EUSE: Effects of Urbanization on Stream Ecosystems

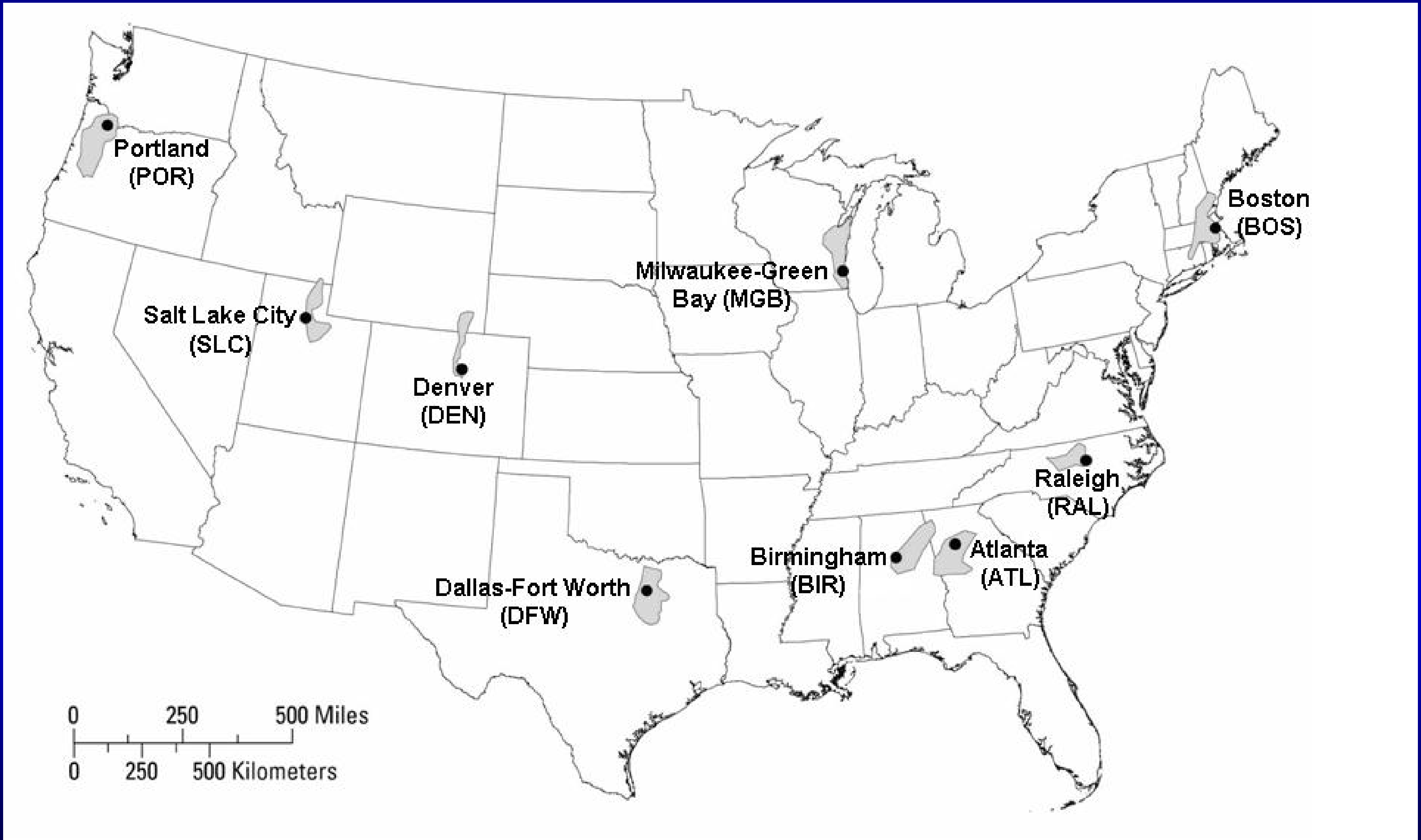
T.F. Cuffney and G. McMahon
U.S. Geological Survey
North Carolina Water Science Center
Raleigh, NC

Effects of Urbanization on Stream Ecosystems (EUSE)

Key study questions

- How do physical, chemical, and biological characteristics of streams respond to urbanization?
- What characteristics of urbanization drive this response?
- How do these responses vary across the country?

EUSE: Nine metropolitan areas



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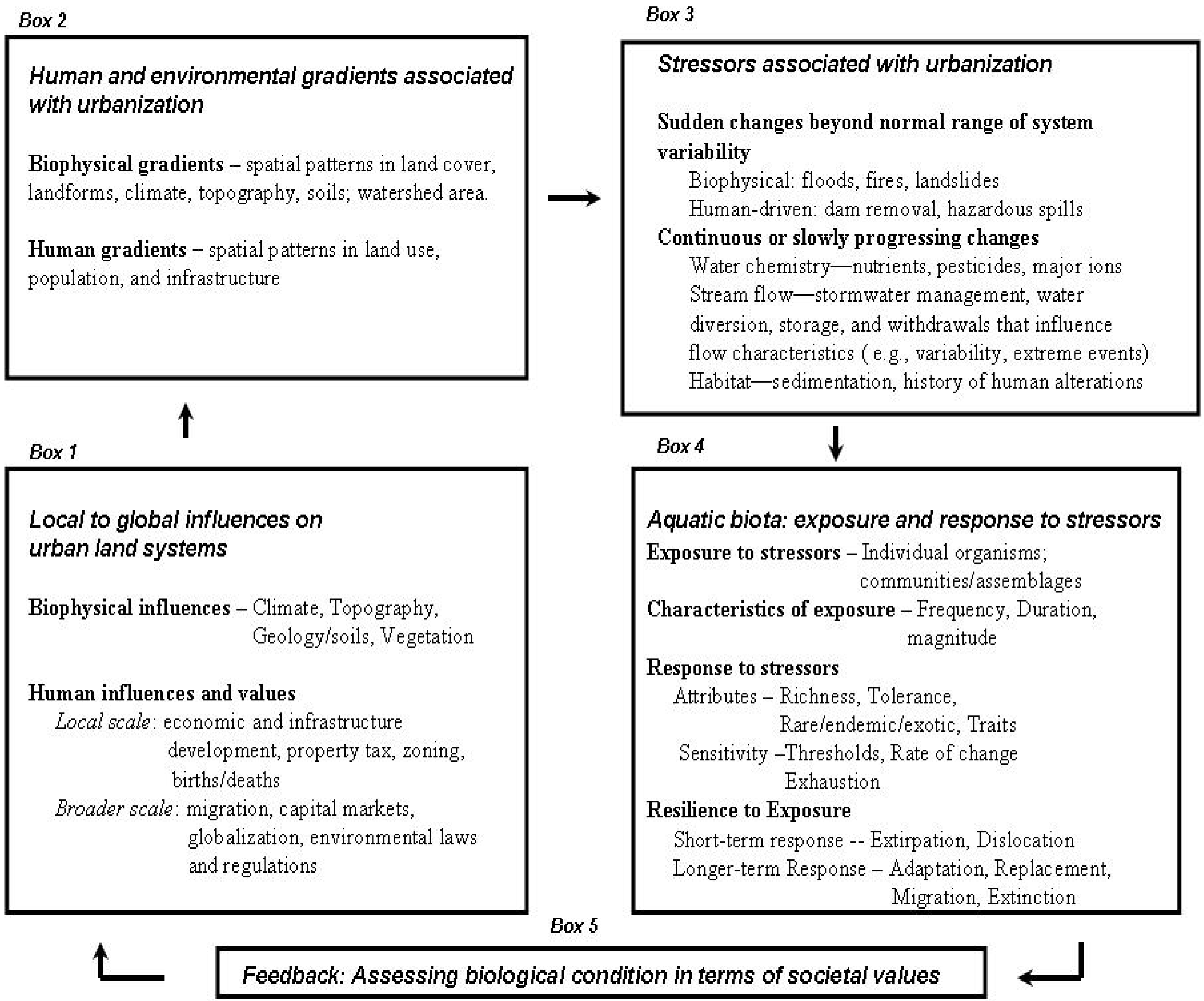
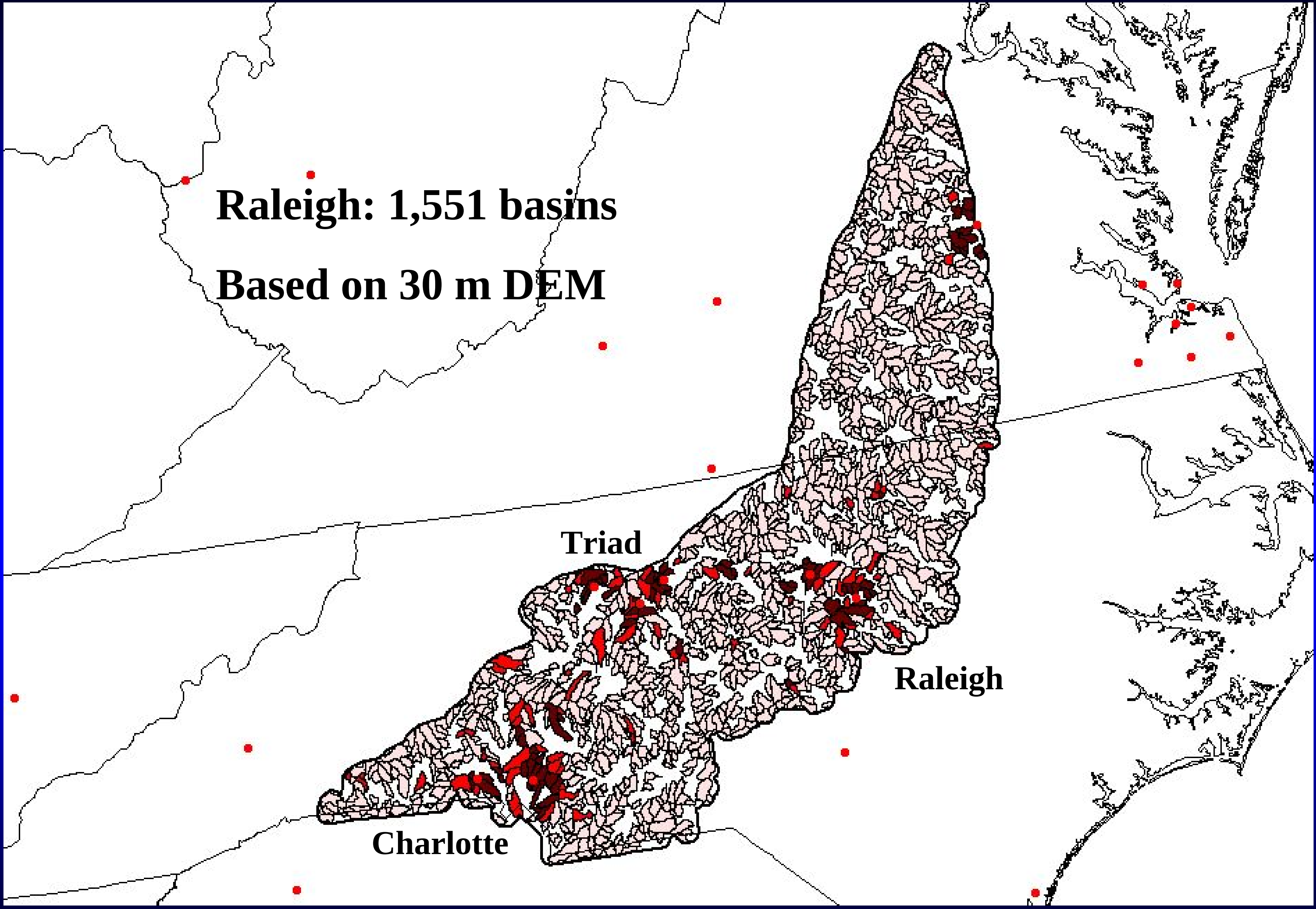

Box 2
Human and environmental gradients associated with urbanization
Biophysical gradients – spatial patterns in land cover, landforms, climate, topography, soils; watershed area.
Human gradients – spatial patterns in land use, population, and infrastructure
Box 3
Stressors associated with urbanization
Sudden changes beyond normal range of system variability
Biophysical: floods, fires, landslides
Human-driven: dam removal, hazardous spills
Continuous or slowly progressing changes
Water chemistry—nutrients, pesticides, major ions
Stream flow—stormwater management, water diversion, storage, and withdrawals that influence flow characteristics (e.g., variability, extreme events)
Habitat—sedimentation, history of human alterations
Box 1
Local to global influences on urban land systems
Biophysical influences – Climate, Topography, Geology/soils, Vegetation
Human influences and values
Local scale: economic and infrastructure development, property tax, zoning, births/deaths
Broader scale: migration, capital markets, globalization, environmental laws and regulations
Box 4
Aquatic biota: exposure and response to stressors
Exposure to stressors – Individual organisms; communities/assemblages
Characteristics of exposure – Frequency, Duration, magnitude
Response to stressors
Attributes – Richness, Tolerance, Rare/endemic/exotic, Traits
Sensitivity –Thresholds, Rate of change Exhaustion
Resilience to Exposure
Short-term response -- Extirpation, Dislocation
Longer-term Response – Adaptation, Replacement, Migration, Extinction
Box 5
Feedback: Assessing biological condition in terms of societal values

Study design

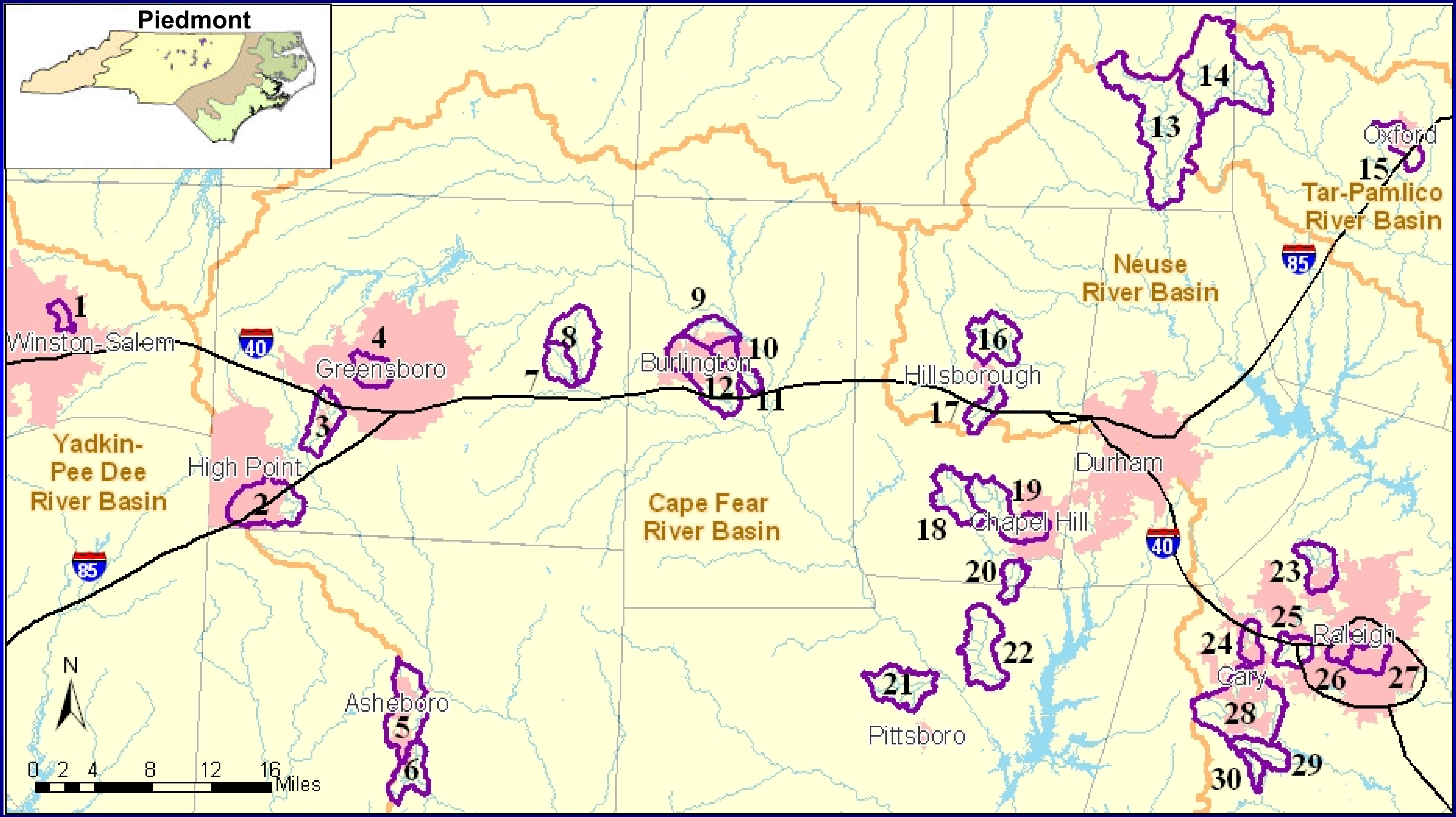
- **Define a population of basins of similar size (2-3 order) within a study area (Piedmont of NC).**
- **Divide basins into groups with similar natural environmental features (environmental setting).**
- **Calculate urban intensity index for each candidate basin.**
- **Select 30 sites to obtain a representation of the gradient of urban intensity within as homogenous a natural environmental setting as possible.**

Raleigh: 1,551 basins

Based on 30 m DEM



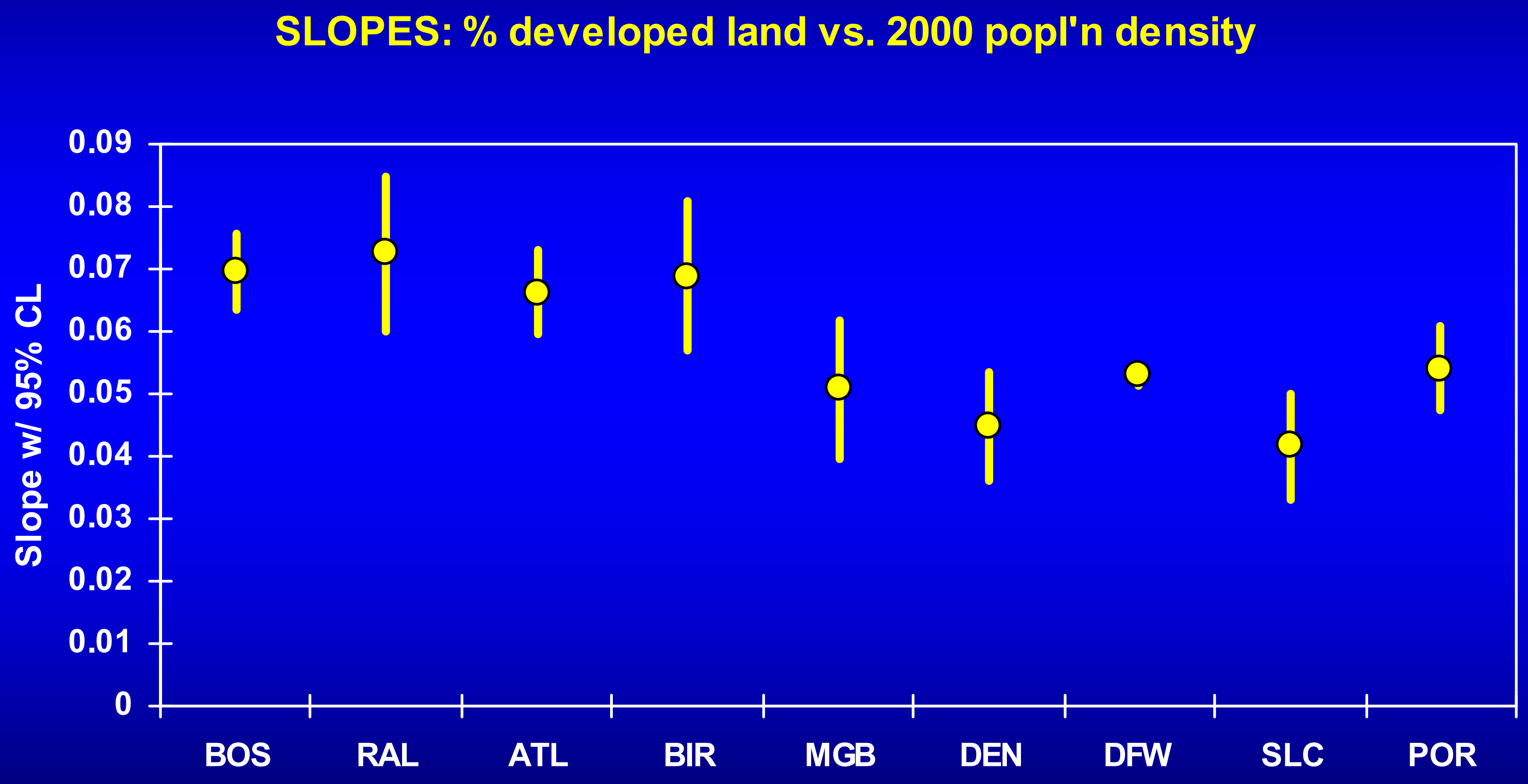
Raleigh Urban Study Area



Urban intensity index

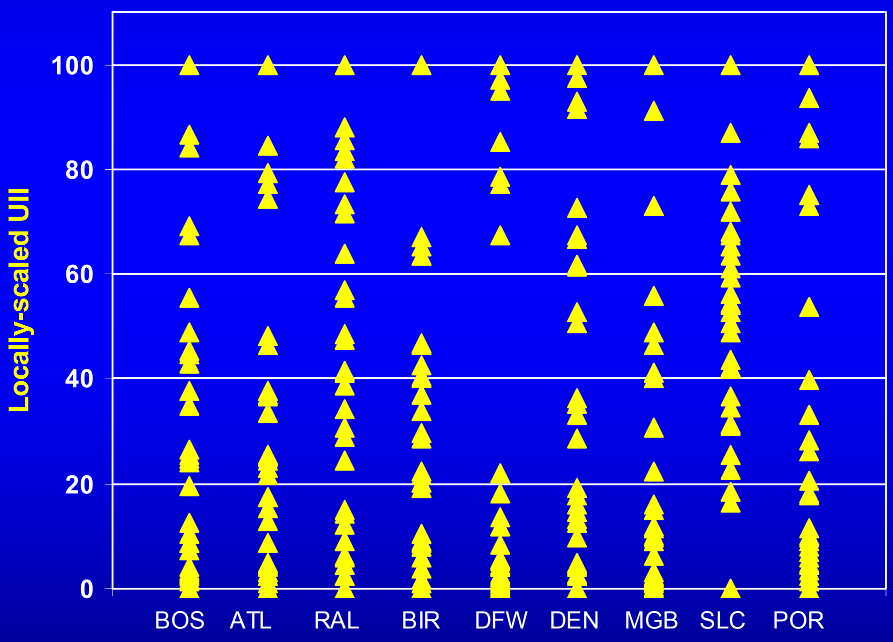
- 3-Variables in index:
  - Housing Unit Density: Census variable
  - % Developed Lands: Land cover variable
  - Road Density: Infrastructure
- Two indices with different scaling….
  - Metropolitan area national urban intensity index (MA-NUII): scaled 0-100 for each metropolitan area.
  - National urban intensity index (NUII): scaled 0-100 for all 9 cities based on max popden00.

Rates at which urban variables respond to changes in population density vary by metropolitan area.

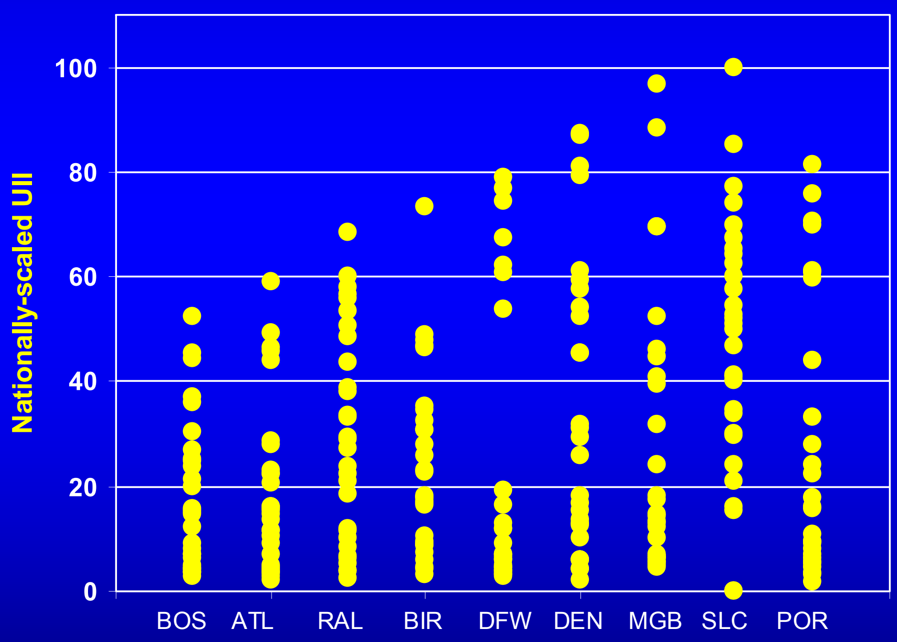


Maximum urban intensity in East is less than in West as indicated by NUII

Constant: MA-NUII



Varies by City: NUII



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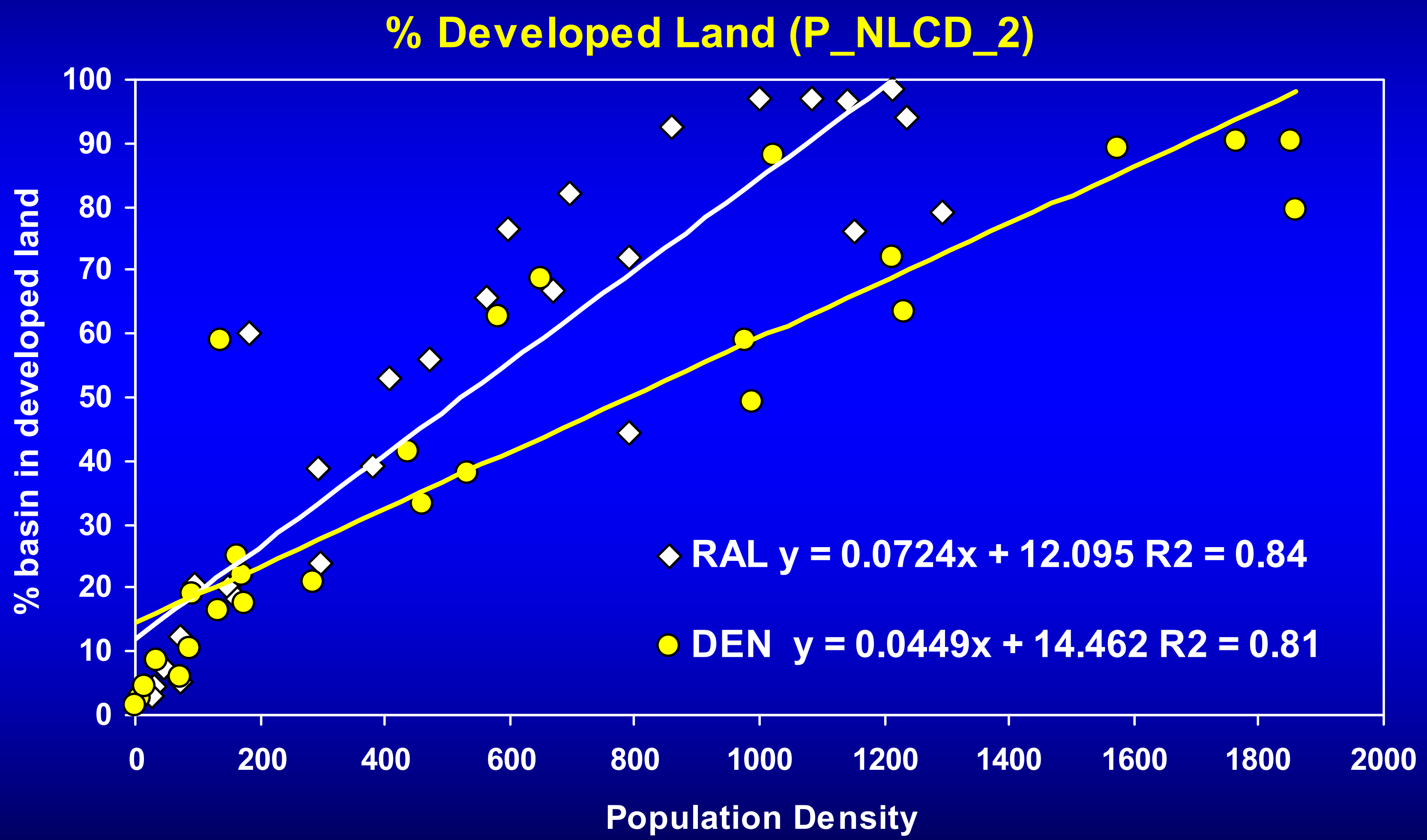
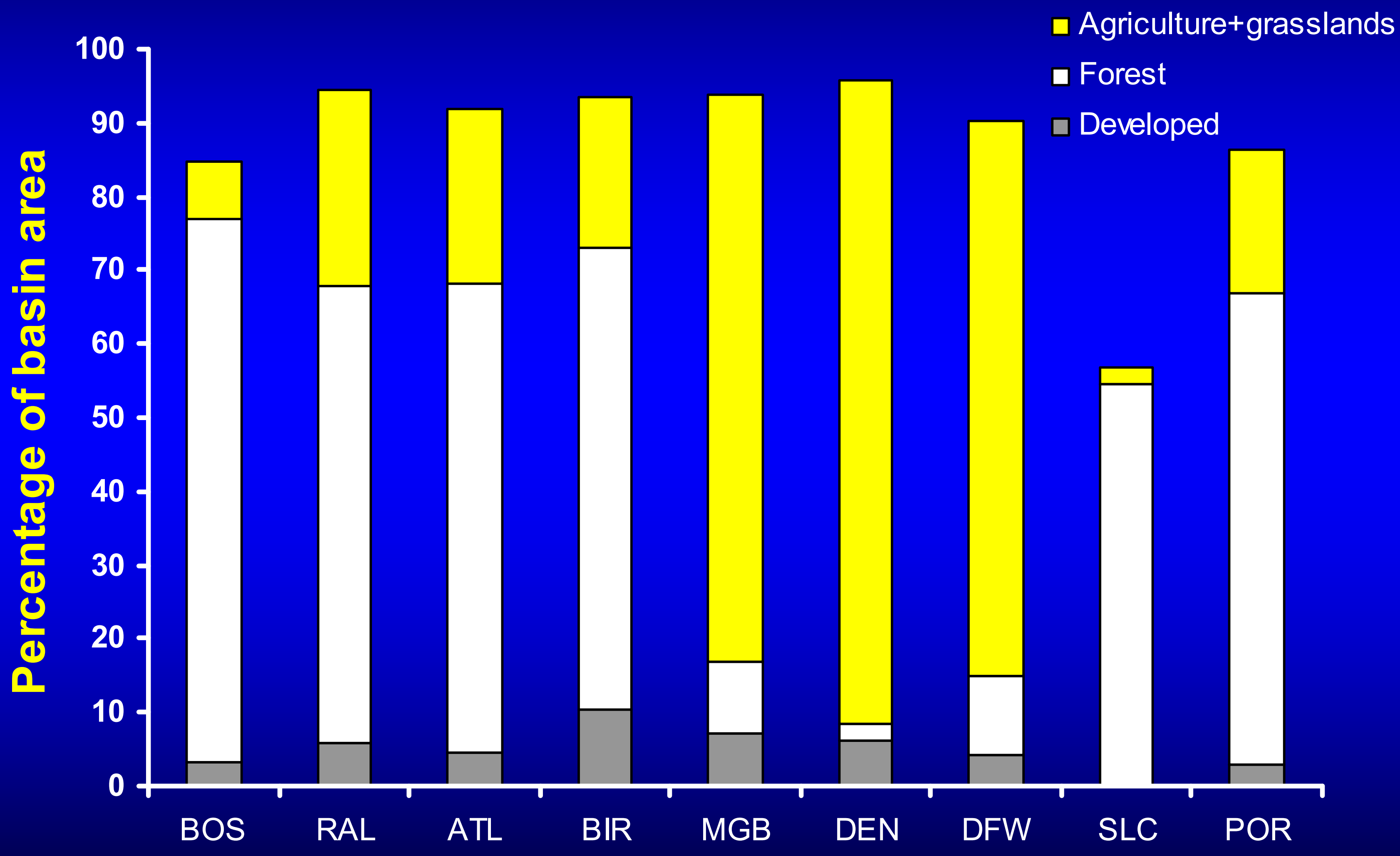
Differences in density of development



Patterns of urbanization

- A distinct geographic pattern in urban development, indicating that there is greater sprawl in the eastern than in the western MAs, was evident across the nine EUSE studies).
- The land cover type that is being converted to urban uses varies among MAs, as indicated by the land cover in basins at the low end of the urban gradient.
- With the exception of the three studies that border the Great Plains region (MGB, DEN, and DFW), the dominant land cover type in the less developed basins is forested land. In MGB, DEN, and DFW, the land that is being urbanized is primarily associated with agricultural uses.

Land cover at background sites
(MA-NUII ≤ 10)



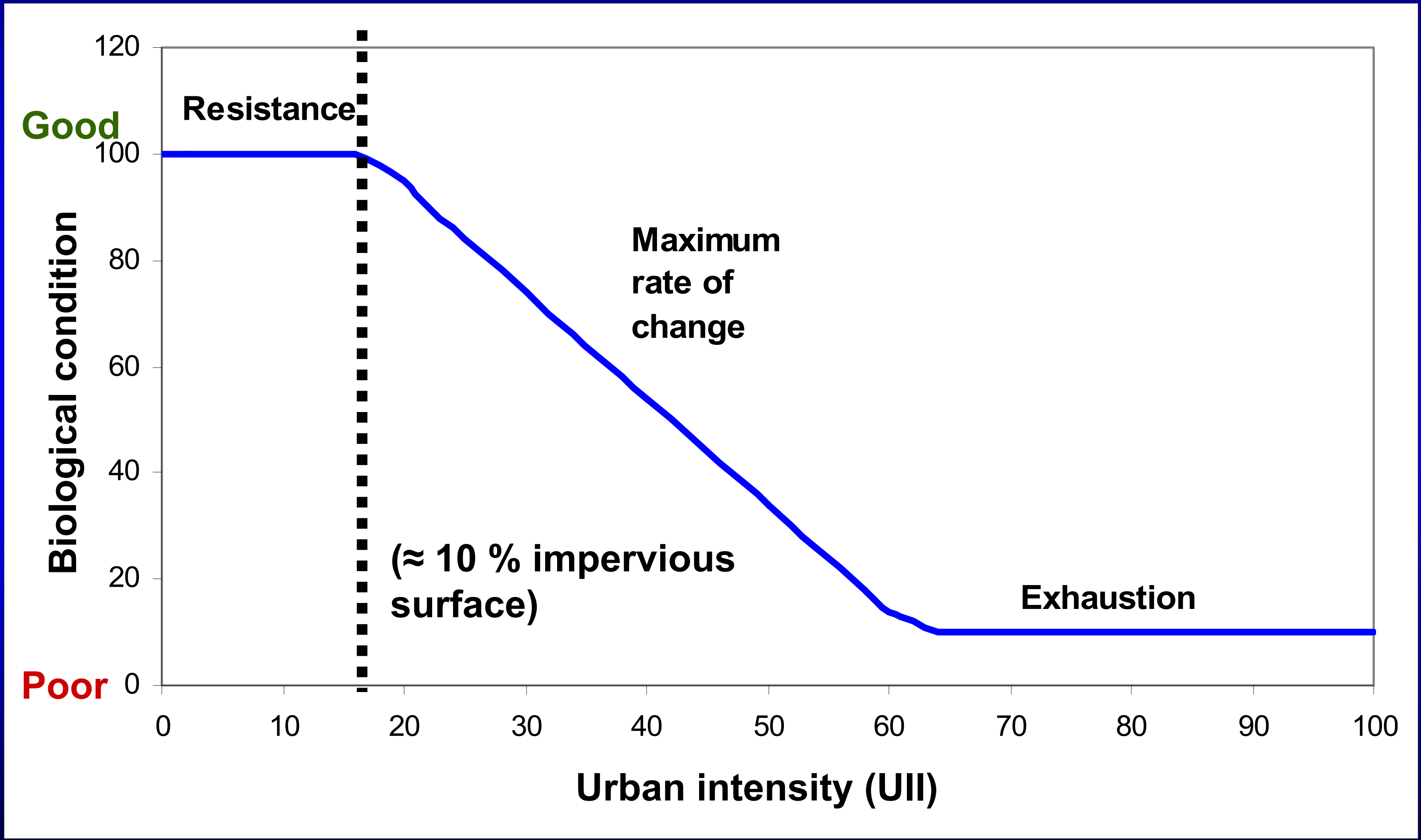
Stressors associated with urbanization: water chemistry

- Where urbanization was occurring on forested land
  - total nitrogen and nitrate concentrations increased with increasing urban land cover
  - Total herbicide concentrations significantly increased as urban land cover increased in ATL, RAL, and POR.
- Where agriculture (MGB and DFW) or shrubland (DEN) were the predominant background land covers
  - Relations between urbanization and total nitrogen and nitrate concentrations were weak
- Total insecticide concentrations significantly increased with increasing urban land cover, regardless of background LC
- The pesticides detected at the highest concentrations (herbicides in all studies but DEN) were not necessarily the pesticides with the greatest potential to adversely affect aquatic life.

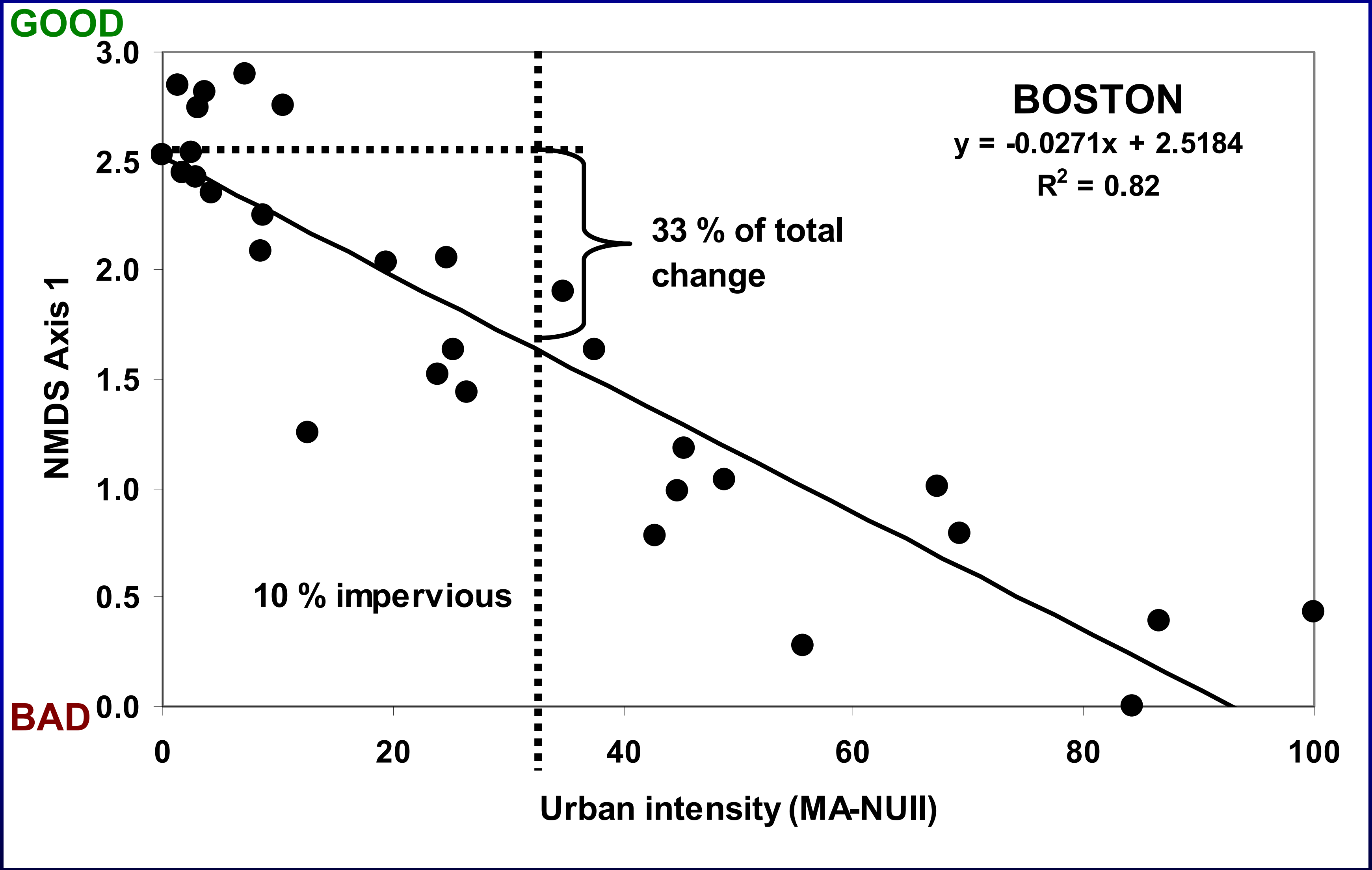
Response of biota: invertebrates key finding # 1

- **Invertebrates showed generally linear responses to urbanization.**
- **No conclusive evidence of resistance to urbanization (i.e., changes were immediate and occur at low levels of urban intensity).**
- **Criterion of 10% impervious areas is not protective.**

Expected response



Biological Responses



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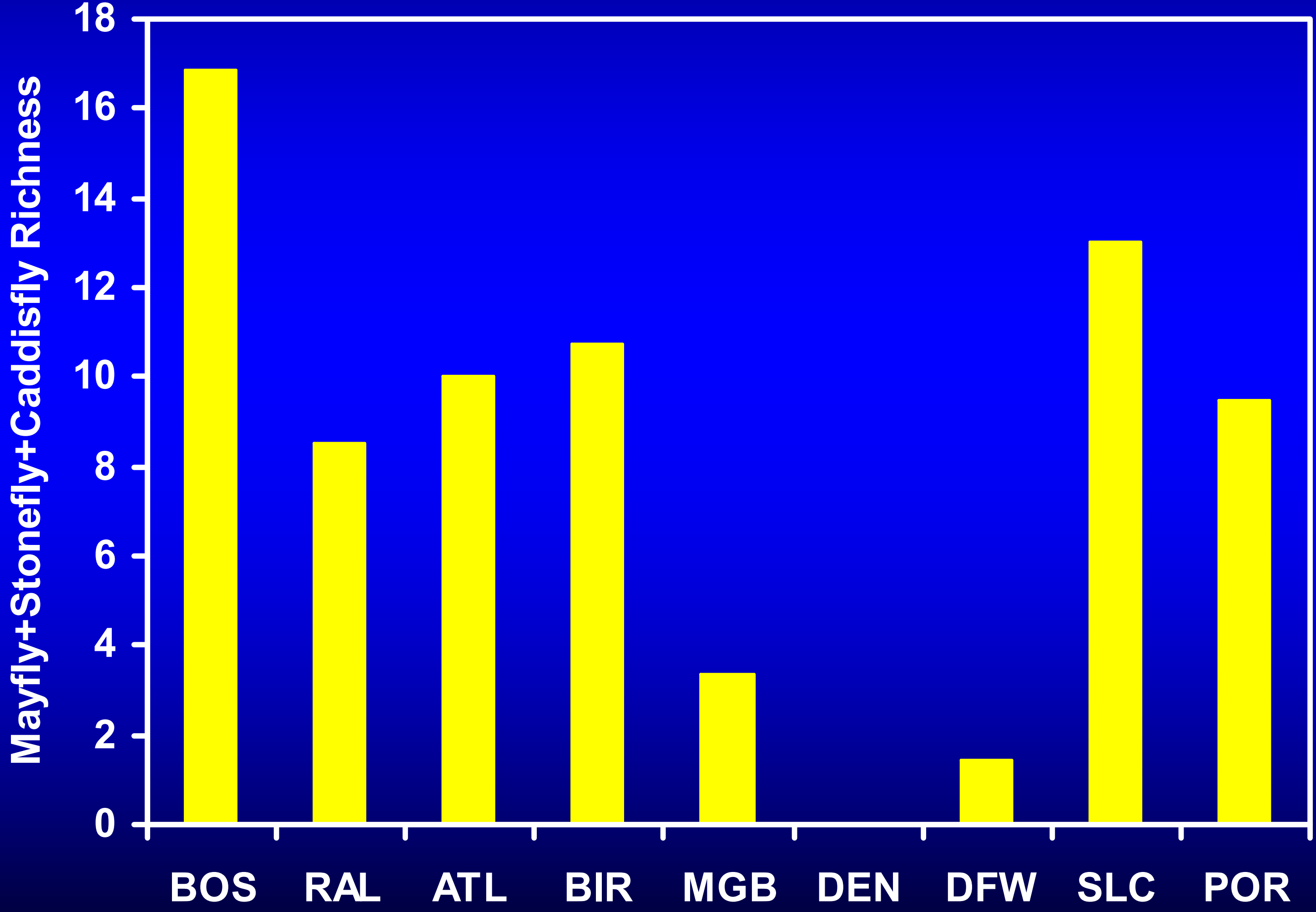
Response of biota: invertebrates key finding # 2

- **Antecedent agriculture severely degrades invertebrate communities and can mask the effects of urbanization.**

Difference in EPT taxa richness between High (≥ 80) and Low (≤ 10) urban sites (MA-NUII)



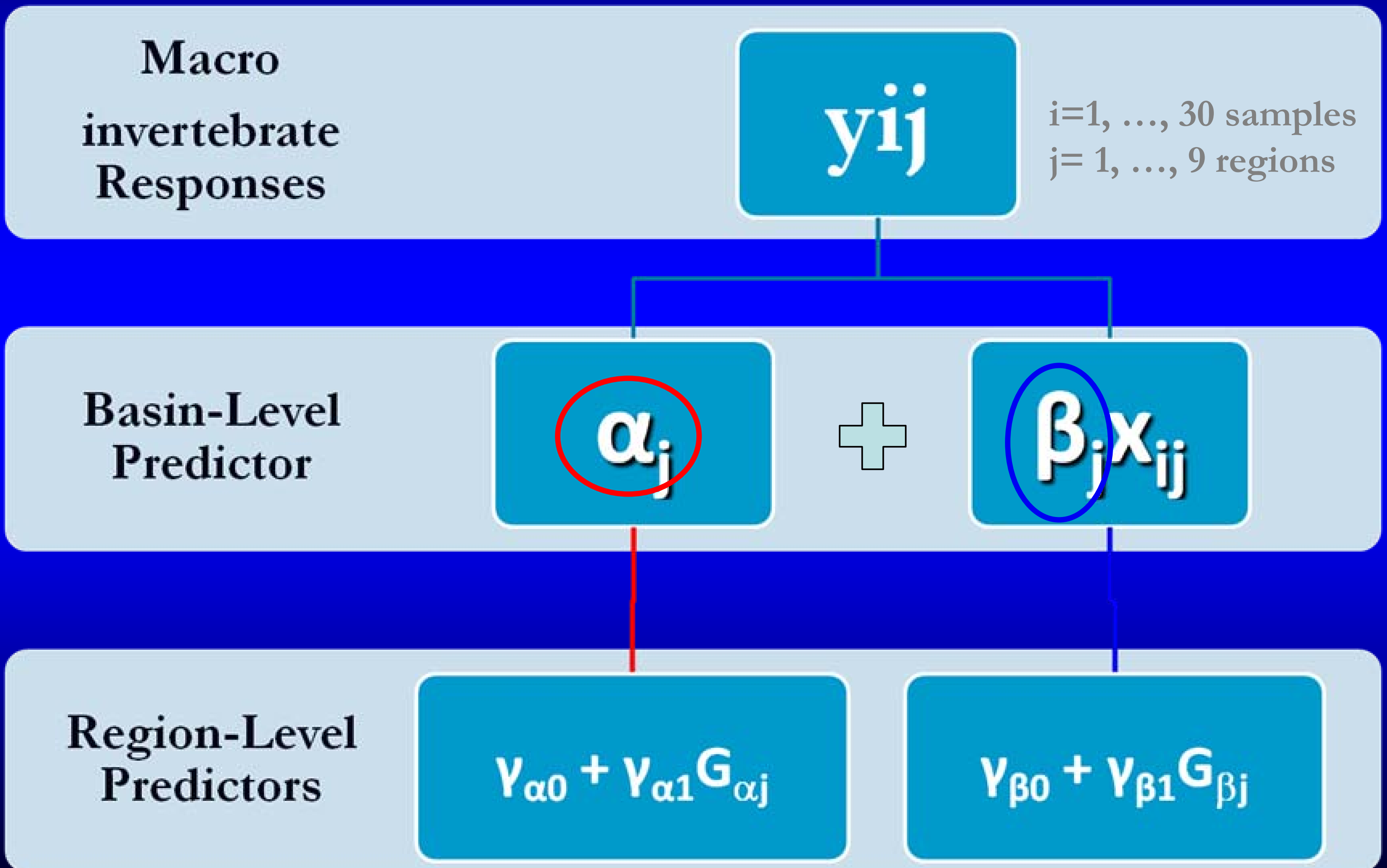
Response of biota: invertebrates key finding # 3

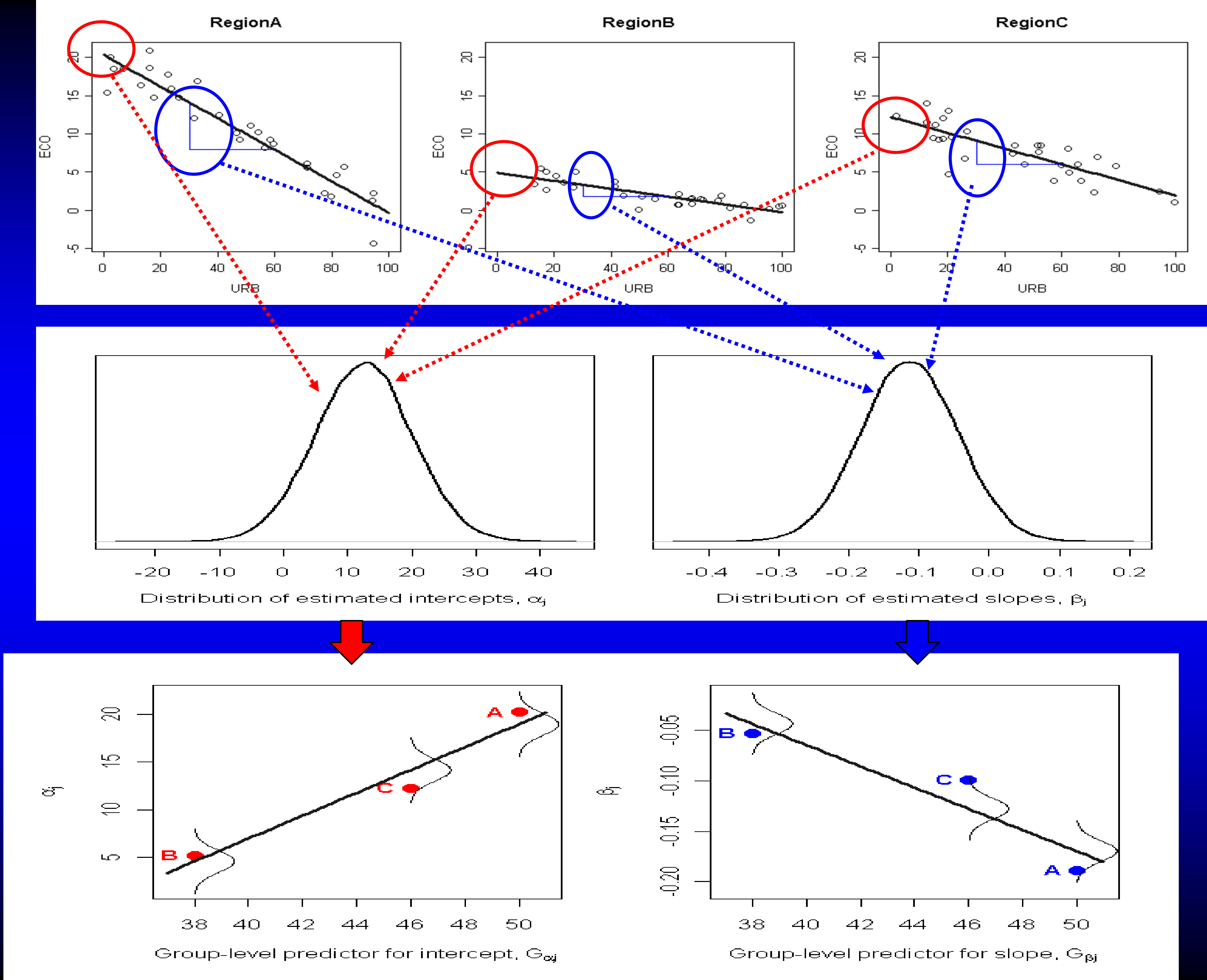
- **Environmental variables associated with invertebrate responses varied among metropolitan areas.**
- **Basin-scale census, land cover, and infrastructure environmental variables were most consistently associated with invertebrate responses.**
- **Reach-scale chemical, hydrologic, temperature, and habitat variables were not consistent across metropolitan areas and were not strongly associated with invertebrate responses.**

Response of biota: invertebrates key finding # 4

- Relatively simple multilevel hierarchical regression models can account for responses within and among metropolitan areas.

Hierarchical Multilevel Modeling





RegionA
RegionB
RegionC
ECO
URB
Distribution of estimated intercepts, α_j
Distribution of estimated slopes, β_j
α_j
β_j
A
B
C
Group-level predictor for intercept, $G_{\alpha j}$
Group-level predictor for slope, $G_{\beta j}$

Multilevel Modeling Variable Design

Regional-level Predictors → Temperature, Precipitation
Erodibility, Background Agriculture

+

Basin-level Predictor → Urban land

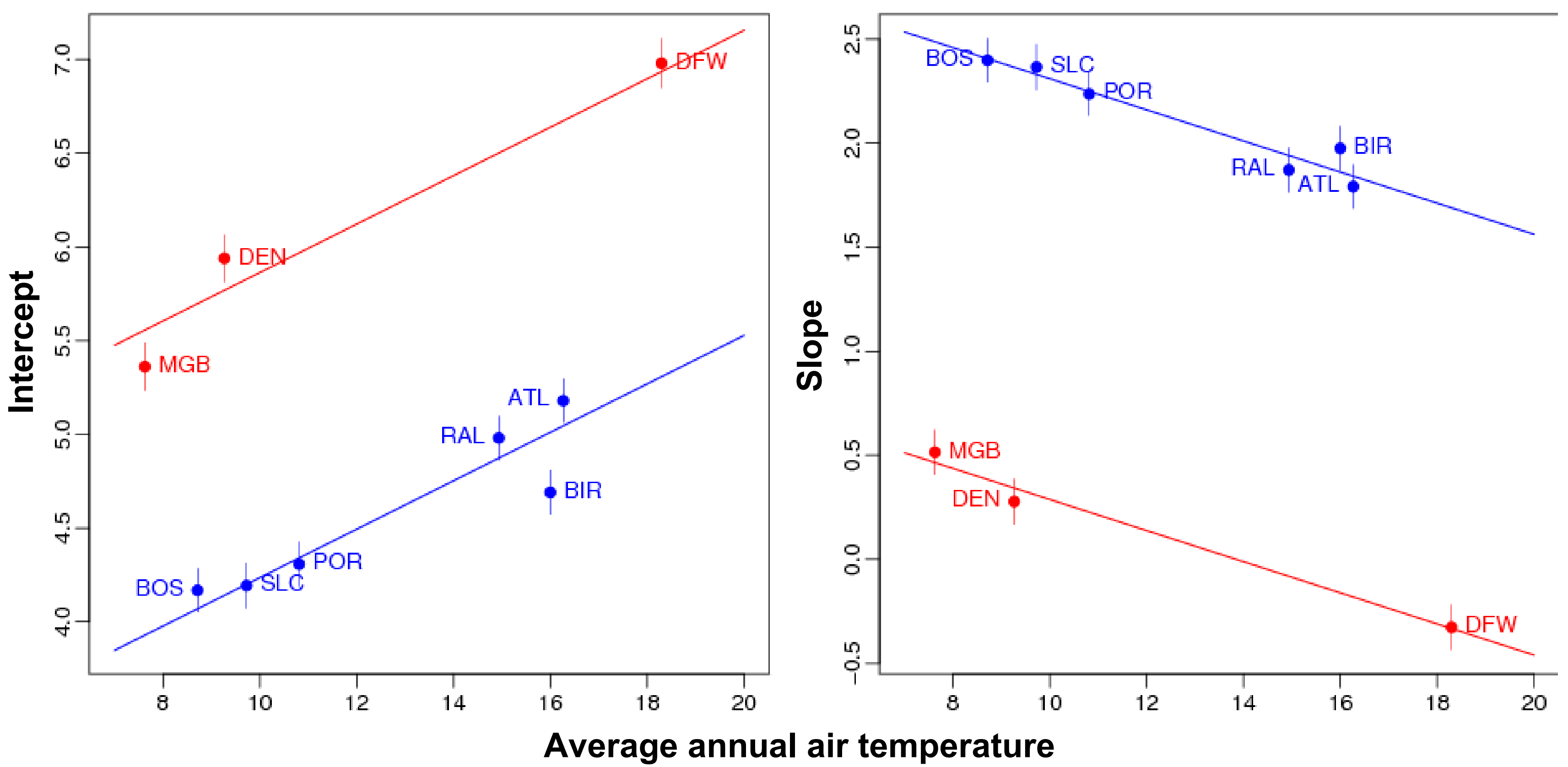
=

Macroinvertebrate Responses → Total Richness
EPT Richness
NMDS1 (ordination basin score)
Richness Tolerance

Average organism tolerance

Watershed level: % developed land
Region level: 1.) categorical antecedent agriculture
2.) average annual air temperature (F)

Average organism tolerance = a + bX X= % developed land in basin



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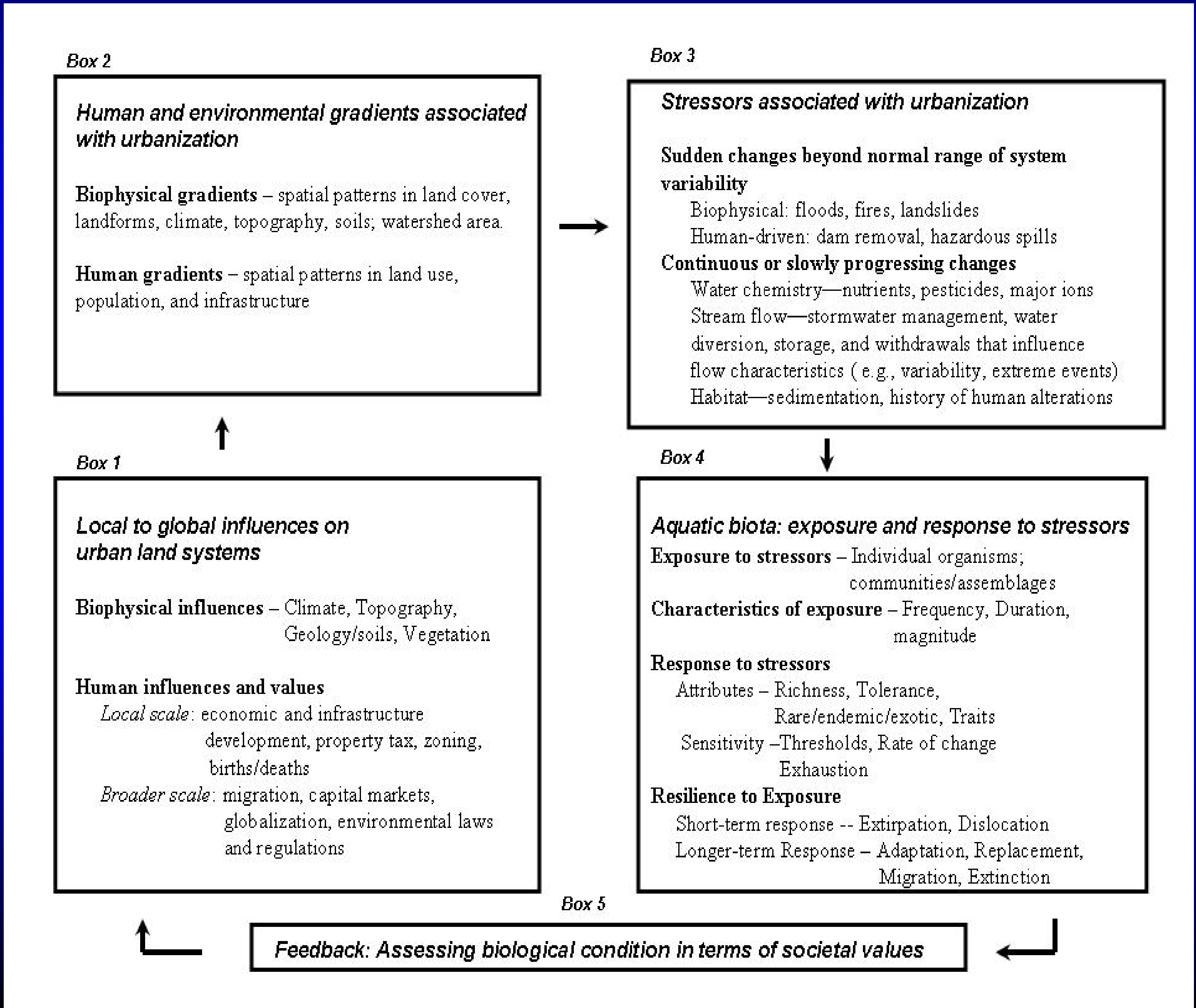
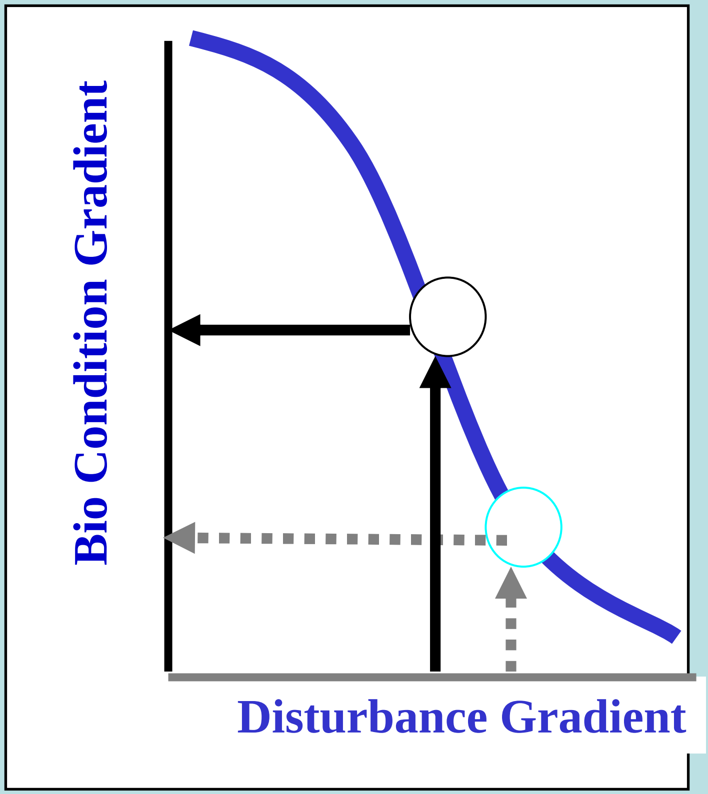
Case study: How can biota response be connected to biological condition (e.g., attaining/non-attaining)?



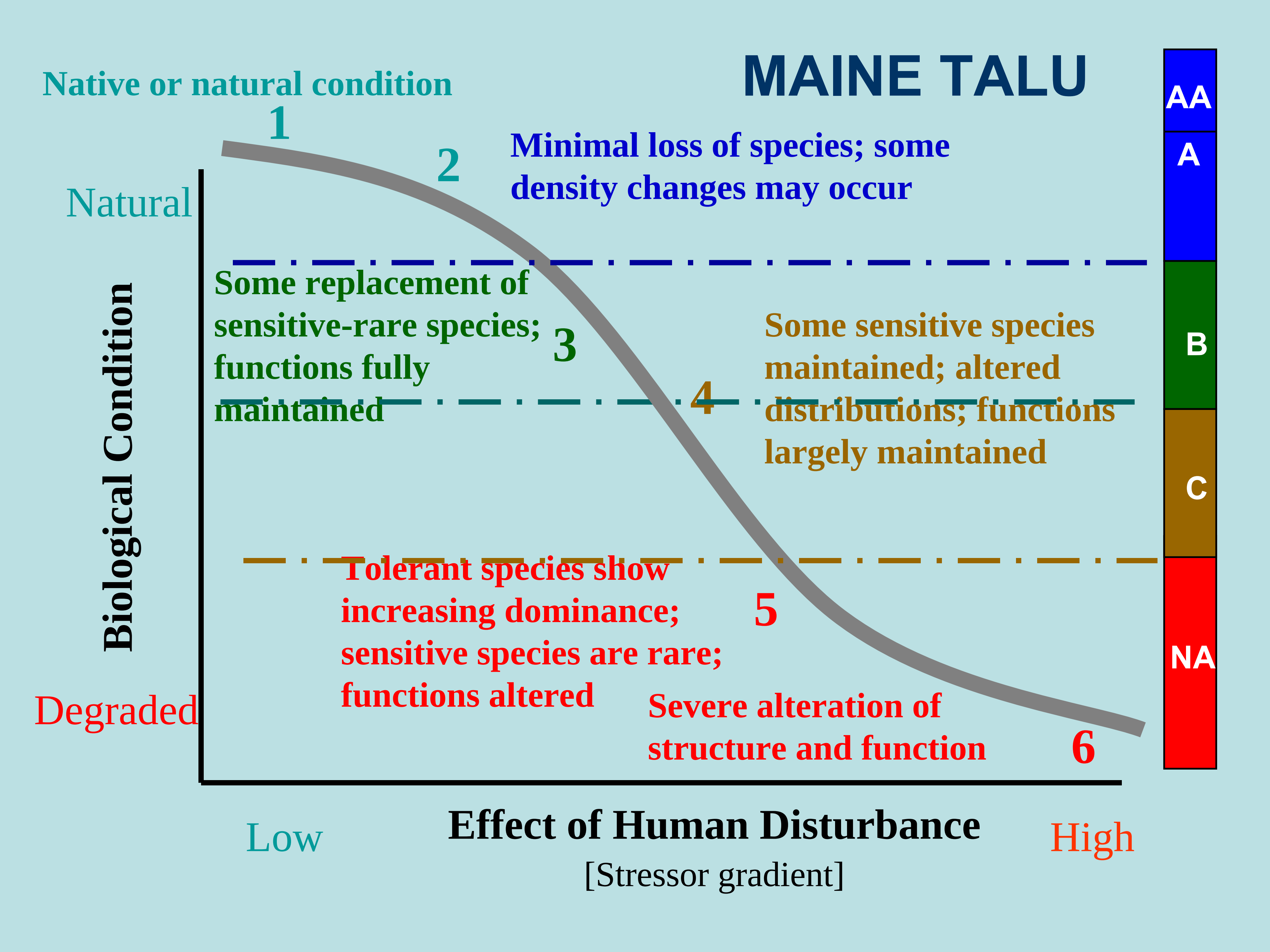
BCG and Tiered Aquatic Life Uses



A Conceptual Model

Class A/AA	***"as naturally occurs"***
Class B	***"support all indigenous species; no detrimental change"***
Class C	***"support indigenous fish (salmonids); maintain structure and function"***

A Water Quality Standards framework


MAINE TALU
Native or natural condition
1
2
Minimal loss of species; some density changes may occur
Natural
Biological Condition
Some replacement of sensitive-rare species; functions fully maintained
3
4
Some sensitive species maintained; altered distributions; functions largely maintained
Tolerant species show increasing dominance; sensitive species are rare; functions altered
5
Degraded
Severe alteration of structure and function
6
AA
A
B
C
NA
Low
Effect of Human Disturbance
High
[Stressor gradient]

Why Tiers?

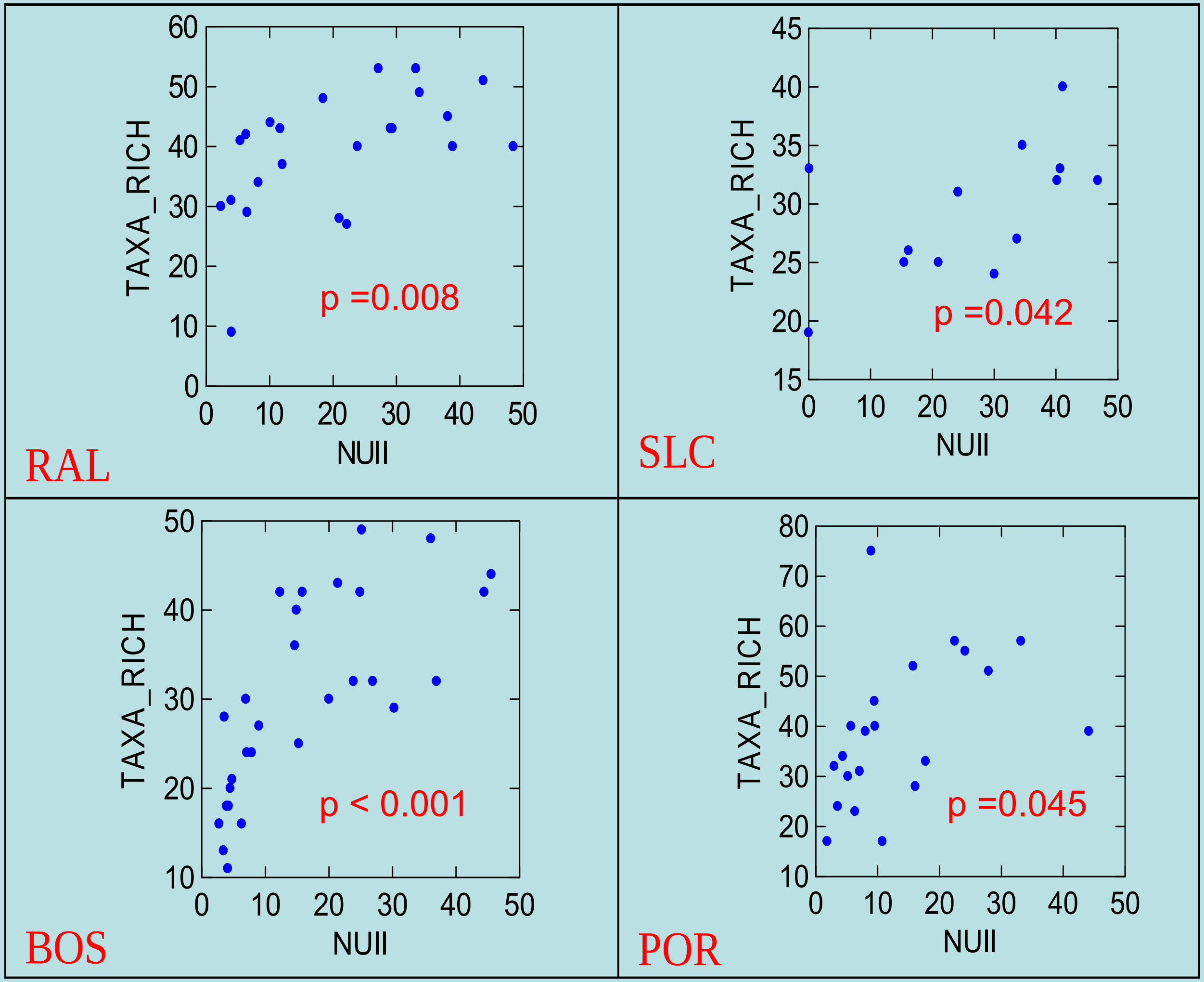
- Supports goal-based, adaptive management
- Provides more benchmarks of condition
  - Provides a range of management options
  - Can assign more appropriate aquatic life uses
  - Triage: focus effort on most serious impairment
  - 3 or 4 categories instead of “pass/fail”
- Better protection for high quality waters
- Recognize and lock in incremental improvement
  - Strengthens antidegradation
  - Highlights gains in water quality from BAT/BMPs

Response of biota: algae key findings

- Across the country, algal assemblages were most strongly influenced by physiographic region.
- The algal response was generally more strongly related to specific reach-scale environmental factors rather than to the watershed-scale urban intensity index (UII).
- In some MAs, algal species richness increased over the initial stages of urbanization.
- The algal response was most strongly related to water quality, although the correlation between water quality and the UII was varied.

Over the initial stages of urbanization,
species richness increased in four MAs
The response occurred over N-UII values 0 - 50.

*No MA showed a significant **decline** in species richness over this range (0-50) of urban intensity.*



To what environmental scale are the algal assemblages responding most strongly?

Watershed

- **Urban Intensity Index**
- Landscape Features
- Demographic Features

Stream Reach

- Physical Habitat
- Water Chemistry
- Streamflow

Algal Assemblage

- Structure (the species)
- Function (what they do)

Algal response
Correlated most strongly to factors at the reach scale

MA	Environmental Scale	Primary Factors
POR	Reach	Ambient Water Quality
SLC	Basin Reach	Vegetative Landcover, Slope Comprehensive Water Quality
DEN	Reach	Ambient Water Quality
DFW	Reach	Ambient Water Quality
MGB	Reach	Ambient Water Quality
BIR	Reach	Ambient Water Quality
ATL	Reach	Ambient Water Quality
RAL	Reach	Ambient Water Quality
BOS	Reach	Ambient Water Quality