Developing linkages between species traits and multiscaled environmental variation to explore vulnerability of stream benthic communities to climate change

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Developing linkages between species traits and multiscaled environmental variation to explore vulnerability of stream benthic communities to climate change

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Abstract. Forecasting responses of benthic community structure and function to anthropogenic climate change is an emerging scientific challenge. Characterizing benthic species by biological attributes (traits) that are responsive to temperature and streamflow conditions can support a mechanistic approach for assessing the potential ecological responses of climate change. However, nonclimatic environmental factors also structure benthic communities and may mitigate transient climatic conditions, and these must be considered in evaluating potential impacts of climate change. Here we used macroinvertebrate and environmental data for 279 reference-quality sites spanning 12 states in the western US. For each sampling location, we described 45 environmental variables that spanned reach to catchment scales and that represented contemporary climate drivers, hydrologic metrics, and nonclimatic habitat features, as well as purely spatial metrics. We described benthic community composition at each site in terms of 7 species traits, including those considered sensitive to temperature increases and streamflow changes. All combined environmental variables explained 67% of the total trait variation across the sites, and catchment-scale climatic and hydrologic variables independently accounted for 19%. Sites were clustered into 3 community types based on trait composition, and a classification-tree analysis confirmed that climatic and hydrologic variables were important in partitioning these groups. Sensitivity of benthic communities to projected climate change was assessed by quantifying the proportion of taxa at sites having the traits of either cold stenothermy or obligate rheophily. Regression-tree analysis showed that temperature and hydrologic variables mostly accounted for the differences in proportion of sensitivity traits across the sites. We examined the vulnerability of sites to climate change by superimposing regional-scale projections of late-21st-century temperature and runoff change on the spatial distribution of temperature- and runoff-sensitive assemblages. Sites with high proportions of cold stenotherms and obligate rheophiles occur throughout the western US, but the degree of temperature and runoff change is projected to be greatest for reference sites in the Upper Colorado River and Great Basin. Thus, our results suggest that traits-based sensitivity coupled with intraregional variation in projected changes in temperature and runoff will cause reference sites in the western US to be differentially vulnerable to future climate change.

Key words: benthic community, species traits, climate change, species vulnerability.

Climate Change in Streams

- Shifts in temperature and precipitation will directly and indirectly influence the stream environment
- These environmental shifts will ultimately affect the stream community
  - Direct: ↑ Air Temperature → ↑ Water Temperature
  - Indirect: ↑ Temperature and/or Δ Precipitation = Δ Hydrology
- How will climate affect stream communities?

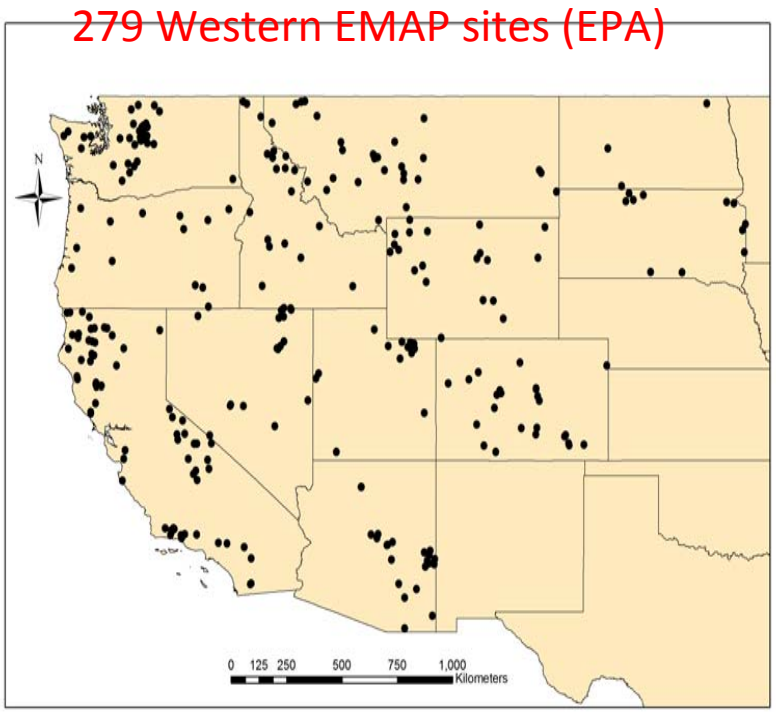
3 components of Vulnerability

- Exposure – the deltas (ΔT, ΔQ)
- Sensitivity – response to the ΔT or ΔQ?
  - Often inferred from empirical range maps, or from indices of sensitivity (e.g., "thermal tolerance")
- Resilience – species' ability to buffer
  - Tolerance (physiological acclimatization)
  - Dispersal (species trait, landscape connectivity)
  - Genetic evolution and adaptation
  - Refugial habitats

Another consideration: other stressors (pollution, diversion, dams, etc.) that <u>interact</u> with CC

How to "isolate" the effect of climate change?

- WEMAP "reference" sites
  - Wadeable, not "pristine"
  - Best places to isolate effects of rapid CC?
- Data:
  - Taxonomic lists of taxa
  - Local habitat variables



Need to:

→ Traits-based approach for common currency for exposure across regions

→ Environmental metrics that define key aspects of exposure (ΔT, ΔQ)

→ Multi-scale environmental factors exacerbate/mitigate resilience

Objectives

(1) Identify traits that might be *sensitive* to rapid CC

(2) Use WEMAP reference sites to define traits-based community "types"

(3) Explain these "types" with multi-scaled environmental variables:

* *direct climatic (temperature, precipitation)*
* *indirect climatic … hydrologic (streamflow)*
* *non-climatic ("habitat" – local and catchment)*

(4) Explore vulnerability of sensitive site types to projected levels of exposure to CC

(5) Give caveats

Traits for 311 taxa of North American lotic insects

(20 traits; 57 states) Poff et al. (2006*, JNABS*)

LIFE HISTORY

- *Voltinism* (3)
- *Development rate* (3)
- *Emergence synchrony* (2)
- *Adult life span* (3)
- *Desiccation resistance* (2)
- *Adult Exiting ability* (2)

MOBILITY

- *Adult female dispersal* (2)
- *Adult flying strength* (2)
- *Occurrence in drift* (3)
- *Maximum crawling rate* (3)
- *Swimming ability* (3)

MORPHOLOGY

- *Size at maturity* (3)
- *Armoring* (3)
- *Shape* (2)
- *Respiration mode* (3)
- *Desiccation tolerance* (2)
- *Degree of attachment* (2)

ECOLOGY

- *Rheophily* (3)
- *Habit* (5)
- *Feeding mode* (5)
- *Thermal preference* (3)

(1) Appropriate traits?

7 potentially important traits that reflect sensitivity and resilience

- Thermal Tolerance – 3 states
  - **** Cold Stenothermal (sensitive to warming?)***
- Rheophily – 3 states
  - **** Erosional Obligate (sensitive to intermittency?)***
- Voltinism – 3 states
- Occurrence in Drift – 3 states
- Female Dispersal – 2 states
- Desiccation Resistance – 2 states
- Habit – 5 states

Trait-based Community Structure

- Climate change should illicit a trait-based response in the aquatic insect community in streams
- Convert community richness into proportion of taxa with each trait state

Epeorus

Baetis

Rhyacophila

Pteronarcys

Hydropsyche

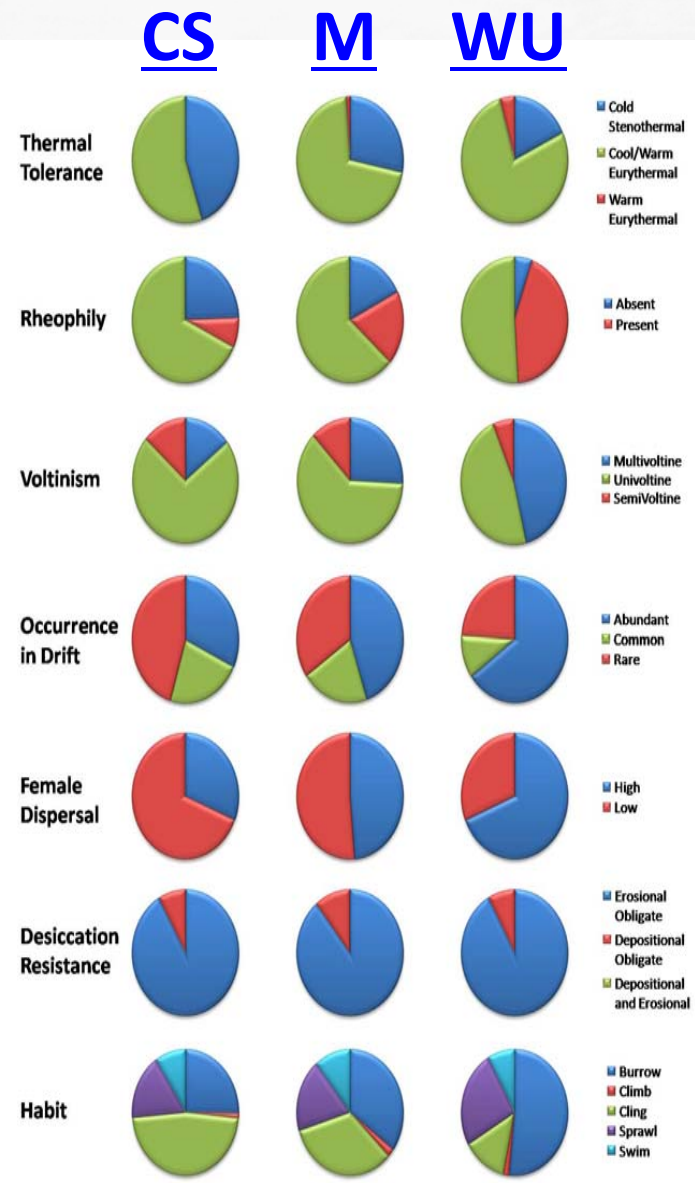
Pericoma

Hexatoma

Erosional Obligate	Depositional Obligate	Both
28%	*14%*	*58%*

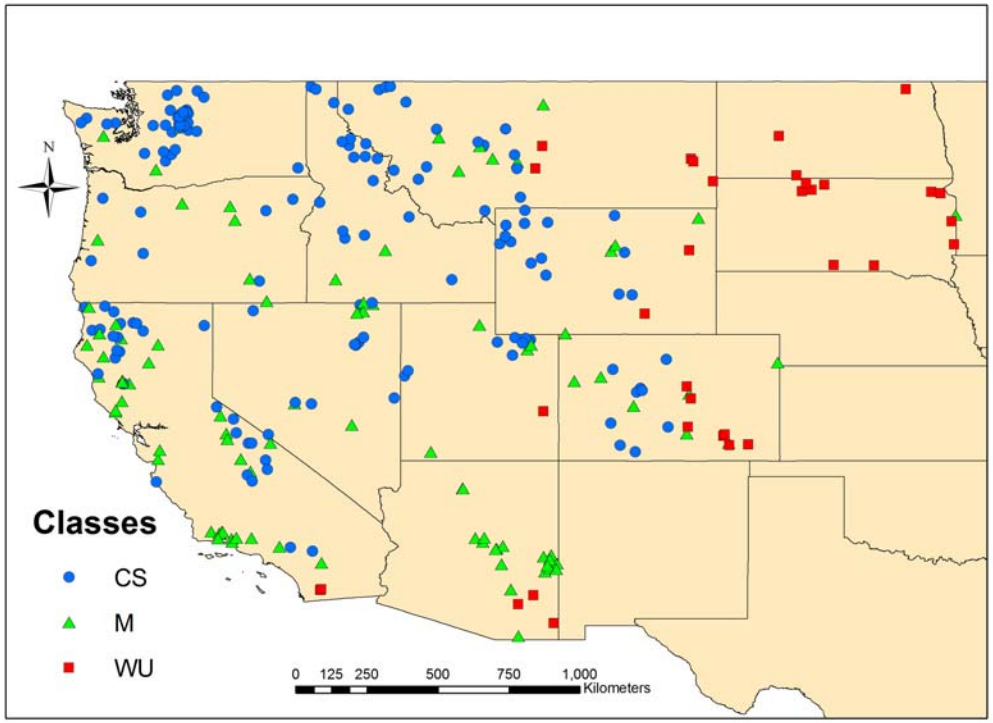
(2) Traits-based "community types"?

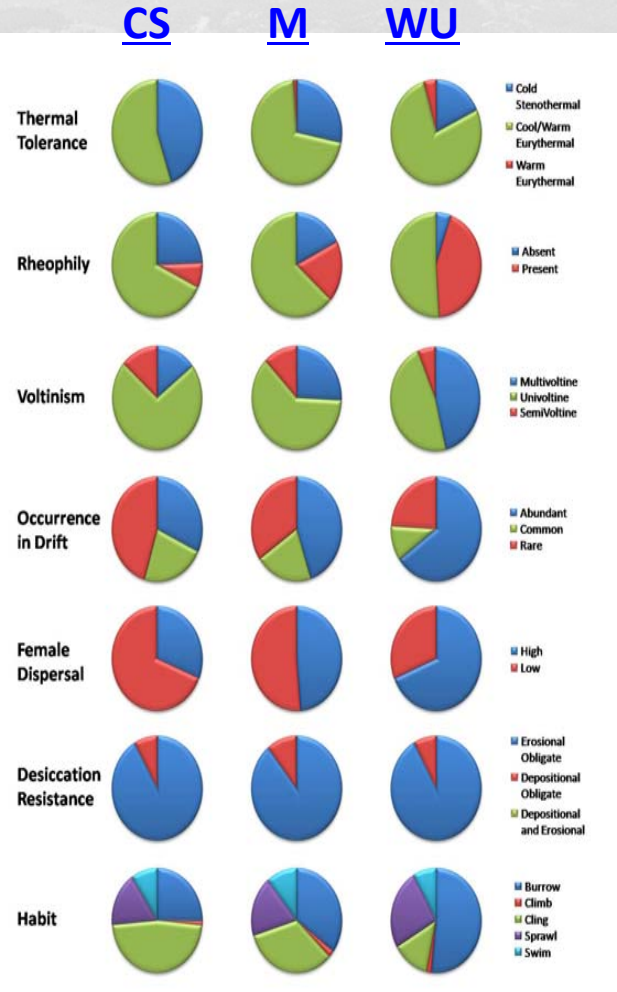
- Cluster Analysis
  - Cold Stable (CS)
    - Cold stenothermal (temp)
    - Erosional obligates (runoff?)
    - Low disturbance traits (e.g., drift, dispersal)?
    - Clingers
  - Warm Unstable (WU)
    - Warm/cool eurythermal and warm eurythermal
    - Depositional obligates
    - More disturbance traits
  - Intermediate (M)
    - intermediate



(3) Do environmental variables explain community types?

Geographic distribution of types





Environmental Variables

Local Scale

- Riparian
- Chemistry
- Stream Structure
  - Sediment/Habitat
  - Geomorphology

Catchment Scale

- *Climate Variables*
  - Precipitation
  - Temperature
- *Climate-influenced Variables*
  - Hydrology
- *Non-Climate Variables*
  - Land-use
  - Geology
  - Geomorphology

Climate Variables (PRISM)

- Precipitation
  - Mean annual Precip
  - % as snow
  - Feb Precip
  - July Precip
- Temperature
  - Mean annual Temp
  - Mean Feb air Temp
  - Mean July air Temp

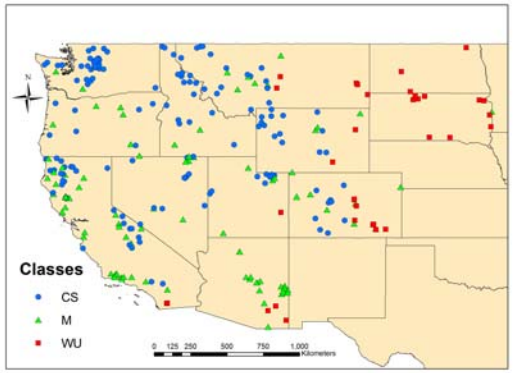
Hydrology Variables

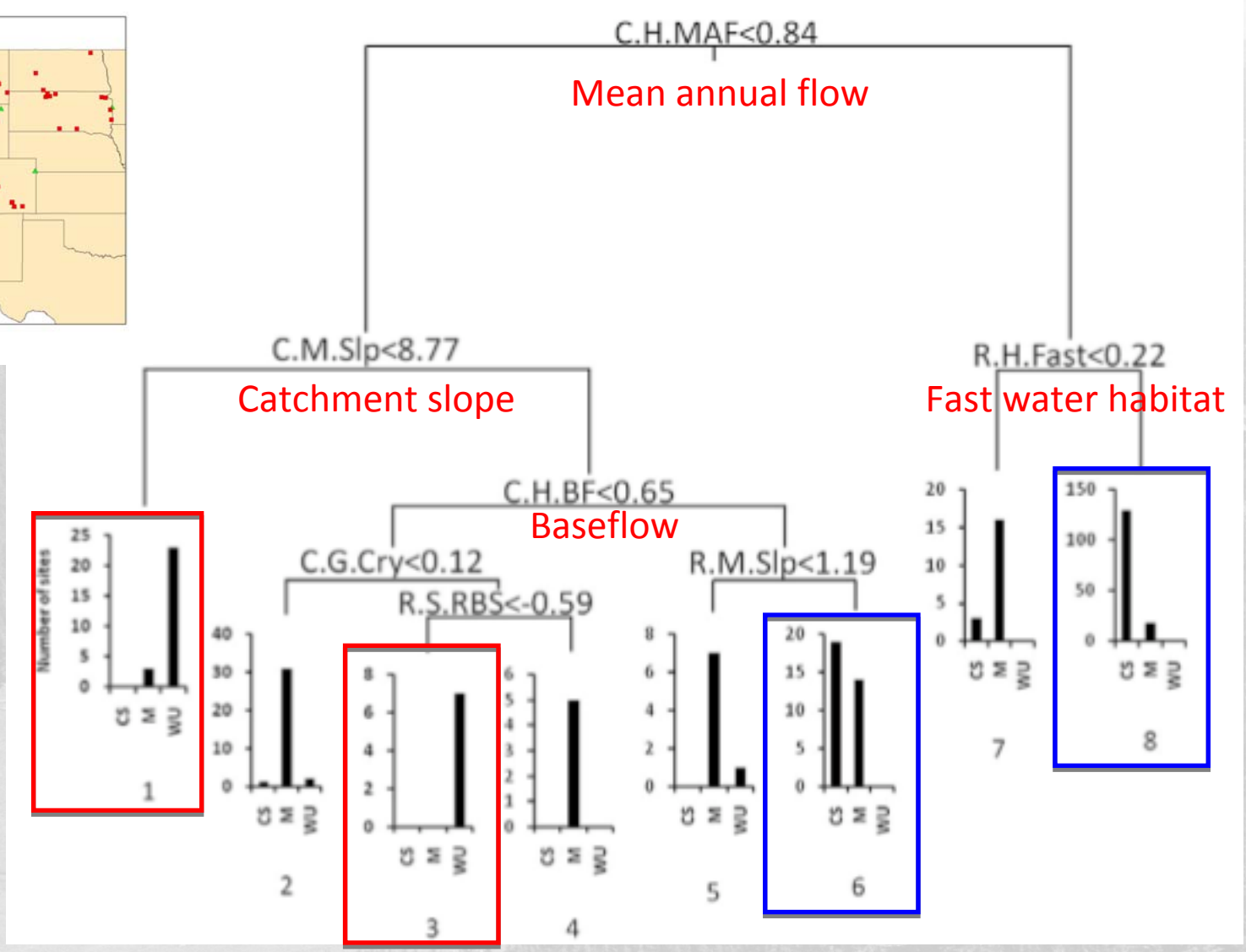
(Carlisle et al. 2009 RRA)

- Mean annual runoff
- Base flow/total flow
- Max flow
  - Pulse count, duration
- Flood interval
- Flood-free days
- Min flow
  - Pulse count, duration
- CV of daily flows

(Not good measures of intermittency)

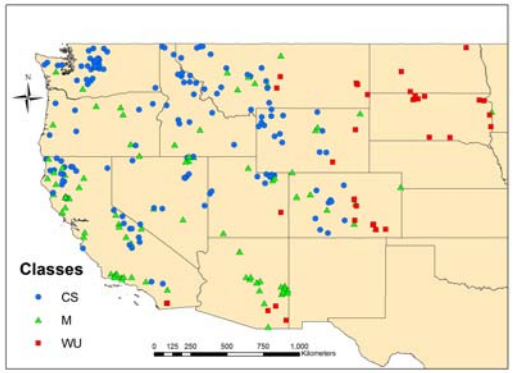
CART analysis

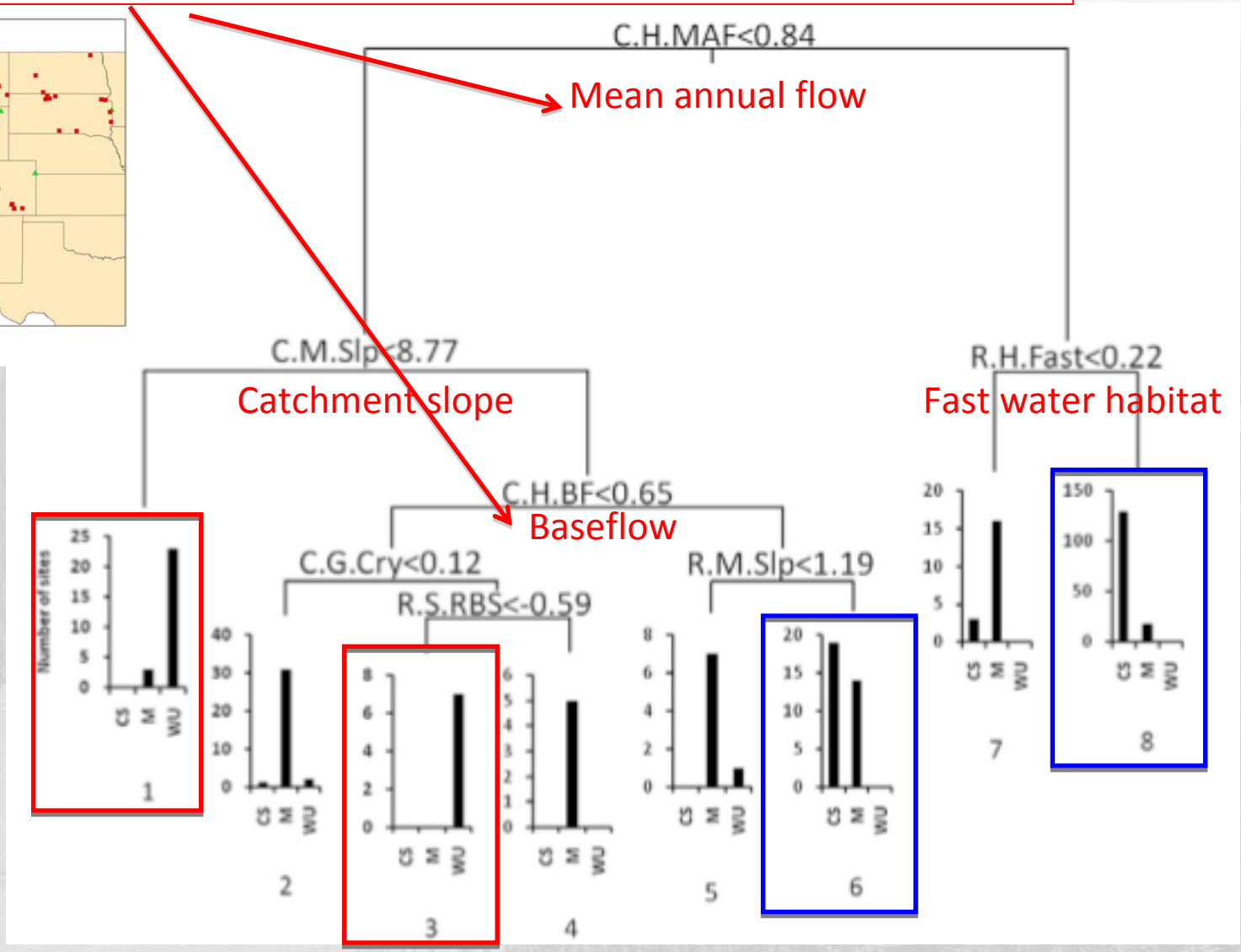




Random Forests – precipitation variables highly weighted

- % precip as snow
- February (winter) precip
- Annual precip (perennial-ness)

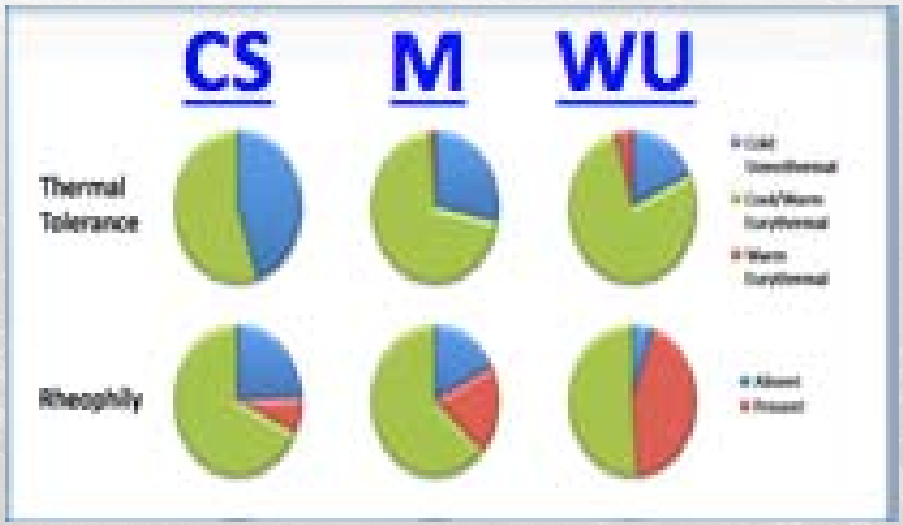




(4) Vulnerability to CC?

2 Sensitivity Traits

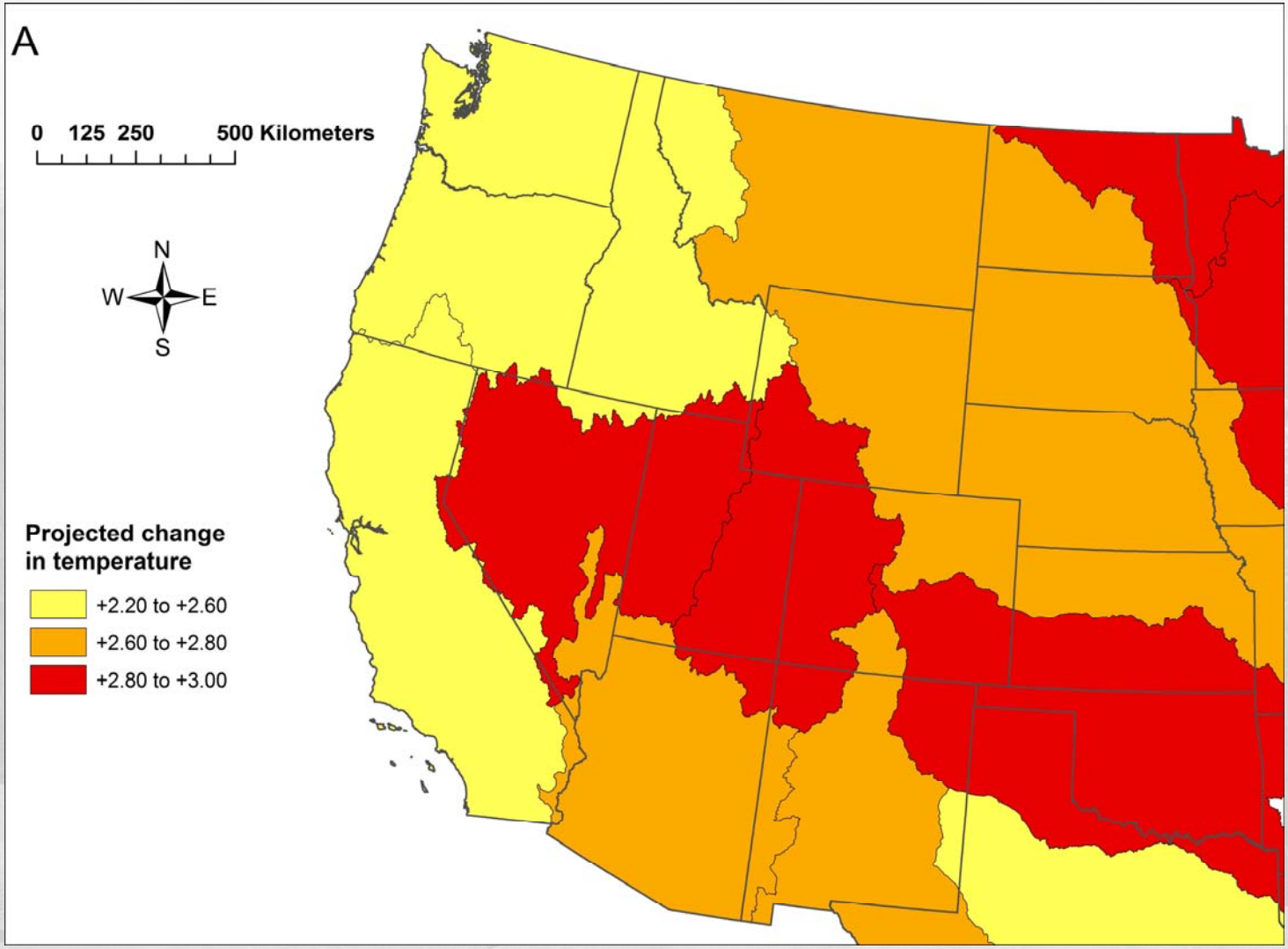
- proportion of cold stenotherm species
- proportion of obligate rheophile species



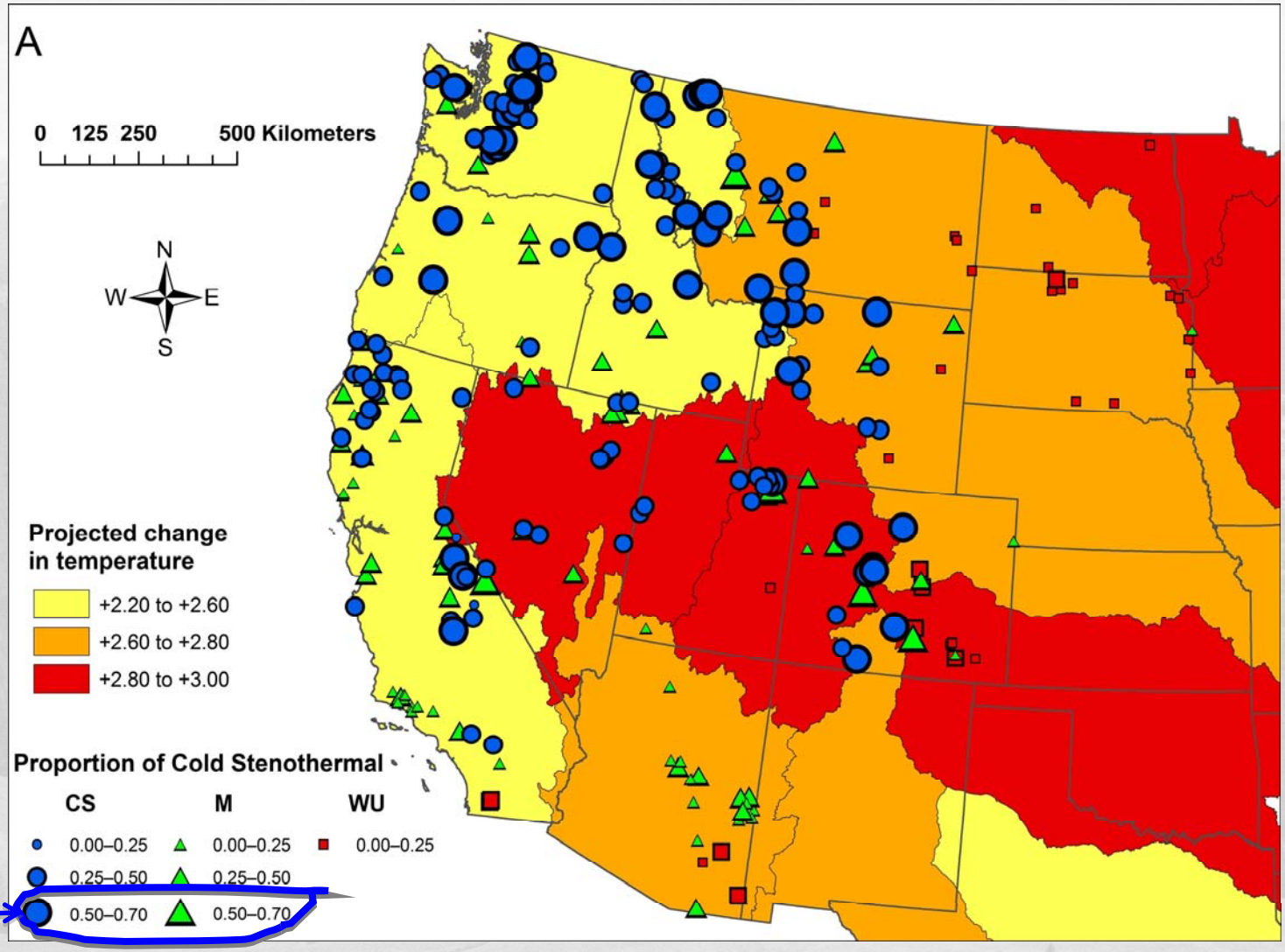
Exposure (late 21st C):

- Temperature increase (ΔT) (CMIP3 multi-model dataset)
- Runoff change (ΔQ) (Lettenmaier et al. 2008)

Regional differences in ΔT

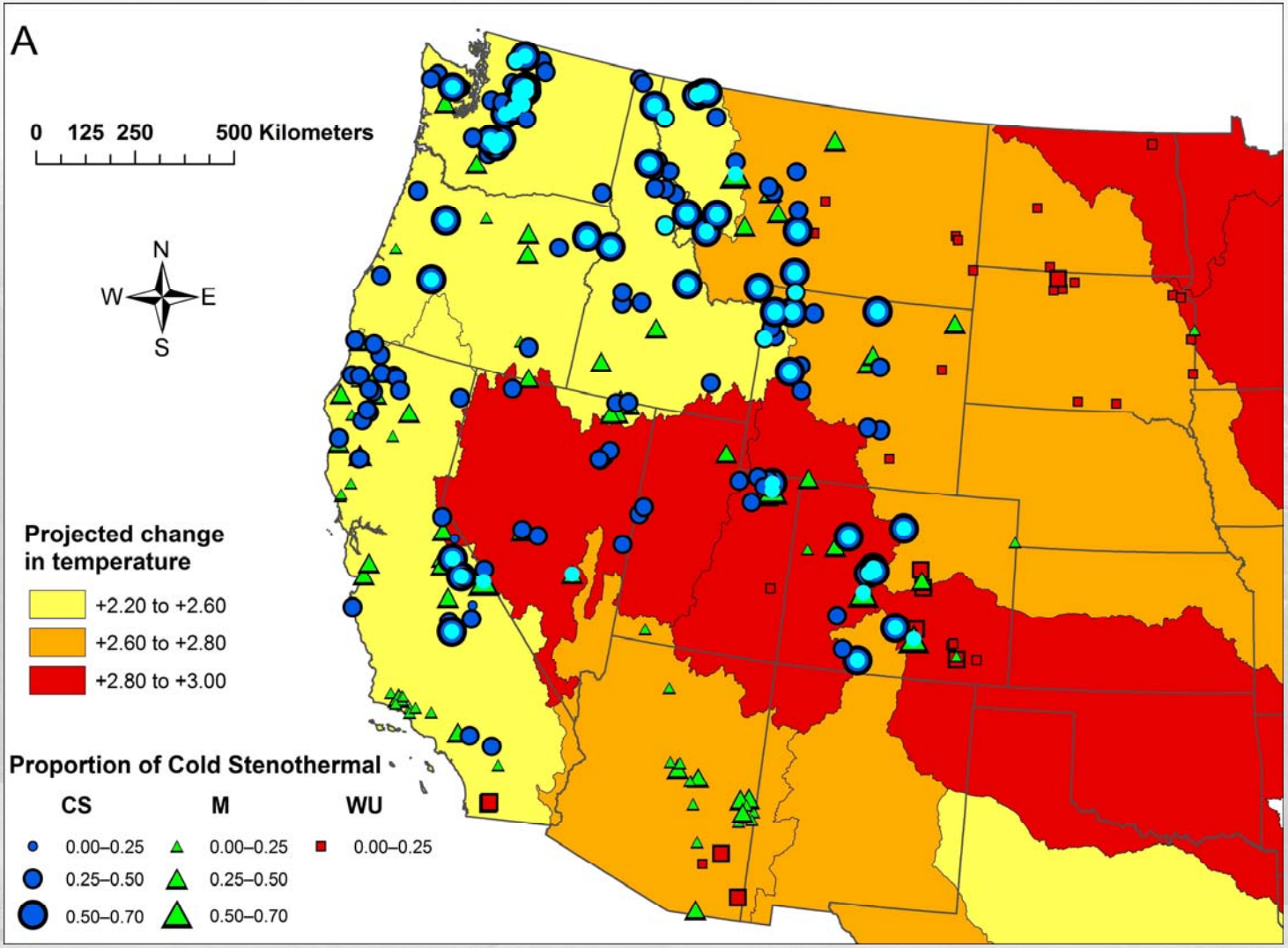


Distribution of *sensitive* sites

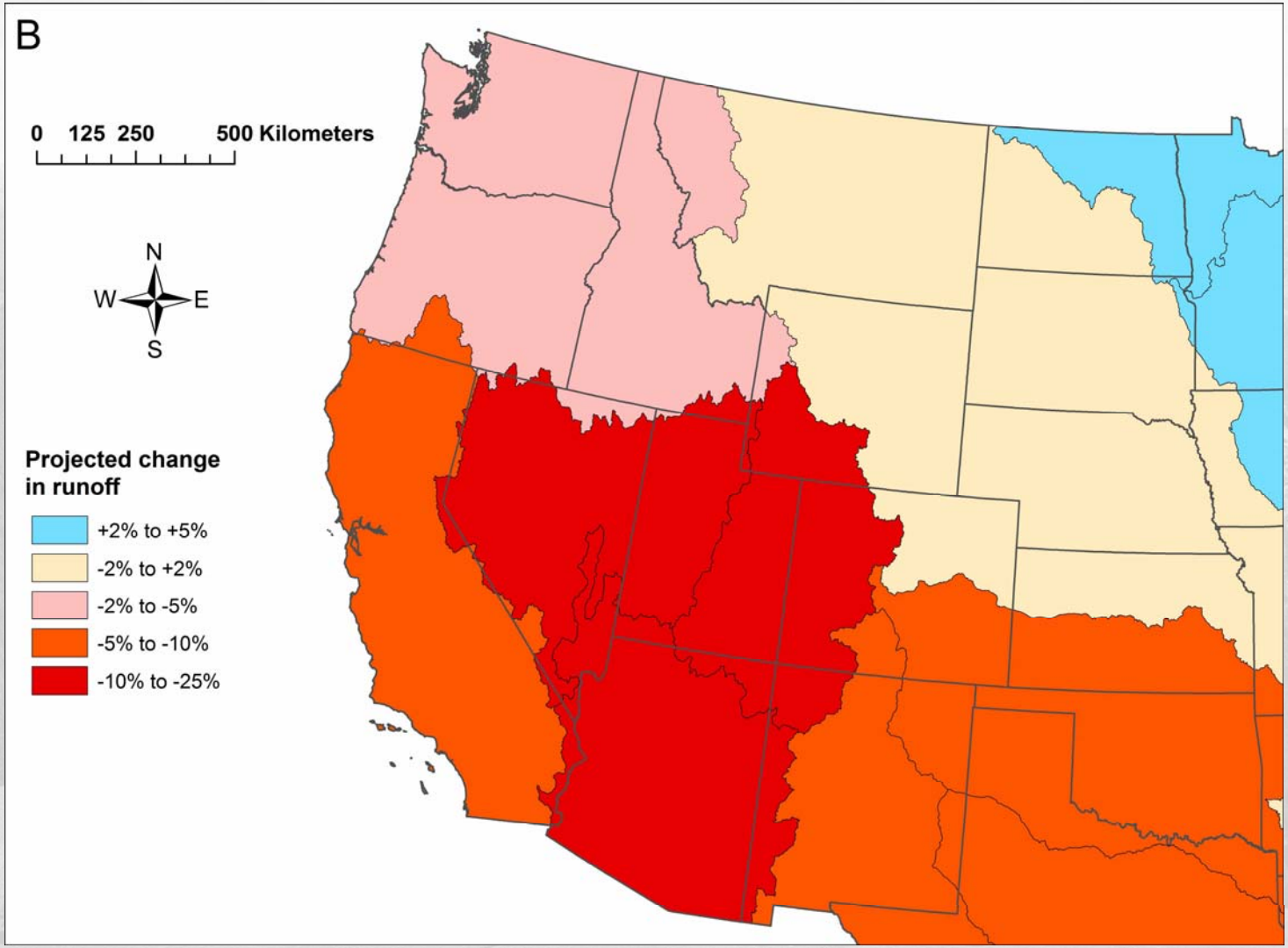


Lots of CS sites with 50-75% taxa; few M; no WU

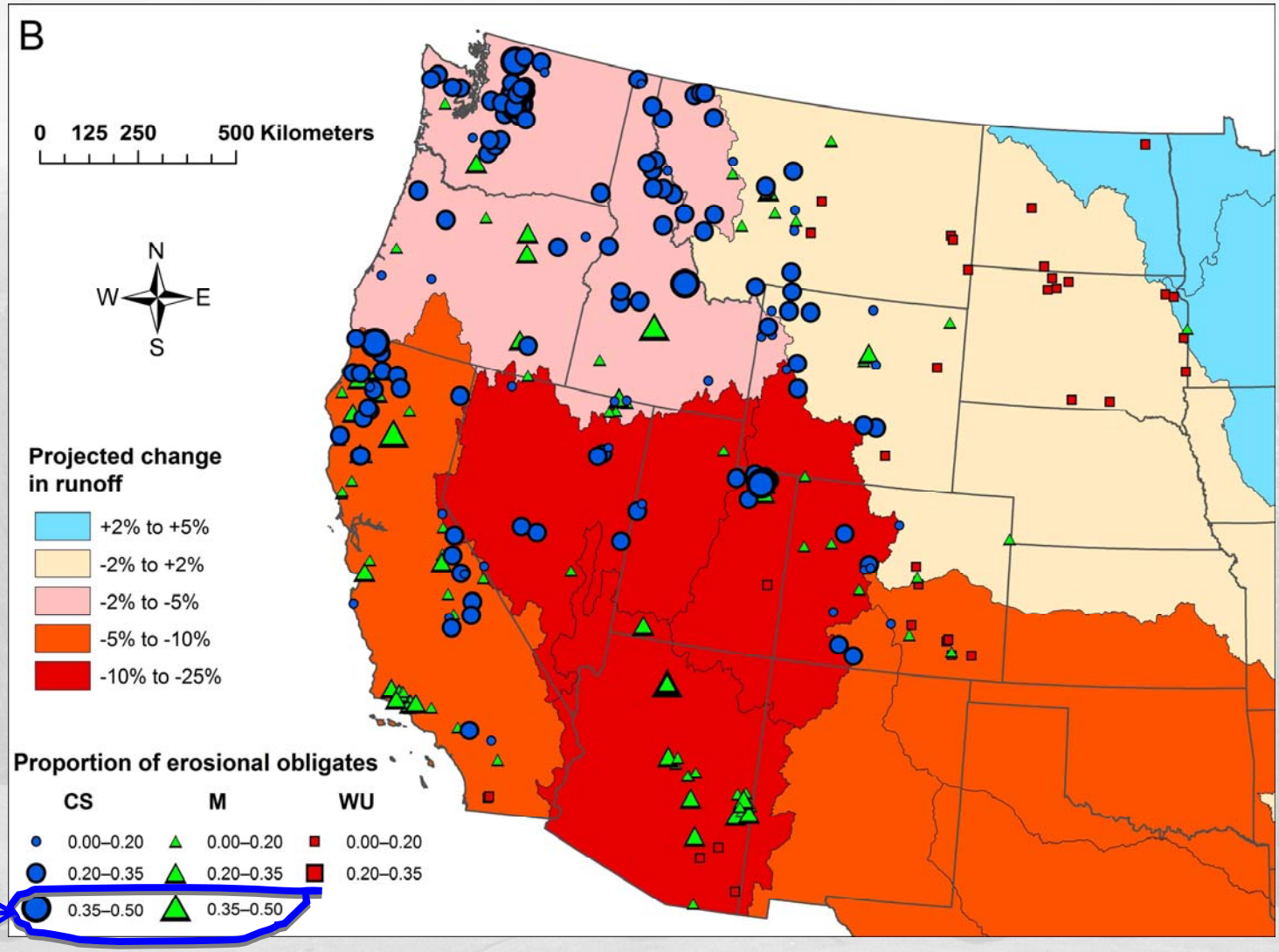
Distribution of vulnerable sites



Regional differences in ΔQ

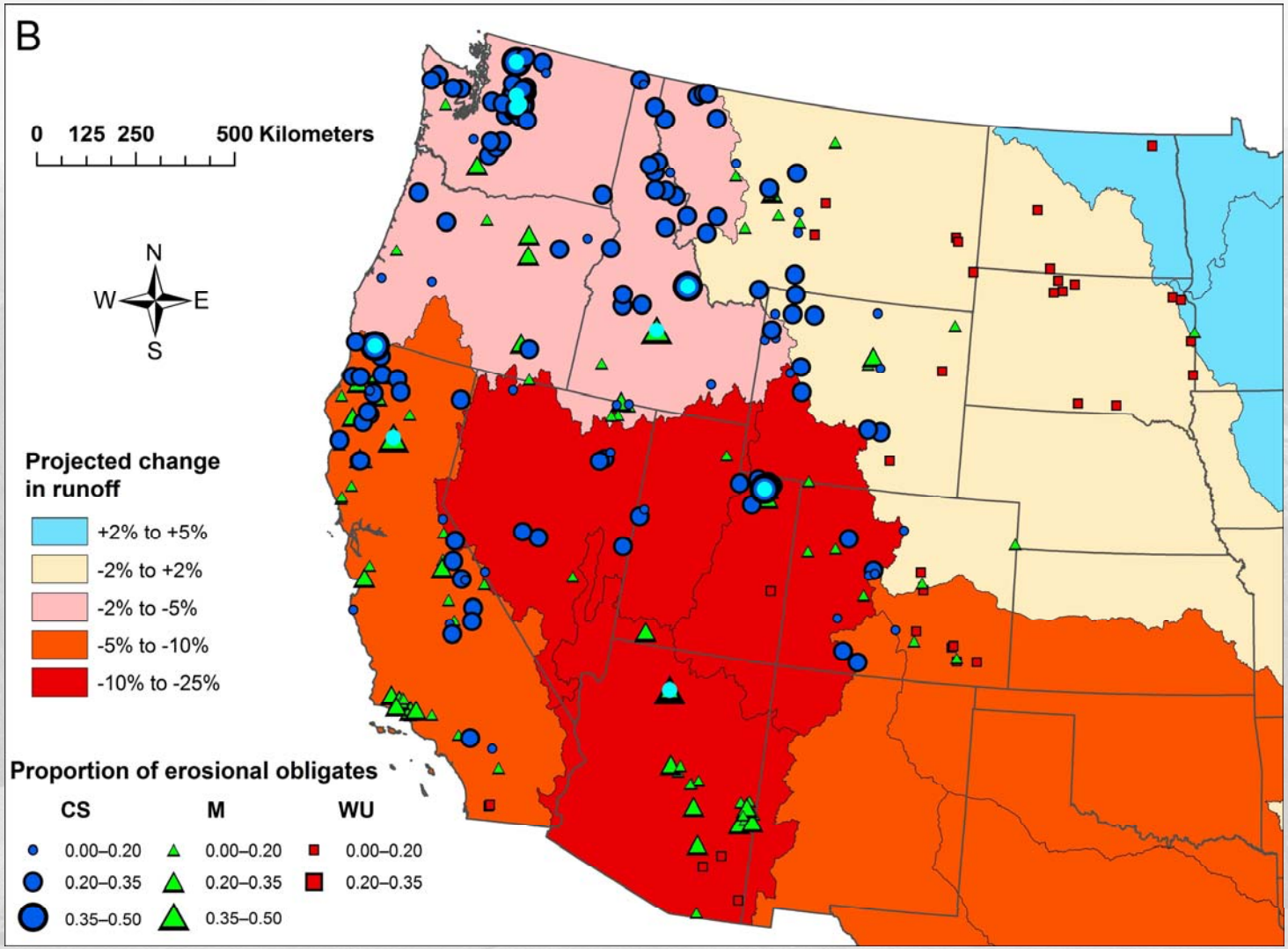


Distribution of *sensitive* sites



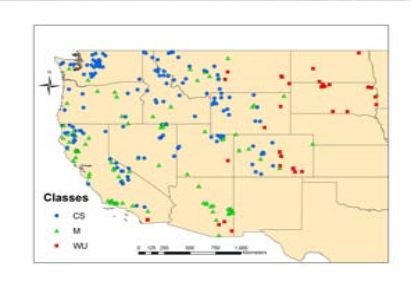
Many CS sites 35-50% taxa; few M; no WU

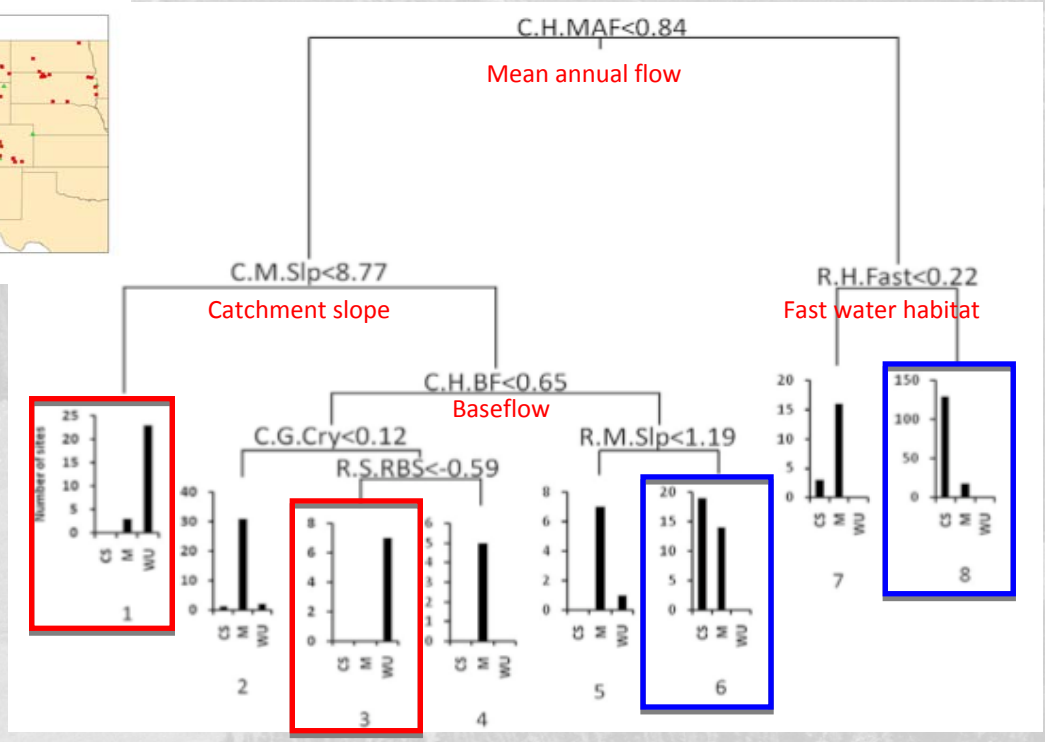
Distribution of vulnerable sites



Conclusions

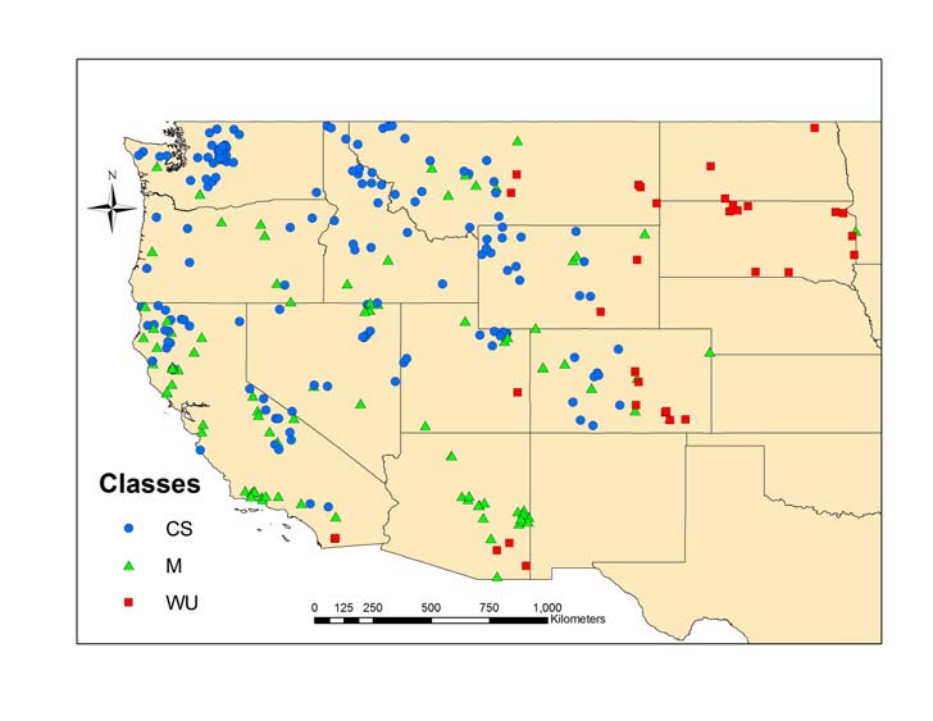
- Climatic variables correlate strongly with traits-based community types of aquatic insects
- Can roughly assess vulnerable sites using traits
  - Potential for a structured, predictive model?

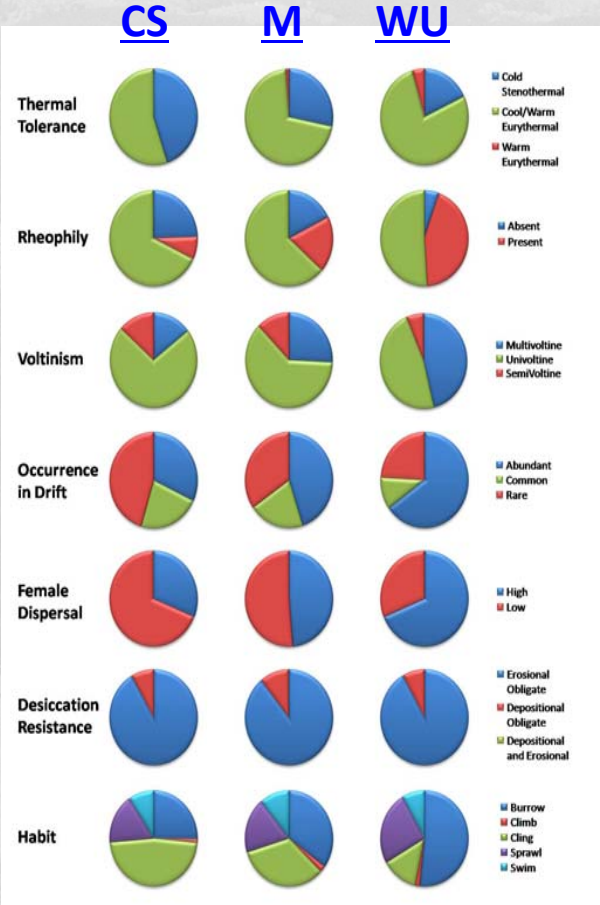




Conclusions

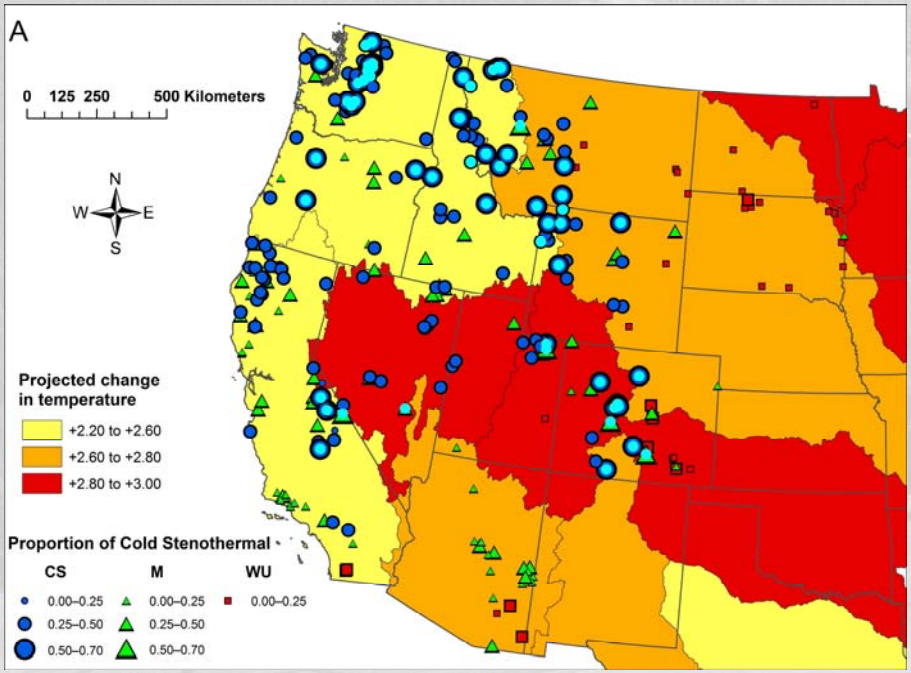
- More than one "traits-based reference type" will be required to assess community responses to climate change

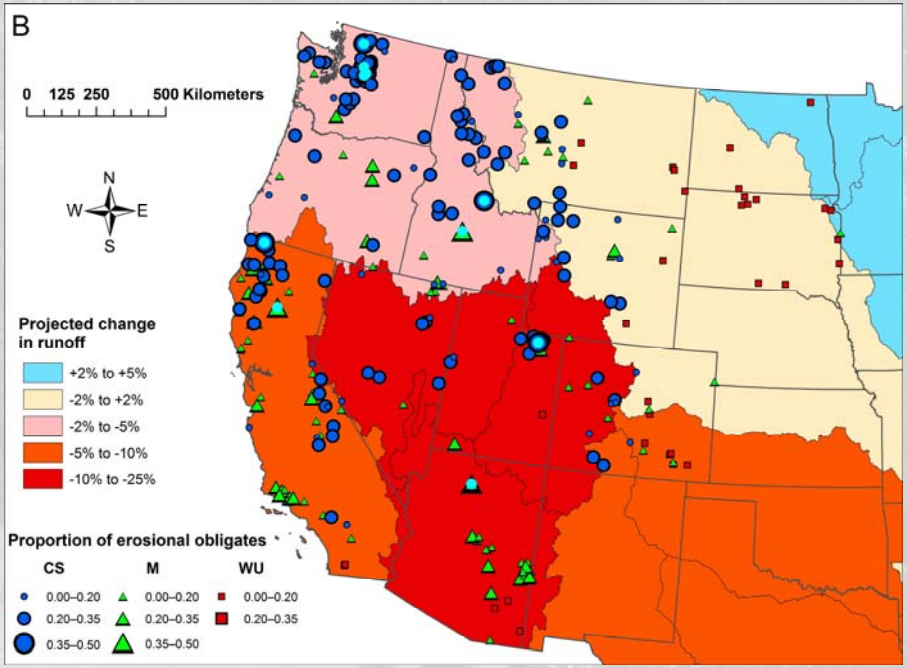




Conclusions

- Vulnerability to ΔT and ΔQ vary with trait community type and are variable at the subregional scale





Implications

- Potential species replacements in most-vulnerable sites (CS sites) may result in a net loss of diversity or a change in ecosystem function, for example …
  - 62% taxa in CS streams of upper Colorado HUC2 are cold stenotherms. Most warm/cool eurytherms that might colonize are depositional obligates or burrowers, habits that are not well supported in high gradient CS stream types.
  - Across all sites, 24 shredders, 16 of which are cold stenotherms and 51 grazer species, 25 of which cold stenotherms.

What's needed next?

- Consider more mechanistic sensitivity traits (e.g., hypoxia, thermal tolerance and acclimation under different temperature, flow conditions)
- Incorporate "local" habitat features that
  - Afford resilience and influence vulnerability (e.g., geomorphic context, groundwater inflows that afford refugia)
  - may limit species re-distribution under altered T and Q
- Good assessments of vulnerability will be harder than we may now imagine and require targeted research.
- Refinement of notion of traits-based "reference" condition?

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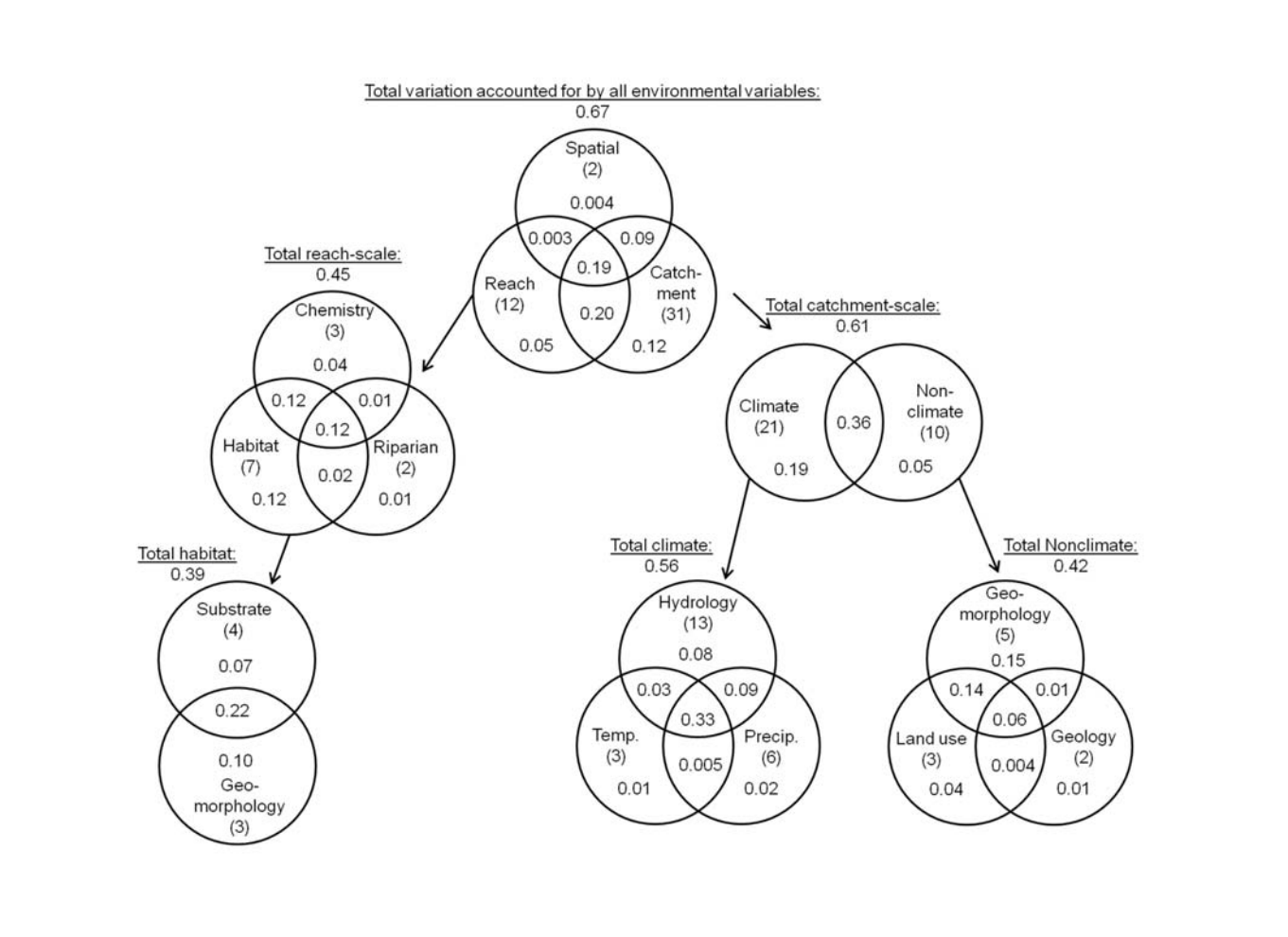

FIG. 1. Results of hierarchical redundancy analysis showing partitioning of explained variation in functional composition of 279 sites according to 45 environmental variables (see Appendix). Total variation explained (67%) was partitioned into spatial, local (reach), and catchment variables and their interactions. All variables were partitioned into reach-scale vs catchment-scale variables. Reach- and catchment-scaled variables explained 45% and 61% of total variation, respectively. Reach-scale variables were further partitioned into component variables (riparian, chemistry, and habitat structure [which consisted of component variables]), and catchment-scale variables were further partitioned into climate and nonclimate variables (each with their component variables). Numbers in parentheses indicate the number of component variables in each partition.