Thermal Regimes of Western Rivers & Streams

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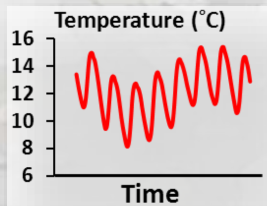
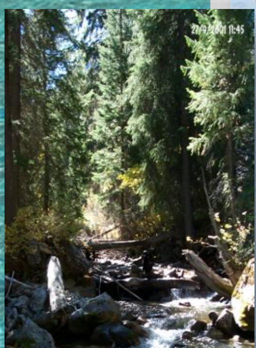
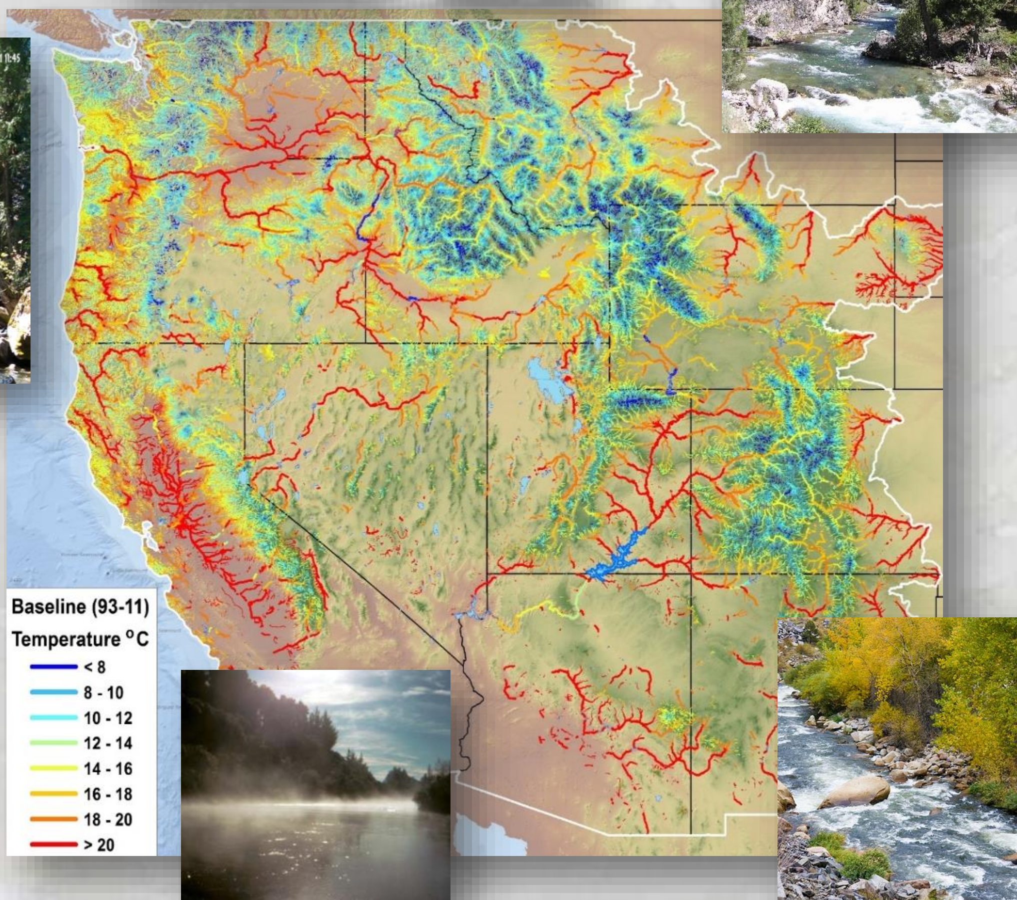
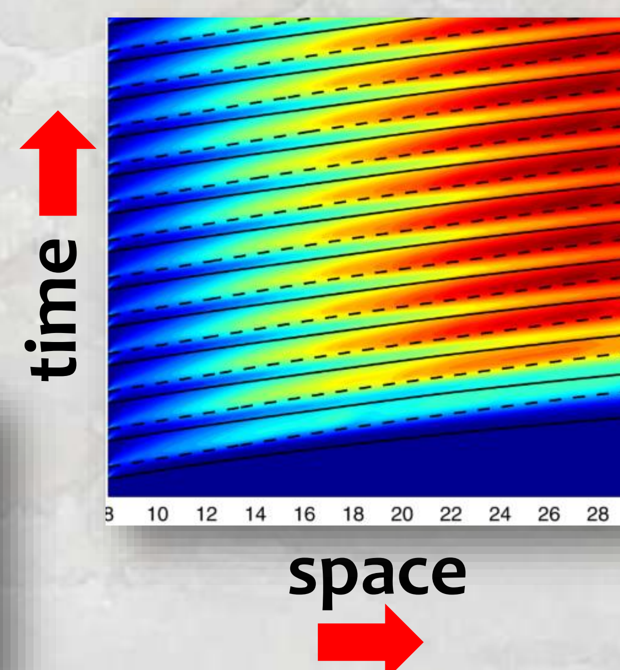






Staab, AqS team & R6 hydros & fish bios

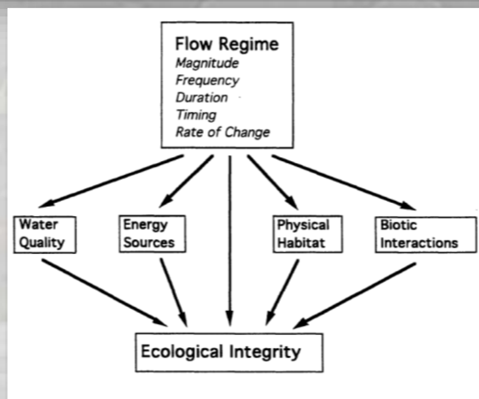


Flow Regimes as a Reference Point

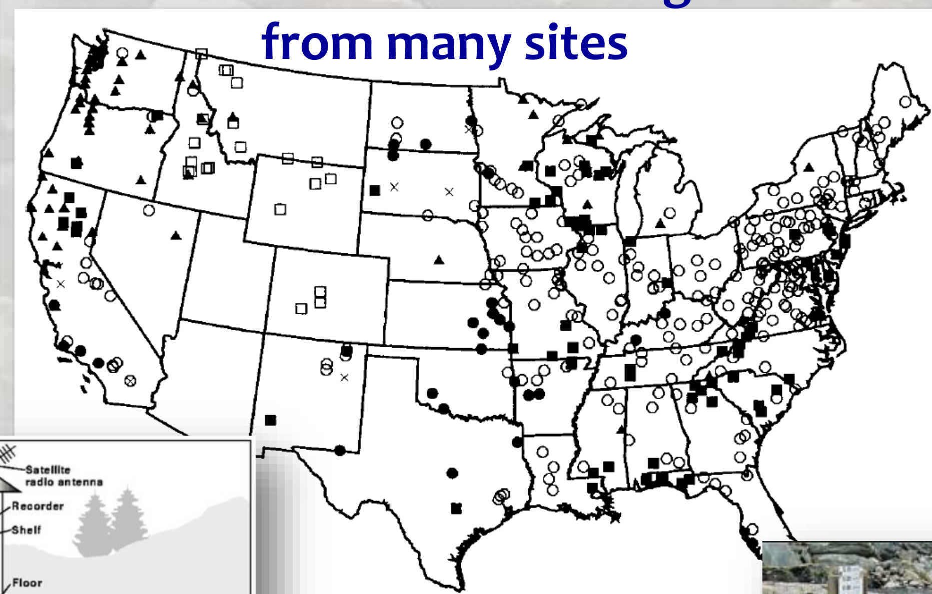
The Natural Flow Regime

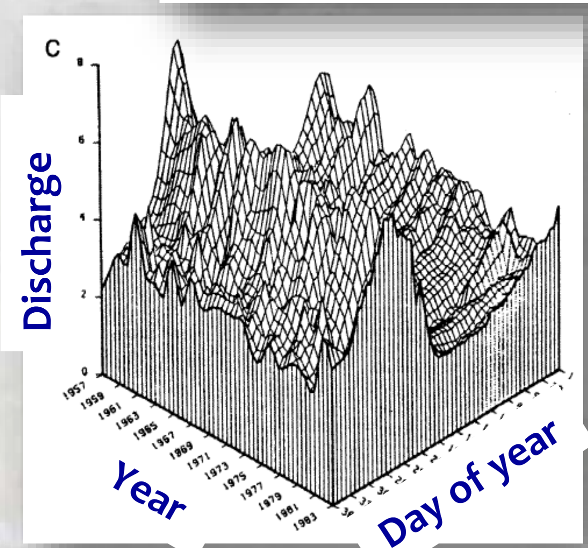
A paradigm for river conservation and restoration

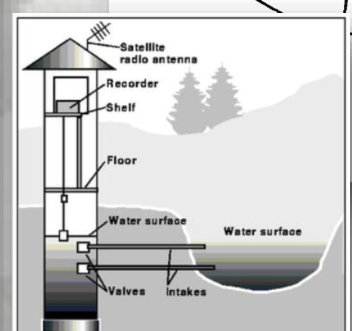
N. LeRoy Poff, J. David Allan, Mark B. Bain, James R. Karr, Karen L. Prestegaard, Brian D. Richter, Richard E. Sparks, and Julie C. Stromberg



Annual monitoring datasets from many sites

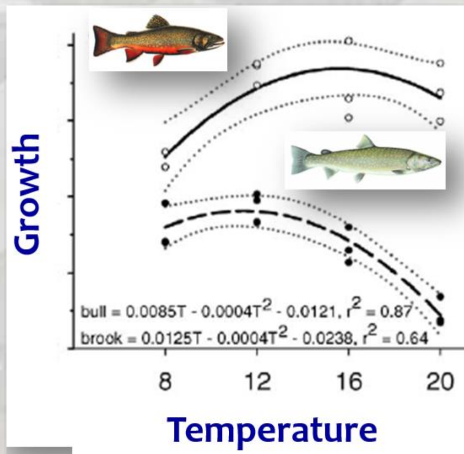


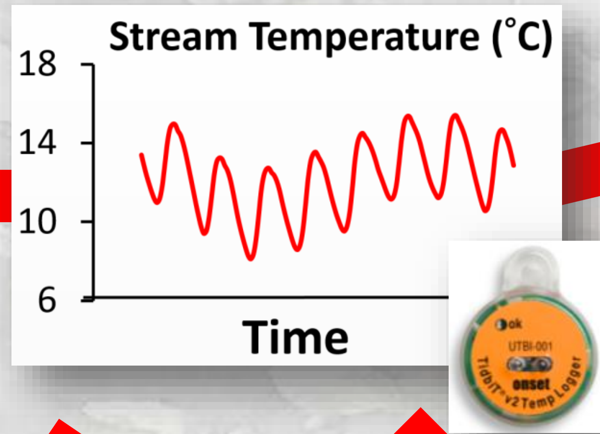




Thermal Regimes ~ Importance of Flow Regimes

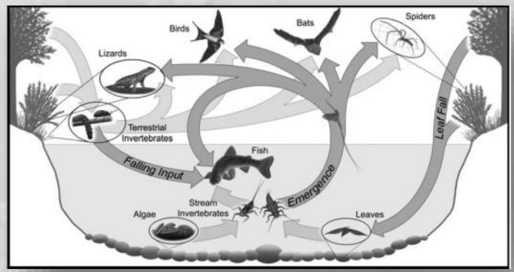
Ectotherm physiology



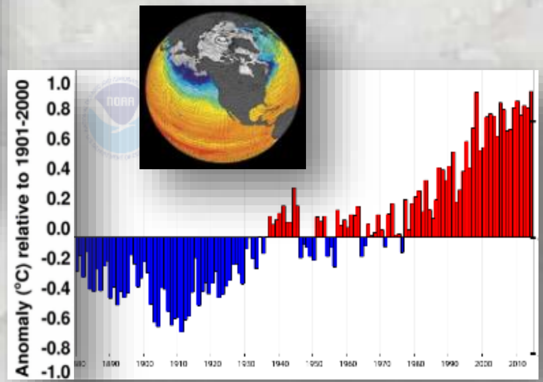


TMDL standards & regulations

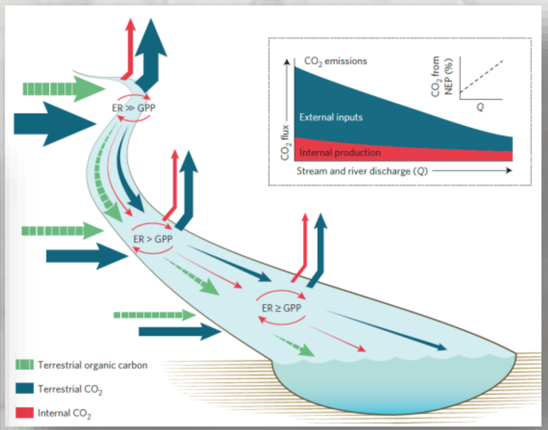
Stream metabolism & ecosystem function



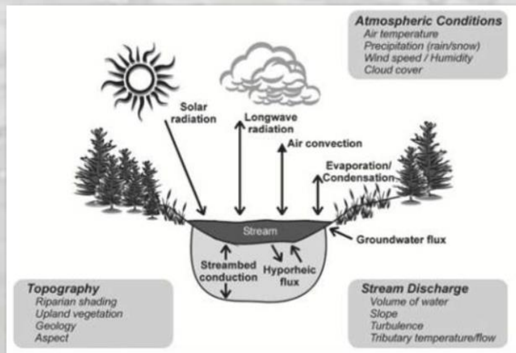
Global warming



Greenhouse gas emissions from streams



Thermal Regimes Understood Conceptually but not Empirically



Freshwater Biology (2006) **51**, 1389–1406

REVIEW ARTICLE

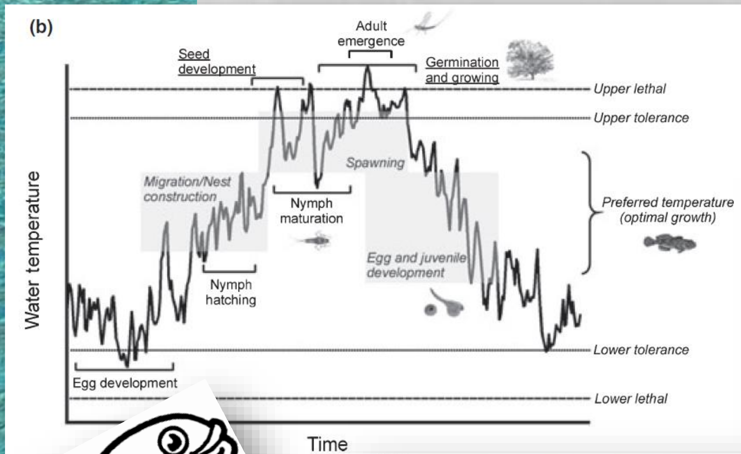
The thermal regime of rivers: a review

D. CAISSIE
Fisheries and Oceans, Oceans and Sciences Branch, Moncton,

Thermal characteristics of running waters

J. V. Ward
Department of Zoology, Colorado State University, Fort Collins, CO 80253, USA

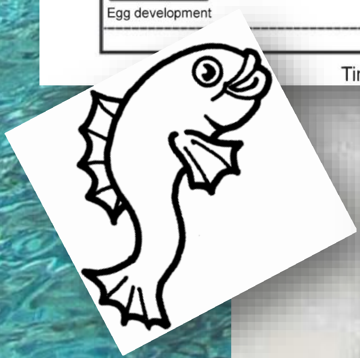
Hydrobiologia 125, 31–46 (1985).



Freshwater Biology (2009) doi:10.1111/j.1365-2427.2009.02179.x

Incorporating thermal regimes into environmental flows assessments: modifying dam operations to restore freshwater ecosystem integrity

JULIAN D. OLDEN AND ROBERT J. NAIMAN

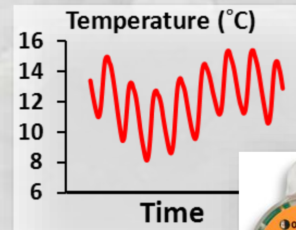


Empirical Descriptions Limited

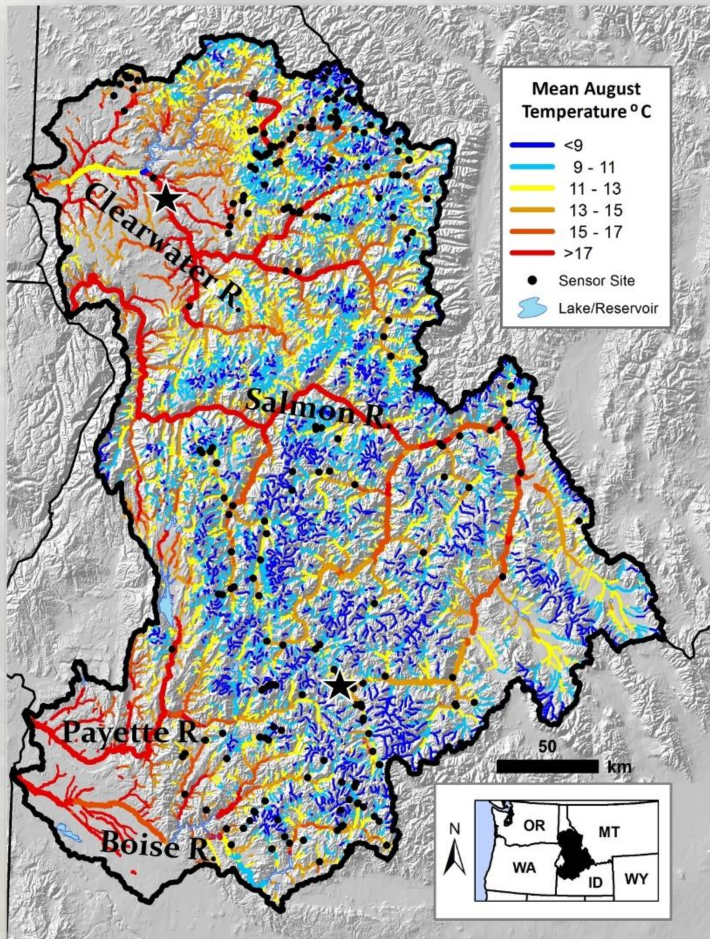
- Small, localized datasets
- Summer data primarily

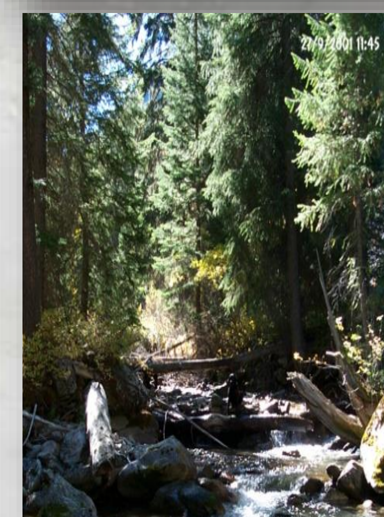
Thermal Regime Study #1

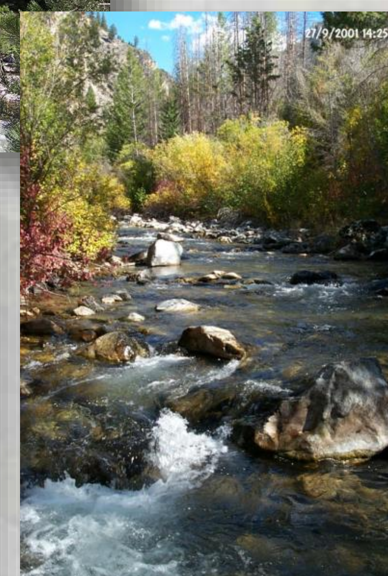
- 226 stream & river sites
- Five-year annual records (2011-2015)
- Mountain networks in Idaho
- USFS lands, wilderness, <10% private



NorWeST Stream Temp

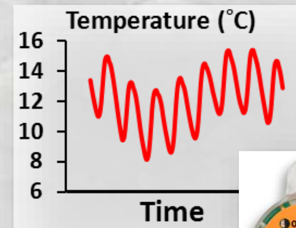




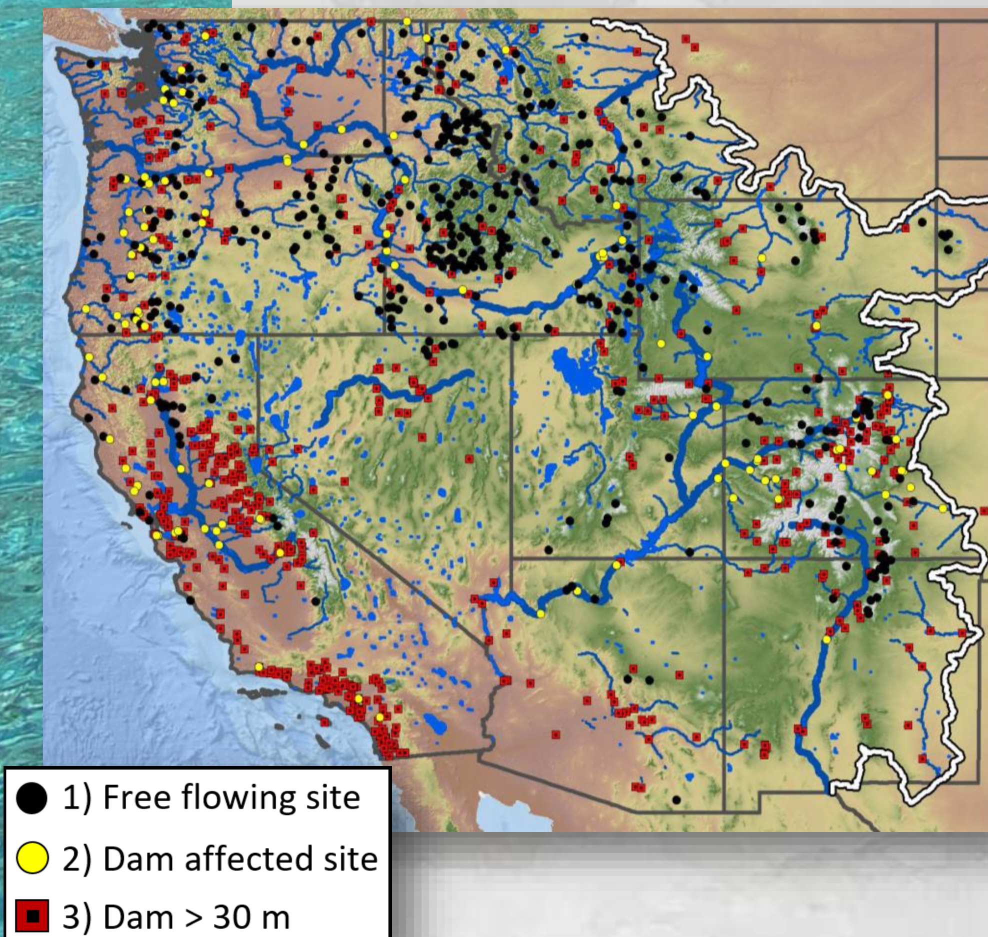


Thermal Regime Study #2

- 578 stream & river sites
- Five-year annual records (2011-2015)
- Networks across the western U.S.
- All lands, regulated and unregulated

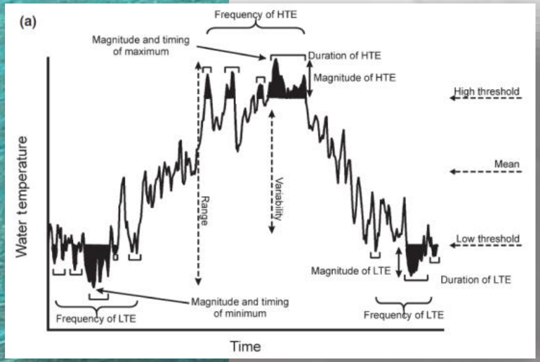


NorWeST Stream Temp



Methods

Summarize temperature records via 34 descriptive metrics in five categories



- **Magnitude** (e.g., mean annual, mean summer, minimum weekly, maximum daily, etc.)
- **Variability** (e.g., annual SD, spring SD, range in annual min/max, etc.)
- **Frequency** (e.g., number of days >20°C, <2°C)
- **Timing** (e.g., date of 5%, 25%, 50%, 75%, & 95% degree days)
- **Duration** (e.g., growing season length, number of consecutive days >20°C, <2°C)

PCA (Principal components analysis) on metrics

PCA on mean daily temperatures at sites (S-mode PCA)

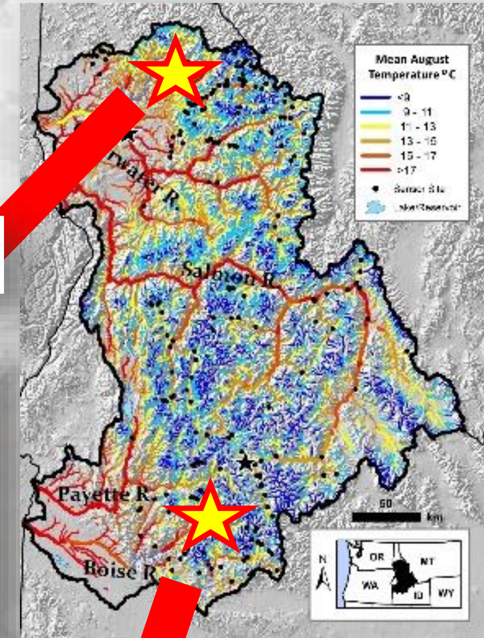
Hierarchical cluster analysis on metrics

Multiple linear regressions models to predict PC scores from covariates & map regime characteristics

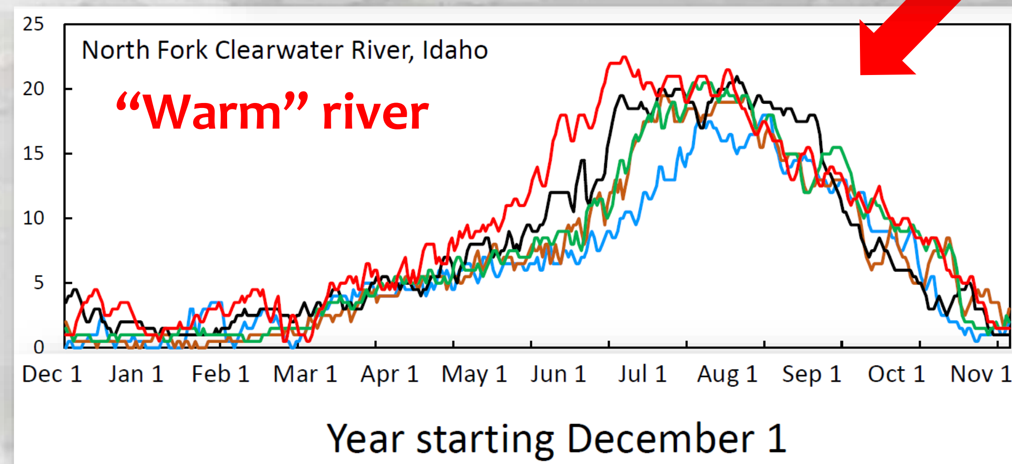
Study 1. Dataset Description

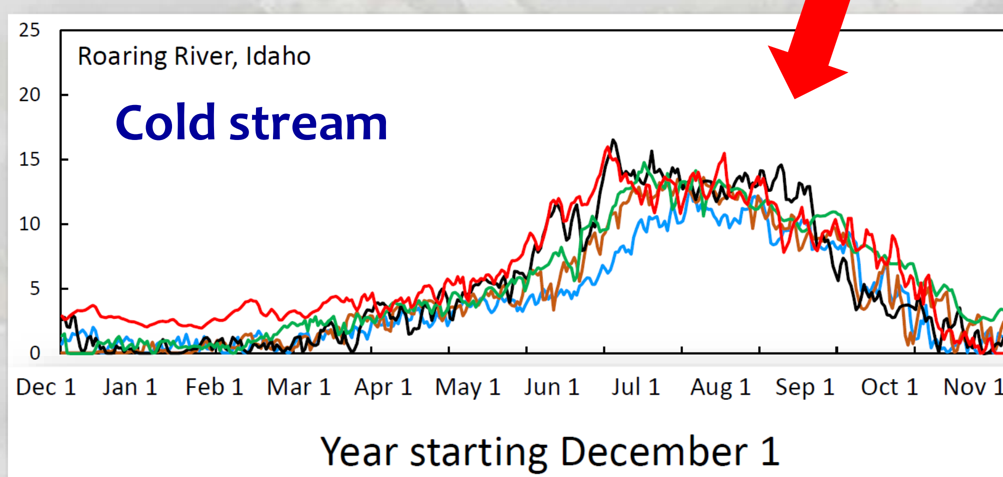
Thermal year: 2011: [blue line] 2012: [orange line]

2013: [black line] 2014: [green line] 2015: [red line]



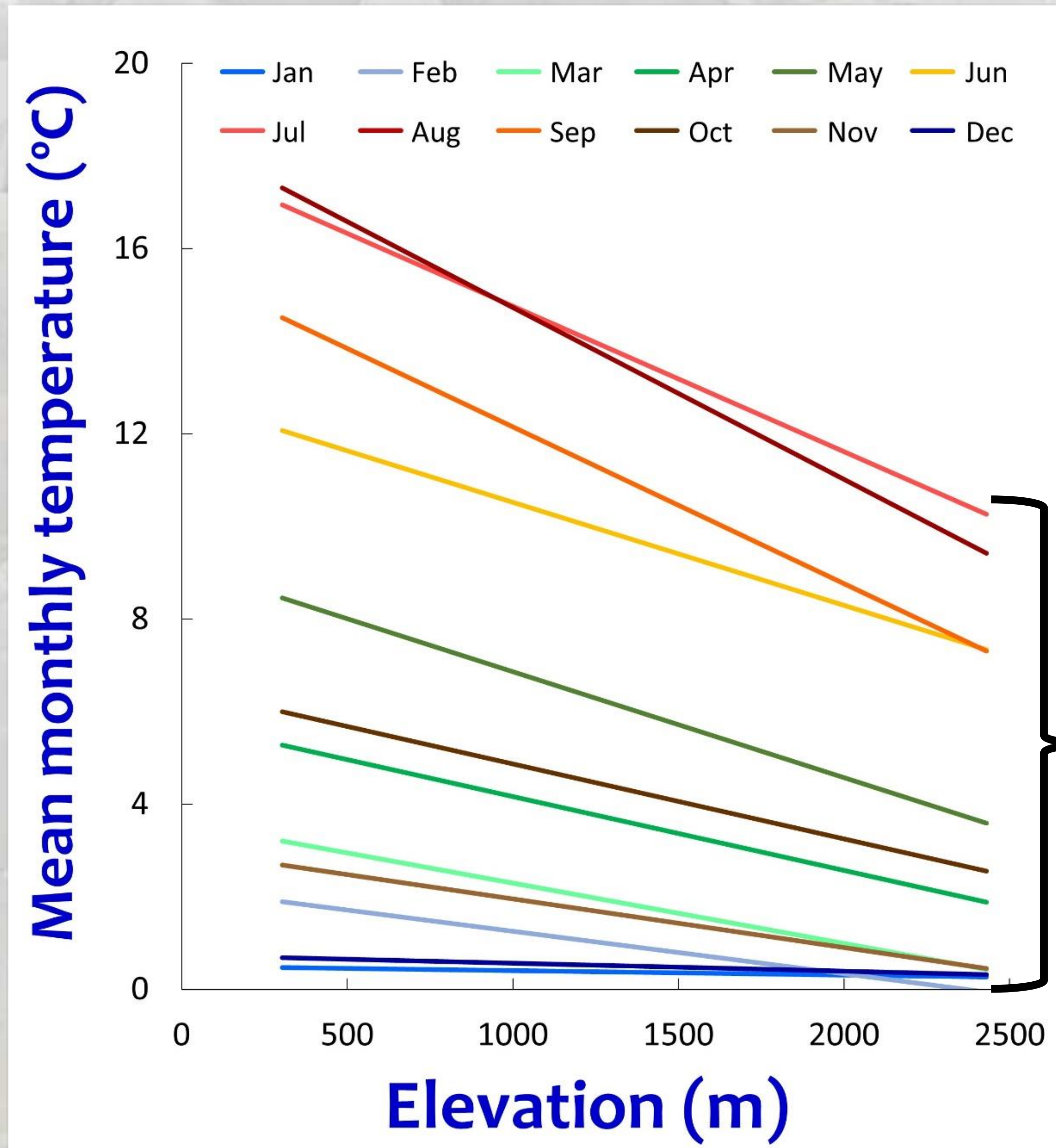
Mean Daily Temperature (°C)

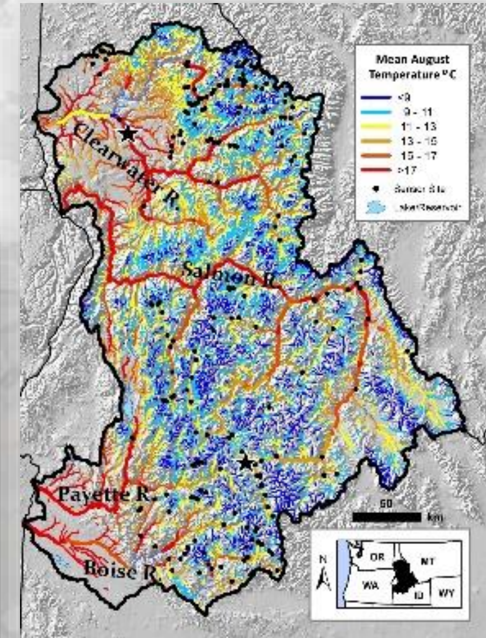




Study 1. Dataset Description

Annual cycle @ 226 sites in 2013





Higher, colder sites are less climatically sensitive

PCA on Thermal Metrics

1) Three PCs account for 88% of total variation

2) Many metrics are highly redundant

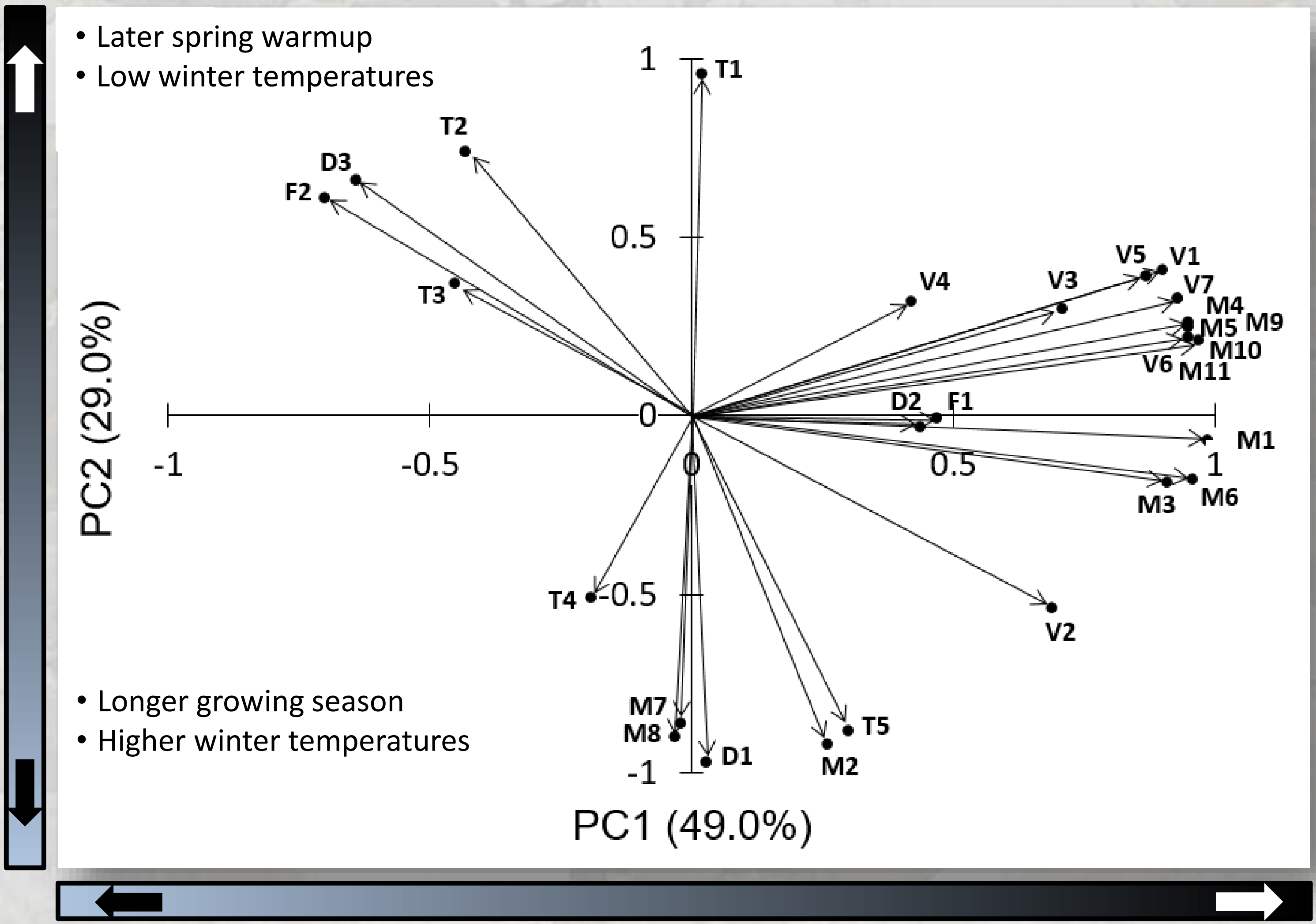
3) Interpretations:

- PC1 (49.0%) = magnitude & variability
- PC2 (29.0%) = length of growing season & minimum winter temps

Temperature metric	PC1	PC2	PC3
M1. Mean annual temperature	**0.99**	-0.07	-0.05
M2. Mean winter temperature	0.26	**-0.92**	0.14
M3. Mean spring temperature	**0.91**	-0.19	-0.25
M4. Mean summer temperature	**0.97**	0.21	-0.06
M5. Mean August temperature*	**0.95**	0.22	0.16
M6. Mean fall temperature	**0.96**	-0.18	0.14
M7. Minimum daily temperature	-0.02	**-0.86**	0.08
M8. Minimum weekly average temperature	-0.03	**-0.90**	0.08
M9. Maximum daily temperature	**0.95**	0.26	0.09
M10. Maximum weekly average temperature	**0.95**	0.25	0.09
M11. Annual degree days	**0.99**	-0.07	-0.05
V1. Annual standard deviation	**0.90**	0.41	0.01
V2. Winter standard deviation	0.69	-0.54	0.16
V3. Spring standard deviation	**0.71**	0.30	-0.55
V4. Summer standard deviation	0.42	0.32	**0.78**
V5. Fall standard deviation	**0.87**	0.39	0.19
V6. Range in extreme daily temperatures	**0.93**	0.33	0.08
V7. Range in extreme weekly temperatures	**0.93**	0.33	0.08
F1. Frequency of hot days	0.47	-0.01	0.30
F2. Frequency of cold days	**-0.70**	0.61	0.09
T1. Date of 5% of degree days	0.02	**0.96**	-0.10
T2. Date of 25% of degree days	-0.43	**0.74**	0.46
T3. Date of 50% of degree days	-0.45	0.37	**0.79**
T4. Date of 75% of degree days	-0.19	-0.51	**0.72**
T5. Date of 95% of degree days	0.30	**-0.88**	0.12
D1. Growing season length	0.03	**-0.97**	0.11
D2. Duration of hot days	0.44	-0.03	0.32
D3. Duration of cold days	-0.64	0.66	0.07
Variance explained (%):	**49.0%**	**29.0%**	**9.8%**
Cumulative variance (%):	**49.0%**	**78.0%**	**87.8%**

PCA on Thermal Metrics

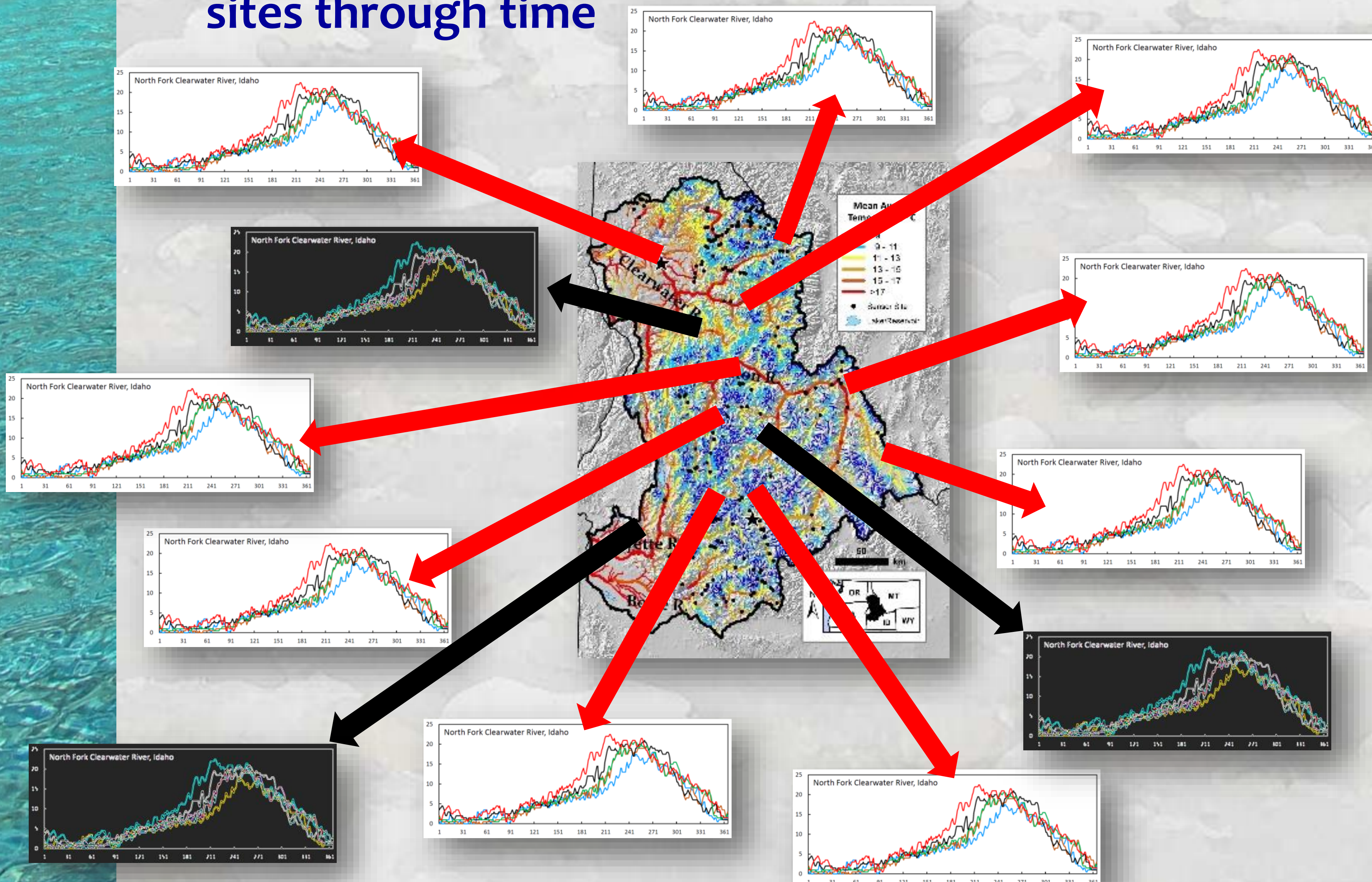
Ordination plot of metrics describing regimes



• Warmer
• More variable

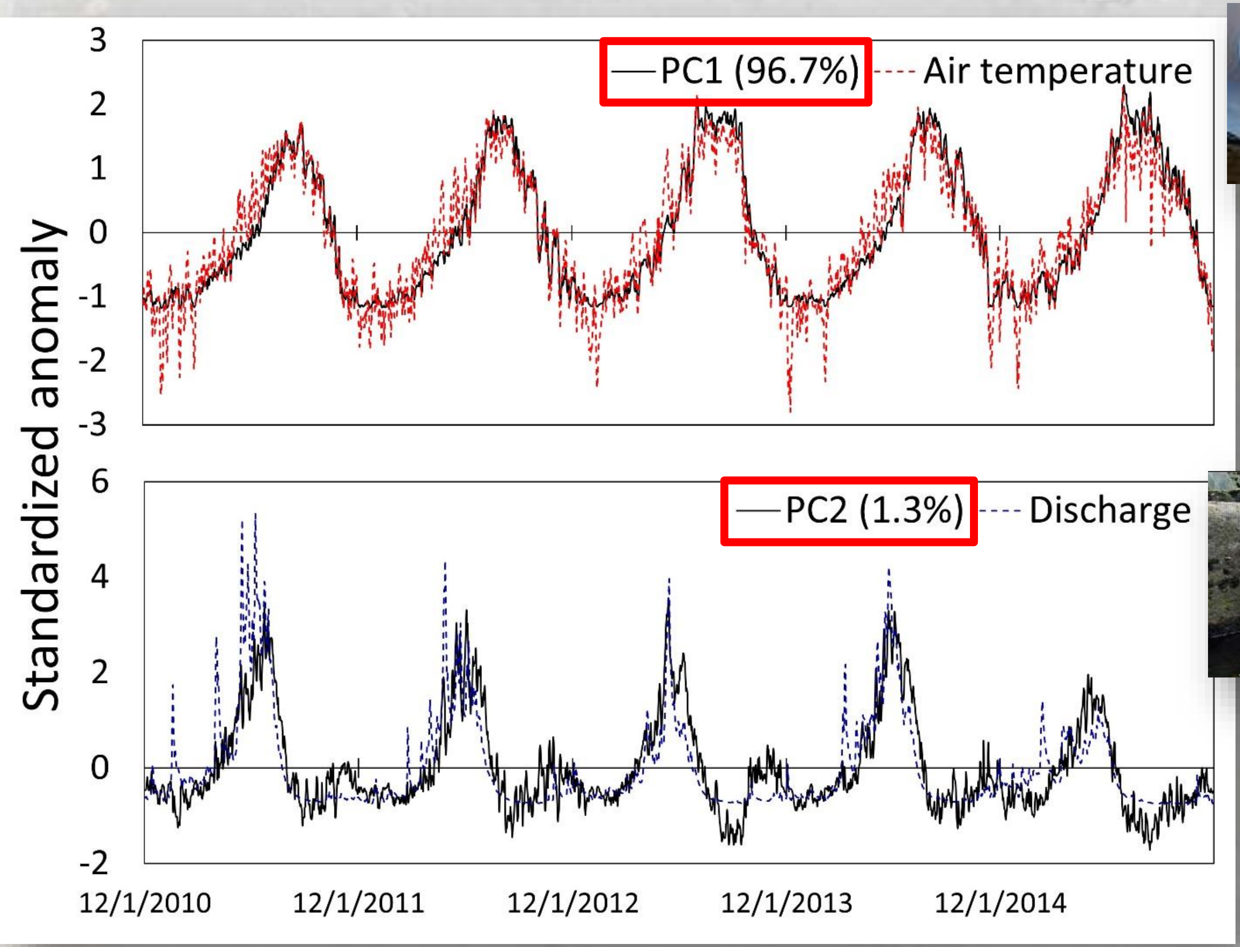
PCA on Mean Daily Temps @ 226 Sites

"S-mode" PCA describes covariation among sites through time



PCA on Mean Daily Temps @ 226 Sites

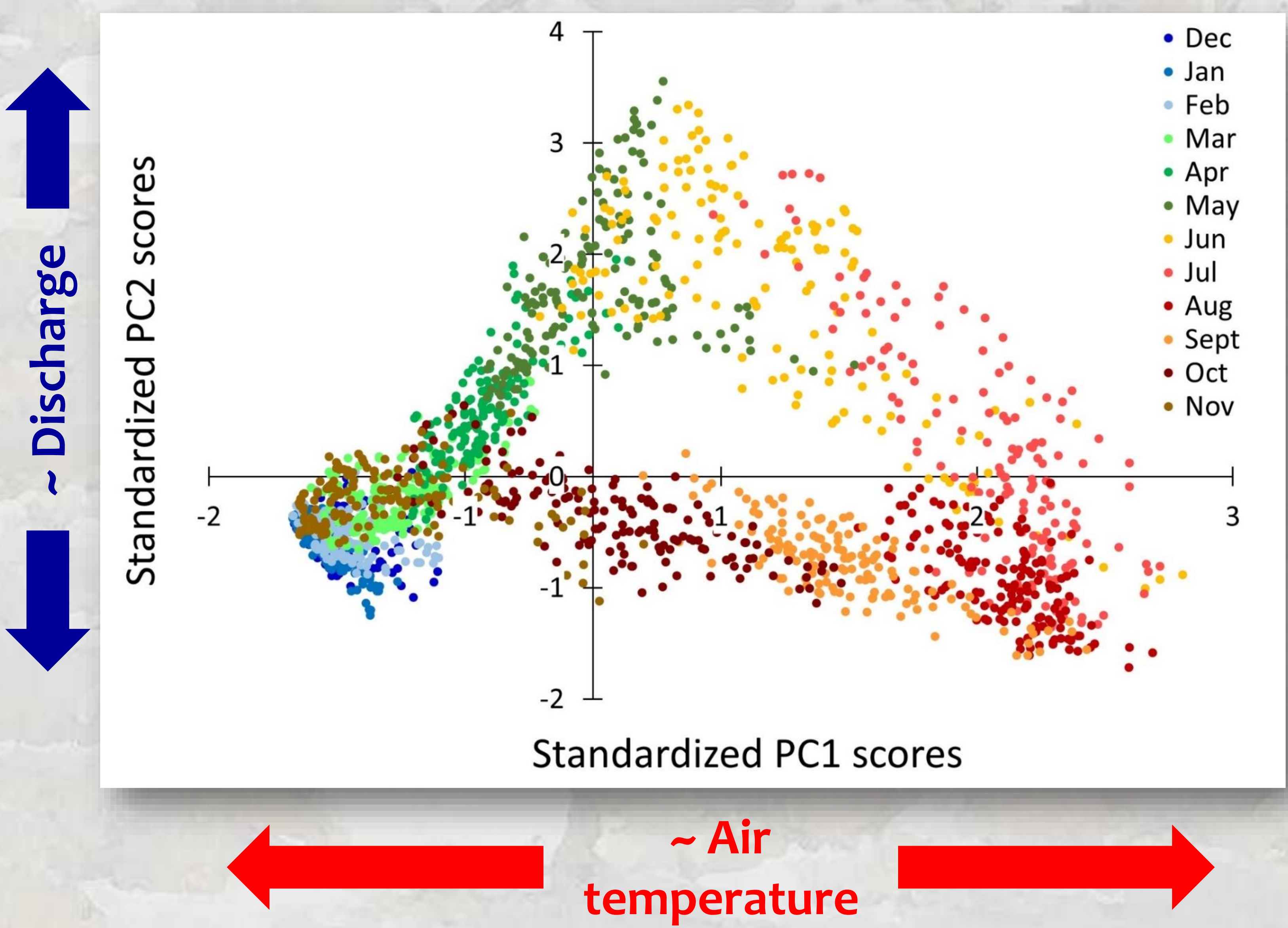
- Two PCs account for 98% of variation
- PC1 correlates with daily air temperature
- PC2 correlates with daily discharge



	Discharge	Air
Air	0.14	-
PC1	-0.05	**0.94**
PC2	**0.83**	0.18

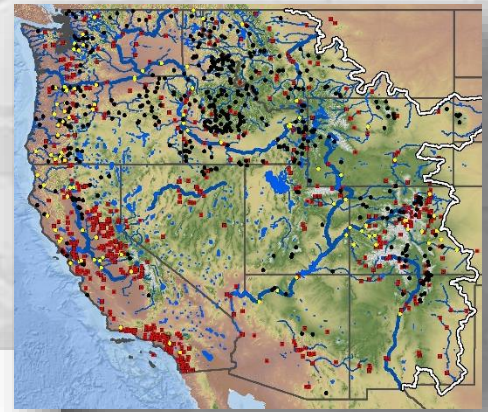
Five year period

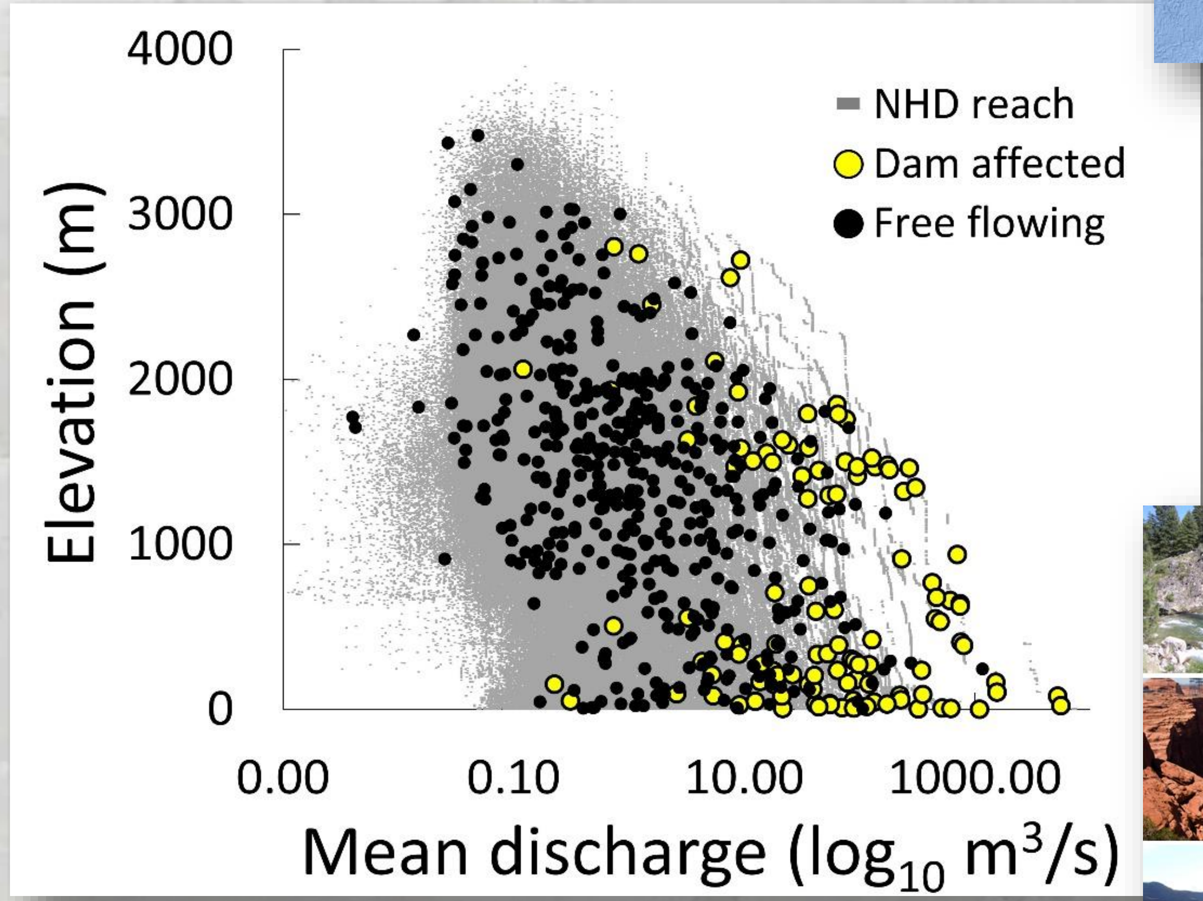
PCA on Mean Daily Temps @ 226 Sites



Study 2. Dataset Description

- Same five year period of 2011-2015
- 578 stream & river sites





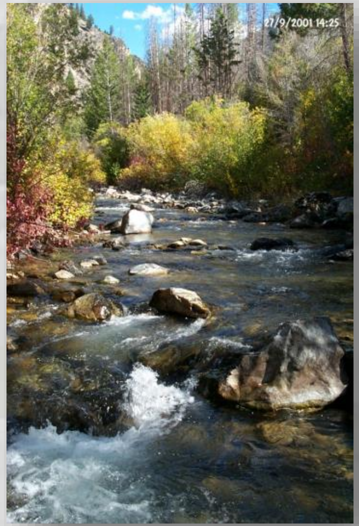
PCA on Thermal Metrics

1) **Three PCs account for 81% of total variation**

2) **Many metrics are highly redundant**

3) **Interpretations:**

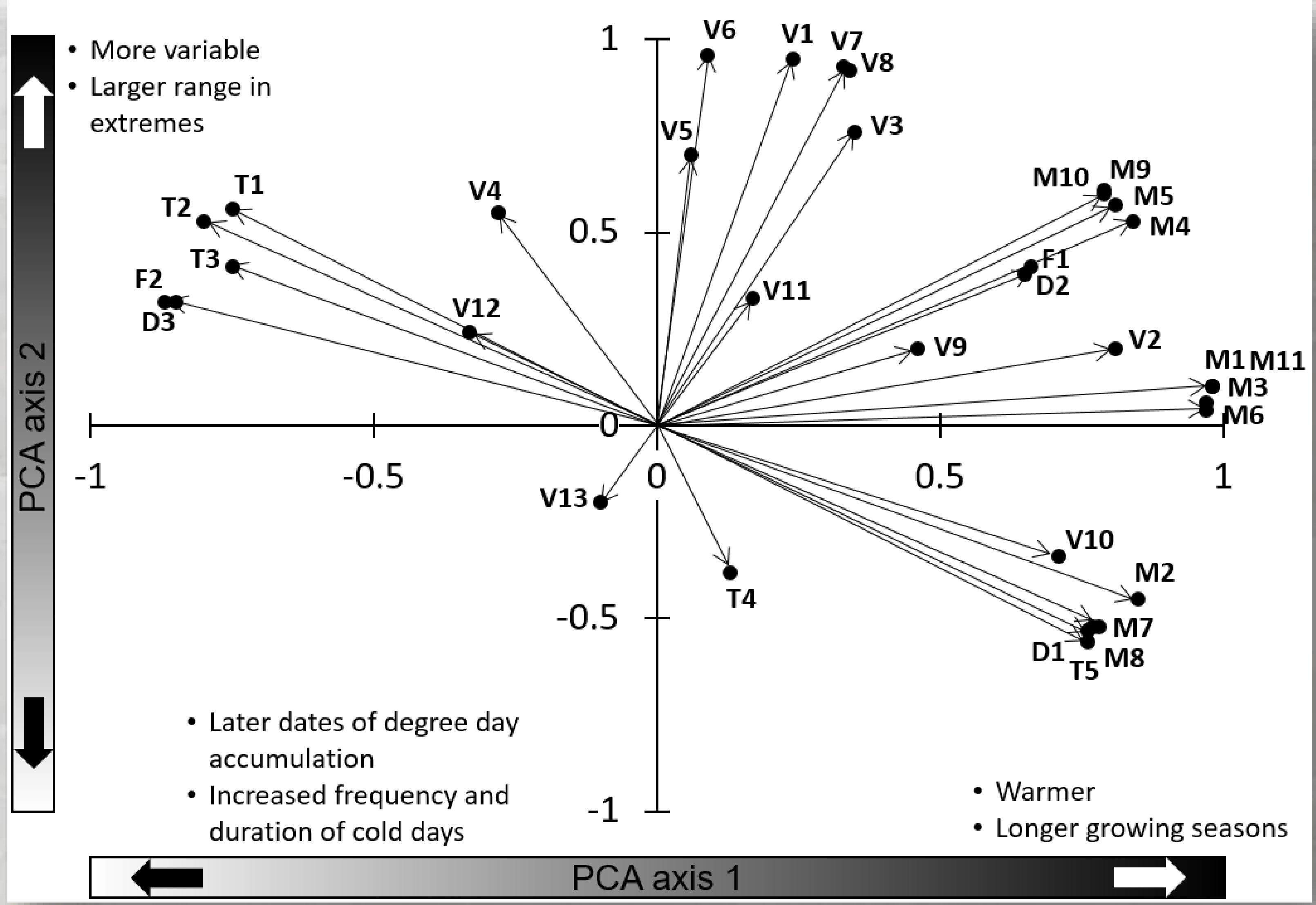
- **PC1 (46.1%) = magnitude, frequency, timing, & duration**
- **PC2 (27.9%) = variability**
- **PC3 (7.1%) = inter-annual variability in magnitude & timing**



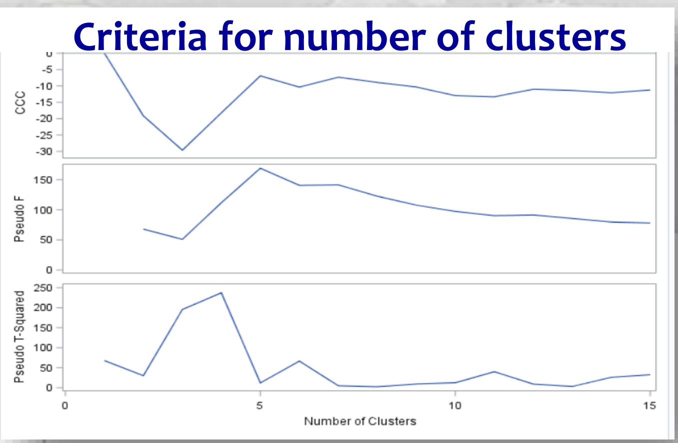
Temperature metric	PC1	PC2	PC3
M1. Mean annual temperature	**0.98**	0.10	-0.04
M2. Mean winter temperature	**0.85**	-0.45	0.02
M3. Mean spring temperature	**0.97**	0.06	-0.13
M4. Mean summer temperature	**0.84**	0.53	-0.07
M5. Mean August temperature	**0.81**	0.57	0.05
M6. Mean fall temperature	**0.97**	0.03	0.06
M7. Minimum daily temperature	**0.77**	-0.53	0.01
M8. Minimum weekly average temperature	**0.78**	-0.53	0.02
M9. Maximum daily temperature	**0.79**	0.60	0.02
M10. Maximum weekly average temperature	**0.79**	0.60	0.02
M11. Annual degree days	**0.98**	0.10	-0.04
V1. Annual SD	0.24	**0.95**	-0.03
V2. Winter SD	**0.82**	0.19	0.05
V3. Spring SD	0.36	**0.76**	-0.27
V4. Summer SD	-0.29	**0.55**	0.54
V5. August SD	0.06	**0.71**	0.15
V6. Fall SD	0.10	**0.96**	-0.01
V7. Range in extreme daily temperatures	0.34	**0.92**	0.02
V8. Range in extreme weekly temperatures	0.33	**0.93**	0.02
V9. Inter-annual SD of mean annual temperature	0.46	0.21	**0.74**
V10. Inter-annual SD of minimum weekly temperature	**0.71**	-0.34	0.18
V11. Inter-annual SD of maximum weekly temperature	0.16	0.34	0.45
V12. Inter-annual SD of 5% degree days	-0.34	0.26	0.42
V13. Inter-annual SD of 50% degree days	-0.12	-0.19	**0.75**
F1. Frequency of hot days	**0.66**	0.43	-0.14
F2. Frequency of cold days	**-0.87**	0.32	-0.06
T1. Date of 5% degree days	**-0.75**	0.56	-0.11
T2. Date of 25% degree days	**-0.80**	0.53	0.11
T3. Date of 50% degree days	**-0.75**	0.41	0.31
T4. Date of 75% degree days	0.13	-0.38	0.52
T5. Date of 95% degree days	**0.76**	-0.53	0.17
D1. Growing season length	**0.76**	-0.56	0.12
D2. Duration of hot days	**0.65**	0.40	-0.14
D3. Duration of cold days	**-0.85**	0.32	-0.07
Variance explained (%):	**46.1**	**27.9**	**7.1**

PCA on Thermal Metrics

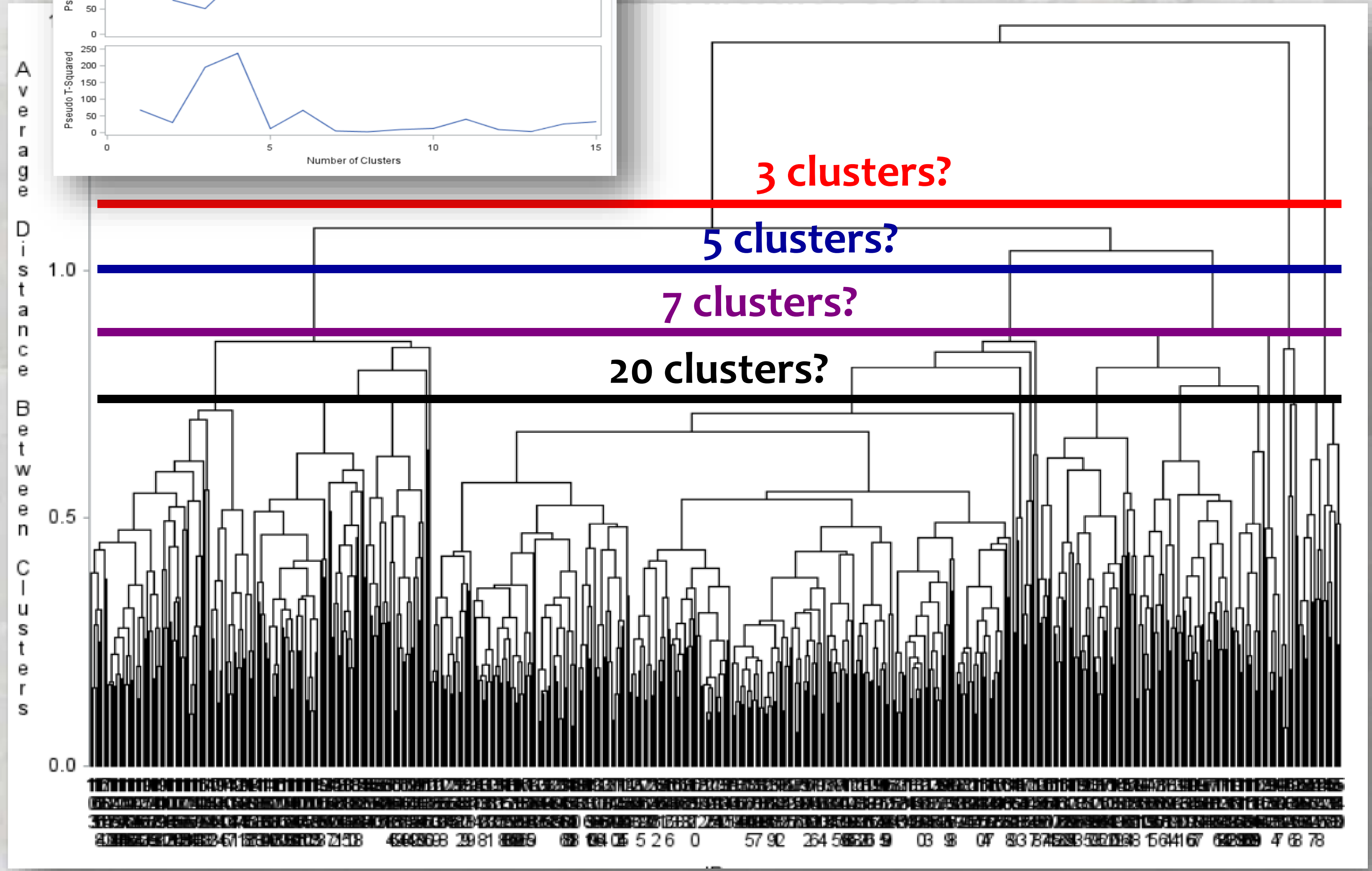
Ordination plot of metrics describing regimes



Cluster Analysis on Thermal Metrics

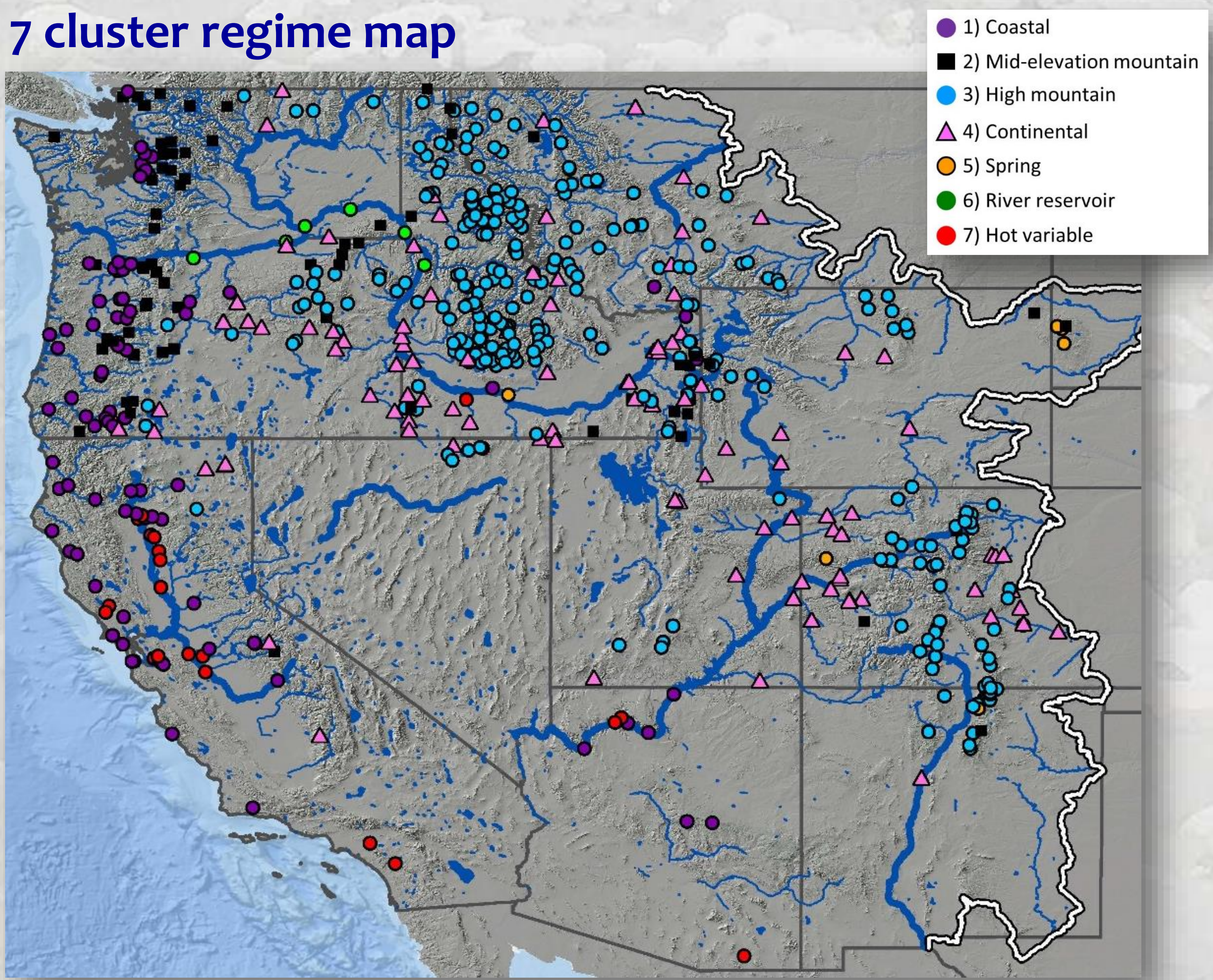


Dendrogram of 578 stream sites



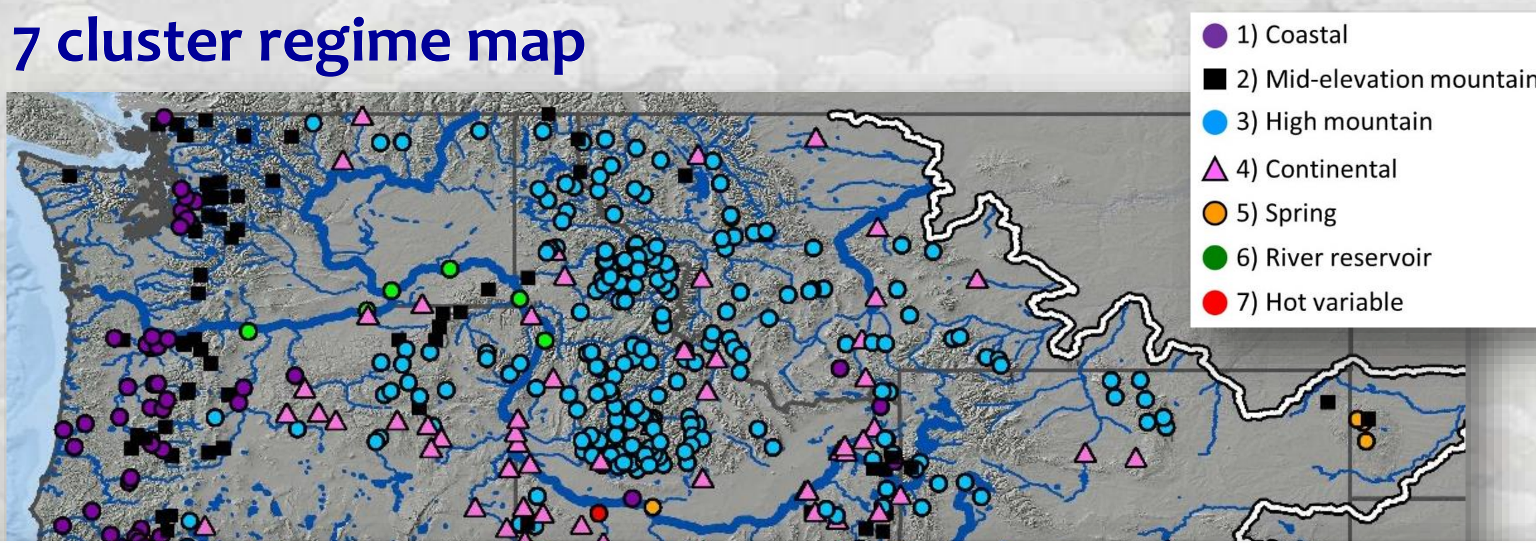
Cluster Analysis on Thermal Metrics

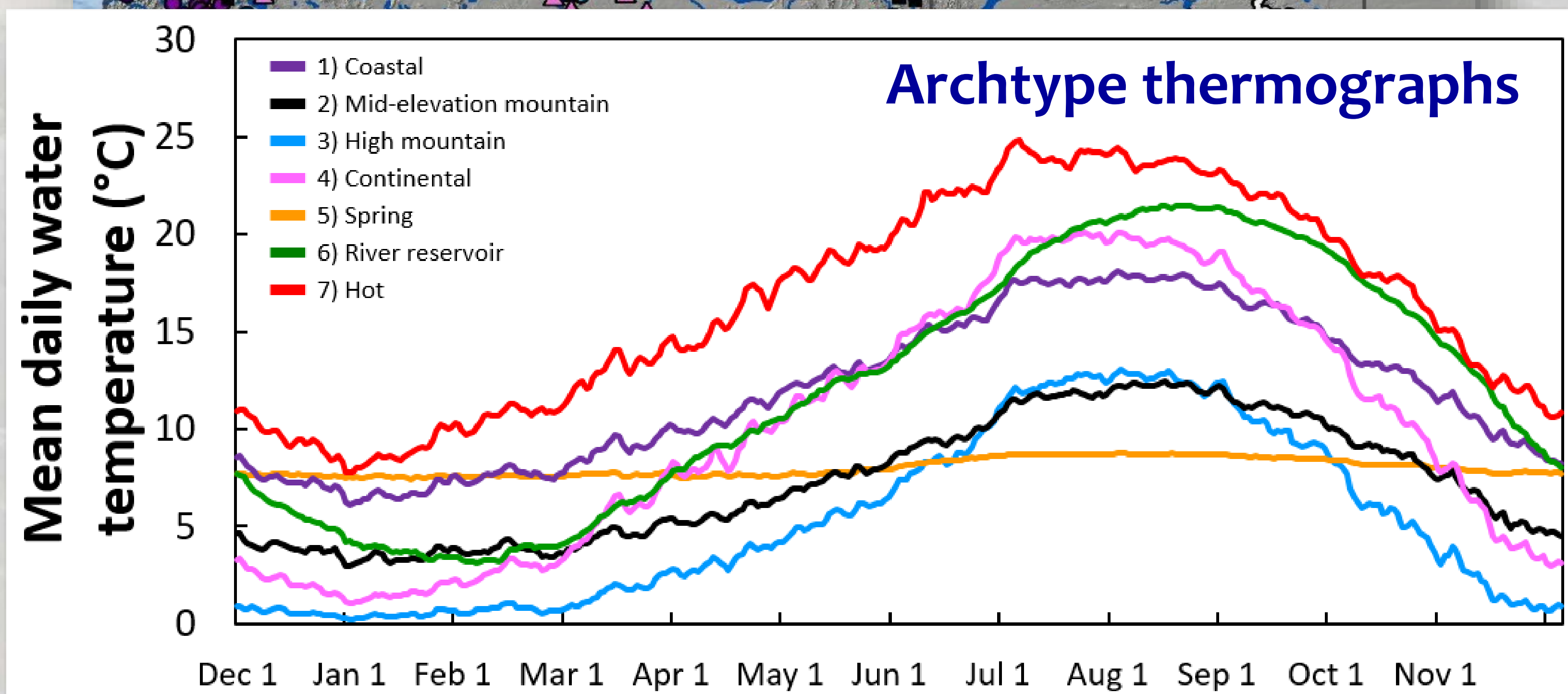
7 cluster regime map



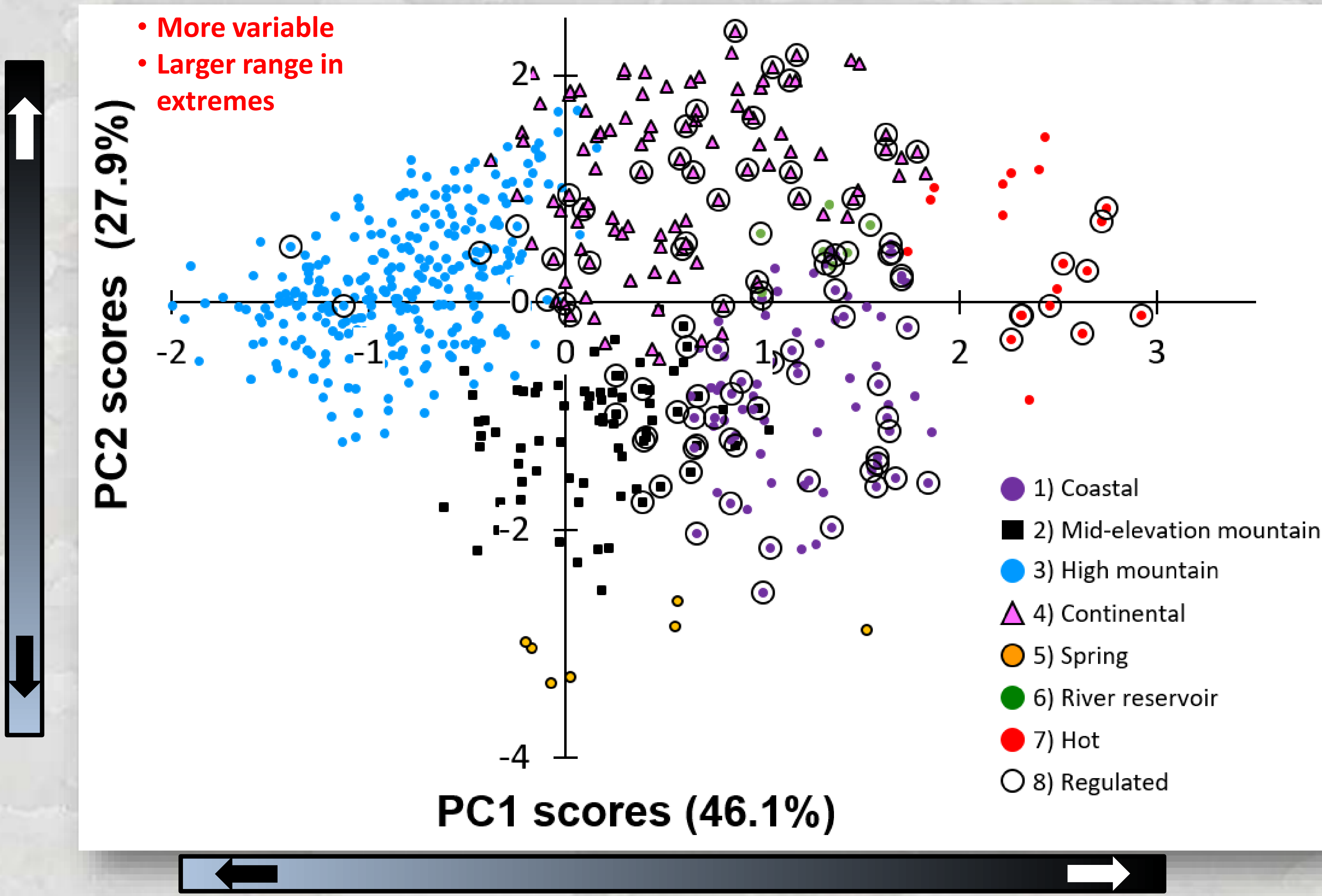
Cluster Analysis on Thermal Metrics

7 cluster regime map





Ordination plot of Site PC scores by Cluster



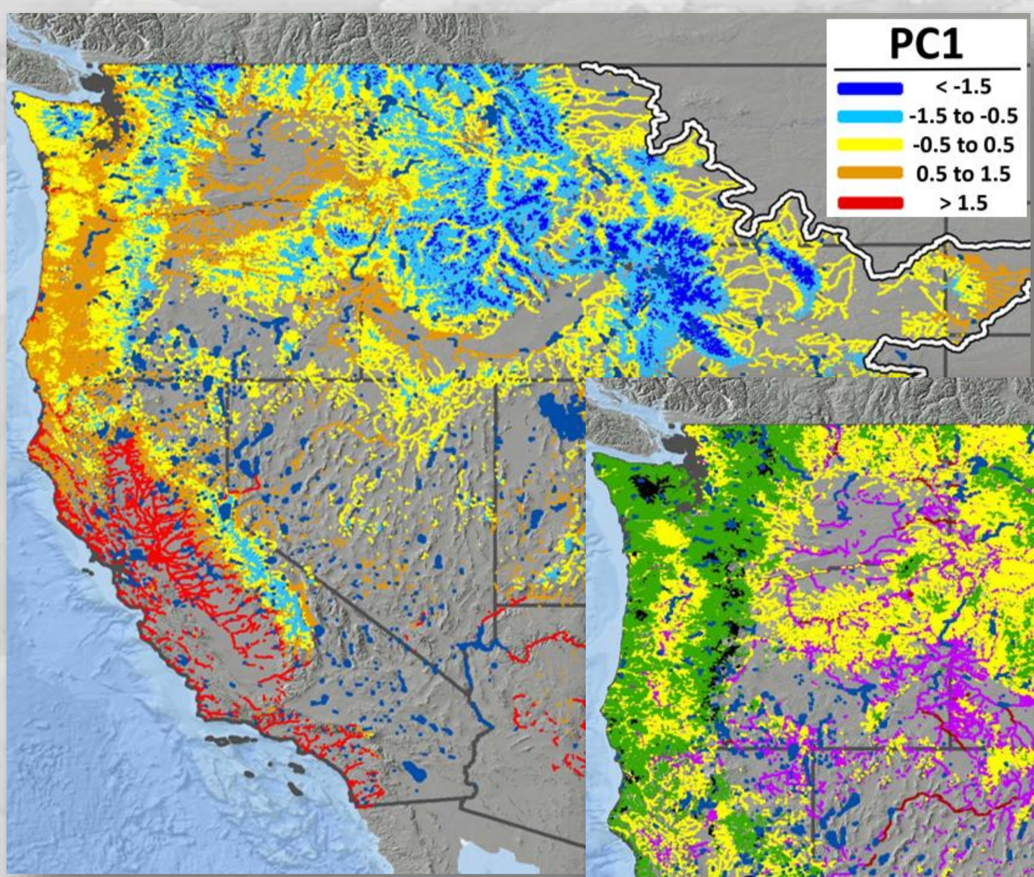
- Later dates of degree day accumulation
- Increased frequency and duration of cold days

- Warmer
- Longer growing seasons

Multiple Regressions of PC1 and PC2 Scores

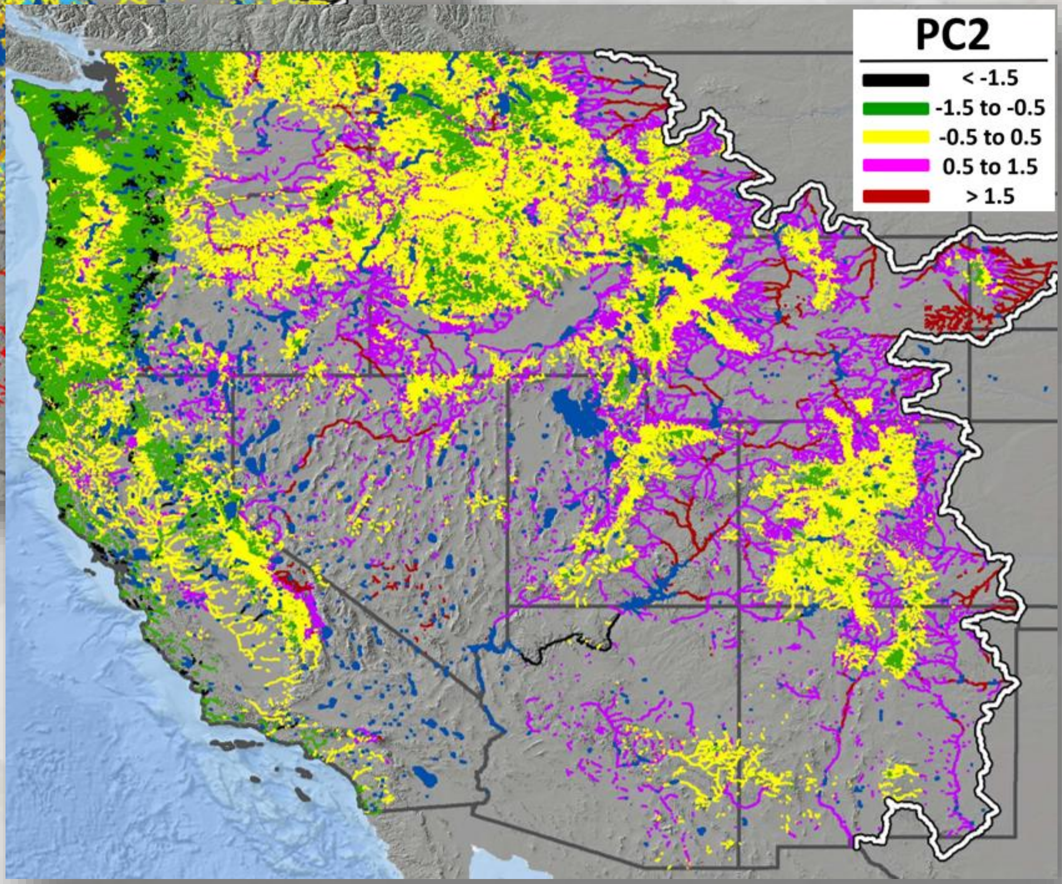
Model	Covariate	*b* (SE)	*t*	p-value	r^2
PC1	Intercept	7.36 (0.23)	31.4	< 0.01	0.87
	Elevation	-0.00104 (0.0000239)	-43.6	< 0.01	
	Latitude	-0.129 (0.00528)	-24.5	< 0.01	
	Riparian canopy	-0.00593 (0.000683)	-8.68	< 0.01	
	Reach slope	-3.32 (0.584)	-5.69	< 0.01	
	Annual precipitation	-0.000200 (0.0000385)	-5.20	< 0.01	
	Lake	0.0671 (0.0153)	4.38	< 0.01	
	Dam height	**0.00213 (0.00114)**	**1.88**	**< 0.01**	
	Dam height^2	**-0.0000203 (7.02×10^{-6})**	**-2.89**	**0.06**	
PC2	Intercept	-11.1 (0.567)	-19.5	< 0.01	0.63
	August stream temperature	0.276 (0.010)	27.6	< 0.01	
	Elevation	0.00107 (0.0000518)	20.7	< 0.01	
	Latitude	0.120 (0.0115)	10.4	< 0.01	
	August SD of air temperature	0.381 (0.125)	3.04	< 0.01	
	Riparian canopy	0.00275 (0.00117)	2.34	0.02	
	Drainage area	-1.24×10^{-6} (6.18×10^{-7})	-2.01	0.05	
	Lake	-0.0498 (0.0254)	-1.96	0.05	
	Dam height	**-0.00124 (0.000837)**	**-1.48**	**0.14**	

Prediction Maps of PC1 and PC2 Scores



Map ~

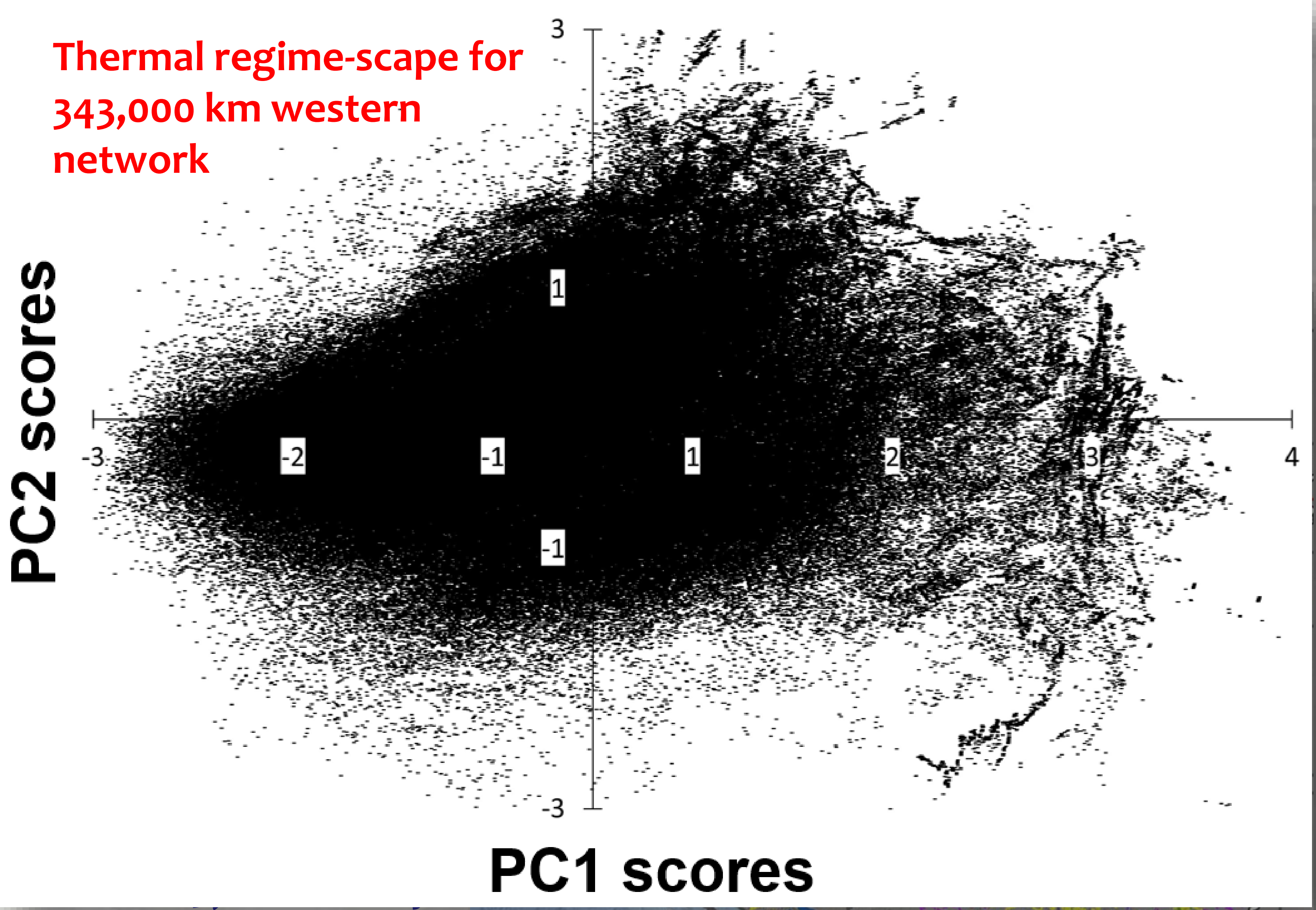
1) Magnitude
2) Timing
3) Duration
4) Frequency



Map ~

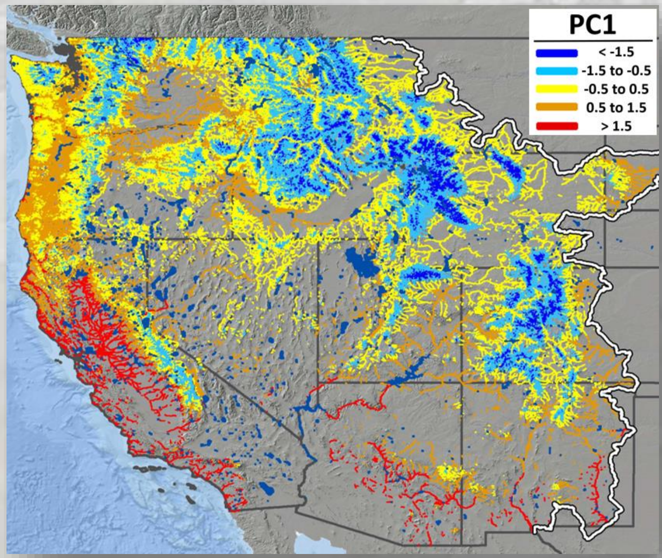
5) Variability

Prediction Maps of PC1 and PC2 Scores

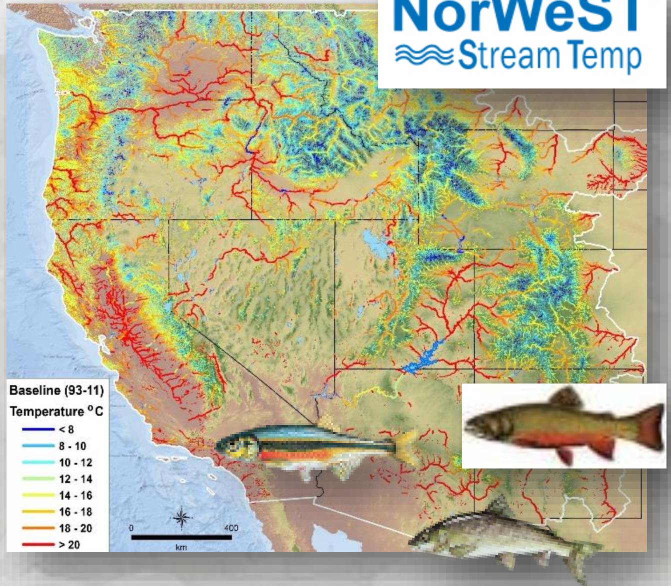


Ecological Relevance of Regime Maps

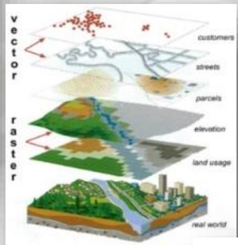
PC1 ~ NorWeST Mean August Scenario



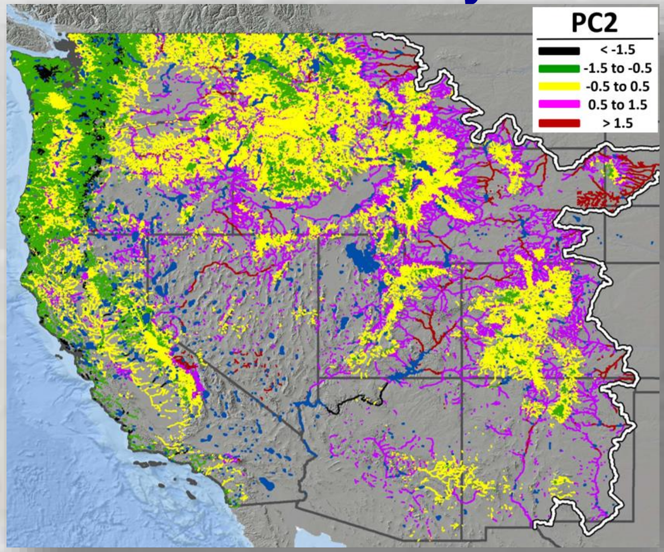
***r* = 0.81**



NorWeST Stream Temp



PC2 ~ Variability



ESRI ArcGIS

esa ECOSPHERE

Beyond the mean: The role of variability in predicting ecological effects of stream temperature on salmon

E. Ashley Steel,[1,†] Abby Tillotson,[2] Donald A. Larsen,[2] Aimee H. Fullerton,[2] Keith P. Denton,[2] and Brian R. Beckman[2]

Transactions of the American Fisheries Society 132:92–99, 2003
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Assessing Temperature Tolerance of Bonneville Cutthroat Trout Based on Constant and Cycling Thermal Regimes

Helene C. Johnstone and Frank J. Rahel*

Key Take Homes:

1) Thermal regimes are relatively simple (especially in mountain headwaters). 2-4 PCs or metrics can capture most of the unique "information" about a regime

2) Annual monitoring data capture important regime information missed by summer monitoring

3) Strong temporal covariation among sites suggest monitoring networks can be sparse.

4) Thermal regimes at broad scales largely controlled by geoclimatic factors. Local land-use effects add "residual noise" that is important to understand & jointly consider

5) Next step could be synthetic assessments of stream hydroclimates via integration of flow & thermal regimes (a.k.a. icthyographs writ large)

For More Information…

Hydrol. Earth Syst. Sci., 22, 6225–6240, 2018
https://doi.org/10.5194/hess-22-6225-2018

Hydrology and Earth System Sciences
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Principal components of thermal regimes in mountain river networks

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U.S. Forest Service, Rocky Mountain Research Station, Aquatic Sciences Lab, Boise, ID 83702, USA

In review…

Freshwater Biology

Thermal Regimes of Flowing Waters in the Western United States and Their Ecological Implications

Daniel J. Isaak, Charles H. Luce, Gwynne L. Chandler, Dona L. Horan, and Sherry P. Wollrab
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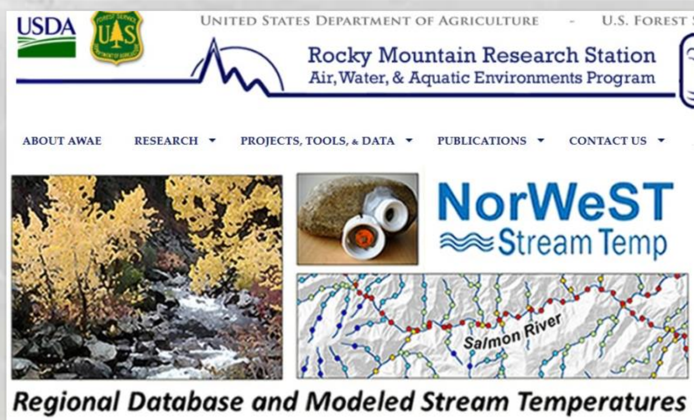

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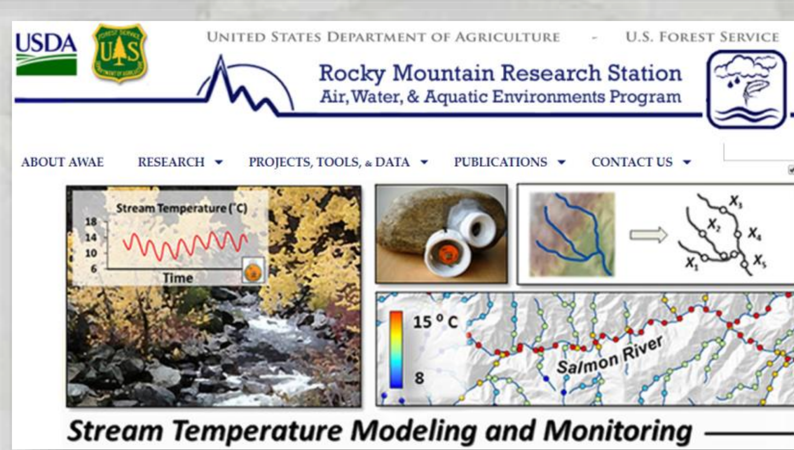

Much thanks to R6 bios, hydros, & Brian Staab