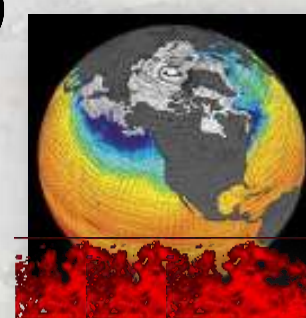
Stream Climate Trends & Adaptive Responses: A 21st Century Strategic Context for Tactical Decision Making

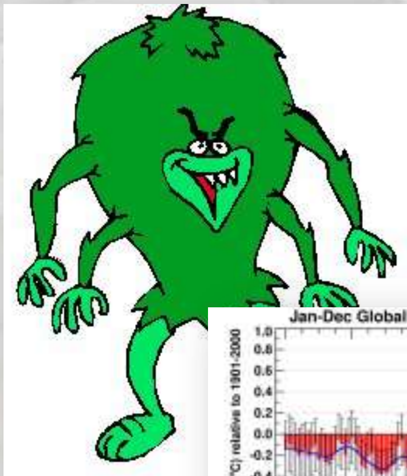
Dan Isaak, US Forest Service

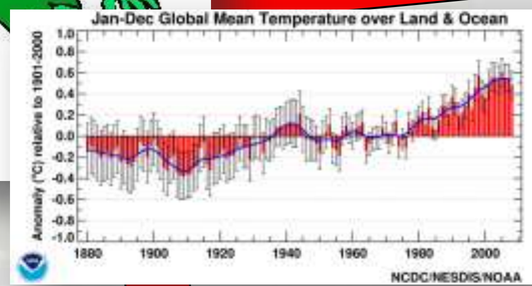
Rocky Mountain Research Station



There's A Lot on the Line…

Climate Boogeyman



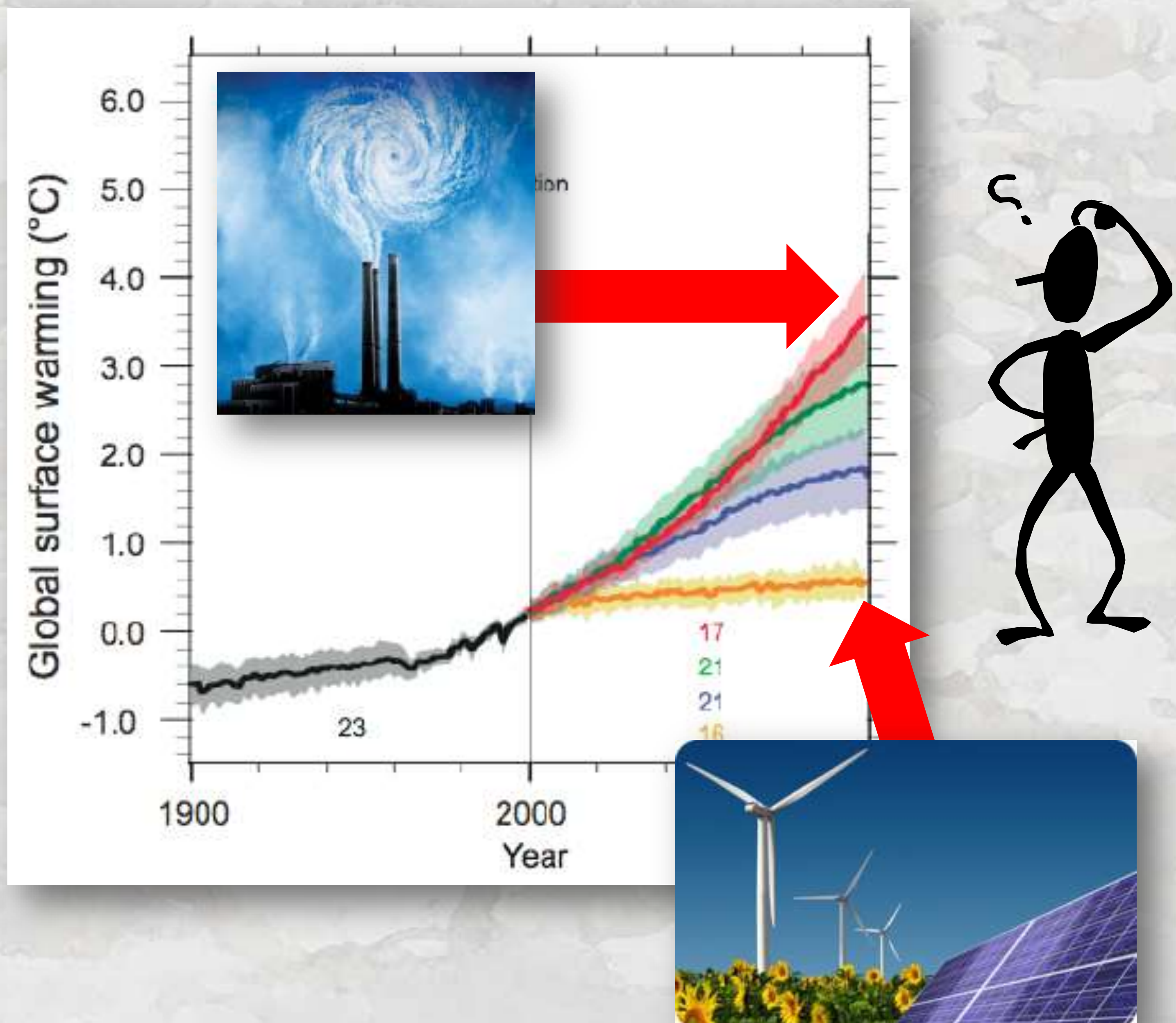


Tribal & Recreational Fisheries

Land Use & Water Development

ESA Listed Species

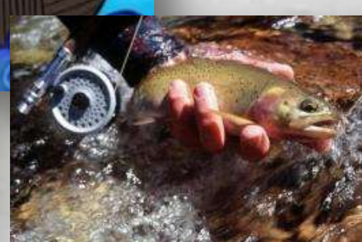
Current Choices Set Future Trajectories

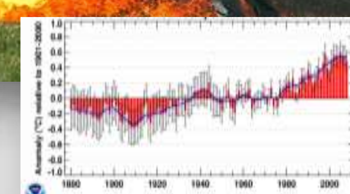


Current Choices Set Future Trajectories

Choice A: Coexistence (do nothing or shape transition to more desirable communities)

Choice B: Resistance (protect key fisheries & other currently valued resources)





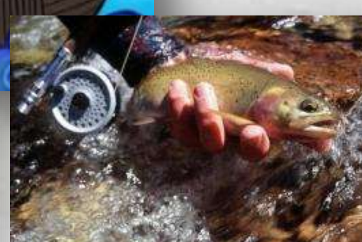
Conservation reserves, important fisheries

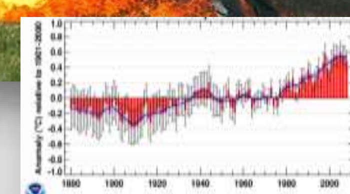
Current Choices Set Future Trajectories

Choice A: Coexistence (do nothing or shape transition to more desirable communities)

OR?

Choice B: Resistance (protect key fisheries & other currently valued resources)





Conservation reserves, important fisheries

Good News: Lots of Things we Can do to Improve Stream Habitat Resilience

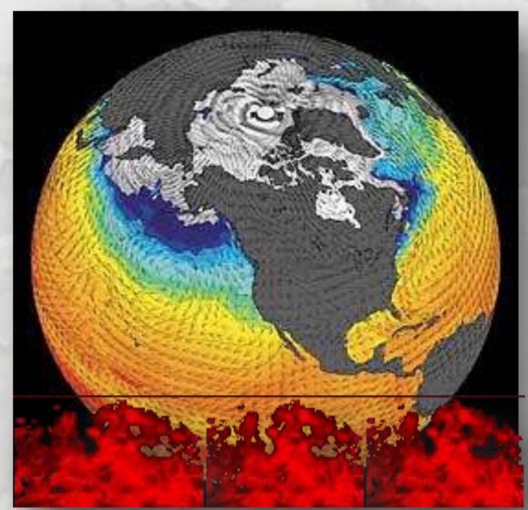
- •Maintaining/restoring flow…
- •Maintaining/restoring riparian…
- •Restoring channel form/function…
- •Prescribed burns limit wildfire risks…
- •Non-native species control…
- •Improve/impede fish passage…

Where to do them?

Is there a grand strategy?

Good Information for Strategic Decision Making is Critical

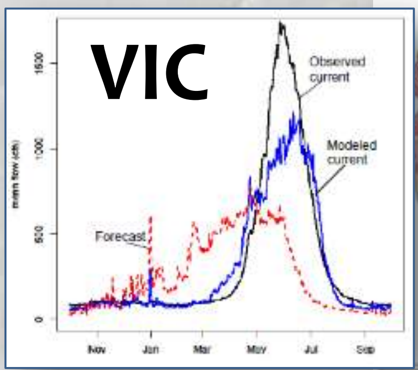
Global climate

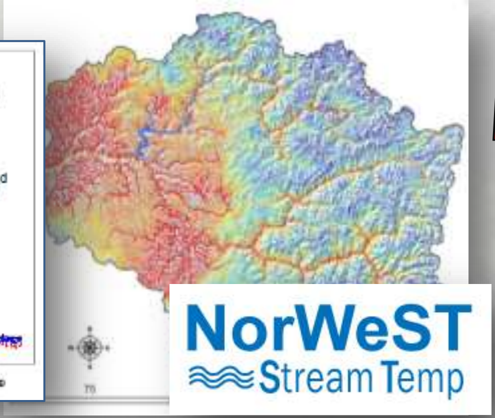


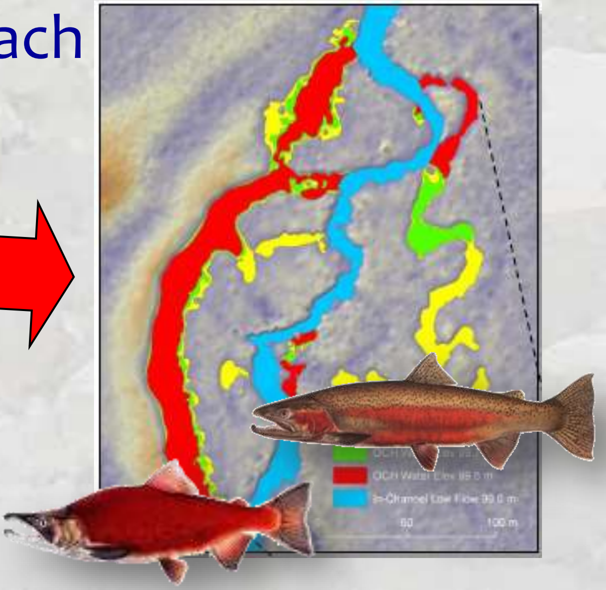
Regional climate

Stream reach

River network temperatures & flow







General outline:

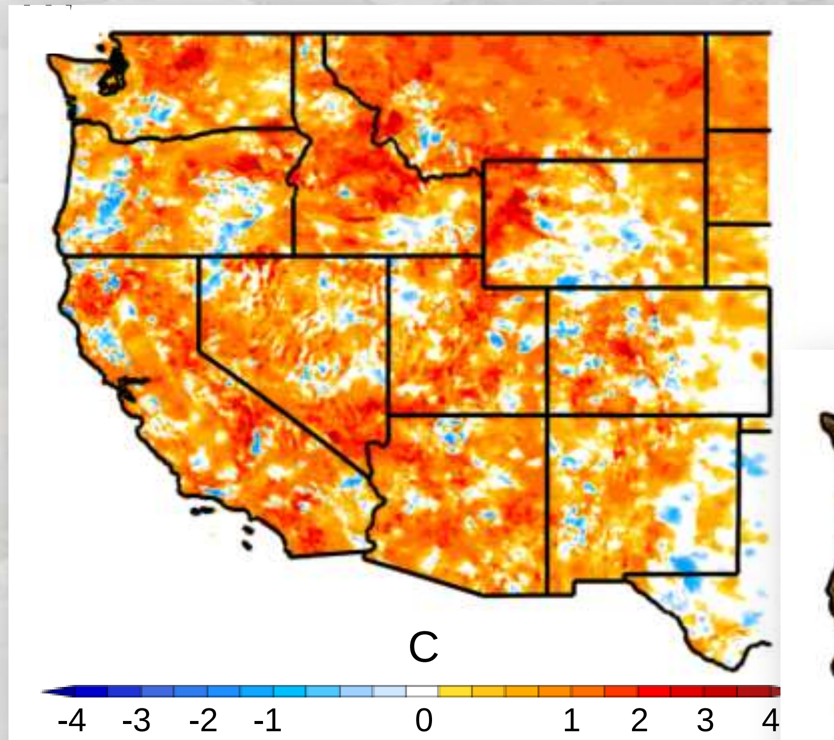
1) Historical trends & future predictions for streams (flow, temperature, sediment regimes)

2) How could salmon & other aquatic resources be affected?

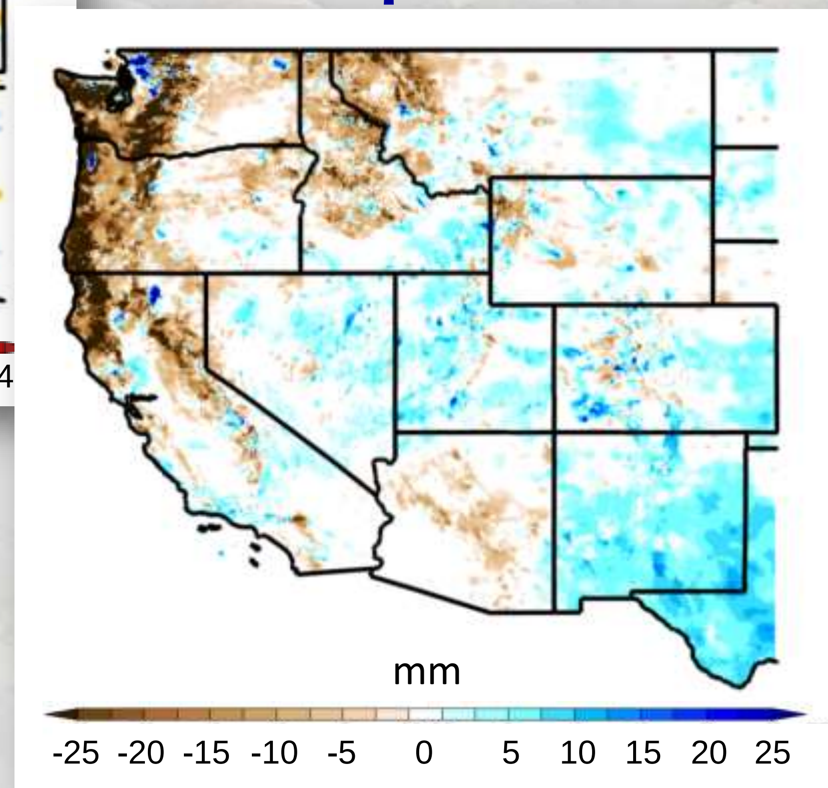
3) What can we do about it? (monitoring, modeling & making choices)

Western US Observed Climate Trends (1950 – 2009)

Air temperatures

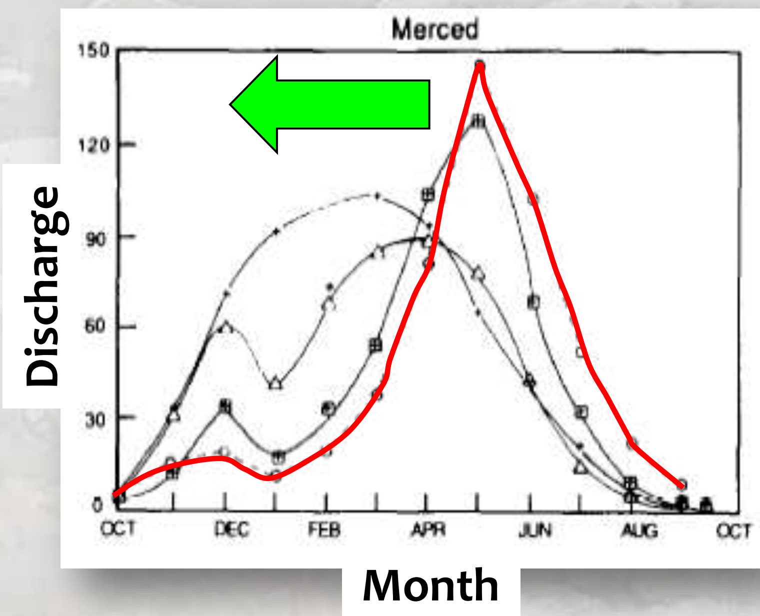


Total Annual Precipitation

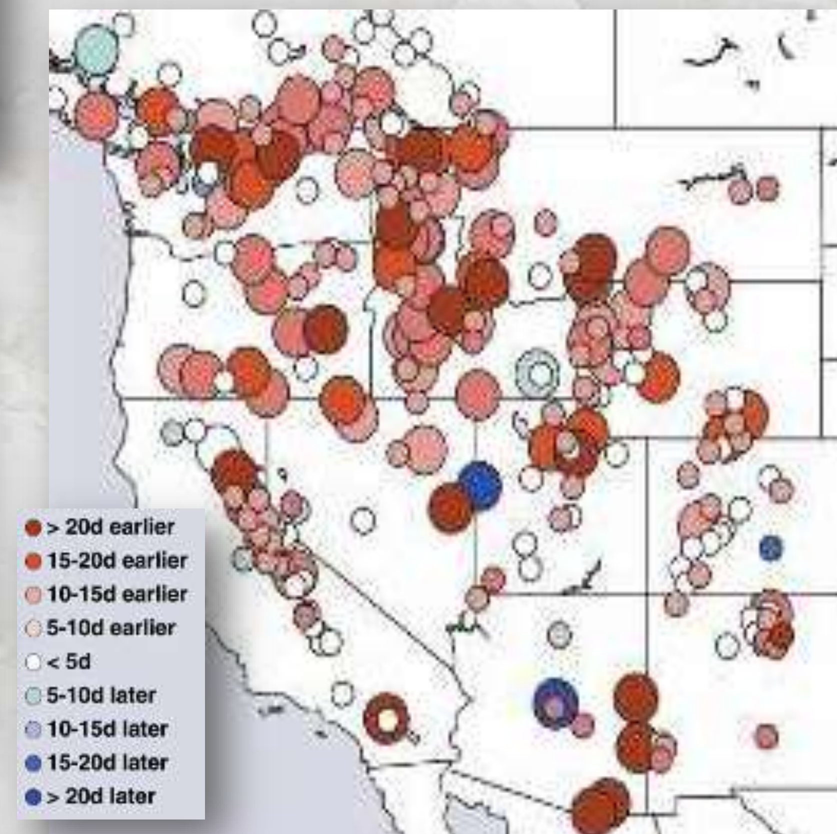


Trends in Stream Runoff Timing

(1948-2000)

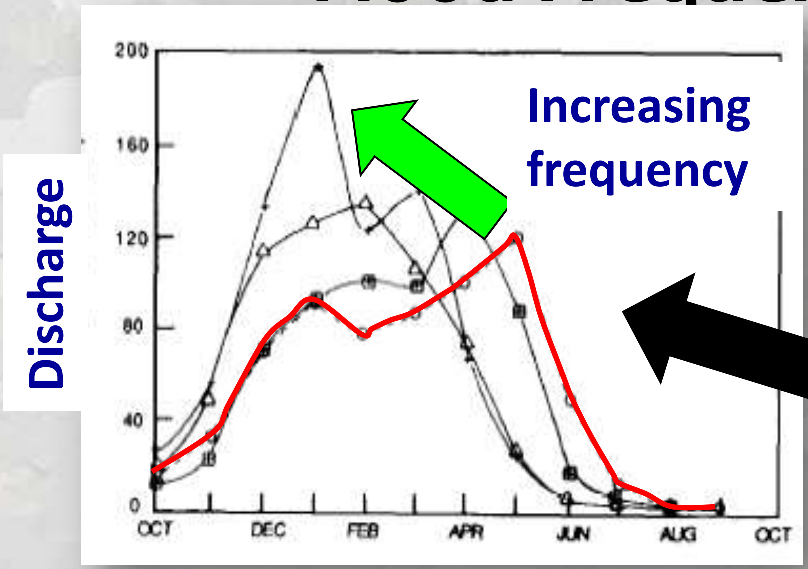


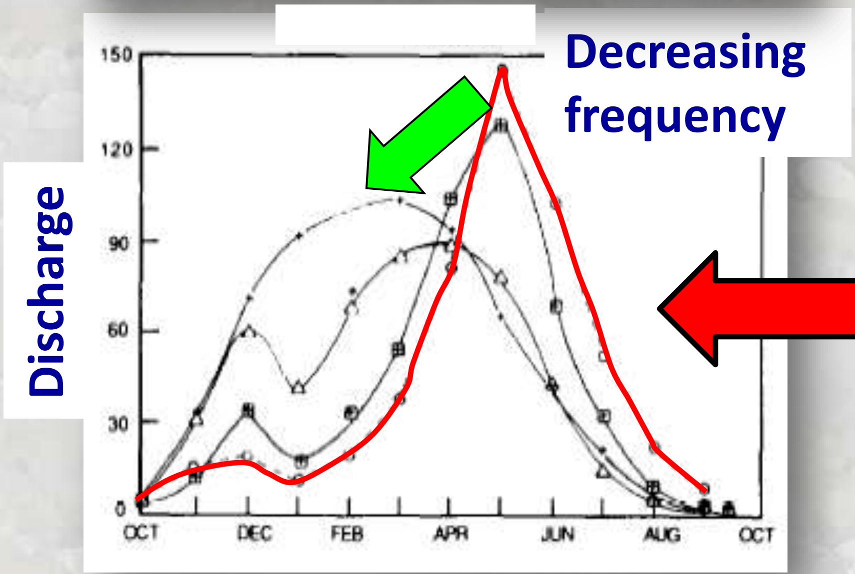
Earlier snowmelt & river runoff

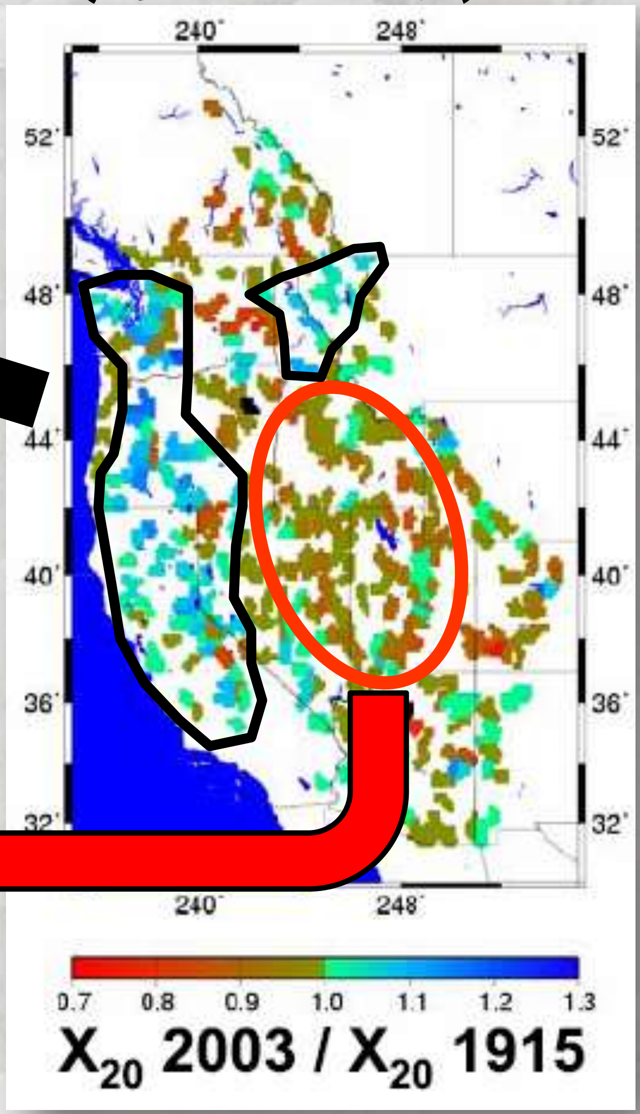


Stewart et al. 2005

20th Century Trends in 20-Year Flood Frequencies (1915–2003)



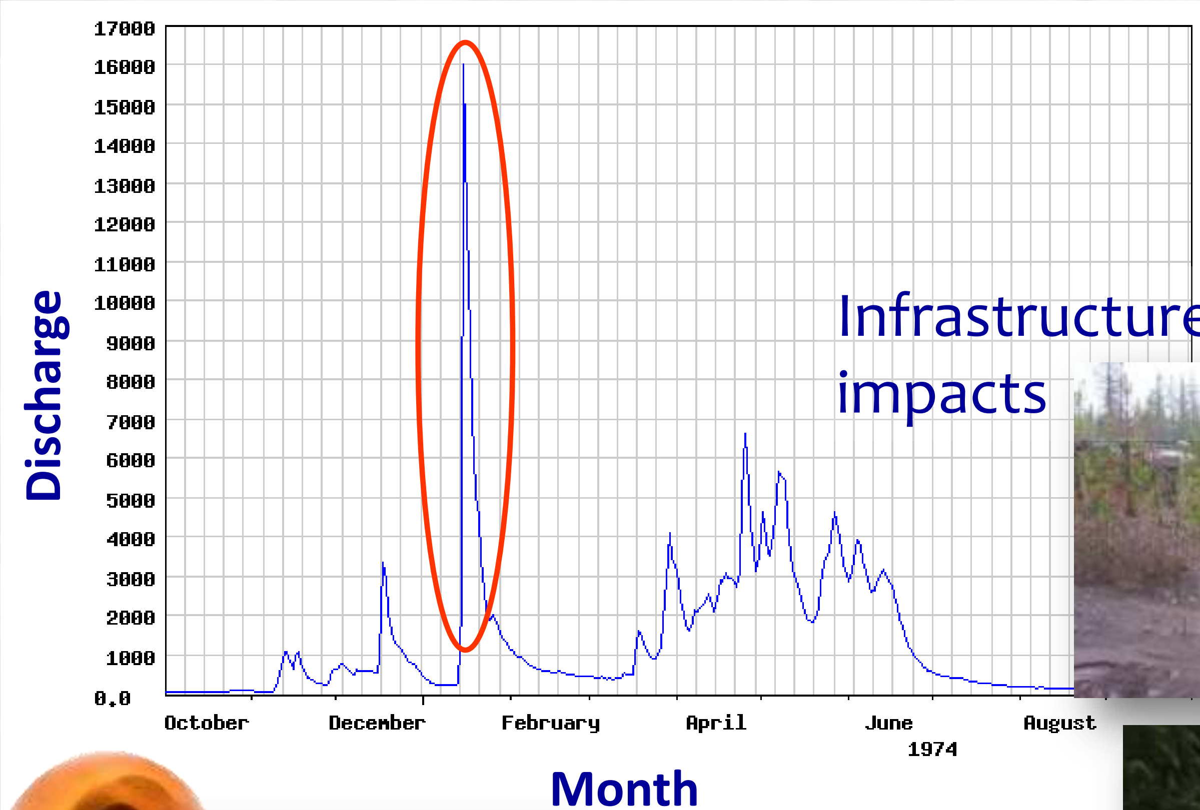




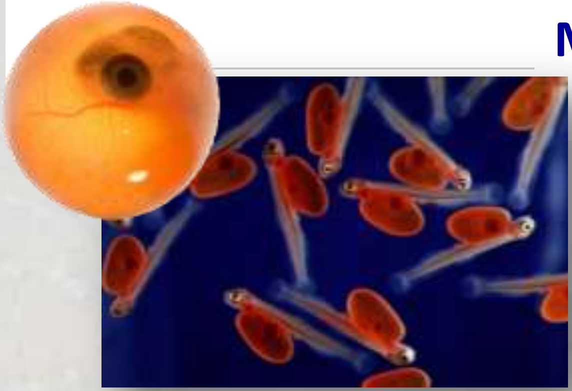
Hamlet and Lettenmaier. 2007. *Water Resources Research* 43, W06427, doi:10.1029/2006WR005099

Increases in Winter Floods

Rain-on-snow events



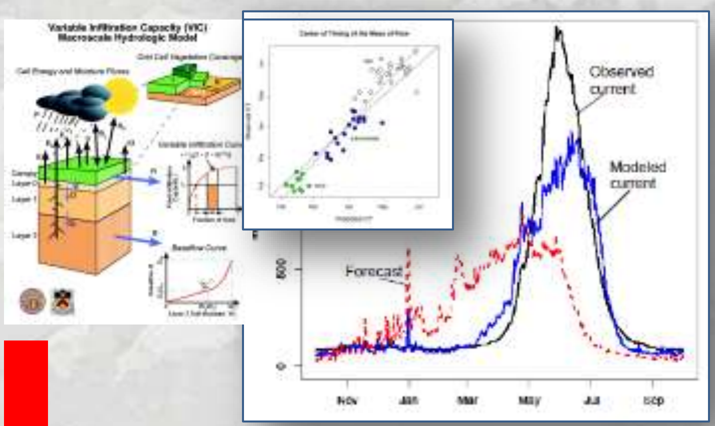
Infrastructure impacts



Fish egg/embryo mortality

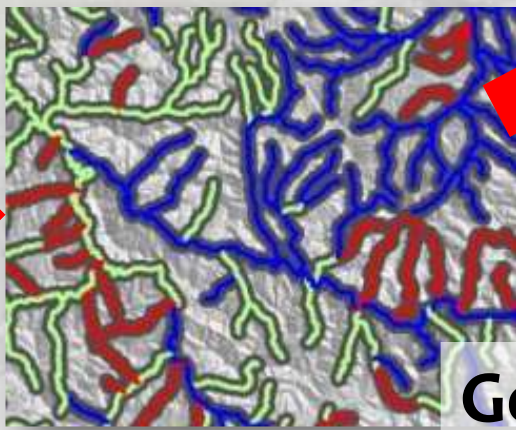
VIC Streamflow Scenarios

Ecological Flow Metrics



A1B IPCC Scenarios for the western U.S.

NHD+ stream segment resolution



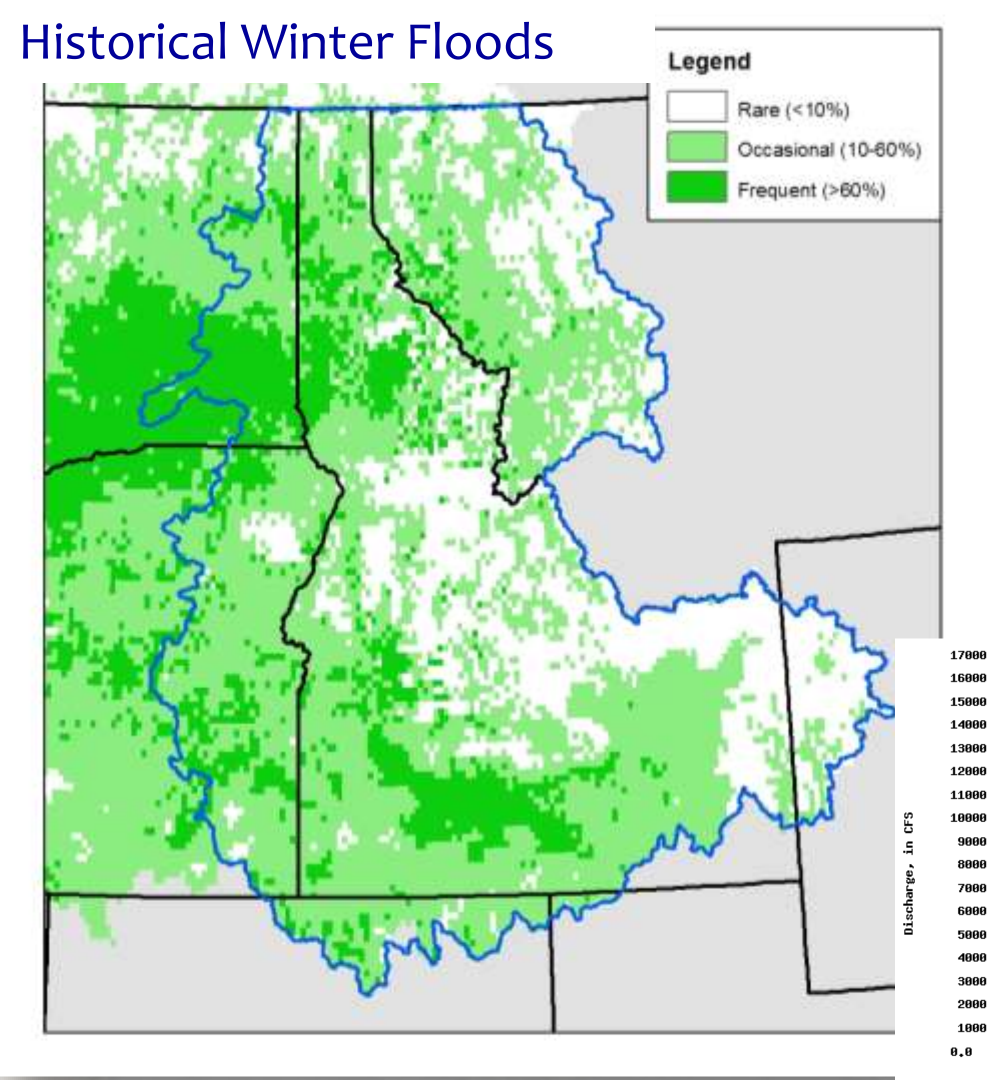
Google "Stream flow Metrics"

Website: http://www.fs.fed.us/rm/boise/AWAE/projects/modeled_stream_flow_metrics.shtml

Wenger et al. 2010. *Water Resources Research* **46**, W09513

VIC Streamflow Scenario

Winter flood frequency (95% event)



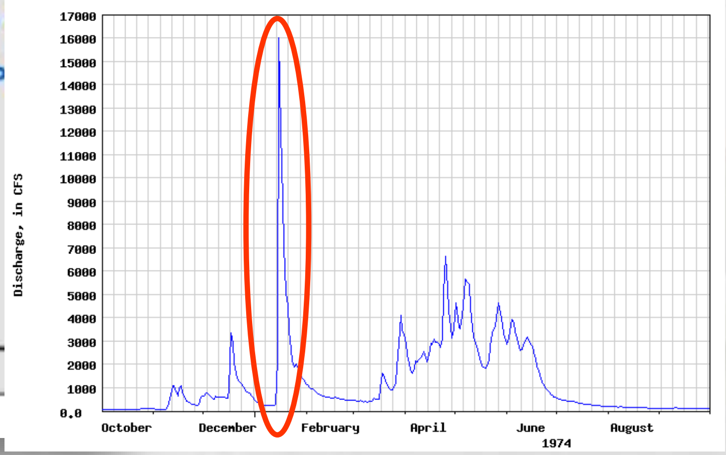
•Predictions linked to stream segments for 1:100,000 NHD Plus

•<u>Scenarios:</u>

1) historical (1980s);

2) A1B mid-century (2040s – ensemble GCMs);

3) A1B late-century (2080s – ensemble GCMs)

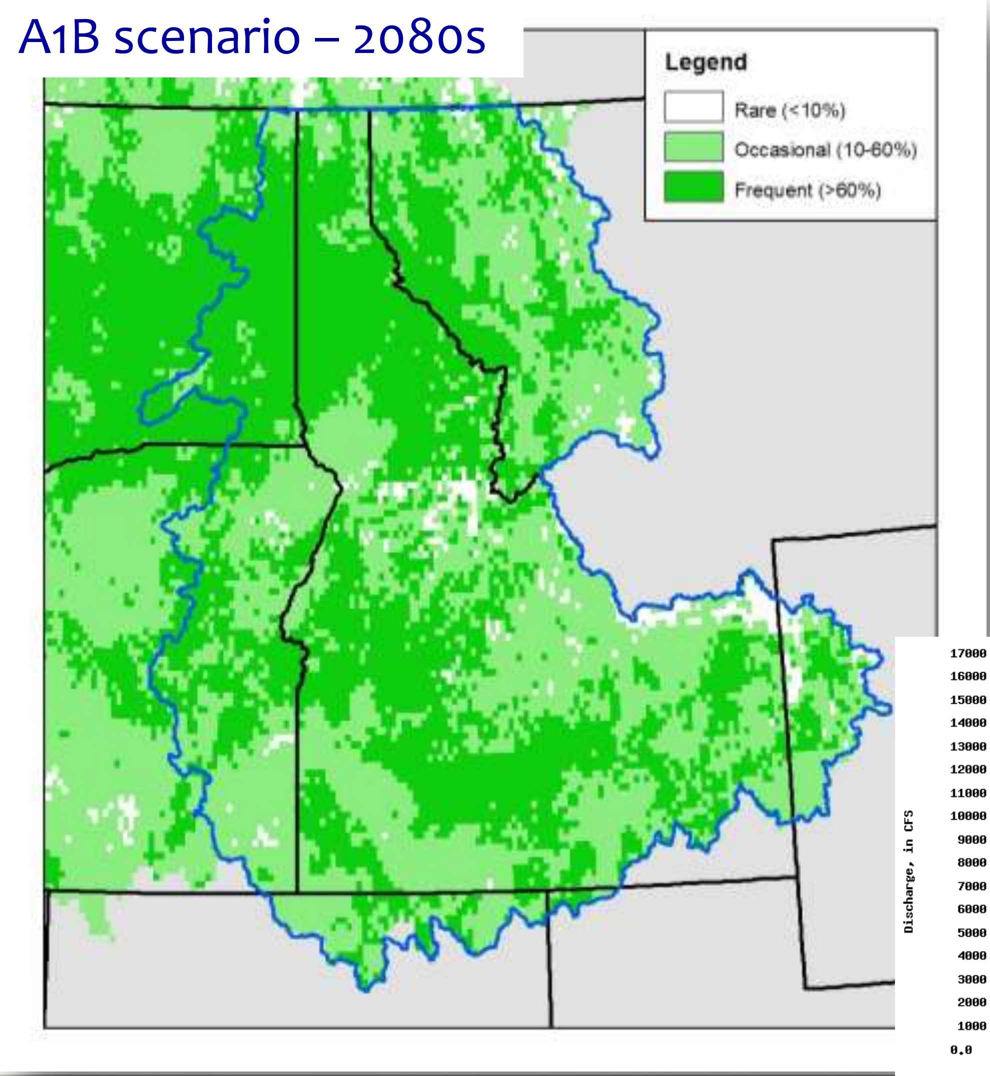


Wenger et al. 2010. *WRR* **46**, W09513; Wenger et al. 2011. *PNAS* **108**:14175-14180

VIC Streamflow Scenario

Winter flood frequency (95% event)

A1B scenario – 2080s



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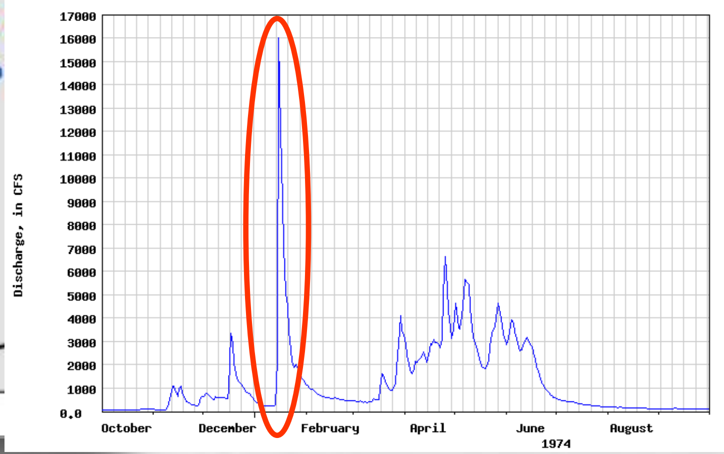
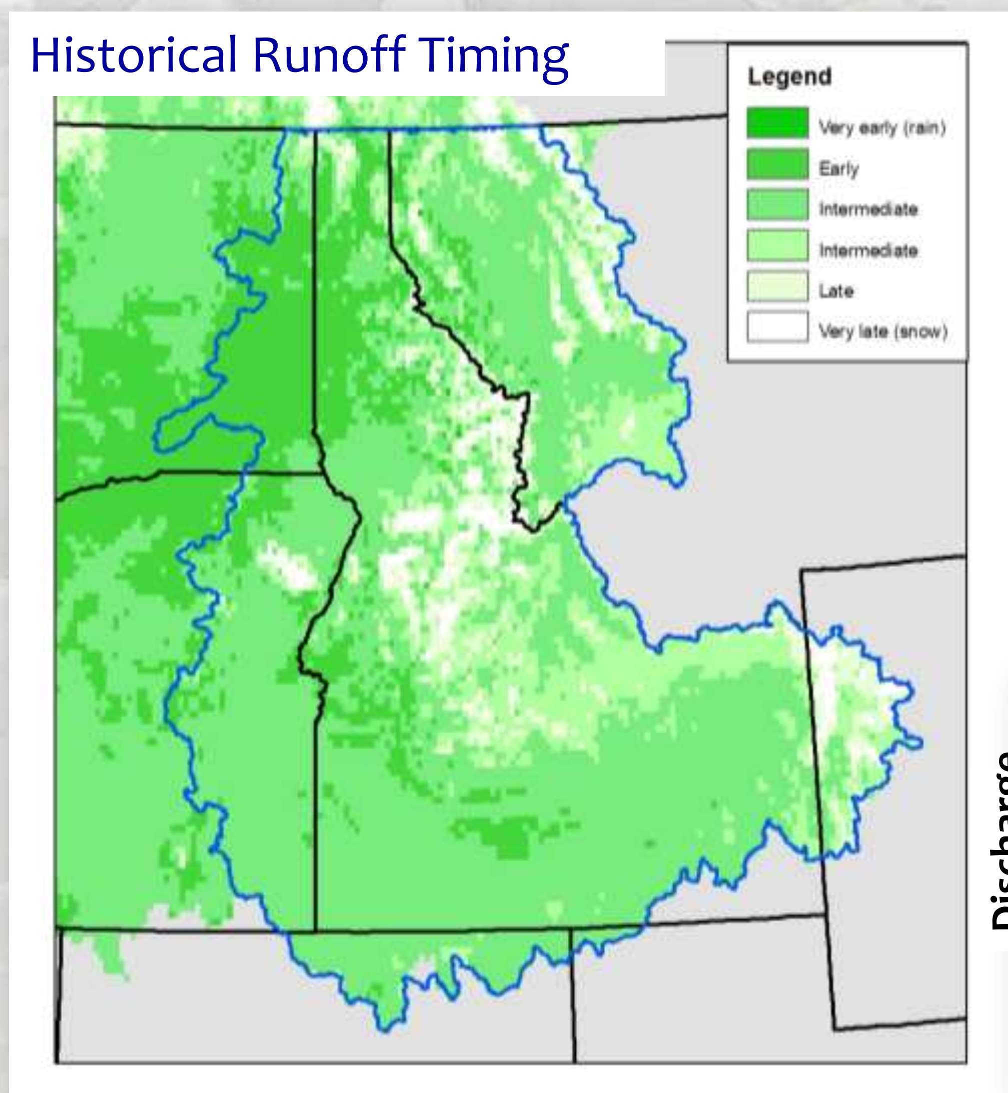


Wenger et al. 2010. *WRR* **46**, W09513; Wenger et al. 2011. *PNAS* **108**:14175-14180

VIC Streamflow Scenario

Runoff timing (Center of annual flow mass)



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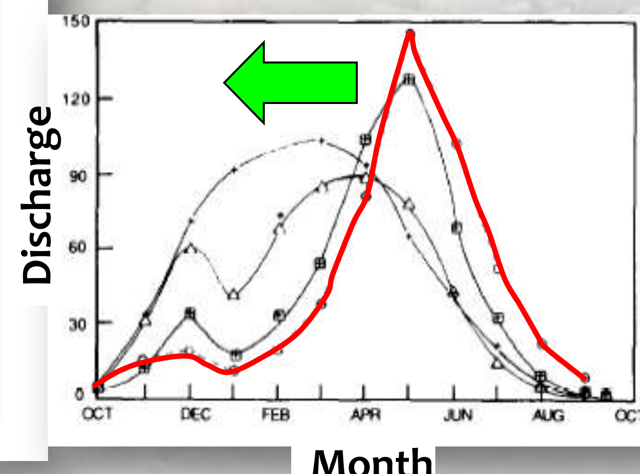

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VIC Streamflow Scenario

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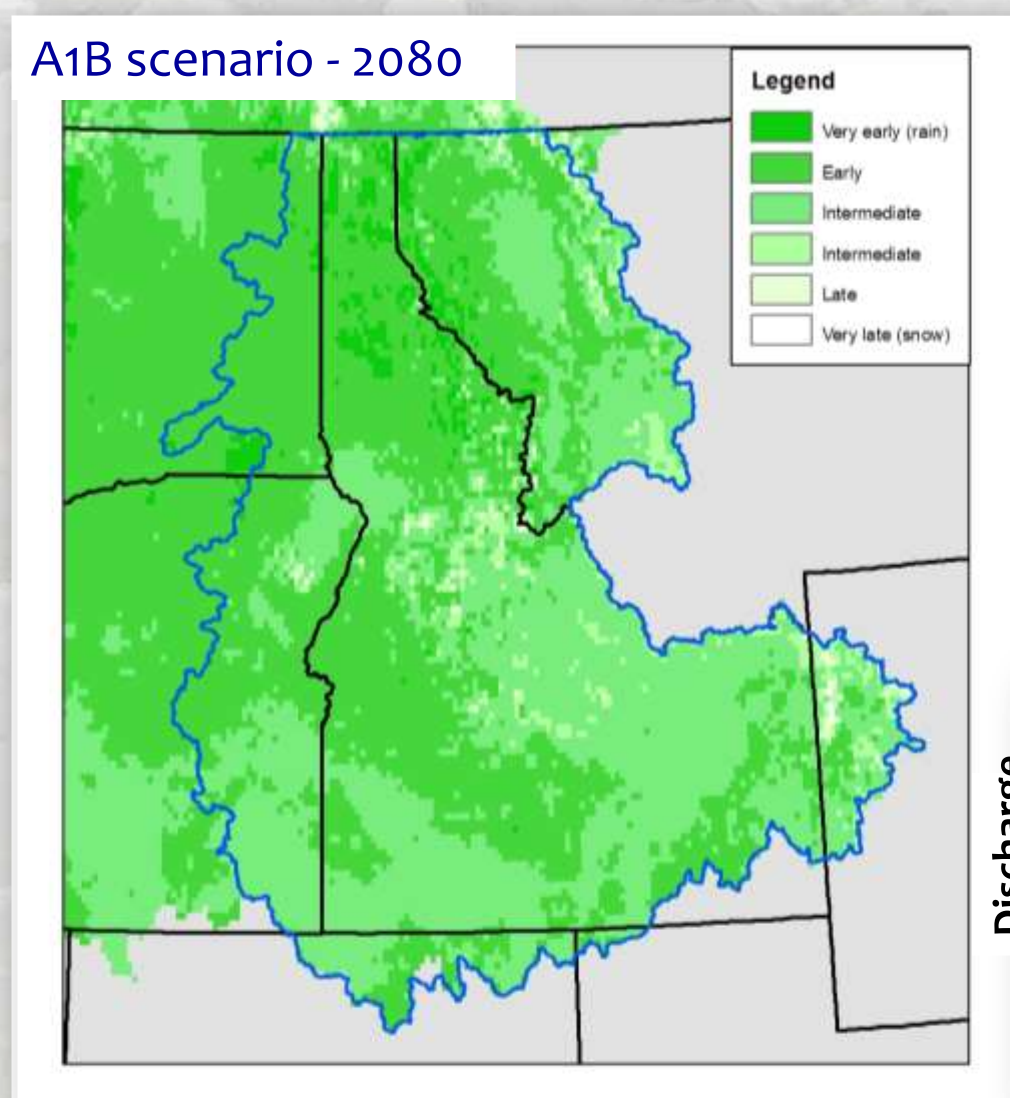

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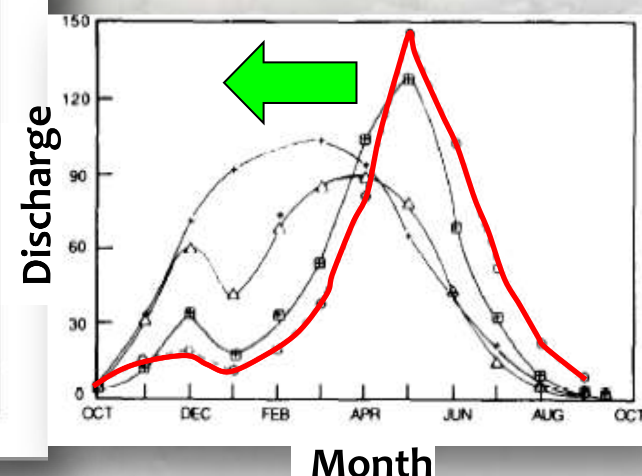
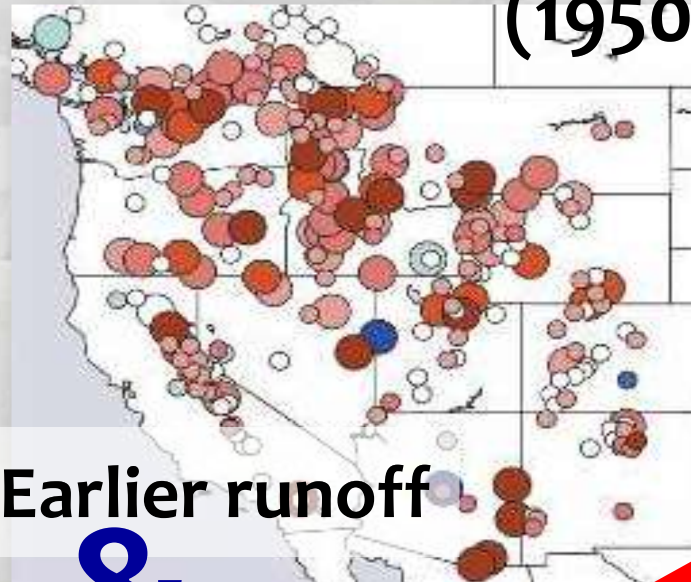


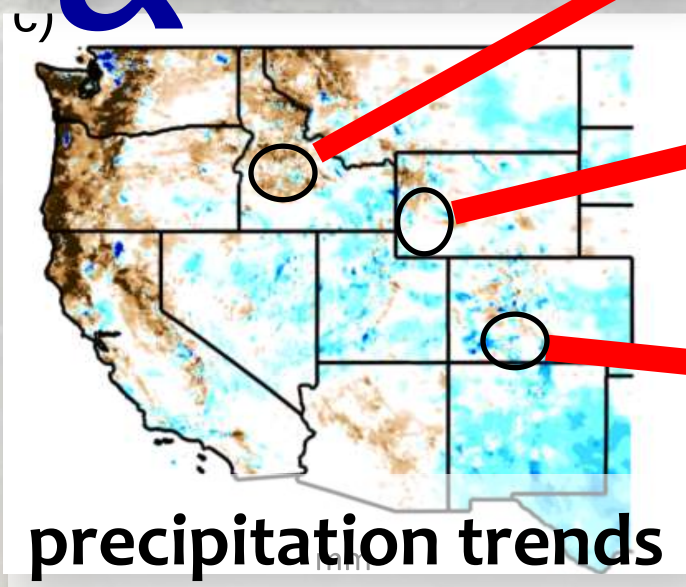
Wenger et al. 2010. *WRR* **46**, W09513; Wenger et al. 2011. *PNAS* **108**:14175-14180

Summer Flow Trends (1950–2009)

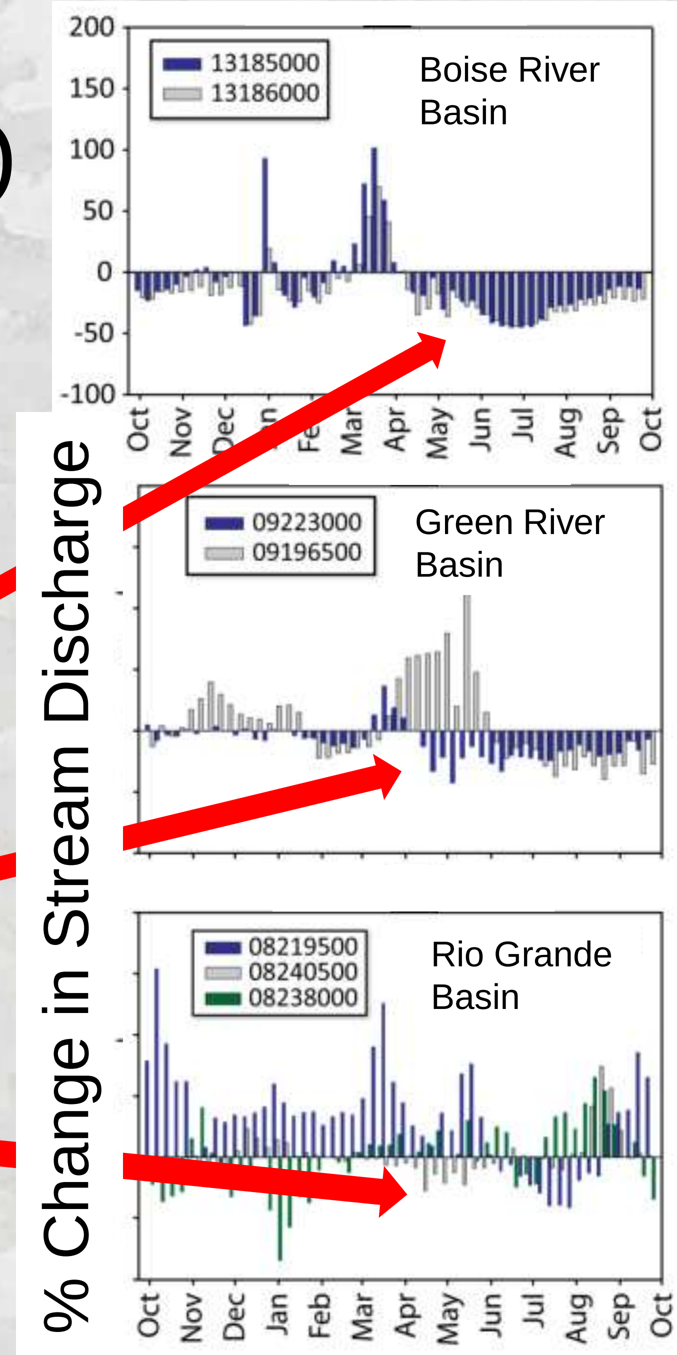


Earlier runoff

&

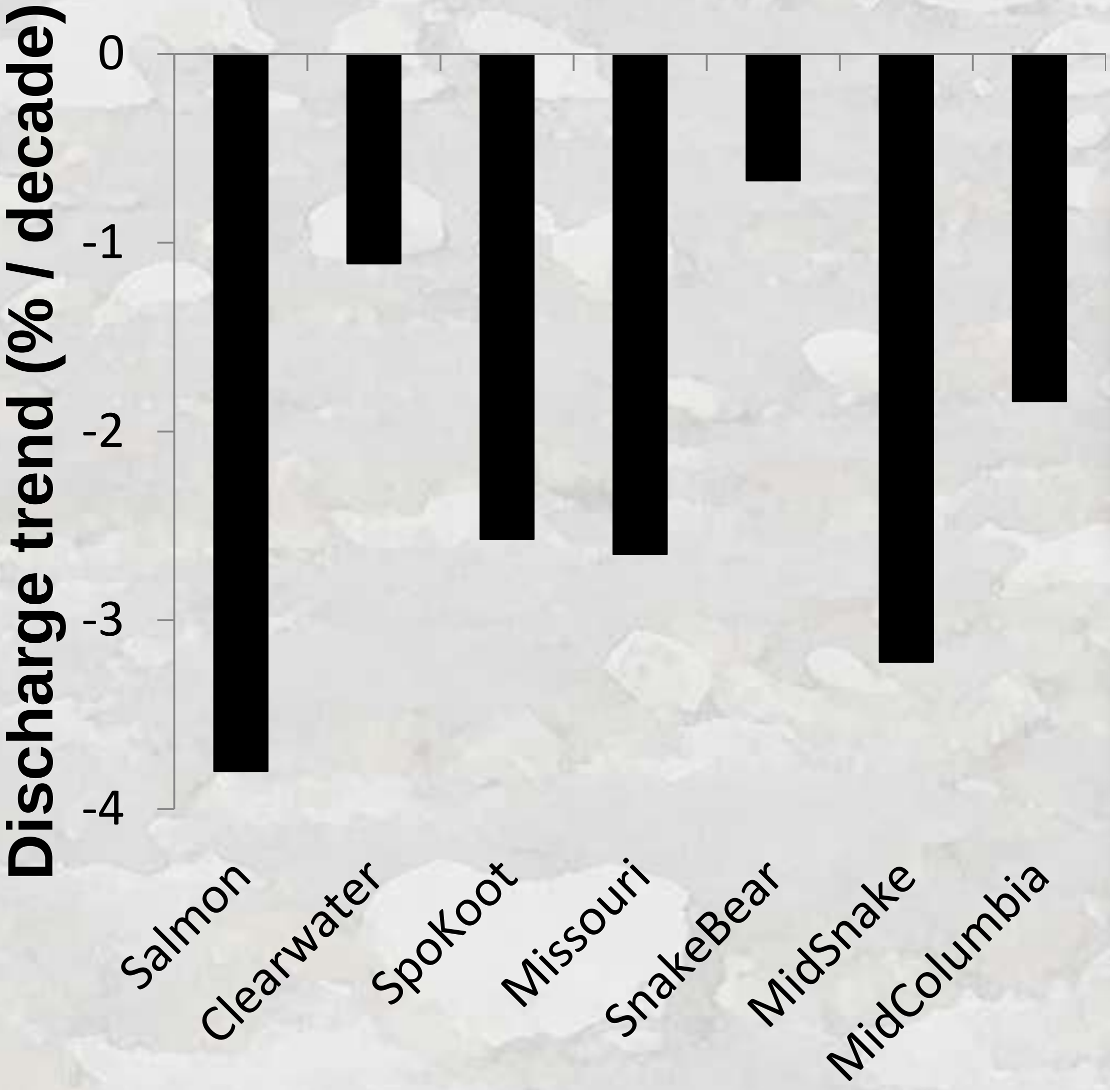


precipitation trends



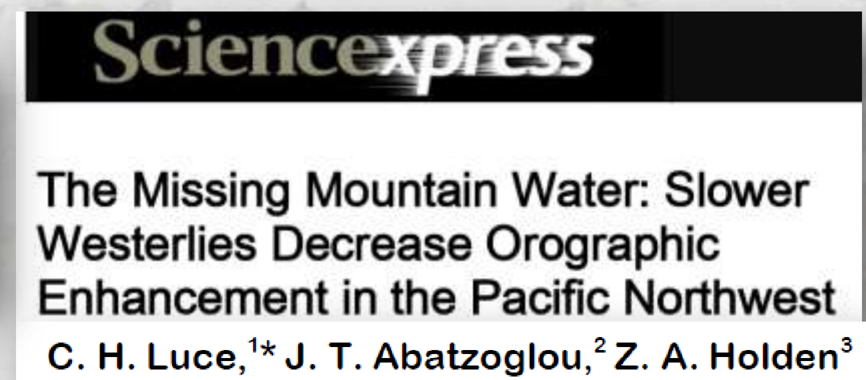
August Flow Trends in PNW River Basins

USGS Gates Unregulated Rivers (1952-2011)



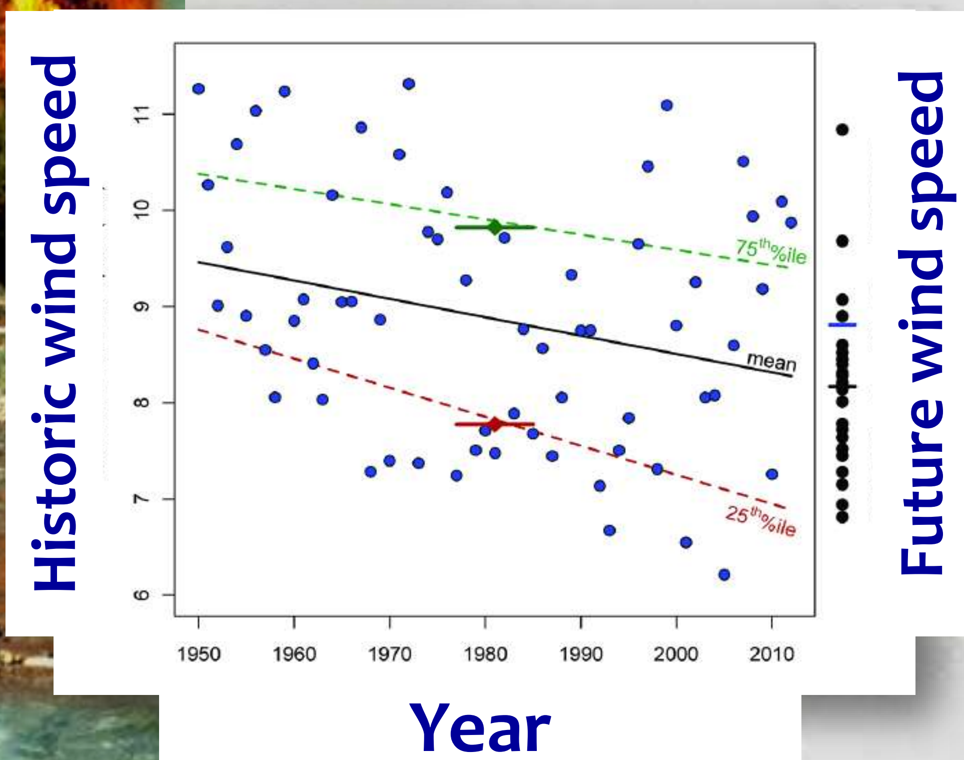
Decreasing Wind Speeds & Snow/Precipitation at High Elevations

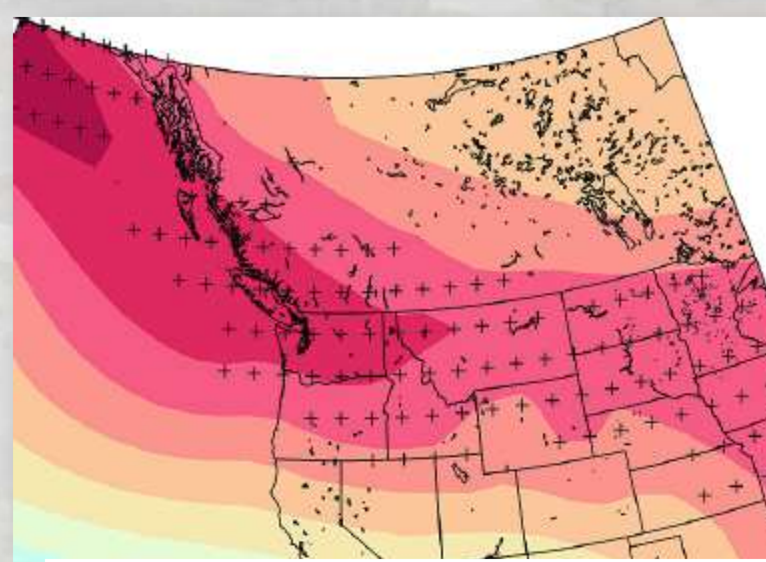
≠


Sciencexpress

The Missing Mountain Water: Slower Westerlies Decrease Orographic Enhancement in the Pacific Northwest

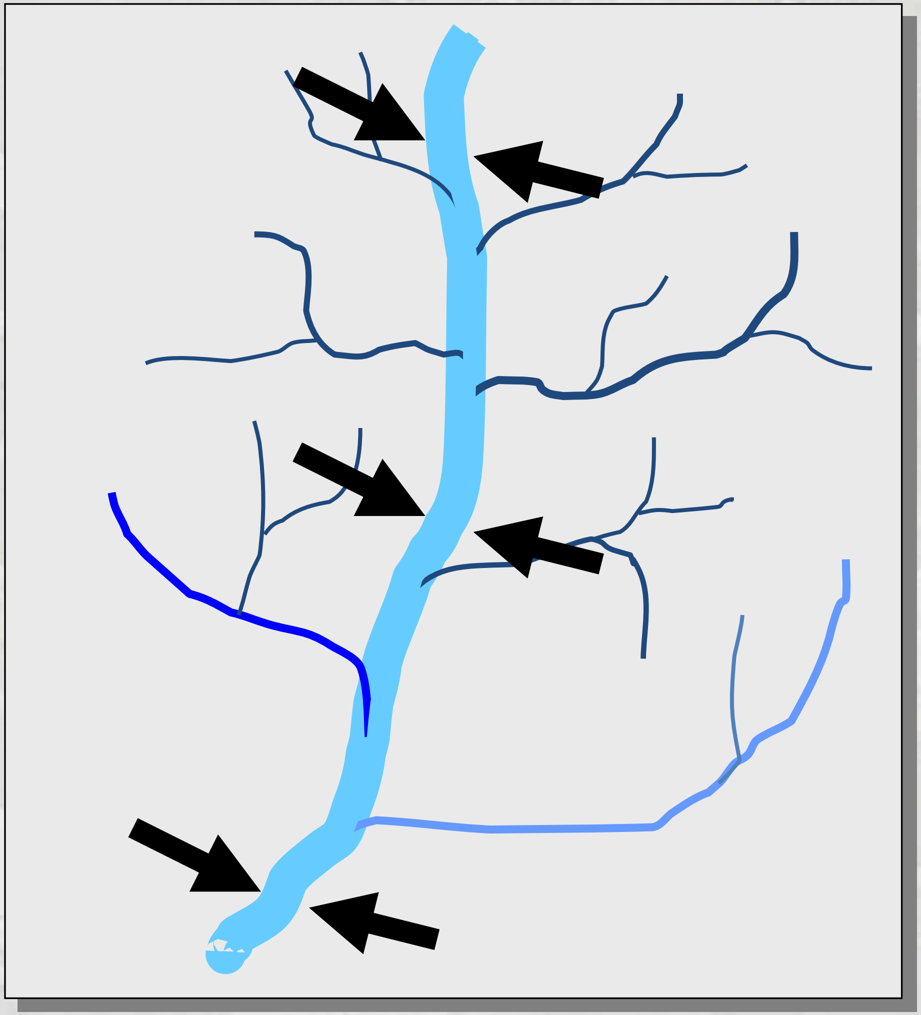
C. H. Luce,[1*] J. T. Abatzoglou,[2] Z. A. Holden[3]





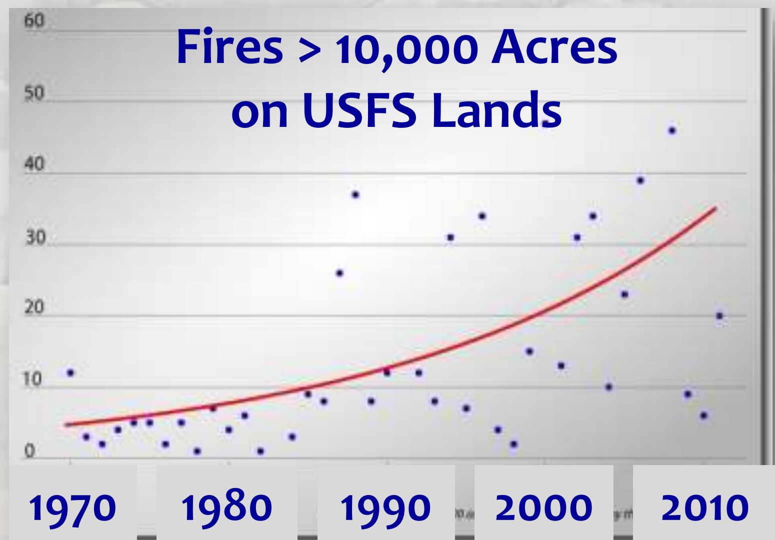
CMIP5 Wind Projections (2070-2100)

Flow Declines ~ Smaller & More Fragmented Habitats

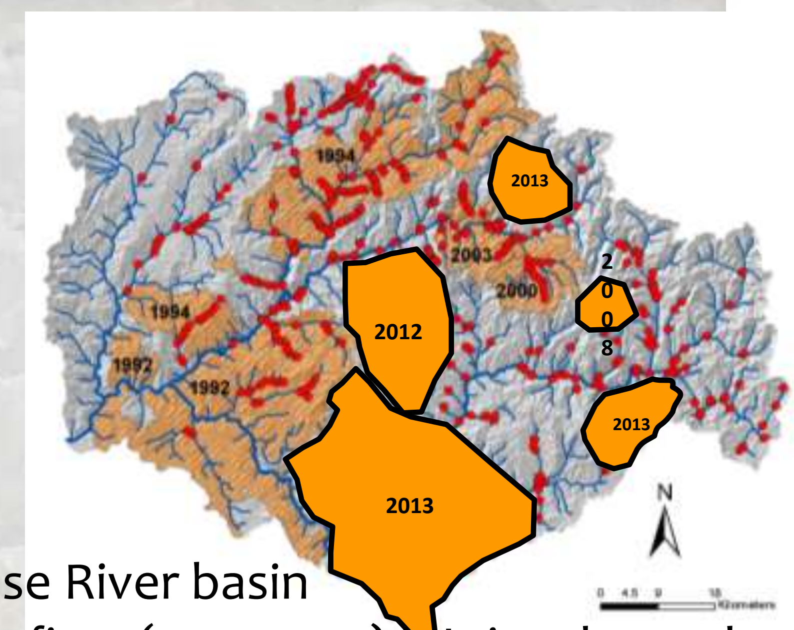


Fish passage issues exacerbated

Wildfires Increasing Westwide



National Research Council. 2011



Boise River basin fires (1992-2013)… It just keeps burning

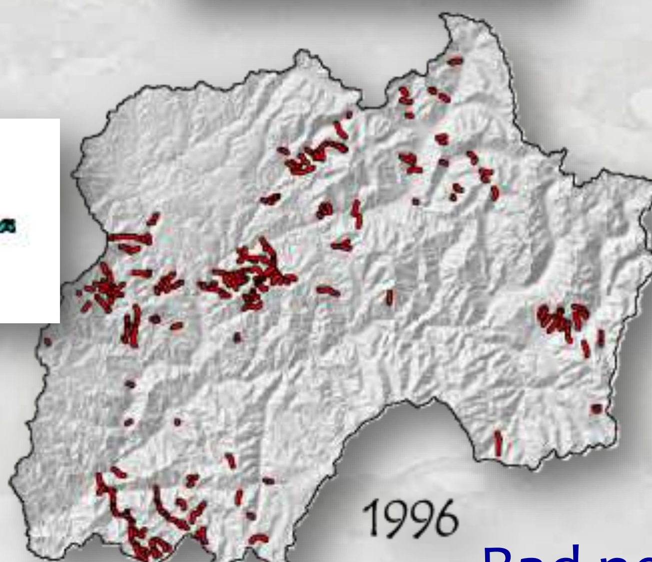
Sediment Loading to Stream Channels

Thunderstorms & debris
flow torrents







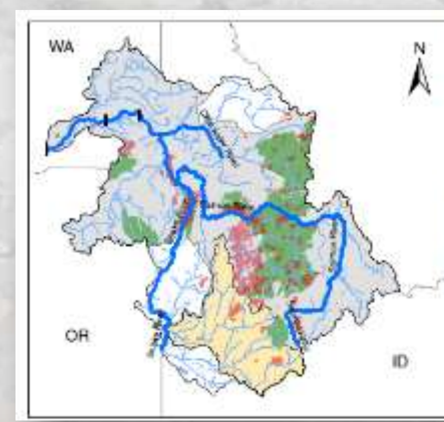


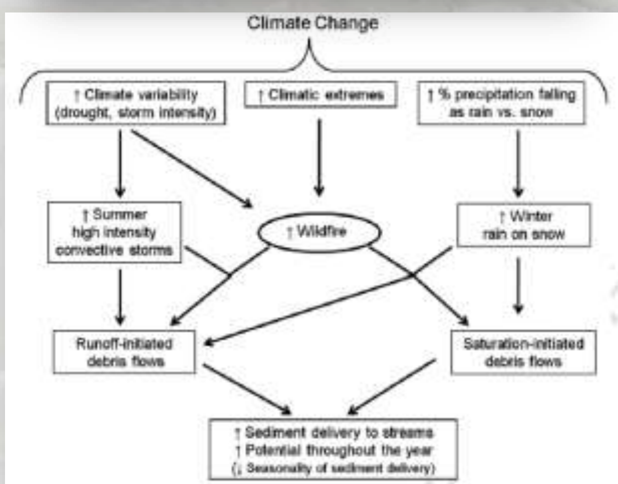
1996

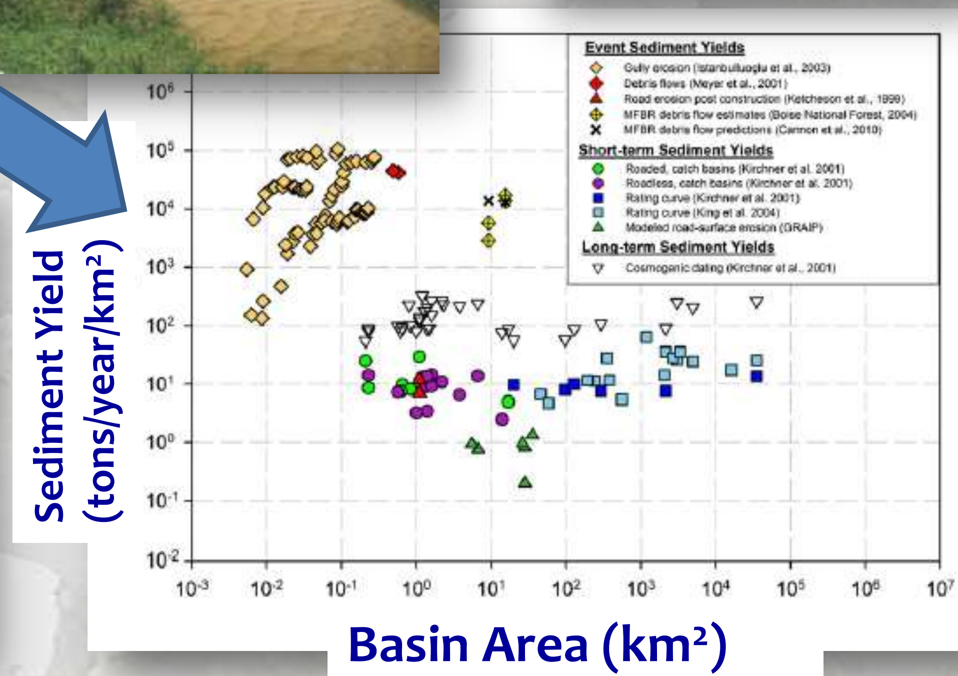
Bad news if you're a fish living here

Sediment Loading to Stream Channels

Channel form & habitats will evolve



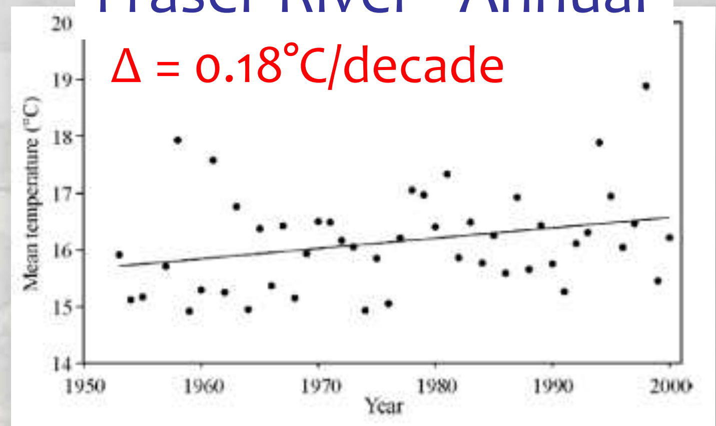




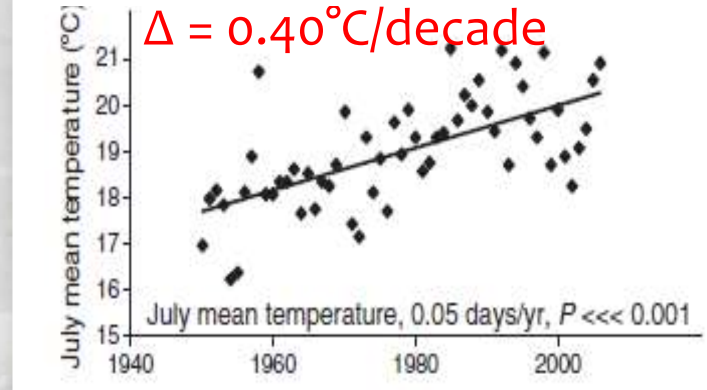
Goode et al. 2011. Enhanced sediment delivery in a changing climate in semi-arid mountain basins: Implications for water resource management and aquatic habitat in the northern Rocky Mountains. *Geomorphology* **139/140**:1-15.

Temperature Trends In Northwest Rivers

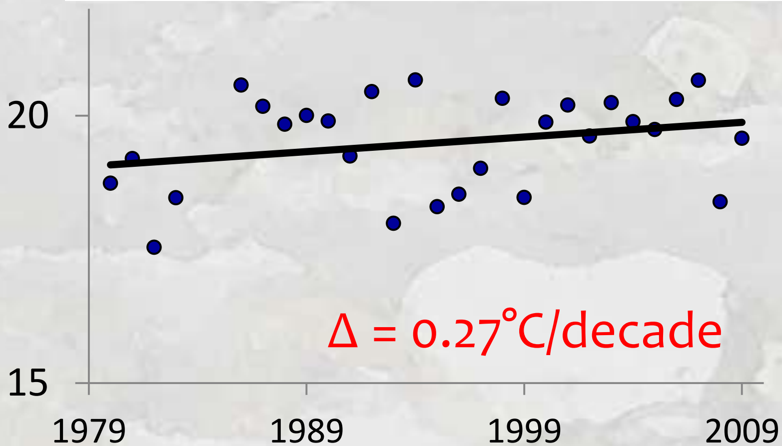
Fraser River - Annual



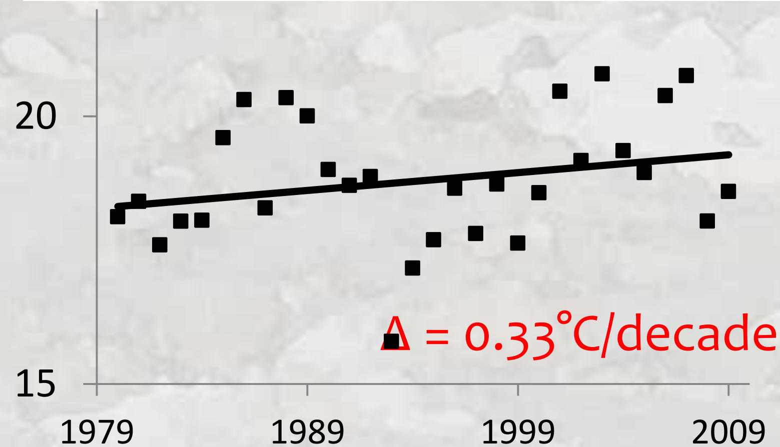
Columbia River - Summer



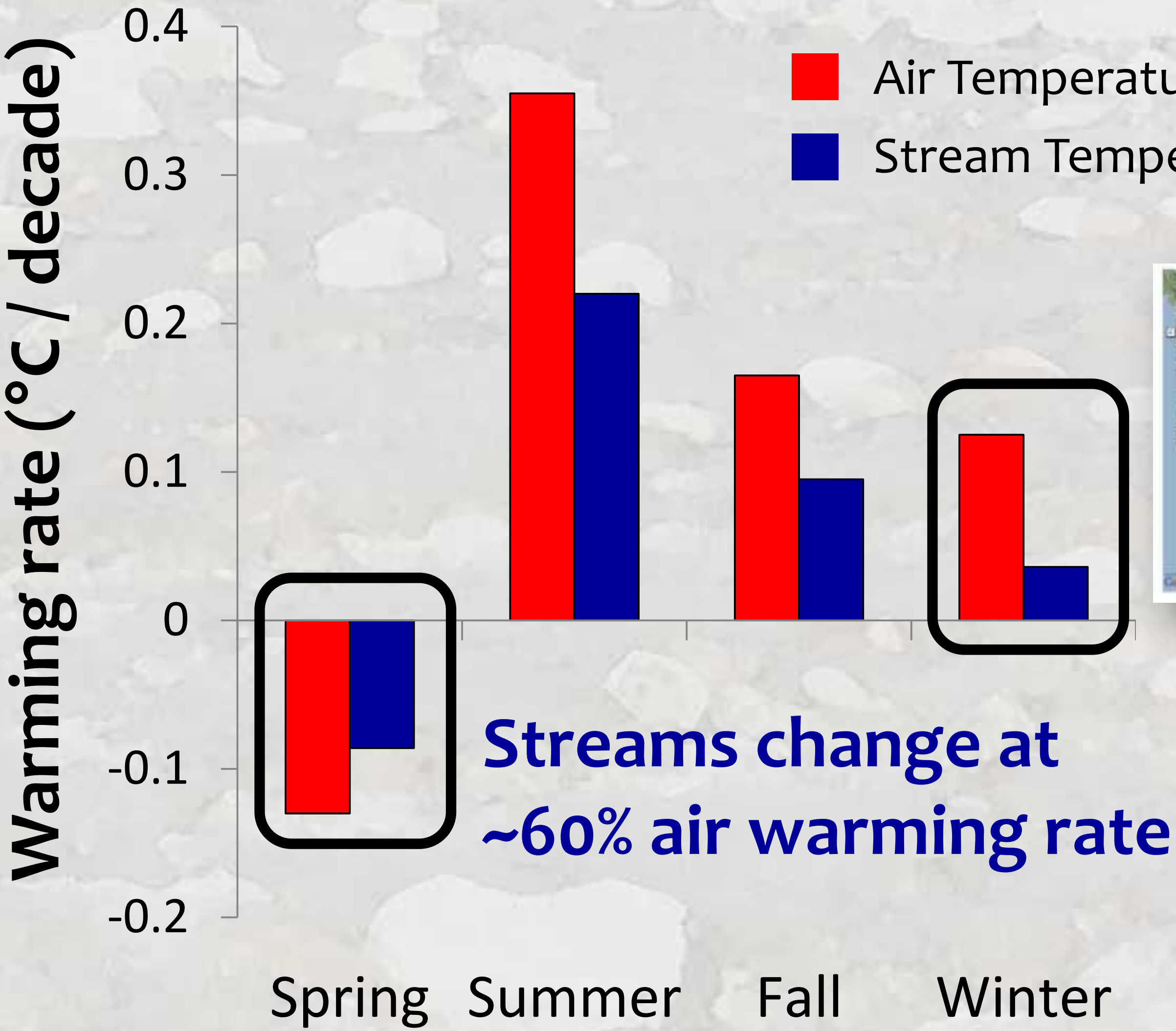
Snake River, ID - Summer



Missouri River, MT - Summer



Stream Temperatures Track Air Trends at Local Weather Stations

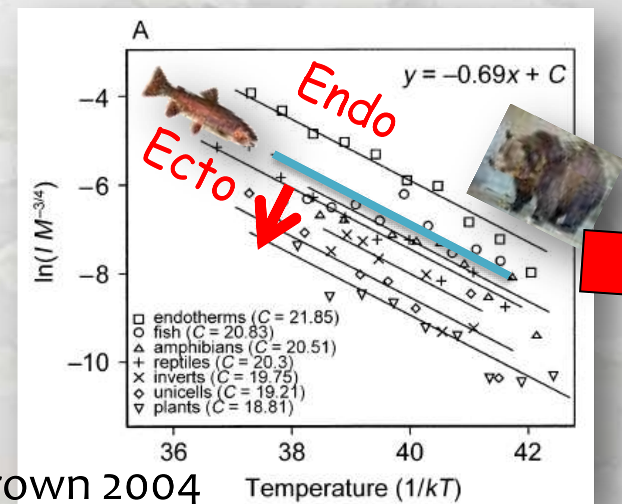


Weather Stations

Isaak et al. 2012. *Climatic Change* **113**:499-524.

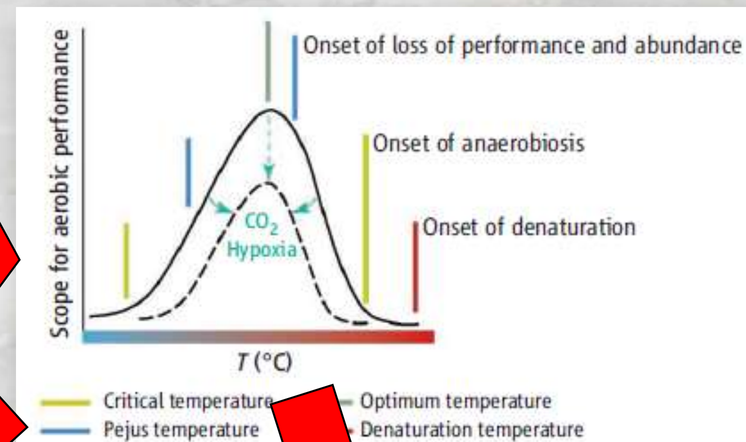
Temperature is “Master Variable” for Salmon & Other Cold-water Species

Metabolism

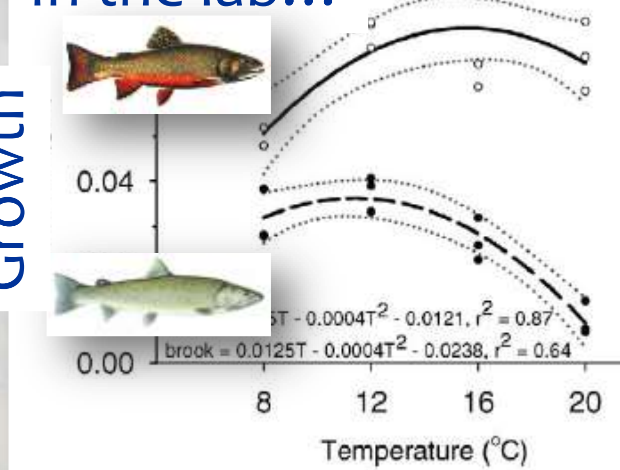


Brown 2004

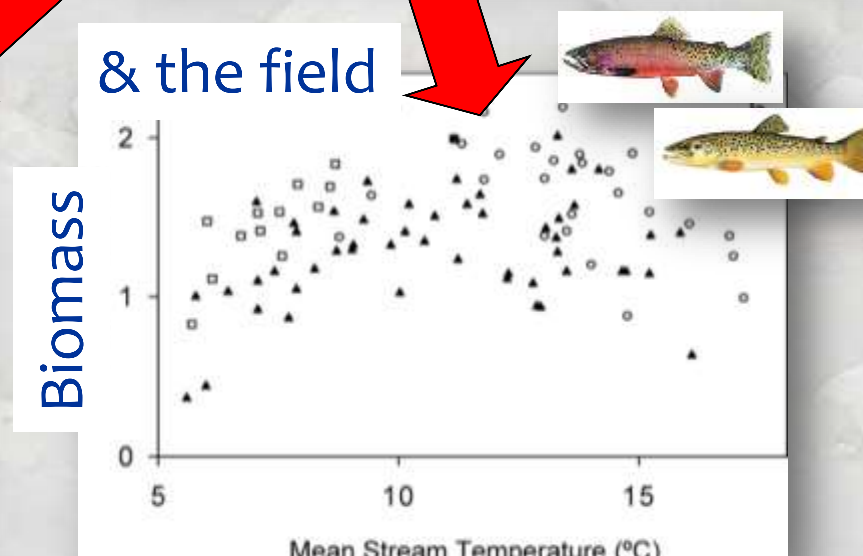
Thermal Niche



In the lab…



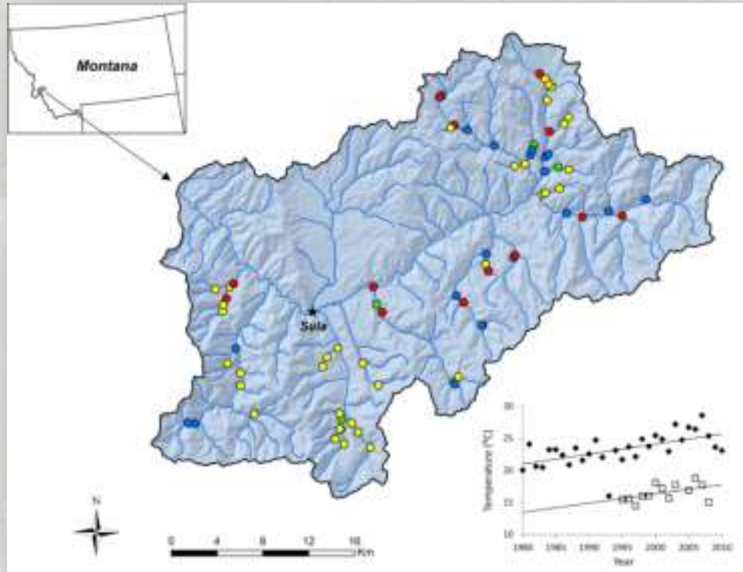
& the field



Fish are Already Responding…

Bull trout distributions in Montana

- Resurveyed 74 Rich et al. (2003) sites 20 years later
- Modeled extirpations/colonizations accounting for detection efficiency

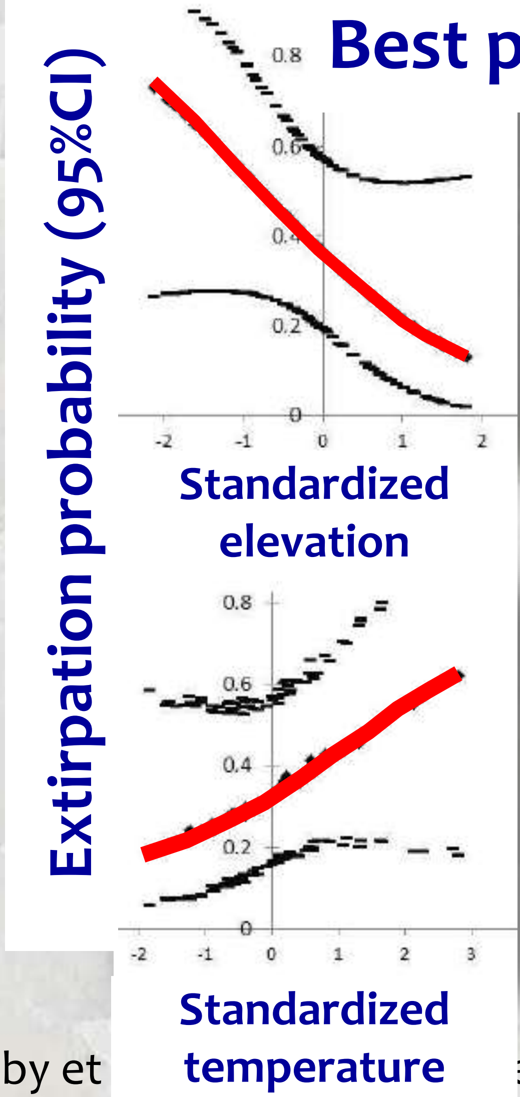


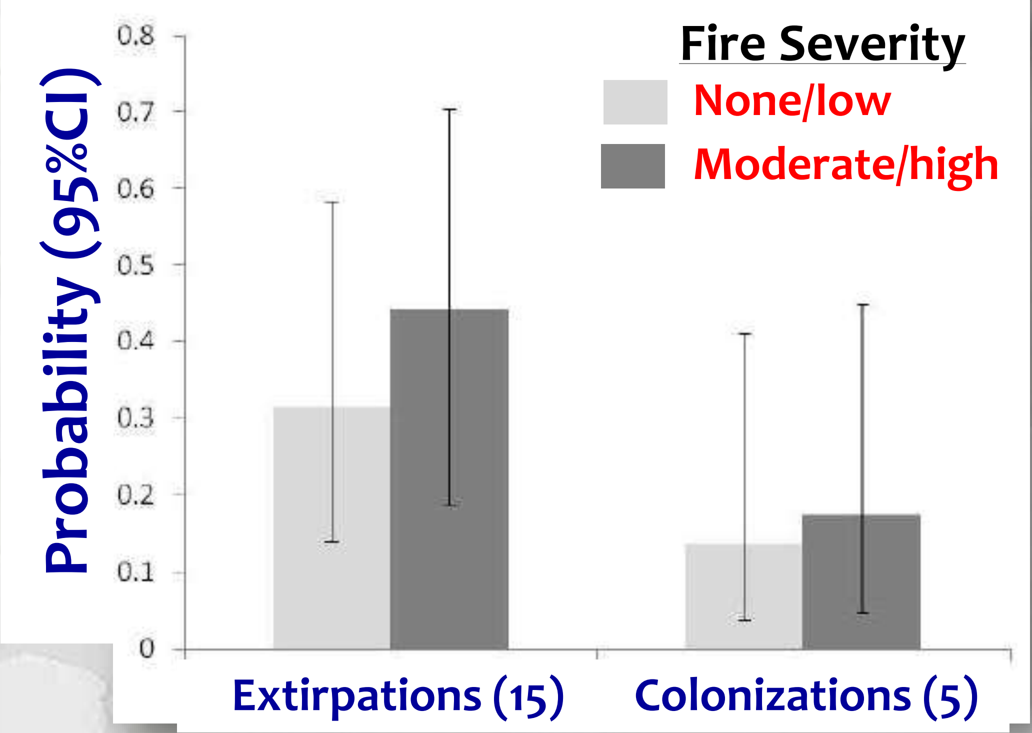
Eby et al. In Press. Evidence of climate-induced range contractions for bull trout in a Rocky Mountain watershed, U.S.A. *PLoS One*

Fish are Already Responding…

Bull trout distributions in Montana

Best predictors

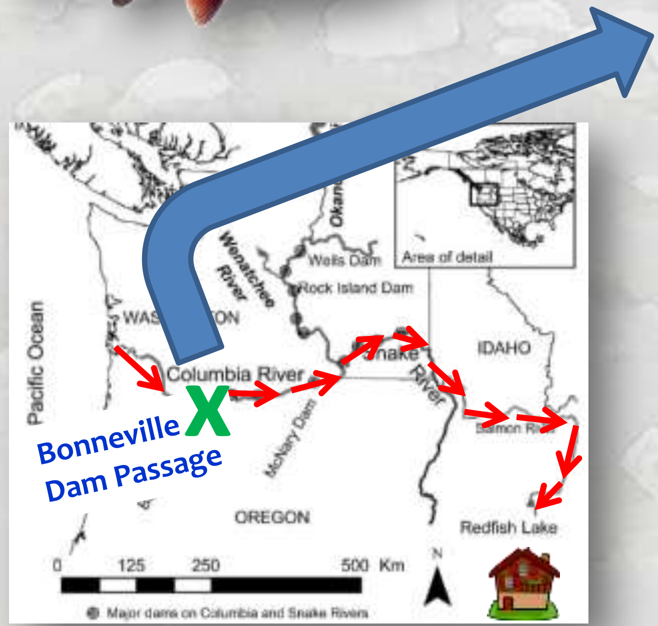


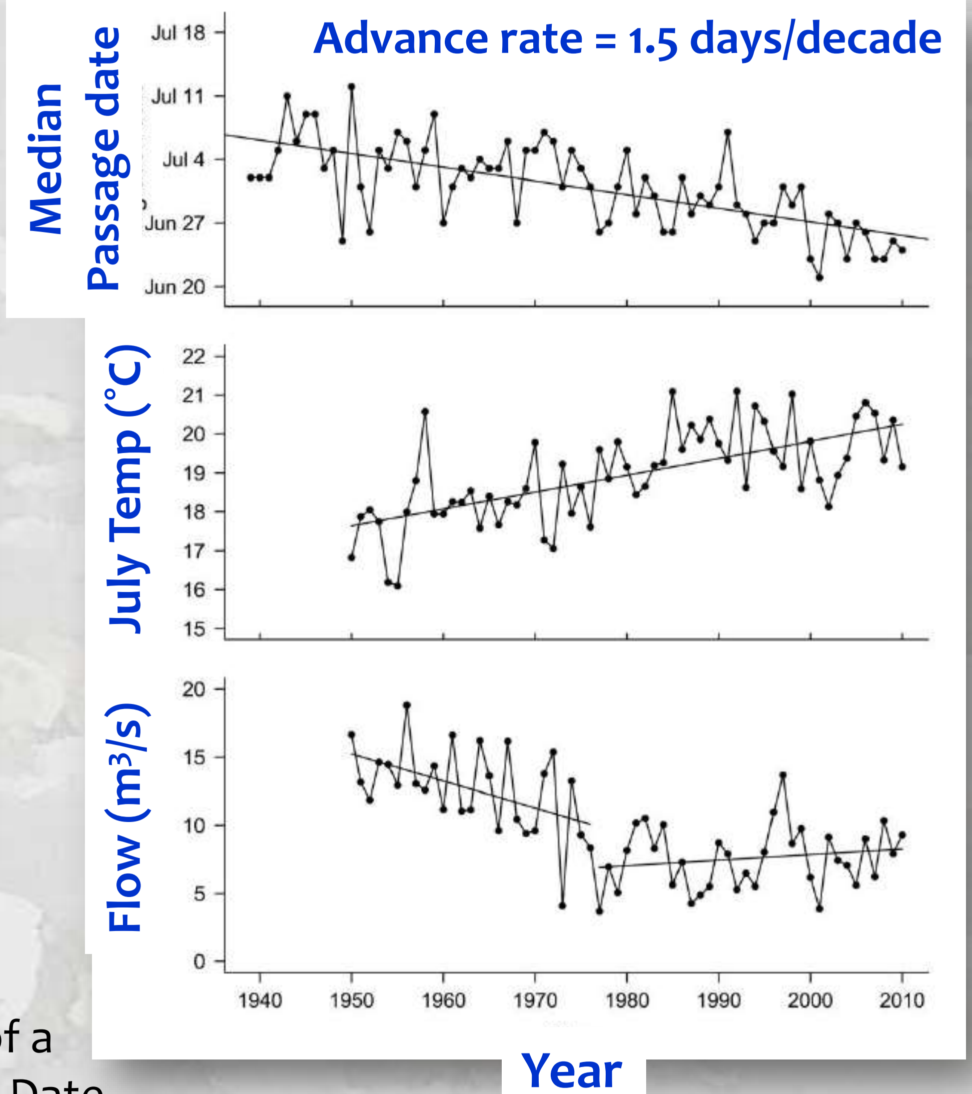


Eby et … e of climate-induced range contractions for bull trout in a Rocky Mountain watershed, U.S.A. *PLoS One*

Fish are Already Responding

Sockeye Migrations Happening Earlier…



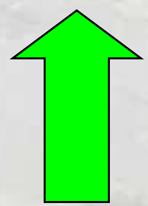


Crozier et al. 2011. A Case Study of a Shift toward Earlier Migration Date in Sockeye Salmon. *The American Naturalist* **178**:755-773.

…Can They Stay Ahead of Changes?

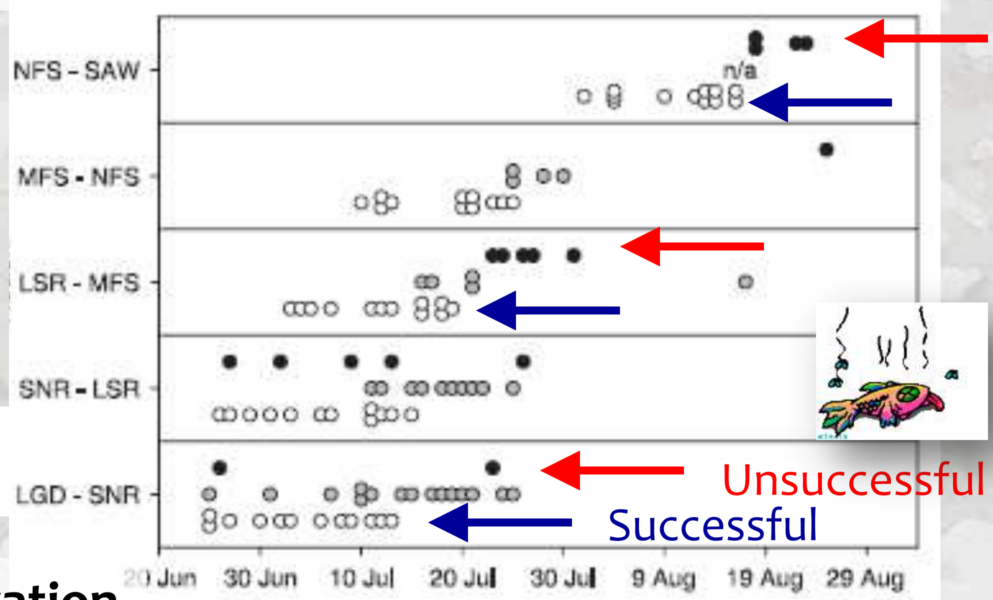
Later Sockeye Return Less Successfully

Natal Areas



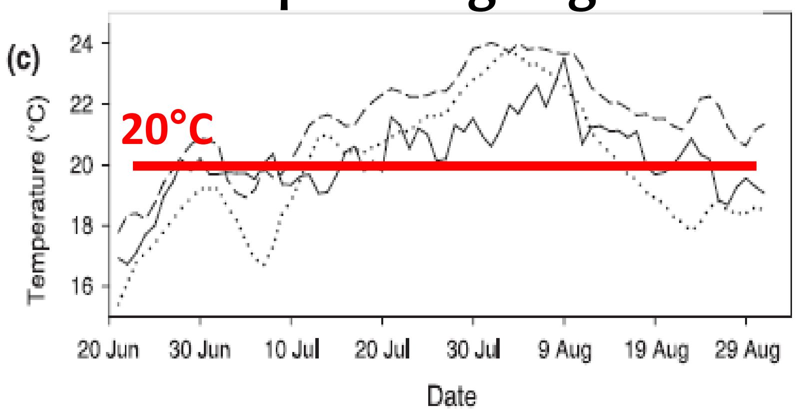
Snake River

Migration Success vs. Timing



Reach Entry Date

Stream Temps During Migration



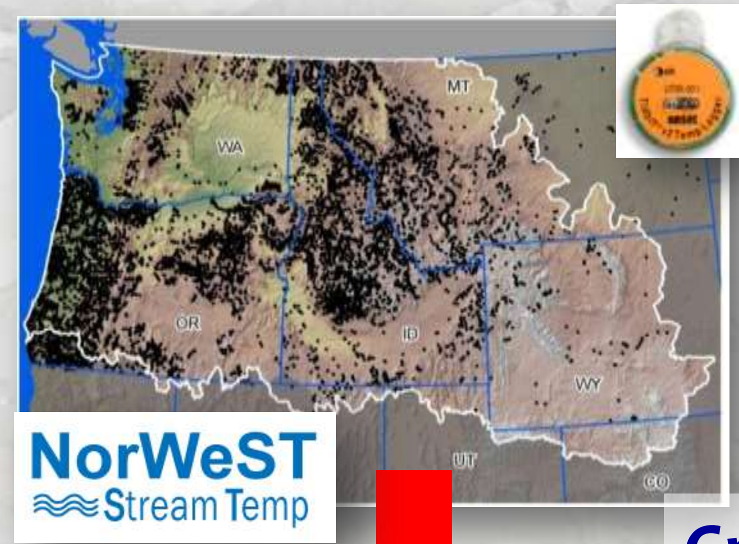
Keefer et al. 2008. *Ecology of Freshwater Fish* **17**:136-145

Lots of Data Exist…

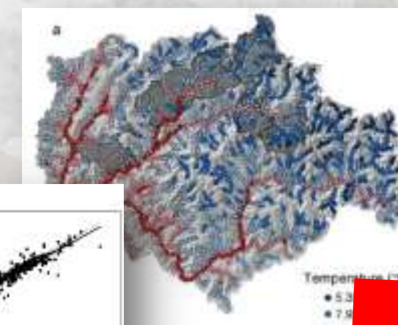
NorWeST Stream Temp

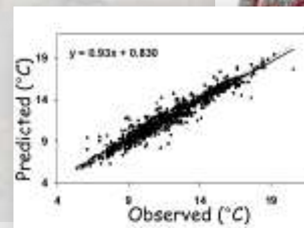
>50,000,000 hourly records
>15,000 unique stream sites
>70 resource agencies

A Need for a Regional Temperature Model

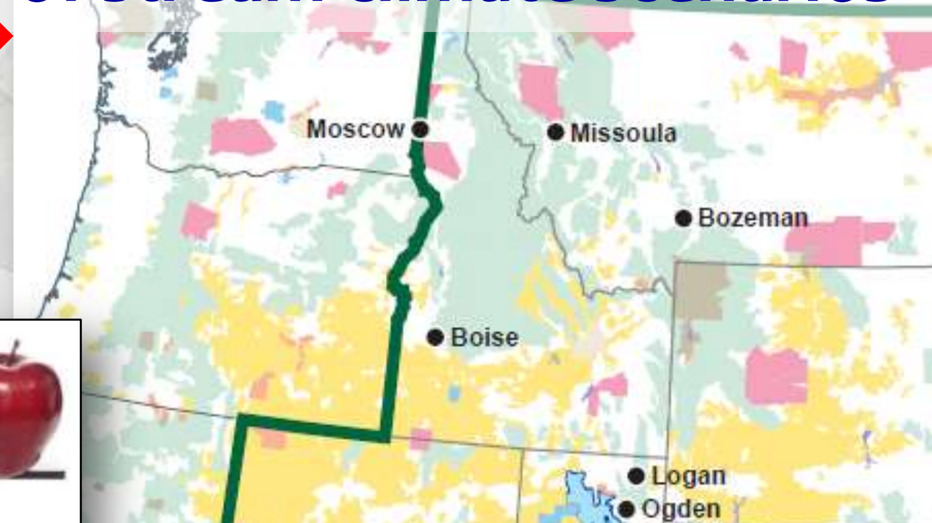


Accurate stream temp model

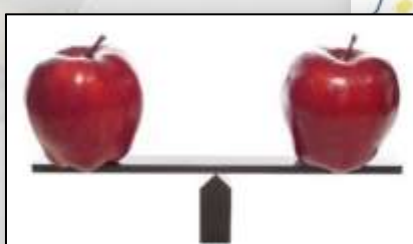




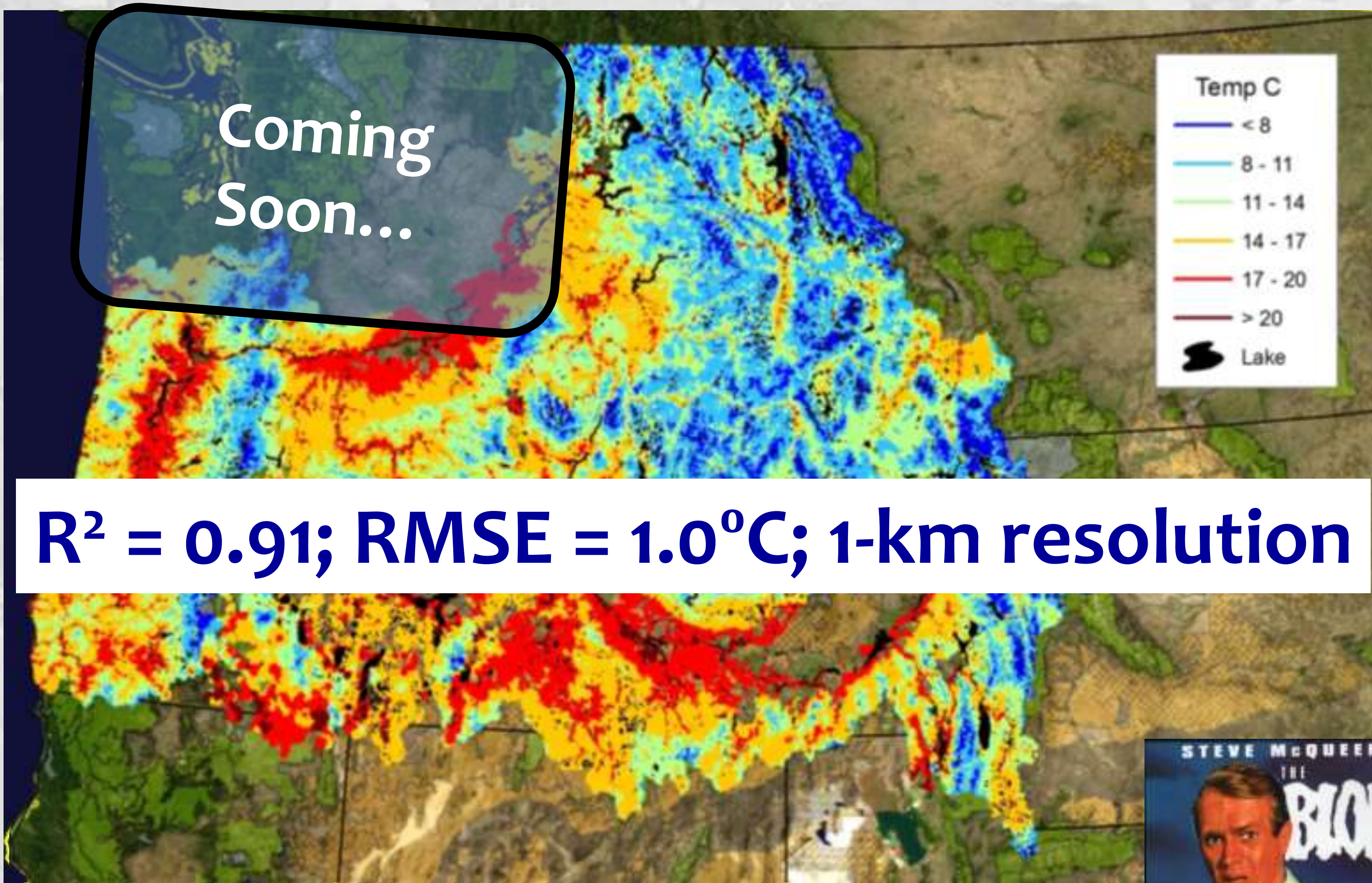
Cross-jurisdictional "maps" of stream climate scenarios



Consistent datum for strategic assessments across 600,000 stream kilometers



High-Resolution Stream Temp Scenarios



R^2 = 0.91; RMSE = 1.0°C; 1-km resolution

The BLOB… it just keeps growing…

- 40,397 summers of data swallowed
- 380,000 stream kilometers of thermal ooze

NorWeST Historical Scenarios

Scenario	Description
S1_93_11	Historical scenario representing 19 year average August mean stream temperatures for 1993-2011
S2_02_11	Historical scenario representing 10 year average August mean stream temperatures for 2002-2011
S3_1993	Historical scenario representing August mean stream temperatures for 1993
S4_1994	Historical scenario representing August mean stream temperatures for 1994
Etc…	
S21_2011	Historical scenario representing August mean stream temperatures for 2011

***Extensive metadata on website**

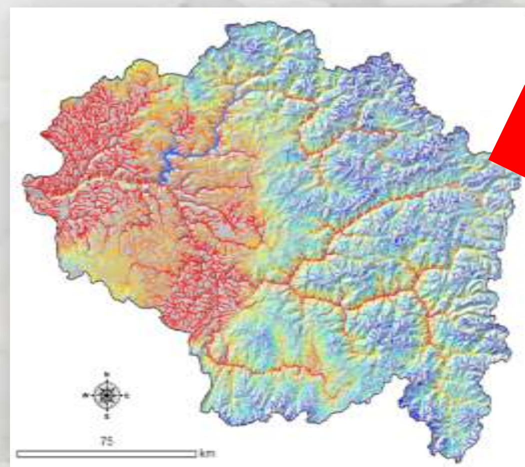
10 NorWeST Future Scenarios

Scenario	Description
S23_1C	Future scenario adds 1ºC to S1_93-11
S24_1C_D	Future scenario adds 1ºC to S1_93-11 & incorporates differential stream sensitivity
Etc…	For +2ºC & +3ºC
S29_2040	Future scenario based on August air and VIC flow deltas at 2040s from A1B GCM ensemble.
S30_2040_D	Future scenario based on August air and VIC flow deltas at 2040s from A1B GCM ensemble. Adjustment applied for differential sensitivity.
S31_2080	Etc…

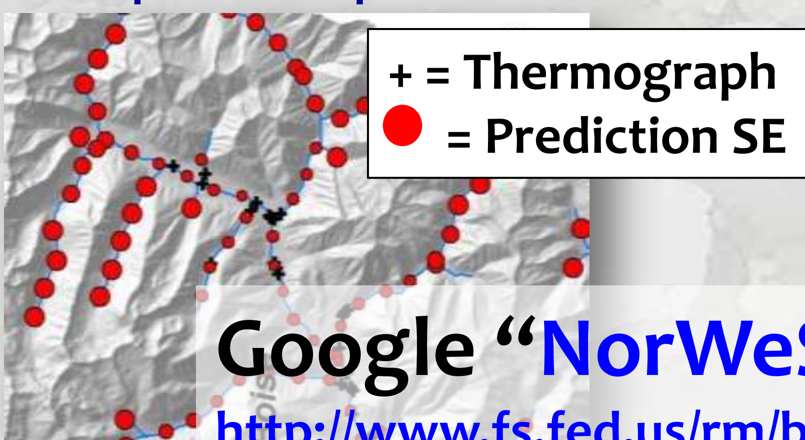
***Extensive metadata on website**

Website Distributes BLOB Scenarios & Temperature Data as GIS Layers

1) GIS shapefiles of stream temperature scenarios



2) GIS shapefiles of stream temperature model prediction precision



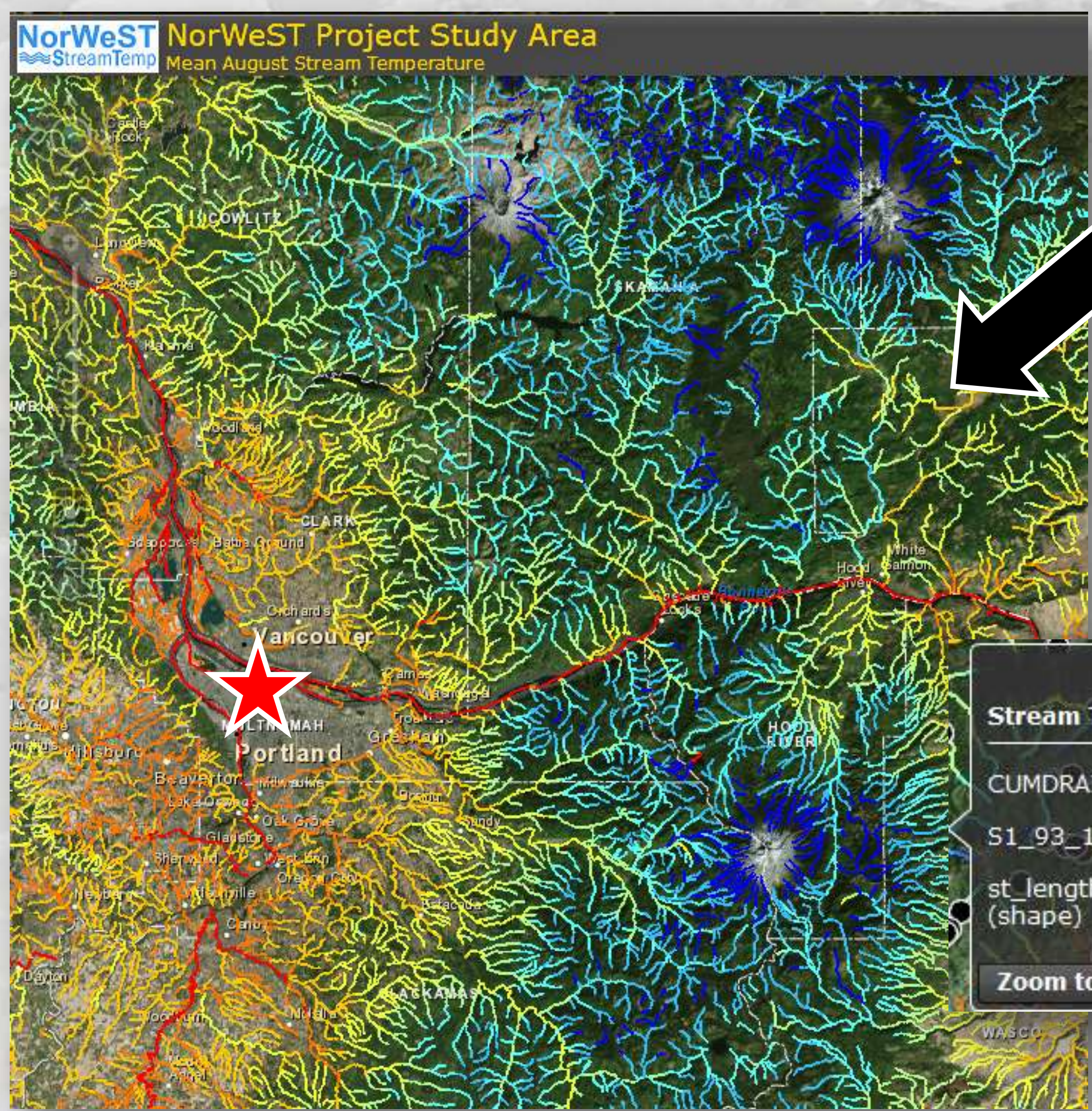
3) Temperature data summaries

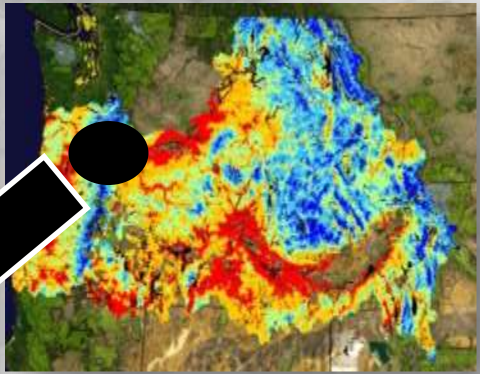
Google "NorWeST" or go here…

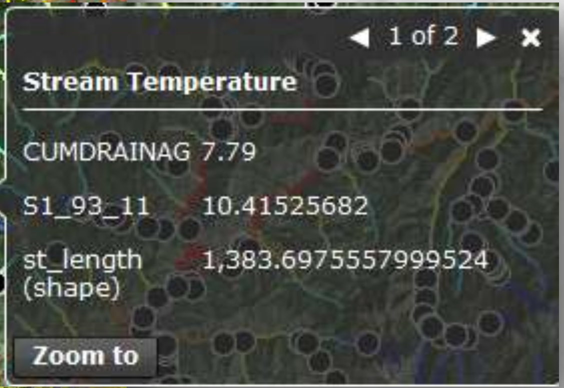
http://www.fs.fed.us/rm/boise/AWAE/projects/NorWeST.shtml

Websurf the BLOB on…

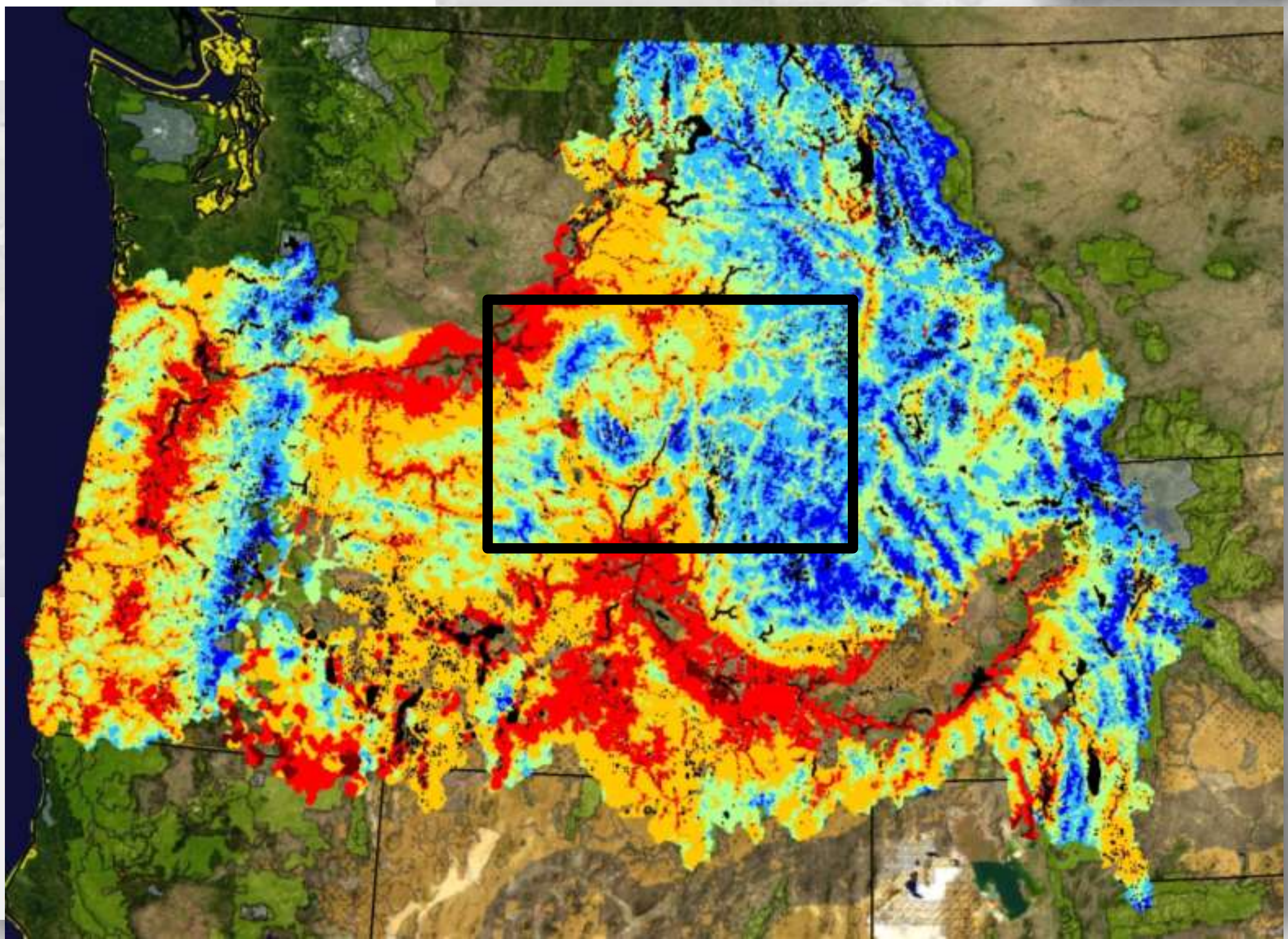
Dynamic Online Map Viewer



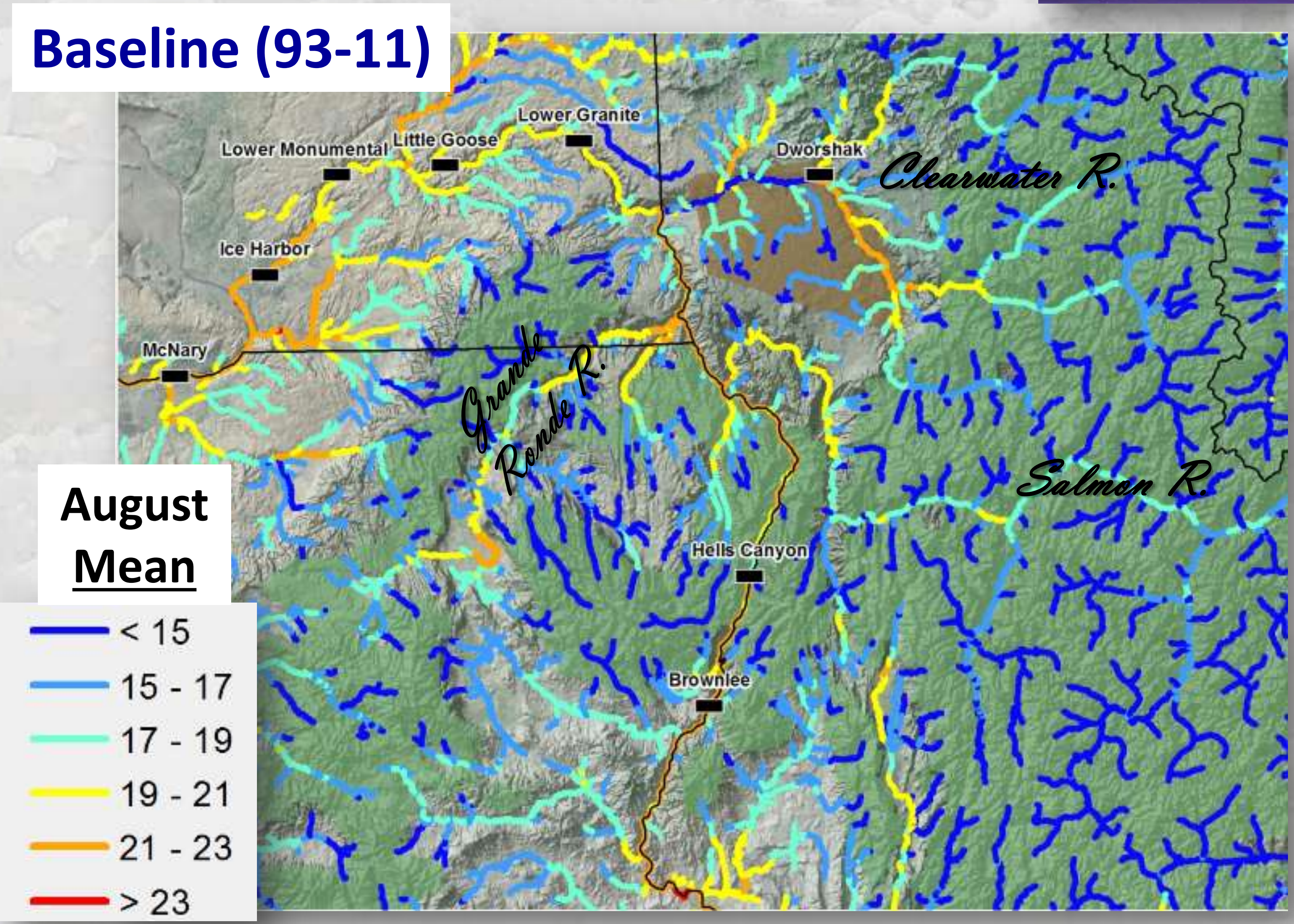




What Does Future Look Like in Salmon/Steelhead Rivers?

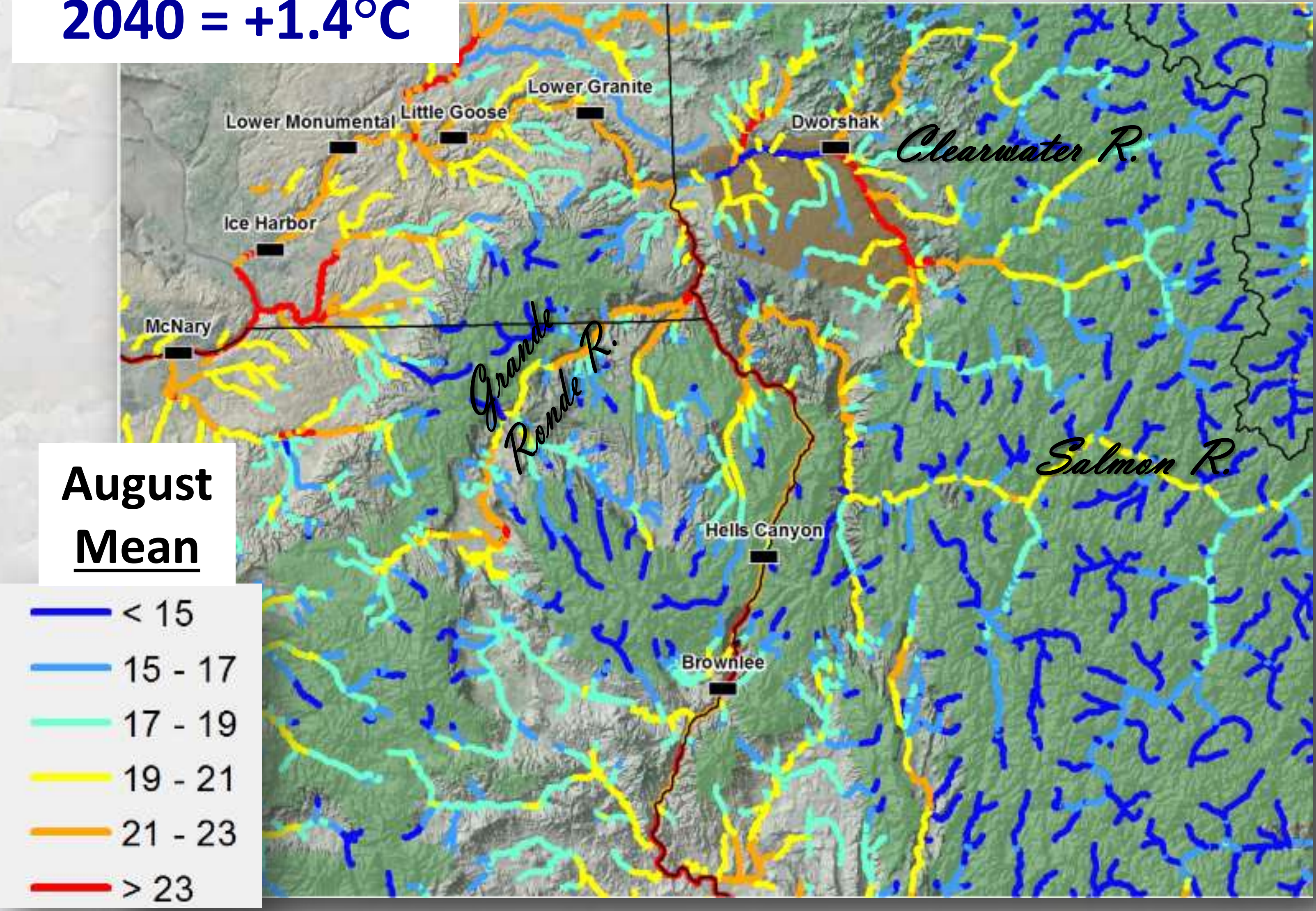


What Does Future Look Like in Salmon/Steelhead Rivers?



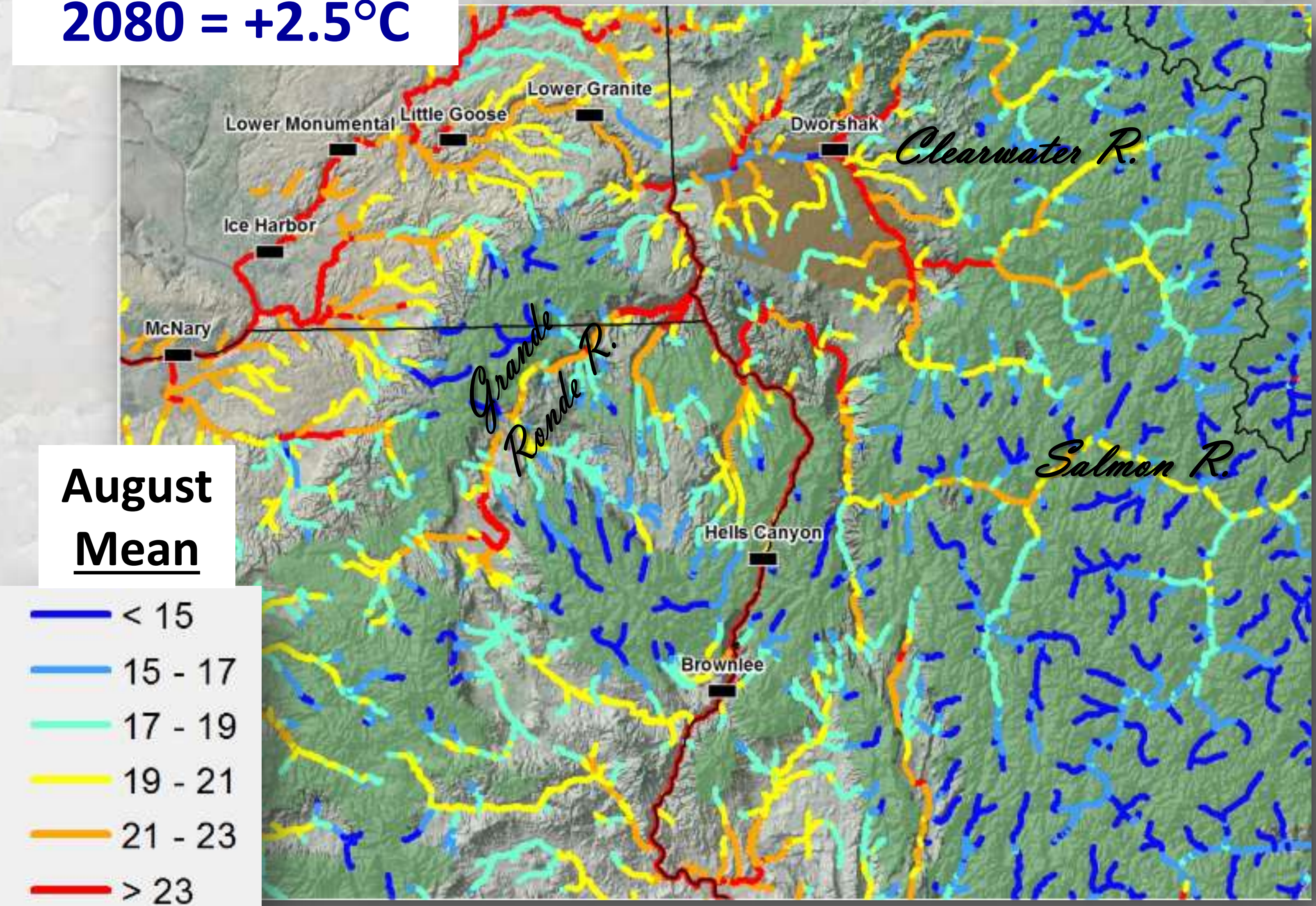
What Does Future Look Like in Salmon/Steelhead Rivers?

2040 = +1.4°C

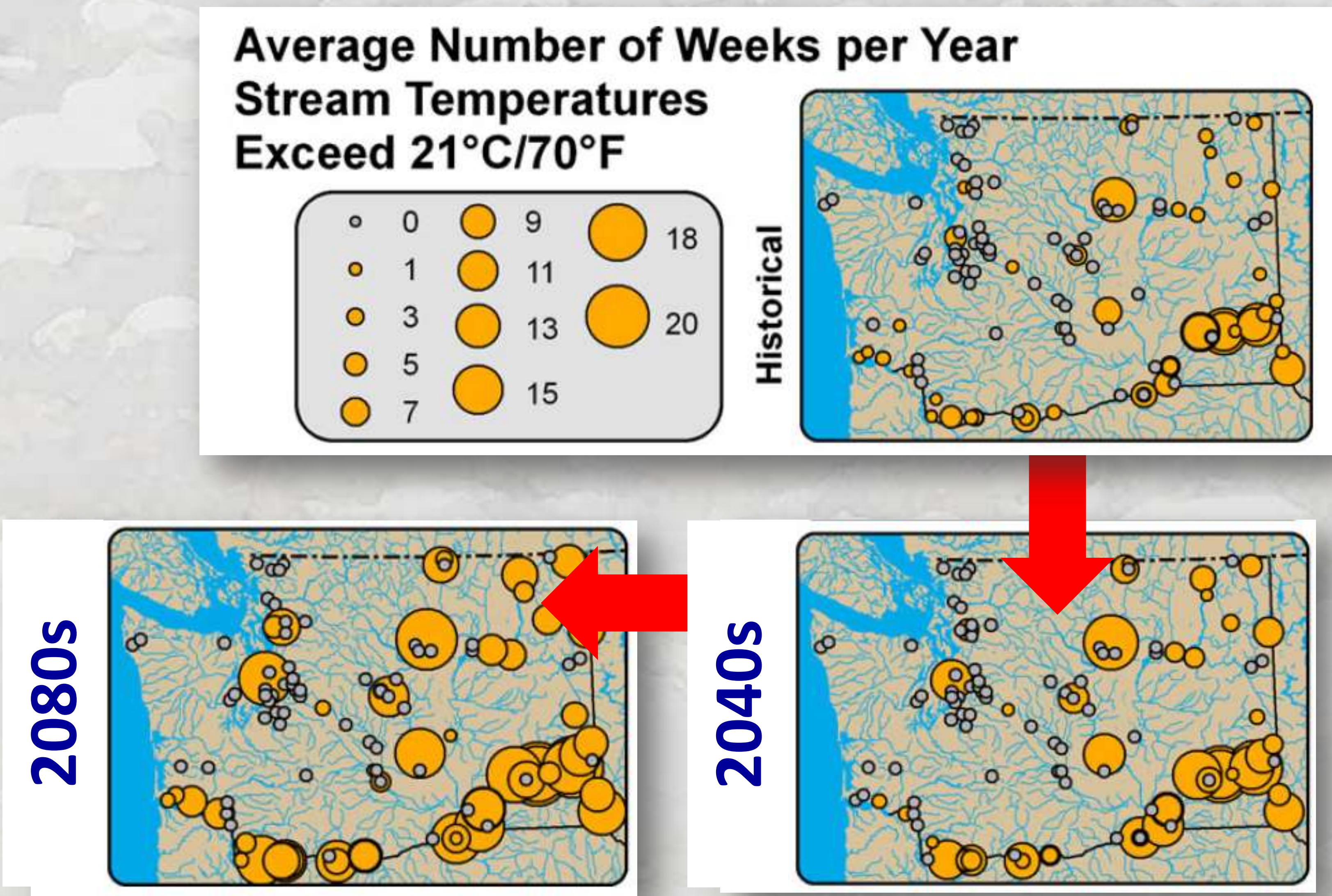


What Does Future Look Like in Salmon/Steelhead Rivers?

2080 = +2.5°C



Annual Duration of High Temperatures



Mantua et al. 2010. *Climatic Change* **102**:187-223.

Evidence that Some Salmon Populations are Already Thermally Stressed

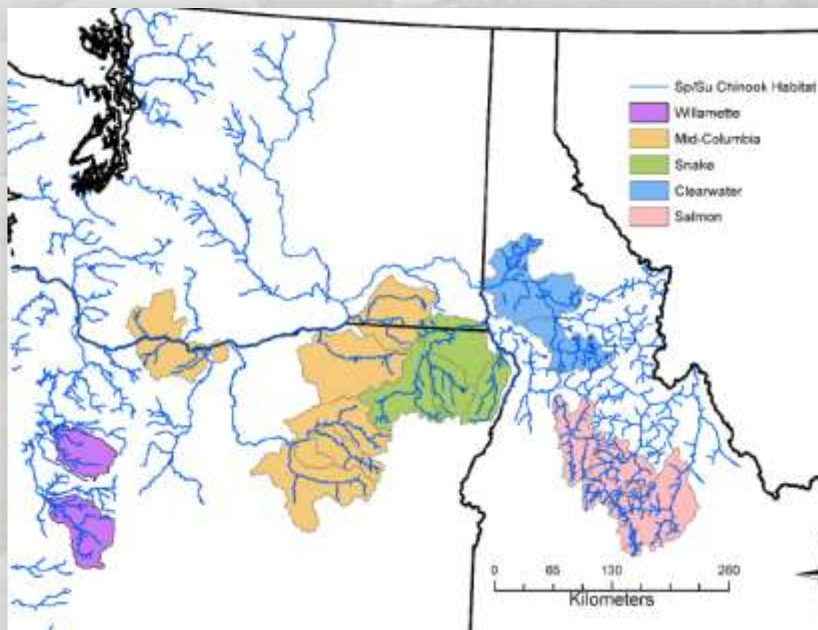
Symptoms include…

1) Migration delays & clustering near coldwater refuges

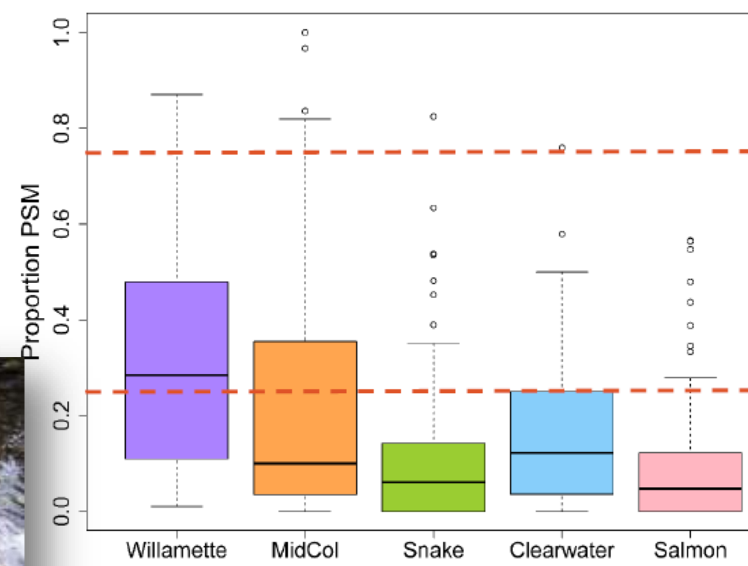
2) Prespawn mortality linked to thermal exposure

3) Mass mortality events:
   a) upriver stocks of Fraser river sockeye "disappear"
   b) spawning ground fish kills (John Day, Grande Ronde, Red River)

NorWeST Temperature & Prespawn Mortality in Salmon

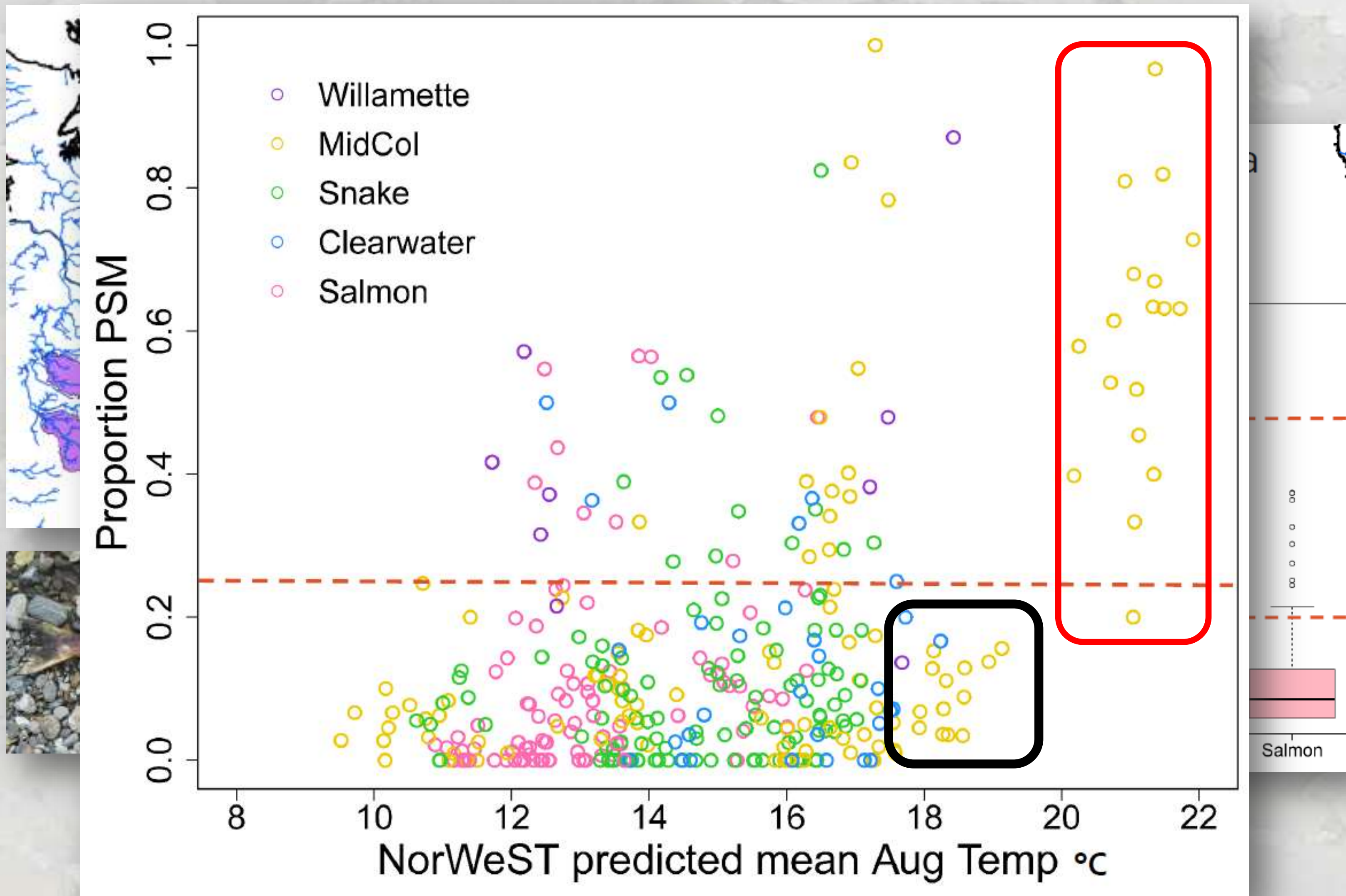


450 site years of PSM data
8 different agencies
3 ESUs



Bowerman, Keefer, & Caudill – U. Idaho

NorWeST Temperature & Prespawn Mortality in Salmon



Bowerman, Keefer, & Caudill – U. Idaho

Good News: Lots of Things we Can do to Improve Stream Habitat Resilience

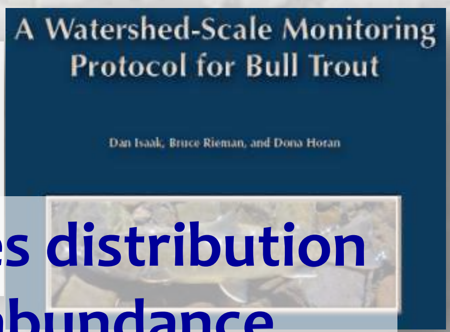
- •Maintaining/restoring flow…
- •Maintaining/restoring riparian…
- •Restoring channel form/function…
- •Prescribed burns limit wildfire risks…
- •Non-native species control…
- •Improve/impede fish passage…

Where to do them?

Options for Cooling Largest Rivers?

Long-term Monitoring Data are Important

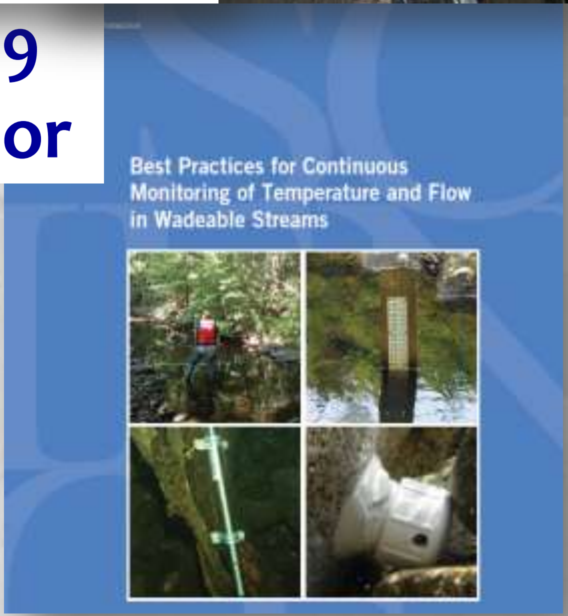
Standard Protocols & Inexpensive Sensors



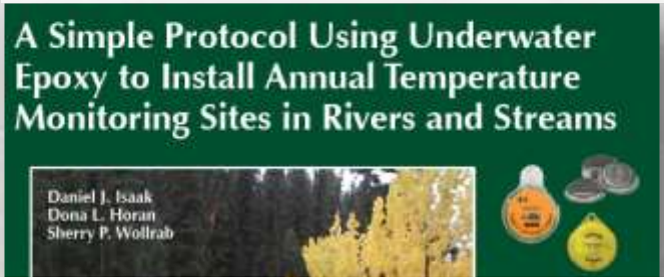
Species distribution & abundance

Stream discharge

$299 sensor



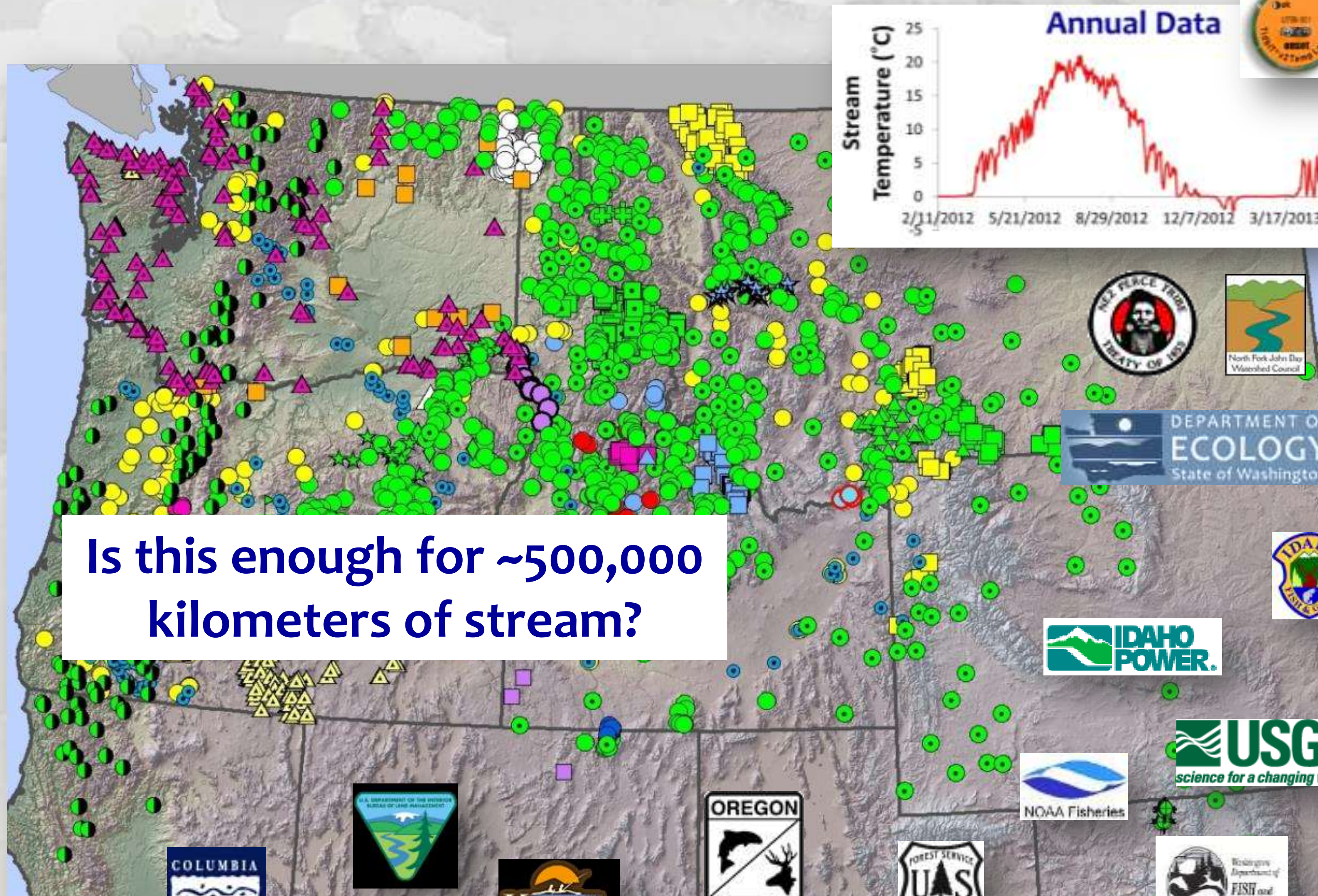
Stream Temperature



$130 = 5 Years of Data

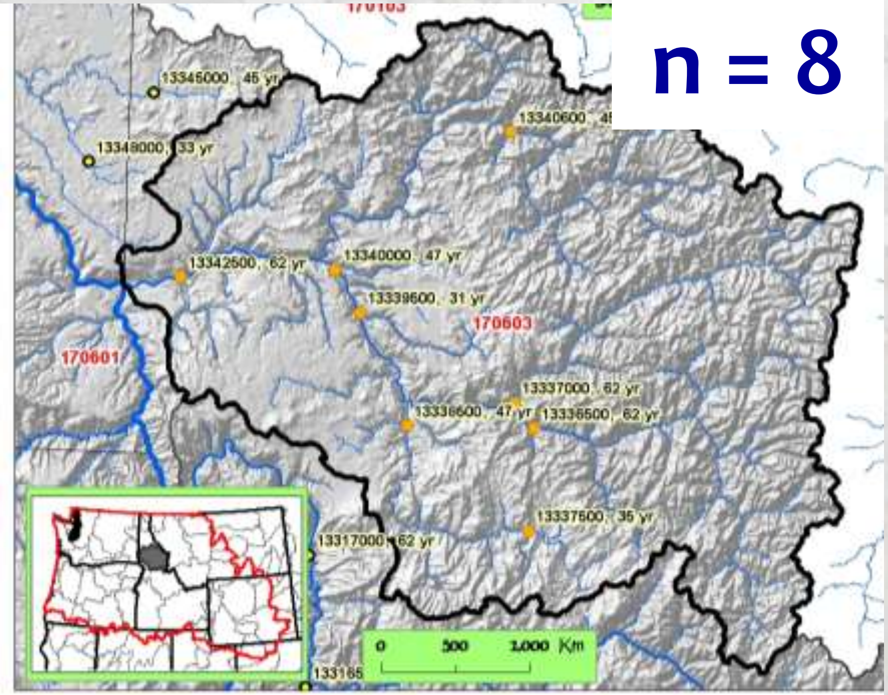
Annual Temperature Monitoring Network

~3,000 sites in Pacific Northwest



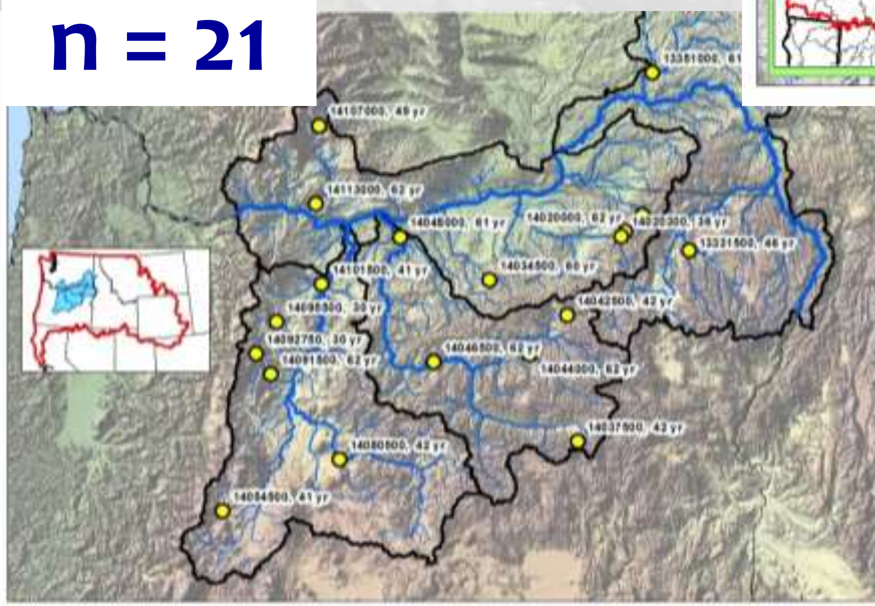
Is this enough for ~500,000 kilometers of stream?

Flow Gage Monitoring Network



n = 8

n = 21



Are a few dozen enough?

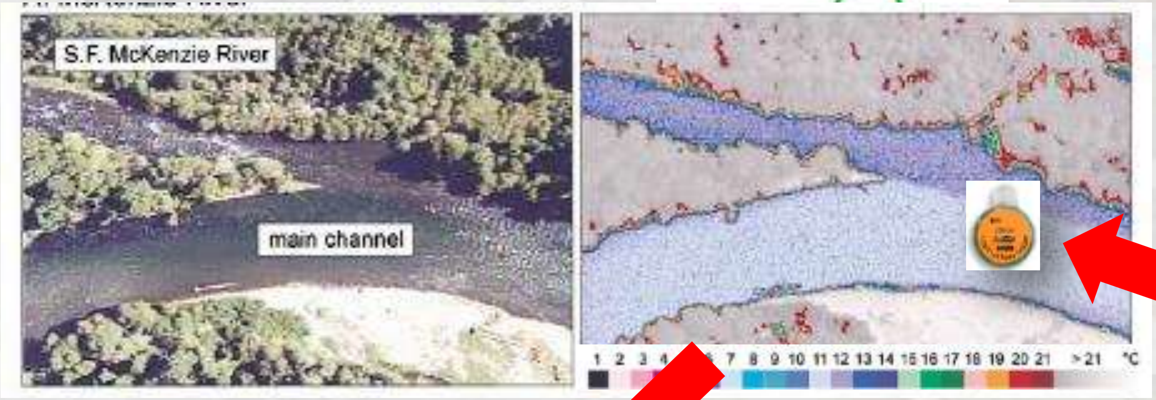
Develop Census of Cold-water Reguges

Spatially continuous thermal maps

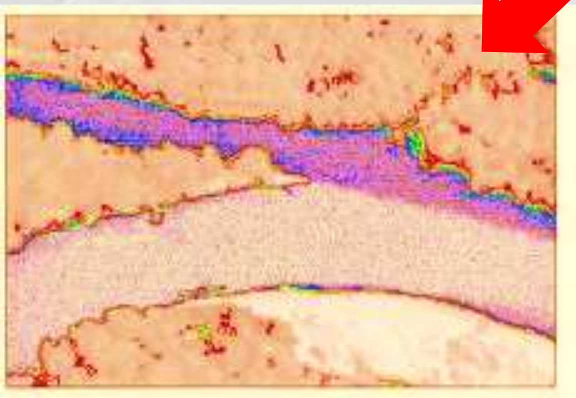
TIR

Torgersen et al. 1999, 2001

Flight during thermally stressful period identifies refuges



Calibration provided by existing large array sensor



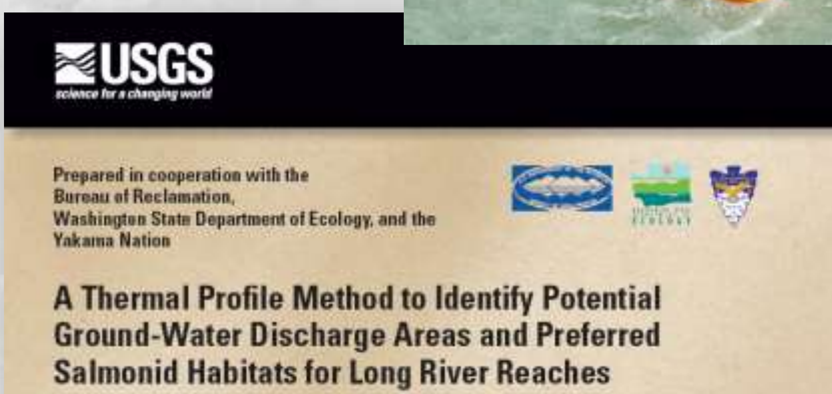
Repeat flight describes temporal variation

Dugdale, Bergeron, and St-Hilaire 2013

Torgersen et al. 2012. Primer for identifying cold-water refuges to protect and restore thermal diversity in riverine landscapes. Region 10, EPA 910-C-12-001.

Less Expensive (& More Fun) Thermal Censusing of Small- to Medium-Rivers

Tow temperature sensors on float trips



USGS
science for a changing world

Prepared in cooperation with the
Bureau of Reclamation,
Washington State Department of Ecology, and the
Yakama Nation

A Thermal Profile Method to Identify Potential Ground-Water Discharge Areas and Preferred Salmonid Habitats for Long River Reaches

Vaccaro & Maloy. 2006.

Drone mounted cameras

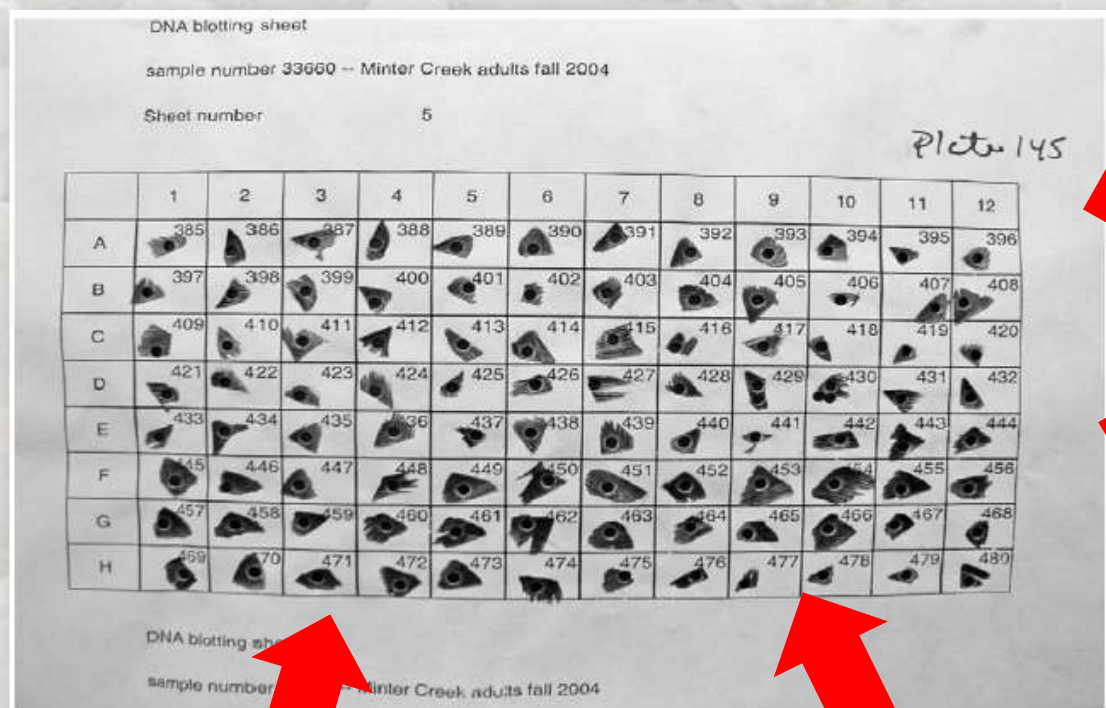
Develop Census of All Stream Critters

Monitoring the biodiversity portfolio with eDNA

- Pioneering this approach for identification and detection
- Optimizing for local to range-wide assessments
- Developing user-driven applications
- Costs: pennies on the dollar

USFS National Genomics Center - Missoula

Fin Tissue Samples are an Invaluable BioDiversity Archive – Dry Preservation Possible



DNA blotting sheet

sample number 33660 -- Minter Creek adults fall 2004

Sheet number 5

Plate 145

	1	2	3	4	5	6	7	8	9	10	11	12
A	385	386	387	388	389	390	391	392	393	394	395	396
B	397	398	399	400	401	402	403	404	405	406	407	408
C	409	410	411	412	413	414	15	416	417	418	419	420
D	421	422	423	424	425	426	427	428	429	430	431	432
E	433	434	435	36	437	438	439	440	441	442	443	444
F	45	446	447	448	449	50	451	452	453	54	455	456
G	457	458	59	460	461	62	463	464	465	466	467	468
H	69	70	471	472	473	474	475	476	477	478	479	480

DNA blotting sh

sample number … Minter Creek adults fall 2004

LaHood et al. 2008. A rapid, ethanol-free fish tissue collection method for molecular genetic analysis. *Trans. American Fisheries Society* **137**:1104-1107.

A New Sculpin Species Swimming in our Midst…

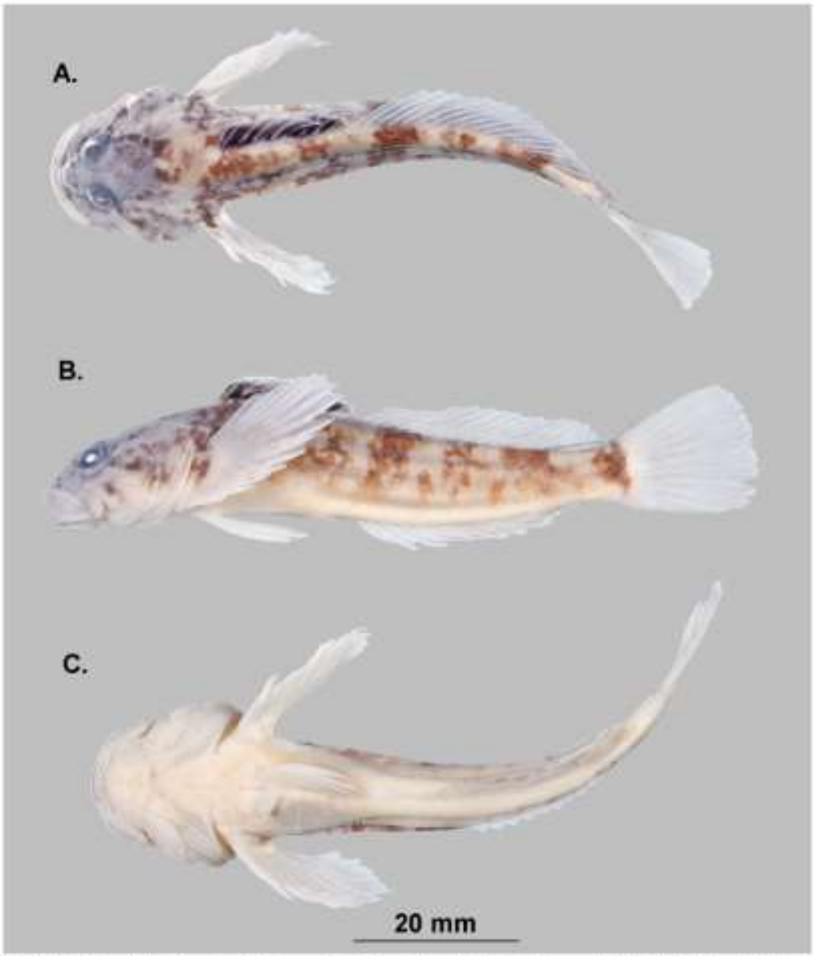
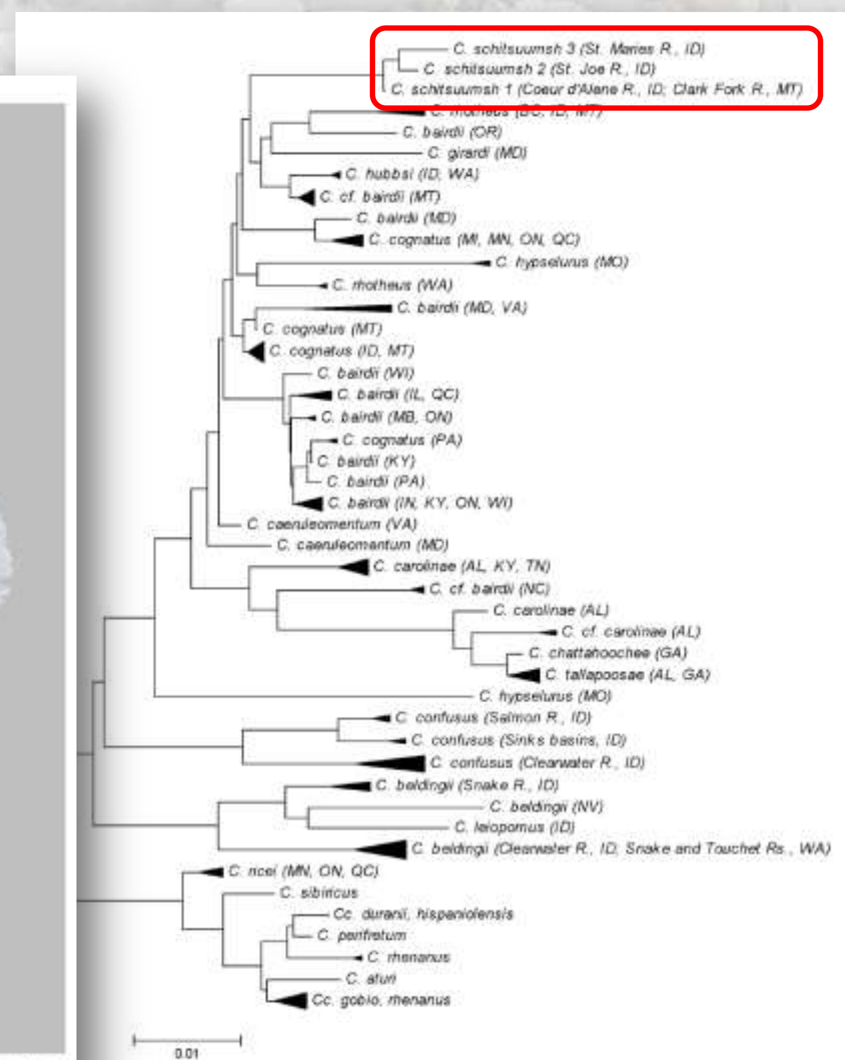
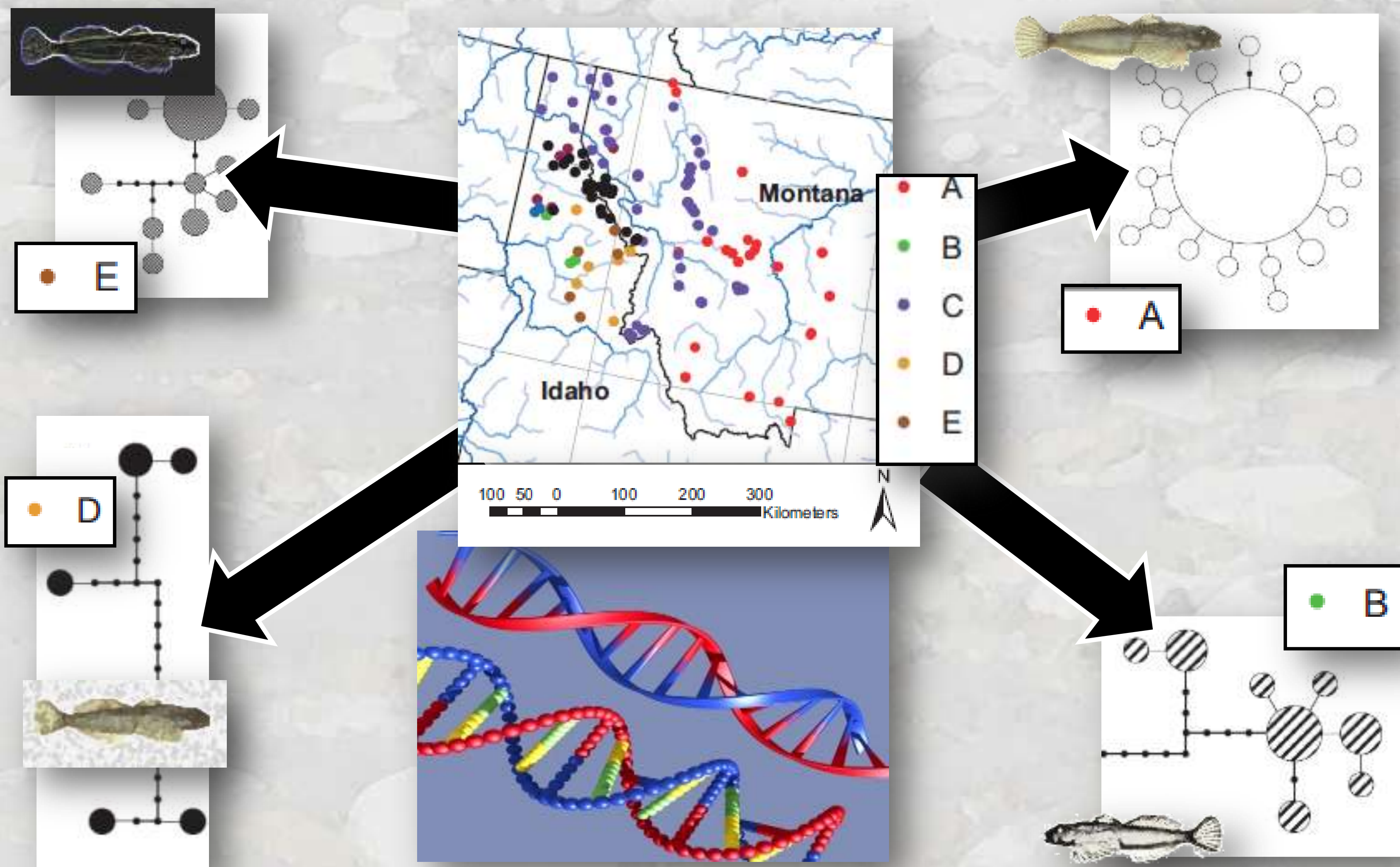


FIGURE 5. Dorsal, lateral, and ventral views of a 73 mm SL male *Cottus schitsuumsh* (UW 152969) from West Fork Steamboat Creek (47.71718°N, 116.2038°W), Shoshone County, Idaho, 7 September 2011. A pelvic fin was removed for genetic sequencing. Photographs by Zachary Randall.



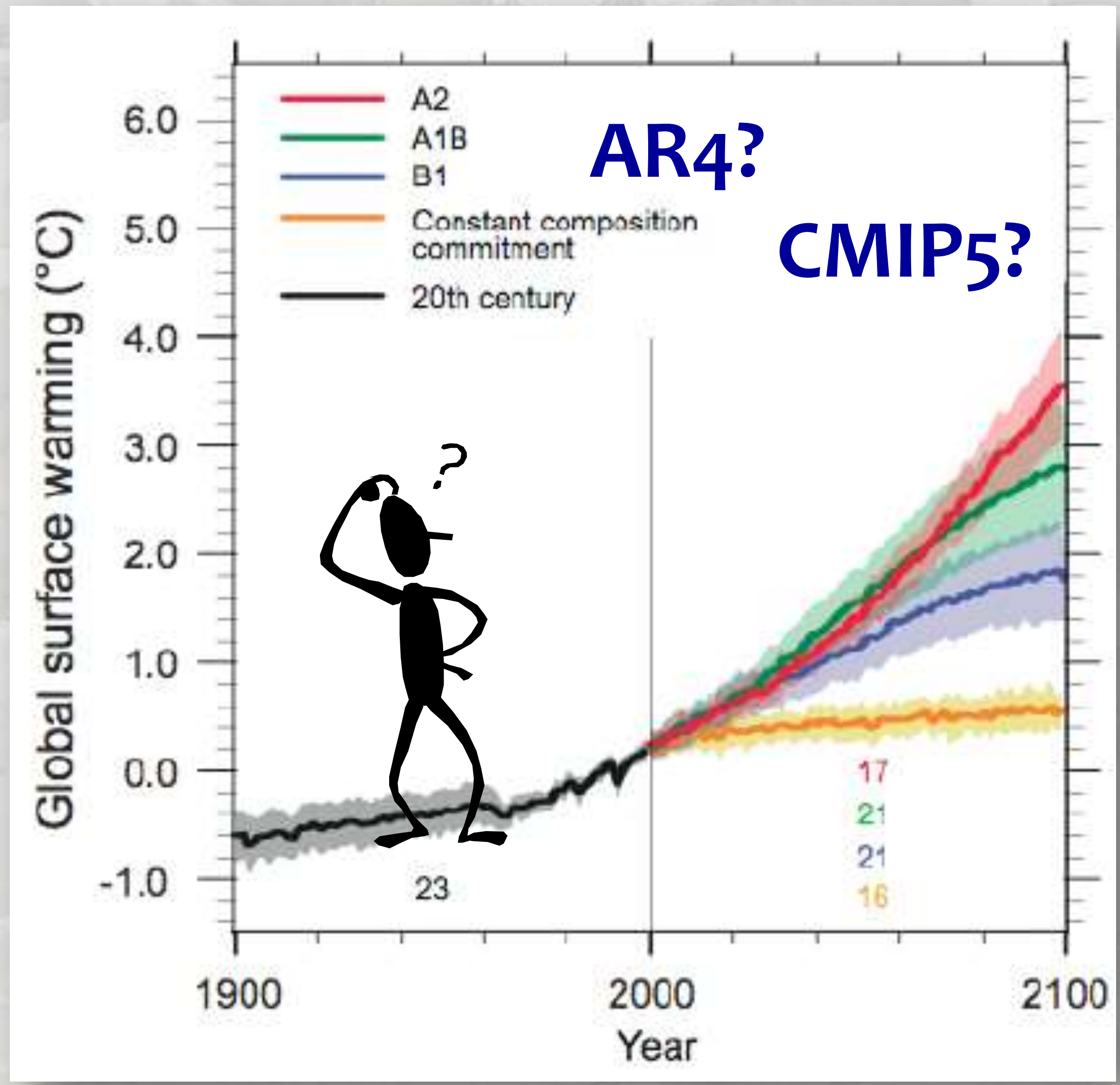
Lemoine et al. 2014. *Cottus schitsuumsh*, a new species of sculpin in the Columbia River basin, Idaho-Montana, USA. *Zootaxa* **3755**:241-258

DNA Barcoding = Inexpensive, High-Resolution Genetic Inventories



Young et al. 2013. DNA barcoding at riverscape scales: assessing biodiversity among fishes of the genus *Cottus* in northern Rocky Mountain streams. *Molecular Ecology* doi: 10.1111/1755-0998.12091

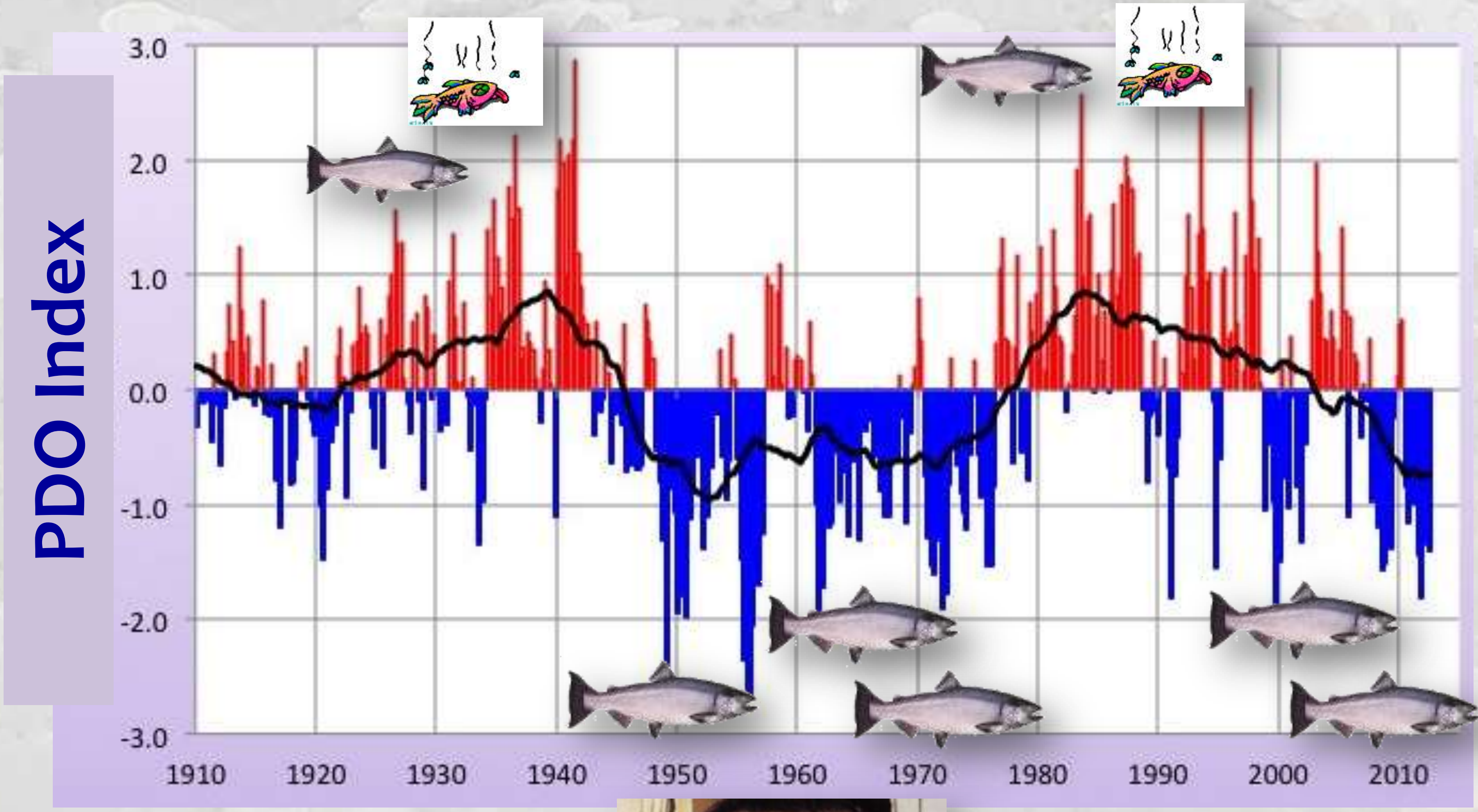
The Future is Uncertain…



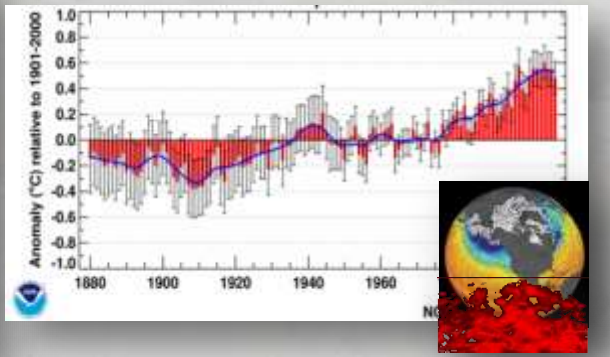
The Specifics are an "Unknowable Unknown"

… except that it will gradually get warmer

PDO Is Buying us Time…



“but I’ll be Back…”



Current Choices Set Future Trajectories

Choice A: Coexistence (do nothing or shape transition to more desirable communities)





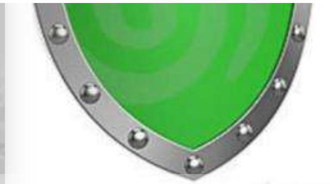
What do we Choose?

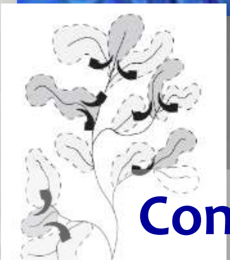
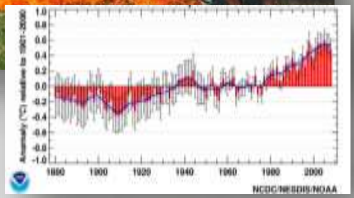
Where do we Choose It?

Choice B:

&

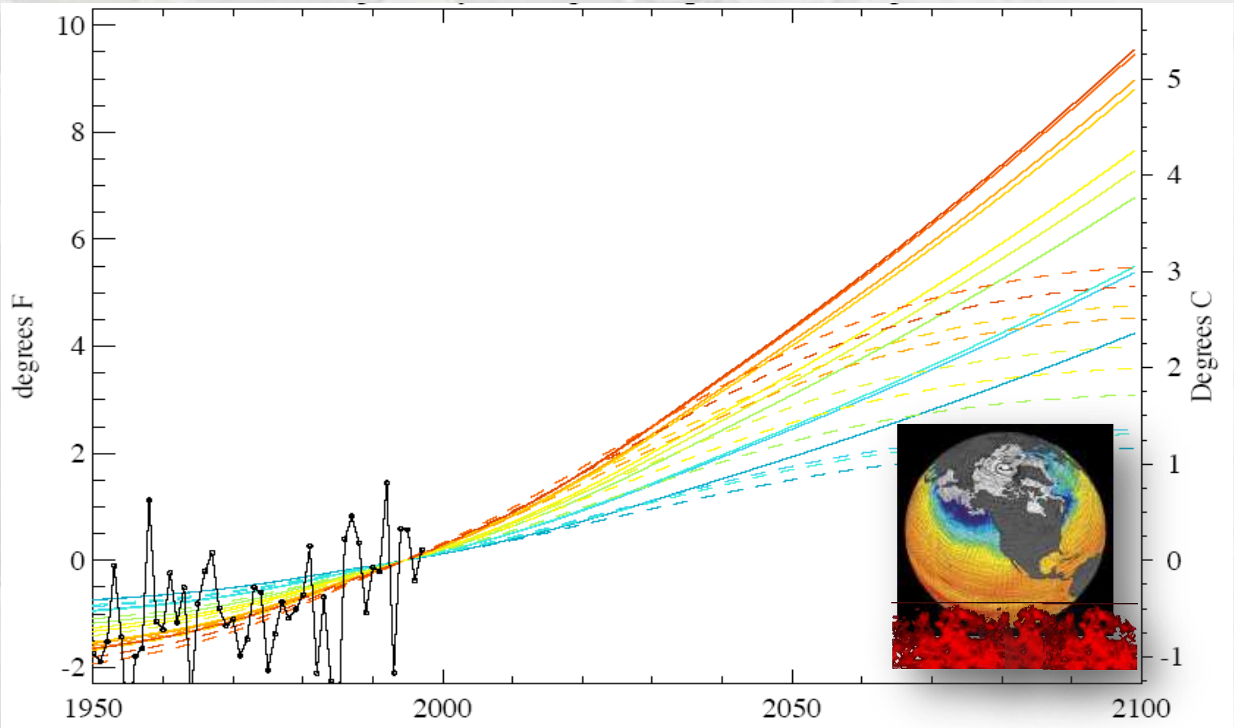




Conservation reserves, important fisheries

The Sooner (& Smarter) We Act, The Bigger the Long-term Impact…




The End
Global Warming Is ...
NOT COOL!