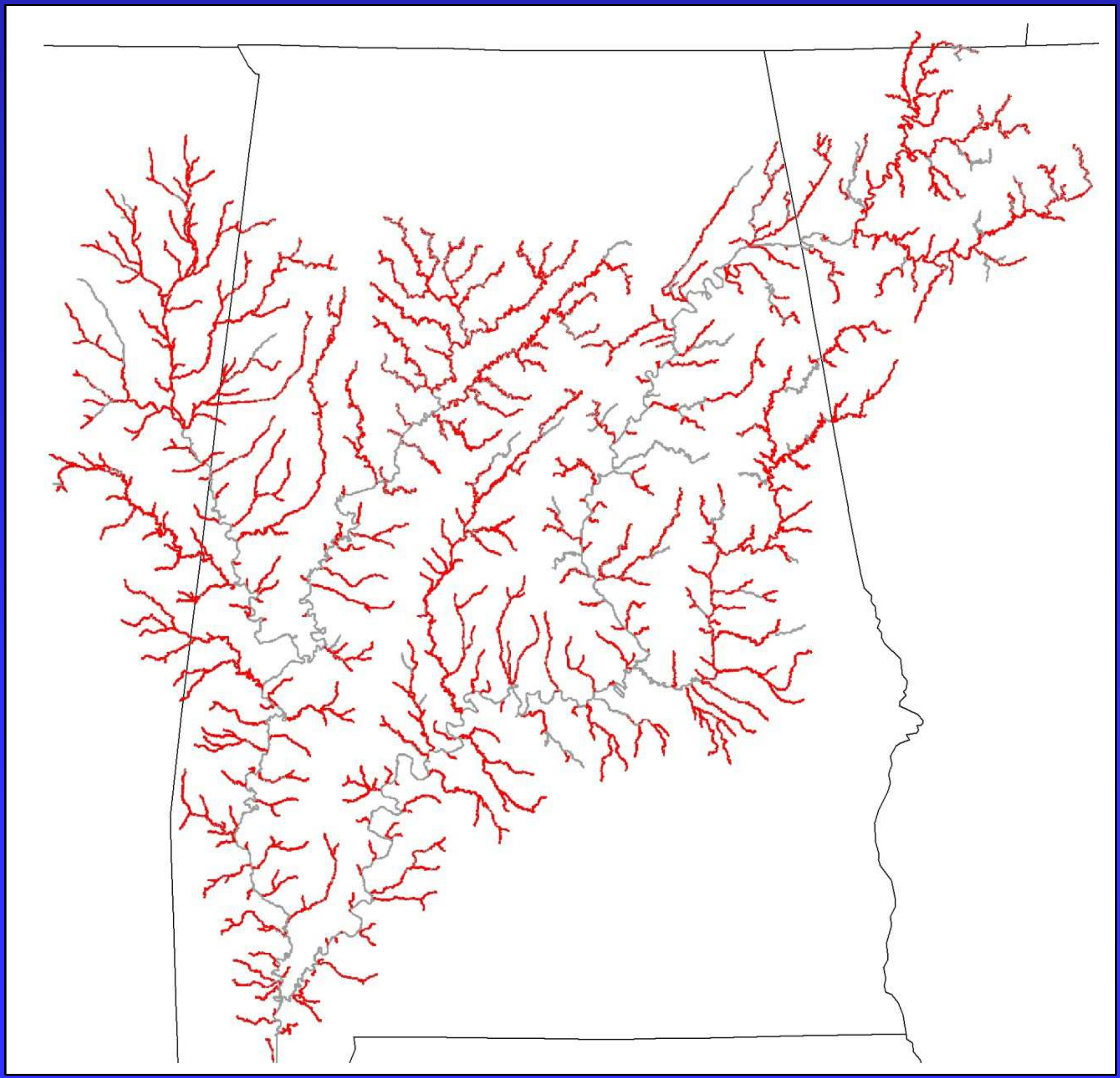
<u>Future Medium Flow</u>

-19.7%



Current and future habitat availability

Etheostoma stigmaeum



Future Low Flow
-17.5%

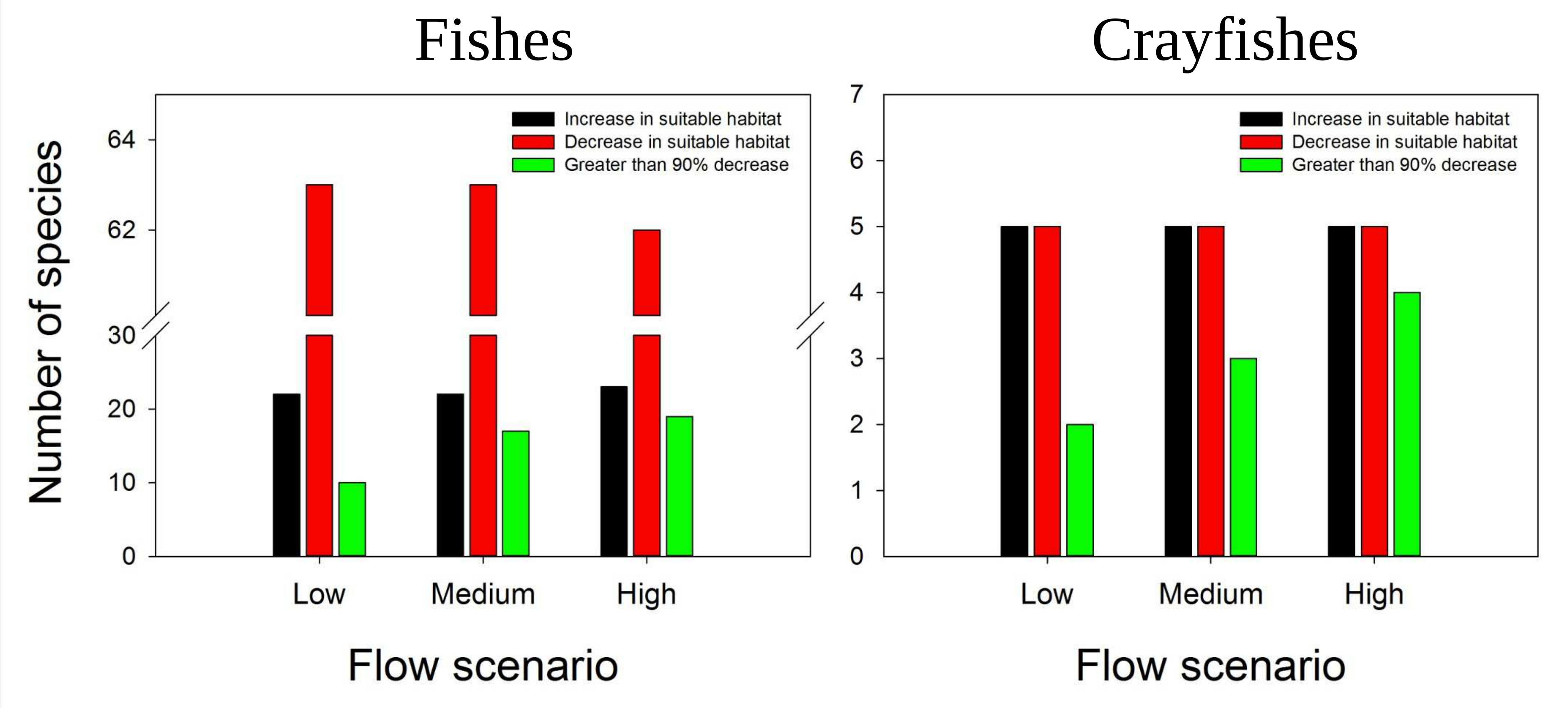
Results

Fishes – 85 of 103 species with significant models

Crayfishes – 10 of 12 species with significant models

Mussels – 1 of 16 species with significant models

Changes in available flow habitat



Summary

- Flow volume is predicted to decrease in the Mobile River basin, while seasonality in flow is predicted to increase and shift.
- A range of responses to changes in flow by fishes and crayfishes, flow does not appear to be a good predictor of mussel distributions.
- Species' responses are fairly consistent among scenarios, although the most impacted species may be differentially affected based on the particular GCM scenario.

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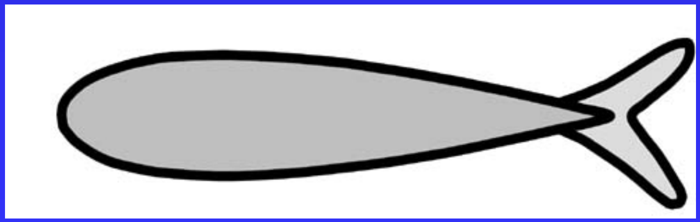
The relationship between flow and species morphology

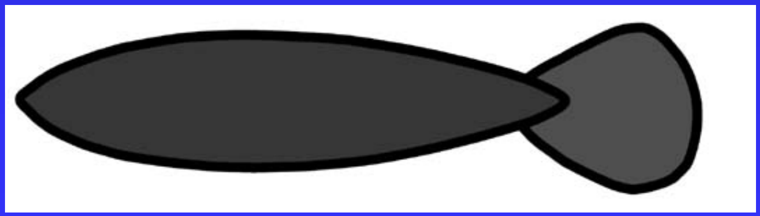
<u>High Flow</u>

- Shallow/narrow caudal peduncle
- Deep/wide anterior body

<u>Low Flow</u>

- Large caudal peduncle
- Deep posterior body





Langerhans & Reznick 2009

Predicting current and future stream flow in Midwestern watersheds using SWAT

- Future flows predicted across the Rock, Illinois, Kaskaskia, and Wabash River drainages based on 26 model scenarios

  - nine climate models (CGCM3.1, CNRM-CM3, GFDL-CM2.0, GFDL-CM2.1, IPSL-CM4, MIROC3.2 ECHO-G, ECHAM5/MPI-OM, MRI-CGCM2.3.2)

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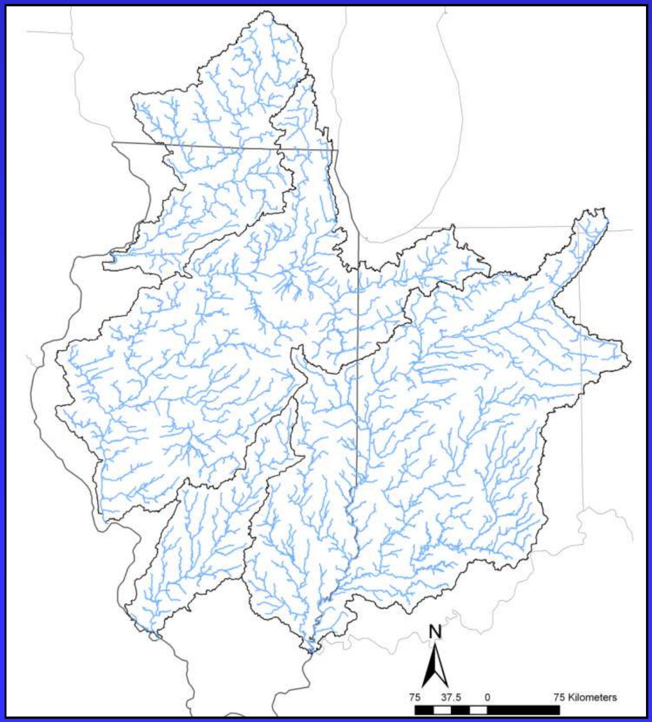
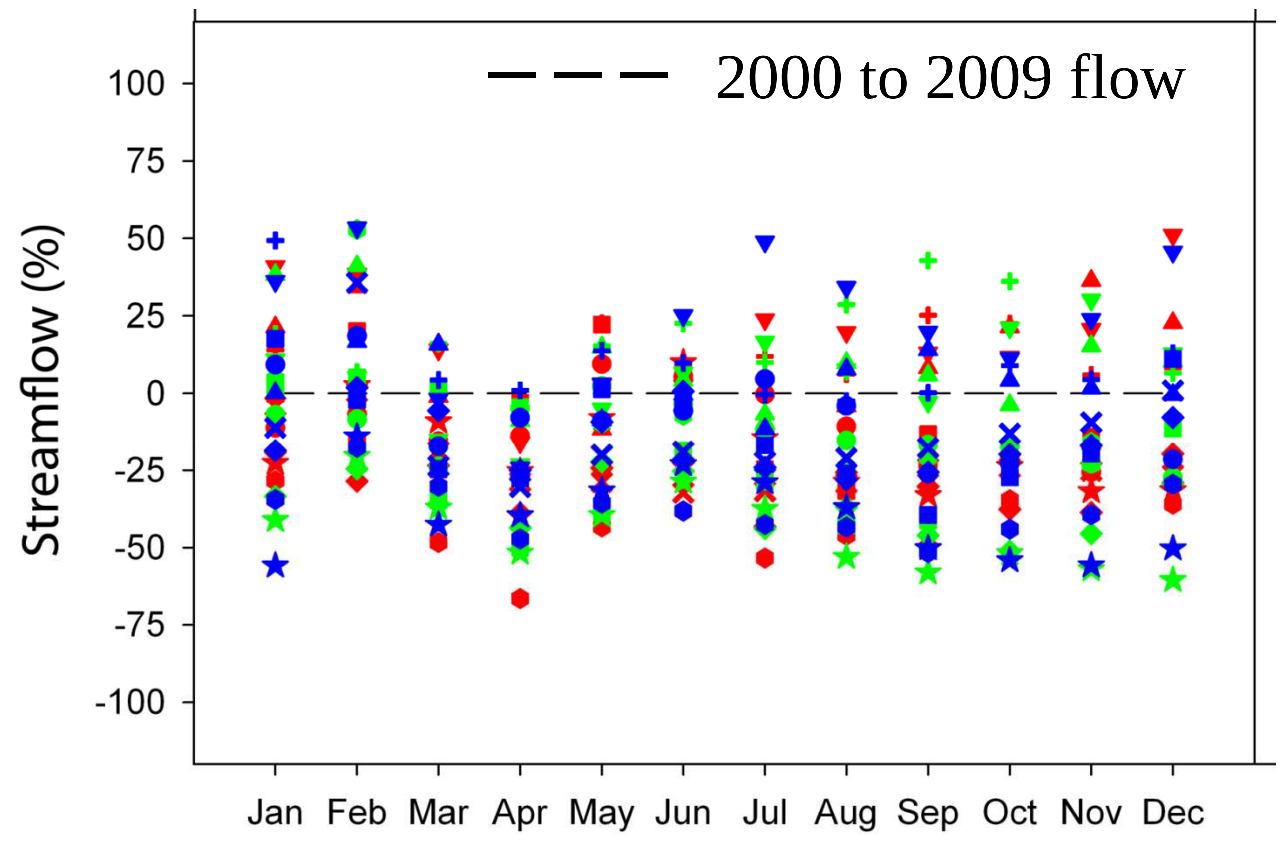


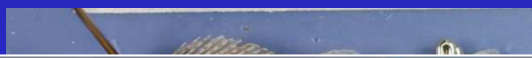
Chien, Yeh, and Knouft (2013) *Journal of Hydrology*

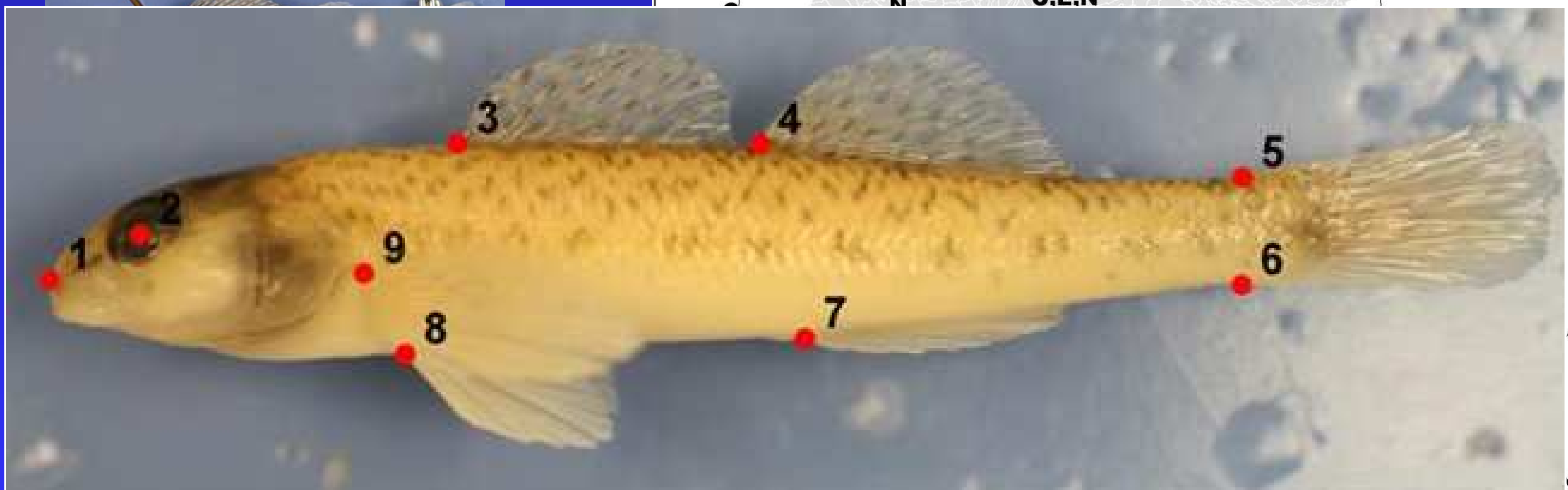
Streamflow (2051-2060)

Rock River watershed



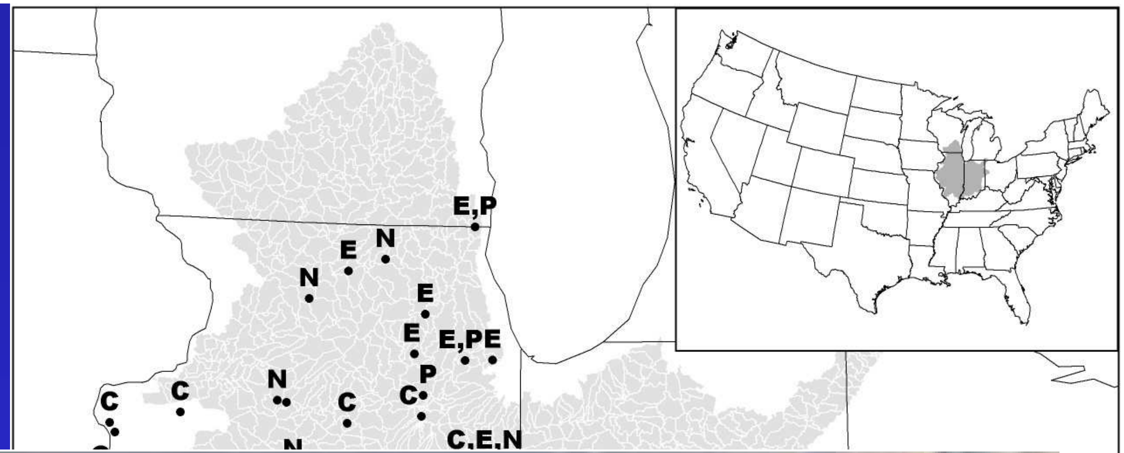
Stonecat
(*Noturus flavus*)





(*Etheostoma nigrum*)

Red shiner
(*Cyprinella lutrensis*)

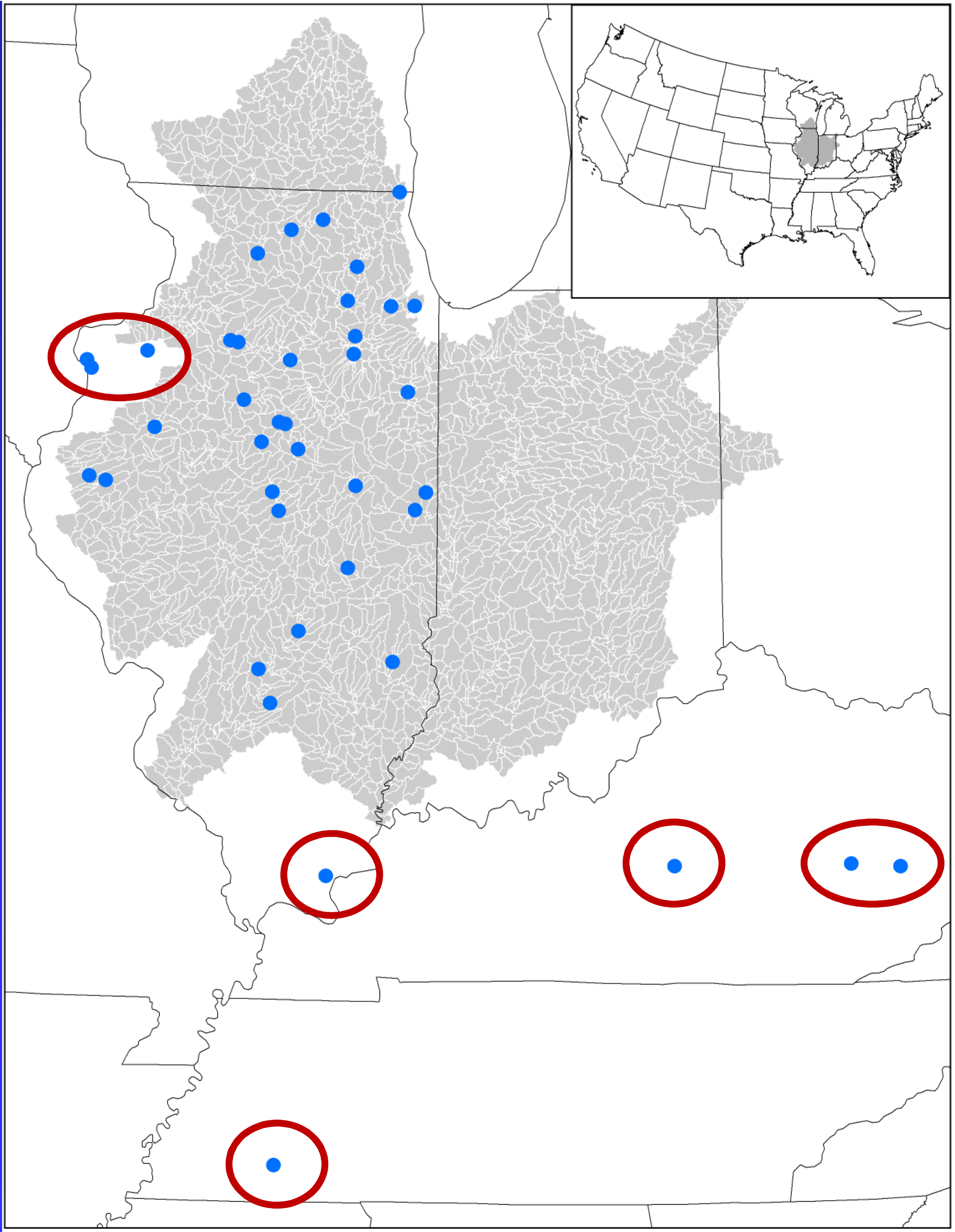


Estimation of flow

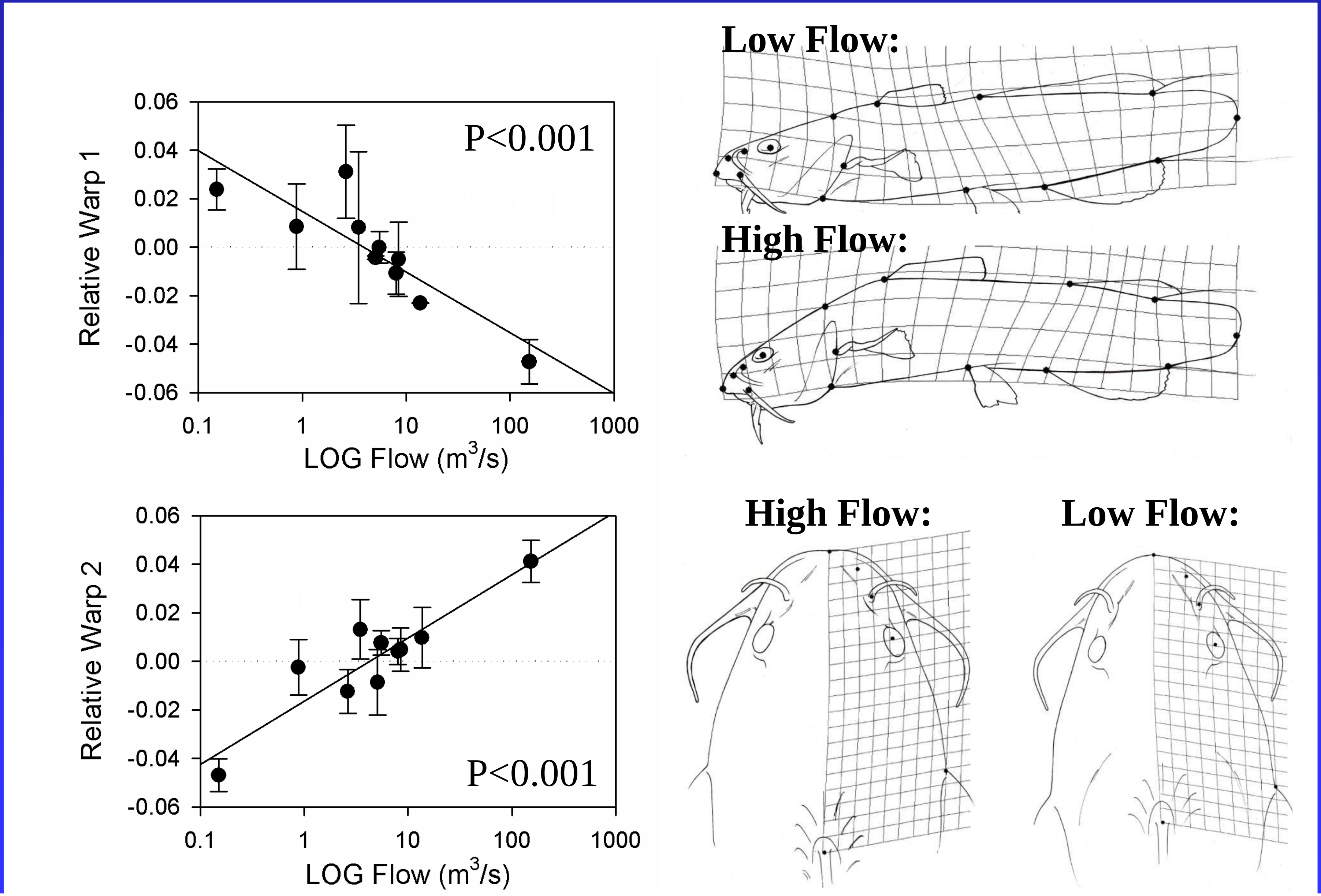
1. SWAT hydrologic models:

2. National Water Information System (NWIS) stream gauges

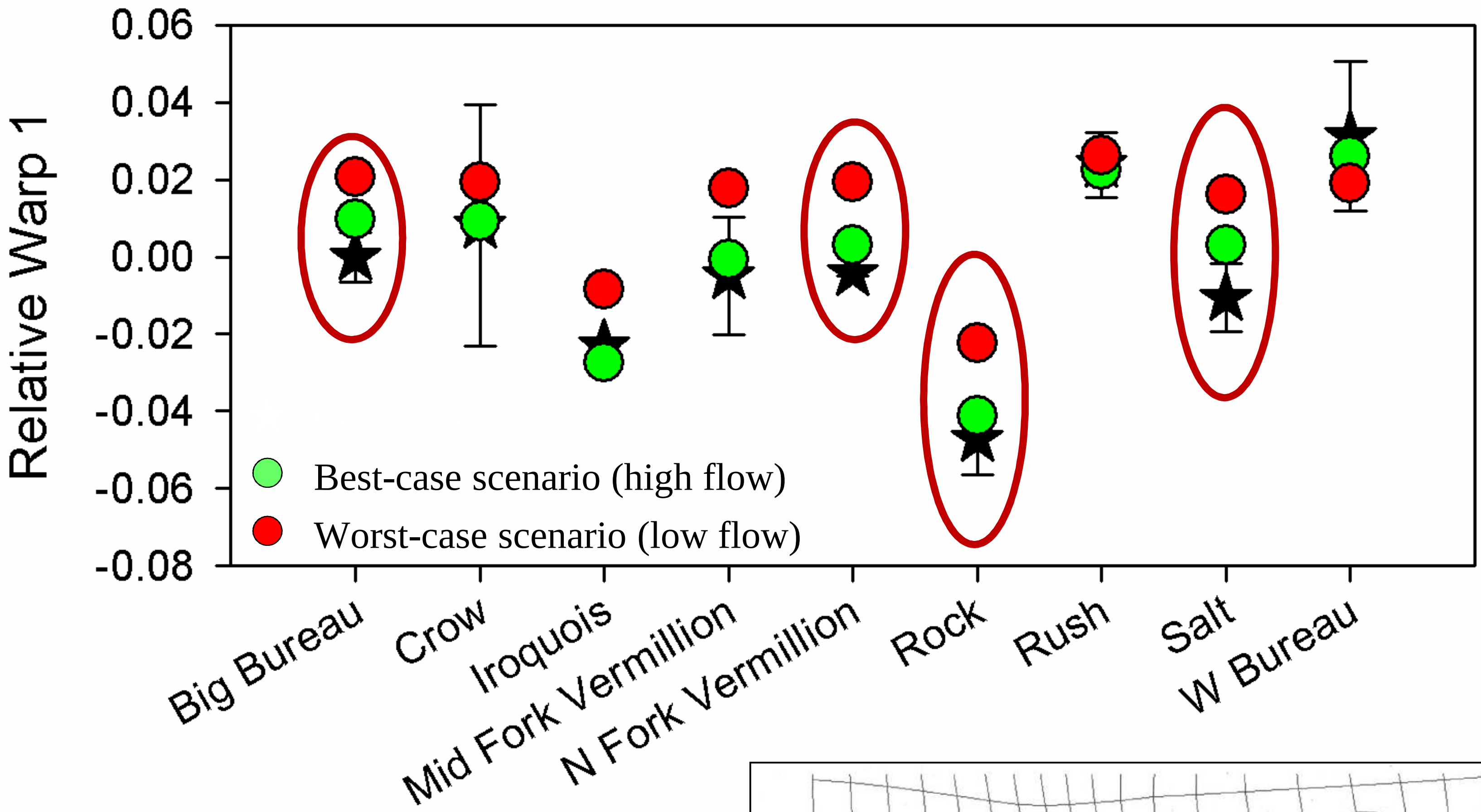
Monthly stream flow data at gauges < 500 m from collection localities



Results – Body shape & flow (*N. flavus*)

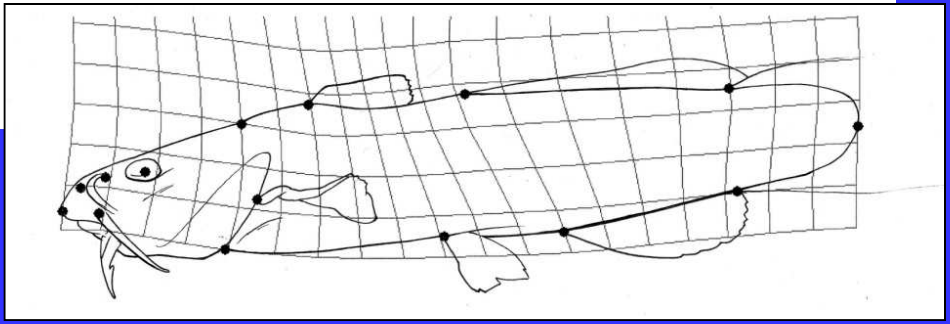


Morphological response to changes in stream flow



Noturus flavus

lateral view



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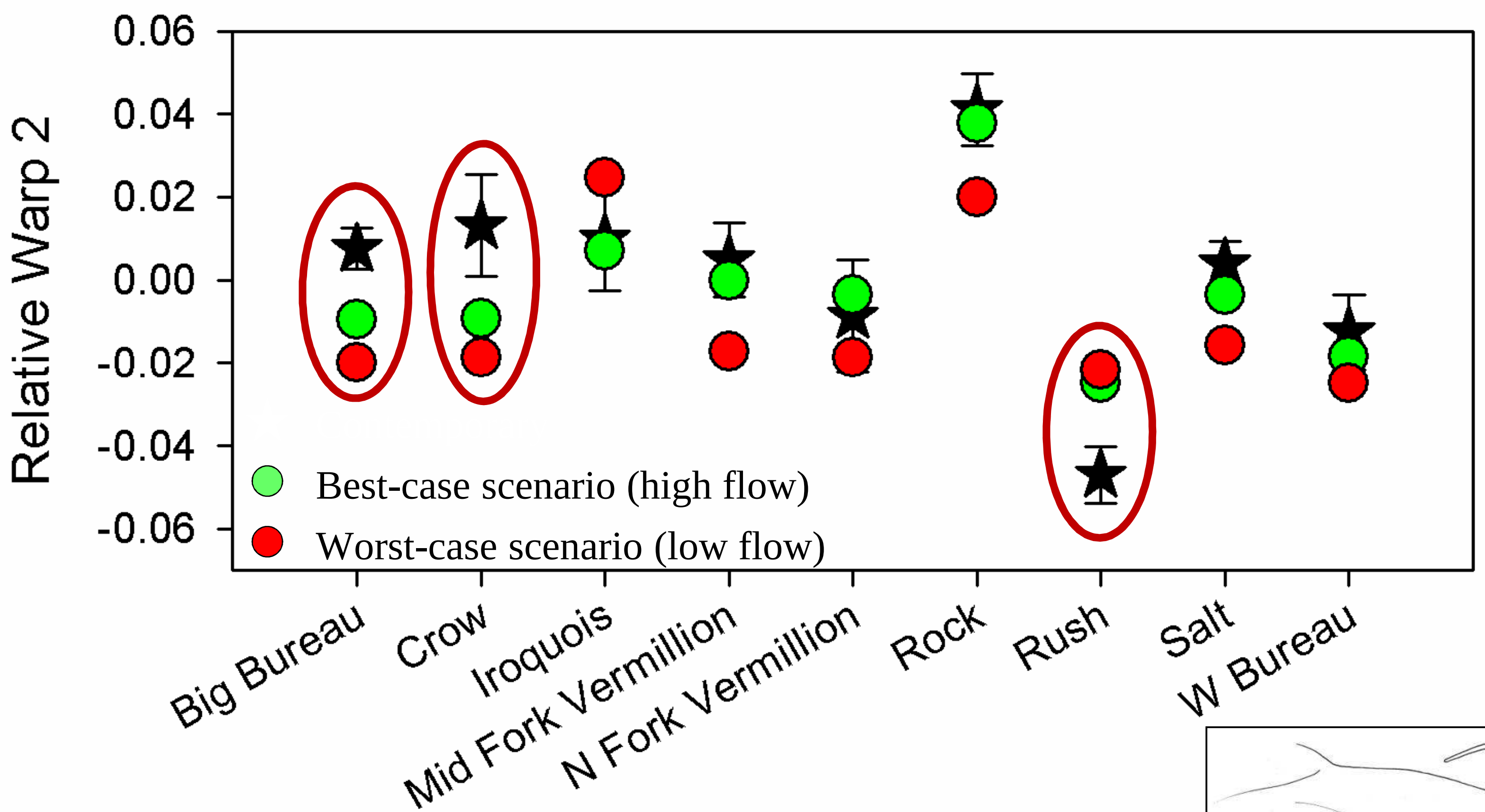
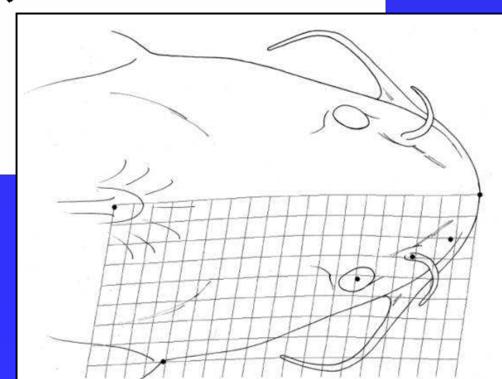


Noturus flavus
dorsal view



Summary from morphological study

- Some species are morphologically adapted to flow regimes.
- Degree of response required to adapt to future flow regimes varies among populations.

Conclusions

- Predicting the responses of freshwater biodiversity to changes in climate requires a systems-level understanding of the physical environment.

- The value in biodiversity collections deserves appropriate efforts to quantify the physical environment.

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