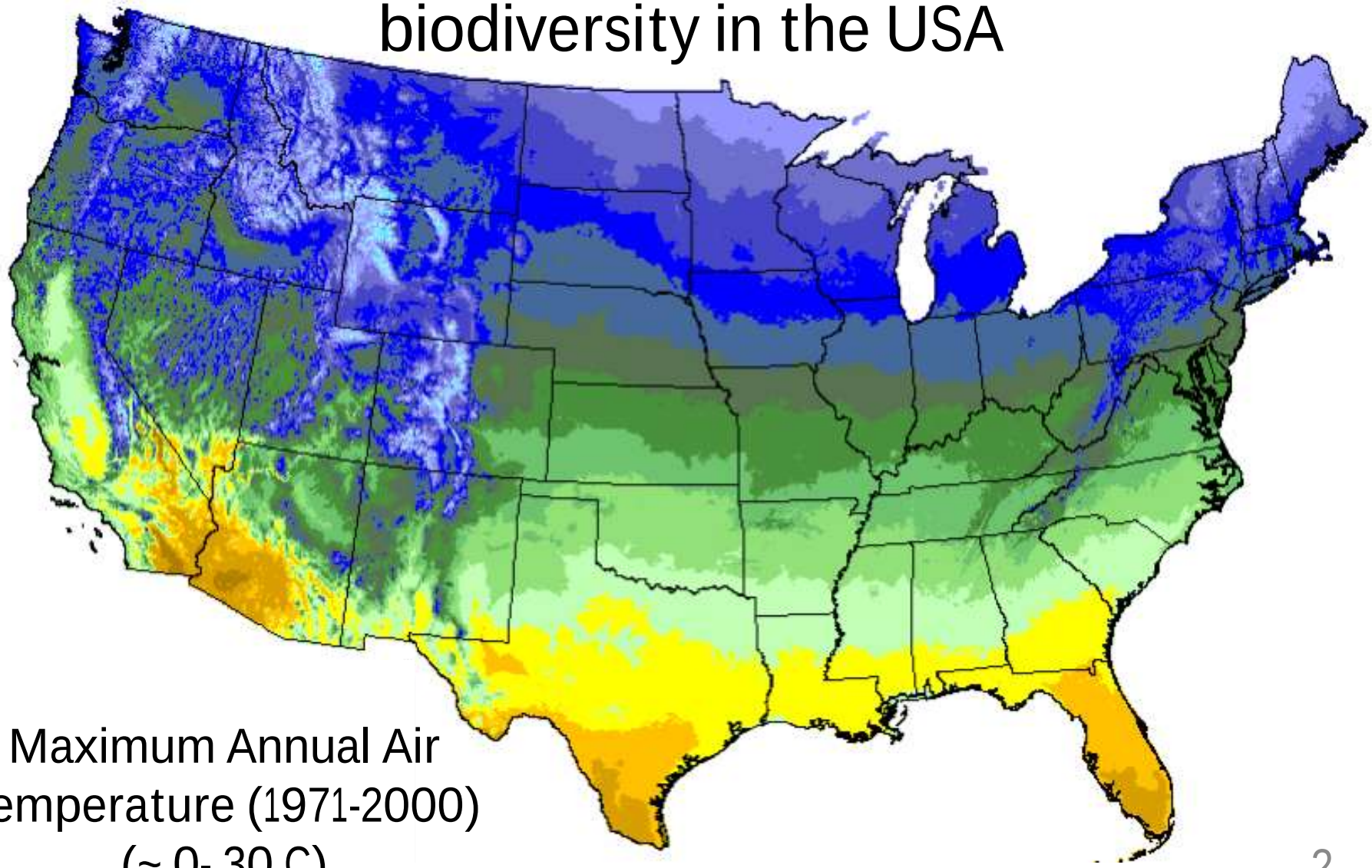
Predicting effects of climate change on stream ecosystems in the conterminous United States: results from a pilot study in California

Charles P. Hawkins

Jiming Jin, David Tarboton,

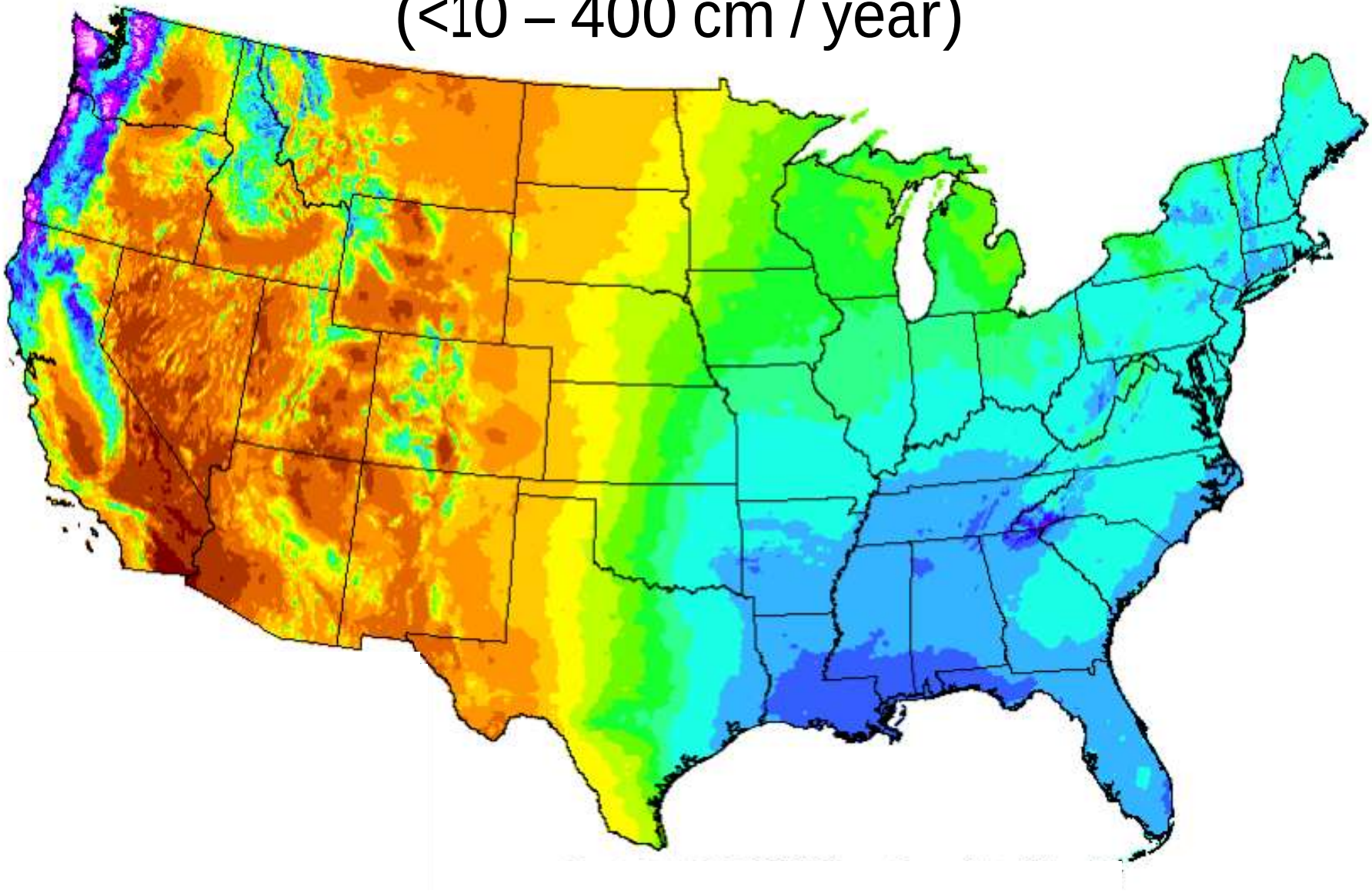
John Olson

USEPA-STAR funder project: Predicting effects of climate change on stream biodiversity in the USA



Maximum Annual Air Temperature (1971-2000) (~ 0- 30 C)

Annual Mean Precipitation (1971-2000)
(<10 – 400 cm / year)

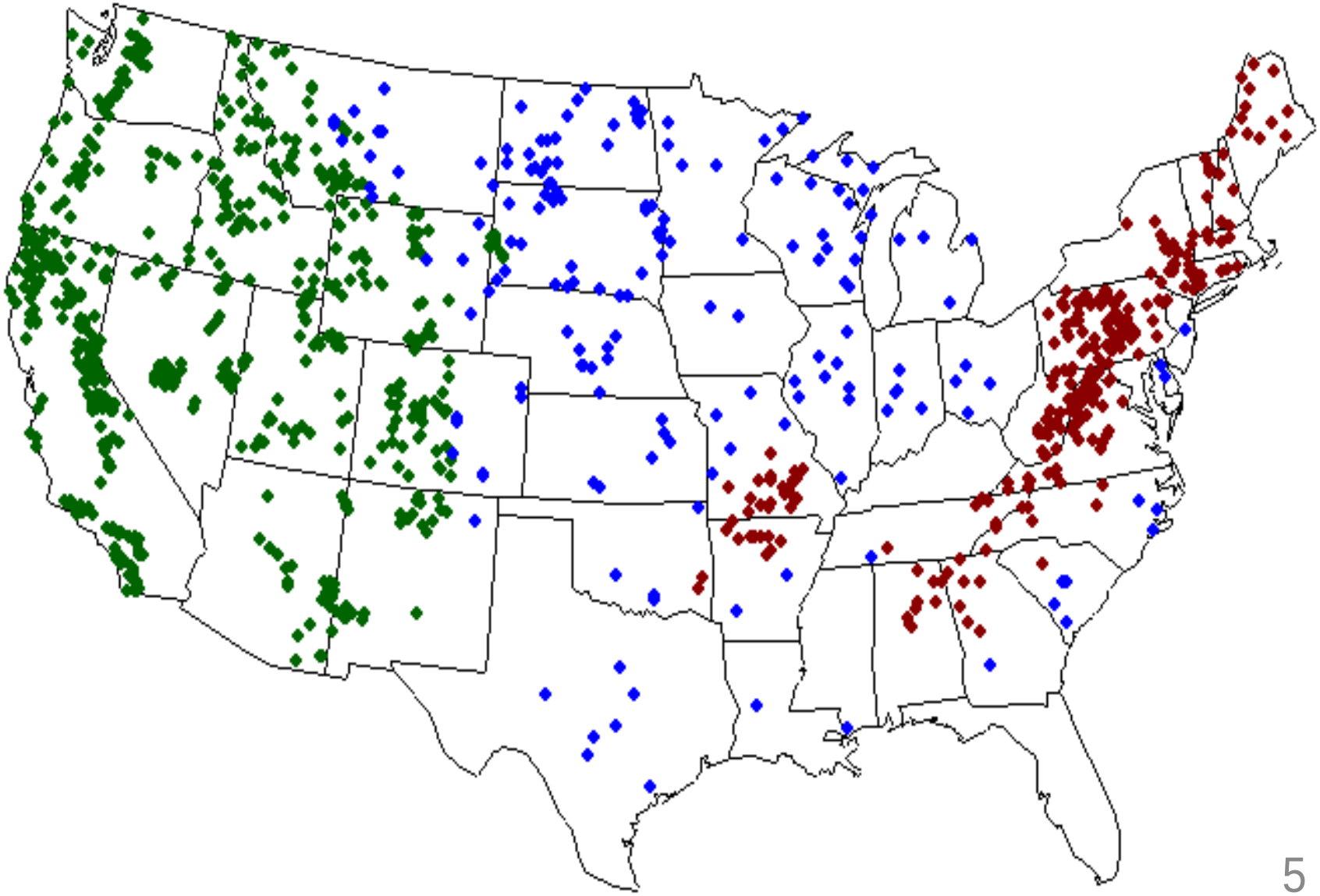


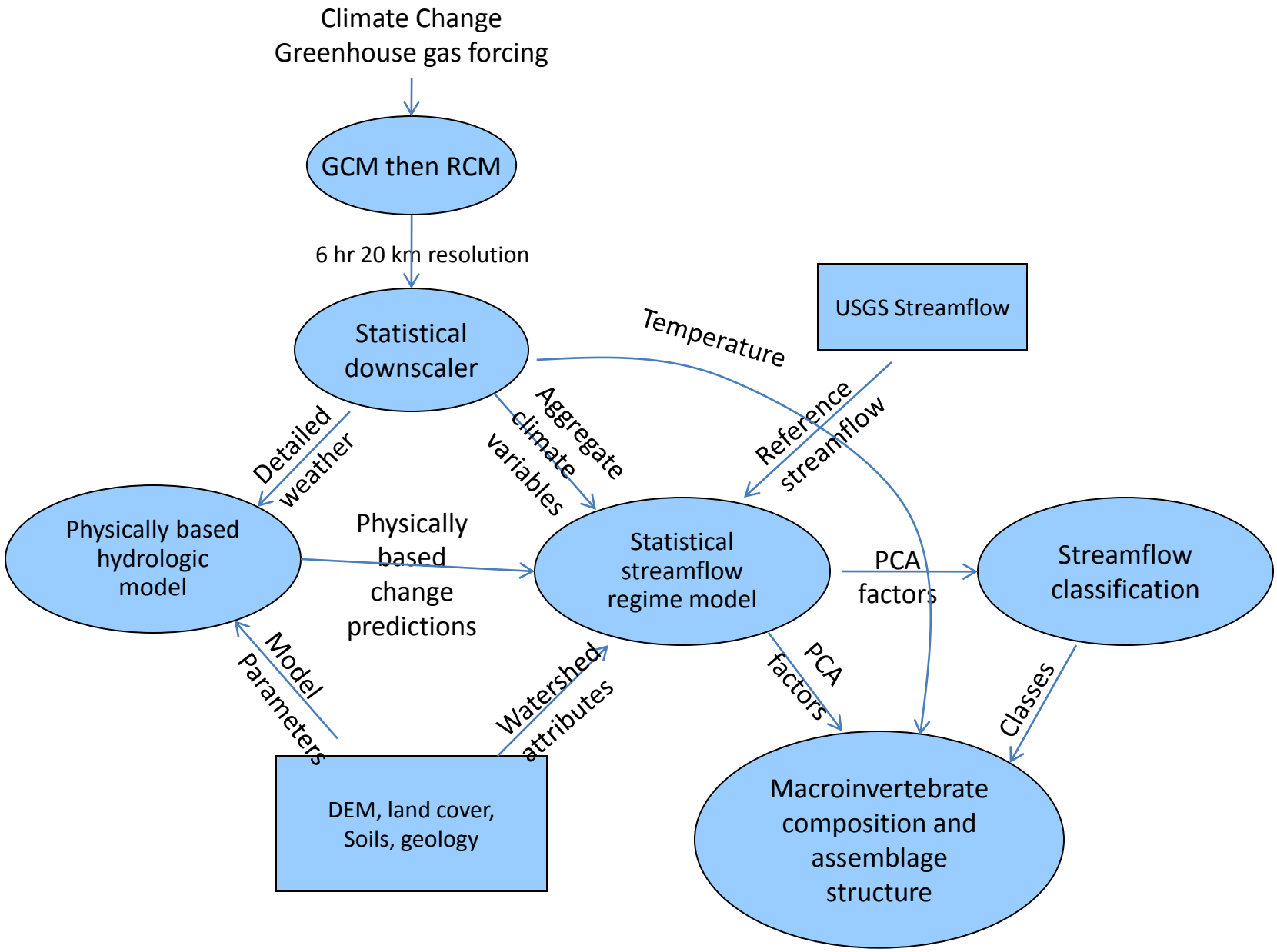
How will climate change affect stream invertebrate faunas at both reference and previously stressed sites?

Will effects of climate change confound biological assessments?

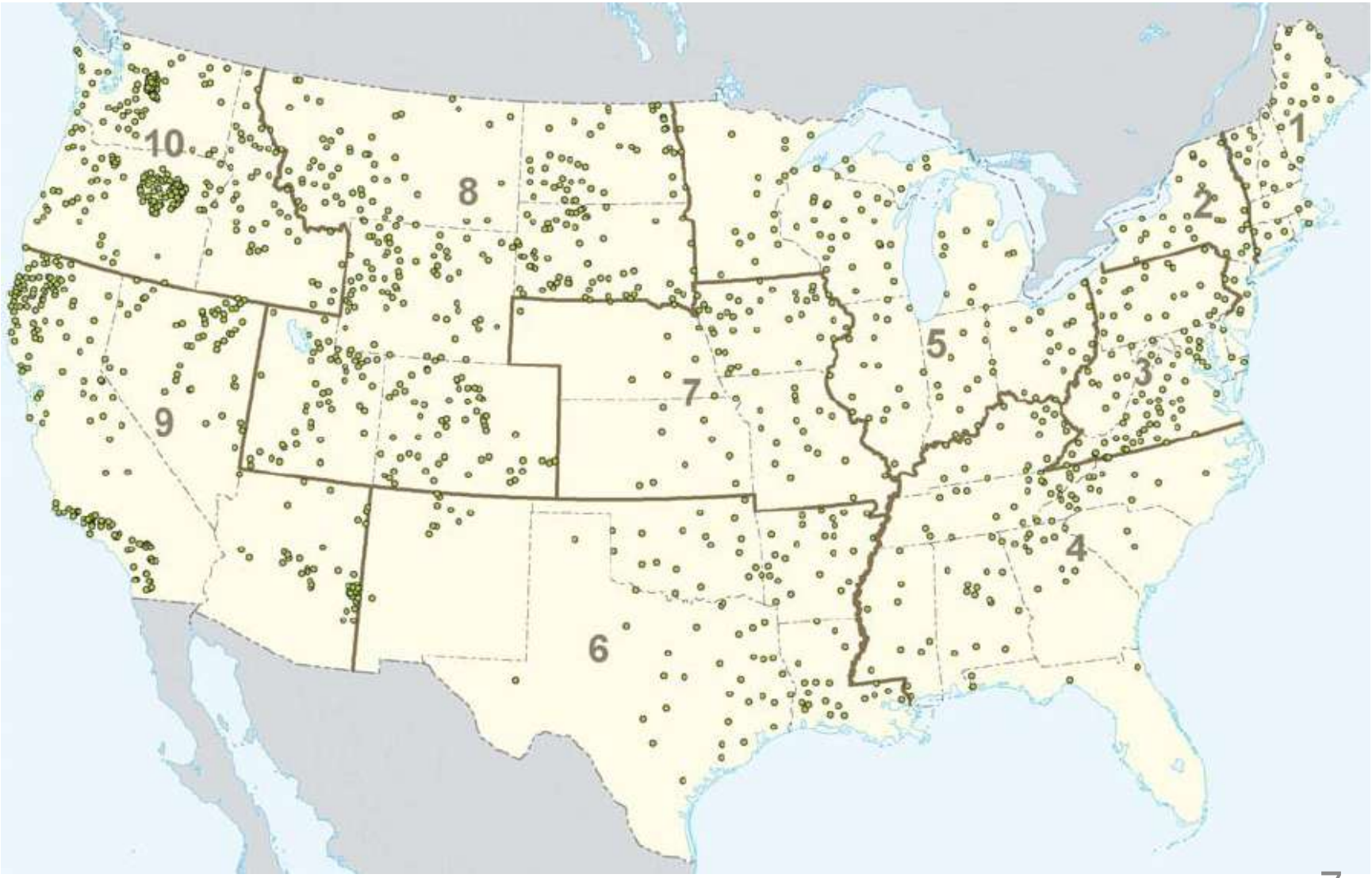
Are certain taxa and types of streams more vulnerable to climate change than others?

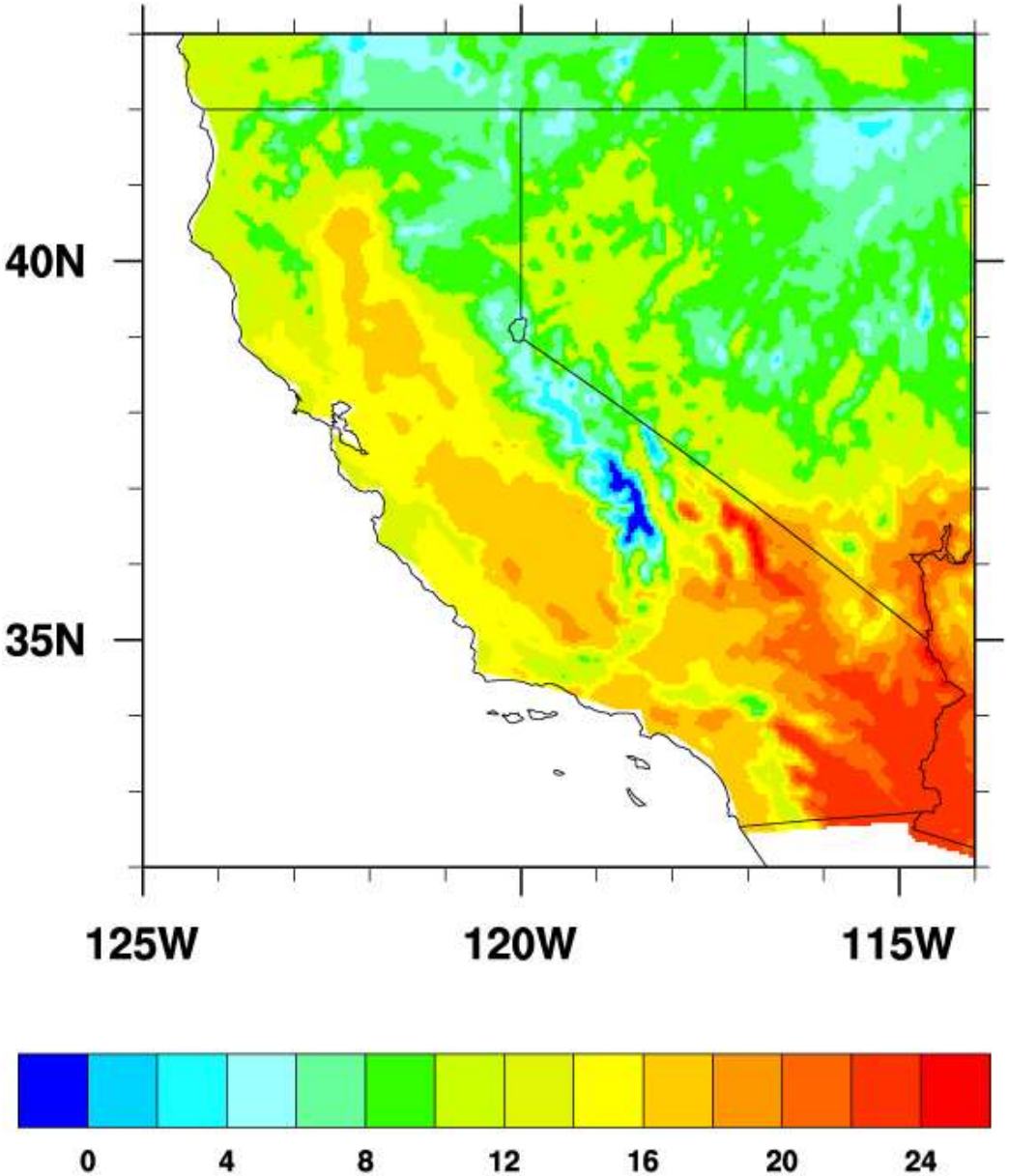
National Wadeable Stream Assessment Reference Sites




Climate Change
Greenhouse gas forcing
GCM then RCM
6 hr 20 km resolution
Statistical downscaler
Temperature
USGS Streamflow
Detailed weather
Aggregate climate variables
Reference streamflow
Physically based hydrologic model
Physically based change predictions
Statistical streamflow regime model
PCA factors
Streamflow classification
Model Parameters
Watershed attributes
PCA factors
Classes
DEM, land cover, Soils, geology
Macroinvertebrate composition and assemblage structure

WSA Probabilistic Sites





California as a pilot study

1999 variation in mean annual temperature (°C) (PRISM data)

©2007 Jeffrey Pippen

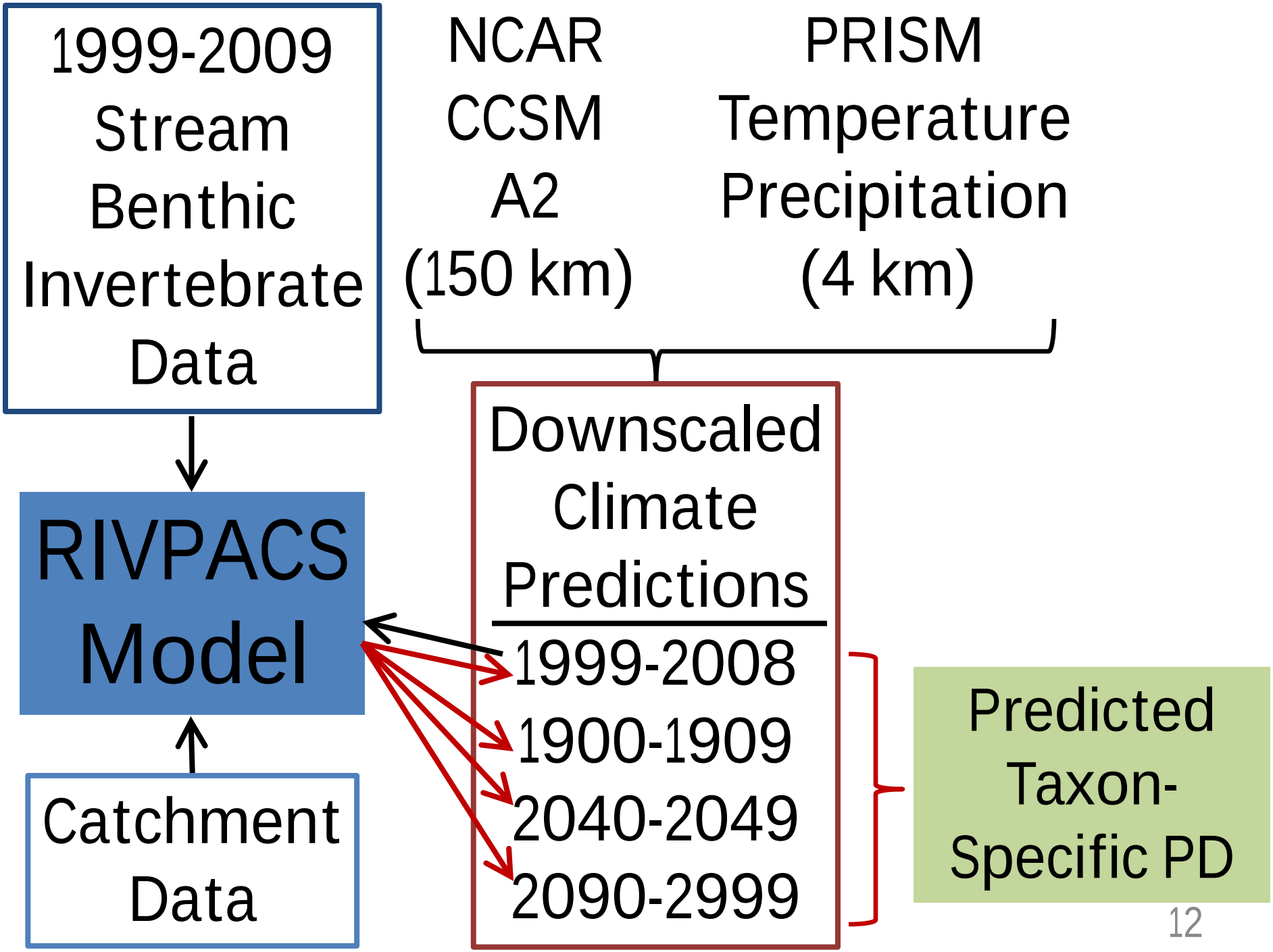
Probabilities of detection (PD): A foundation for estimating biodiversity and calculating biological indices

PD are associated with both abundance and richness:

- MMIs:
  - Abundance-based metrics
  - Richness metrics
- $O/E = \sum O / \sum PD$

Hypothetical Changes in PD & Taxa Richness

Taxon	1999	1900	2040	2090	2090-1999
A	0.87	0.85	0.41	0.22	-0.65
B	0.01	0.03	0.20	0.36	+0.35
C	0.92	0.88	0.71	0.58	-0.34
D	0.74	0.75	0.77	0.74	0.00
E	0.16	0.20	0.05	0.00	-0.16
etc.	0.60	0.64	0.50	0.31	-0.29
NTaxa	3.30	3.35	2.64	2.21	-1.09


1999-2009
Stream
Benthic
Invertebrate
Data
NCAR
CCSM
A2
(150 km)
PRISM
Temperature
Precipitation
(4 km)
RIVPACS
Model
Downscaled
Climate
Predictions
1999-2008
1900-1909
2040-2049
2090-2999
Predicted
Taxon-
Specific PD
Catchment
Data

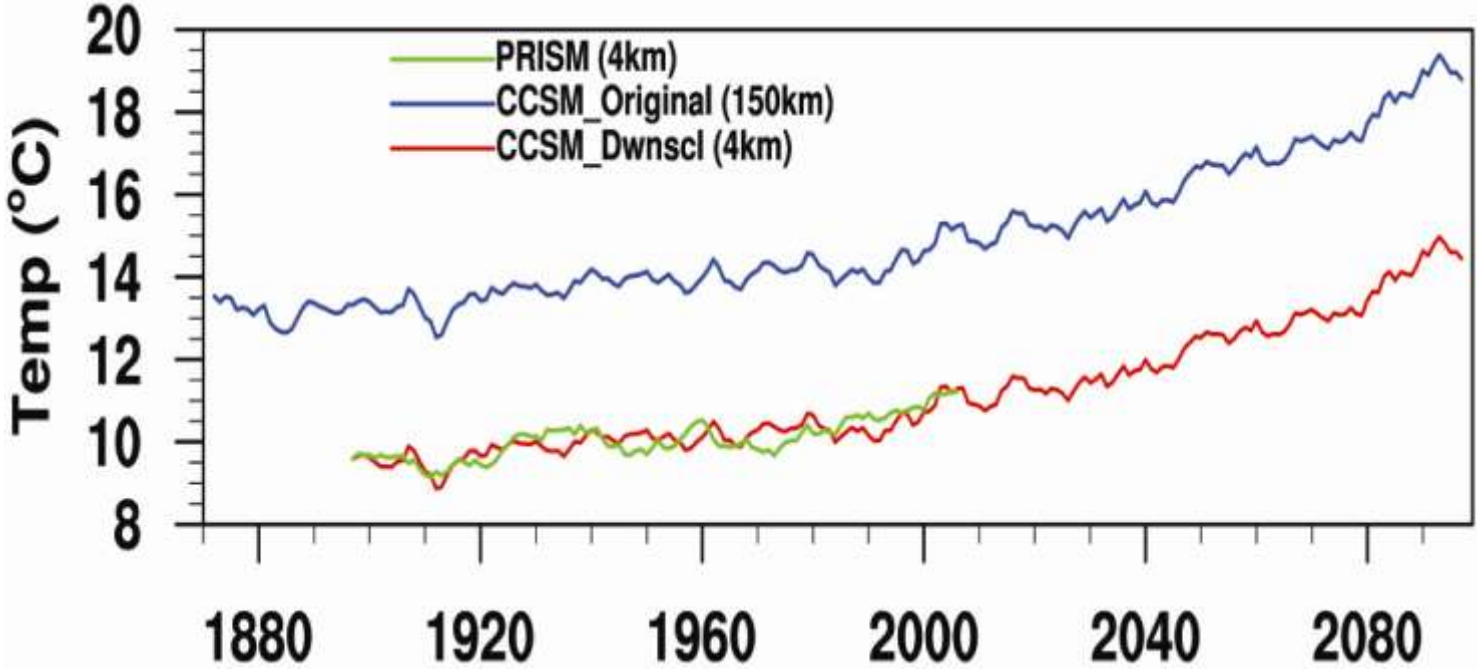
Estimating O/E

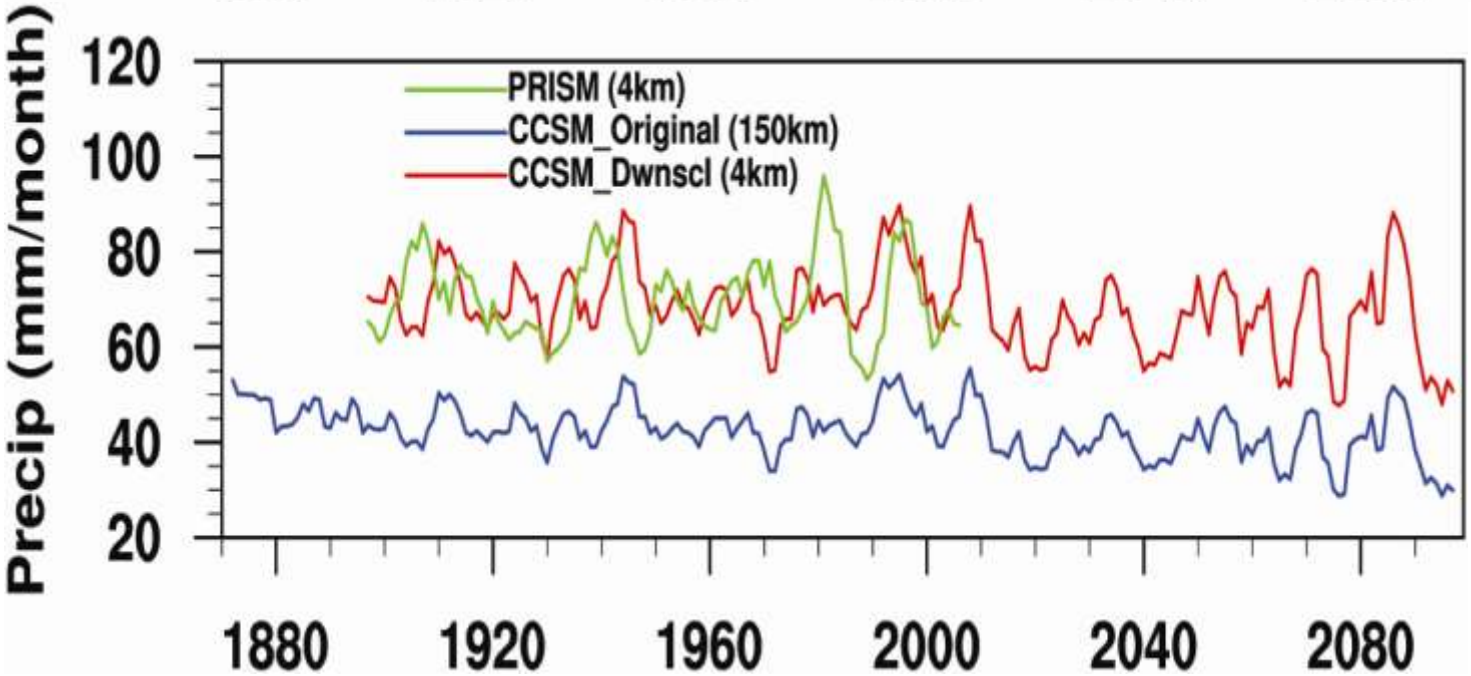
1999 calibration:

$\sum O / \sum pd$

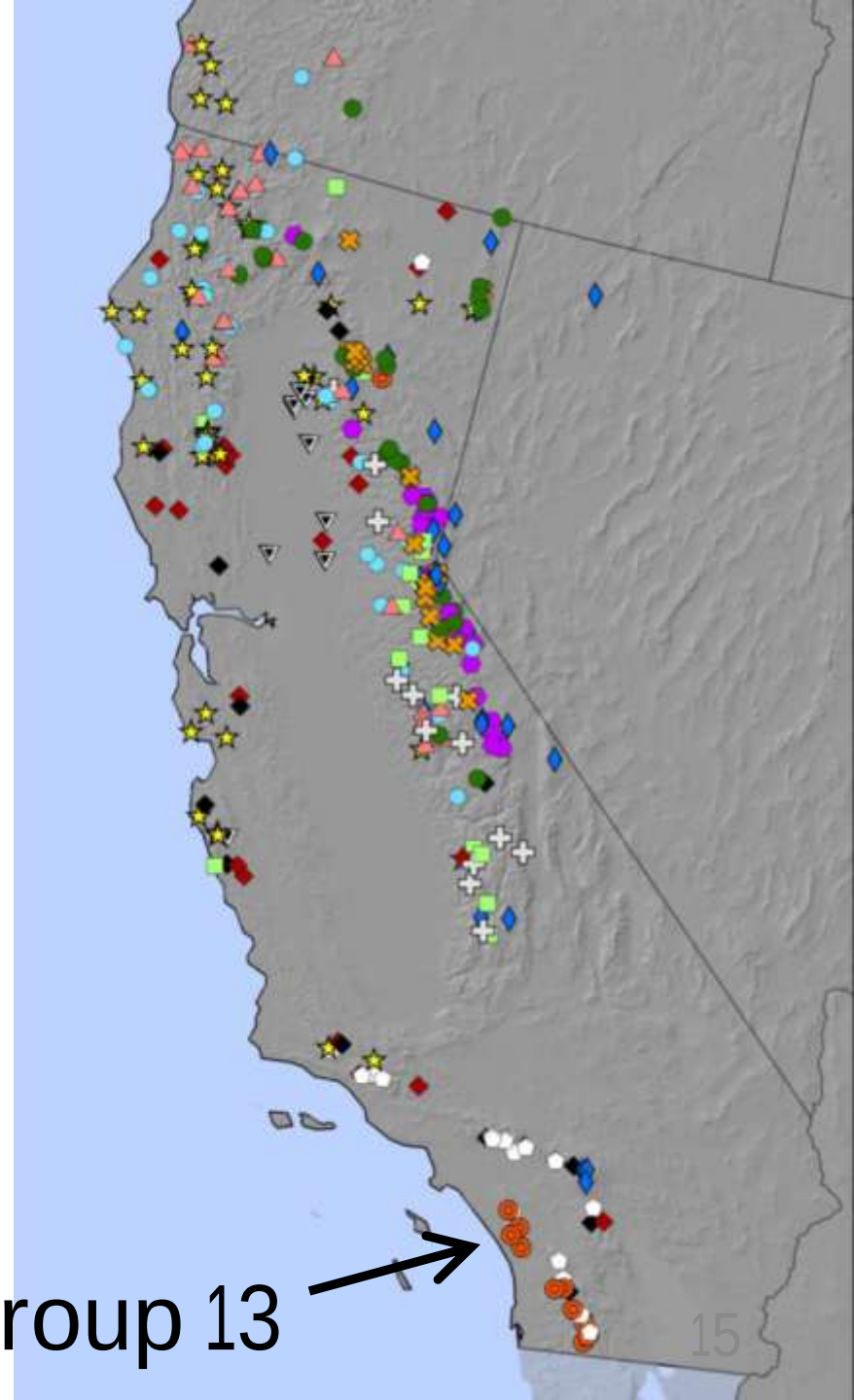
1900, 2040, 2090 predictions:

$\sum pd_{(year)} / \sum pd_{(1999)}$


Temp (°C)
20
18
16
14
12
10
8
PRISM (4km)
CCSM_Original (150km)
CCSM_Dwnscl (4km)
1880
1920
1960
2000
2040
2080

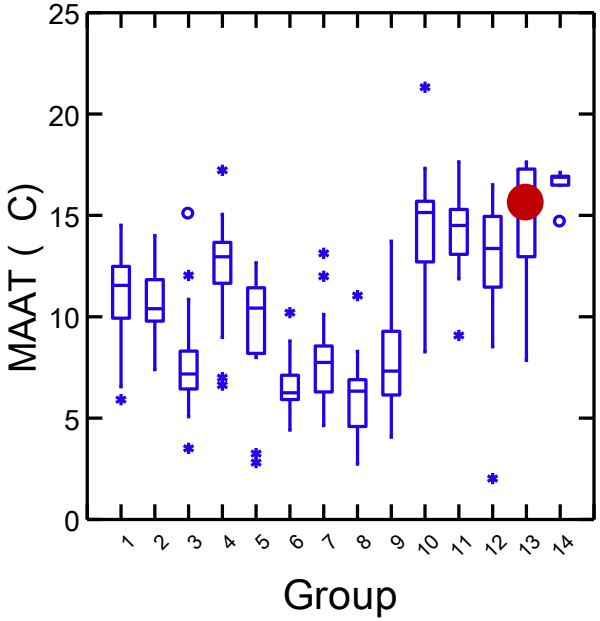

Precip (mm/month)
120
100
80
60
40
20
PRISM (4km)
CCSM_Original (150km)
CCSM_Dwnscl (4km)
1880
1920
1960
2000
2040
2080

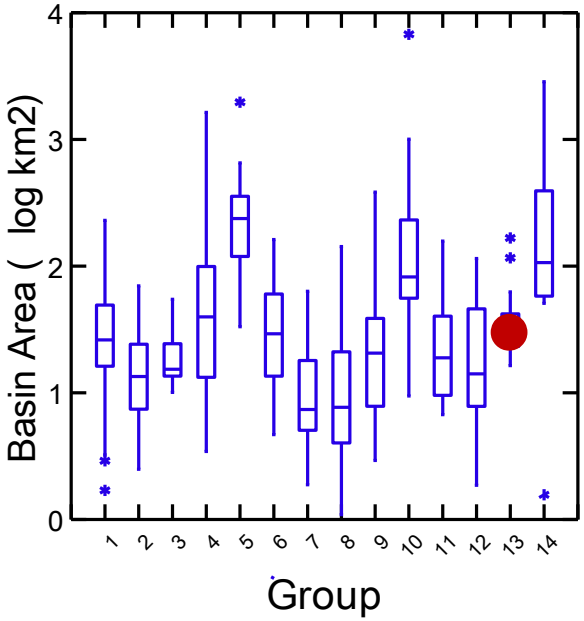
The California reference sites:
340 taxa.
327 sites classified into 14 groups for model building.

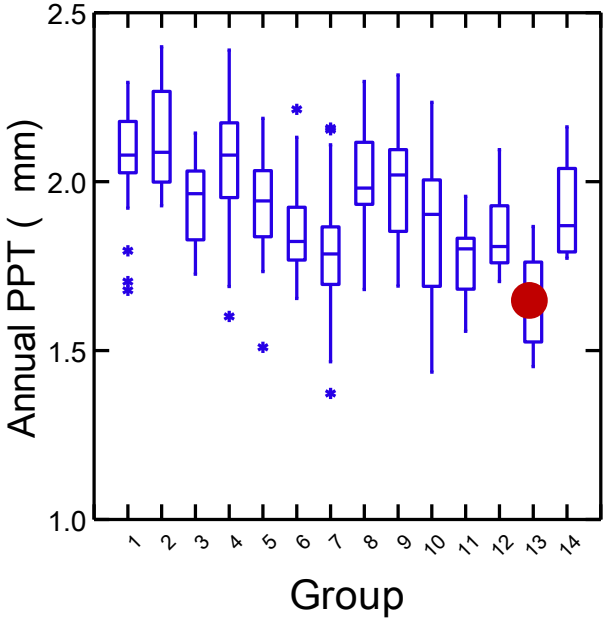


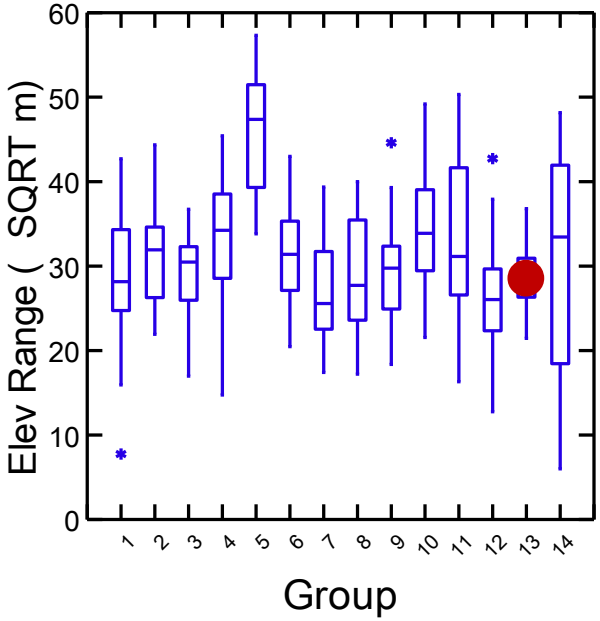
5 Predictors

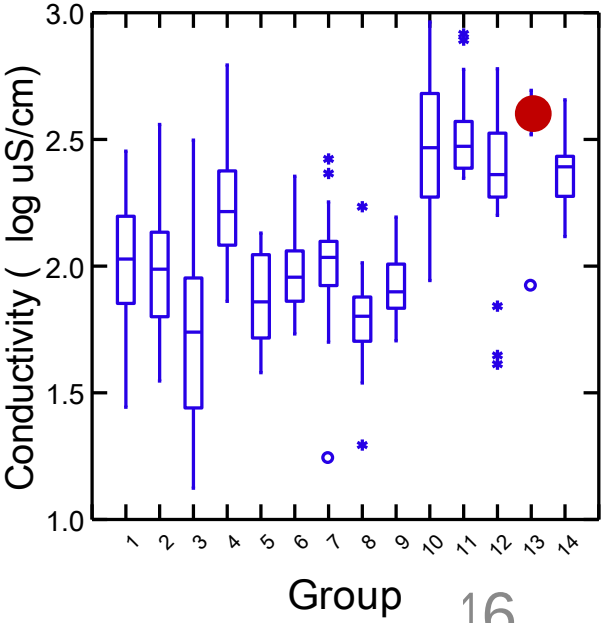
Group 13: warmest driest highest TDS



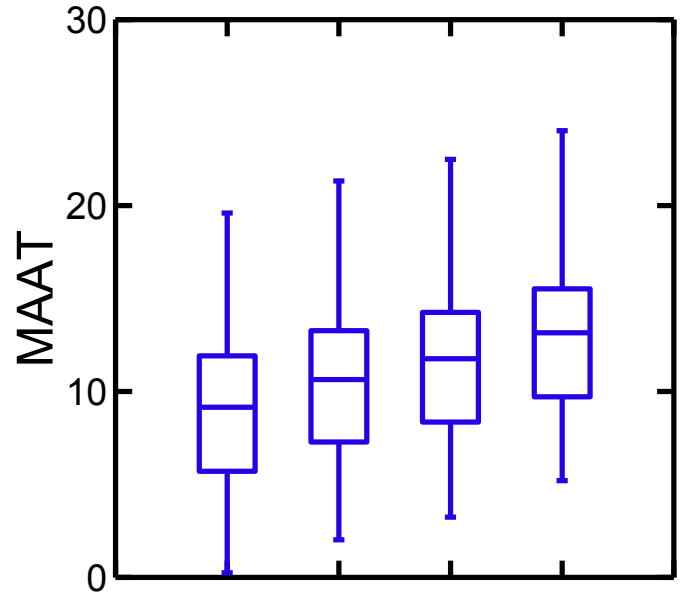


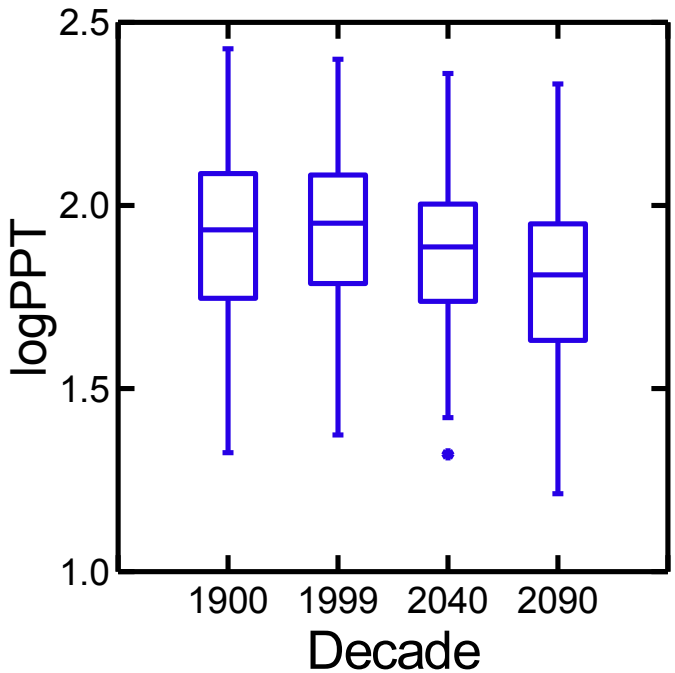


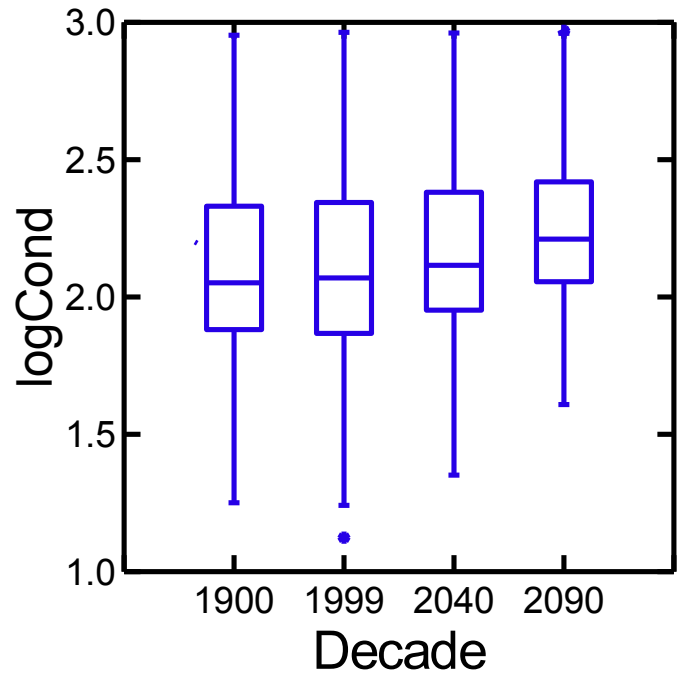




Predicted changes in climate-sensitive predictors



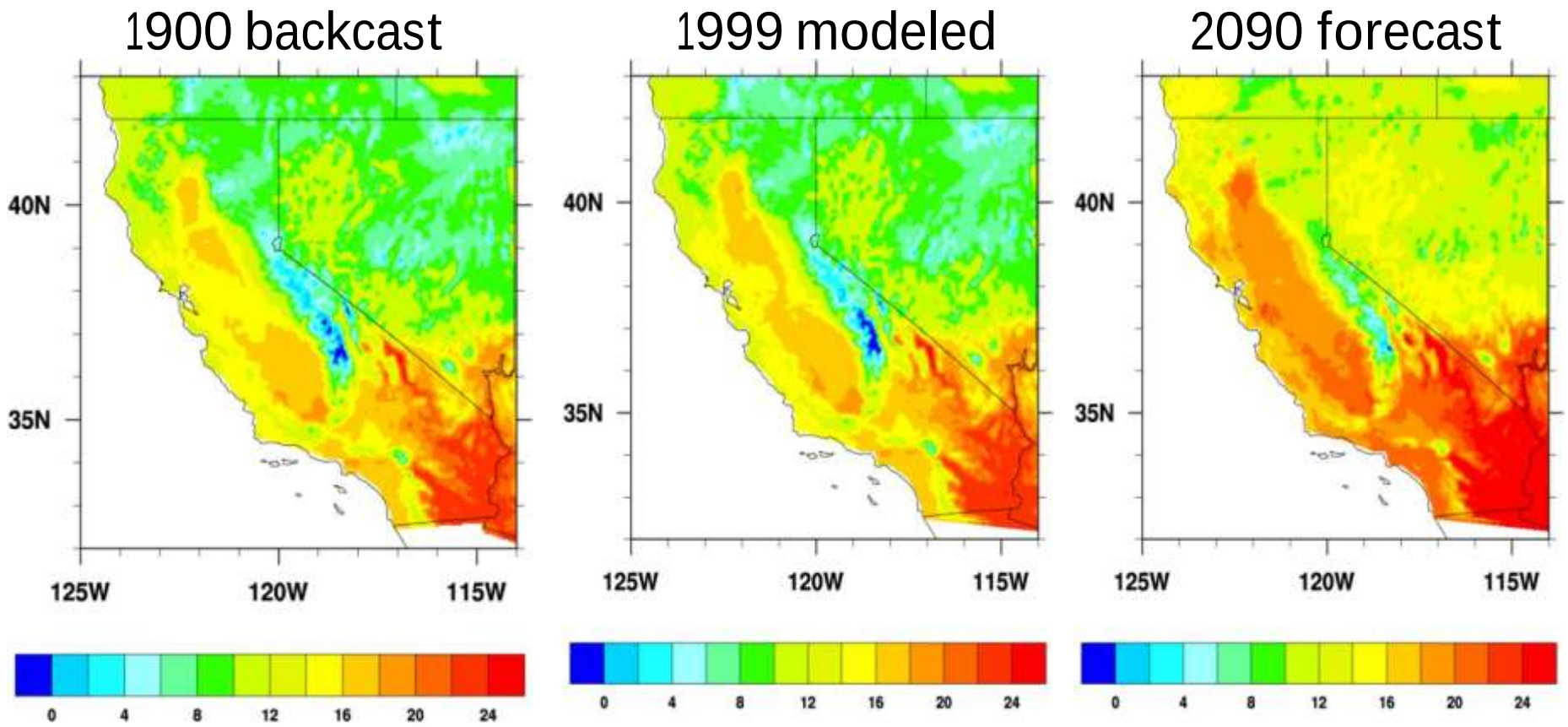




A2 Climate Change Scenario

(CCSM 250 -> 4 km empirically downscaled predictions)

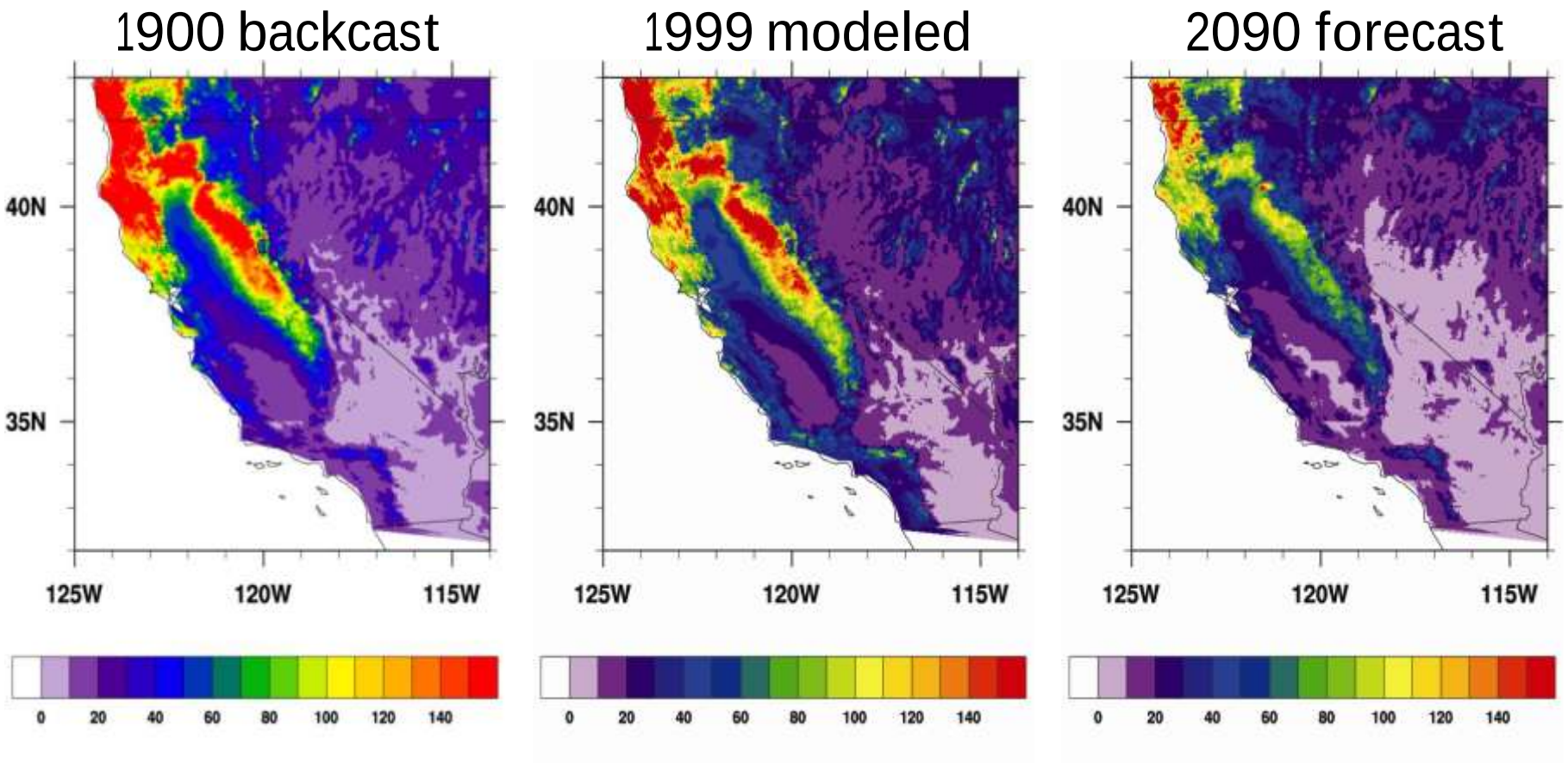
Mean Annual Temperature (°C)



A2 Climate Change Scenario

(CCSM 250 -> 4 km empirically downscaled predictions)

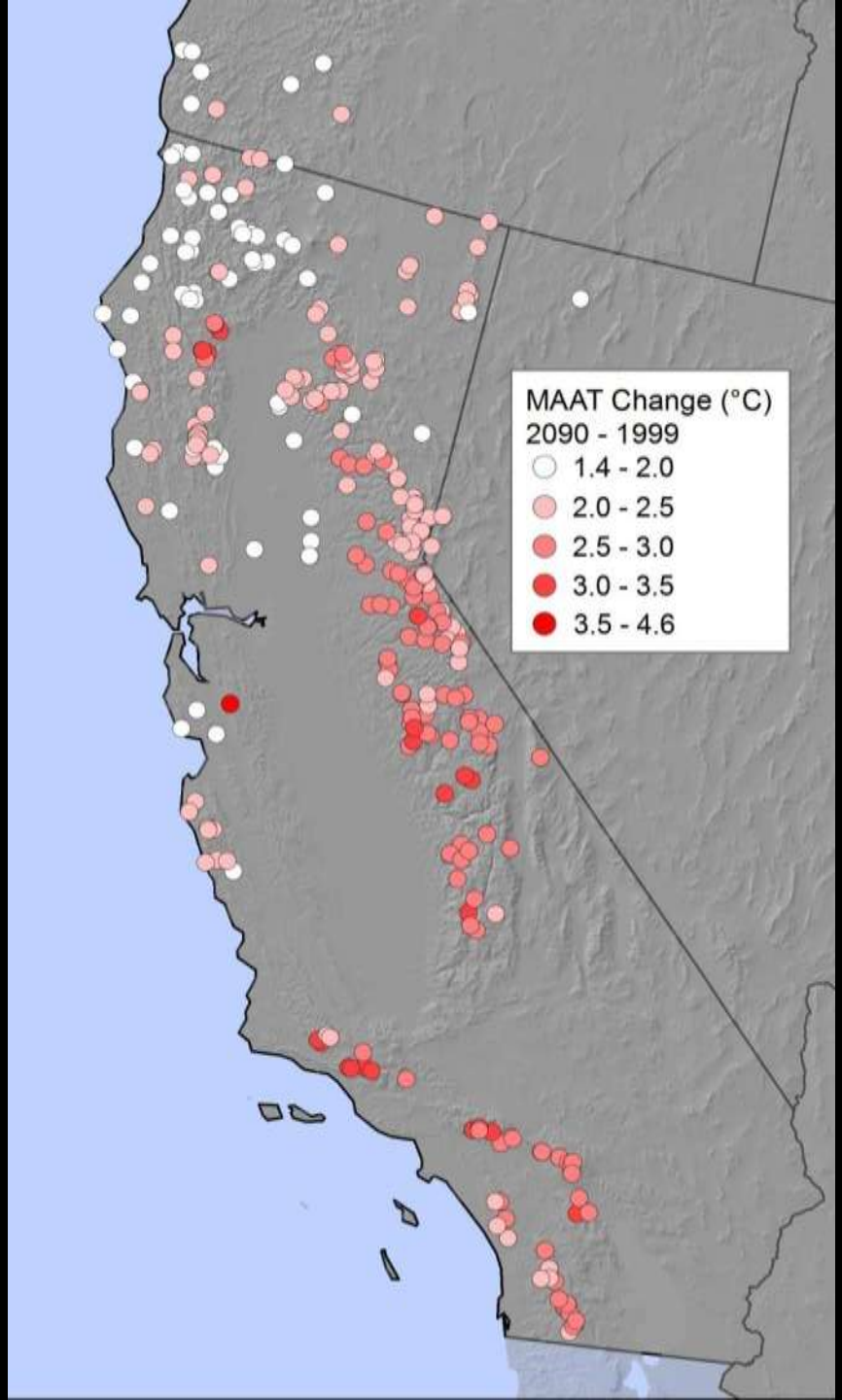
Mean Monthly Precipitation (mm)

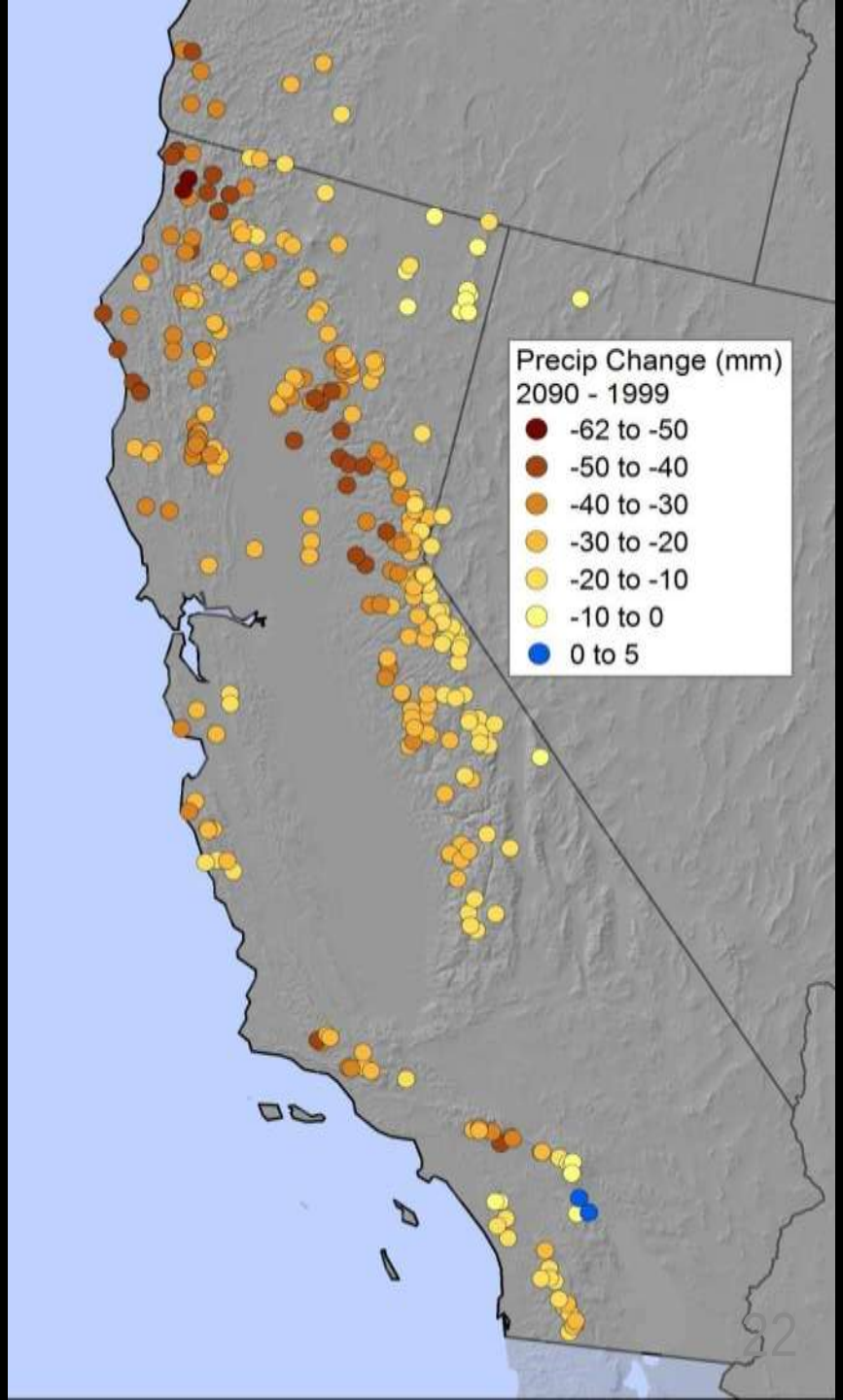


2090-1999 comparisons

Changes in climate-sensitive predictors (2090-1999) across 327 reference sites

Statistic	Precipitation (mm)	Temp (C)	Cond (μS/cm)
Mean	-26	2.4	48
Minimum	-61	1.4	-30
Maximum	+5	4.6	180

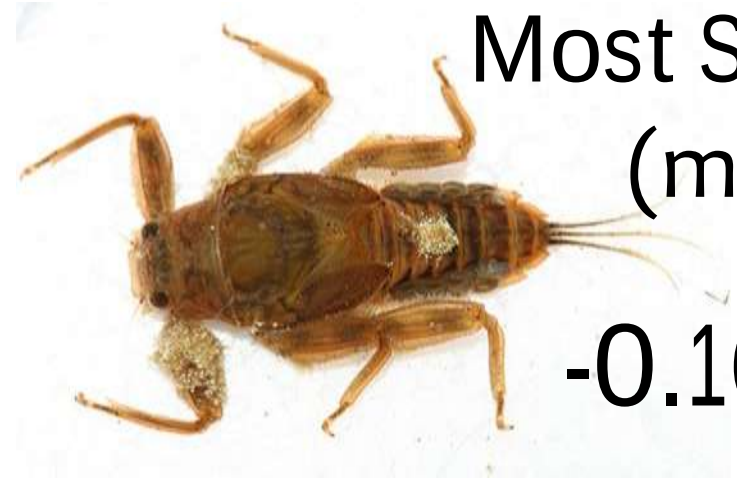

MAAT Change (°C)
2090 - 1999
1.4 - 2.0
2.0 - 2.5
2.5 - 3.0
3.0 - 3.5
3.5 - 4.6


Precip Change (mm)
2090 - 1999
-62 to -50
-50 to -40
-40 to -30
-30 to -20
-20 to -10
-10 to 0
0 to 5

Individual taxa

- Average changes in PD
  - 172 decreasers ($8 \leq 0.1$)
  - 168 increasers ($1 \geq 0.1$)
- Many predicted local extinctions (rare taxa).
- No predicted regional extinctions.

Most Sensitive Taxa (mean ΔPD)



-0.16

+0.10

-0.14

+0.08

-0.13

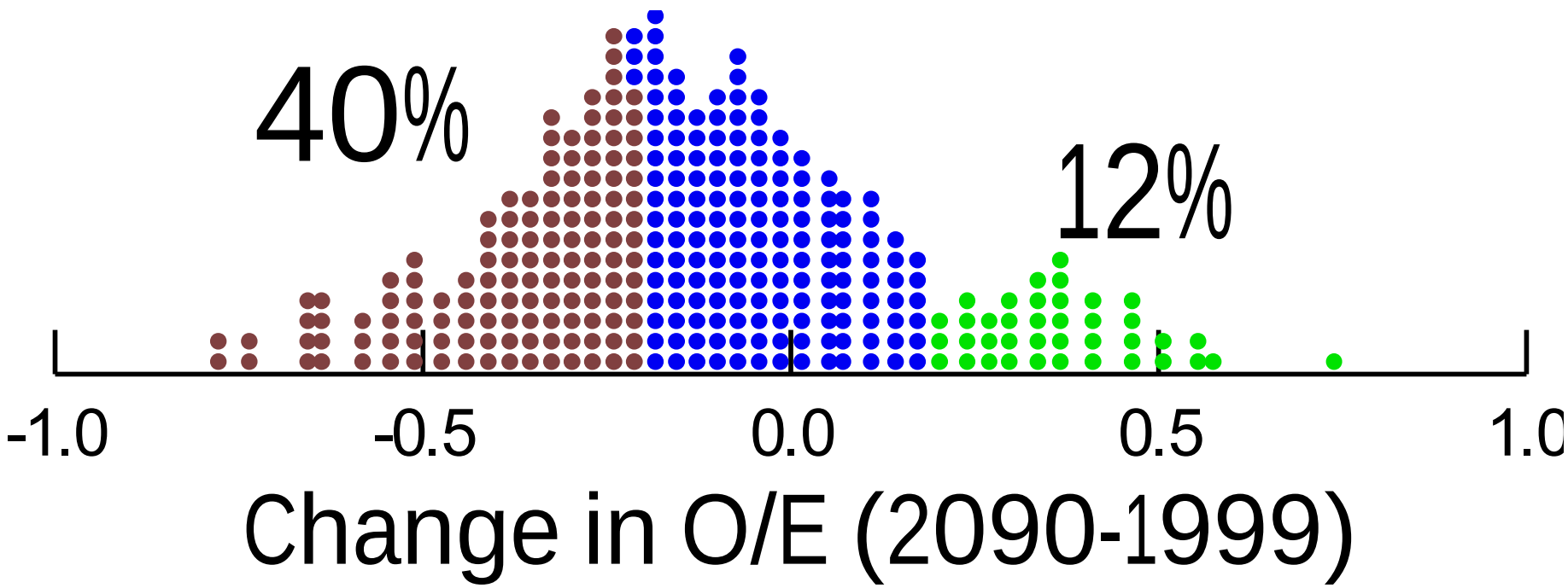
+0.07

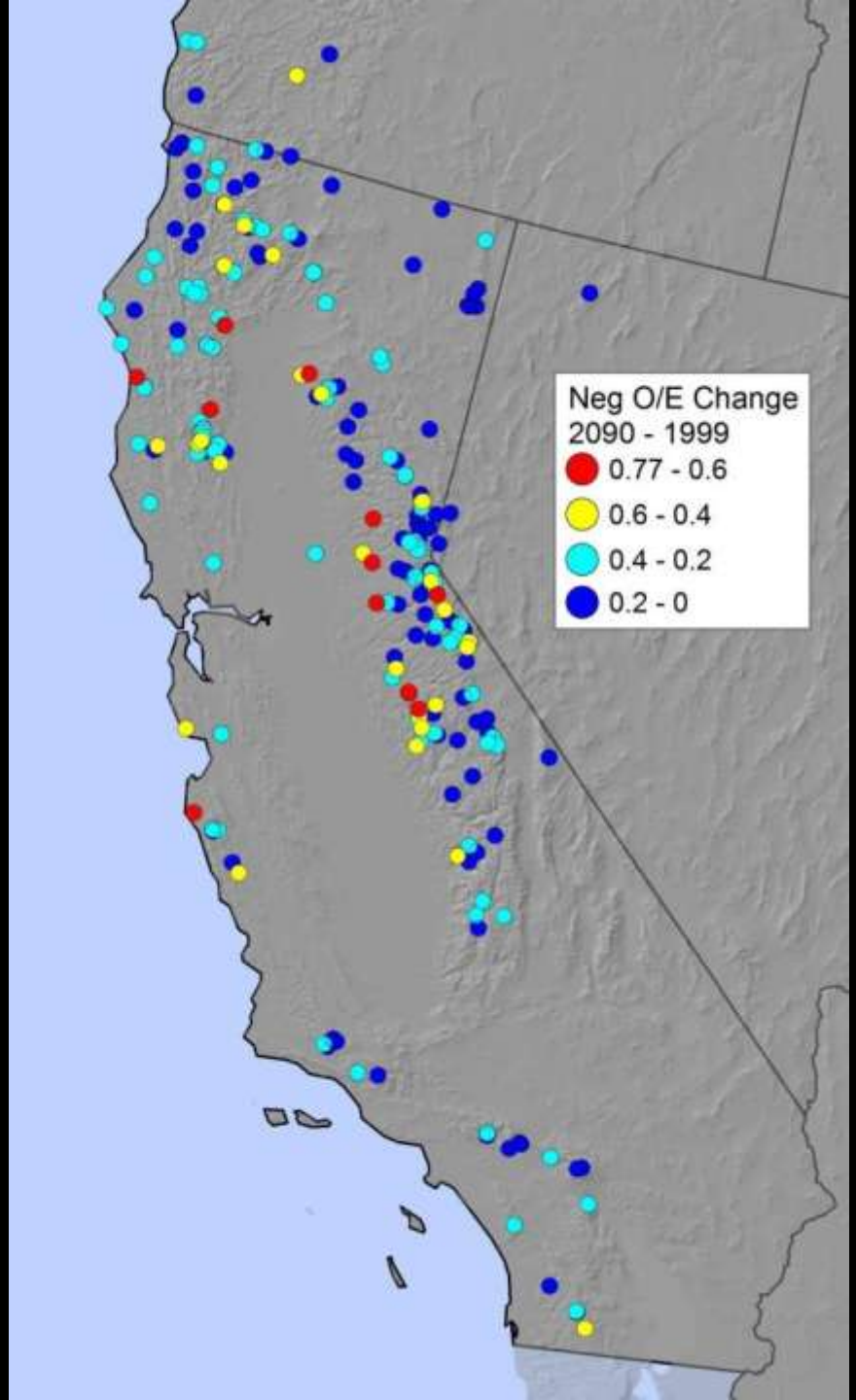
What is the consequence for reference site taxa richness and O/E?

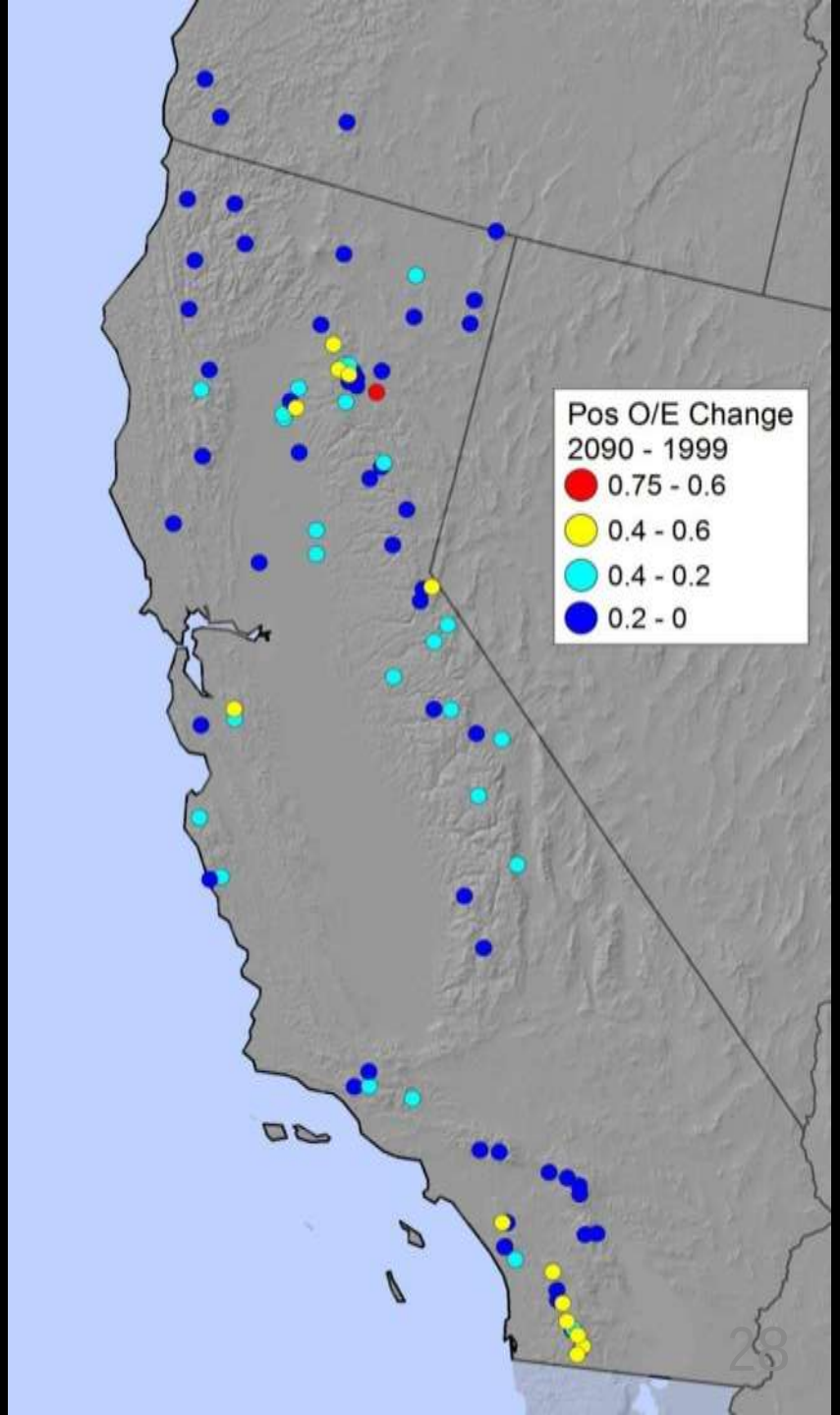
~10% loss in mean site richness by 2090

No loss in regional richness

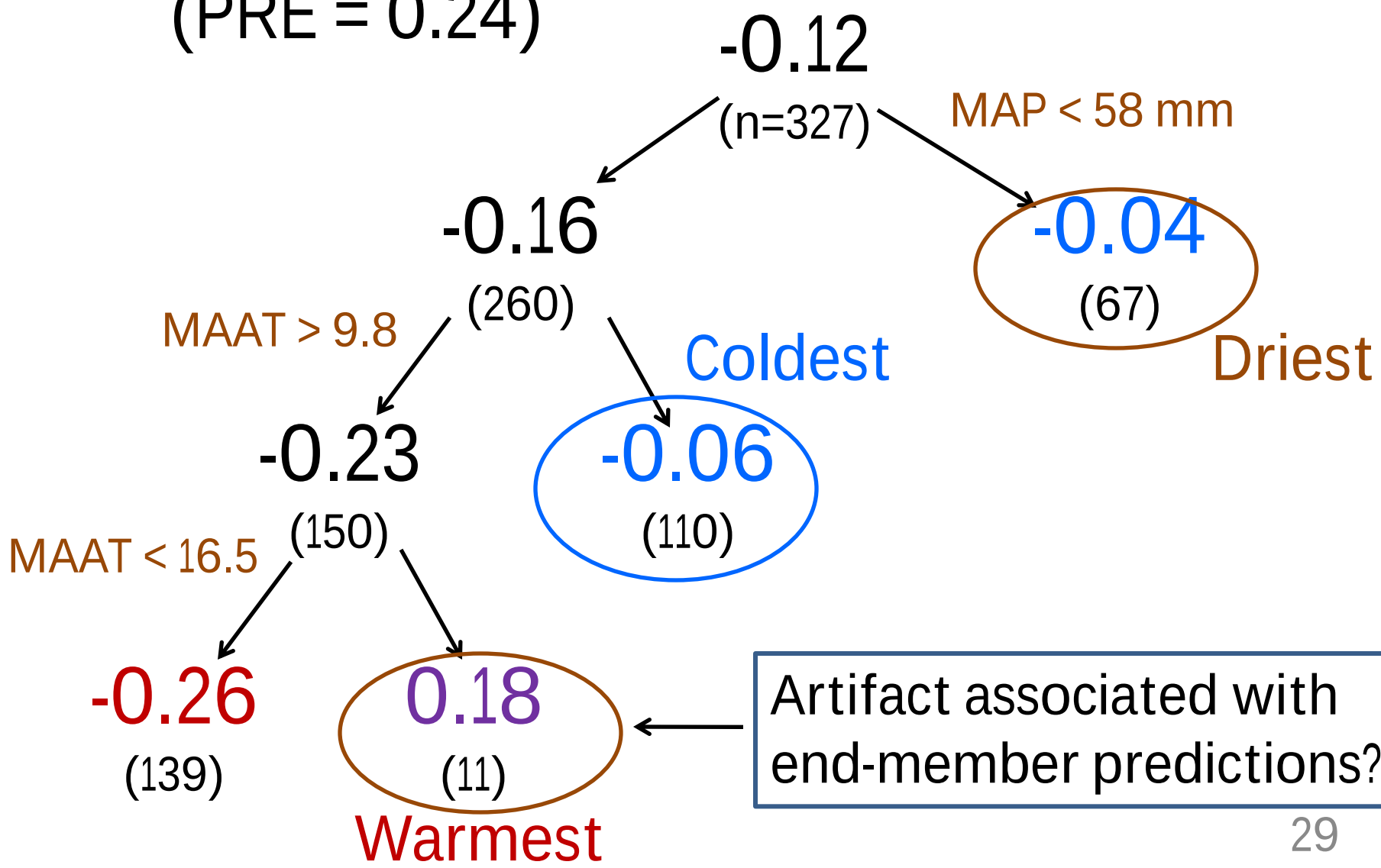
Mean ΔO/E = -0.12




Neg O/E Change
2090 - 1999
0.77 - 0.6
0.6 - 0.4
0.4 - 0.2
0.2 - 0


Pos O/E Change
2090 - 1999
0.75 - 0.6
0.4 - 0.6
0.4 - 0.2
0.2 - 0

Predictors of Site Vulnerability (Δ O/E) (PRE = 0.24)



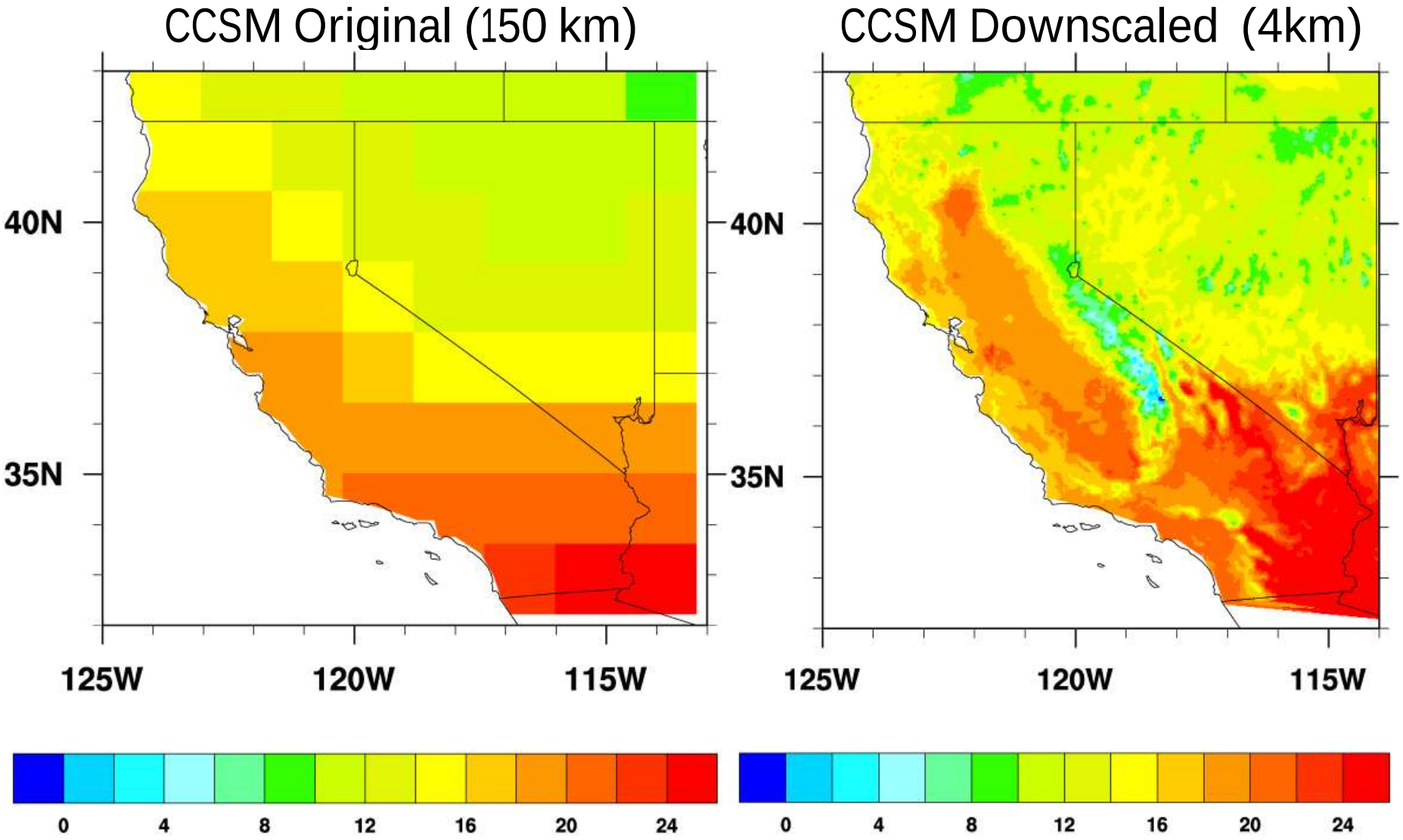
How realistic are these predictions?

- Climate predictions?
  - Accuracy of CCSM?
  - Accuracy of downscaling?
- Biota predictions?
  - General accuracy of RIVPACS model?
  - End-member problem?

Related Issues and Work

- Downscaling – some caveats
  - Empirical versus dynamic
  - Yearly/seasonally versus regime
- Invertebrate-environment relationships
  - Stream temperature models
  - Flow models

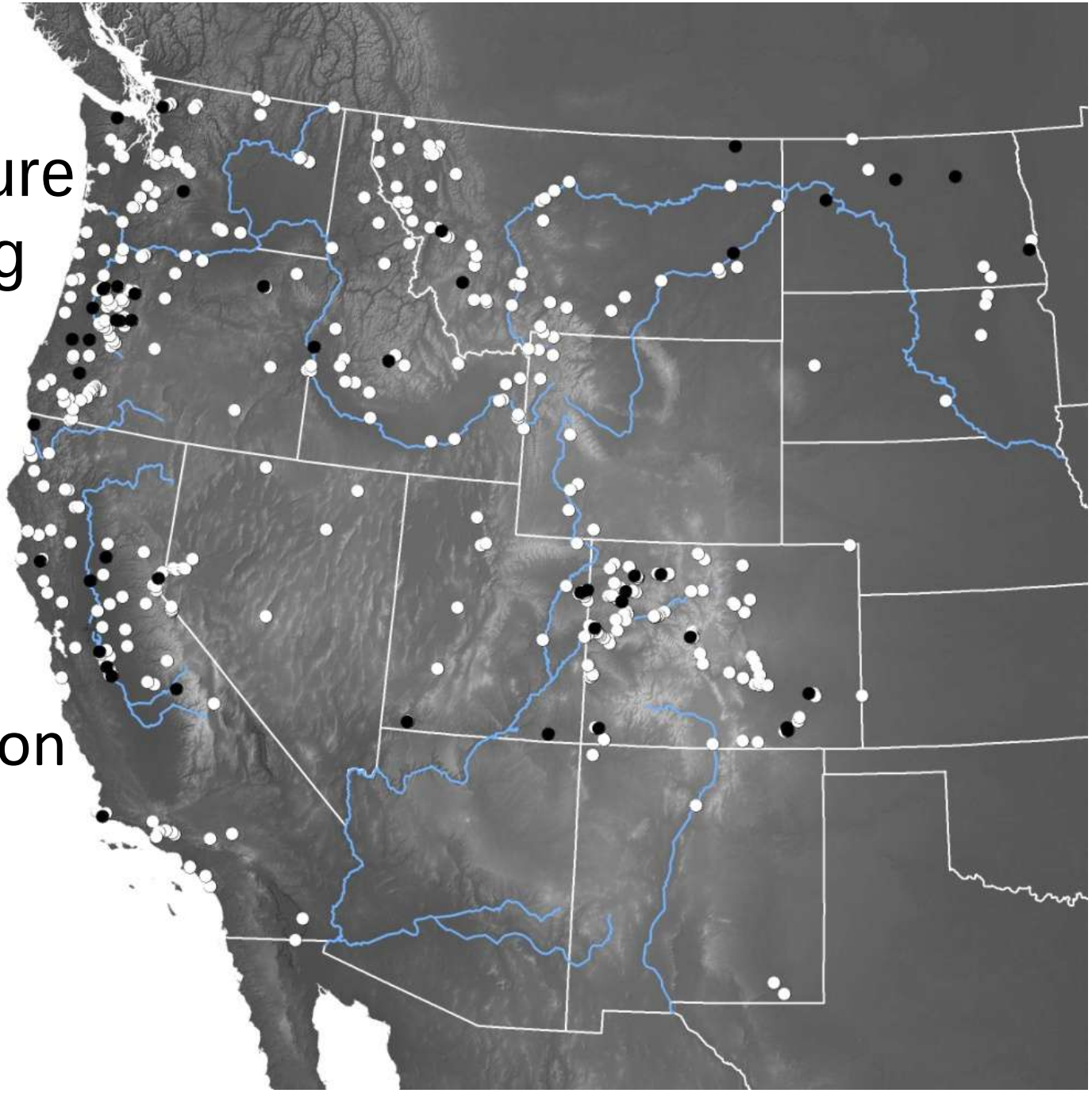
A2 2090 Temperature (ºC)



Stream Temperature Modeling

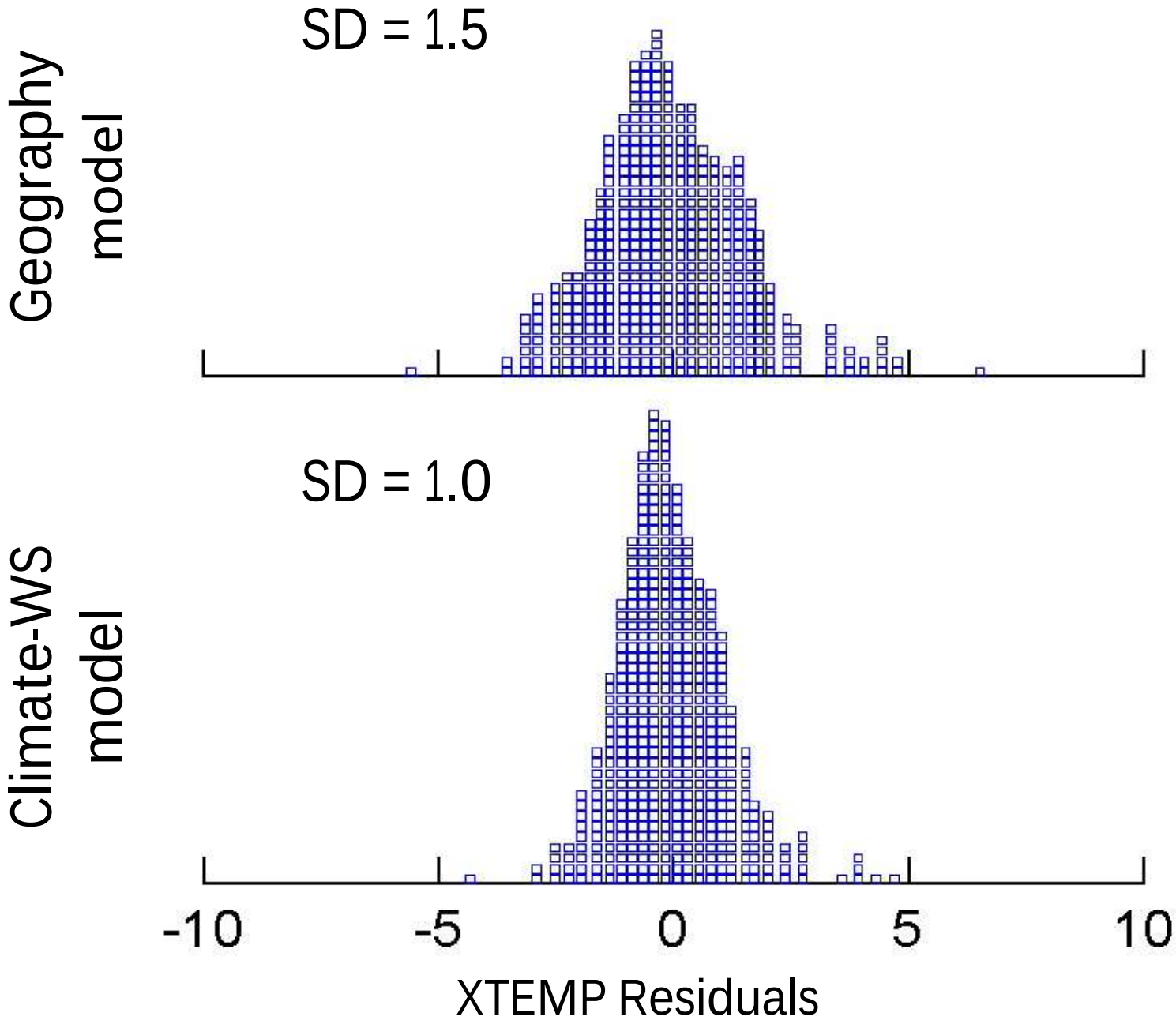
Pilot Study

N = 455
50 validation



Modeling (MLR) XTEMP

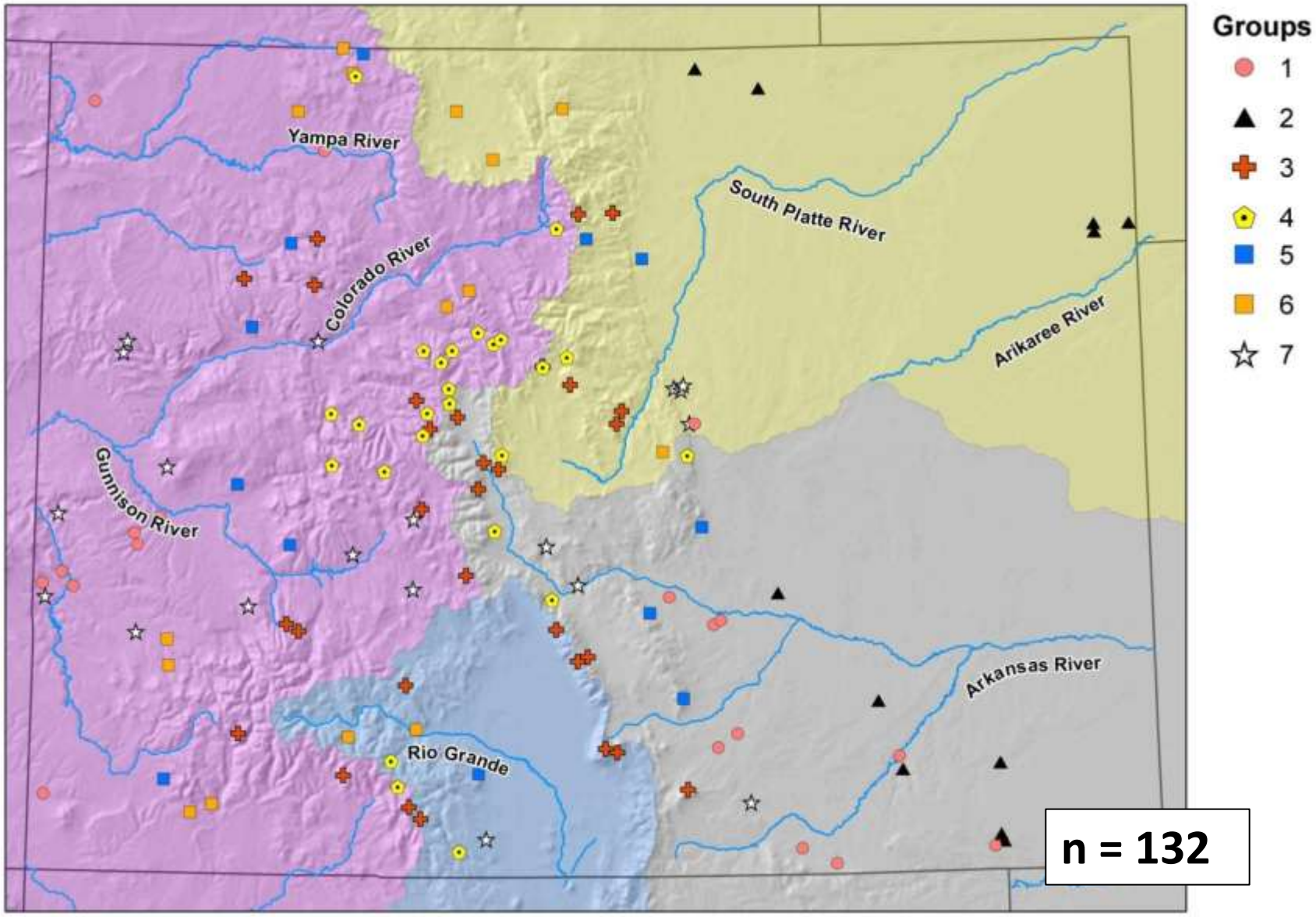
Model	Predictors	R^2	RMSE
Geography	elevation latitude WS area longitude	0.75	1.3º
Climate-WS	elevation **mean air temperature** latitude WS area **# of frost-free days** others	0.86	1.0º


SD = 1.5
Geography model
SD = 1.0
Climate-WS model
-10
-5
0
5
10
XTEMP Residuals

Variable	Predictors	R^2	RMSE
XTEMP	elevation **mean air temperature** latitude **# of frost-free days** WS area	0.86	1.0°
SUMMER	**maximum air temperature** **# of frost-free days** latitude soil bulk density WS area	0.73	2.2°
WINTER	**mean air temperature** **minimum air temperature** soil permeability % granitic geology depth to water table	0.75	1.7°

Do modeled stream temperatures improve predictions of biota?

7 classes of CO reference sites



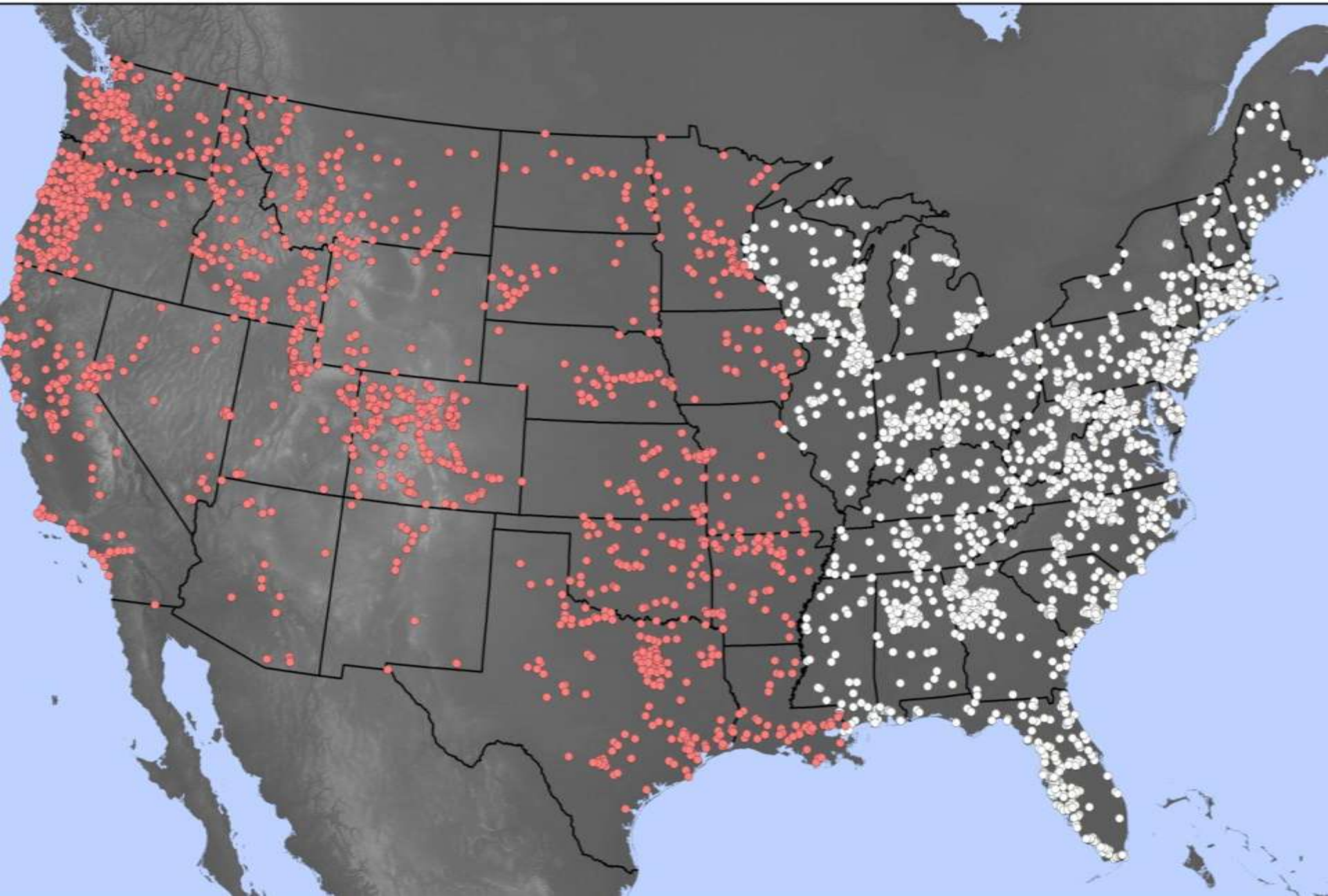
How well did 2 RIVPACS-type models predict invertebrate composition in Colorado reference streams?

Model	Predictors
Both	Day of year Long-term precipitation Previous year precipitation Local topographic relief
Geography	Latitude Elevation WS area
Predicted Temperature	SUMMER WINTER

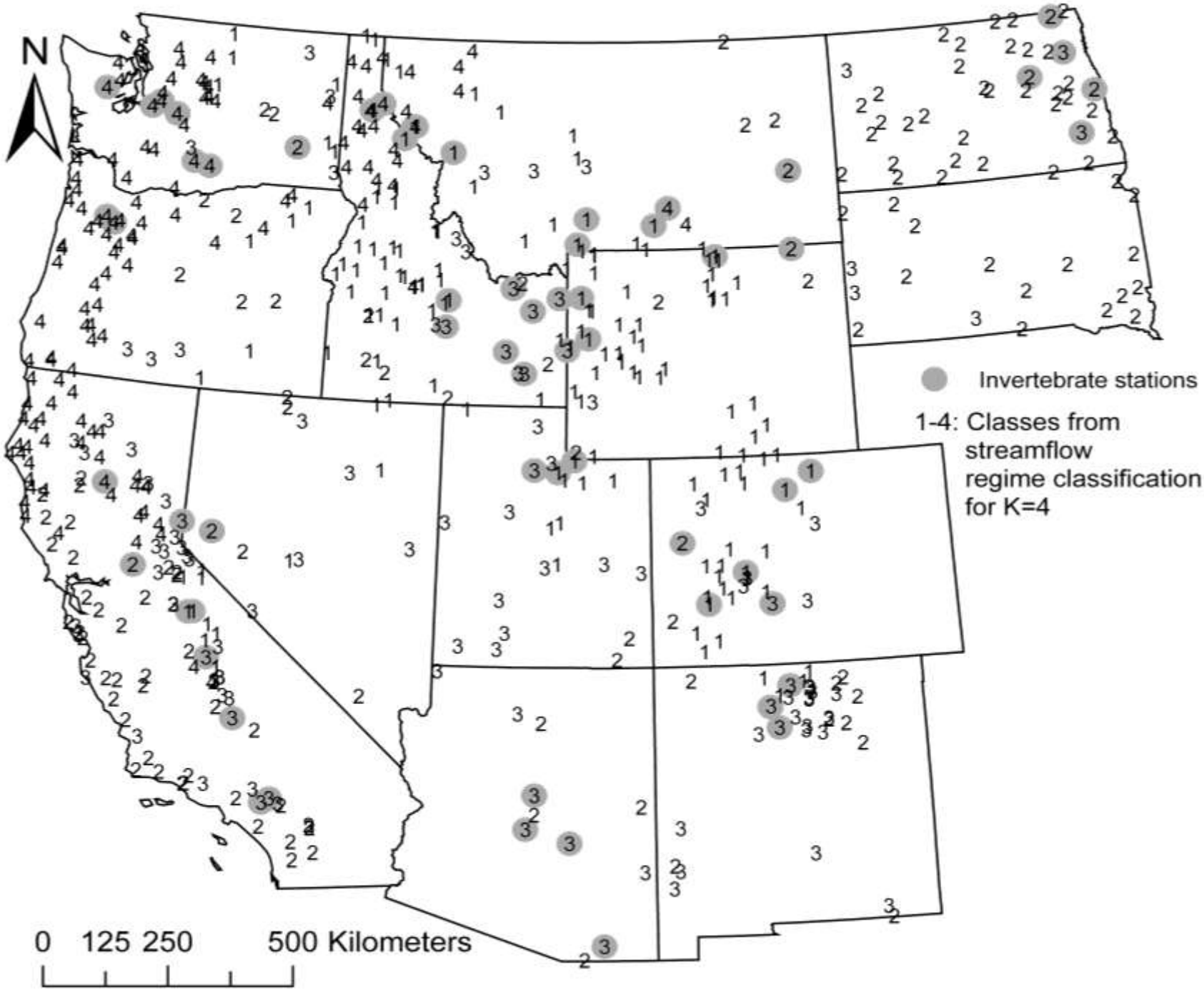
	% correct by model		
Groups	Surrogates	3 Temps	Change
1	47	47	0
2	73	82	+9
3	73	73	0
4	64	80	+16
5	8	33	+25
6	33	60	+27
7	53	53	0
Total	54	63	9

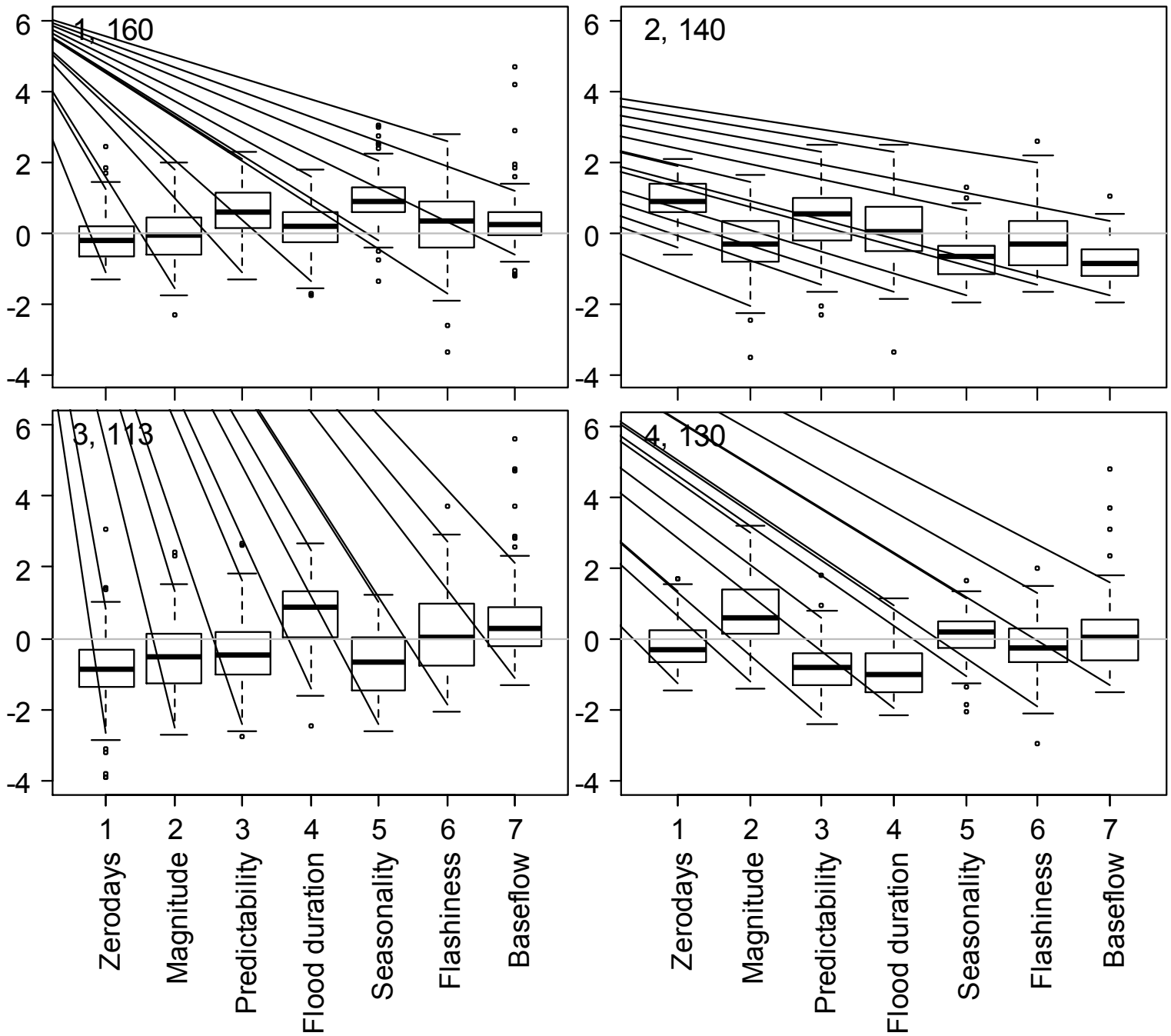
Expanded stream temperature modeling EPA-STAR grant & USGS/NAWQA collaboration

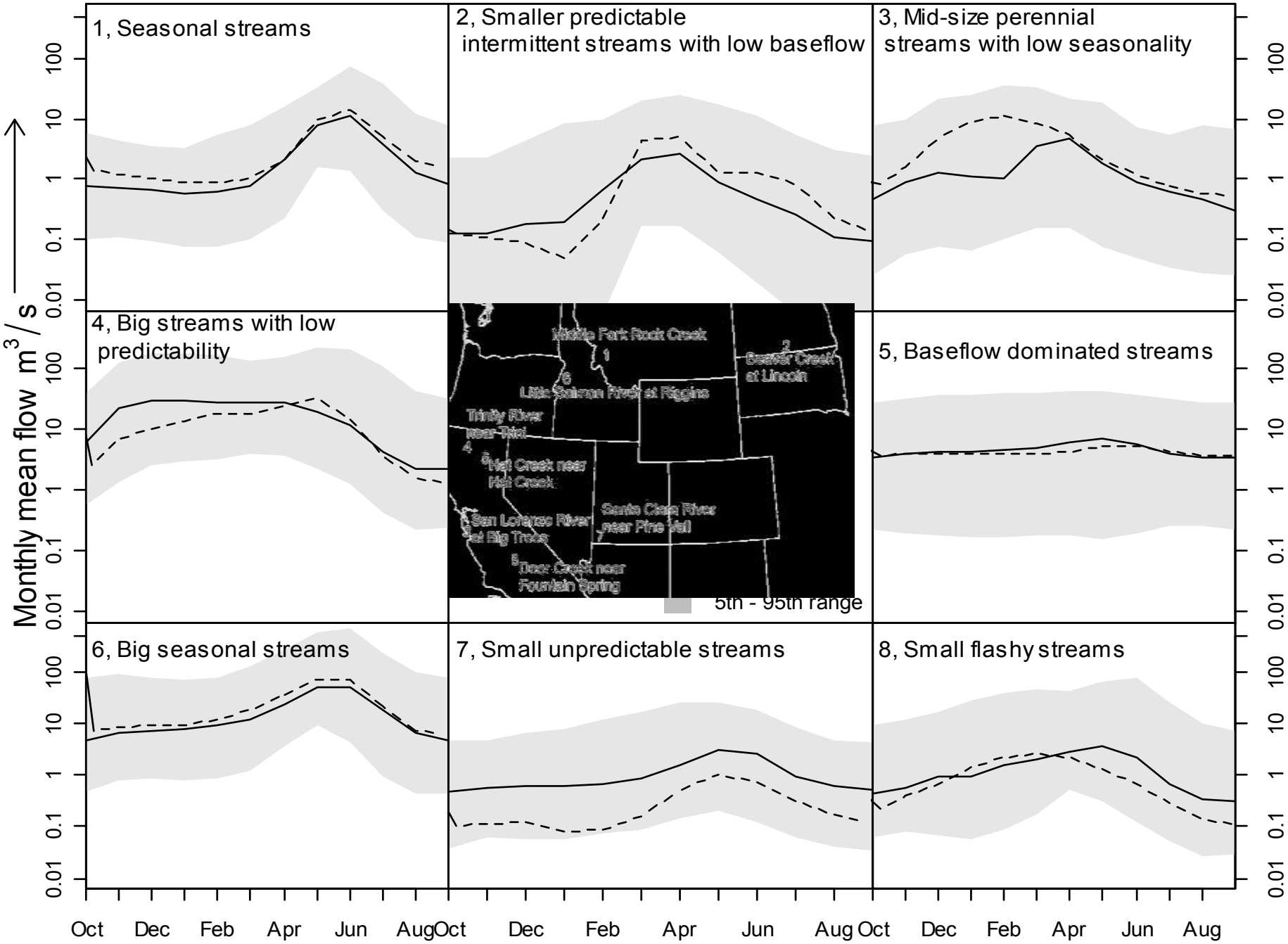
Stream temperature candidate reference sites



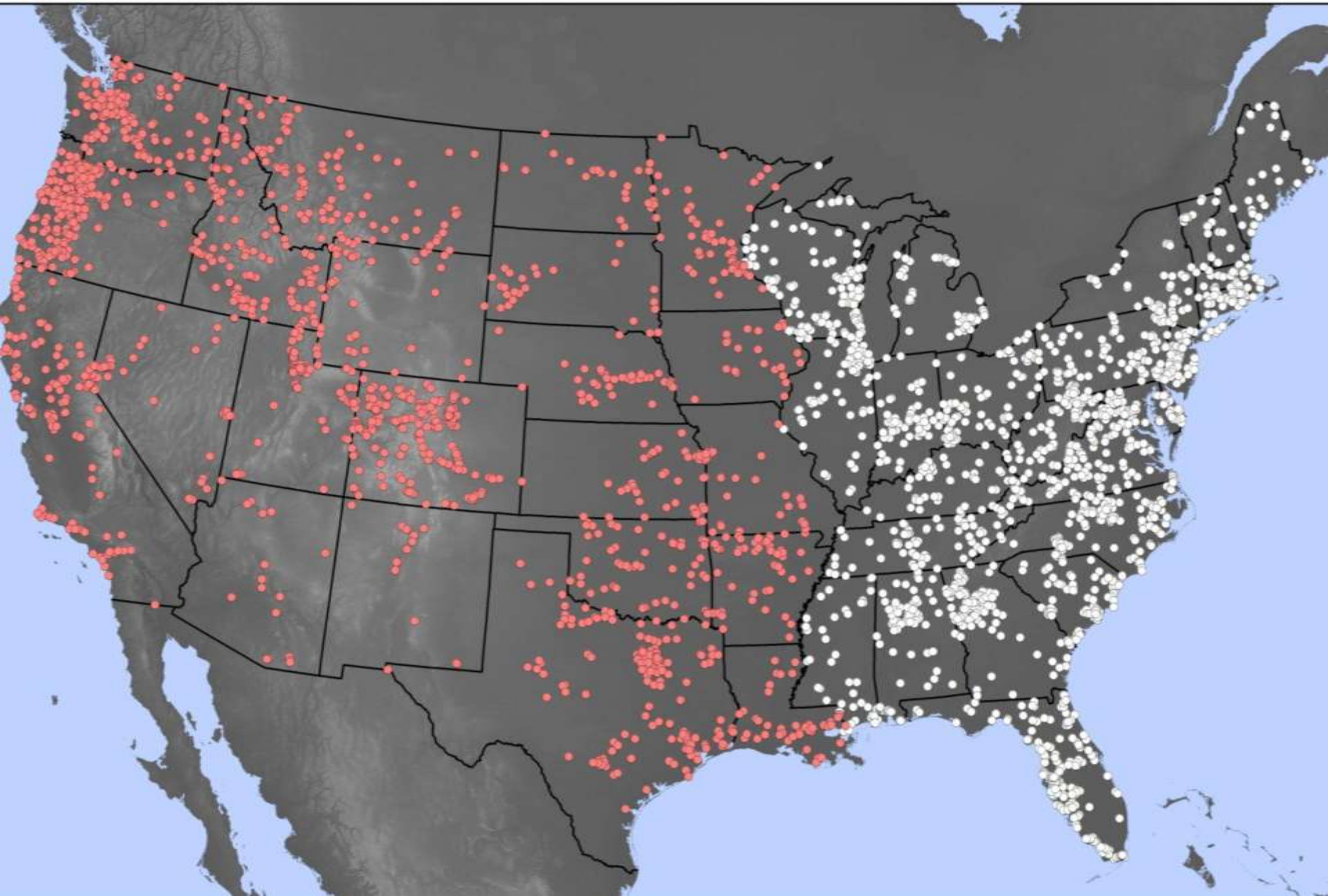
Stream flow modeling
by
David Tarboton and students


N
Invertebrate stations
1-4: Classes from streamflow regime classification for K=4
0 125 250 500 Kilometers


1, 160
2, 140
3, 113
4, 130
6
4
2
0
-2
-4
1
2
3
4
5
6
7
Zerodays
Magnitude
Predictability
Flood duration
Seasonality
Flashiness
Baseflow


1, Seasonal streams
2, Smaller predictable intermittent streams with low baseflow
3, Mid-size perennial streams with low seasonality
4, Big streams with low predictability
5, Baseflow dominated streams
6, Big seasonal streams
7, Small unpredictable streams
8, Small flashy streams
Monthly mean flow m3/s
0.01
0.1
1
10
100
Oct
Dec
Feb
Apr
Jun
Aug
Middle Fork Rock Creek
Beaver Creek at Lincoln
Little Salmon River at Riggins
Trinity River near Trinity
Hell Creek near Hell Creek
San Lorenzo River at Big Trees
Santa Clara River near Pine Hill
Deer Creek near Fountain Spring
5th - 95th range

Modeled stream flows and temperatures improve predictions of stream invertebrates

Model	O/E 10th %
Null	0.58
Flow (7 factors)	0.73
Temperature (3 variables)	0.67
Flow + Temperature	0.80

Flow and temperature modeling sites