Effects of projected climate change on USA stream biodiversity: update on climate, hydrology, stream temperature, stream water chemistry, and biodiversity models.

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Utah State University
DEPARTMENT OF WATERSHED SCIENCES

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Project Participants

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Overarching Questions

How will climate change affect the biodiversity of streams and rivers at local and regional scales?

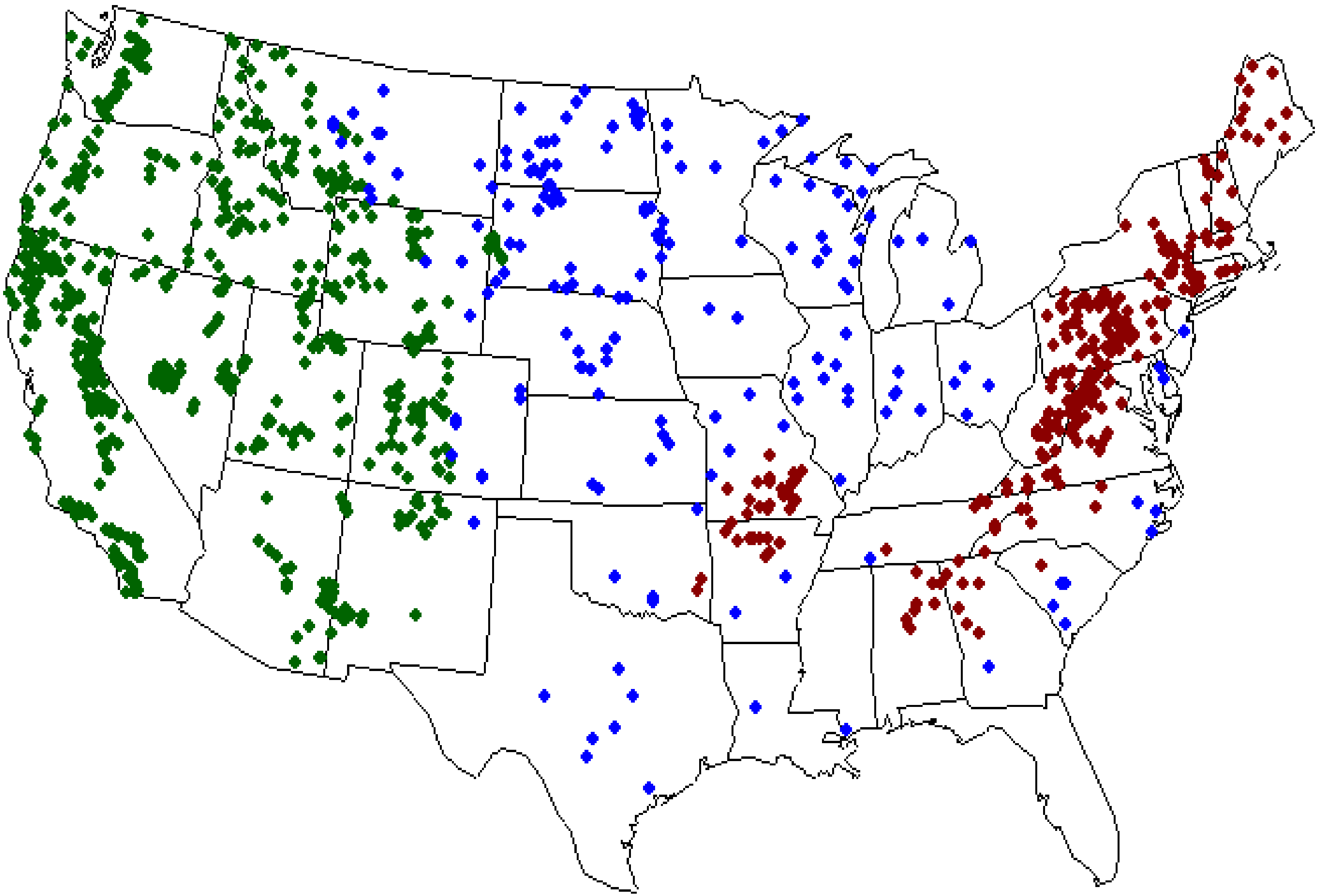
How will biotic response to climate change confound interpretation of biological assessments?

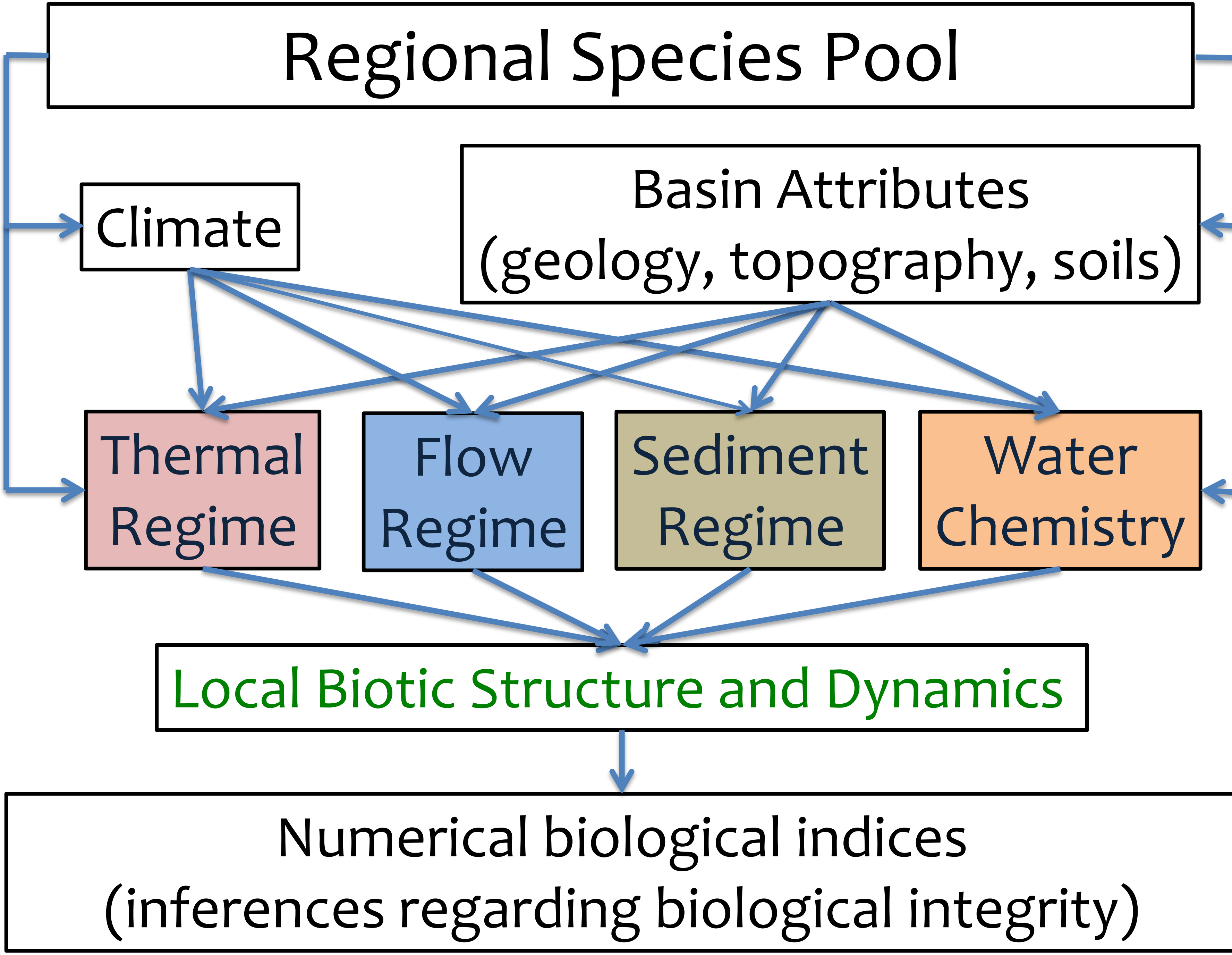
Take Home Messages

- Downscaling climate predictions suffer from high uncertainty.
- Accurate/useful prediction is hard:

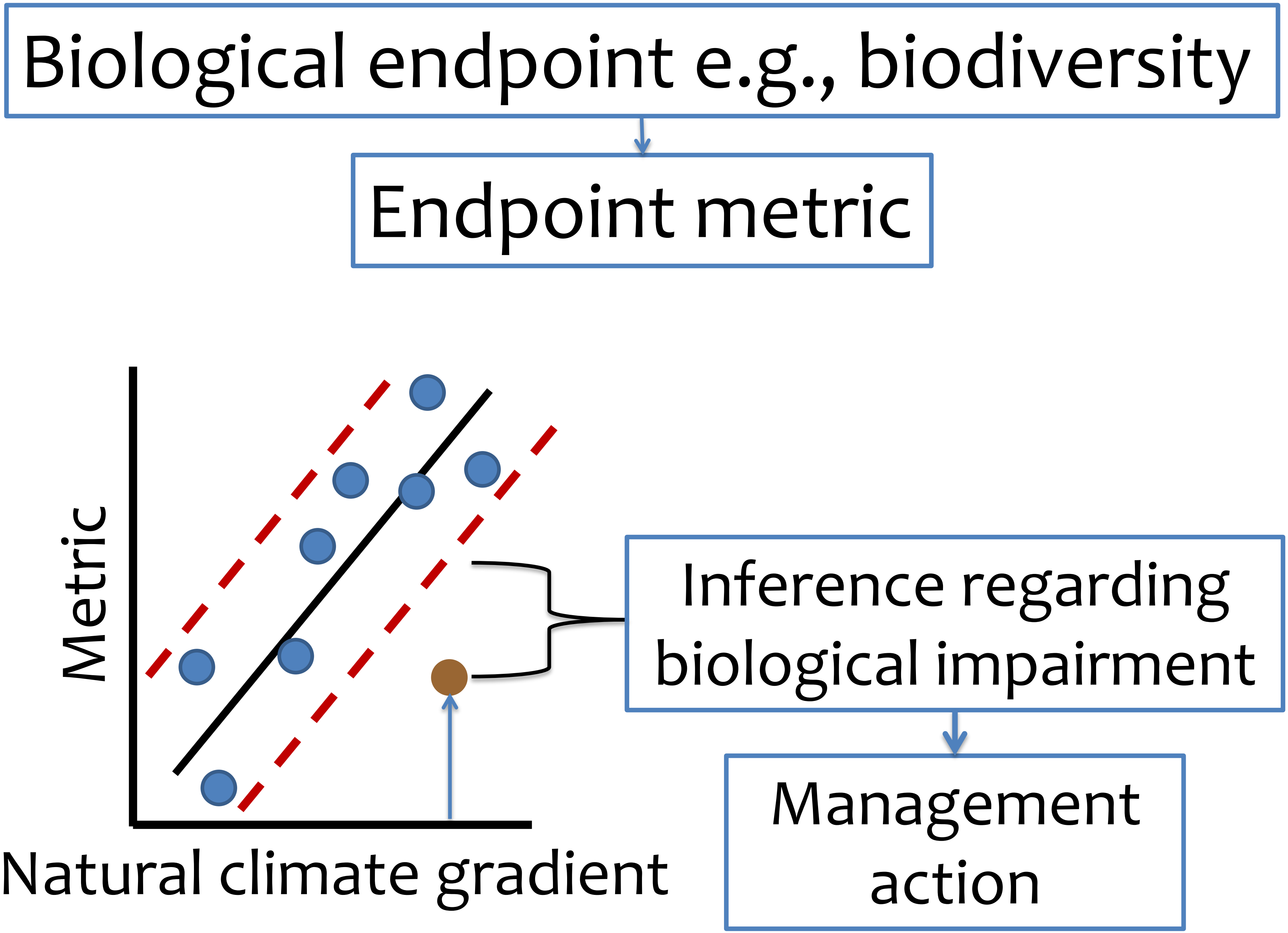
  CC > Flow regime > Biota > Chemistry > Temperature.
- Biotic vulnerability to CC is context dependent.
- Climate induced changes in stream invertebrate biodiversity will greatly confound interpretation of indices of biological integrity.

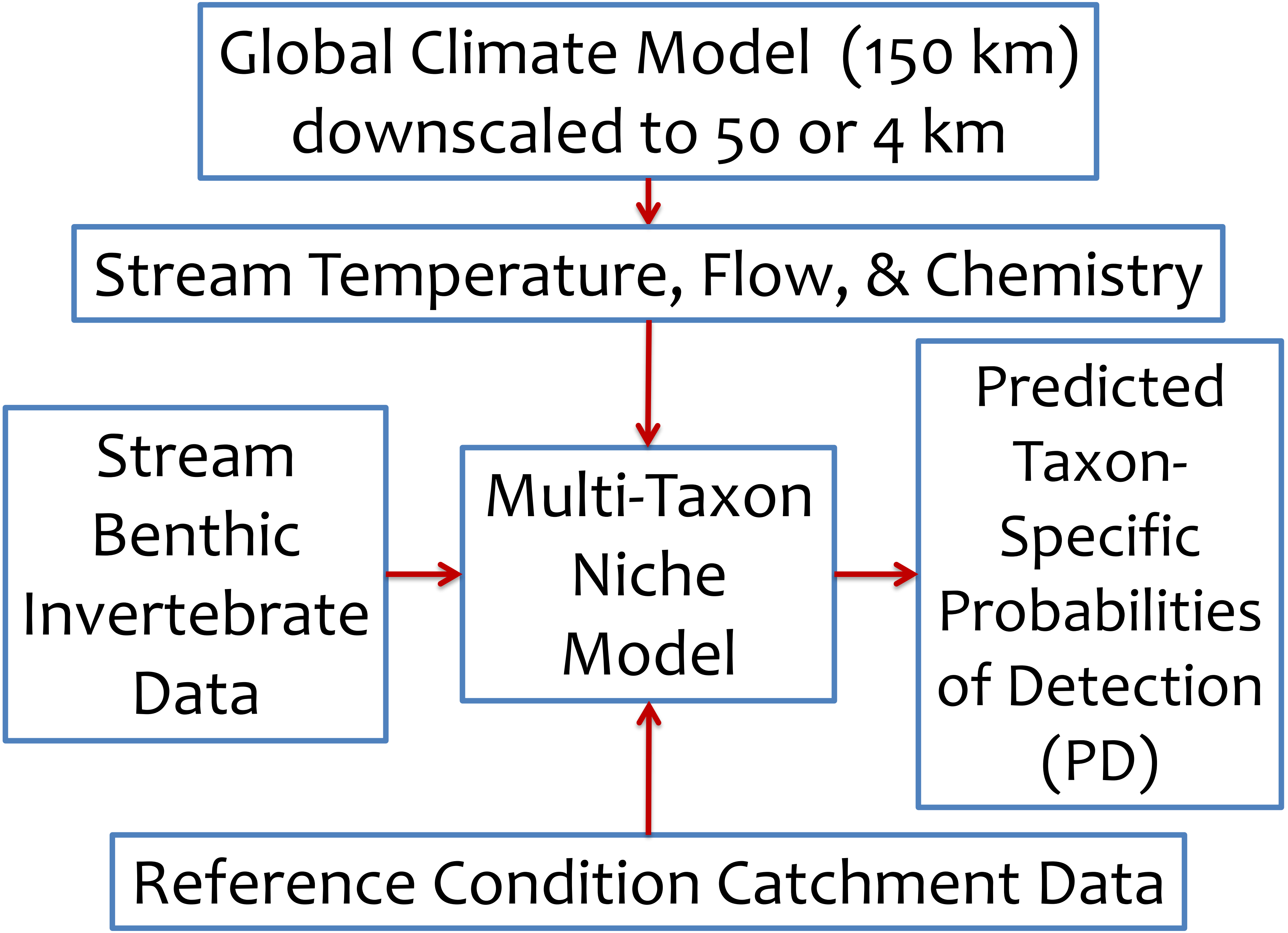
National Wadeable Stream Assessment Reference Sites





Regional Species Pool
Climate
Basin Attributes
(geology, topography, soils)
Thermal Regime
Flow Regime
Sediment Regime
Water Chemistry
Local Biotic Structure and Dynamics
Numerical biological indices
(inferences regarding biological integrity)


Biological endpoint e.g., biodiversity
Endpoint metric
Metric
Natural climate gradient
Inference regarding biological impairment
Management action


Global Climate Model (150 km) downscaled to 50 or 4 km
Stream Temperature, Flow, & Chemistry
Stream Benthic Invertebrate Data
Multi-Taxon Niche Model
Predicted Taxon-Specific Probabilities of Detection (PD)
Reference Condition Catchment Data

Use of niche model output

Species	PD
1	1.0
2	0.8
3	0.5
4	0.5
5	0.4
6	0.3
…	…
n	0.0

<u>Biodiversity:</u>
Expected number of local taxa: $E = \sum PD$

<u>Bioassessment:</u>
O/E is a measure of community alteration, where O = observed # of expected taxa.

The Practical Challenge

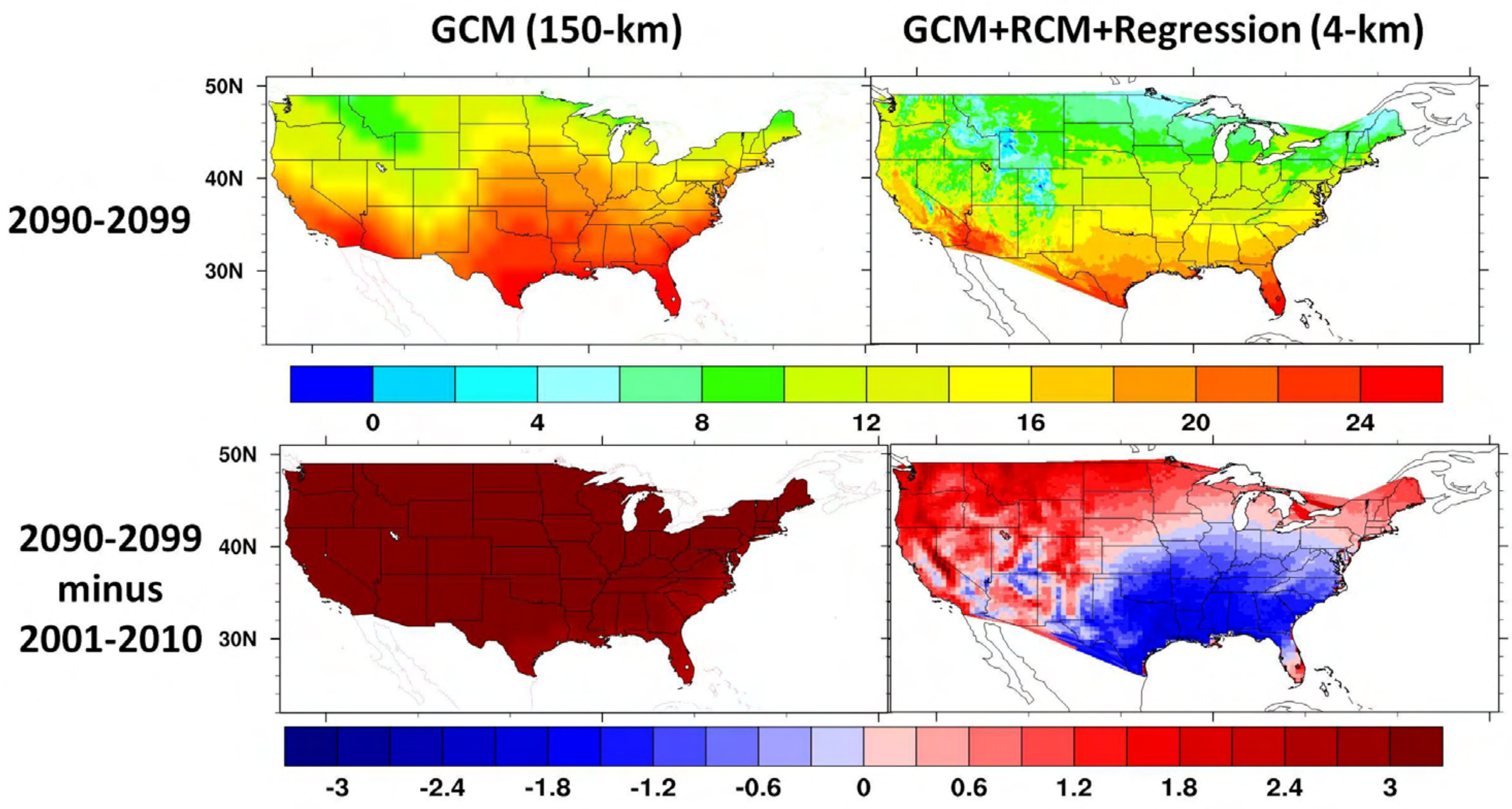
Progress to Date
(details in 6 posters)

- Climate prediction
- Stream temperature prediction
- Flow regime characterization and prediction
- Baseflow water chemistry prediction
- Niche modeling
  - Biodiversity response to climate change
  - Effect on interpretation of biological assessments

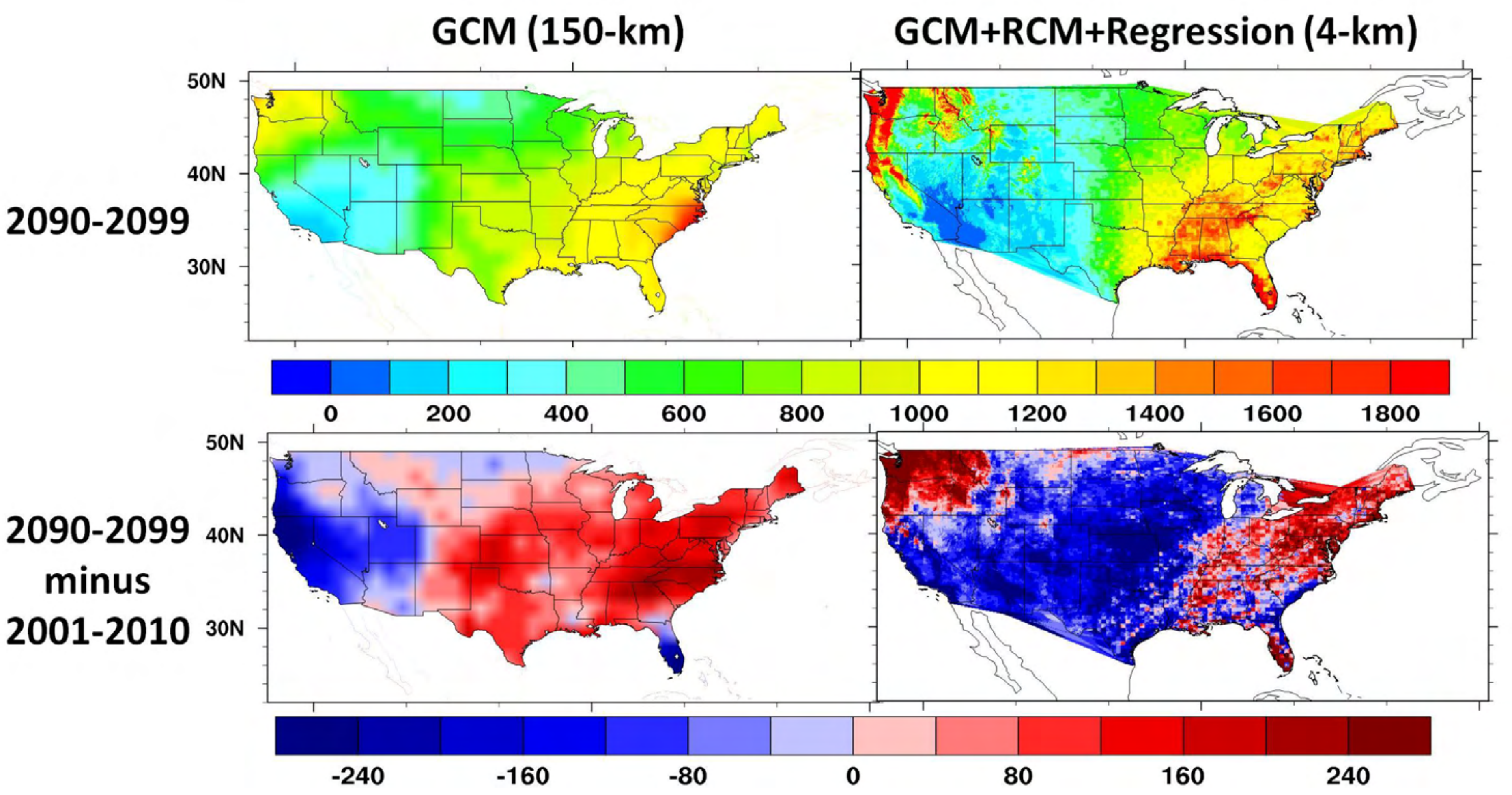
Climate modeling
(Jin poster)

- Assume A2 scenario.
- Focus on estimating climate regimes for 3 periods:
  - 2000-2009, 2040-2049, 2090-2099.
- Two-prong approach:
  - Statistical downscaling of GCM (CCSM) calibrated with PRISM data (observation).
  - Dynamic downscaling: GCM->RCM->PRISM.
- Products to date:
  - Assessment of dynamic model sensitivities (Meyer and McCoy posters).
  - Both statistical and dynamic downscaling completed for the contiguous USA (Jin poster).

Differences between the GCM and the RCM for end of the century mean annual air temperatures (°C)

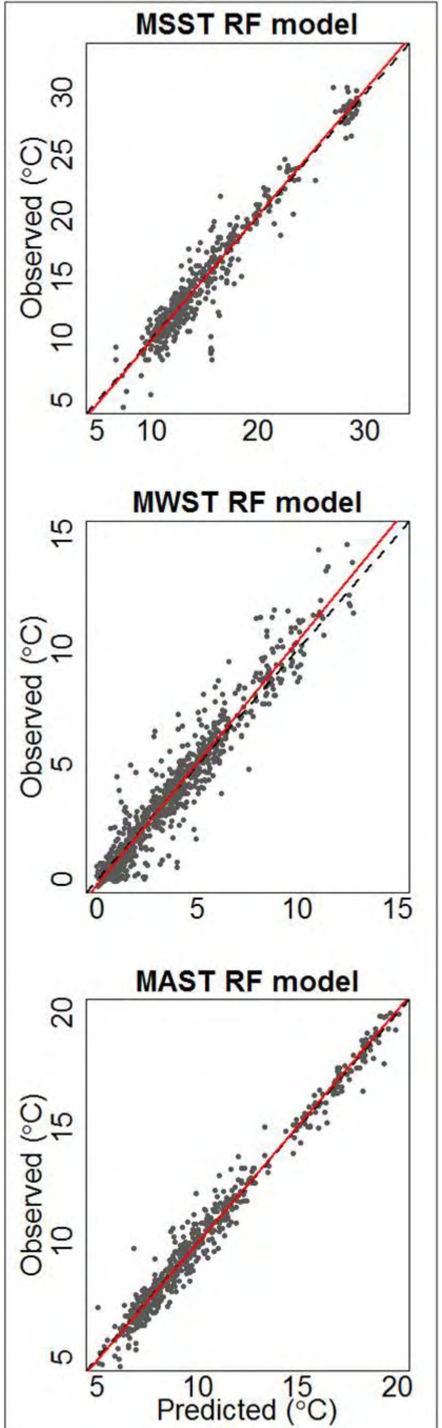


Differences between the GCM and the RCM for end of the century mean annual precipitation (mm)



Empirical temperature modeling (RF) (Hill poster)

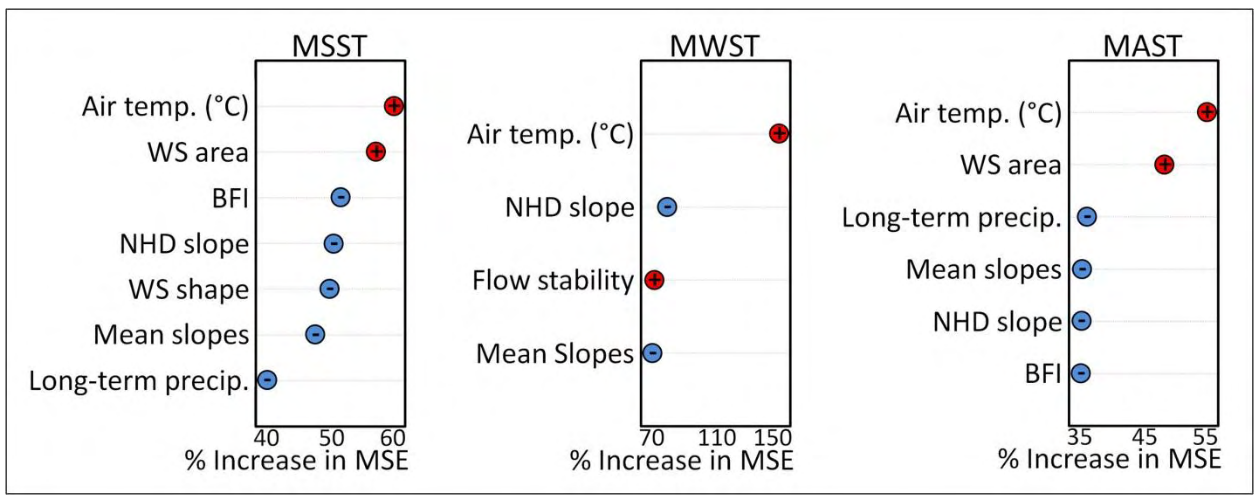
- Initial focus west of the Mississippi.
- 1,798 USGS stations: MAST, MSST, MWST.
- Modeled effects of natural and anthropogenic factors to identify reference-quality streams.
- Developed a reference condition model based on natural climate and watershed attributes.
- All 3 models perform well.
- Eastern USA streams by 1 January 2012.
- Estimating stream temperature improves prediction of biota.



Model performance statistics

	Reference sites		All sites	
Model	R^2	RMSE (°C)	r^2	RMSE (°C)
MSST	0.95	1.2	0.90	1.7
MWST	0.92	0.8	0.89	1.4
MAST	0.98	0.5	0.95	0.9

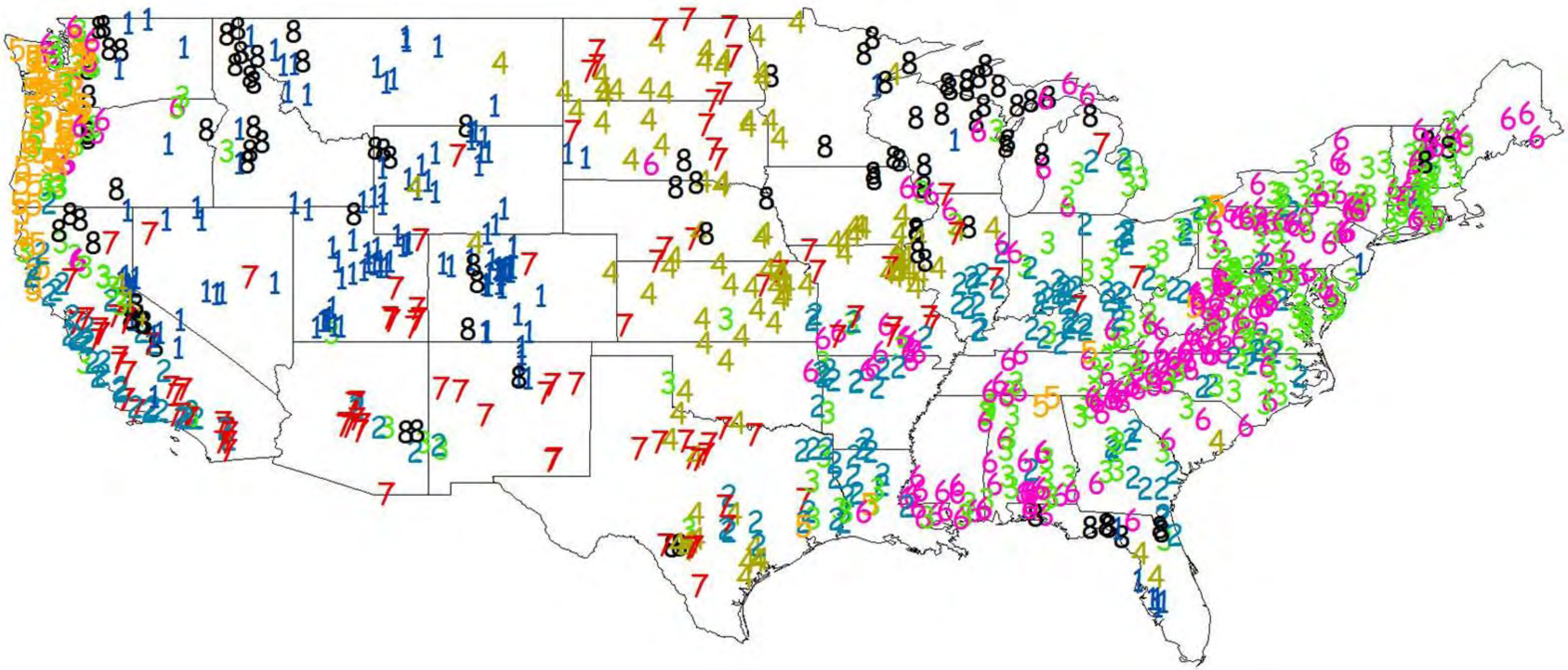
Predictor Variables



Flow characterization/modeling (Dhungel poster)

- Initial focus on understanding spatial distribution and temporal behavior of 17 flow attributes.
- 1,124 reference-quality basins.
- Current work focuses on classification of flow regimes based on TIMP.
- Next steps: predict flow regimes from climate and watershed features:
  - Quantifying flow regime improves prediction of biota.
  - Intermittency biologically critical but most difficult to predict.

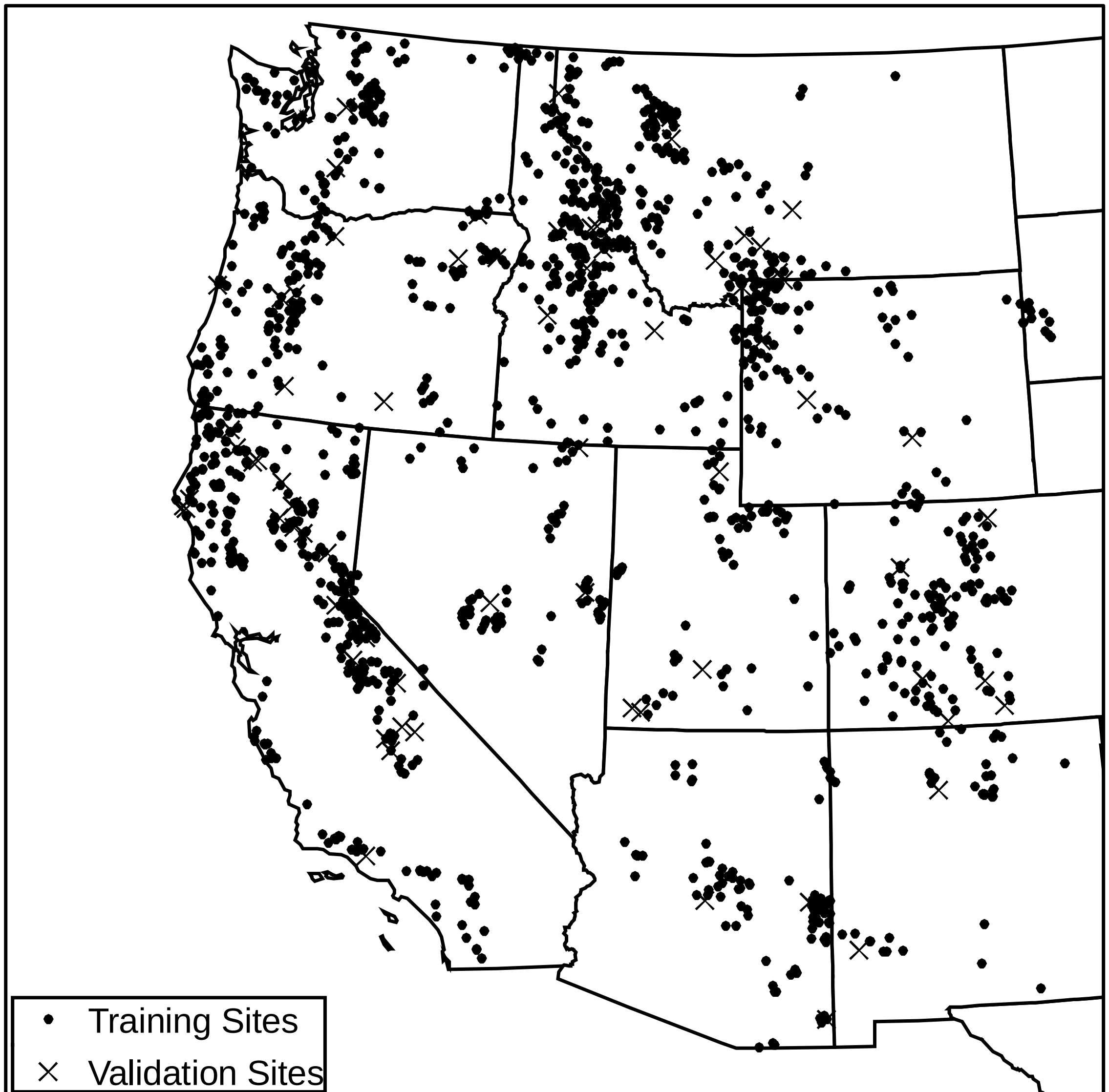
Classification of reference streams into 8 flow regime classes based on magnitude, timing, predictability, and intermittency of flow



Water chemistry modeling (Olson – no poster)

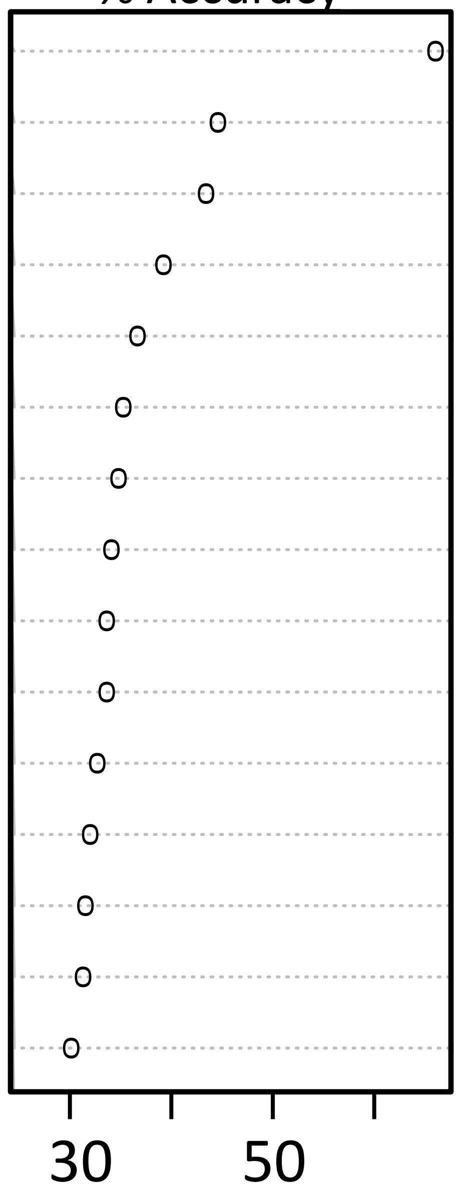
- Work funded by previous STAR grant.
- Focus on linking basin geology and climate to stream baseflow water chemistry.
- Completed west-wide (13 states) models for conductivity (EC), alkalinity, Ca, Mg, SO4, TP, and TN.
- Modeled WC improves prediction of biota.
- But, … need to complete geologic characterization for the rest of the country.

Models based on water chemistry samples from reference-quality watersheds



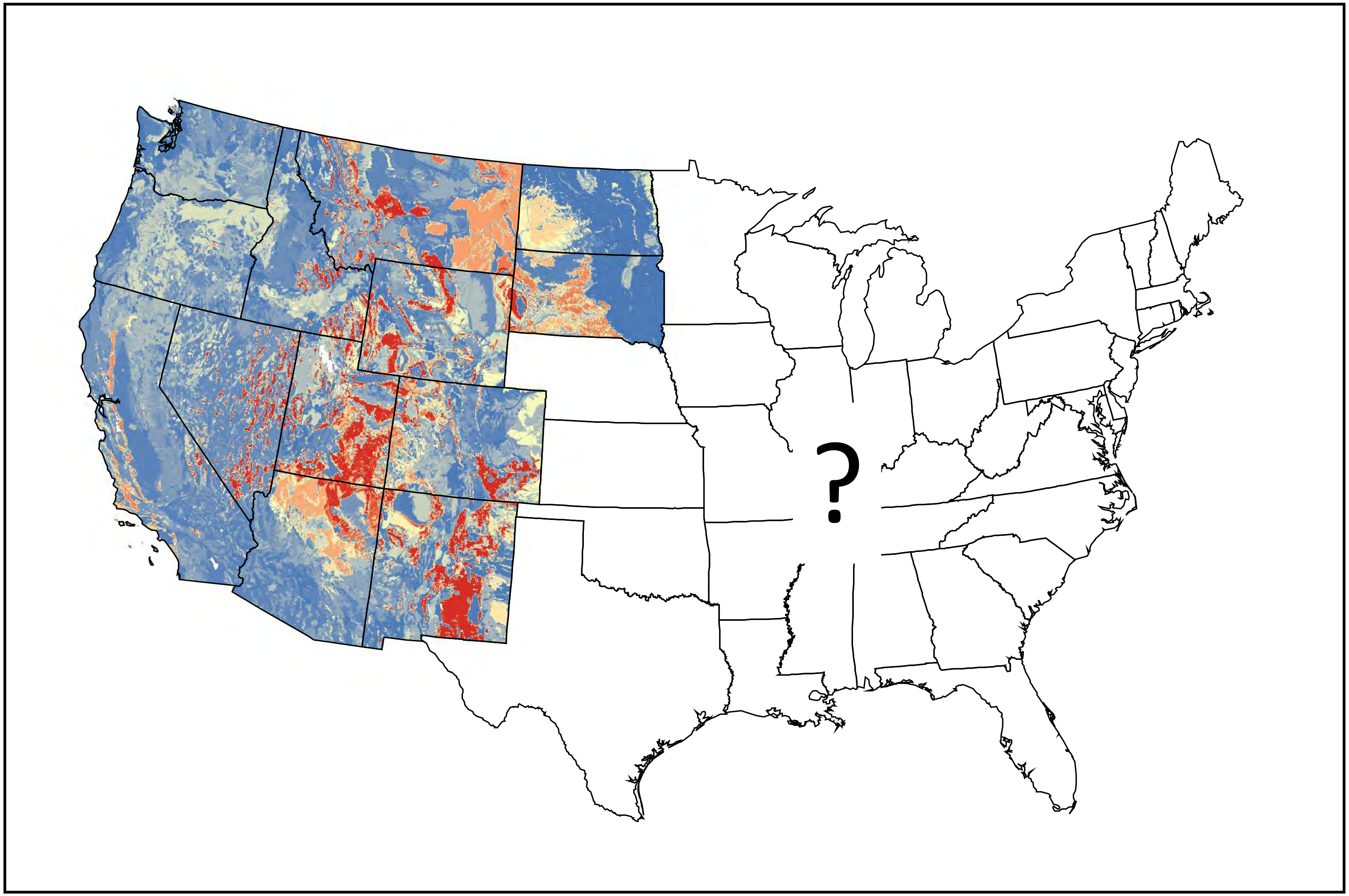
- 1487 cal sites
  - 1390 EC
  - 1323 ANC
  - 795 Ca
  - 754 Mg
  - 449 SO_4
  - 893 TP
  - 731 TN
- 73 val sites

Random Forest Conductivity Model: $R^2 = 0.71$



19 Variables:	Direction	Interpretation
% Rock CaO	+	Source
% Rock S	+	Source
Max Temperature	+	Concentration/Wx rate
Mean # Wet Days	-	Dilution
Mean Precipitation	-	Dilution
Soil Bulk Density	+	Rate Control
Soil Permeability	-	Rate Control
Atm Mg Deposition	+	Source
Atm Ca Deposition	+	Source
% Rock MgO	+	Source
Atm SO_4 Deposition	+	Rate Control
Vegetation Index	+	Rate Control
Rock Strength	-	Rate Control
Min Precipitation	-	Dilution
Max # Wet Days	-	Dilution

*



Niche modeling, Biodiversity, & Bioassessment (Hawkins - poster)

- Pilot study in California.
- 327 reference sites and 340 taxa.
- MAAT and MAP best predictors of taxon occurrence.
- Climate change will produce novel climate conditions outside of the experience of the model.
- Vulnerability of local taxa loss related to initial climatic conditions.
- 2090 climate change effect similar to that by current land use / waterway alteration.



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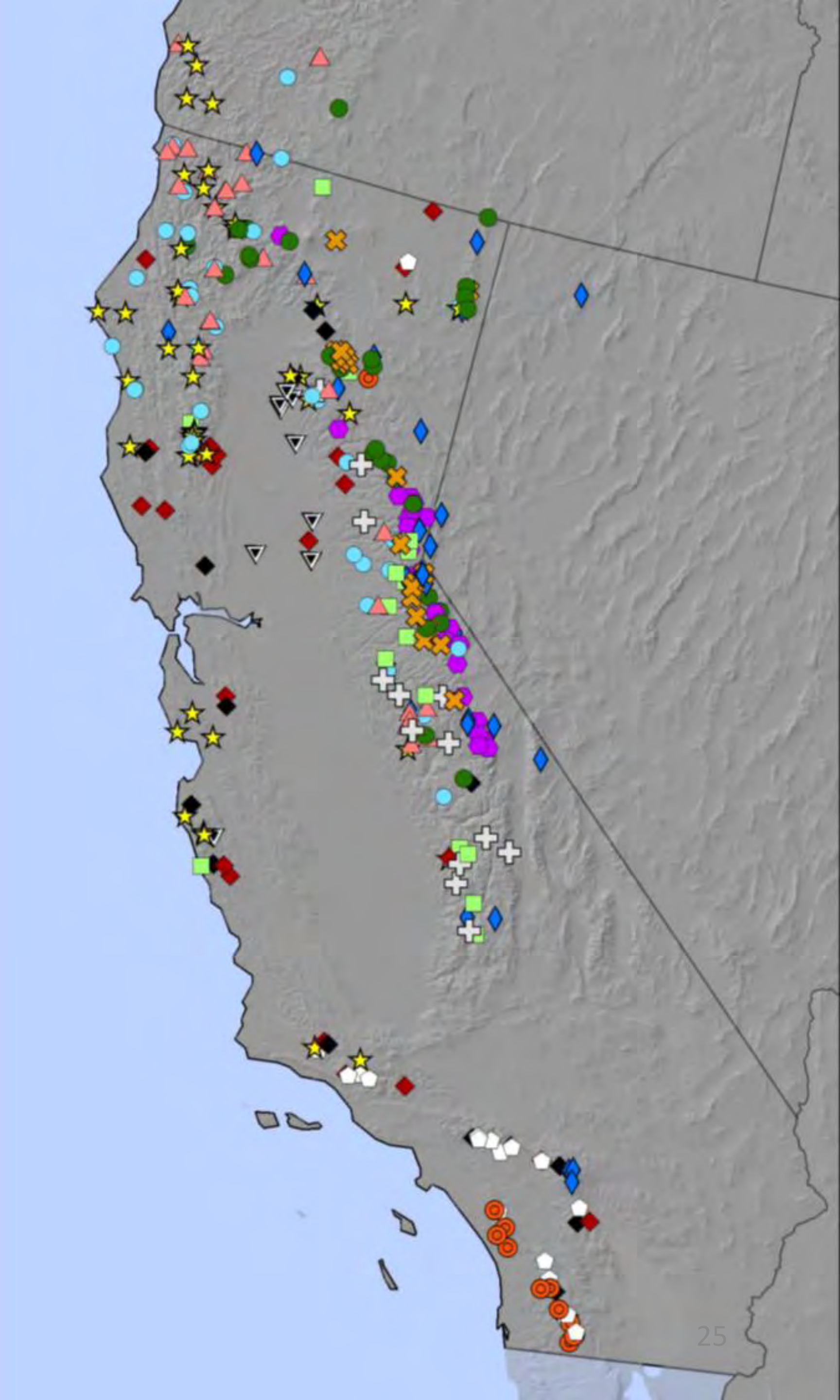
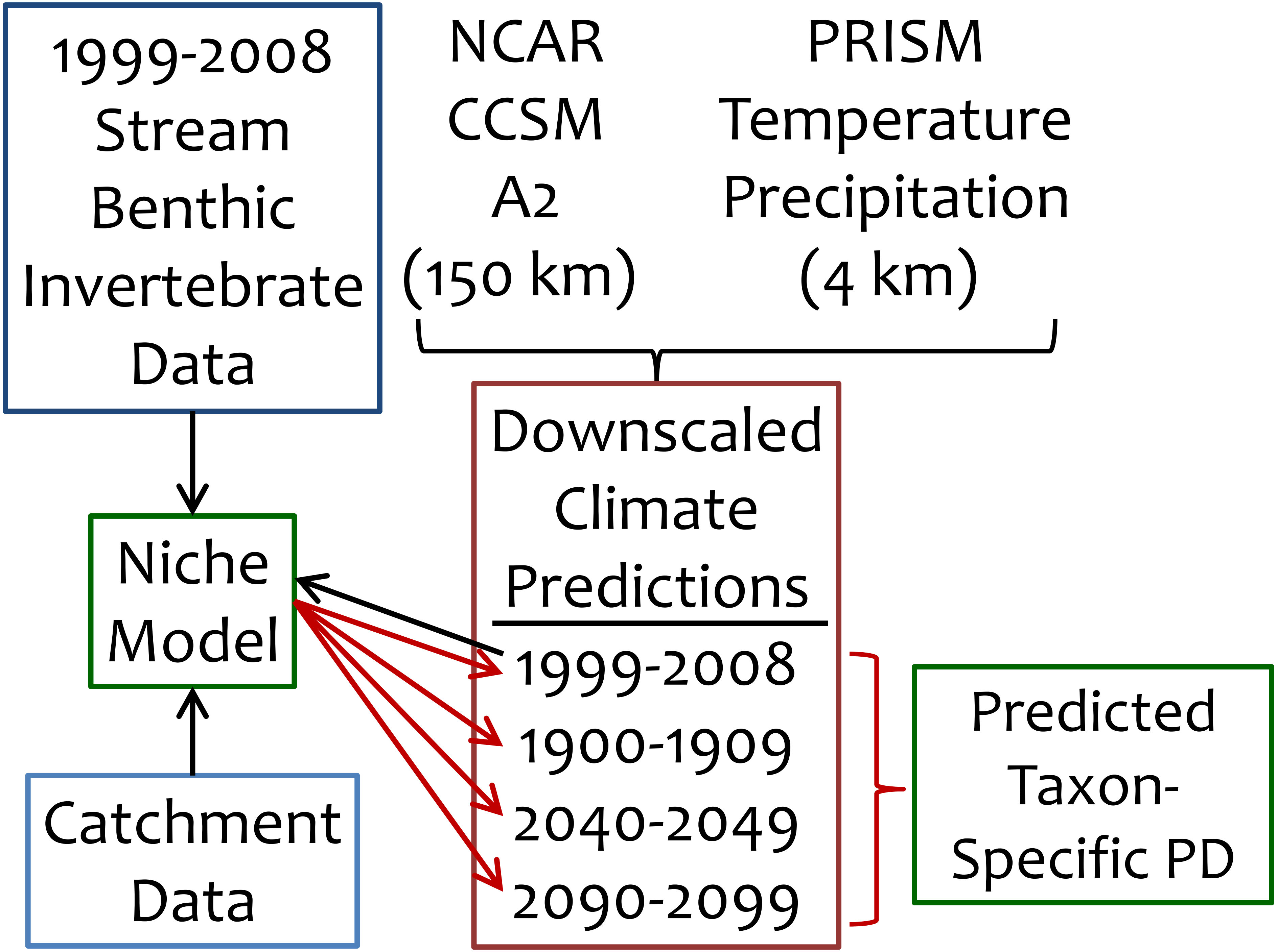
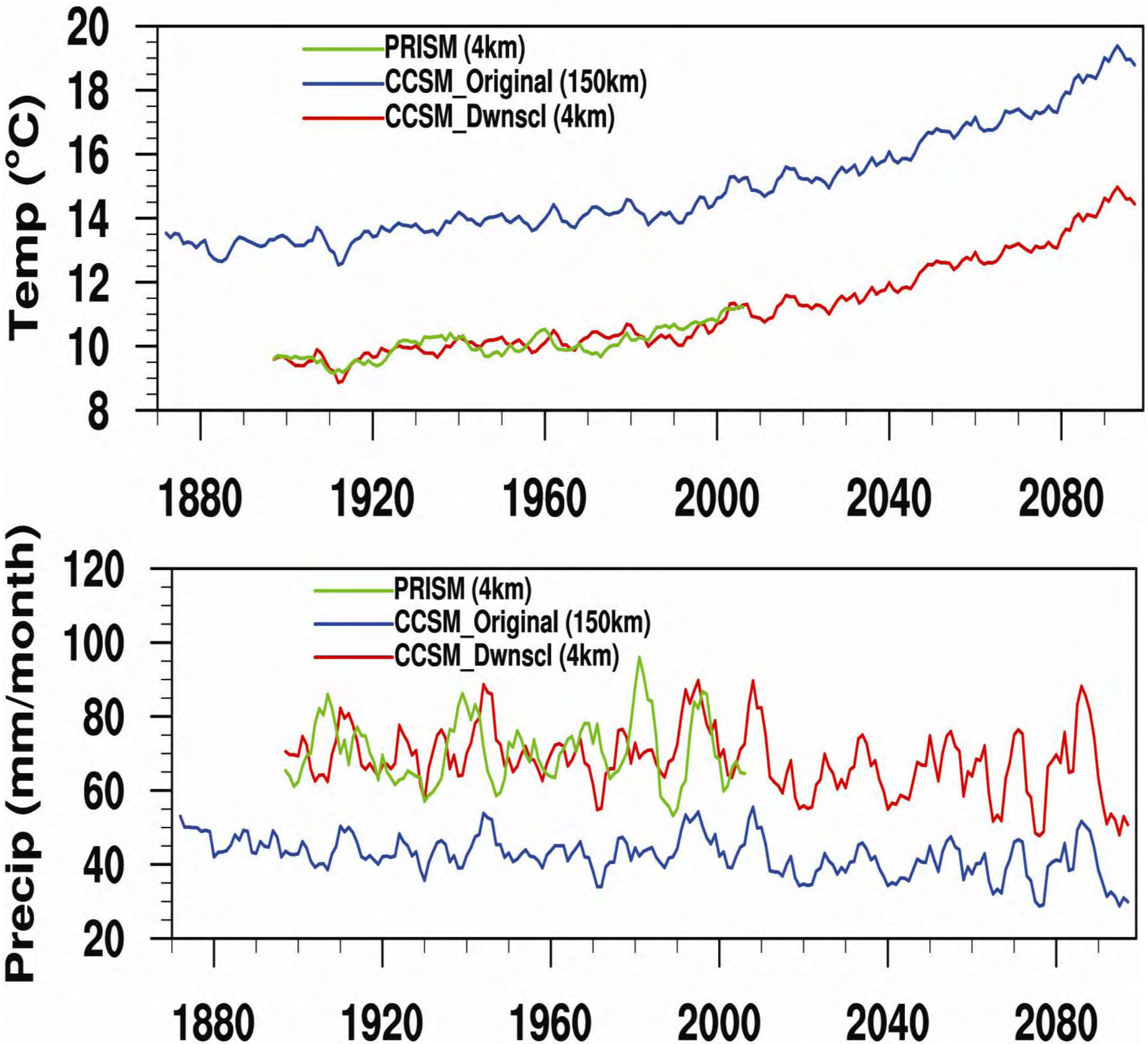
327
reference sites.

340 taxa.



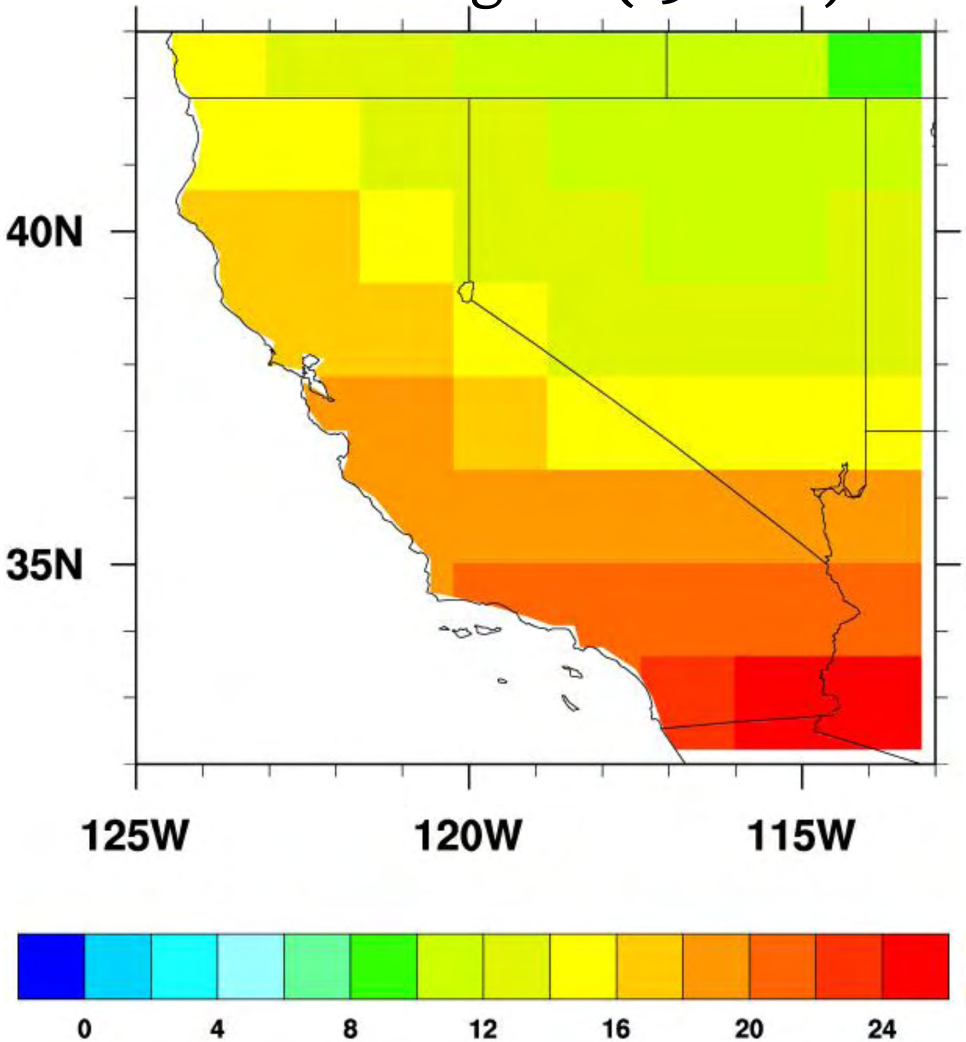

1999-2008 Stream Benthic Invertebrate Data
NCAR CCSM A2 (150 km)
PRISM Temperature Precipitation (4 km)
Downscaled Climate Predictions
1999-2008
1900-1909
2040-2049
2090-2099
Niche Model
Catchment Data
Predicted Taxon-Specific PD



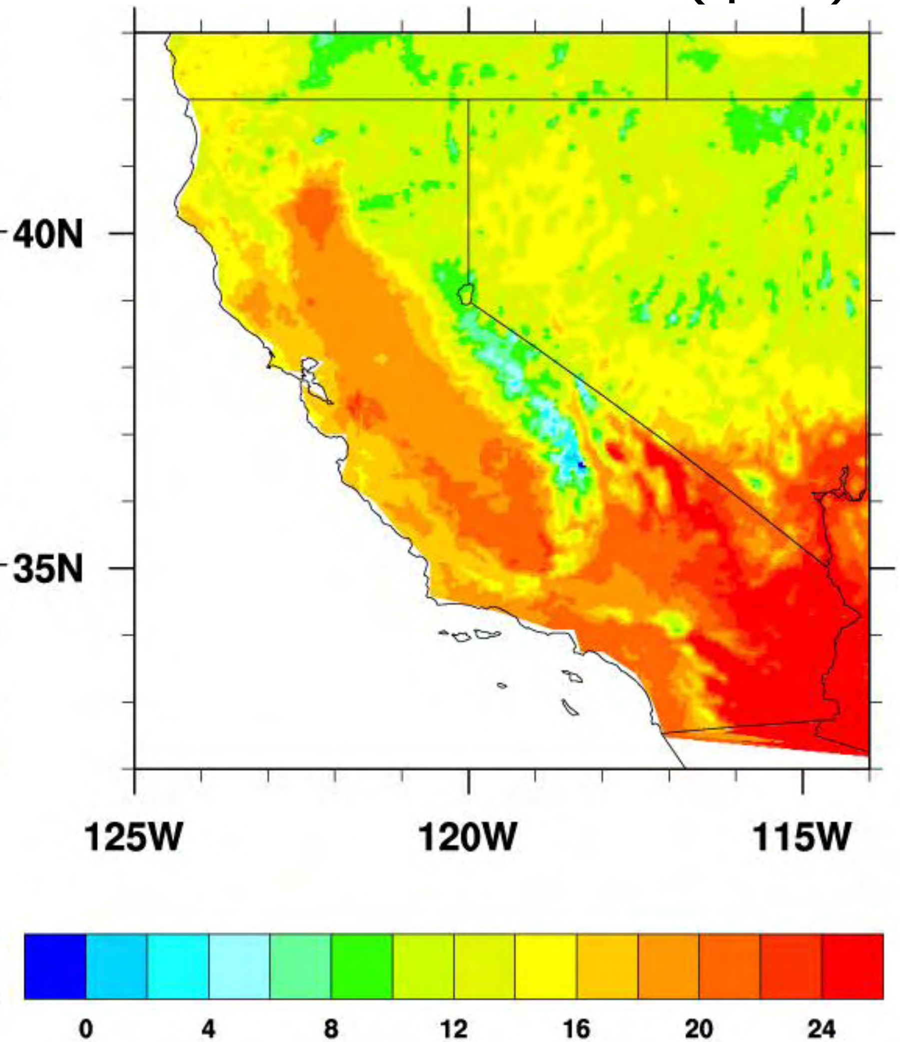
Temp (°C)
20
18
16
14
12
10
8
PRISM (4km)
CCSM_Original (150km)
CCSM_Dwnscl (4km)
1880
1920
1960
2000
2040
2080
Precip (mm/month)
120
100
80
60
40
20
PRISM (4km)
CCSM_Original (150km)
CCSM_Dwnscl (4km)
1880
1920
1960
2000
2040
2080

A2 2090 Temperature (ºC)

CCSM Original (150 km)



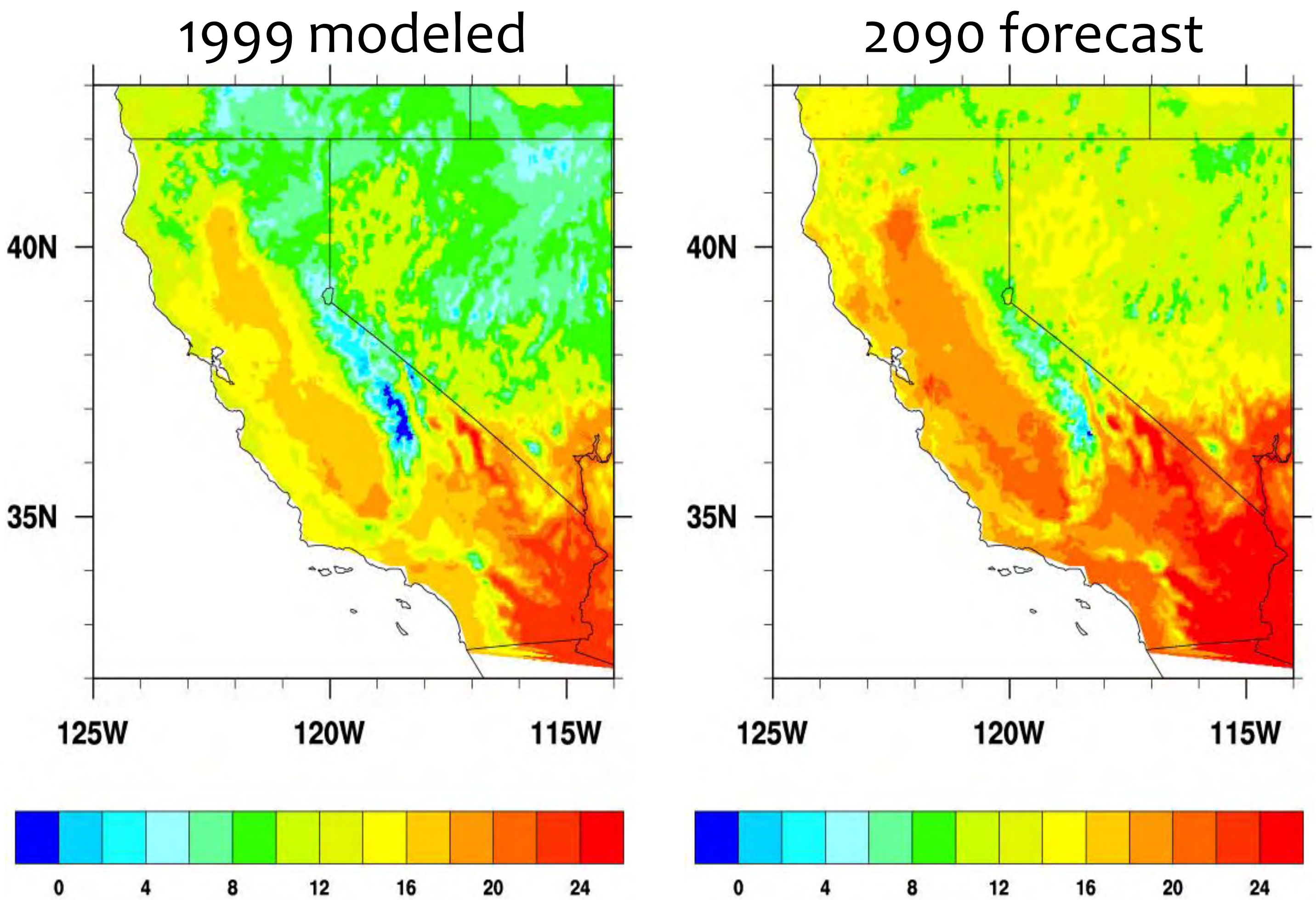
CCSM Downscaled (4km)



A2 Climate Change Scenario

(CCSM 150 -> 4 km empirically downscaled predictions)

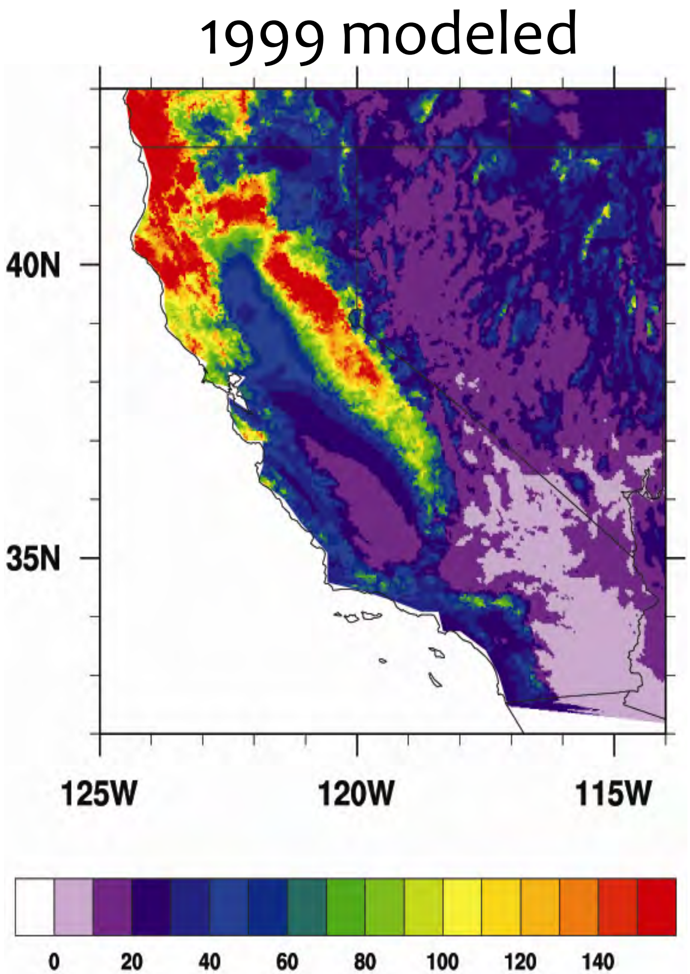
Mean Annual Temperature (°C)

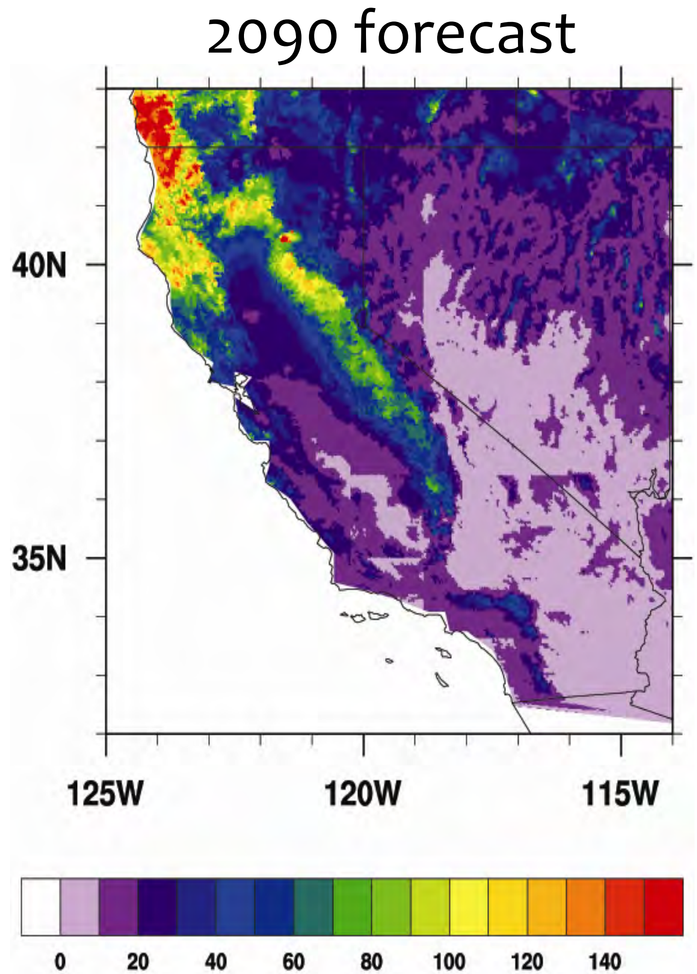


A2 Climate Change Scenario

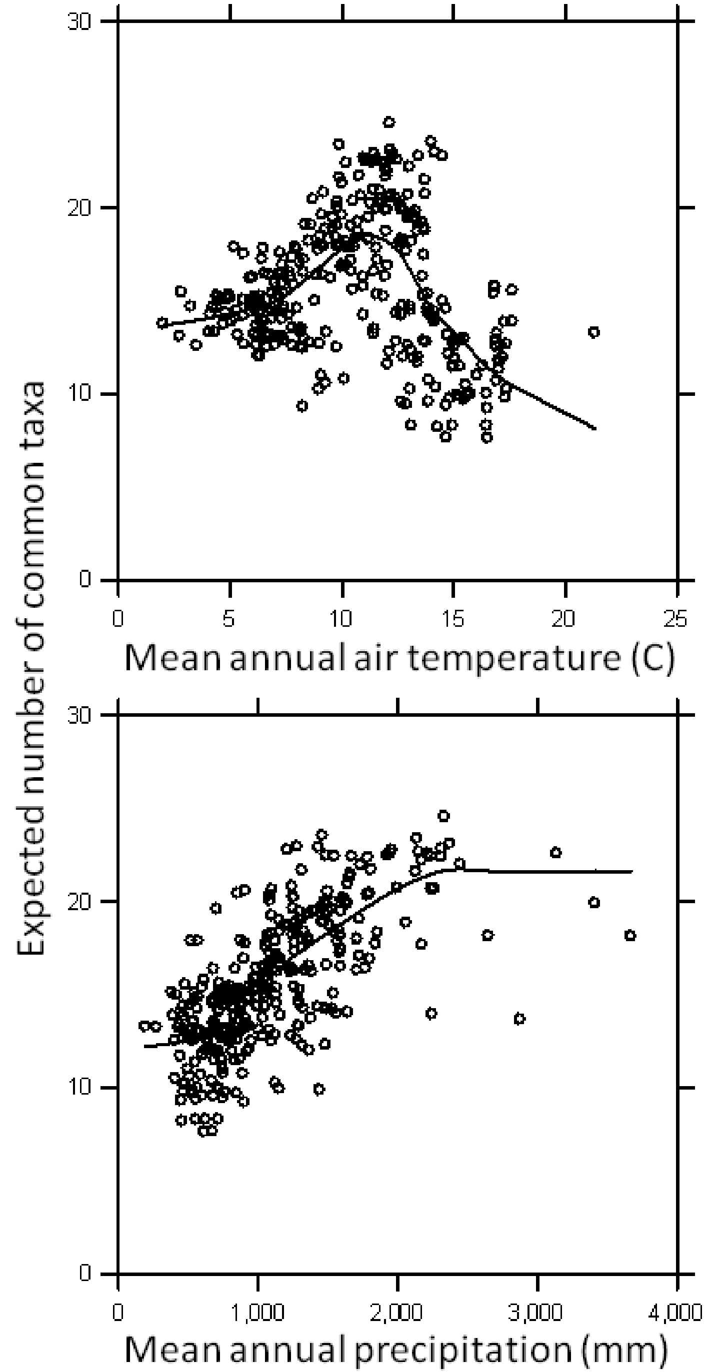
(CCSM 150 -> 4 km empirically downscaled predictions)

Mean Monthly Precipitation (cm)





MAAT and MAP were the strongest predictors of variation in taxa richness across sites.
Other predictors included basin size, basin elevation range, and stream EC.



Predicted Biodiversity Response

- Changes in mean PD:
  - 172 decreasers
  - 168 increasers
- Many local extinctions.
- ~10% loss of local richness.
- No loss of regional richness!

Most Sensitive Taxa
(Δ% of sites "detected")

-42%

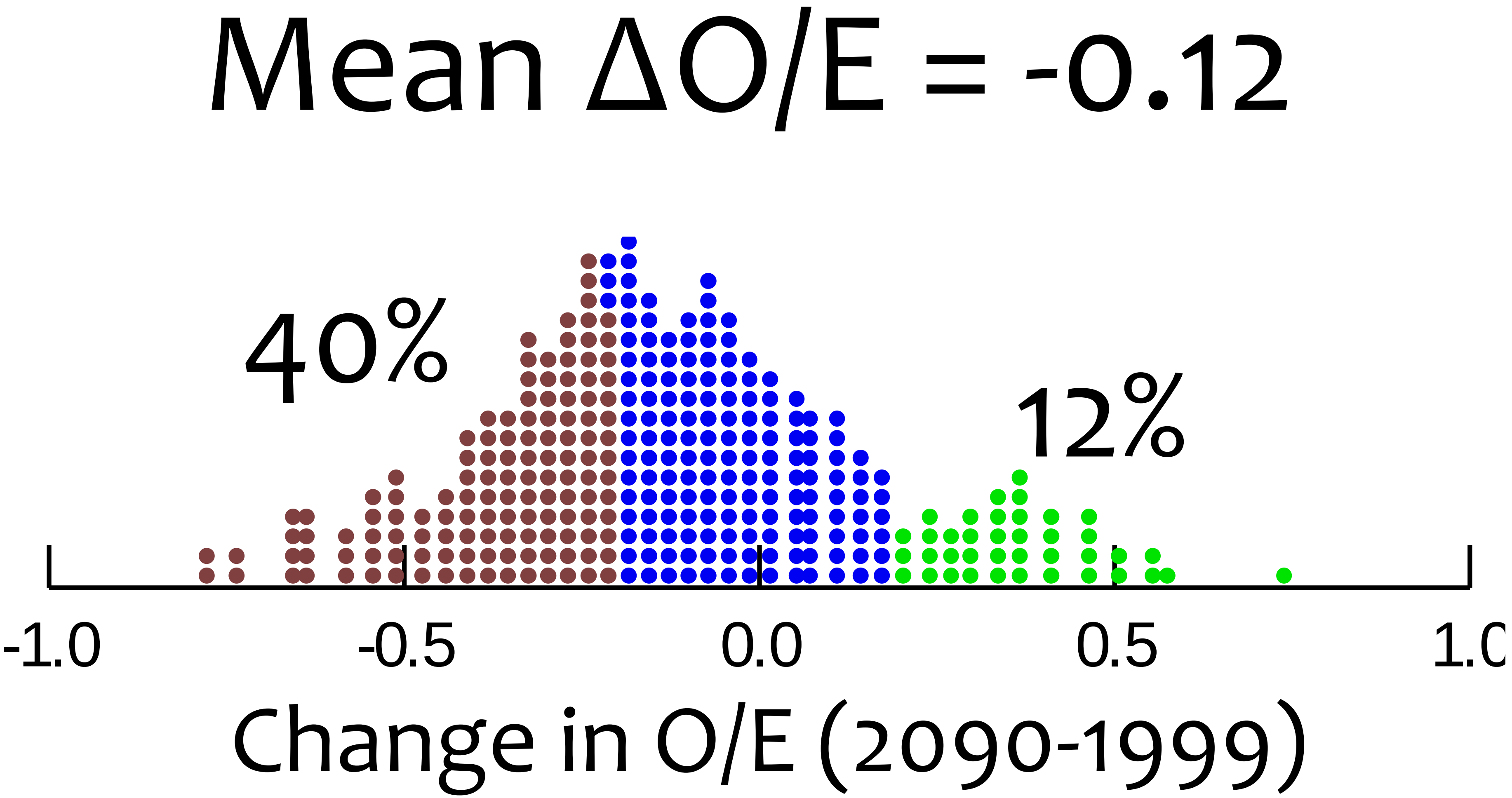
+126%

-37%

+113%

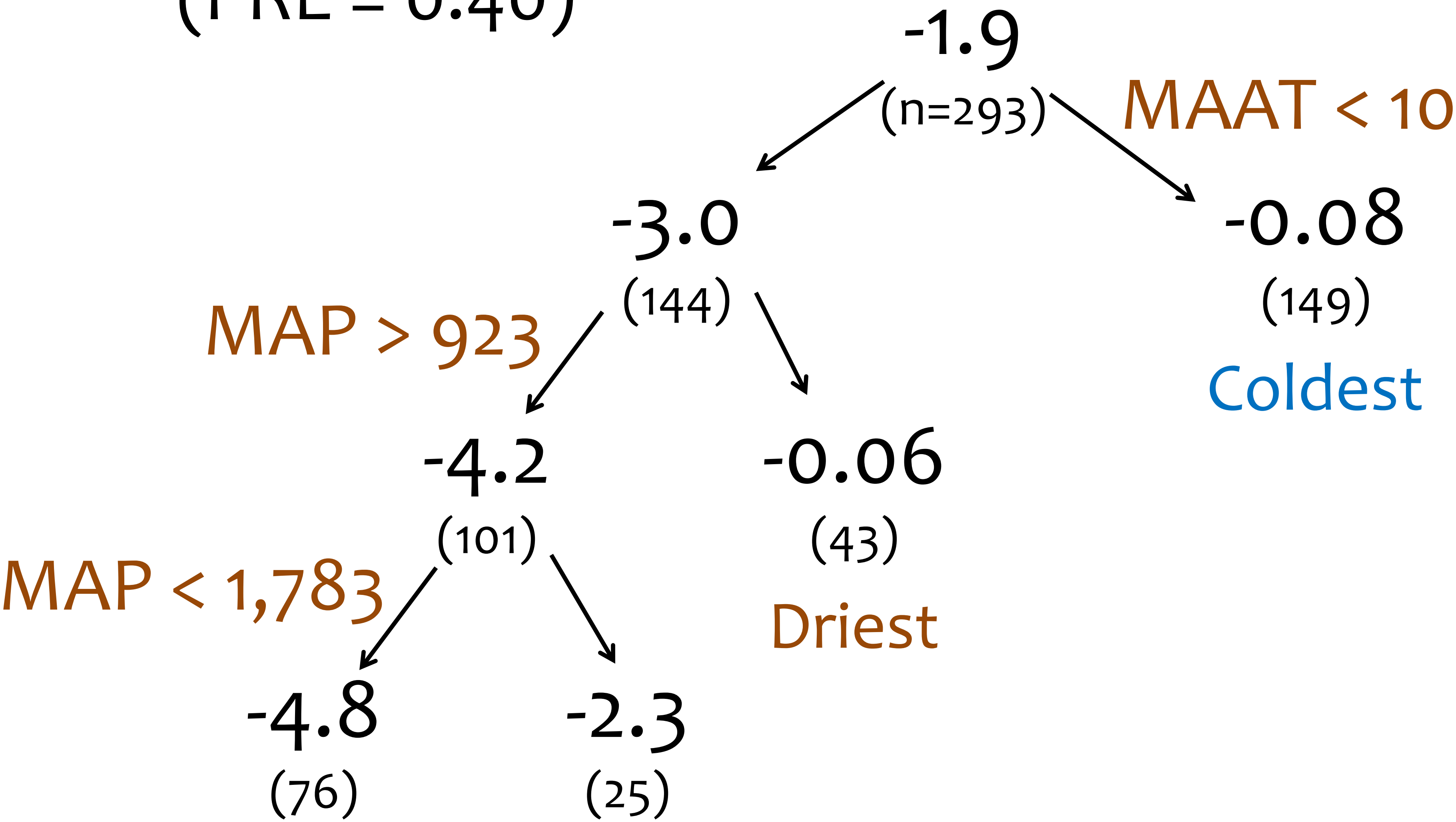
-0.30%

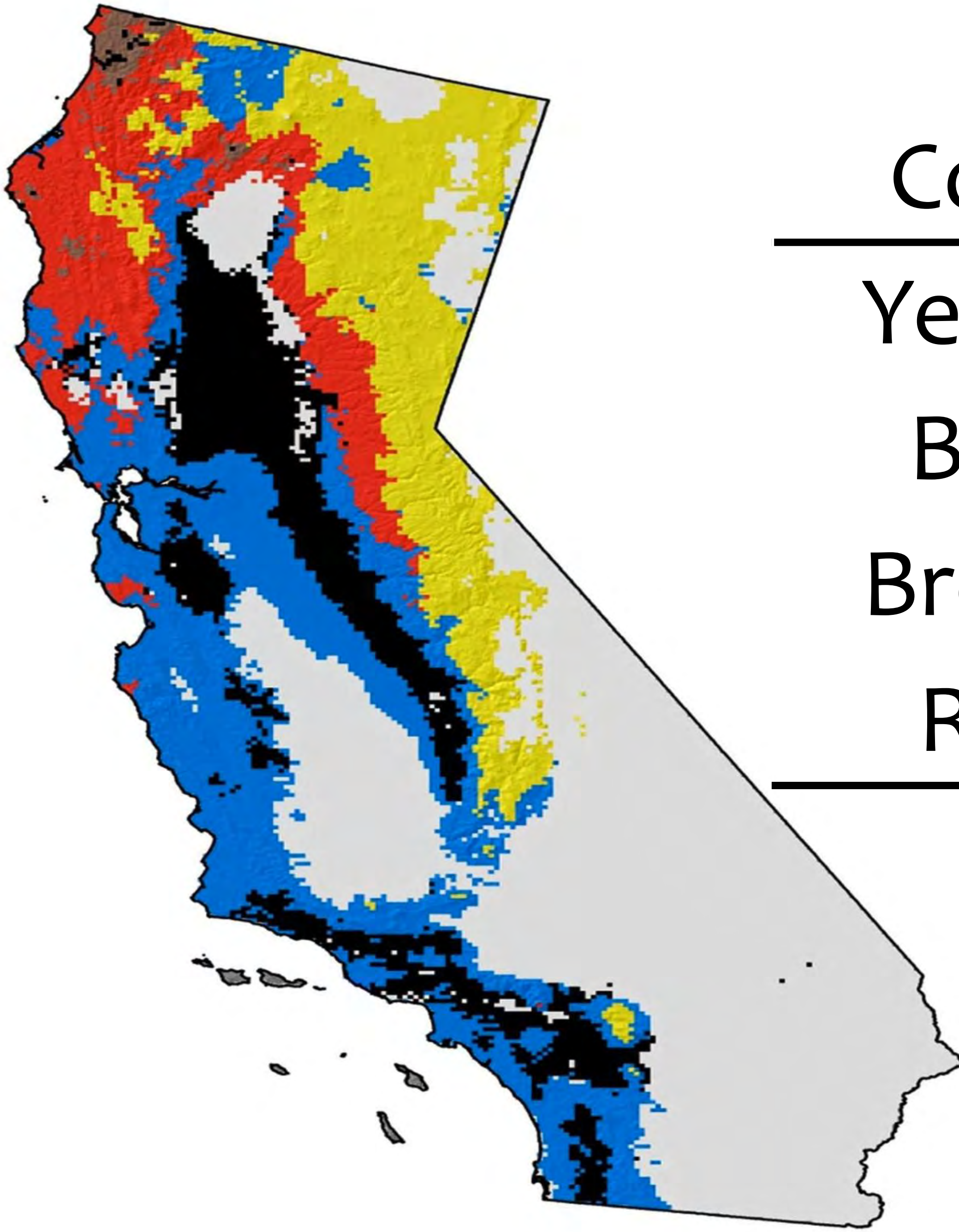
+84%



Mean ΔO/E = -0.12
40%
12%
-1.0
-0.5
0.0
0.5
1.0
Change in O/E (2090-1999)

Predictors of Site Vulnerability (Δ E) (PRE = 0.40)





Color	Change in Richness
Yellow	-0.8
Blue	-0.3
Brown	-2.3
Red	-4.8

Caveats

- Estimate of effects of CC on local SIB of managed streams likely conservative.
  - Increasing human demand for water will interact with direct effects of CC to amplify effects on SIB.
- In contrast, it is possible that regional SIB may actually increase because of migration of warm-water taxa into California.

Where to from here?

- Sort out why climate models differ.
- Complete empirical models predicting flow regime and check against physical model (TopNet, DHSVM) results for selected catchments.
- Refine/expand niche modeling and O/E work:
  - use predicted temperature and flow (and EC?)
  - apply model(s) to contiguous USA.
- Continue engaging with OW and States:
  - Accept shifting baselines?
  - Tease out climate signal from ‘traditional pollutants’?