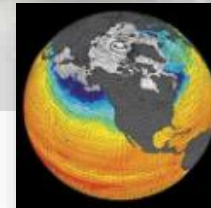
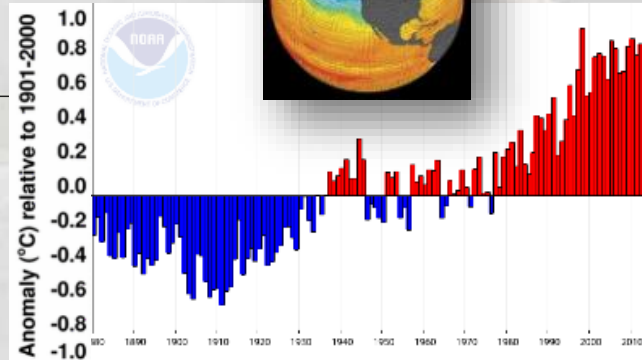
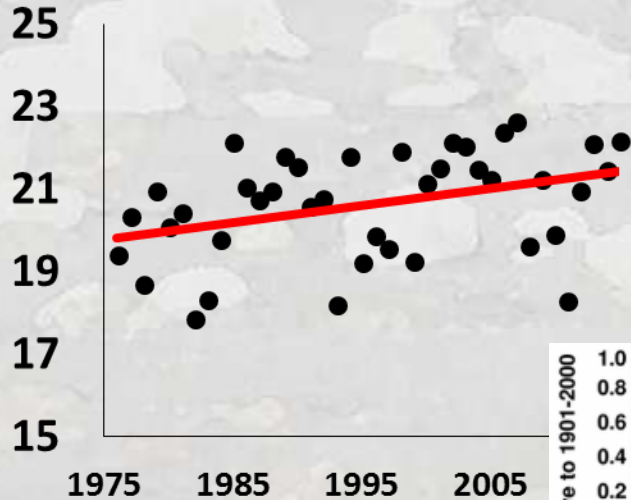


Global Warming of Salmon and Trout Rivers in the Northwest: Road to Ruin or Path Through Purgatory?

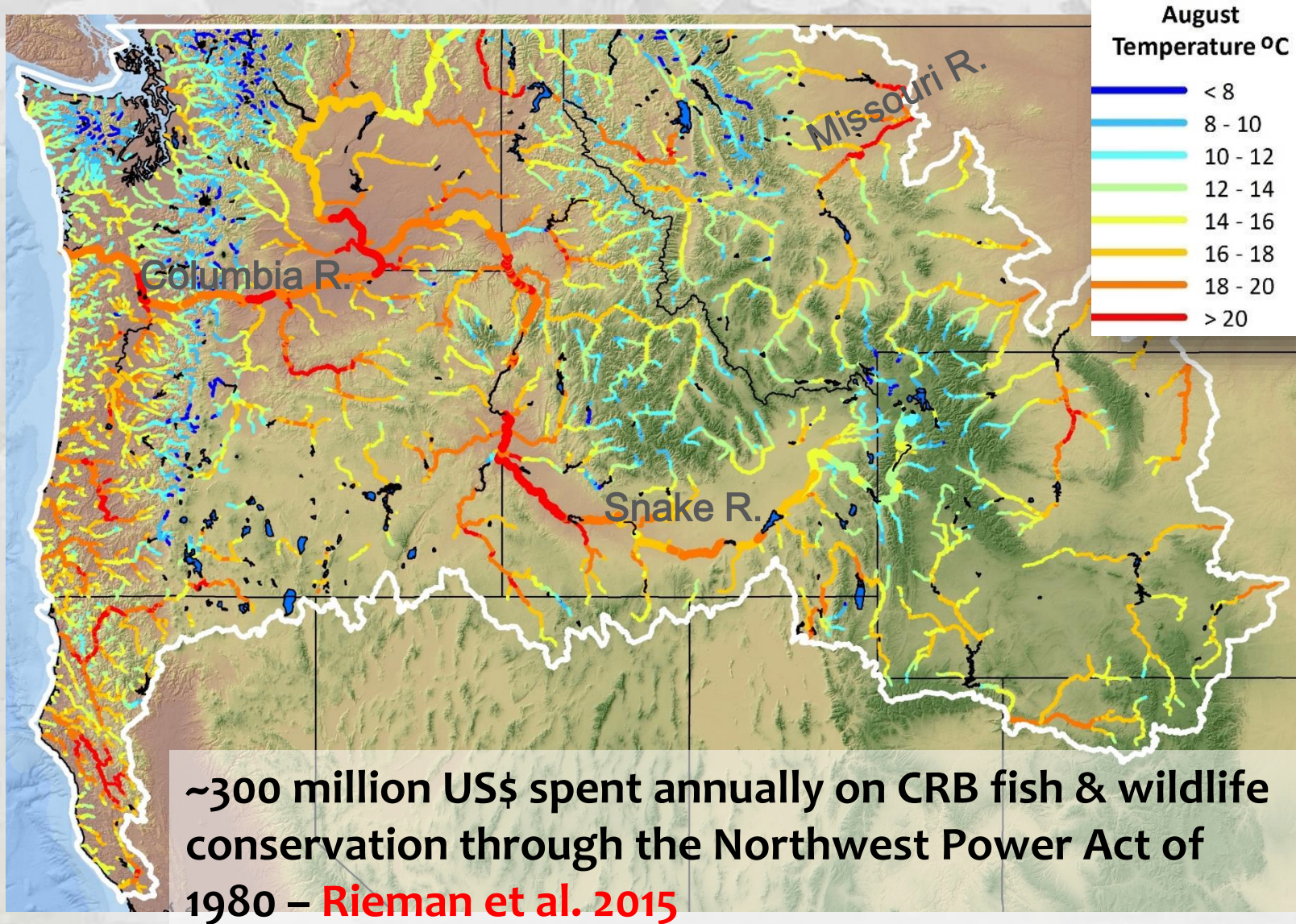


US Army Corps of Engineers.



The Billion \$ Network of Concern

56,000 kilometers of rivers >100 cfs annual flow



High Value Resources & Key Habitats



Thermal Constraints on Cold-Water Fish Populations are Common...

Symptoms include...

- 1) Migration delays & clustering in coldwater refuges
- 2) Selective gradients based on run timing
- 3) Mass mortality events:
 - a) upriver stocks of Fraser river sockeye “disappear”
 - b) spawning ground fish kills

Keefer et al. 2010; Crozier 2011; Caudill et al. 2013

- 4) Fishing season closures
- 5) Fish disease outbreaks?
- 6) Shifting distributions

Eby et al. 2014; Al-Chokhachy et al. 2016



High Water Temperature In Grande Ronde Kills 239 Adult Spring Chinook
Columbia Basin Bulletin, August 14, 2009 (PST)



CANADA August 11, 2015 1:35 pm Updated: August 12, 2015

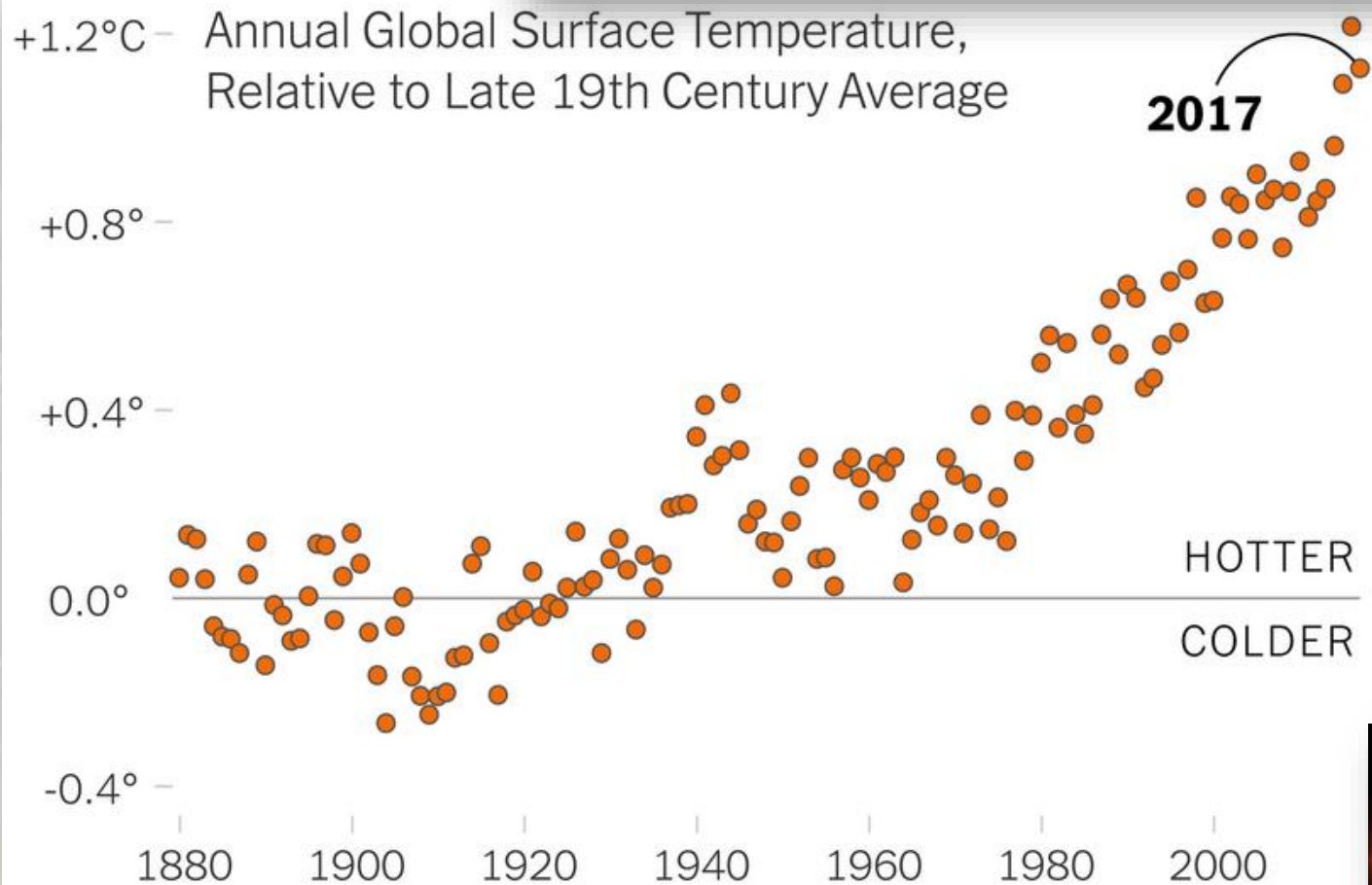
Fishing closures in southern Alberta due to hot weather

By Melissa Gilligan
Online Reporter, Global News

Thermal Constraints Will be More Common

1880-2017 Global Air Temperature Trend

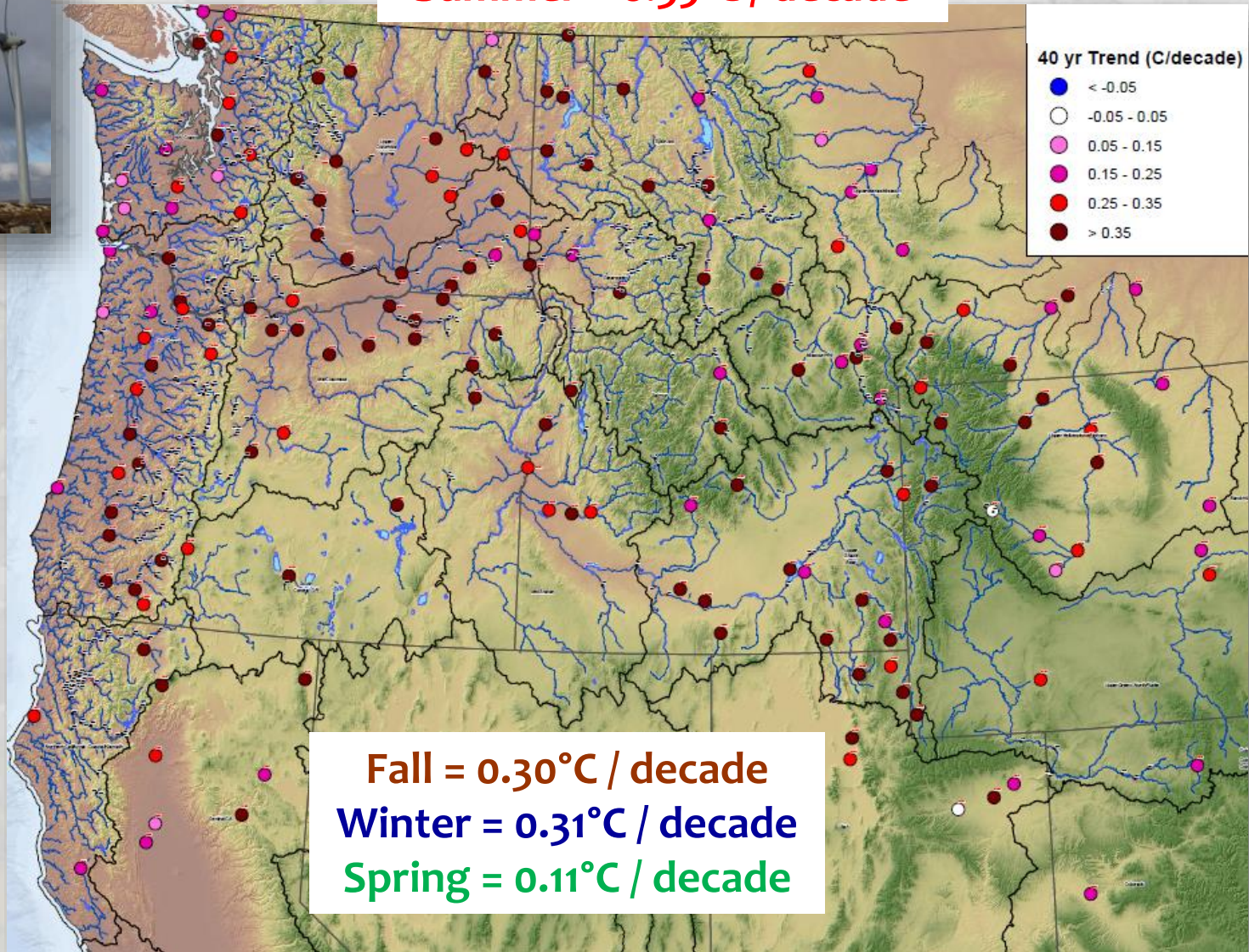
NASA Ranks 2017 as the Second-Warmest Year on Record



Regional Air Temp Trends (1976–2015)

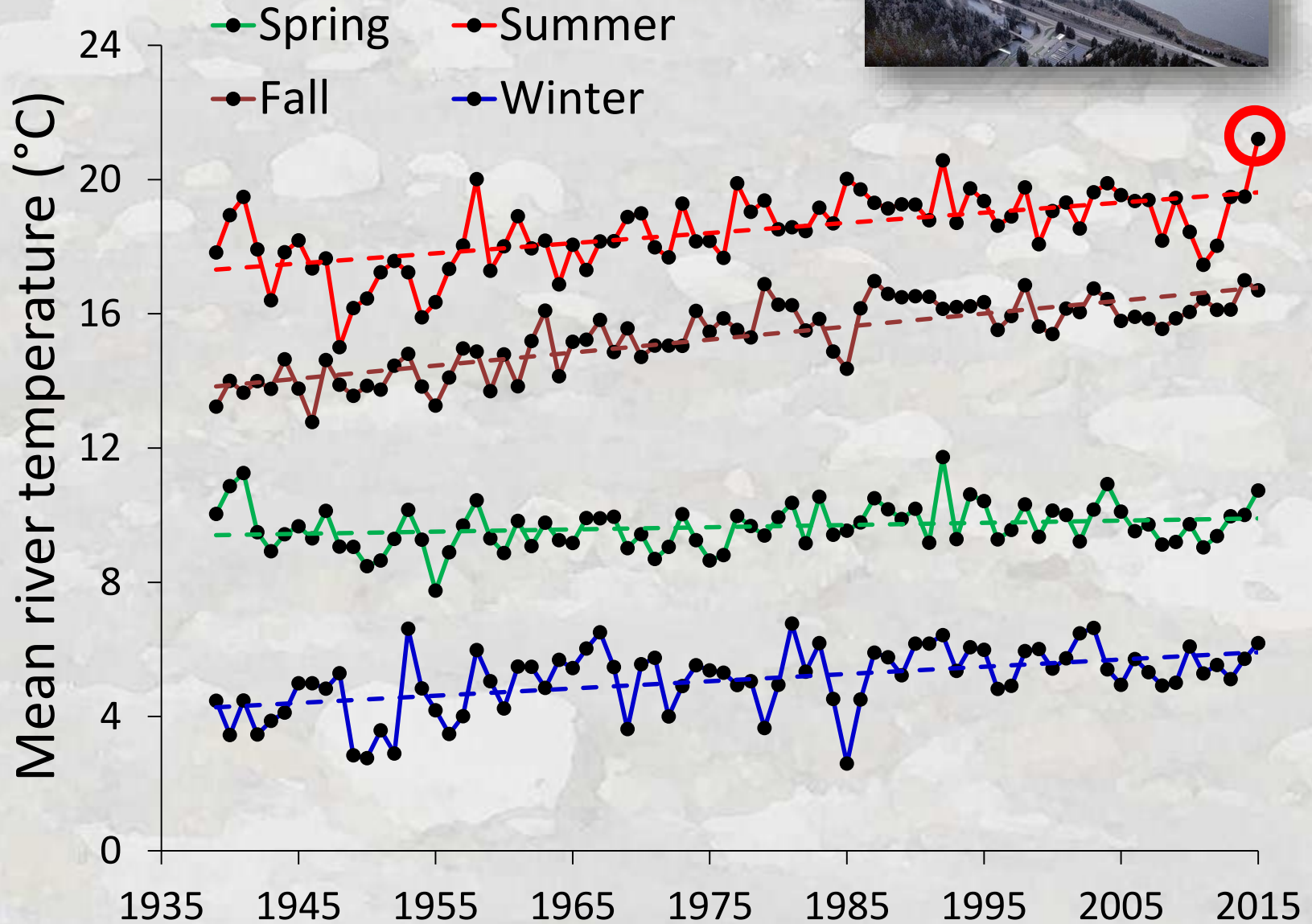
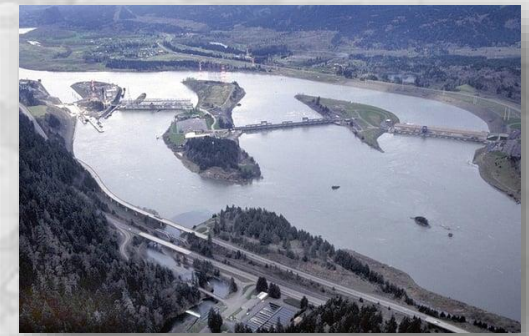
Global Historical Climatologic Network V3 Dataset

Summer = $0.35^{\circ}\text{C} / \text{decade}$



What About our Rivers?

Bonneville Dam has Longest Record



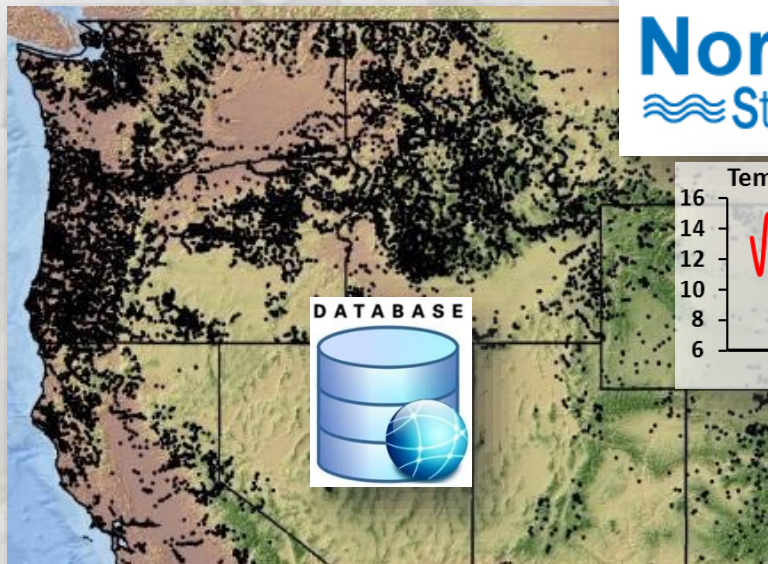
Where are Other Long-term River Records?

>220,000,000 hourly recordings

>22,700 stream sites

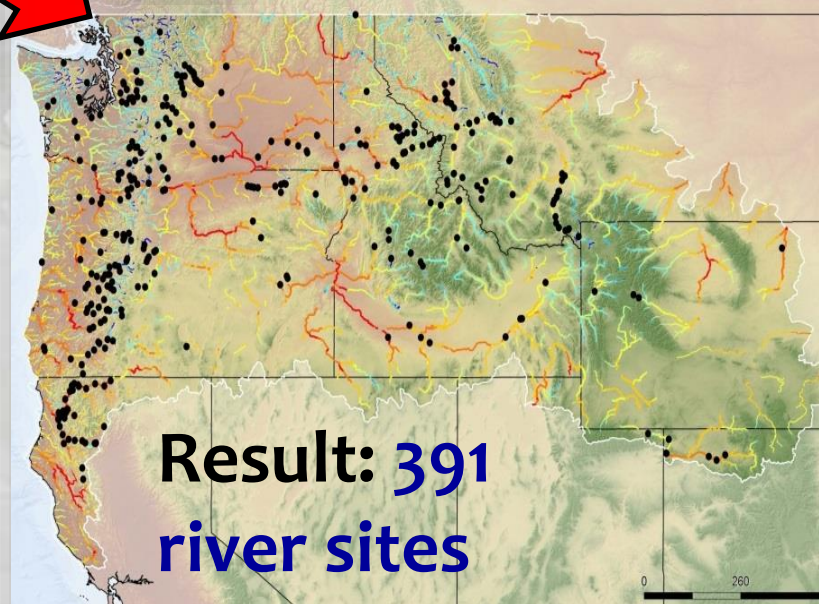


>100 agencies

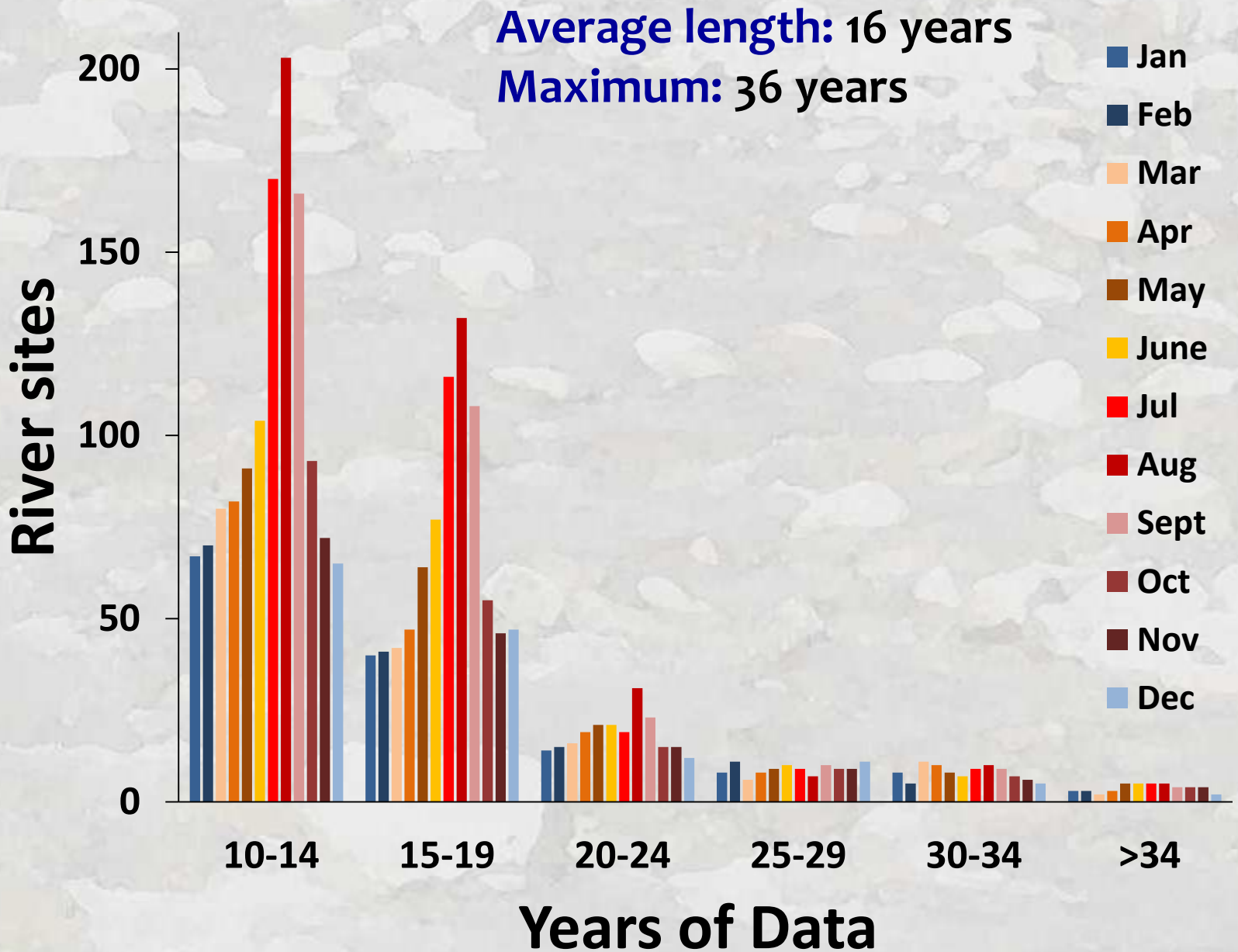


Database query:

- 1) How many sites have >10 years of monitoring during at least one month of year?
- 2) How many sites occur on rivers with >100 cfs flow?



Monitoring Record Length by Month at 391 sites

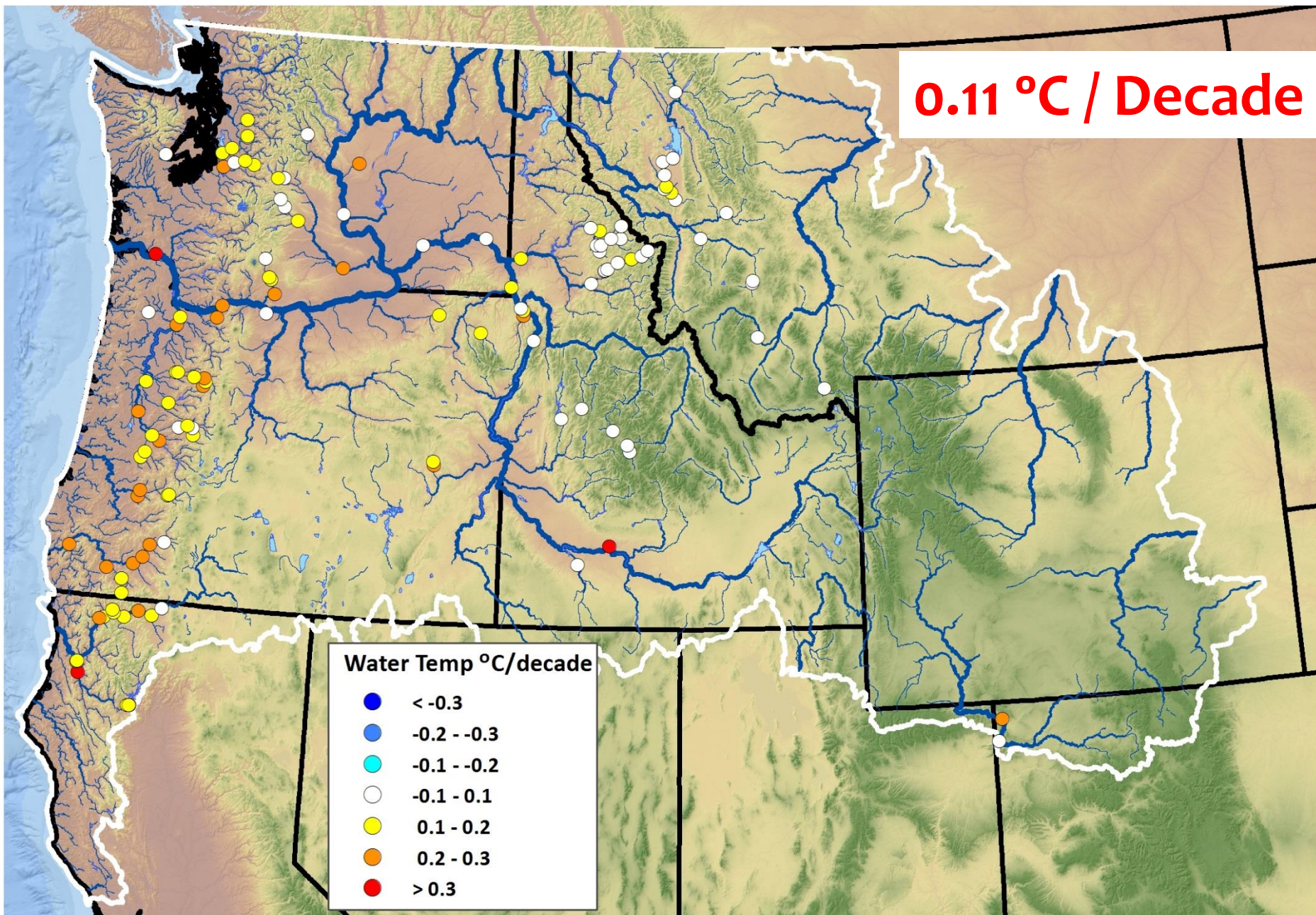


Methods for Completing Time-Series:

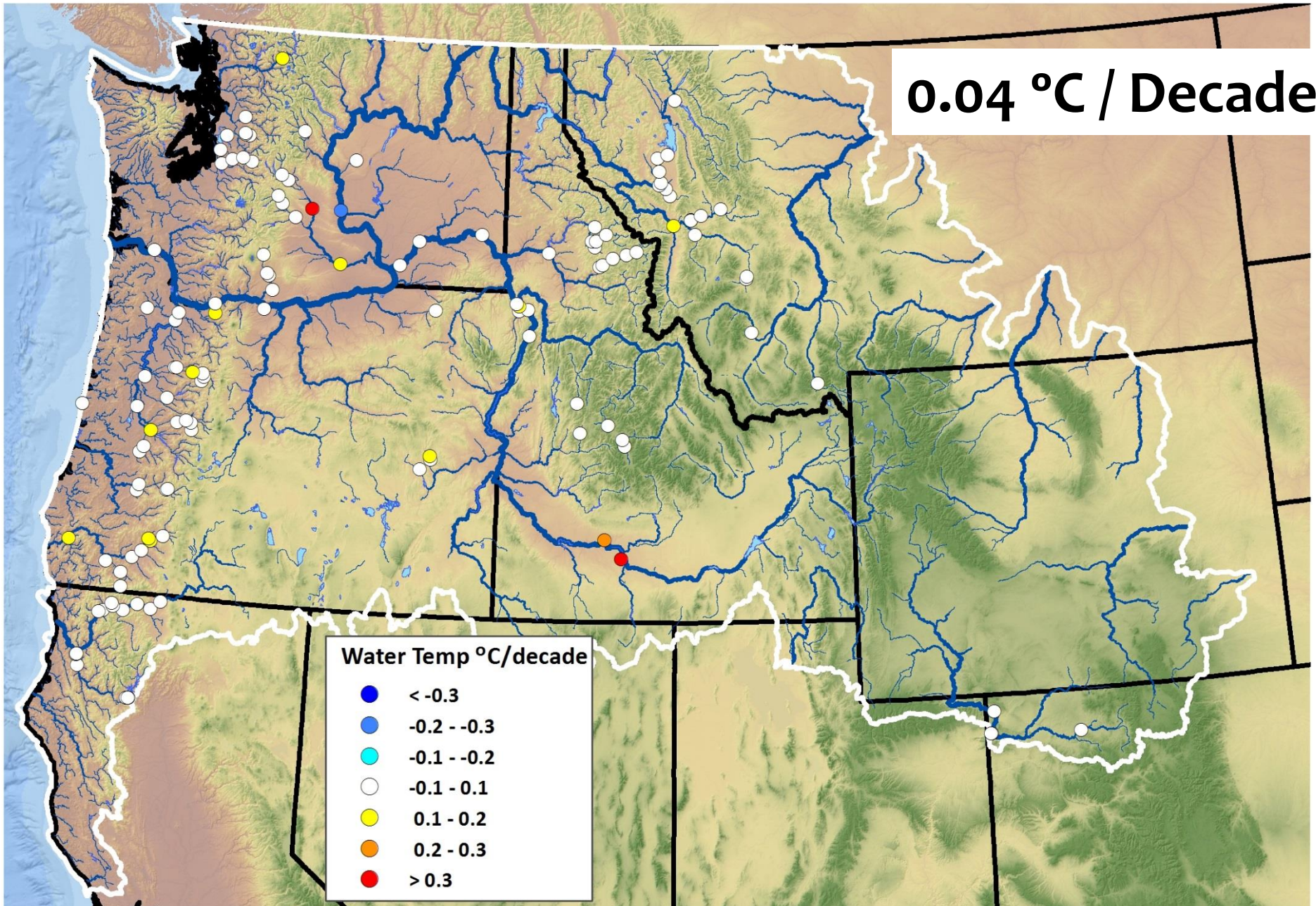
- Summarized monthly air temperatures for forty year period of 1976-2015 from Global Historical Climate Network V3 dataset for 168 sites
- Summarized monthly river discharge from USGS NWIS, BOR HydroMet, & DART for 320 gage and dam sites
- Aligned data series for RivTemp, air temperature, and discharge into twelve monthly matrices (40 years x 879 sites)
- Imputed missing monthly RivTemp values using PCAs calculated with the MissMDA package in R (Missing Values with Multivariate Data Analysis)
- Retained completed RivTemp time series if $r > 0.8$ between observed and fitted values (average $r = 0.9$)
- Regressed RivTemp on year & calculated decadal trends for **20 & 40** year periods that end in 2015



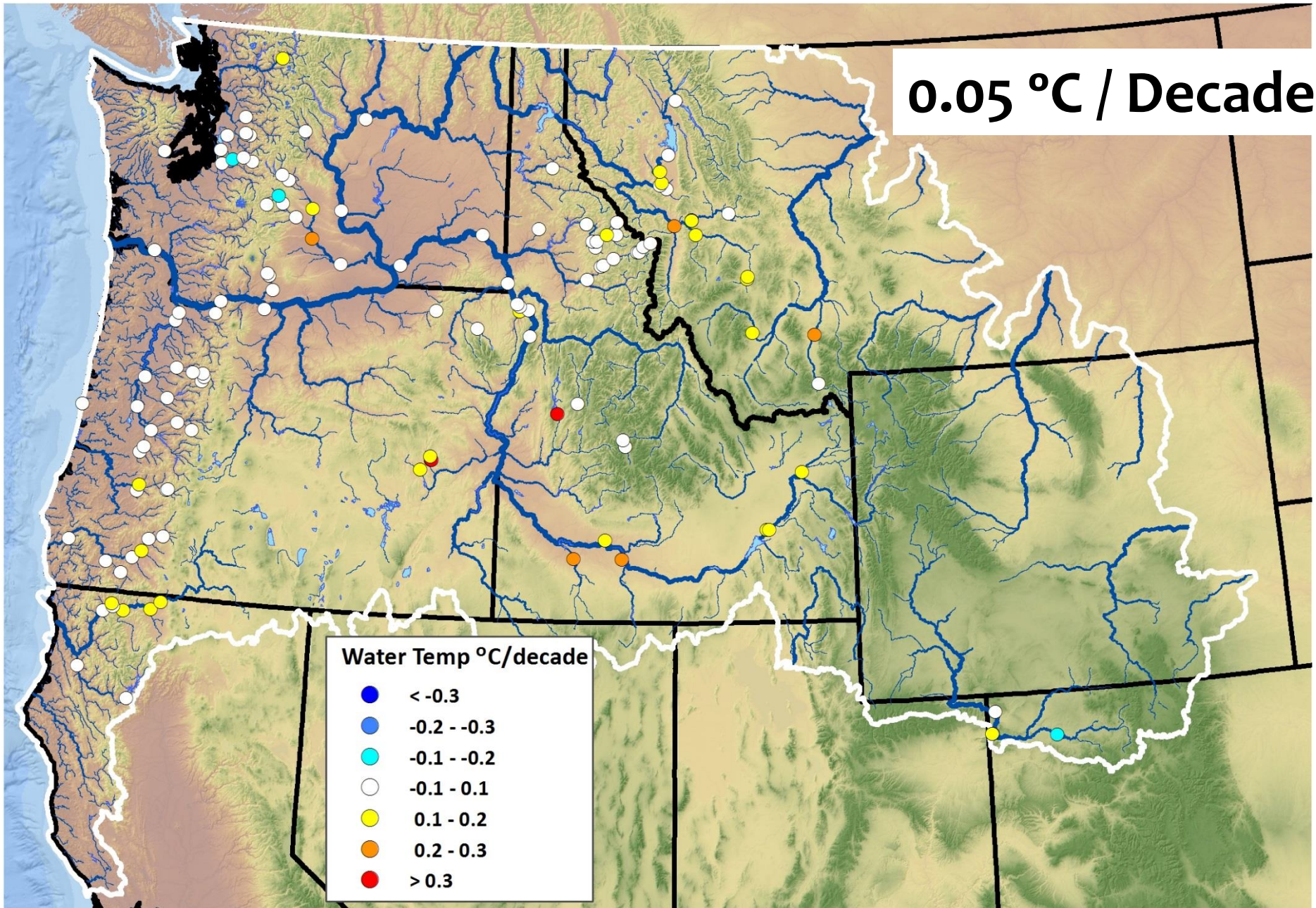
40 Year (1976–2015) Monthly River Temperature Trend - January



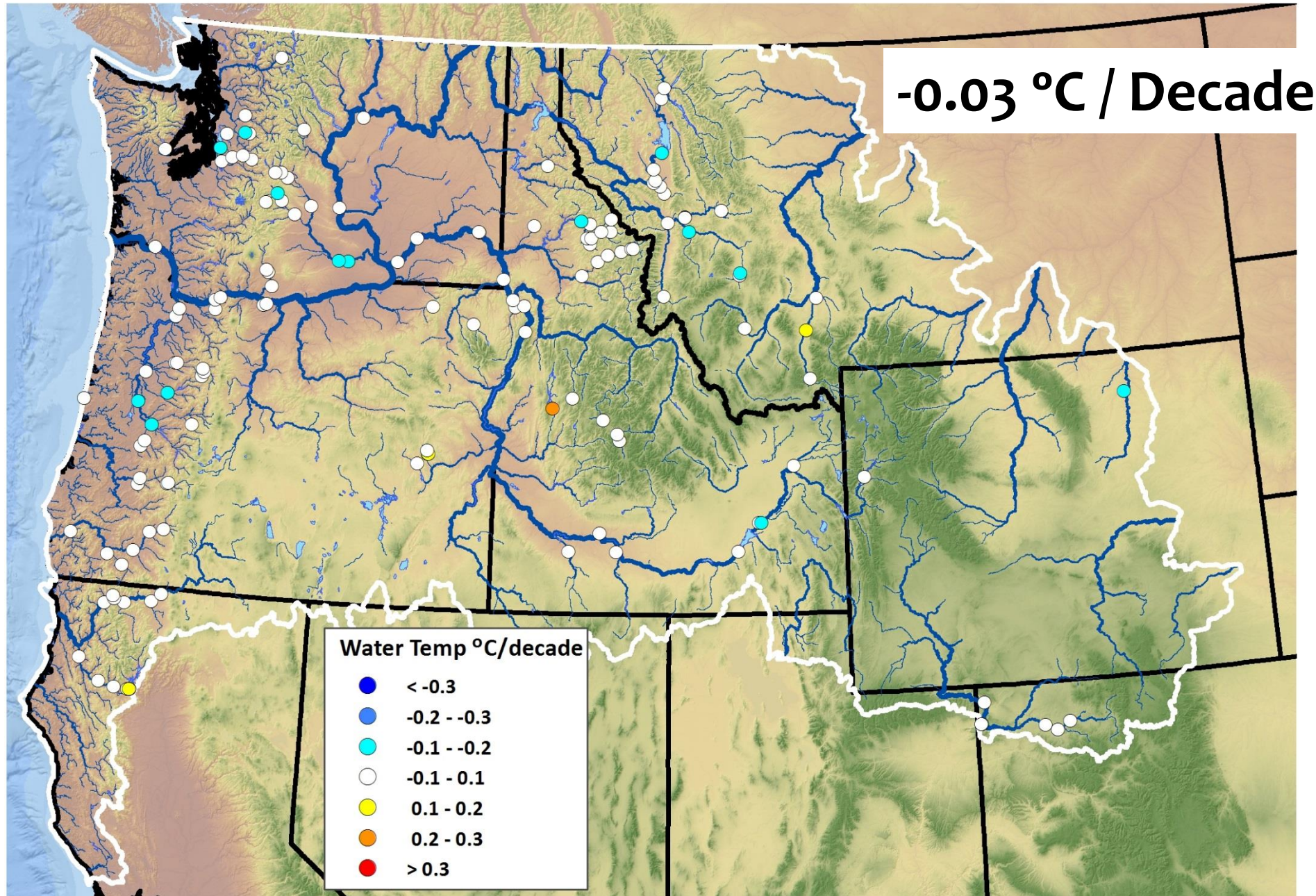
40 Year (1976–2015) Monthly River Temperature Trend - February



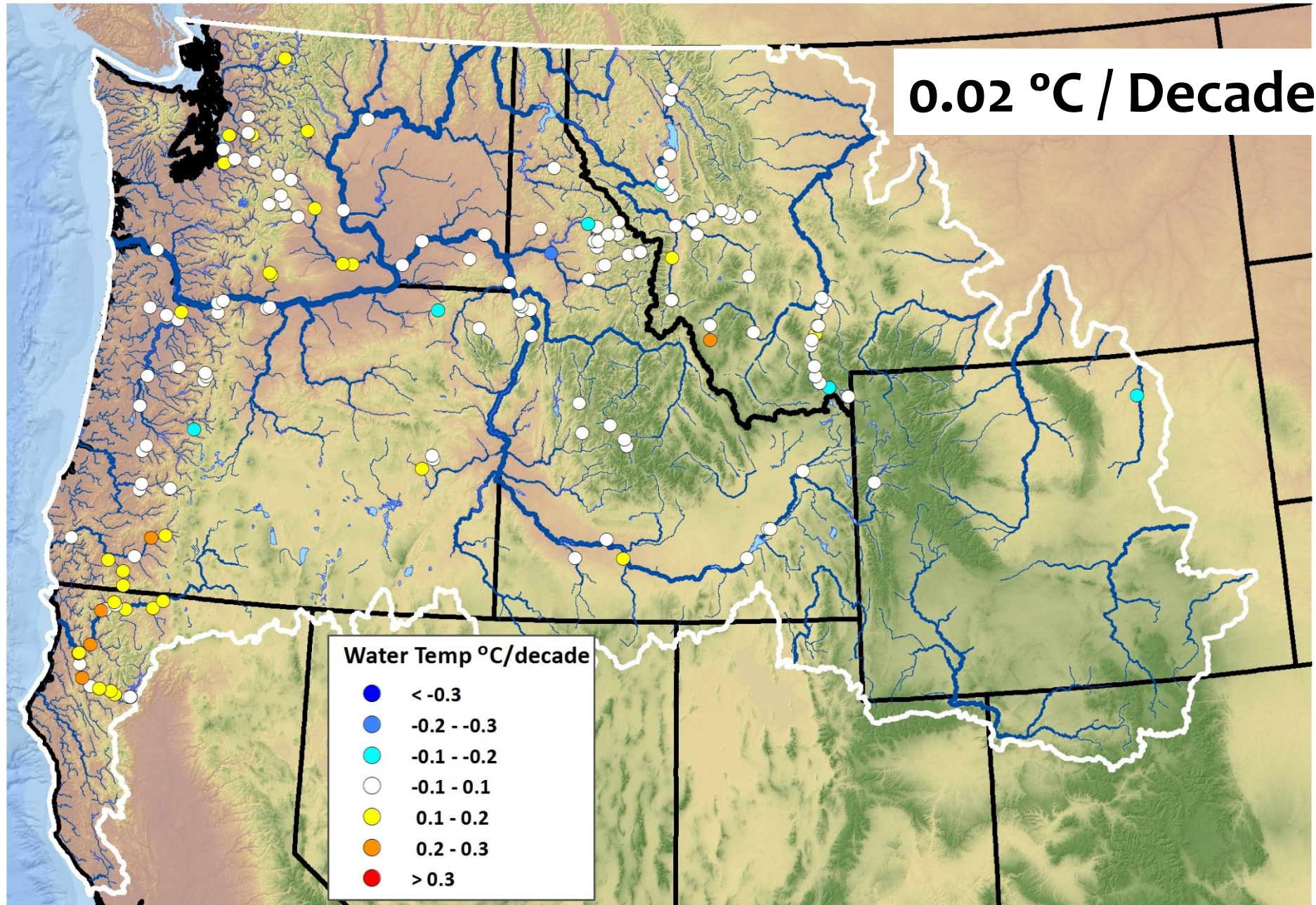
40 Year (1976–2015) Monthly River Temperature Trend - **March**



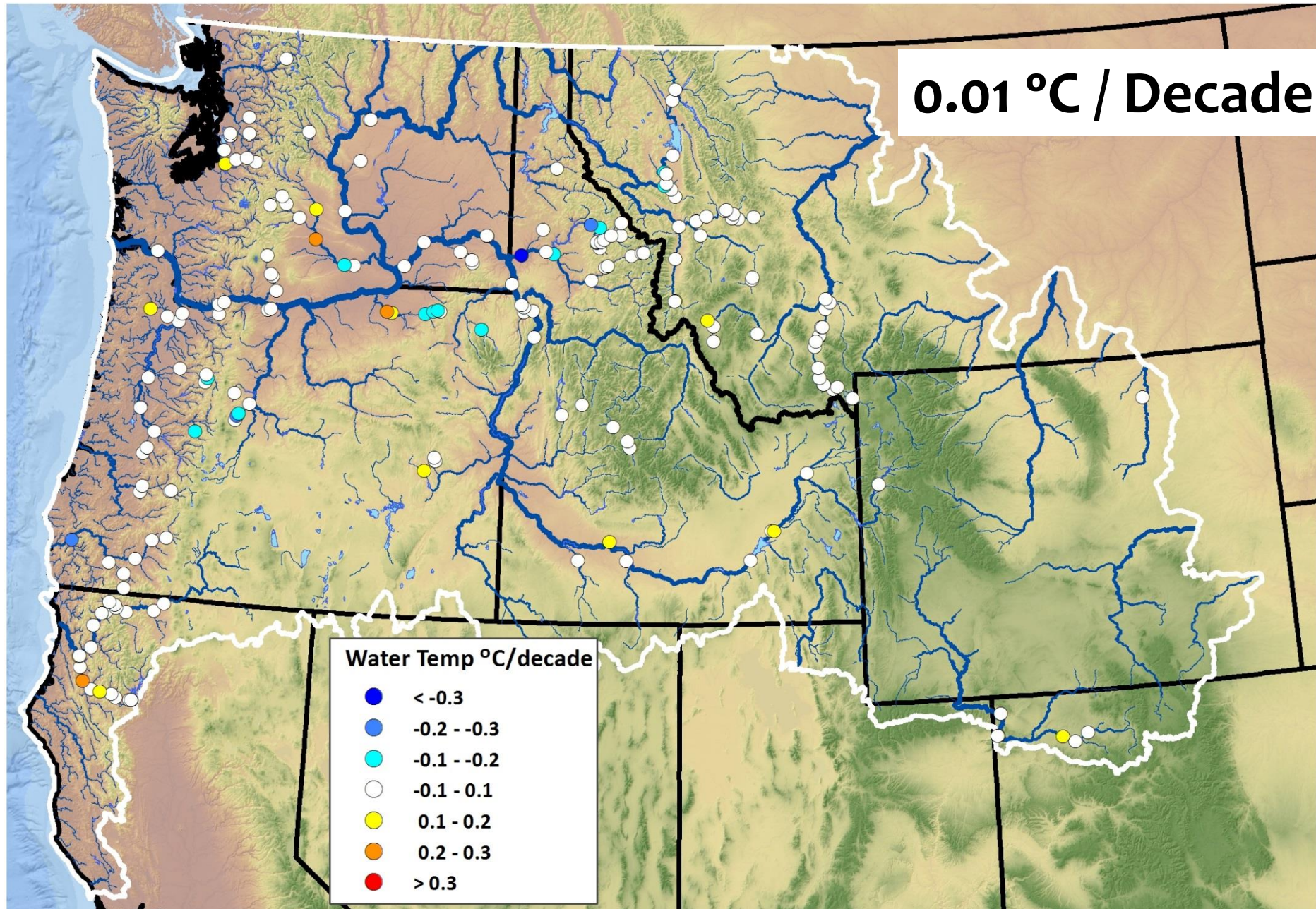
40 Year (1976–2015) Monthly River Temperature Trend - April



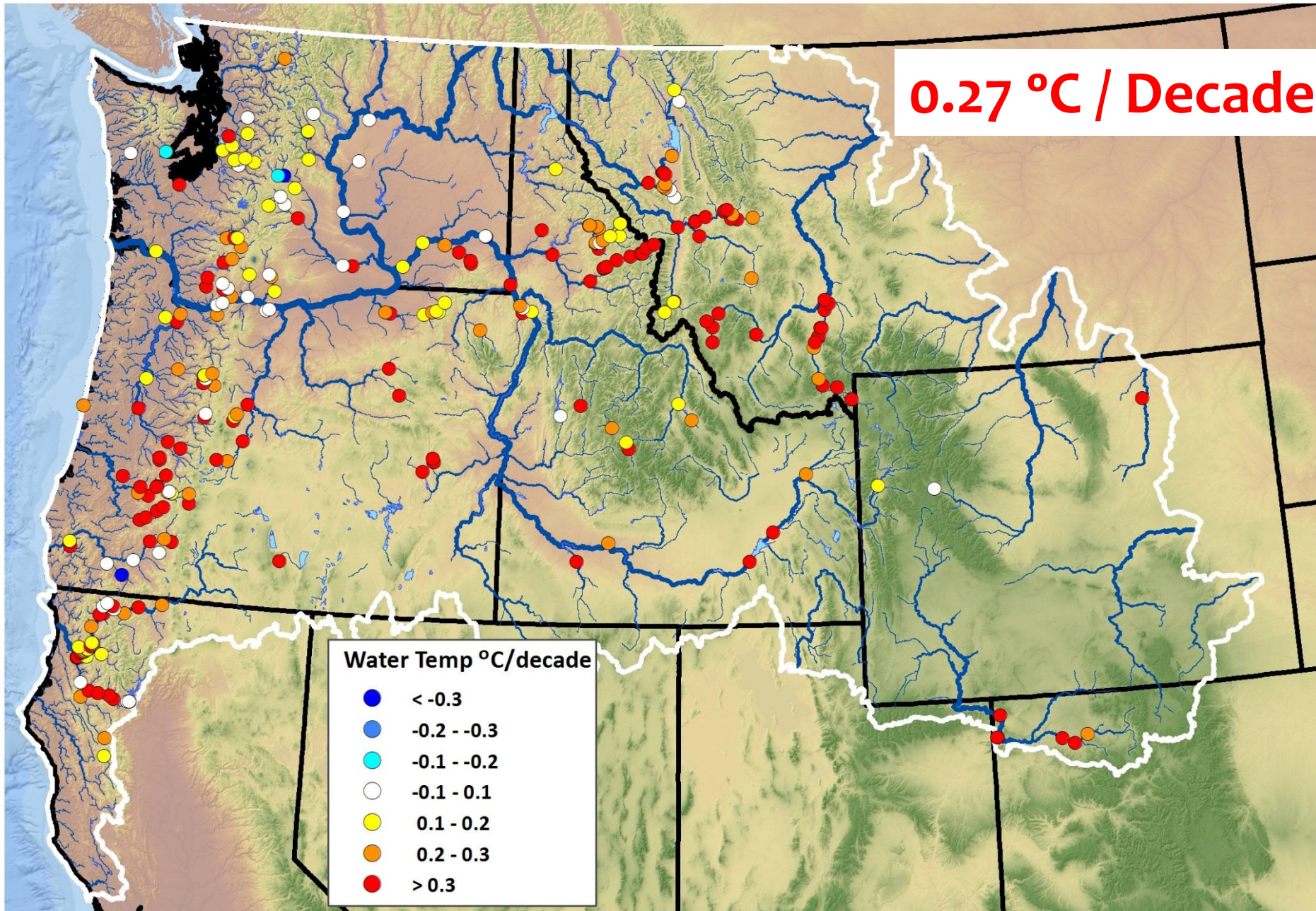
40 Year (1976–2015) Monthly River Temperature Trend - **May**



40 Year (1976–2015) Monthly River Temperature Trend - June

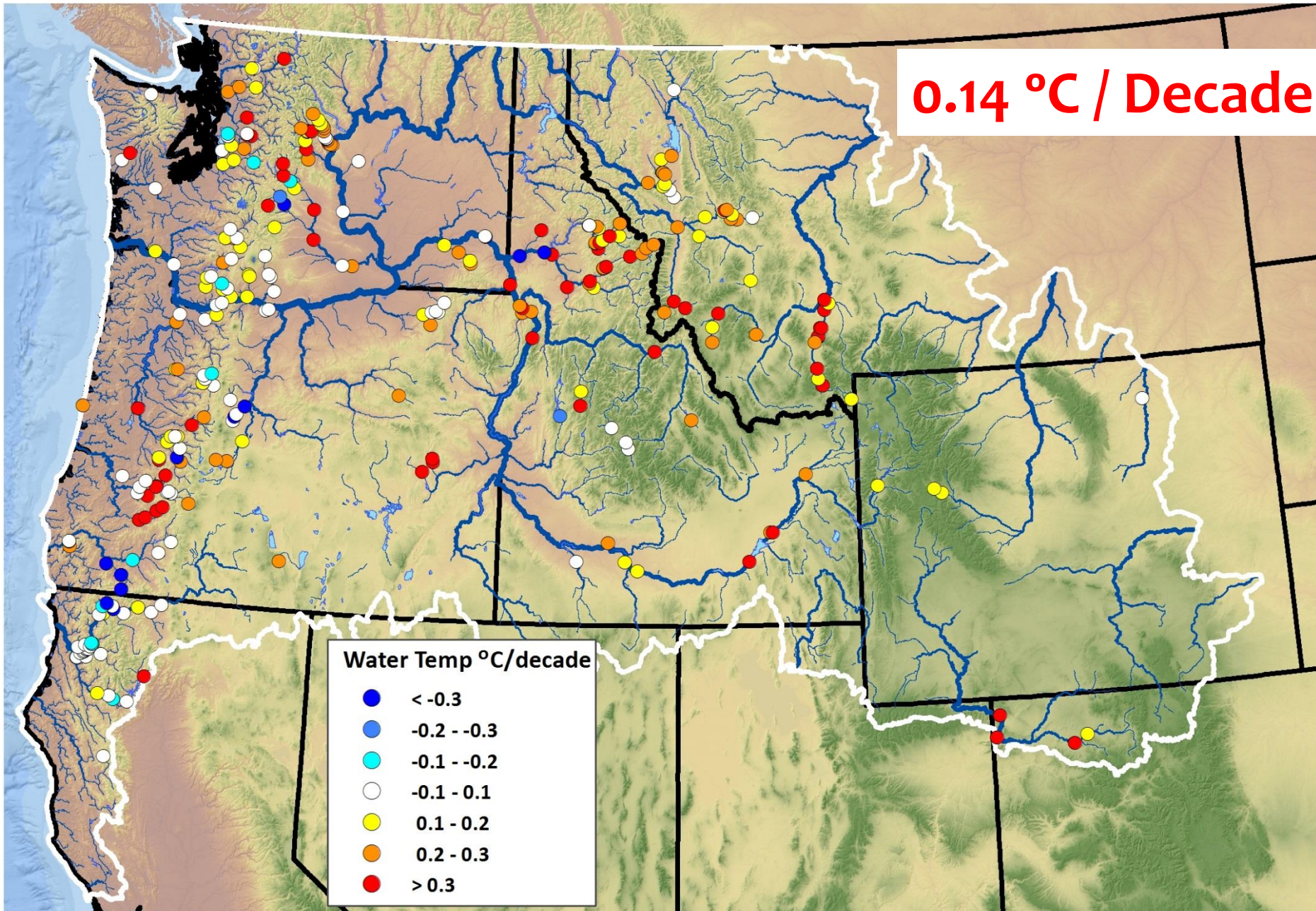


40 Year (1976–2015) Monthly River Temperature Trend - July

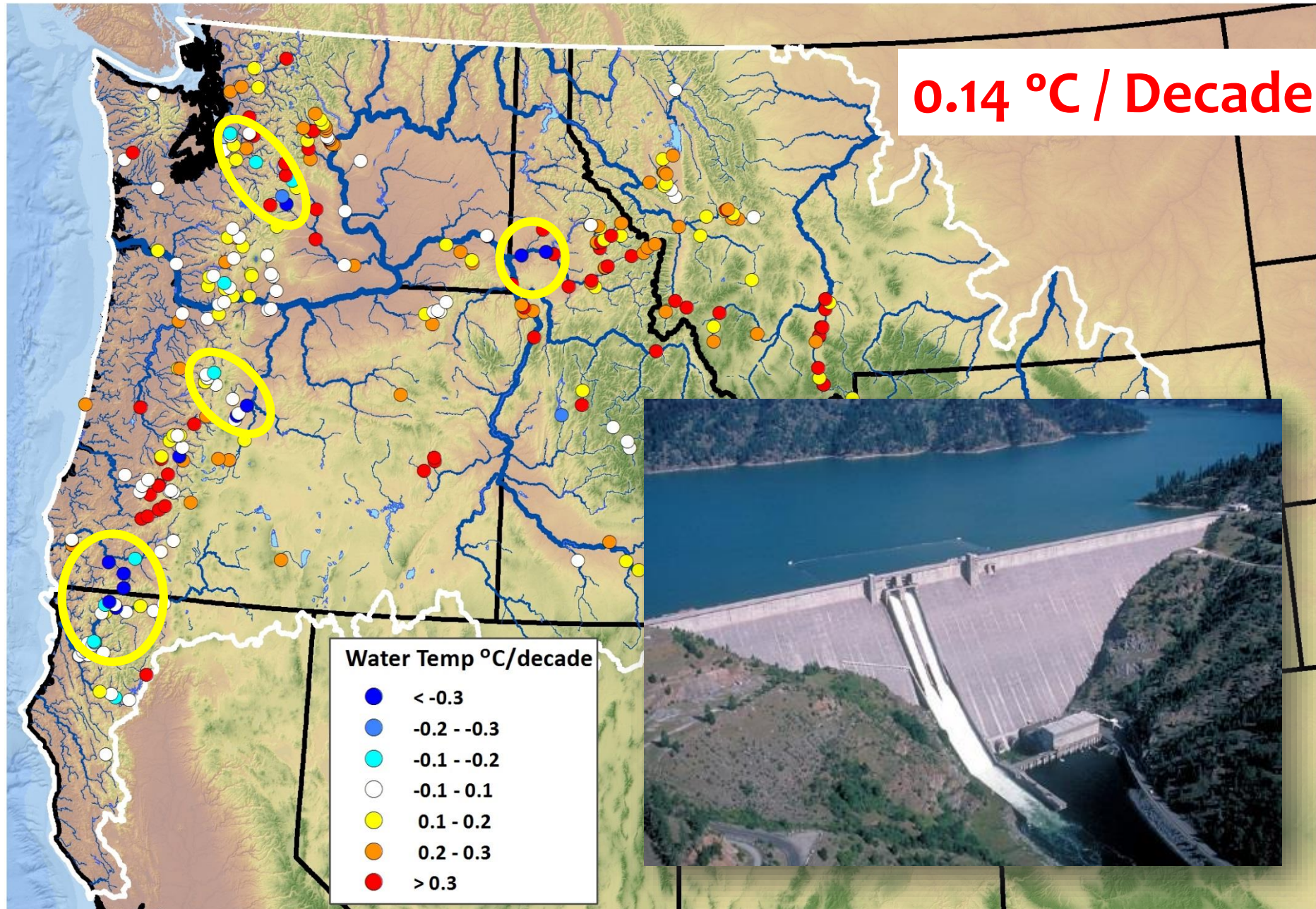


40 Year (1976–2015) Monthly River Temperature Trend - August

0.14 °C / Decade

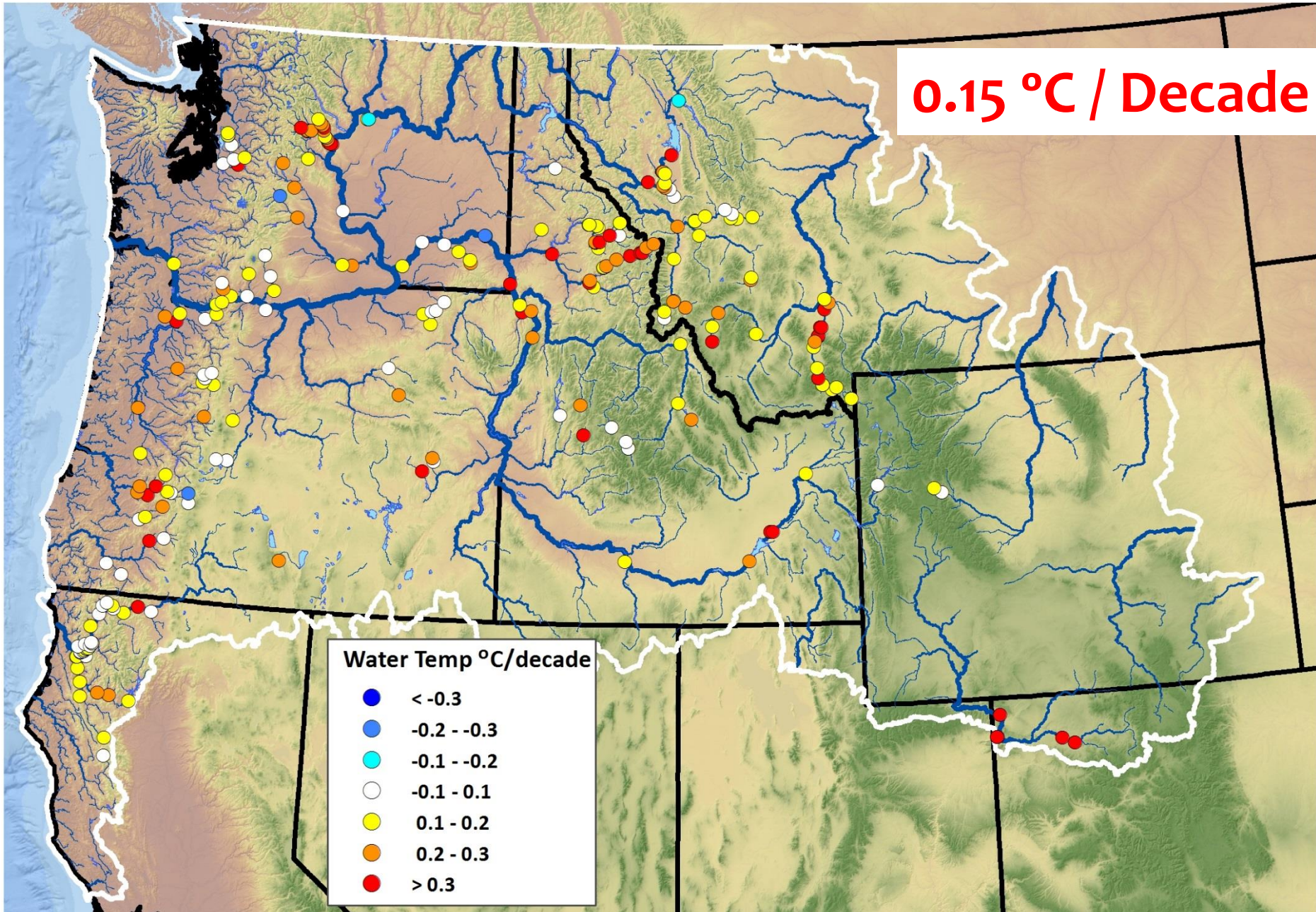


40 Year (1976–2015) Monthly River Temperature Trend - August

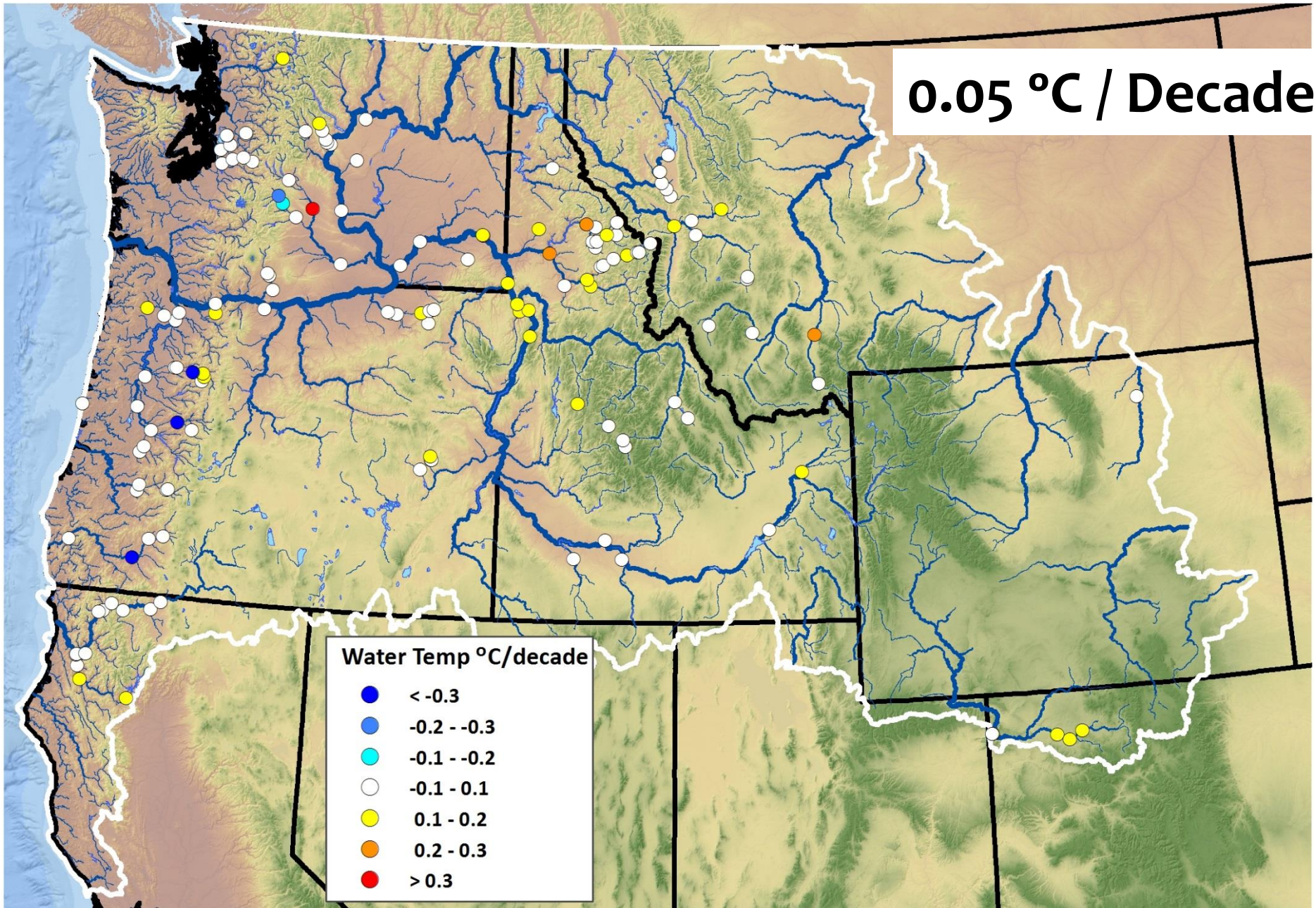


40 Year (1976–2015) Monthly River Temperature Trend - September

0.15 °C / Decade

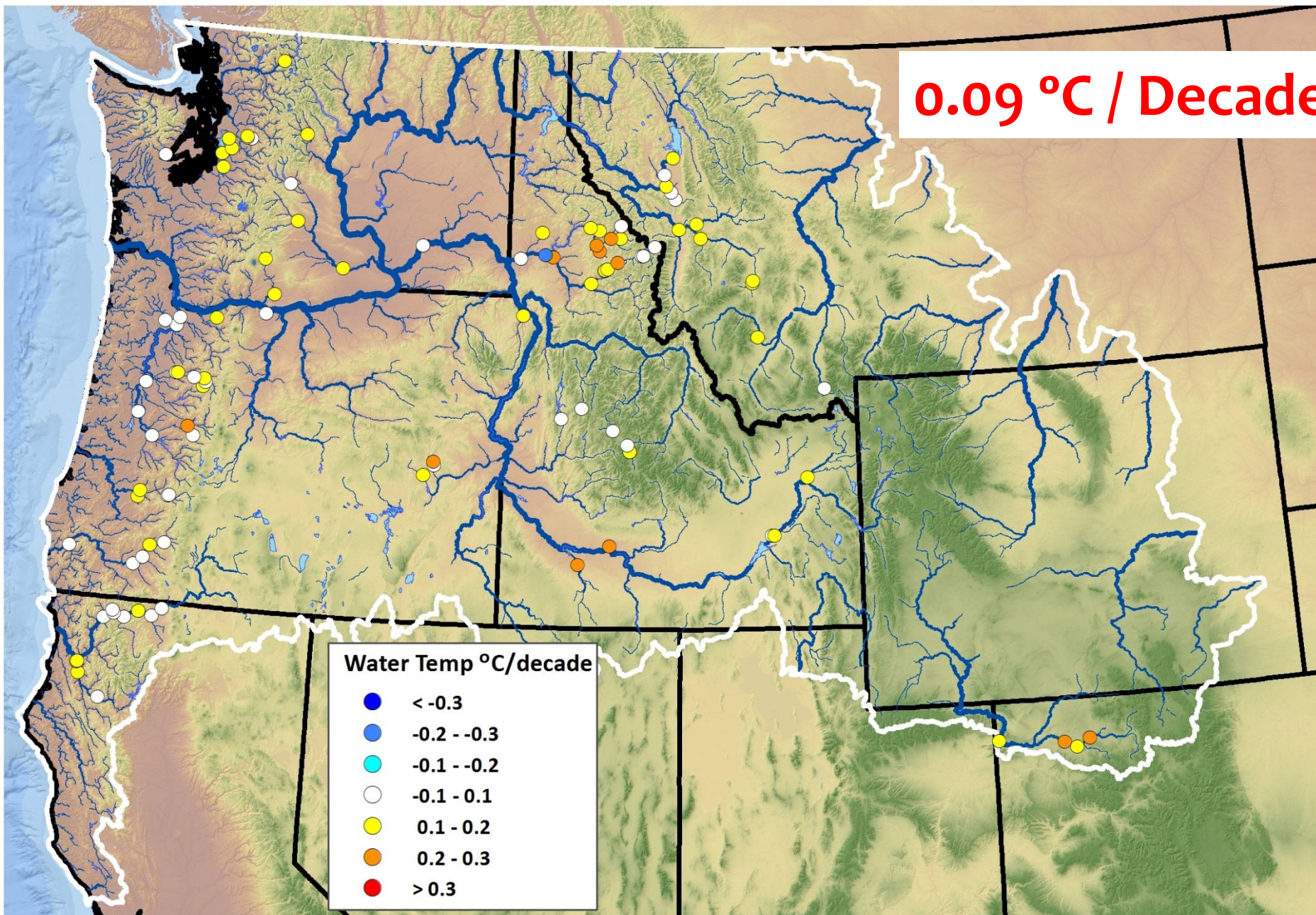


40 Year (1976–2015) Monthly River Temperature Trend - **October**

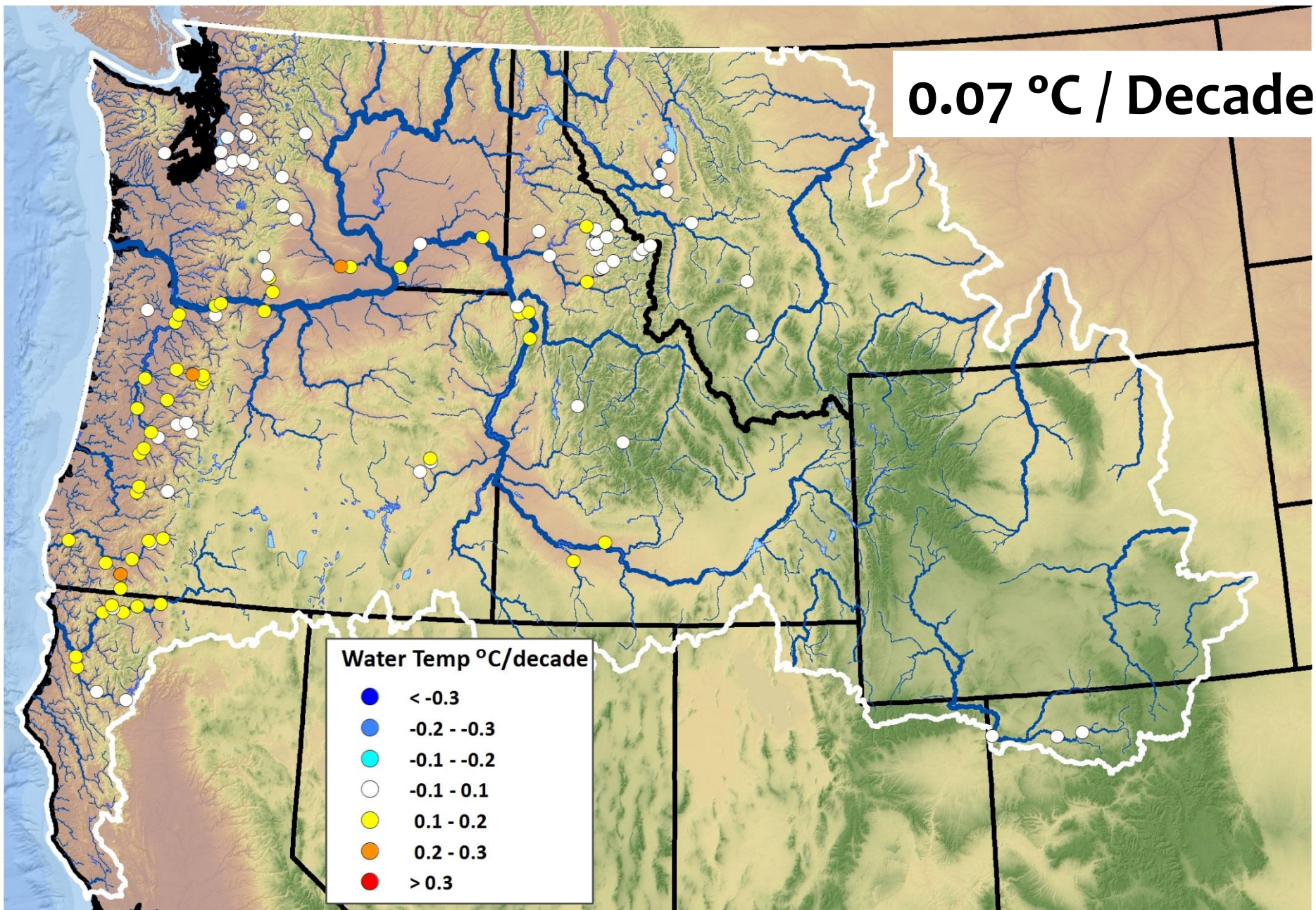


40 Year (1976–2015) Monthly River Temperature Trend - November

0.09 °C / Decade

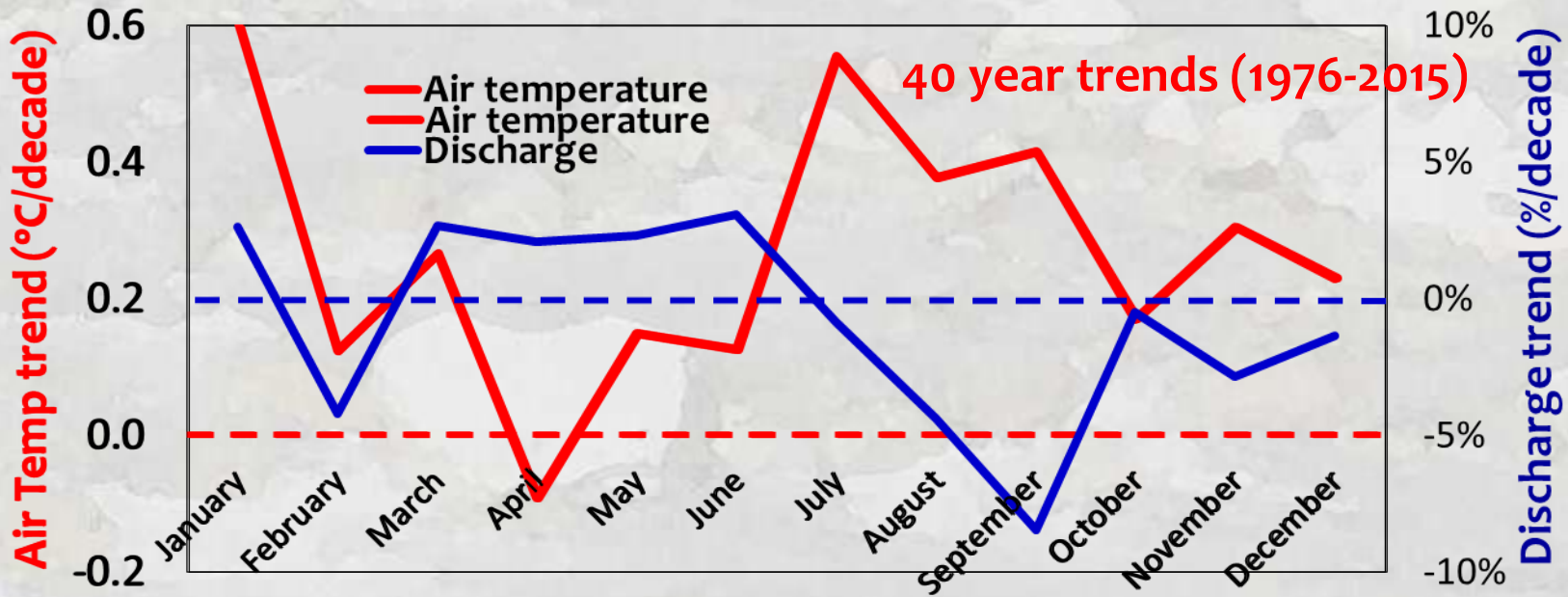
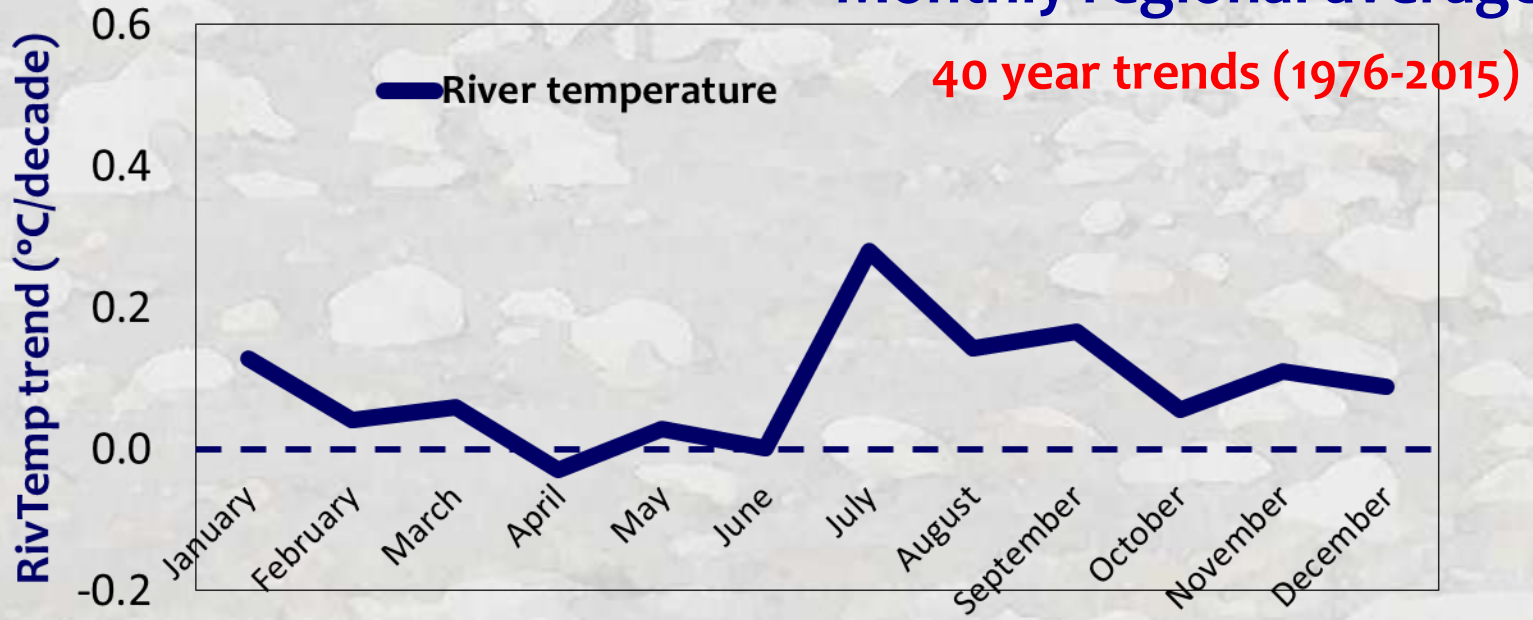


40 Year (1976–2015) Monthly River Temperature Trend - **December**



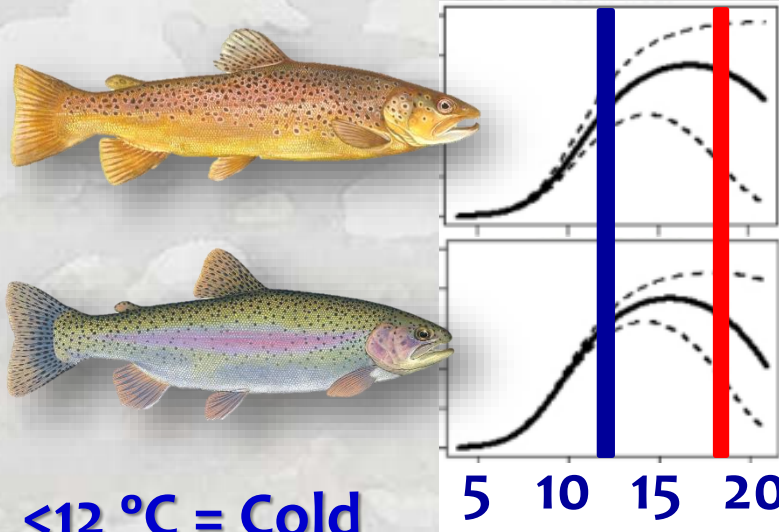
What's Driving River Temperature Trends?

Monthly regional averages



Biological Consequences for Riverine Trout Populations

August mean RivTemps

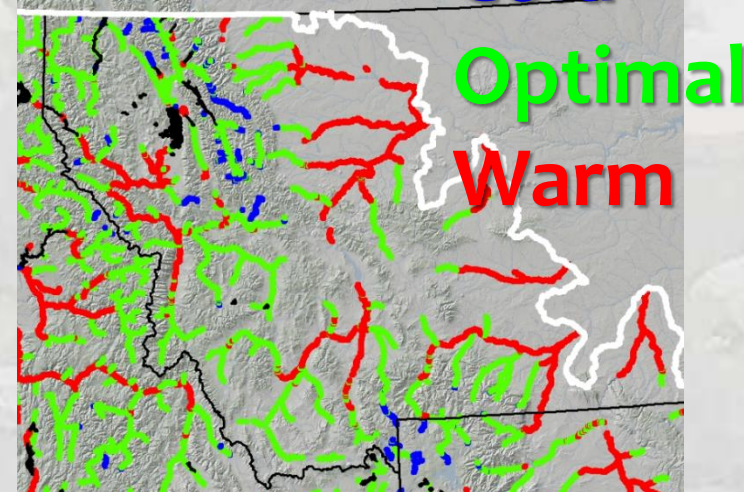
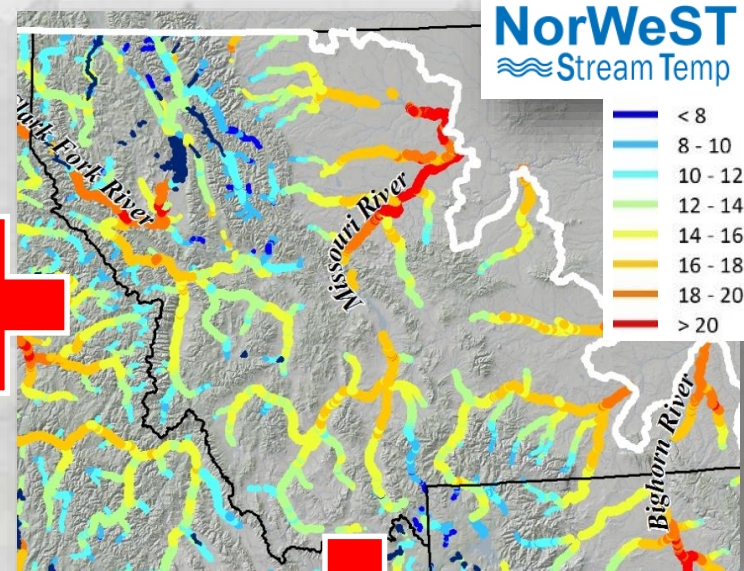


<12 °C = Cold

12–18 °C = Optimal

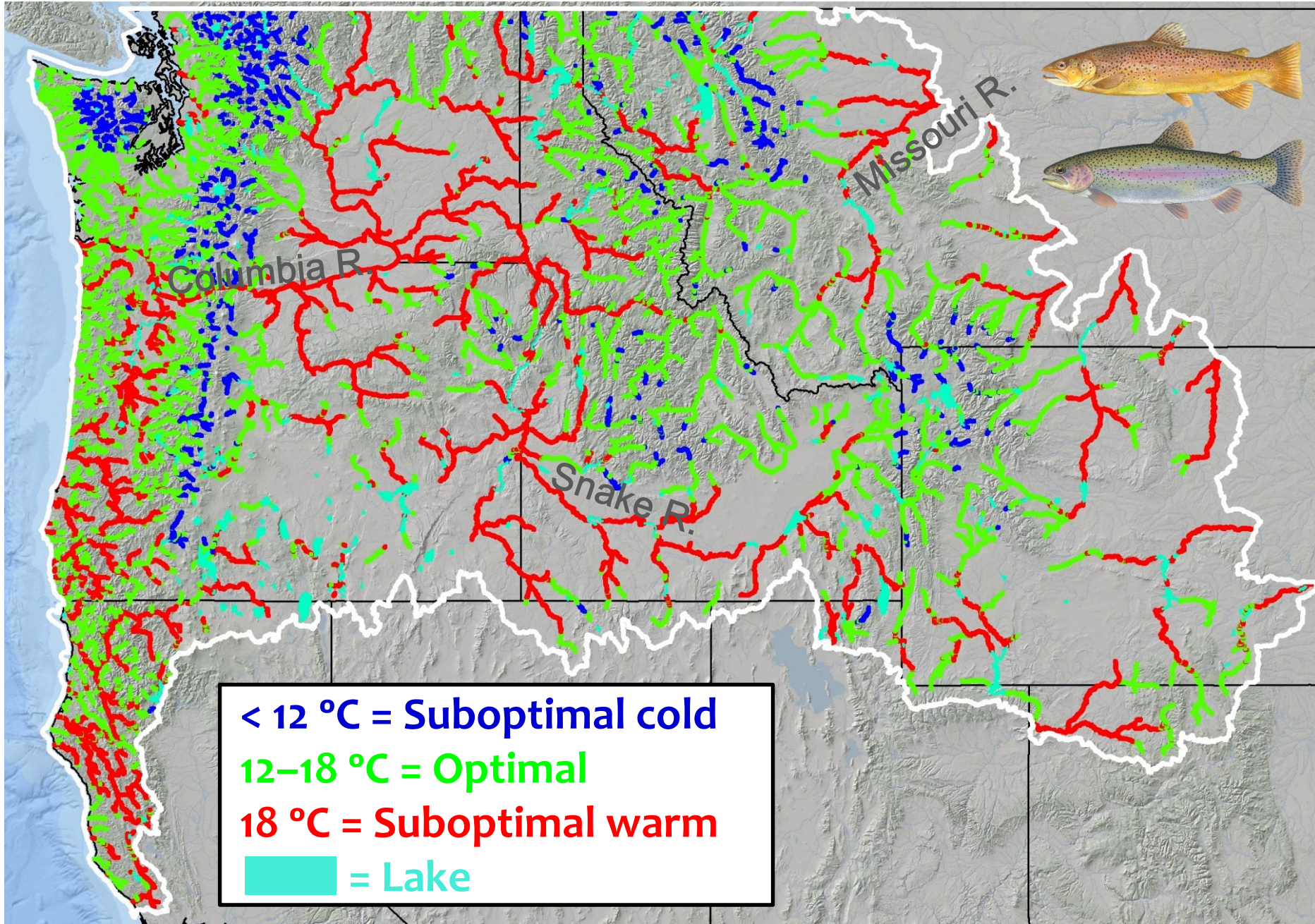
>18 °C = Warm (~22 °C MWMT)

Isaak et al. 2017. Big biology meets microclimatology: Defining thermal niches of aquatic ectotherms at landscape scales for conservation planning. *Ecological Applications* 27:977-990.



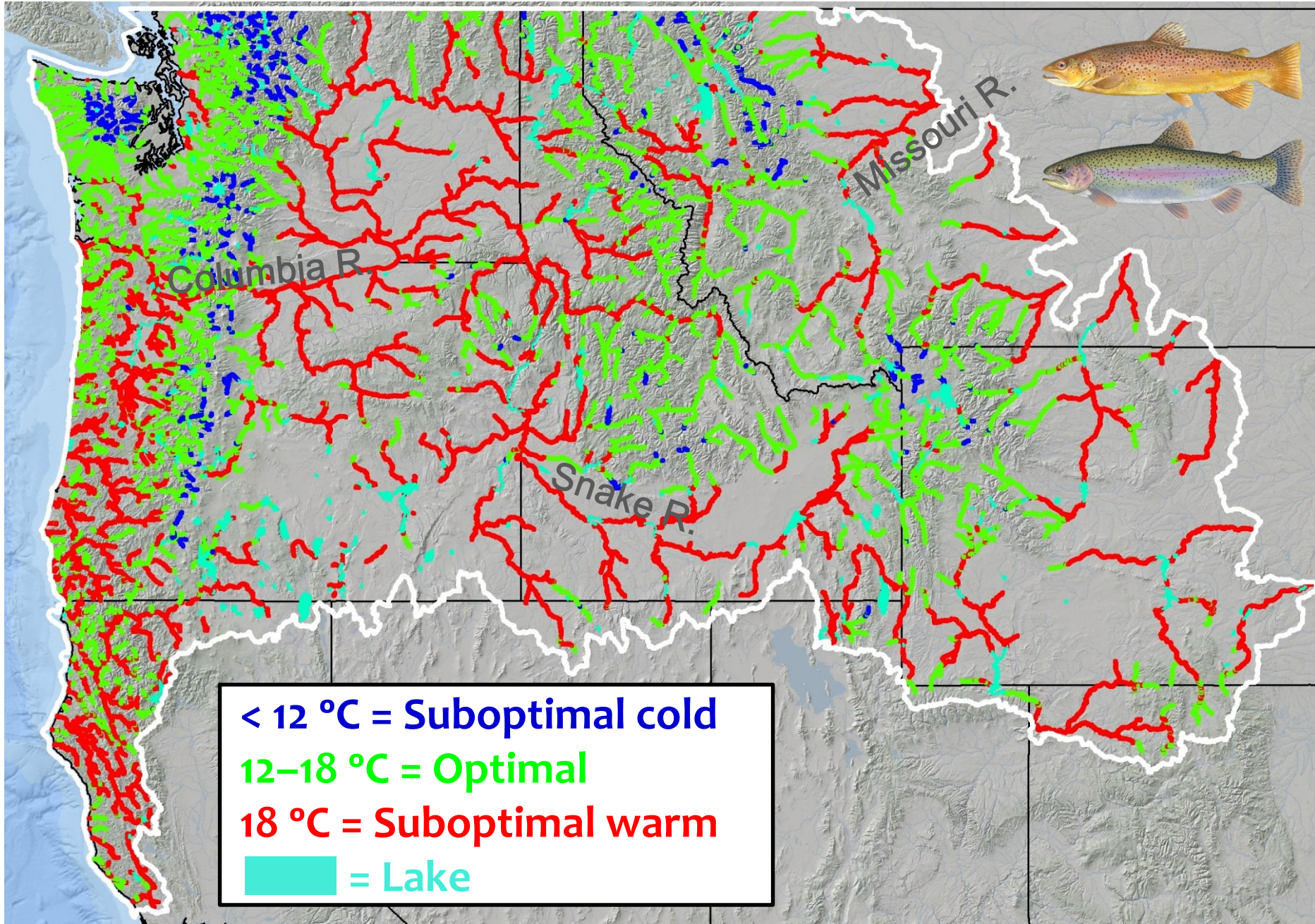
Biological Consequences for Trout?

+0°C



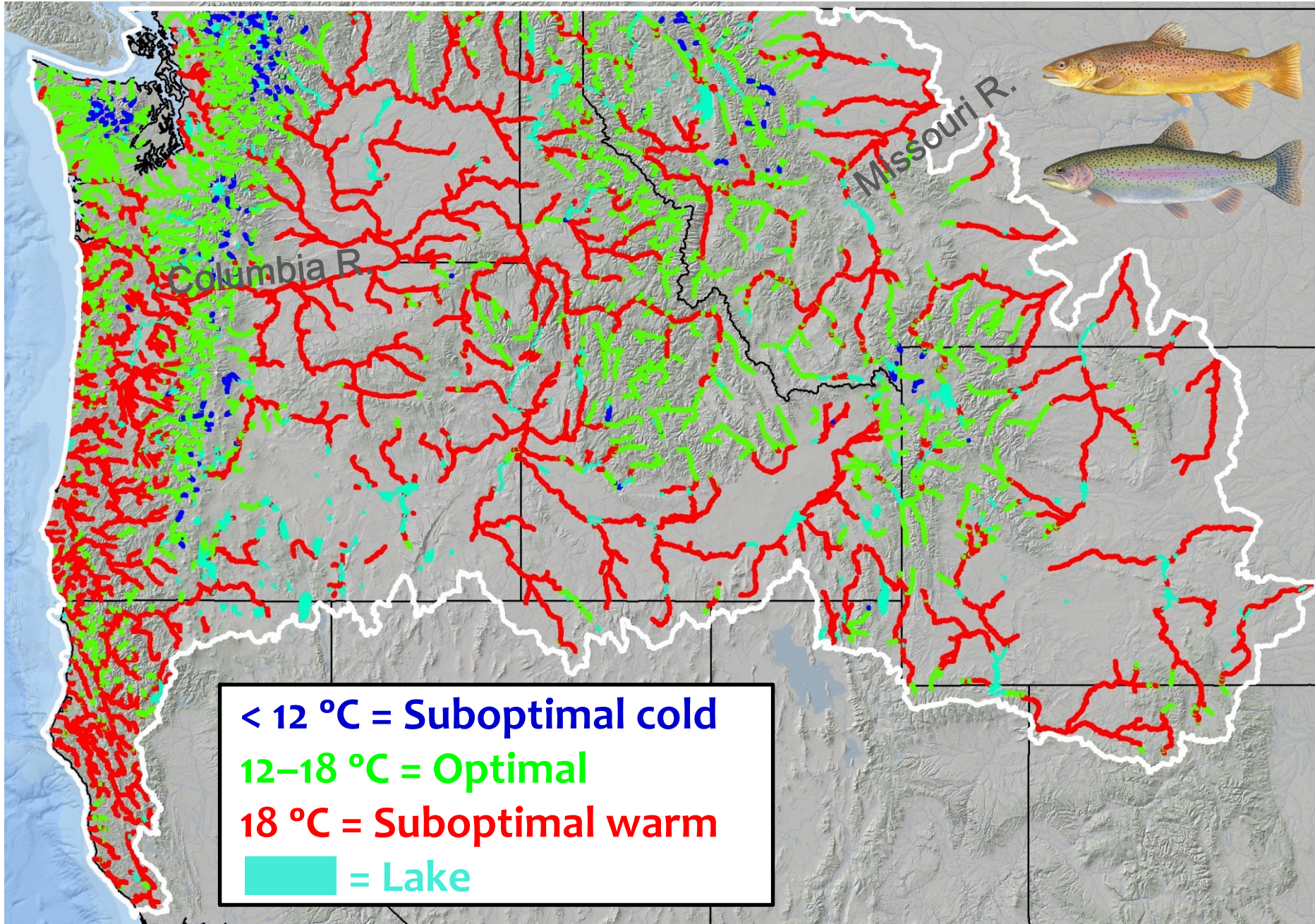
Biological Consequences for Trout?

2050: +1°C



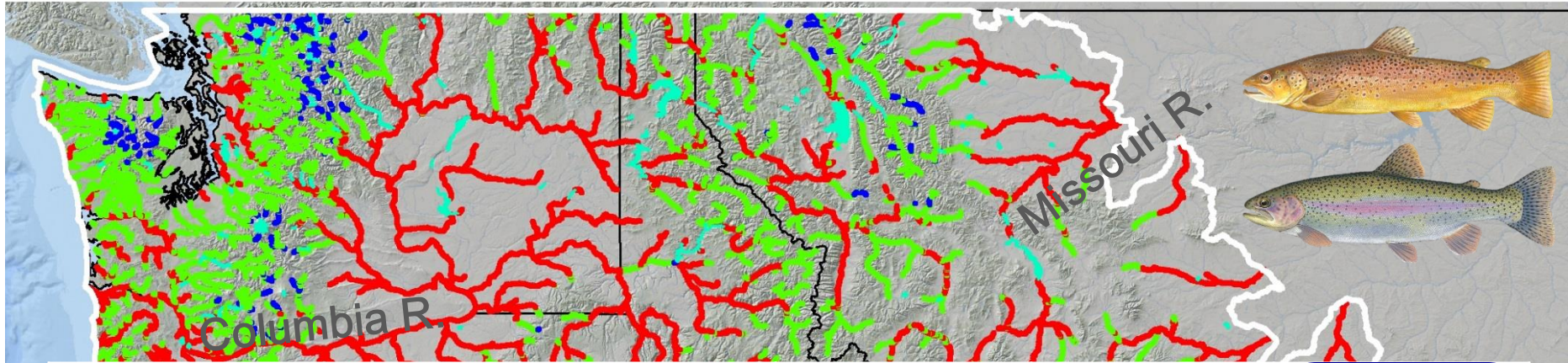
Biological Consequences for Trout?

2080: +2°C



Biological Consequences for Trout?

2080: +2°C



River kilometers that are:	< 12°C	12-18°C	18-21°C	TOTAL
Baseline scenario	4,734	30,257	15,216	50,207
Mid century +1°C scenario	2,656 (-44%)	25,515 (-16%)	18,058 (18%)	46,230 (-8%)
Late century +2°C scenario	1,233 (-74%)	20,361 (-33%)	19,744 (29%)	41,340 (-18%)

< 12 °C = Suboptimal cold

12-18 °C = Optimal

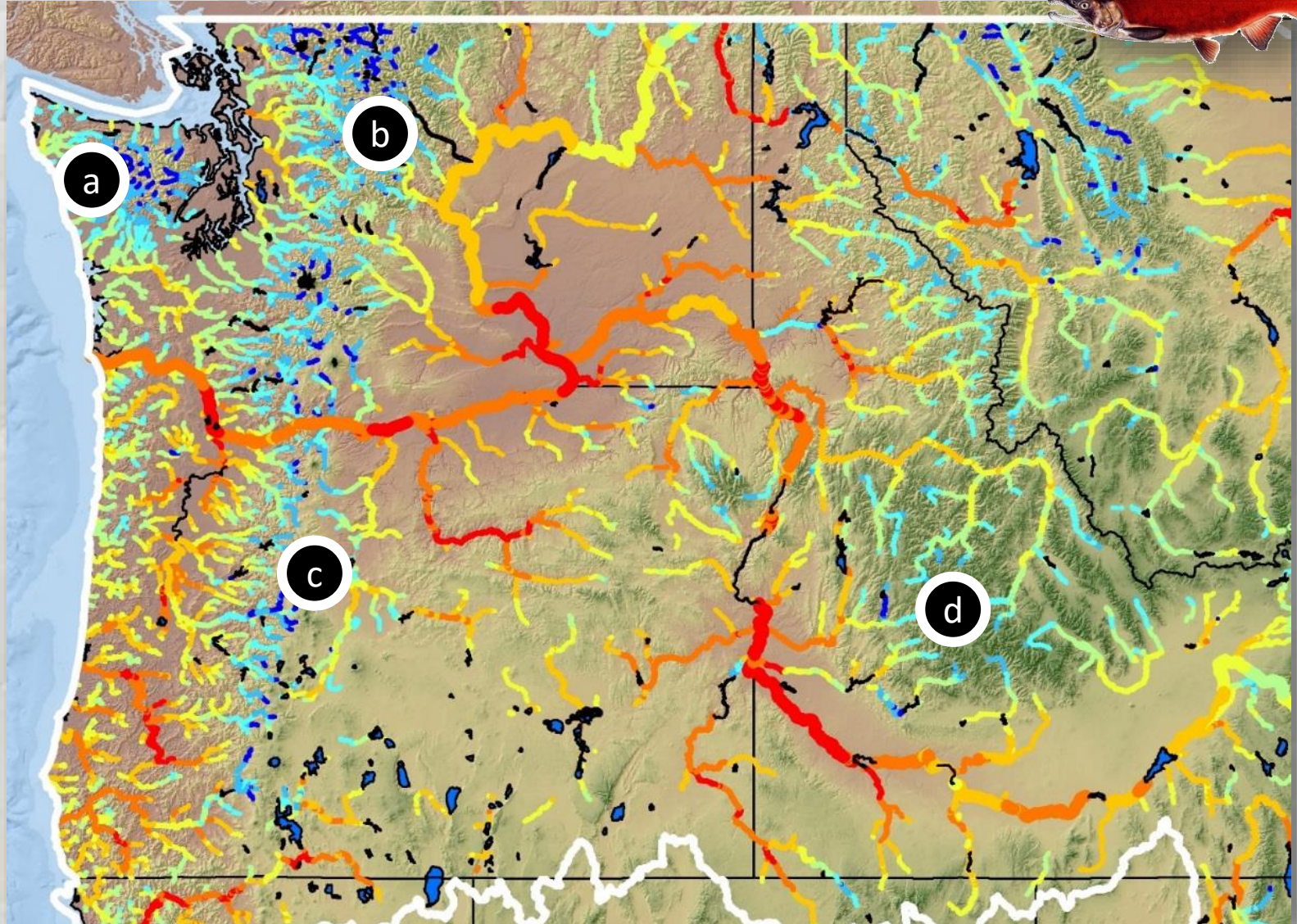
18 °C = Suboptimal warm

■ = Lake

Biological Consequences for Migrating Salmon?

A. Thermal exposure during adult sockeye migration

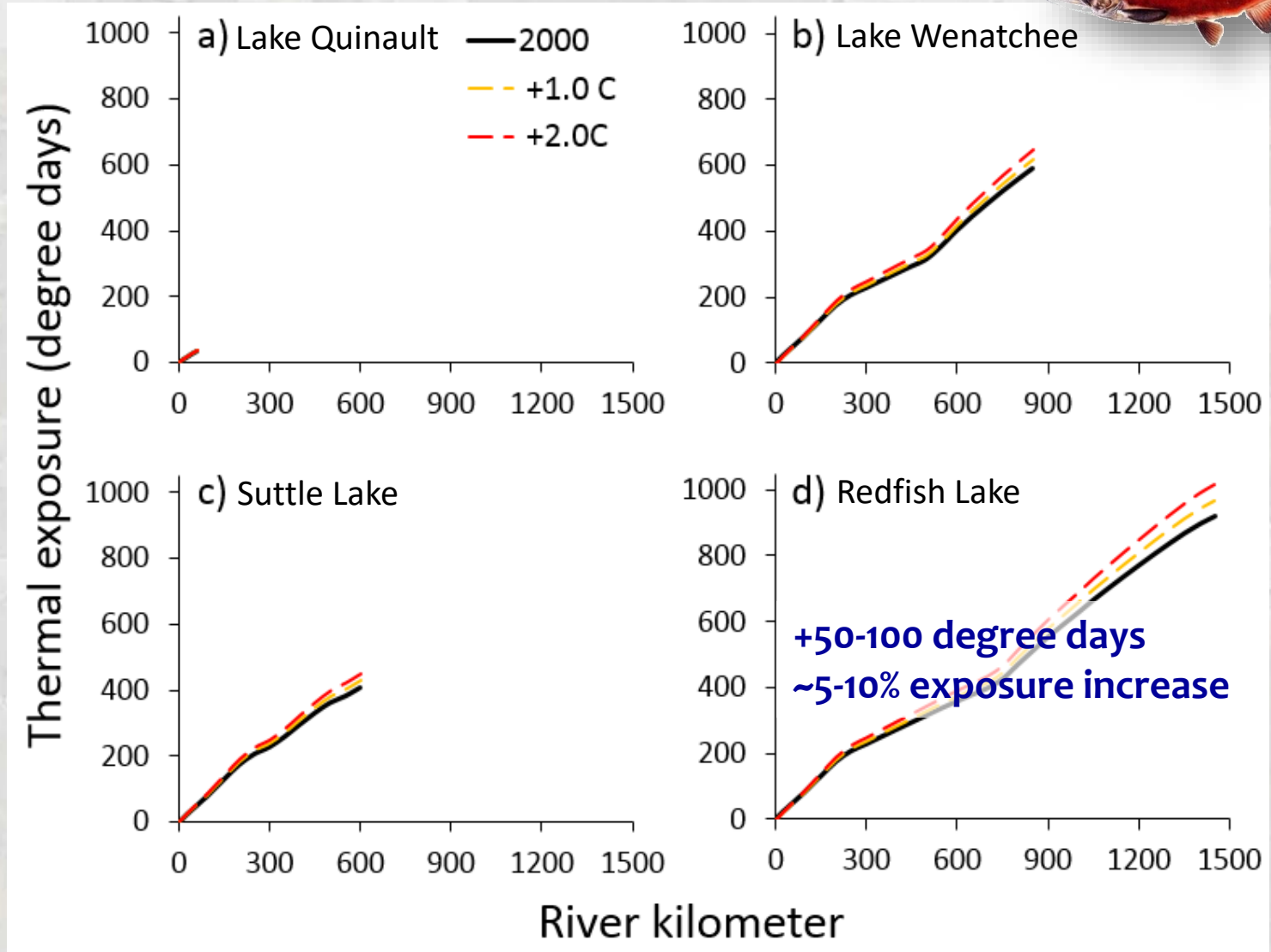
Exp = River distance \times temperature \times swimming speed



Biological Consequences for Migrating Salmon?

A. Thermal exposure during adult sockeye migration

Exp = River distance \times temperature \times swimming speed

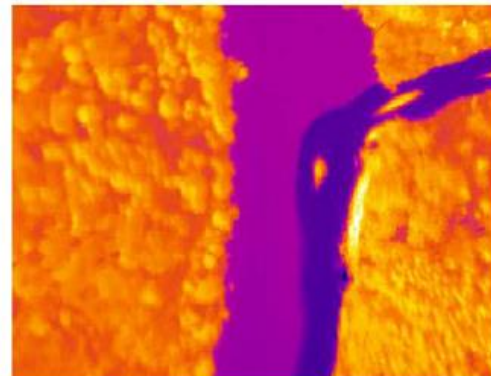


Options for Cooling Smaller Rivers

- 1) Maximize riparian shade
- 2) Maximize summer flows
- 3) Restore channel complexity to force hyporheic exchange



- 4) Identify, protect, & enhance cold microrefugia



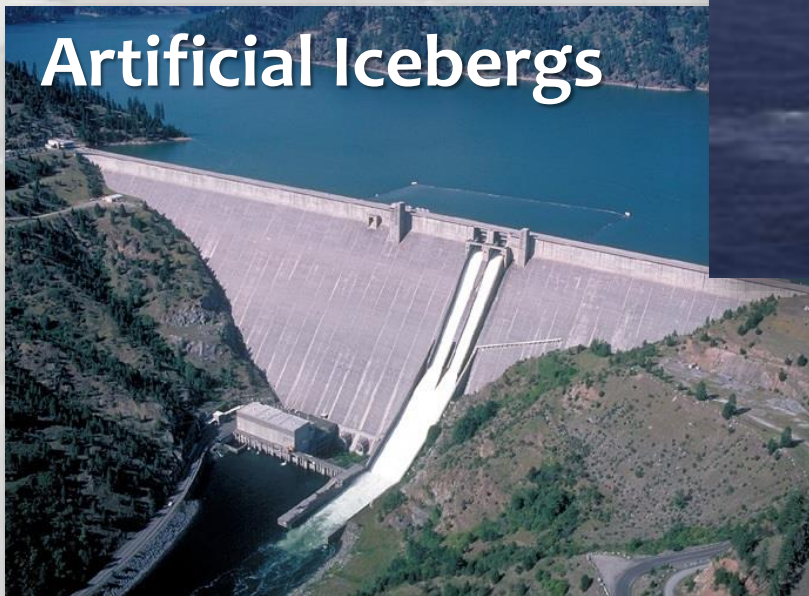
Drone mounted cameras

Options for Cooling Largest Rivers are Limited...



Options for Cooling Largest Rivers are Limited...

Artificial Icebergs

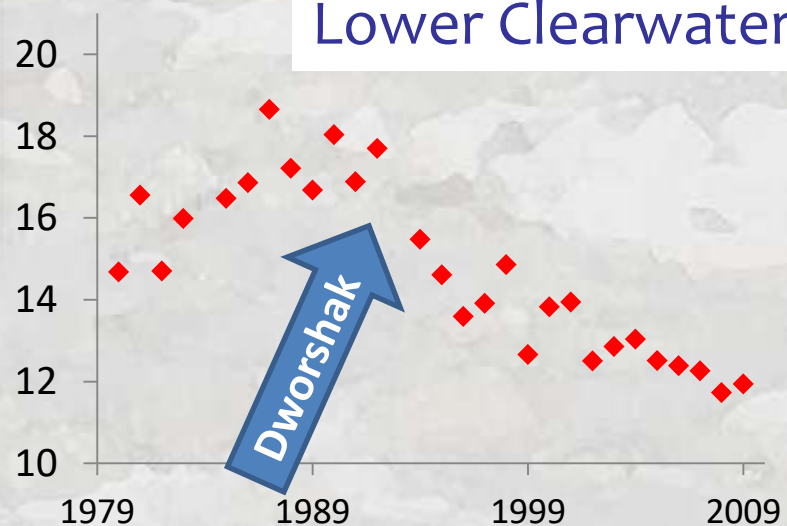


Icebergs



★ Deep reservoir needed for cold water creation

Lower Clearwater



Human Adaptation in Future Decades

- 1) Accept that fish communities *in some rivers* will change & communicate that information to public
- 2) Develop emergency action plans for extreme years like **2015** (e.g., fish rescue operations, protocols for rapid suspension of fishing seasons)
- 3) Strategically target thermal restoration actions where benefits to cold-water fish populations are most likely
- 4) Anglers diversify tackle boxes to include plugs for bass, snakeheads, & TBD critters
- 5) Continue enjoying cold-water fisheries in many rivers this century



It's Bubba-time!



For more information:

Isaak, D.J., C. Luce, D. Horan, G. Chandler, and S. Wollrab. 2018. Global warming of salmon and trout rivers in the Northwestern U.S.: Road to ruin or path through purgatory? *Transactions of the American Fisheries Society* 147:566-587.

ArcGIS river temperature scenarios @ the NorWeST website:
<https://www.fs.fed.us/rm/boise/AWAE/projects/NorWeST.html>



The End

