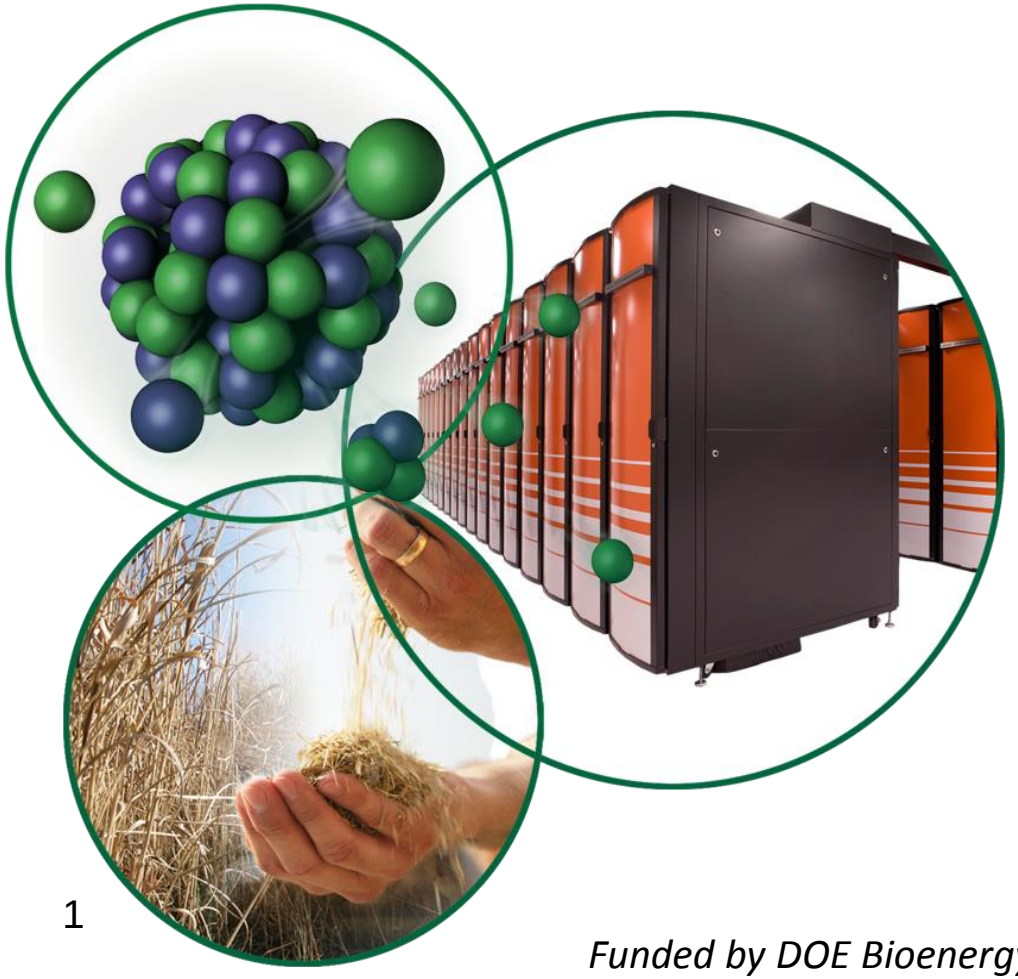
Aquatic Macroinvertebrates for Assessing Water Quality Effects associated with Bioenergy



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Center for Bioenergy sustainability

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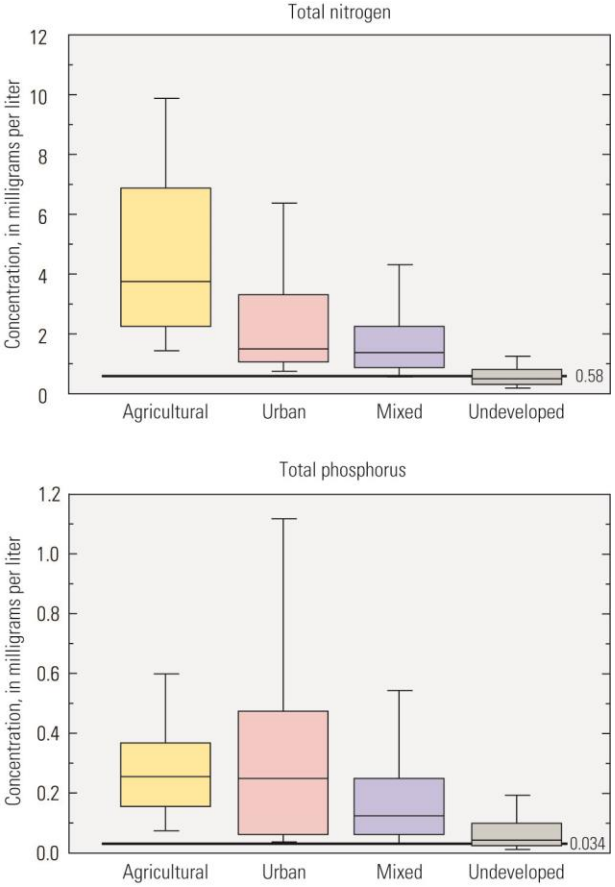
Energy crops in an agricultural landscape

- Agricultural land uses are leading causes for stream impairment
  - Nutrient enrichment, habitat degradation, hydrologic alteration, and loss of biotic integrity
- With bioenergy futures there can be changes to the agricultural landscape
- 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)
- Possible land-use changes and environmental implications need to be monitored



Source - Dubrowsky et al. 2010 (http://water.usgs.gov/nawqa/nutrients/pubs/circ1350)

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

- Previous studies have demonstrated reduced nutrient and sediment loads with bioenergy crops in the landscape (e.g., Jager et al. 2014)
- Water quality and biodiversity are key components to assessing sustainability of the bioenergy system
- Measuring water quality indicators are important, but key indicators can be expensive and time intensive to monitor.

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

Measuring water quality indicators –Aquatic Macroinvertebrates?

- Key component of the food chain
- Sensitive to changes in water quality and ecosystem disturbances
  - Nutrient enrichment, changes in primary production, and dissolved oxygen.
  - Changes in stream habitat (turbidity and stream substrate)
- Limited mobility
- Indicators of stream health (biomonitoring)
- Rapid bioassessment protocols (RBP) can help conduct cost-effective, but scientifically valid procedures for biomonitoring

•Ephemeroptera (mayfly)

•Plecoptera (stonefly)

•Trichoptera (caddisfly)

Source for images – www.epa.gov

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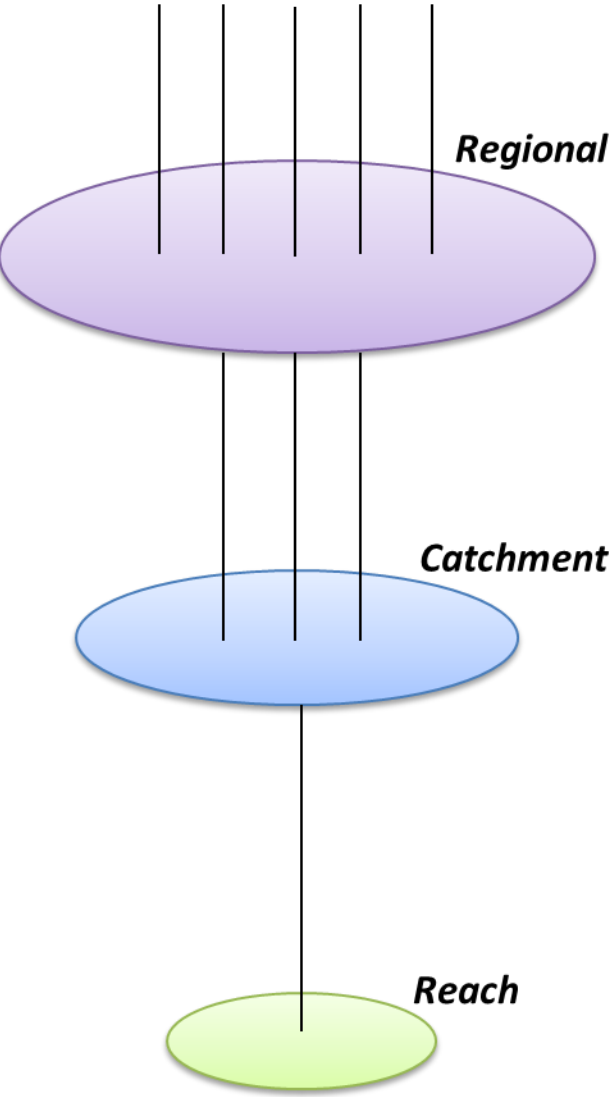
Modeling aquatic macroinvertebrate and land-use interactions

- Invertebrate metrics have strong correlations to nutrients and agricultural disturbance, but that the strength varies regionally (e.g., Waite 2013)
- 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
- EPT taxa richness (taxa in Ephemeroptera, Plecoptera and Trichoptera orders) is a standard indicator that is sensitive to environmental perturbations
    - Mostly intolerant to changes in water quality and sediment (e.g., Lenat 1988)



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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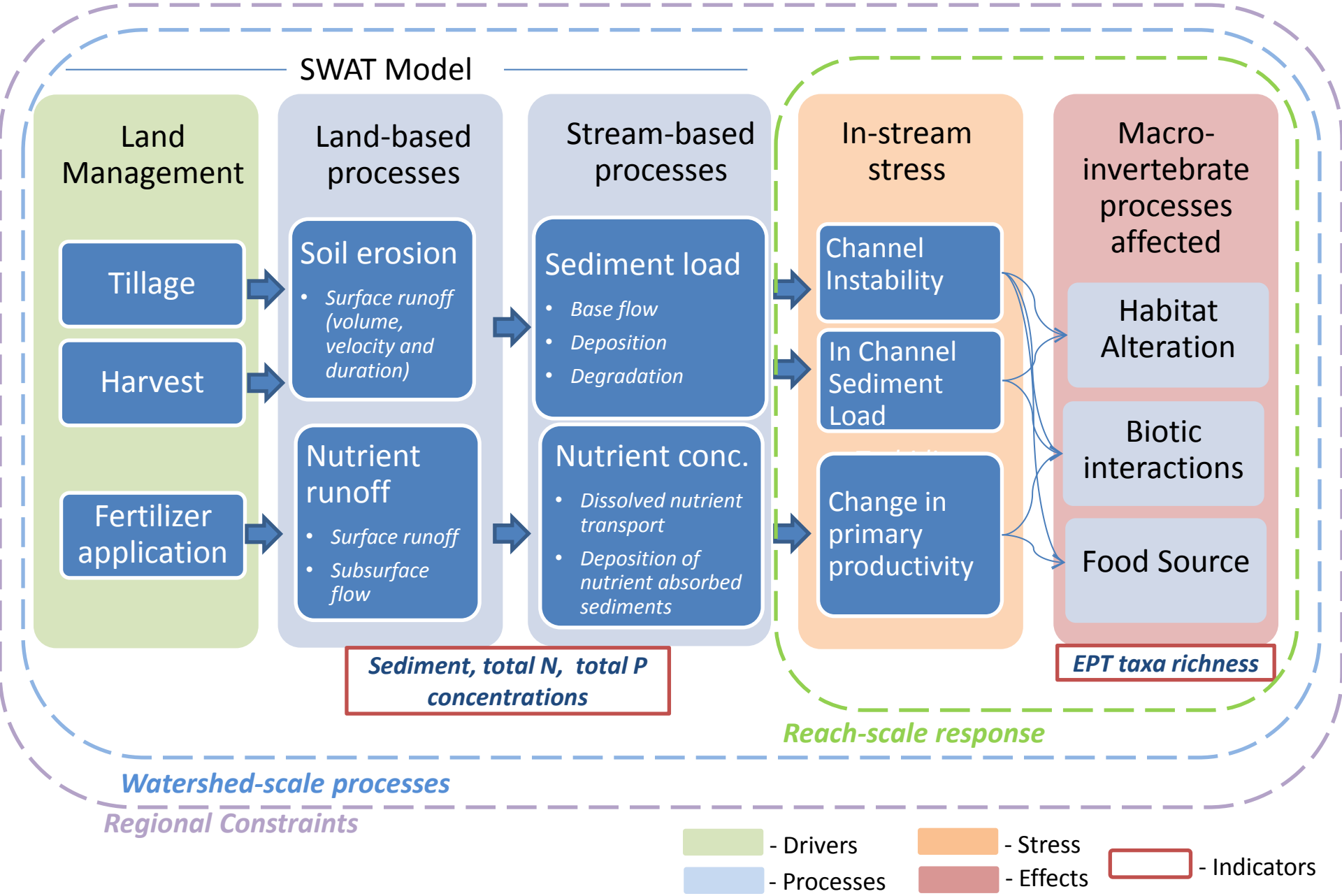
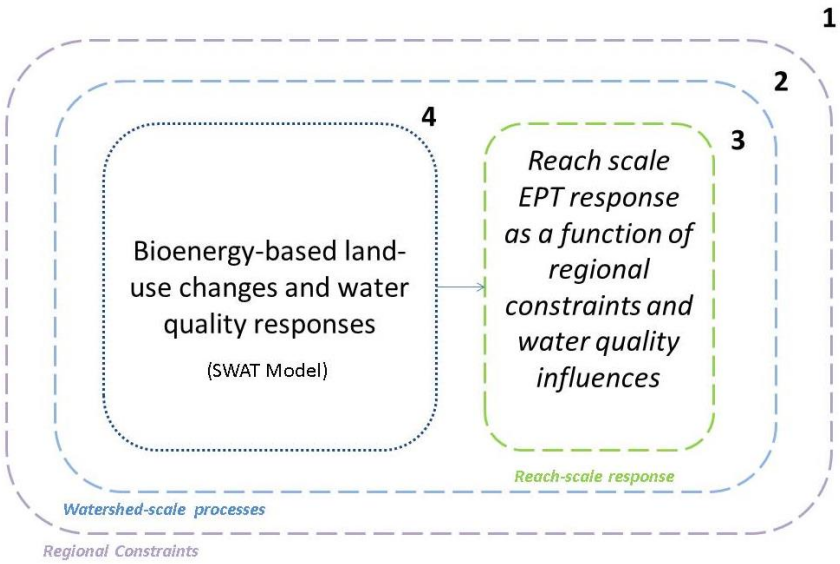
Research Framework



Methods

- Establish regional setting
  - 1. Identify appropriate ecoregion classification
  - 2. Model regional constraints
- Model water quality influences within regional setting
  - 3. Model effects of water quality variables after accounting for regional variables
  - 4. Model water quality effects of bioenergy-based land-use changes using SWAT
- Assess model validity



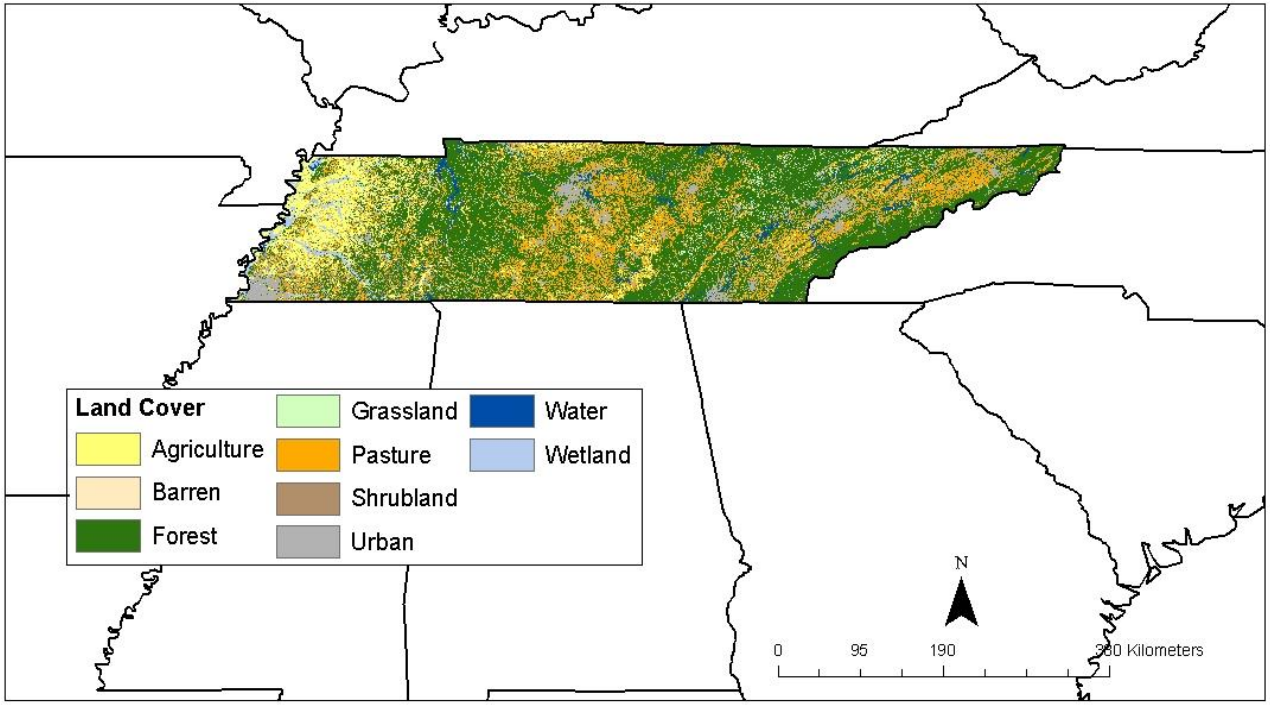
1: Identify appropriate ecoregion classification

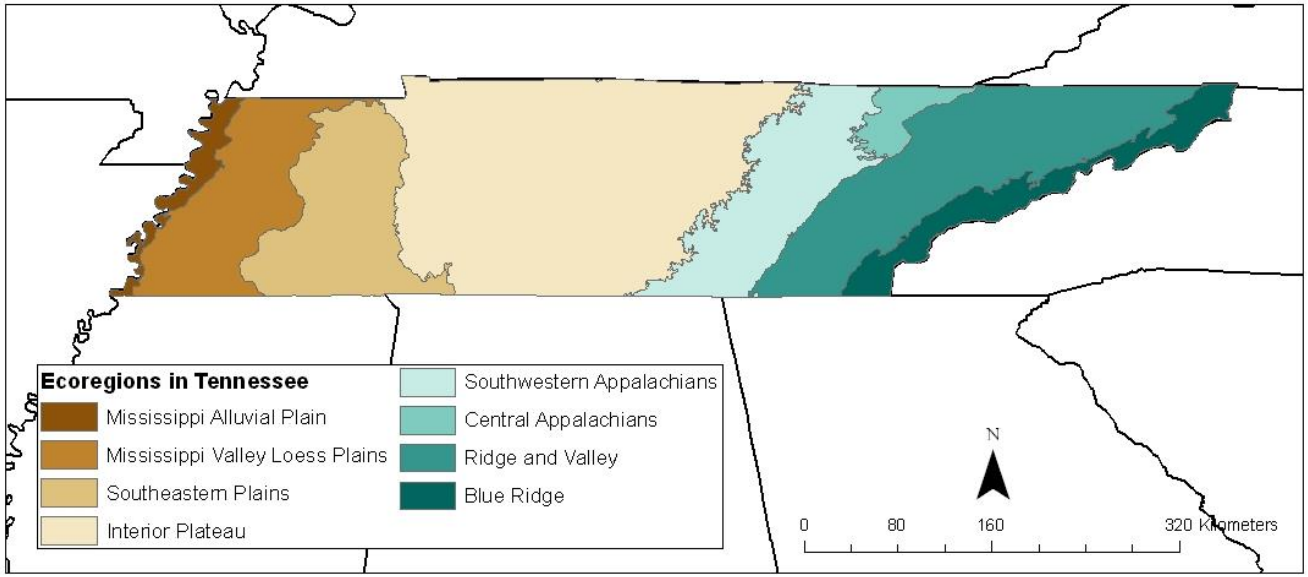
2: Model regional constraints

3: Model water quality influences within regional constraints

4: Model water quality influences of bioenergy-based land-use changes at selected watersheds

Study Region

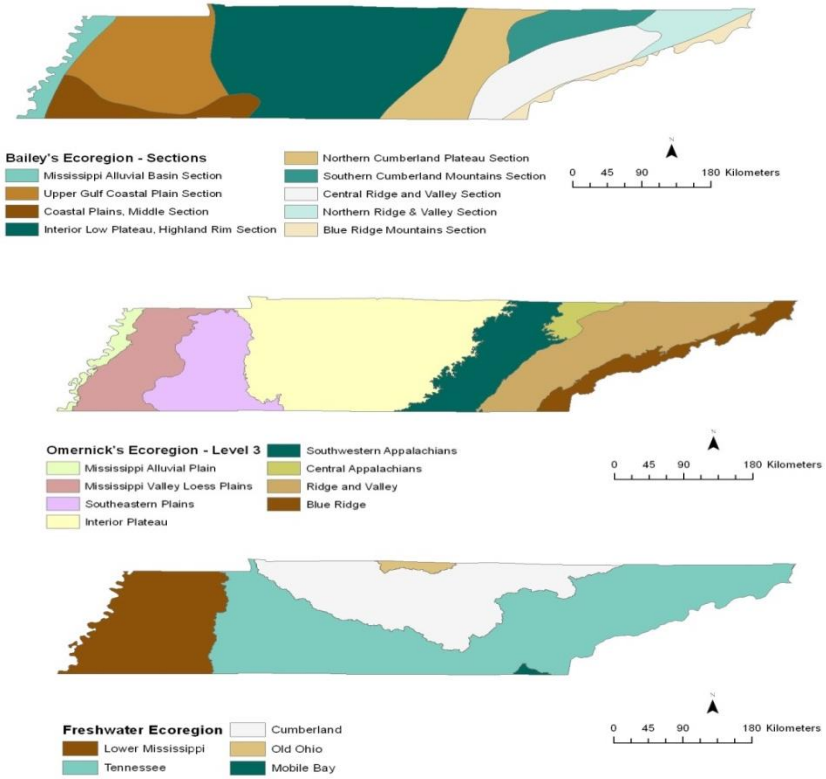




Data

- 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

Establishing the regional setting

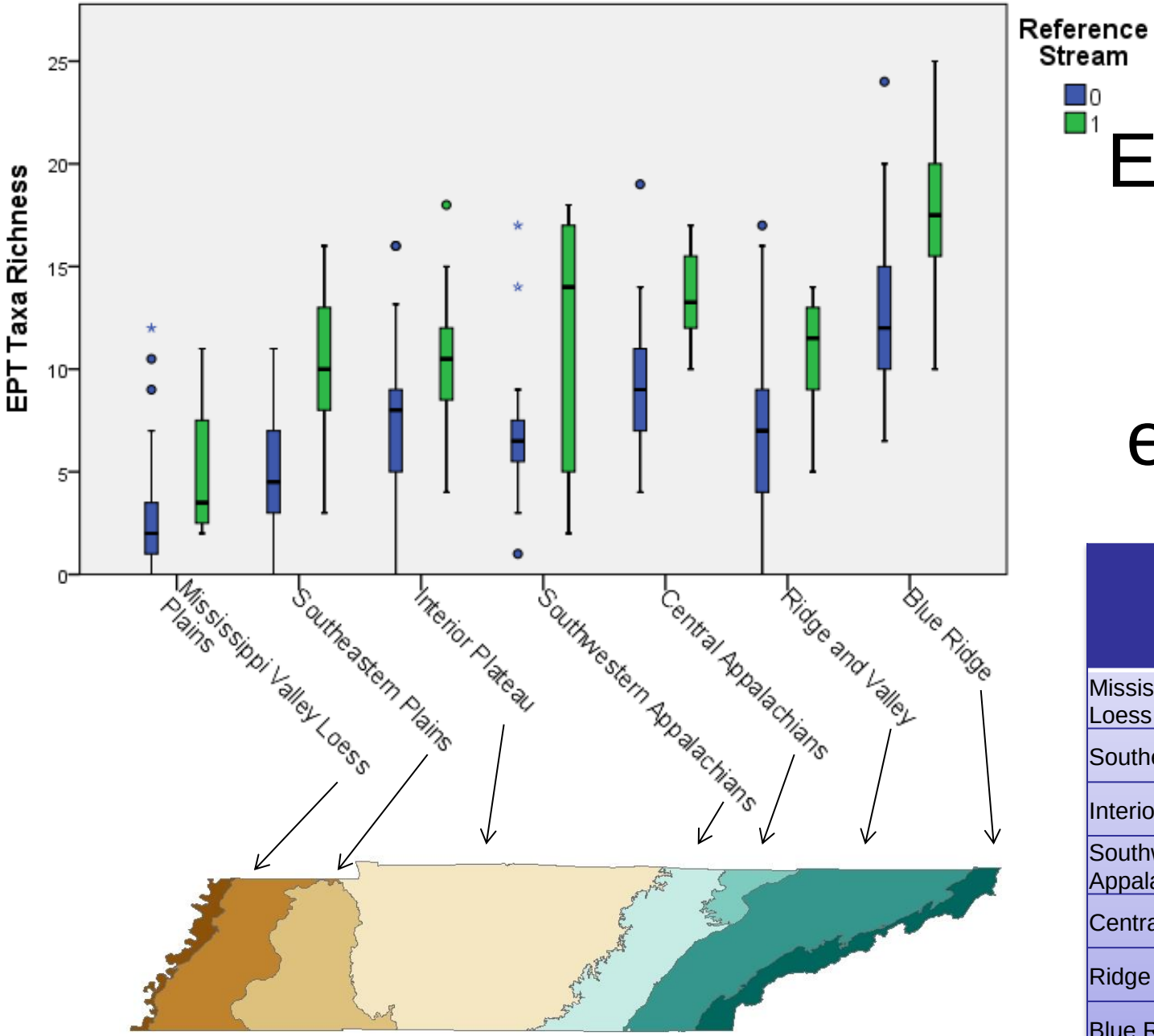


Ecoregion – regions differentiated by biotic and abiotic phenomena that affect or reflect differences in ecosystem quality

Ecoregion classifications and the proportion of pair-wise classes distinguished across various regional variables.

Ecoregion Classification	Temp	Precip	Rock Depth	% Sand	% Silt	% Clay	Slope	Stream Flow	Velocity	Stream order	Sum
Omernick's	0.61	0.39	0.50	0.50	0.36	0.32	0.43	0.14	0.50	0.75	3.00
Bailey's	0.67	0.49	0.56	0.07	0.18	0.31	0.22	0.13	0.29	0.60	1.80
Freshwater	0.67		0.50	0.17	0.33	0.50	0.33	0.33	0.50	0.75	2.92

EPT taxa richness by ecoregion



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

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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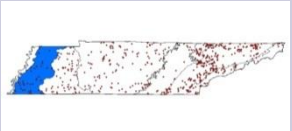
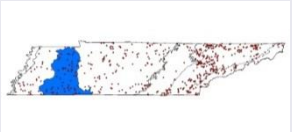
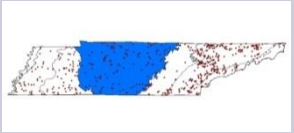
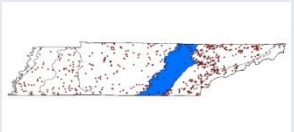
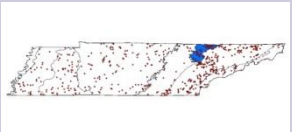
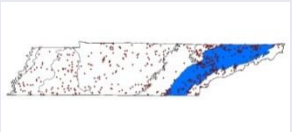
Correlation of EPT taxa richness with regional variables by Omernick's ecoregion classification

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

Modeling water quality influences within regional setting

- Identify significant regional parameters for each ecoregion
- Model EPT taxa richness with significant parameters and extract residuals
- Correlate residuals with water quality variables
- Significance of variables varied by ecoregion

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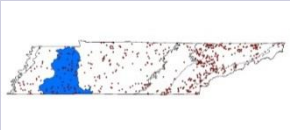
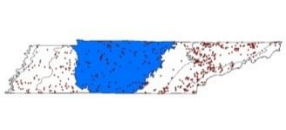
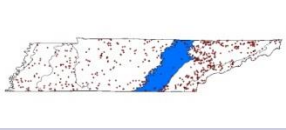
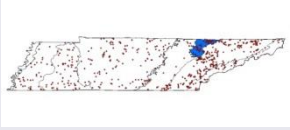
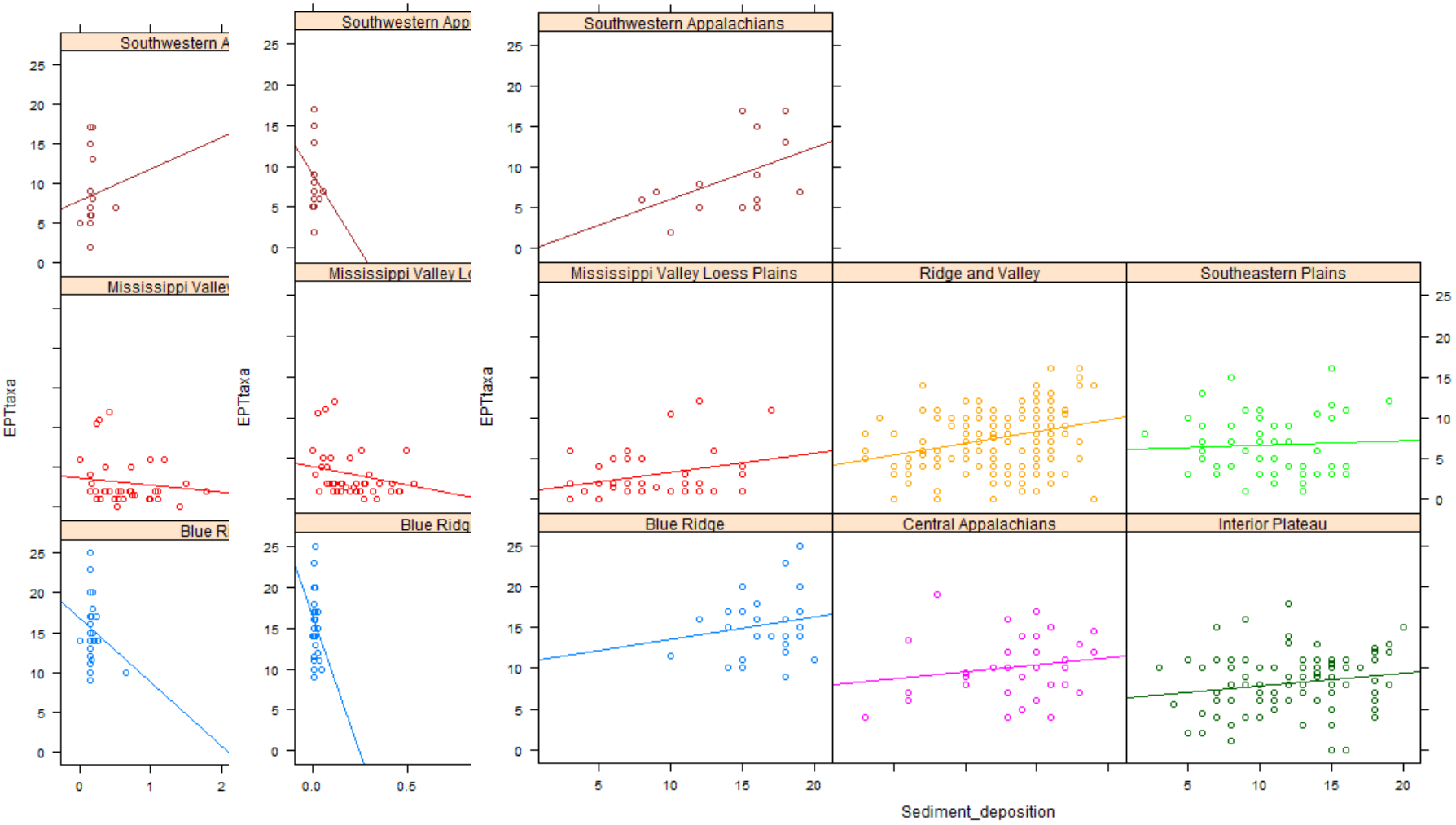
Ecoregion	R^2	Correlation of residuals with water quality variables					Map
		Total N	Total P	Ammonia	NO2	Sediment	
Mississippi Valley Loess Plains	0.536		*				
Southeastern Plains	0.336	*		*			
Interior Plateau	0.202			*		*	
Southwestern Appalachians	0.27					*	
Central Appalachians	0.222		*	*	*		
Ridge and Valley	0.283	*	*	*	*	*	
Blue Ridge	0.254						

Previous analysis was useful, but did not account for regional factors to predict EPT taxa richness

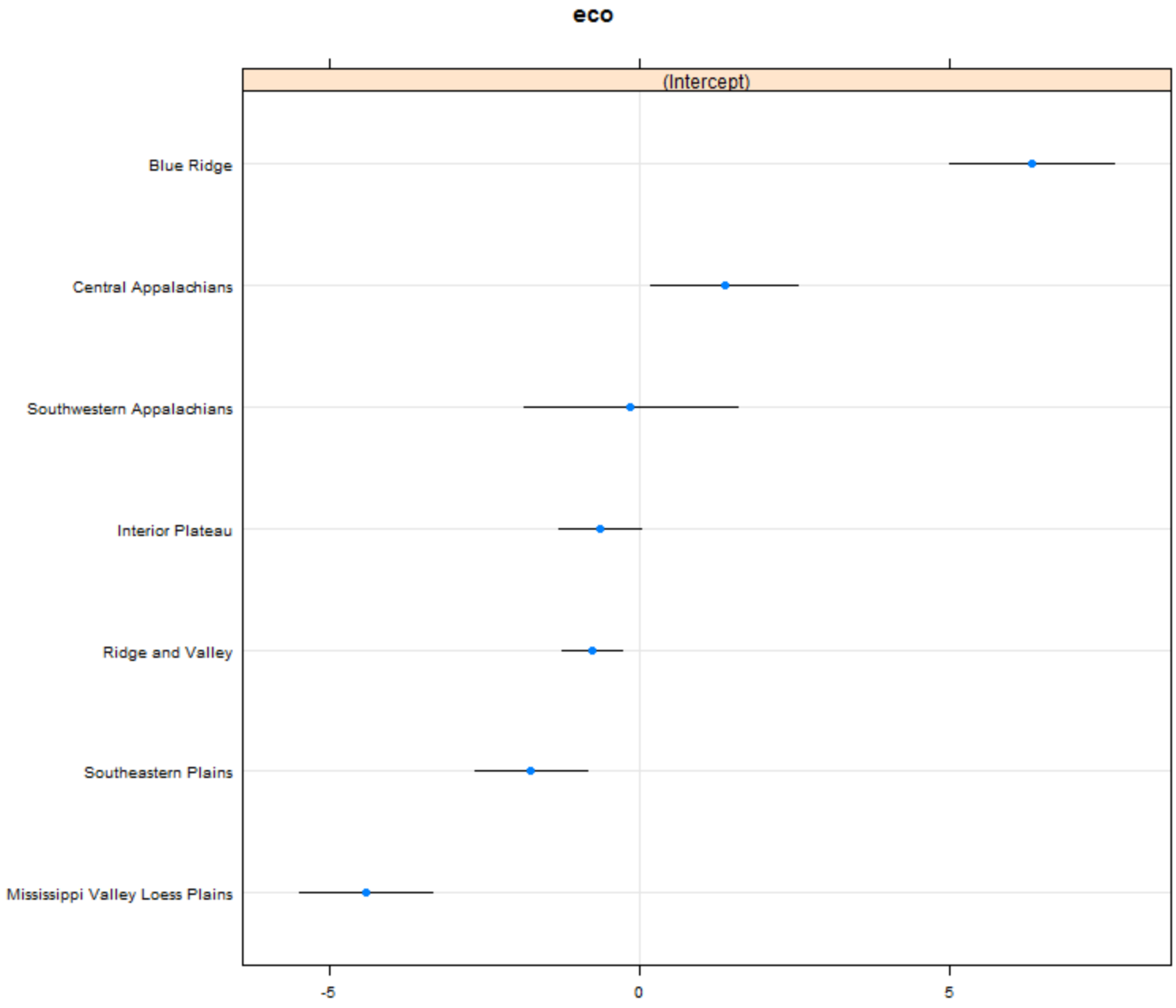


Multilevel modeling

- Accounts for ‘fixed’ and ‘random’ effects
- Can construct hierarchical models or models with cross scale interactions
- `EPTtaxa ~ TotKN + Sediment + (1+Sediment_deposition|eco) + (1+TotKN | eco)`

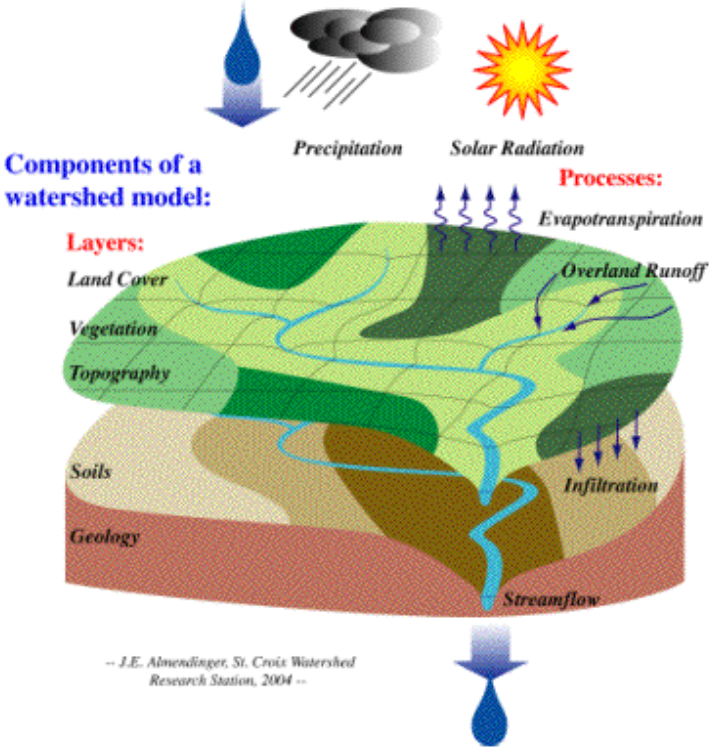
```
Fixed effects:    Estimate        Std. Error      df       t value  Pr(>|t|)
(Intercept)       6.16321         1.28793         9.70     4.785    0.000812 ***
TotKN             -2.51856        0.65144         4.800    -3.866   0.012863 *
Sediment           0.22795        0.04174         466.10   5.461    7.7e-08 *** -
--
```

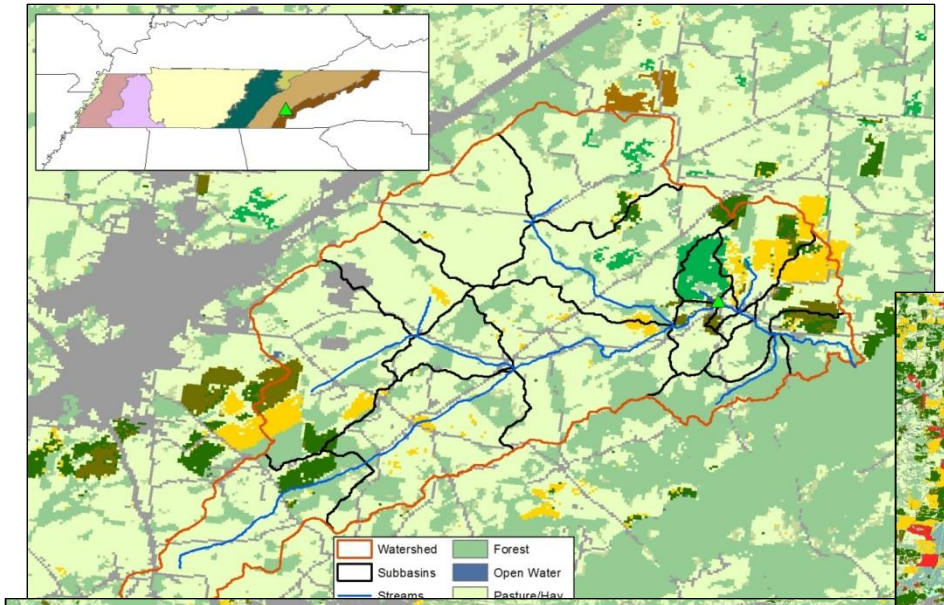
```
(Intercept)            TotKN
Blue Ridge             -5.0845194
Central Appalachians   -3.0983143
Interior Plateau       -2.3069090
Mississippi Valley LP  -0.5750651
Ridge and Valley       -2.2256160
Southeastern Plains    -1.9886936
Southwestern Appal      -2.3507996
```

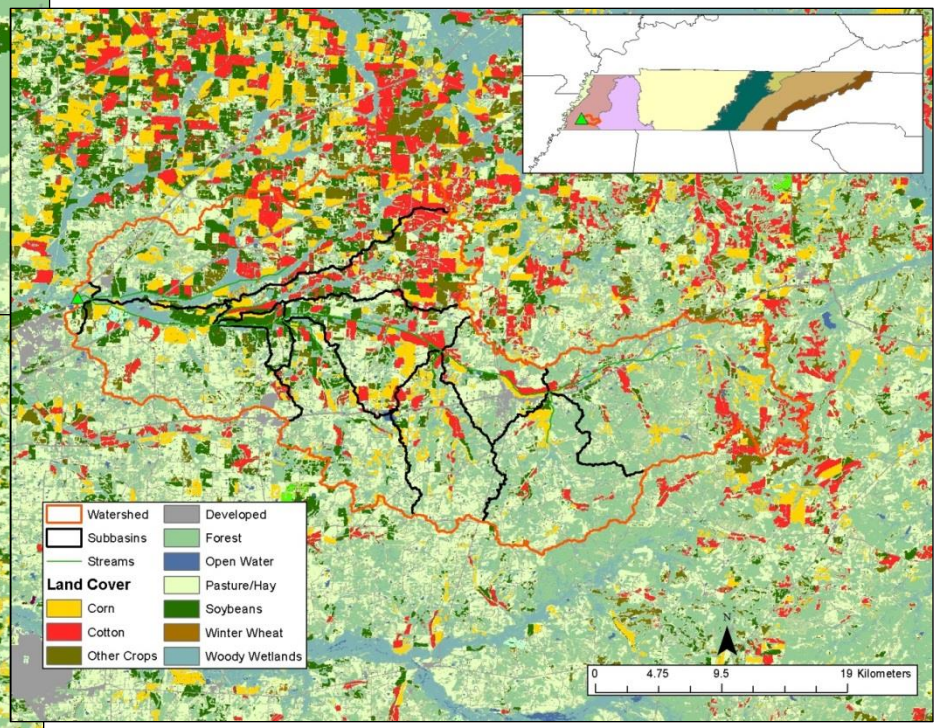

eco
(Intercept)
Blue Ridge
Central Appalachians
Southwestern Appalachians
Interior Plateau
Ridge and Valley
Southeastern Plains
Mississippi Valley Loess Plains
-5
0
5

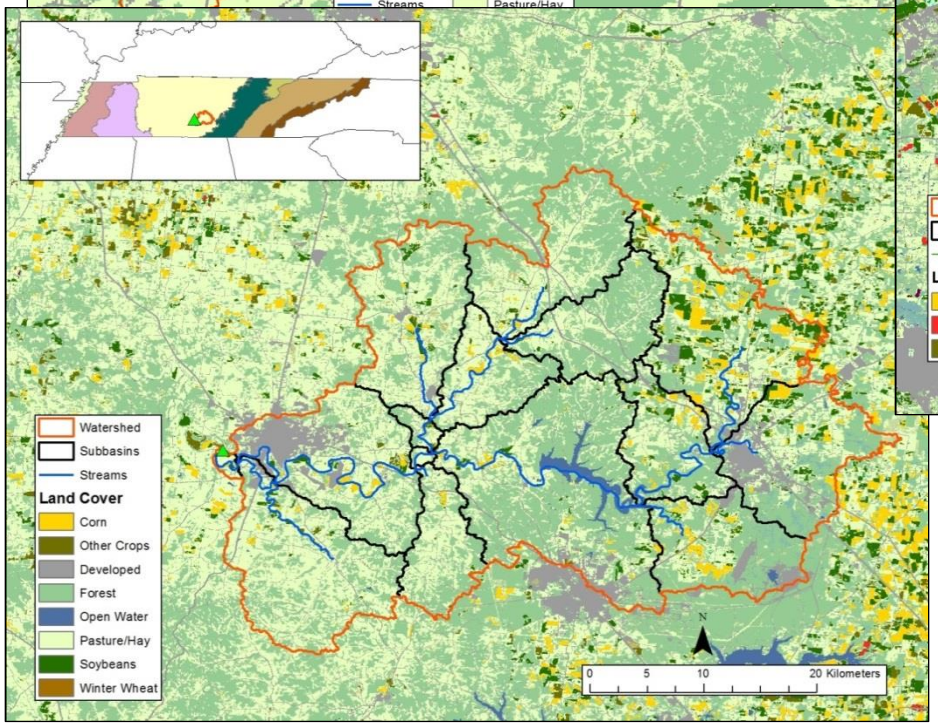
Bioenergy-based land-use changes: watershed scale

- 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.




Watershed
Subbasins
Streams
Forest
Open Water
Pasture/Hay


Watershed
Subbasins
Streams
Land Cover
Corn
Cotton
Other Crops
Developed
Forest
Open Water
Pasture/Hay
Soybeans
Winter Wheat
Woody Wetlands
0
4.75
9.5
19 Kilometers


Watershed
Subbasins
Streams
Land Cover
Corn
Other Crops
Developed
Forest
Open Water
Pasture/Hay
Soybeans
Winter Wheat
N
0
5
10
20 Kilometers

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
  - Sensitivity of SWAT model results

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Thank you!

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