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
1) Efforts to relate climate and biodiversity

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Global temperature change

Global Warming Predictions

2070-2100 Prediction vs. 1960-1990 Average

Based on HadCM3

Temperature Increase (°C)
Global precipitation change

Projected changes in precipitation from 1980–99 to 2090–99

Percent Change

- +20
- +10
- +5
- 0
- -5
- -10
- -20
- unclear change

Source: Climate Change 2007: The Physical Science Basis, Summary for Policymakers, Intergovernmental Panel on Climate Change
Predicting species responses to climate across broad spatial scales

Climate

Direct prediction

Biodiversity

temperature
precipitation
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

Climate
- temperature
- precipitation

Biodiversity

- Tree
- Fish
- Amphibian
Predicting species responses to climate across broad spatial scales

Climate

Physical model

Biodiversity

temperature
precipitation
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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

2000 to 2009 streamflow
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

Geographic Space
- Species distribution data
- Occurrence points from native distribution
- Current range prediction
- Climate change prediction

Ecological Space
- Ecological niche modeling
- Model of niche in ecological dimensions
- Flow variability
- Flow volume
- Projection back onto geography using climate change predictions

GIS-based Environmental data
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

Future Medium Flow
-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

**Fishes**
- **Low** flow scenario: Increase in suitable habitat, Decrease in suitable habitat, Greater than 90% decrease
- **Medium** flow scenario: Increase in suitable habitat, Decrease in suitable habitat, Greater than 90% decrease
- **High** flow scenario: Increase in suitable habitat, Decrease in suitable habitat, Greater than 90% decrease

**Crayfishes**
- **Low** flow scenario: Increase in suitable habitat, Decrease in suitable habitat, Greater than 90% decrease
- **Medium** flow scenario: Increase in suitable habitat, Decrease in suitable habitat, Greater than 90% decrease
- **High** flow scenario: Increase in suitable habitat, Decrease in suitable habitat, Greater than 90% decrease
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

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

Low Flow
- 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)
  - three emissions scenarios (A2, A1B, B1)

Chien, Yeh, and Knouft (2013) *Journal of Hydrology*
Streamflow (2051-2060)

Rock River watershed

2000 to 2009 flow
Stonecat
 (*Noturus flavus*)

Blackside darter
 (*Percina maculata*)

Red shiner
 (*Cyprinella lutrensis*)

Johnny darter
 (*Etheostoma nigrum*)
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*)

Low Flow: High Flow:

P < 0.001

High Flow: Low Flow:

P < 0.001
Morphological response to changes in stream flow

Noturus flavus
lateral view
Morphological response to changes in stream flow

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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