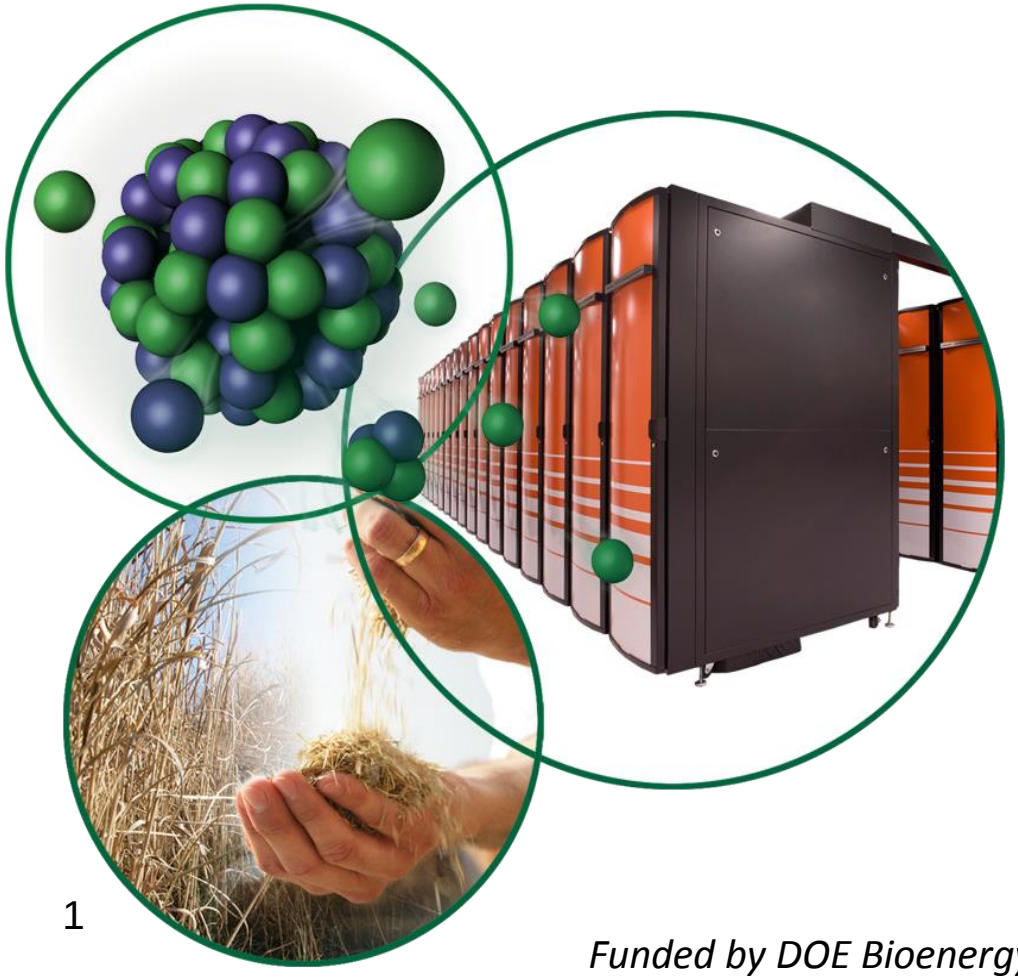
Studying the potential of aquatic macroinvertebrates as indicators of bioenergy-related land-use changes



Latha Baskaran
baskaranl@ornl.gov

Center for Bioenergy sustainability

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Outline

- Bioenergy sustainability
- Why aquatic macroinvertebrates?
  - Scale and context
- Research objectives
- Study region and Data
- Analyzing aquatic macroinvertebrates
  - Regional-scale analysis
  - Watershed-scale analysis
  - Setting the regional context for watershed-scale analysis
- Next steps

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Bioenergy sustainability

- Energy crops have the potential to produce 34 to 400 million dry tons of biomass by 2030*
  - Replace cropland or pasture land (5 million acres to 64 million acres)
- Potential land-use change and environmental implications need to be monitored
- Example of a dedicated bioenergy crop – switchgrass
  - Perennial crop with wide range and adaptability
  - Low fertilizer requirements and lower impact to streams (compared to annual crops)
  - Changes to the streams affects aquatic biodiversity

(* - U.S. Department of Energy, *U.S. Billion-Ton Update*)

Aquatic Macroinvertebrates

- Key component of the food chain
- Sensitive to changes in water quality and ecosystem disturbances
- Limited mobility
- Indicators of stream health (biomonitoring)
  - EPT taxa richness (taxa in Ephemeroptera, Plecoptera and Trichoptera orders)
    - Mostly intolerant to changes in water quality and sediment (e.g., Lenat 1988)

•Ephemeroptera (mayfly)

•Plecoptera (stonefly)

•Trichoptera (caddisfly)

Source for images – www.epa.gov

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Scale and Context

Aquatic macroinvertebrates are affected by natural and anthropogenic factors operating at different spatial scales

- Environmental ‘filters’ constrain the biotic potential at lower scales (Poff 1997)
- These filters are hierarchically organized
- Land use is one of the factors operating under the constraints of other factors
- To understand the influence of land-use changes, the natural context needs to be set

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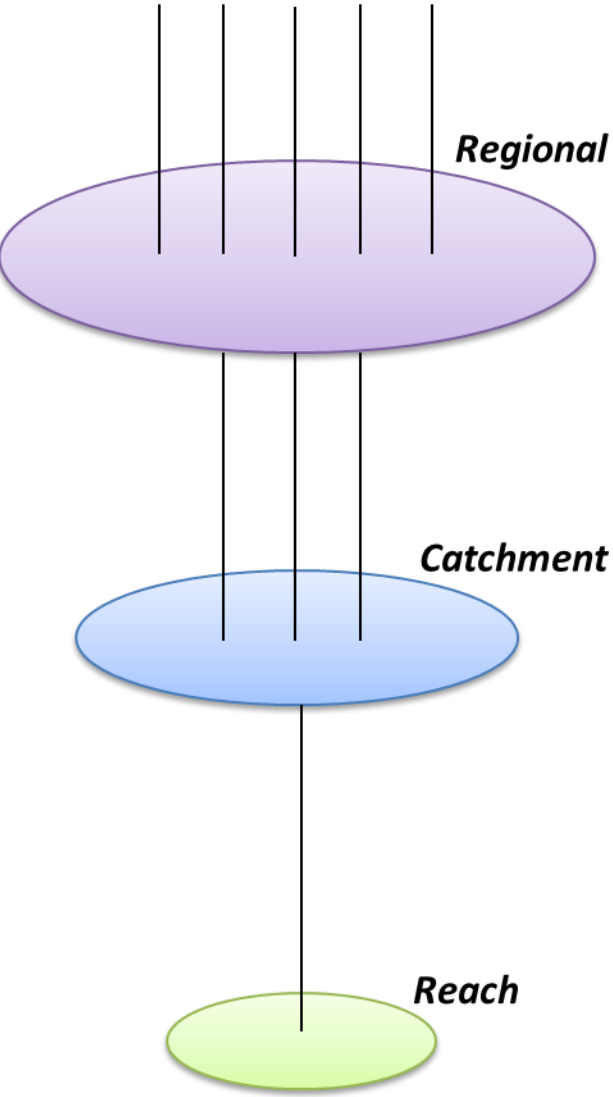

Landscape/ stream features	Related factors that affect macroinvertebrates
Geomorphology	Flow regime, substrate, ion concentration
Climate	Stream flow, temperature
Stream Order	Channel characteristics, food resources
Land Cover	Land disturbance, increased impervious surface area, altered hydrology, transport of non-point source pollutants (e.g. sediment, nutrients) to streams, input of organic matter in the stream
Stream flow	Flow volume, channel dynamics, erosion, floods and low flows
Sediments and Substrate	Turbidity, scouring and abrasion, substrate composition, in-filling interstitial habitat, stream depth heterogeneity
Nutrients	Nutrient enrichment, dissolved oxygen, changes to assemblage composition
pH	pH sensitivity, toxicity

Adapted from Poff (1997)

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Research Objectives

1. Explore how switchgrass-based land-use changes affects stream flow, nutrients and sediments to change EPT taxa richness within different ecoregional settings.
2. Under the defined regional settings, evaluate if EPT taxa richness measures are good indicators of changes in water quality due to switchgrass-based land use changes

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1. Research Questions

- What are the key factors that influence EPT taxa richness in different ecoregions?
- Do the distributions of EPT taxa richness and the factors that affect them vary by ecoregion?
- How can the information derived at regional scales be applied to explore potential stream-level macroinvertebrate responses to land-use change?

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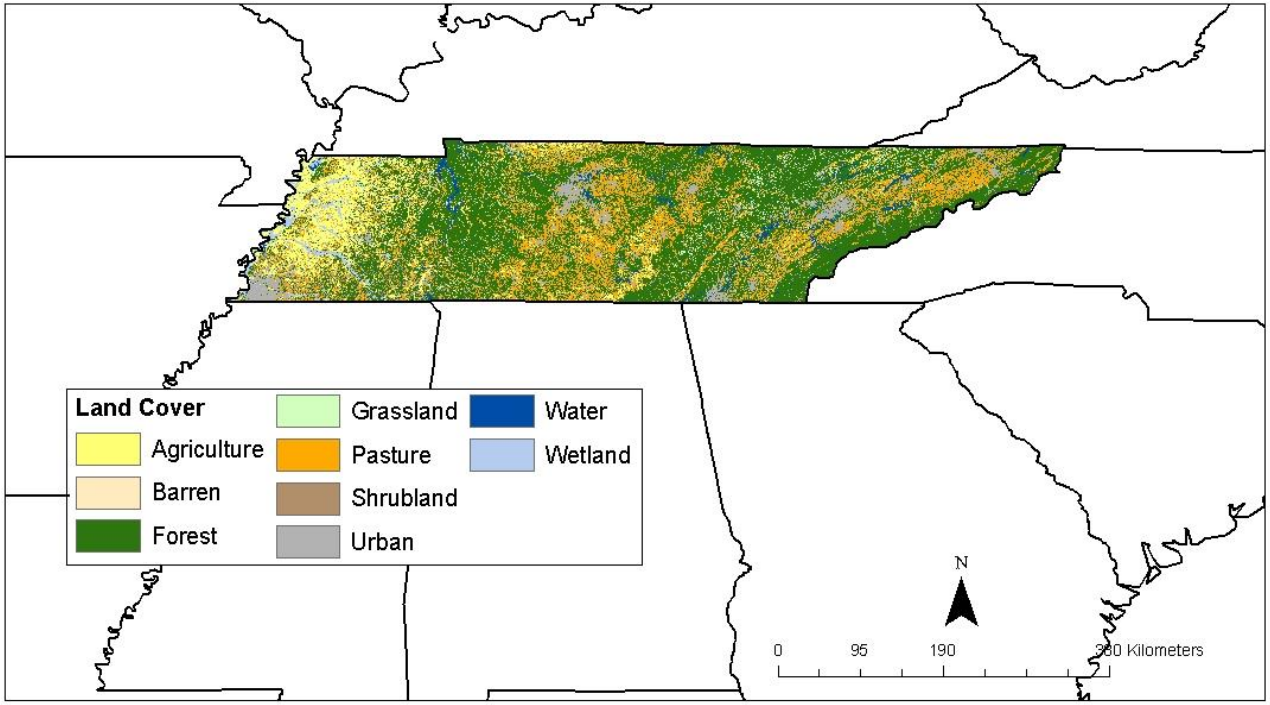
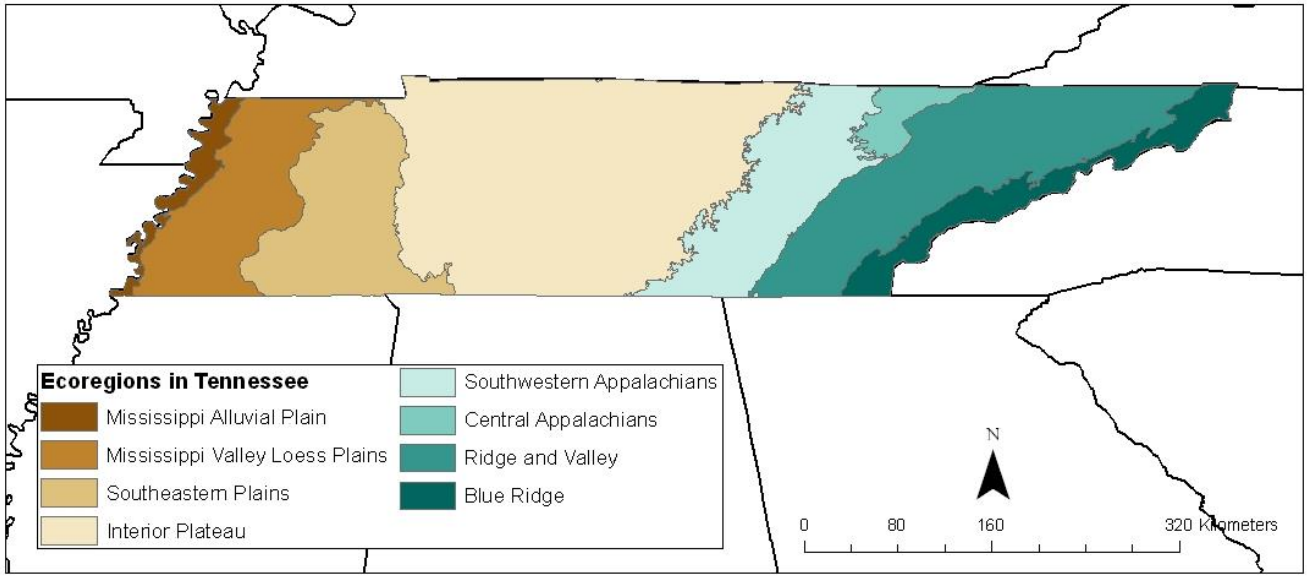
Study Region





Data

- Data from the Tennessee Department of Environment and Conservation (TDEC) for 2007 and 2010
  - Reference streams (unimpaired) and other streams
  - Benthic macroinvertebrate surveys (Total taxa, EPT taxa richness)
  - Nutrient data (Total N, NO_3/NO_2, Total P, Sediment)
  - Stream habitat characteristics (epifaunal substrate, sediment deposition etc.)
- Other sources of Data:
  - Cropland Data Layer (CDL), STATSGO Soils, USGS geology data, National Elevation Dataset, NHD plus data

EPT taxa richness by ecoregion

- Ecoregion – regions differentiated by biotic and abiotic phenomena that affect or reflect differences in ecosystem quality
- Reference streams – least impacted streams representative of different ecoregions
- Analyze the EPT taxa richness across reference streams by ecoregion
  - Based on the Kruskal-Wallis test, the EPT taxa richness values across ecoregions were found to be significantly different at a 0.001 level.
- Statistical analyses to test significance of differences among reference and non-reference streams

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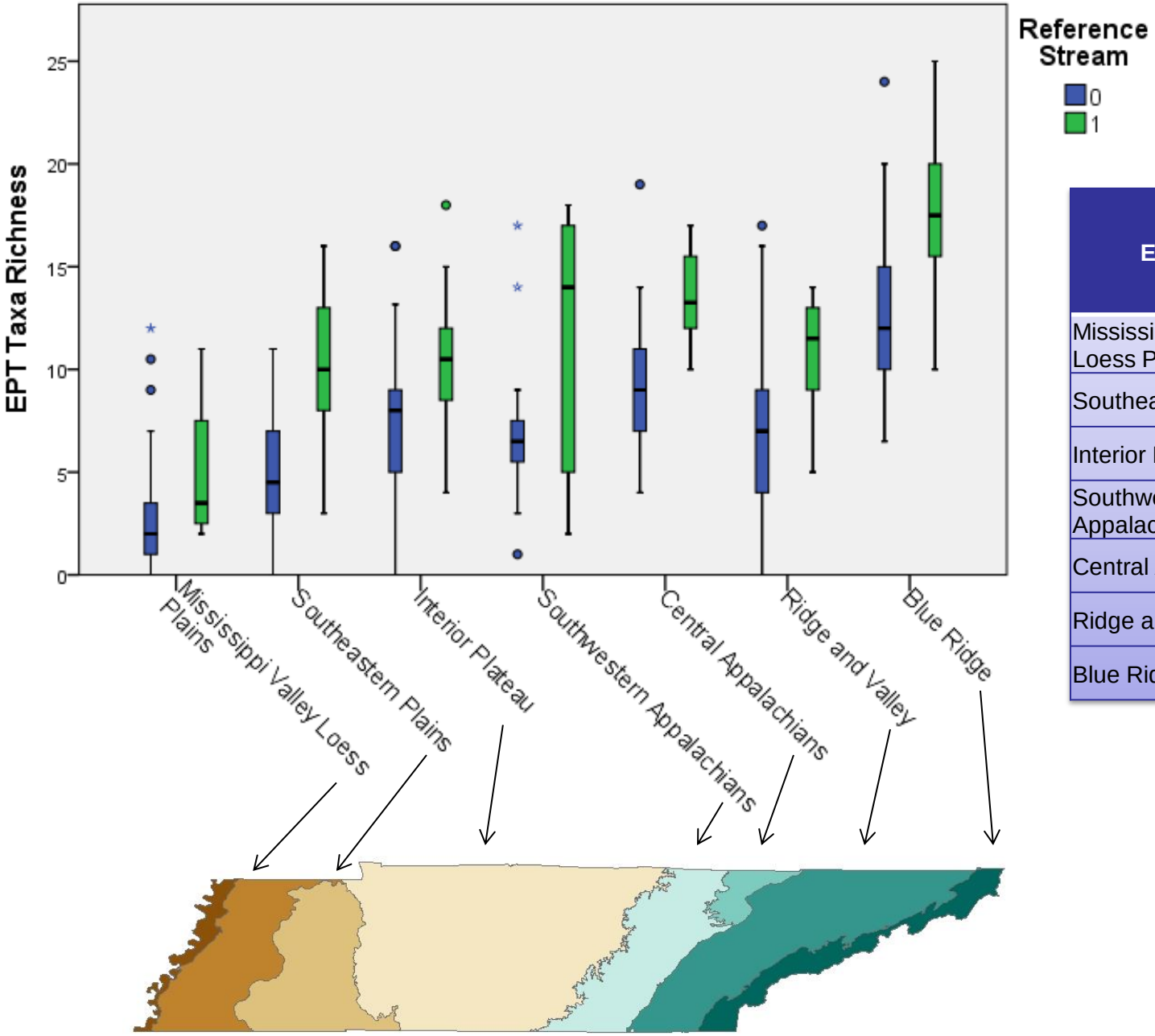
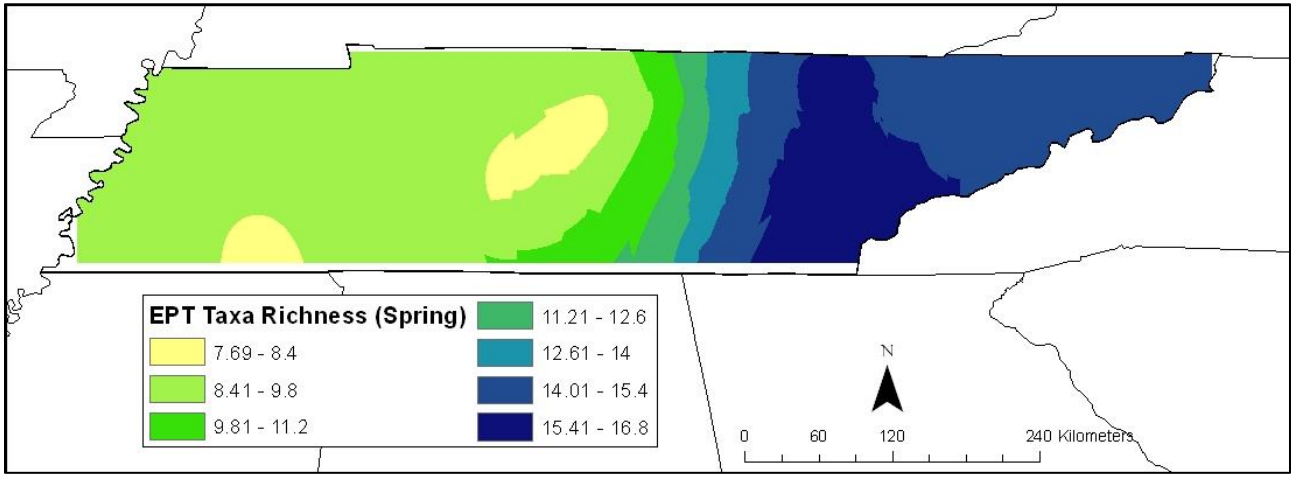
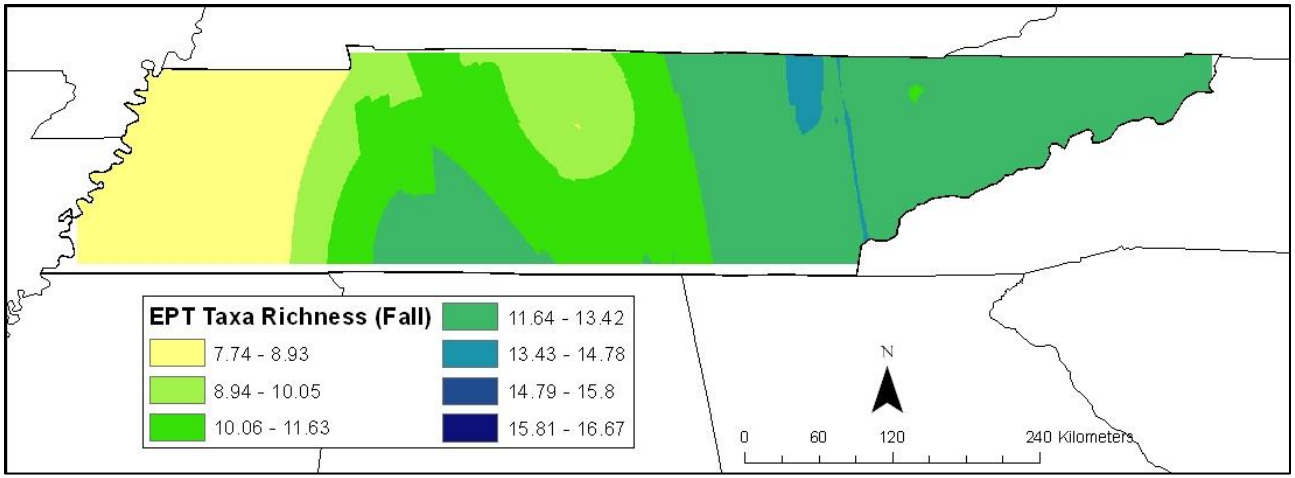


Ecoregion	t-test	p
Mississippi Valley Loess Plains	-1.46	0.151
Southeastern Plains*	-6.08	0
Interior Plateau*	-4.8	0
Southwestern Appalachians	-1.584	0.162
Central Appalachians*	-3.87	0
Ridge and Valley*	-5.04	0
Blue Ridge*	-4.02	0


EPT Taxa Richness (Spring)
7.69 - 8.4
8.41 - 9.8
9.81 - 11.2
11.21 - 12.6
12.61 - 14
14.01 - 15.4
15.41 - 16.8
N
0
60
120
240 Kilometers


EPT Taxa Richness (Fall)
7.74 - 8.93
8.94 - 10.05
10.06 - 11.63
11.64 - 13.42
13.43 - 14.78
14.79 - 15.8
15.81 - 16.67
N
0
60
120
240 Kilometers

Test the correlation between EPT taxa richness and environmental variables

- Climate
  - Temperature and Precipitation (PRISM)
- Soil
  - % of sand and silt (STATSGO)
  - Depth to bed rock (STATSGO)
- Terrain
  - Slope (National Elevation Dataset)
- Stream characteristics
  - Stream flow and velocity (NHD+)
  - Stream order

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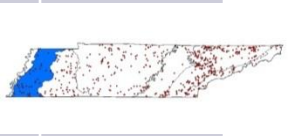
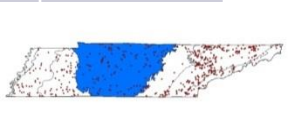
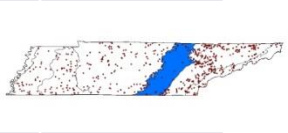
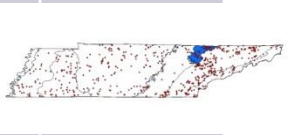
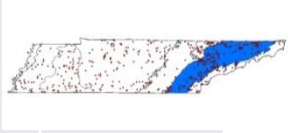
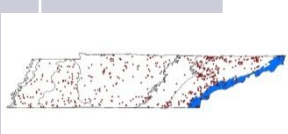
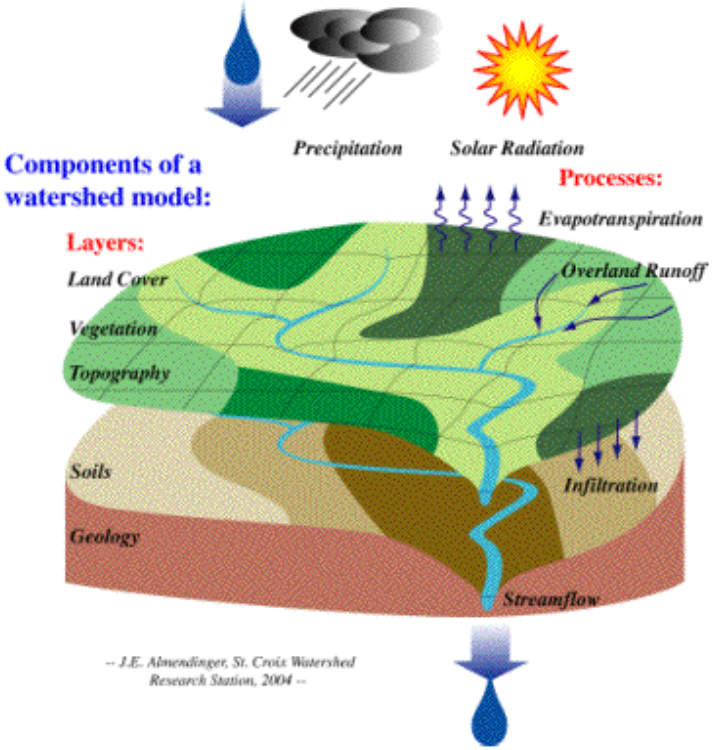
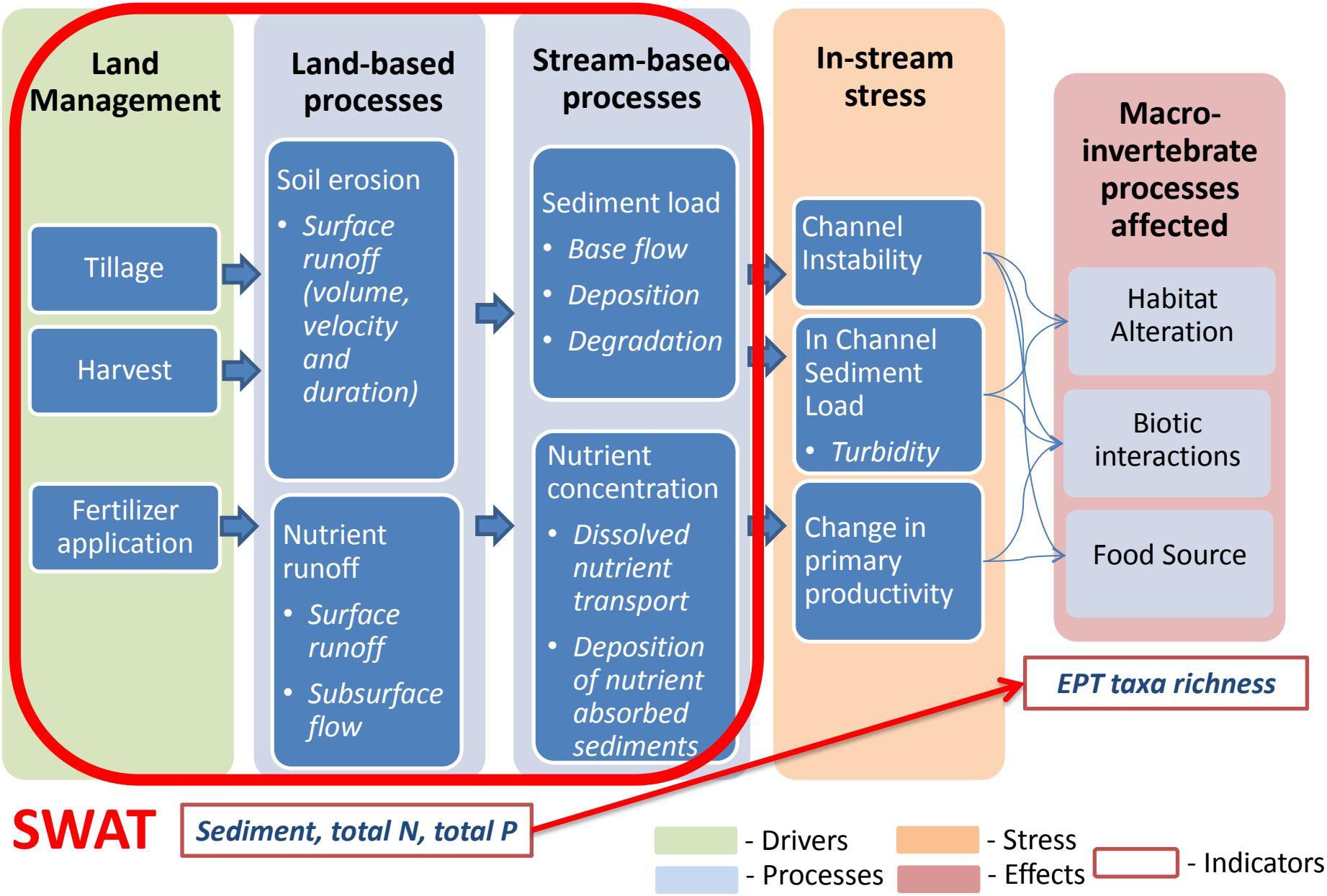
Ecoregion	Stream Flow	Velocity	Temp	Precip	Slope	Stream order	% Silt	Rock depth	
Mississippi Valley Loess Plains	*	*		*		*			
Southeastern Plains		*		*					
Interior Plateau	*	*			*	*	*	*	
Southwestern Appalachians		*							
Central Appalachians			*	*					
Ridge and Valley	*	*	*		*	*			
Blue Ridge	*		*		*	*			

Bioenergy-based land-use changes: watershed scale

- Hydrological model analysis carried out at selected watersheds
- Soil and Water Assessment Tool (SWAT)
  - Watershed scale model to simulate effects of land management on water, sediment, and agricultural chemical yields
  - Land component and stream component, crop growth module
  - Output includes stream flow, nitrates, nitrites, organic N, mineral P, organic P, sediments etc.




Land Management
Tillage
Harvest
Fertilizer application
Land-based processes
Soil erosion
• Surface runoff (volume, velocity and duration)
Nutrient runoff
• Surface runoff
• Subsurface flow
Stream-based processes
Sediment load
• Base flow
• Deposition
• Degradation
Nutrient concentration
• Dissolved nutrient transport
• Deposition of nutrient absorbed sediments
In-stream stress
Channel Instability
In Channel Sediment Load
• Turbidity
Change in primary productivity
Macro-invertebrate processes affected
Habitat Alteration
Biotic interactions
Food Source
EPT taxa richness
SWAT
Sediment, total N, total P
- Drivers
- Processes
- Stress
- Effects
- Indicators

Applying regional results to watersheds

- Customize SWAT model to ecoregion and by factors affecting macroinvertebrates
  - Model setup
    - e.g., in regions with slope as a significant variable, delineate hrus by multiple slope categories
  - Calibration
    - e.g, in regions with stream flow as a significant variable, during calibration stream flow is the first objective function being calibrated for
  - Analysis of output
    - e.g., in regions where soil variables are significant, identify the spatial distribution of soil-related parameters and interpret output at appropriate scale

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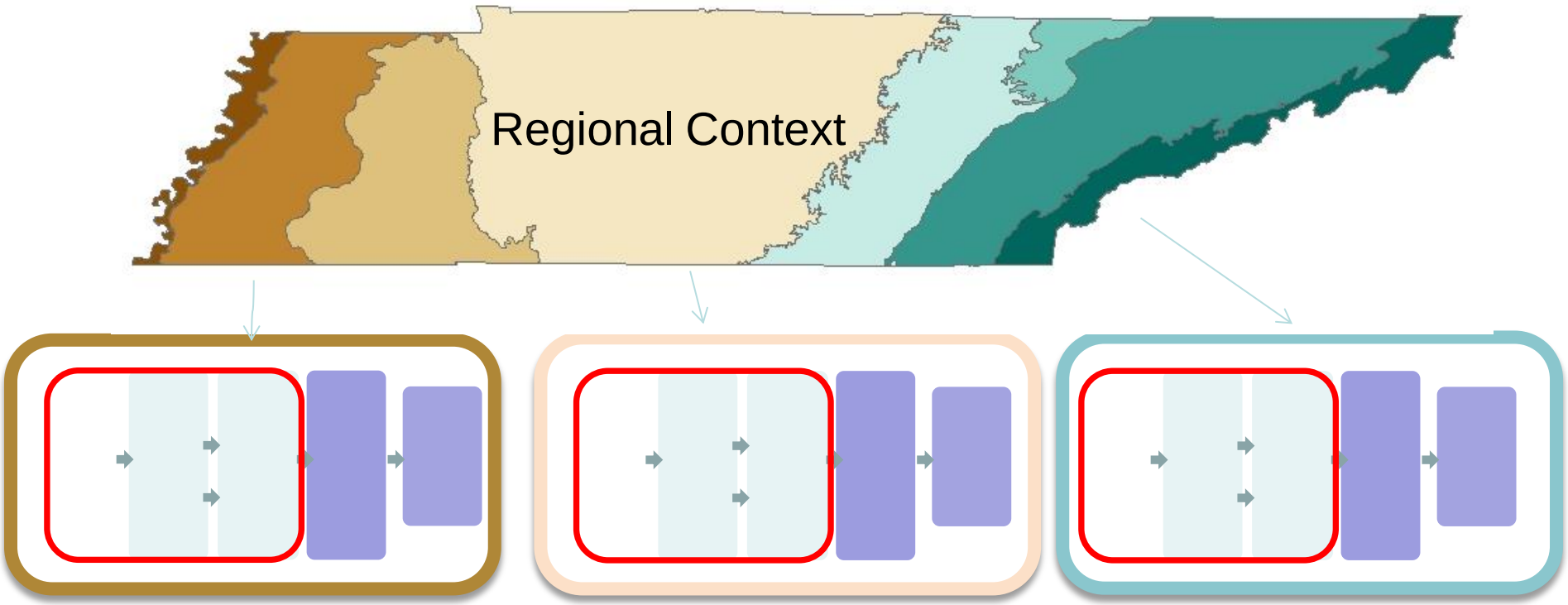
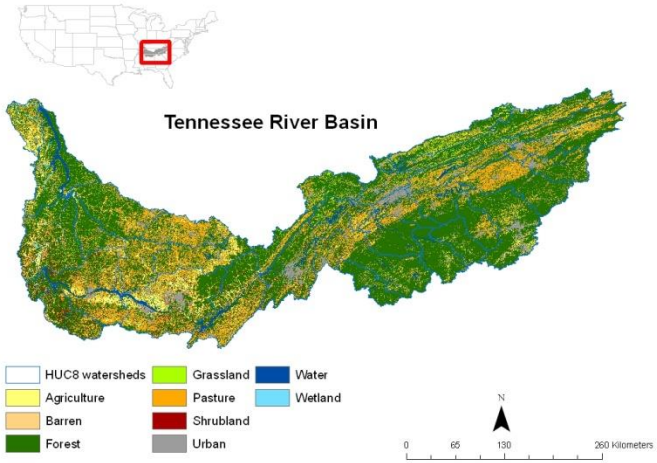
Regional-scale interactions set the context for stream-level effects



Differences in macroinvertebrate distribution and the factors that affect them vary by ecoregion. The responses to land-use changes are also expected to be dependent on the geomorphological context and hence vary by ecoregion

Next Steps

- Under the defined regional settings, evaluate if EPT taxa richness measures are good indicators of changes in water quality due to switchgrass-based land use changes
- SWAT model for the Tennessee River Basin
  - Spatial distribution of changes in water quality



Thank you!

Collaborators:
Dr. Virginia Dale [1]
Dr. Yetta Jager [1]
Dr. Liem Tran [2]

[1] Oak Ridge National Laboratory
[2] University of Tennessee