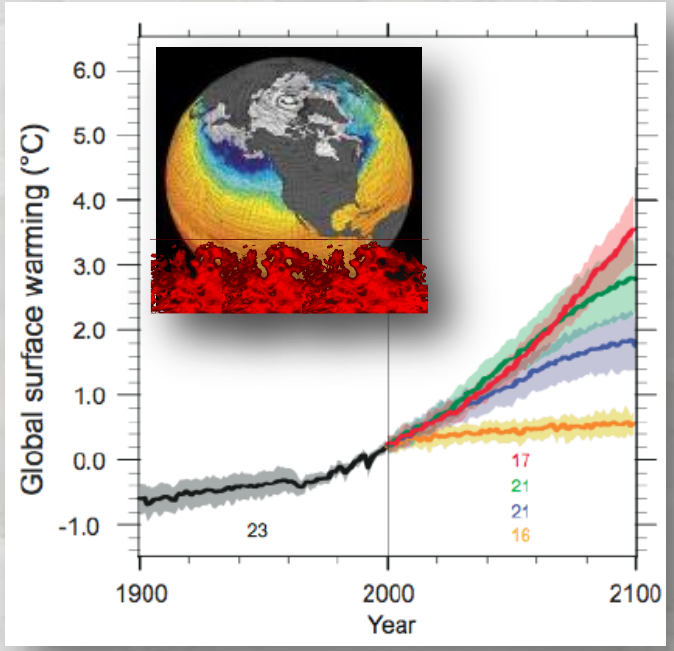
# Identifying, Protecting, & Enhancing Climate Refugia for Salmonids

Dan Isaak & Mike Young

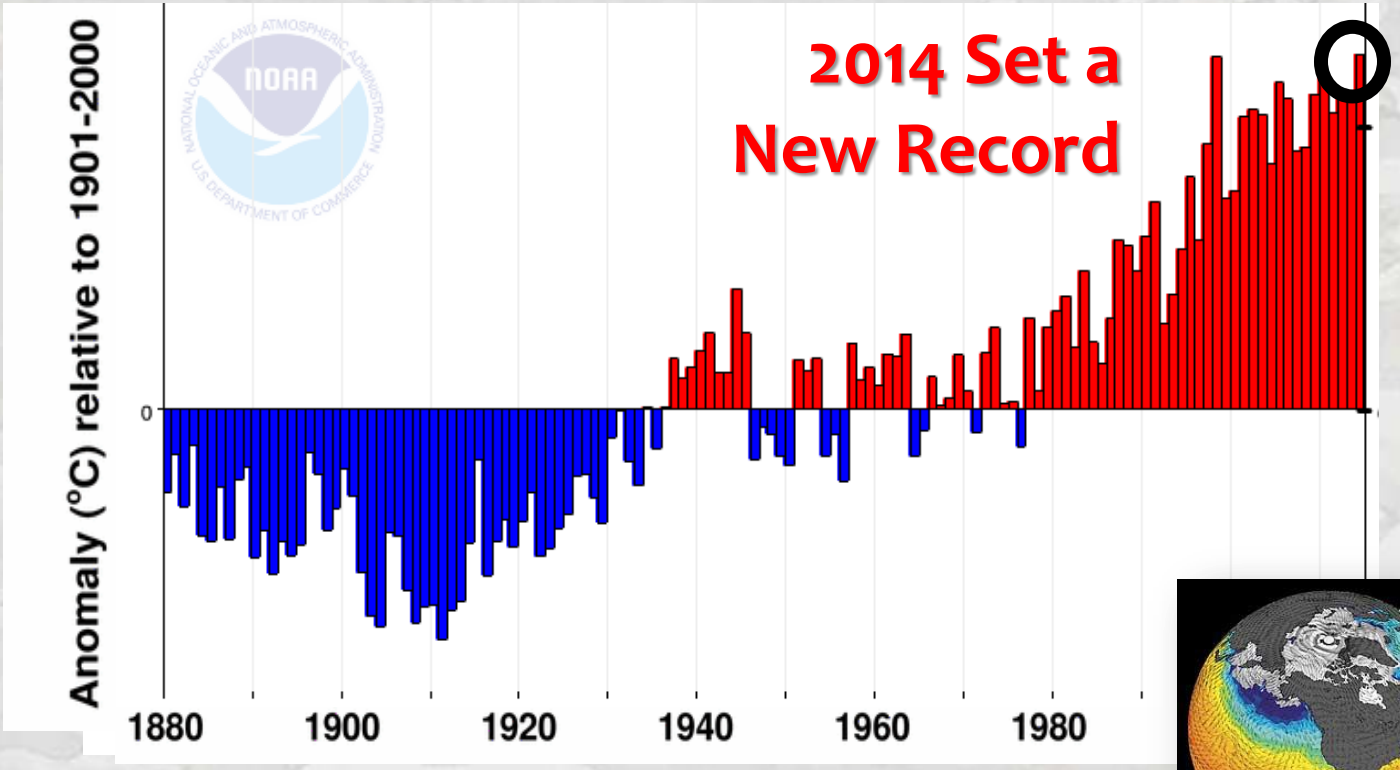
US Forest Service Research

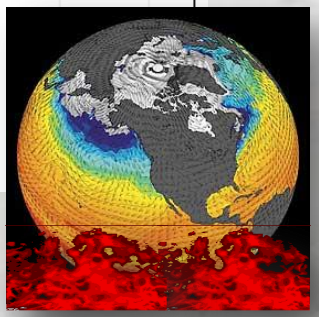




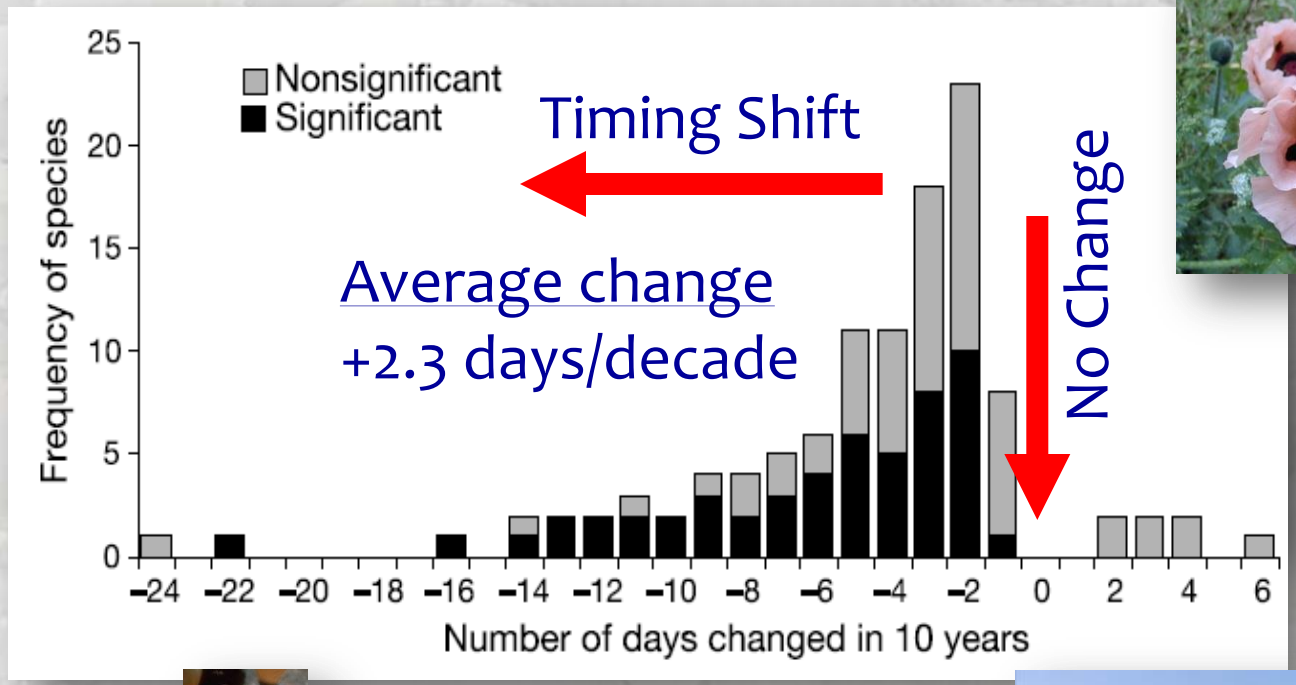
# The New Reality…

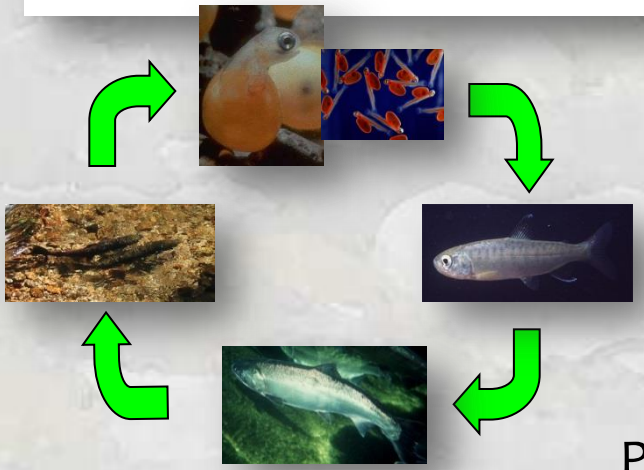
## 1880-2014 Global Air Temperature Trend



# 100s of Studies Show Phenology Shifts in Many Plants & Animals



Parmesan and Yohe. 2003. *Nature* 421:37-42.

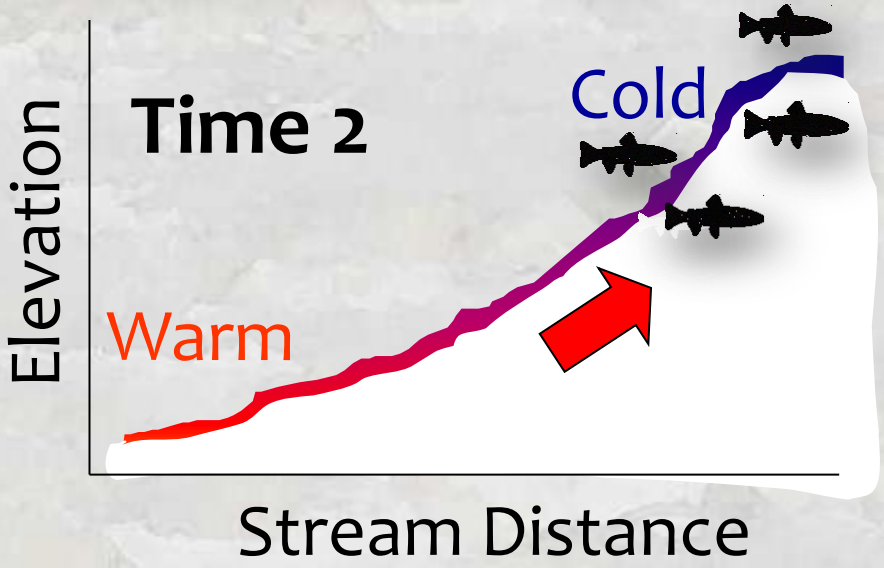
# Species Distributions are Shifting Towards Cooler Areas

Average distribution shift

6.1 km/decade poleward

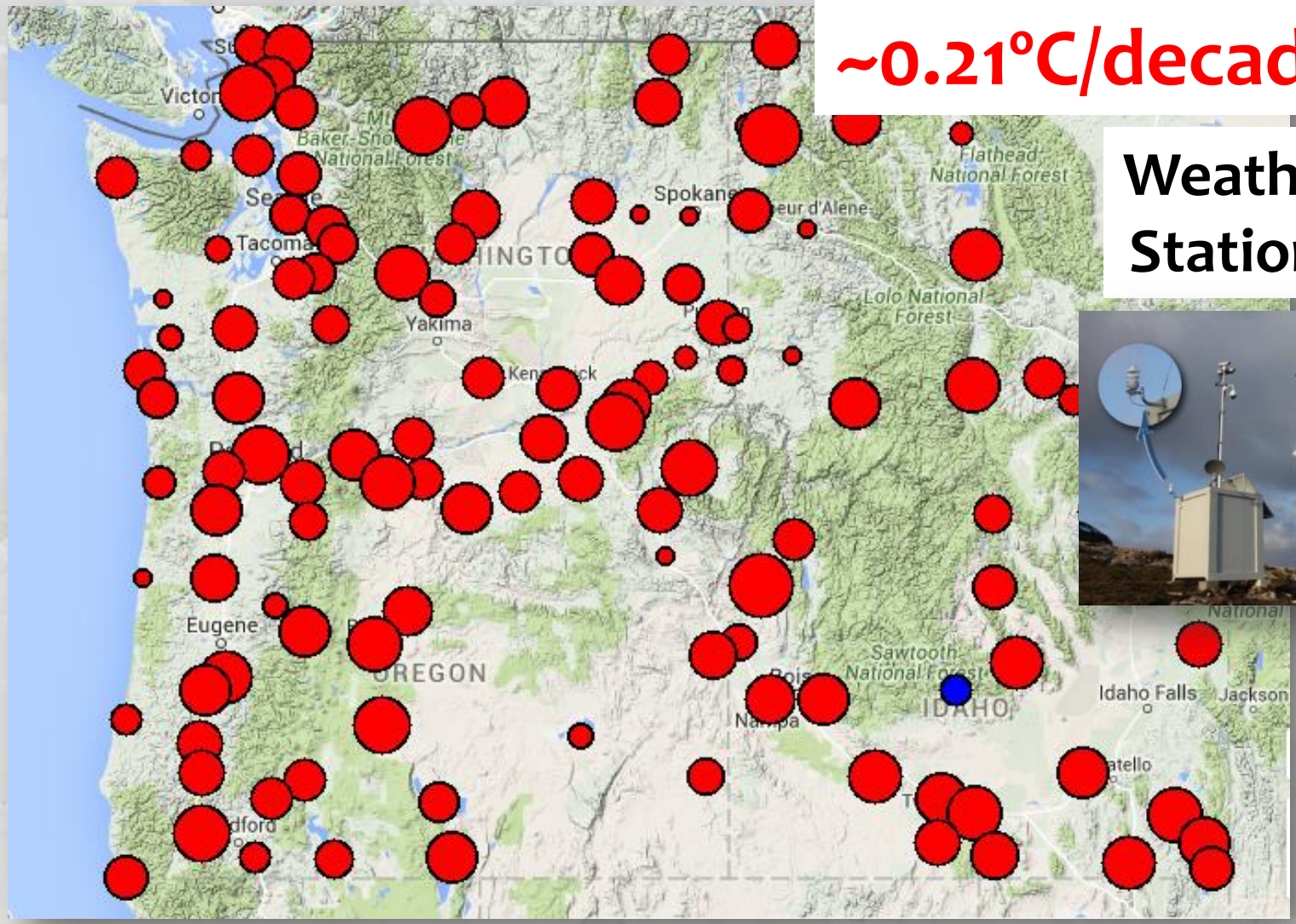
OR

6.1 m/decade higher elevation


Parmesan and Yohe. 2003. *Nature* **421**:37-42.

# Summer Air Temp Trends (1968–2011)

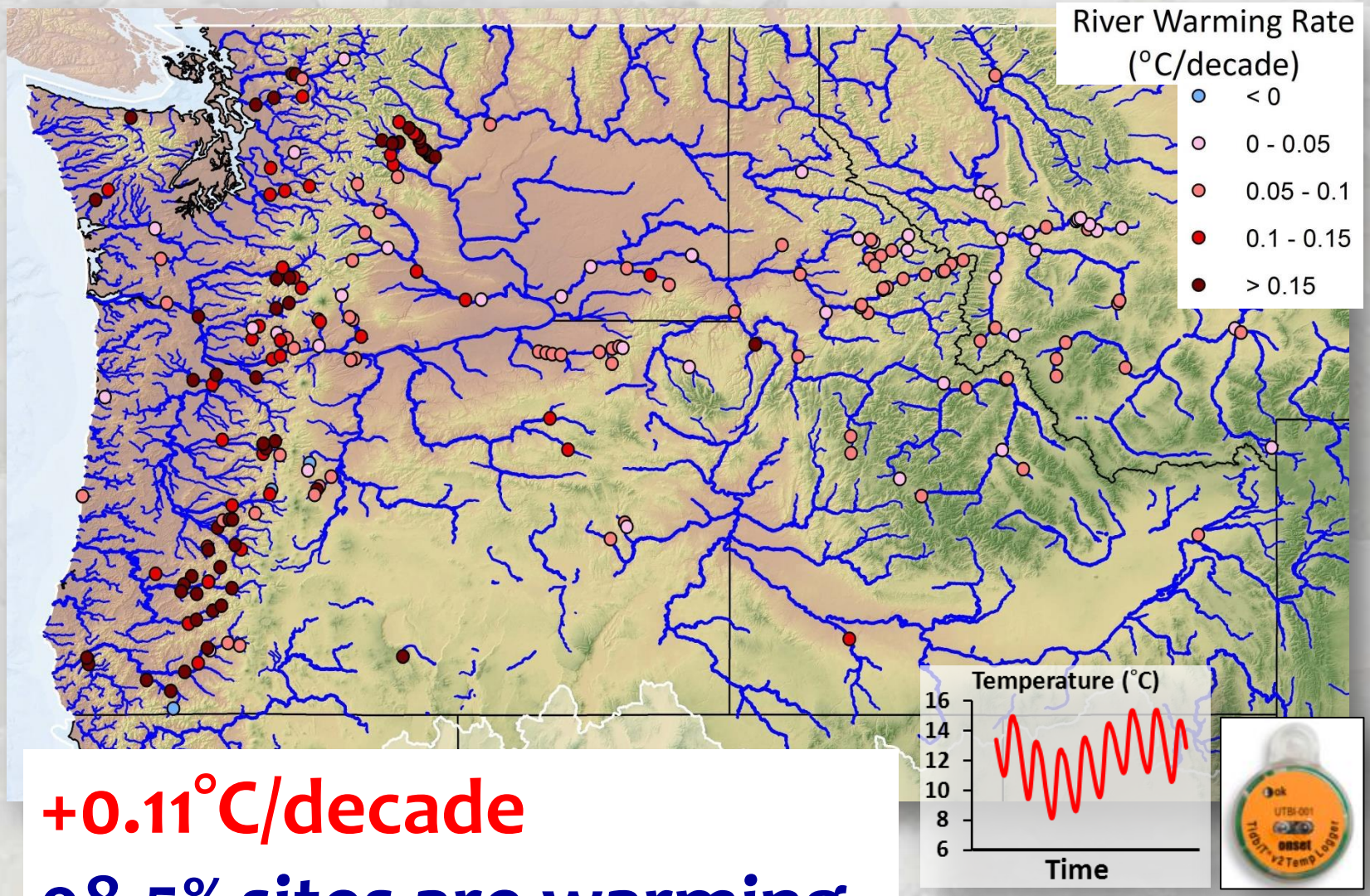



**OWSC Climate Tool map**

http://www.climate.washington.edu/trendanalysis/

# River Temp Trends (1968-2011)

## 245 sites with >10 year monitoring records



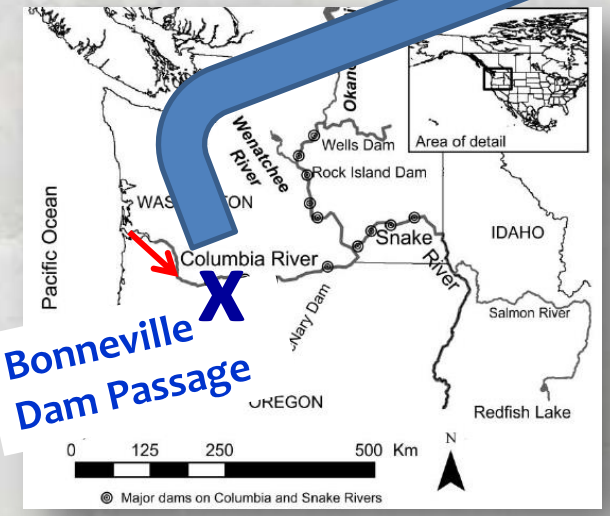

**+0.11°C/decade**

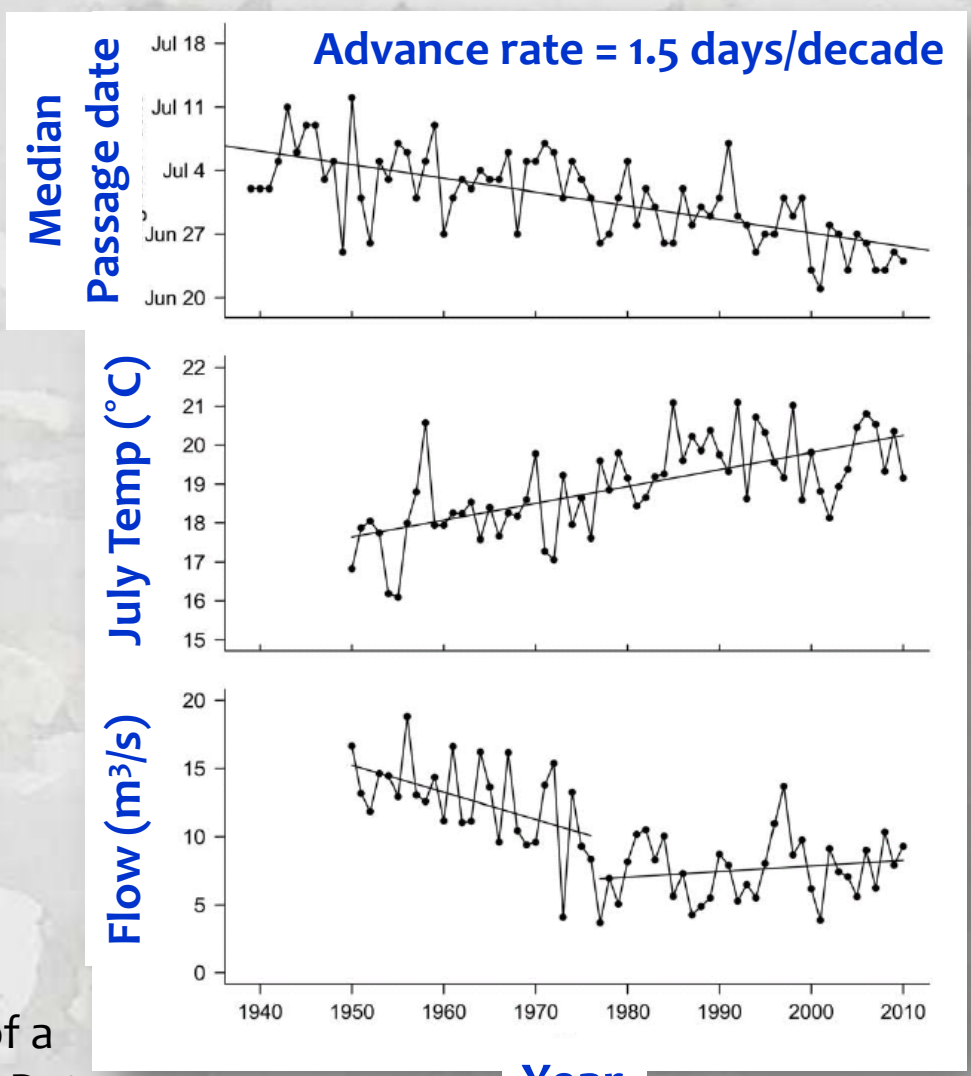
**98.5% sites are warming**

Isaak et al. In Prep.

# Fish are Trying to Follow Climate

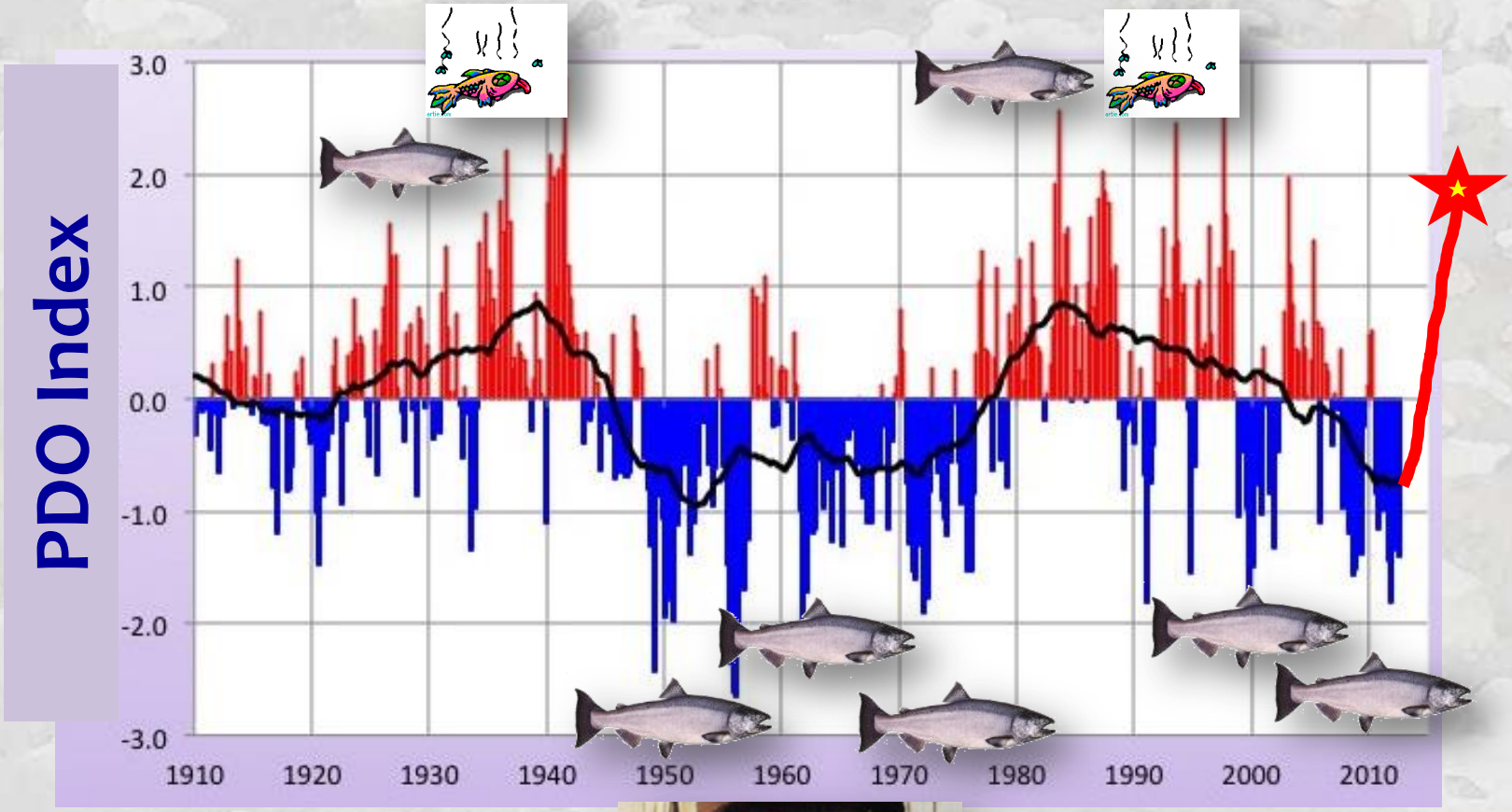
## Sockeye Migrations Happening Earlier…



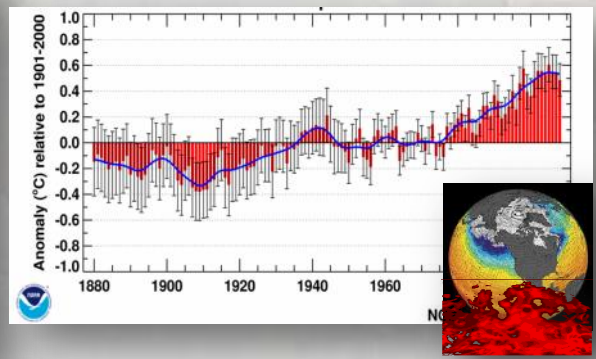




Crozier et al. 2011. A Case Study of a Shift toward Earlier Migration Date in Sockeye Salmon. *The American Naturalist* **178**:755-773.

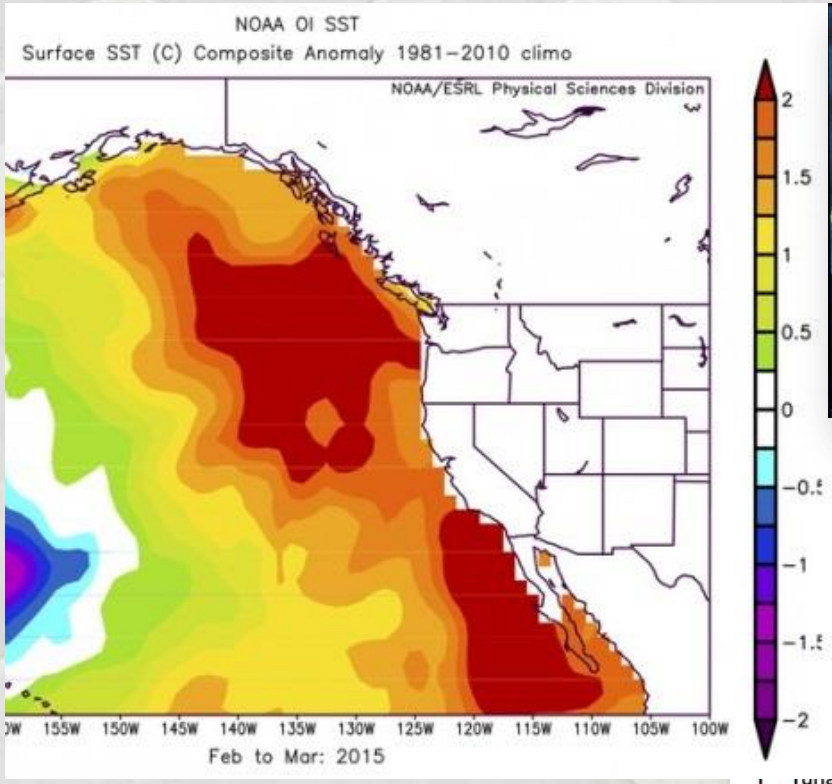
# Climate Cycles (PDO & ENSO)

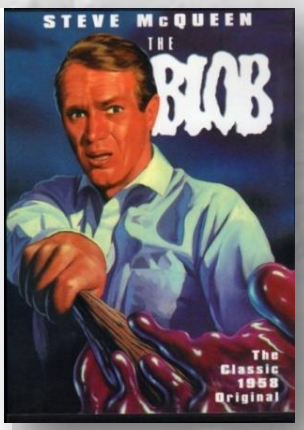



## Jack is Back

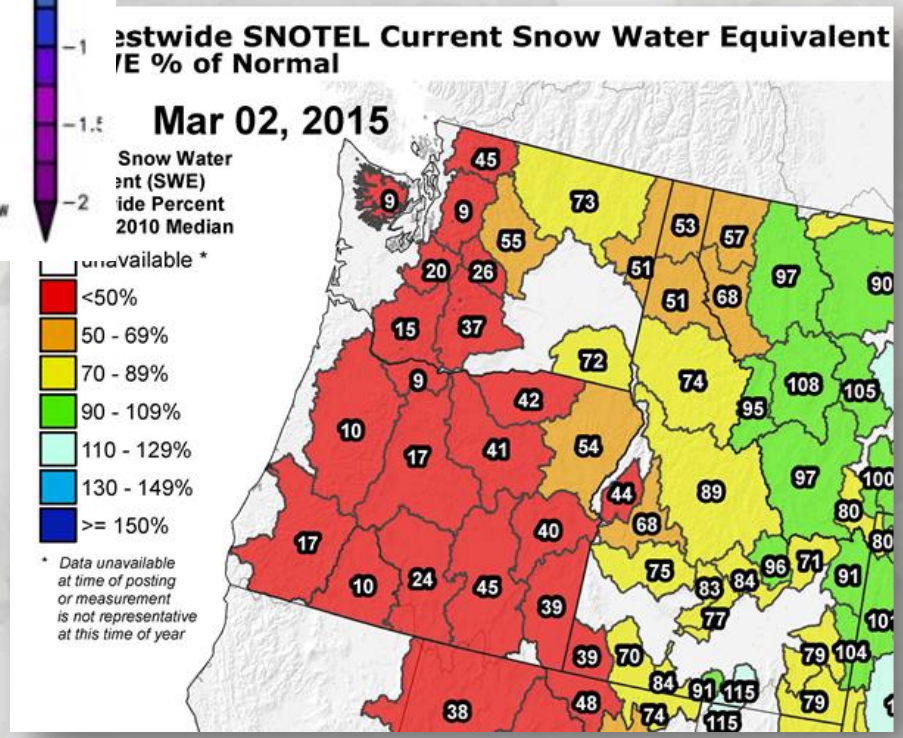


# The Blob Ate Last Year's Snow




## Record Low Snow…



# 2015 Was a "Perfect storm"

## Lots of Fish, Lots of Mortalities

**Summer Chinook Return Forecasted To Be Largest Since 1961; Gillnetters Raise Catch Allocation Issues**

Posted on Friday, July 10, 2015 (PST)

**Climate change is tilting the odds towards more perfect storms**

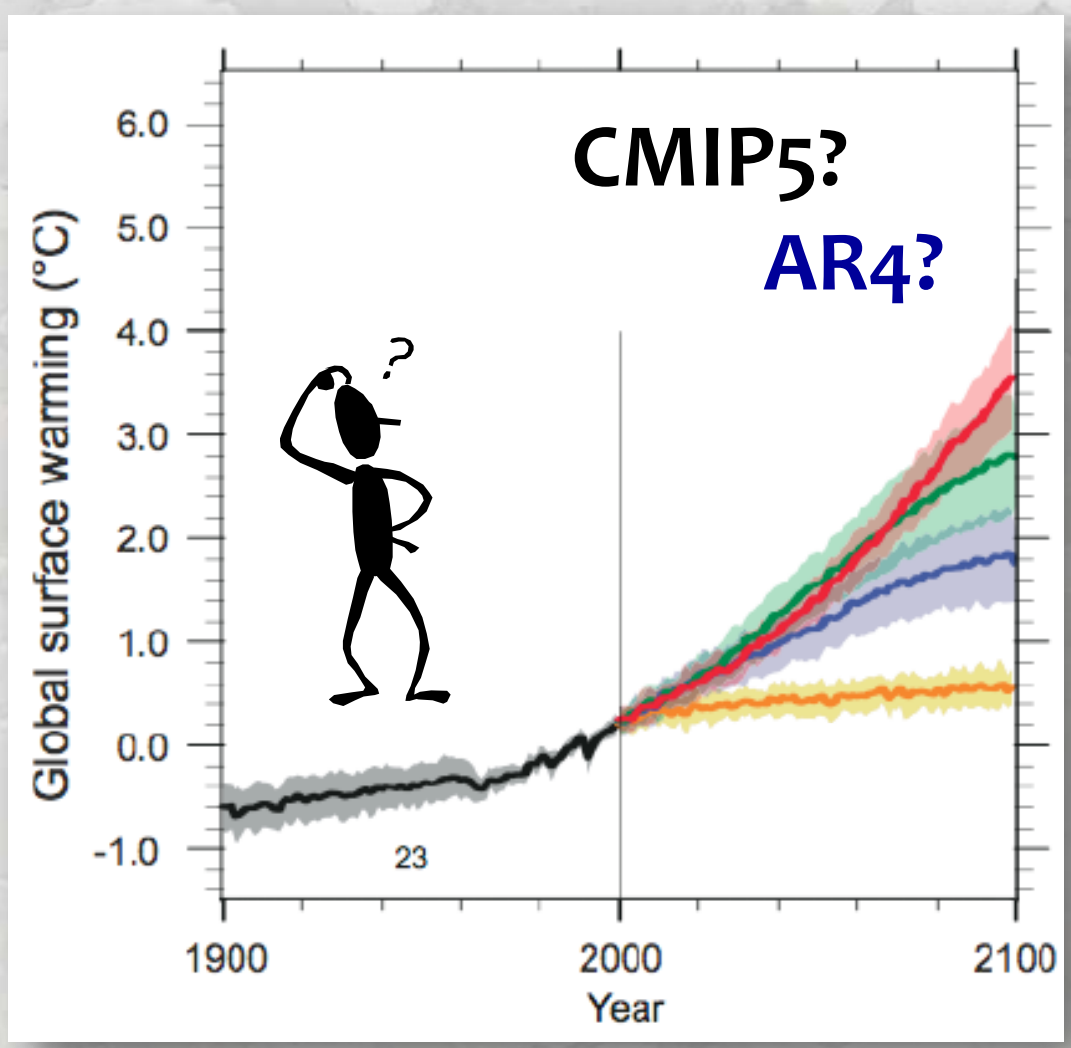
**Snowpack drought has salmon dying in overheated rivers**

Originally published July 25, 2015 at 5:42 pm | *Updated July 28, 2015 at 11:18 am*

The Seattle Times

# How Much Warmer & When?

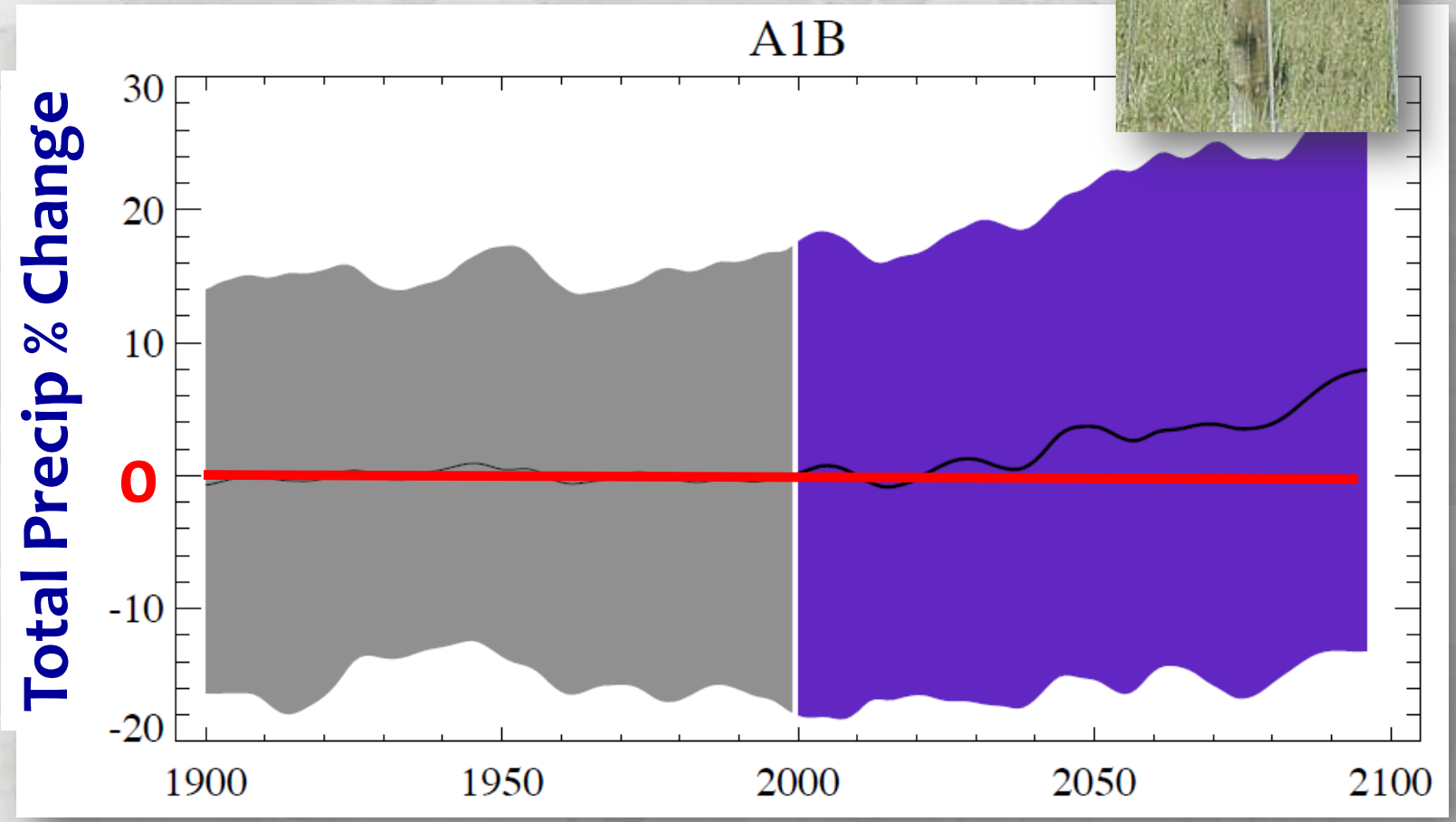
## The Future is Uncertain…



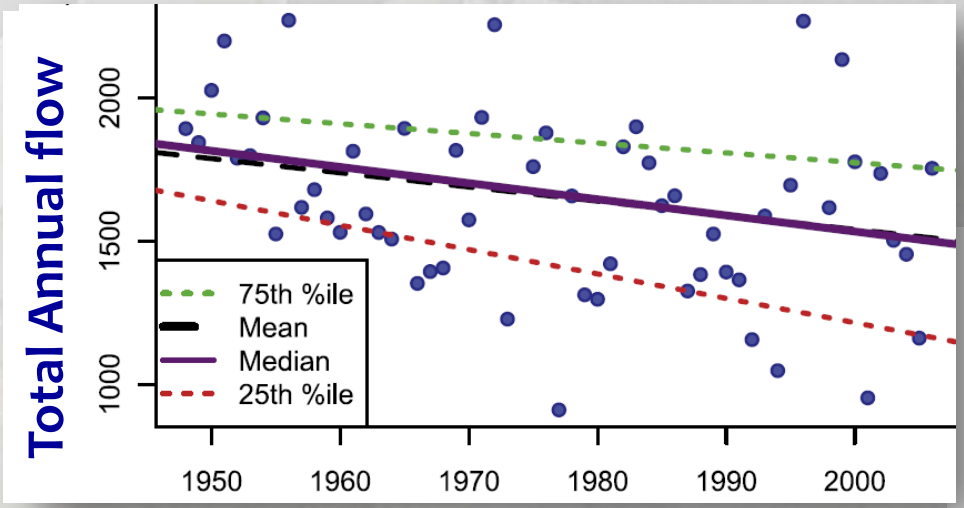

The Specifics are an "Unknowable Unknown"

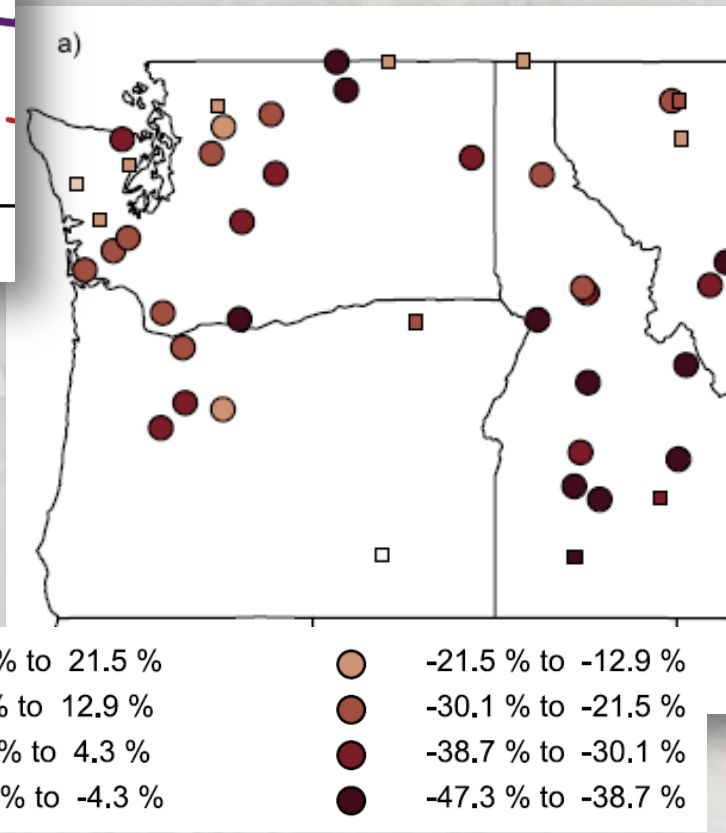
# A Wetter or Drier Future?

## Predictions are less certain



# BUT… Total Annual Flow & Low Flows Have Been Decreasing (1948-2006)

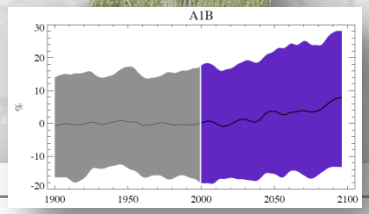



(Luce and Holden 2009)

# Decreasing Wind Speeds & Total Precipitation at High Elevations

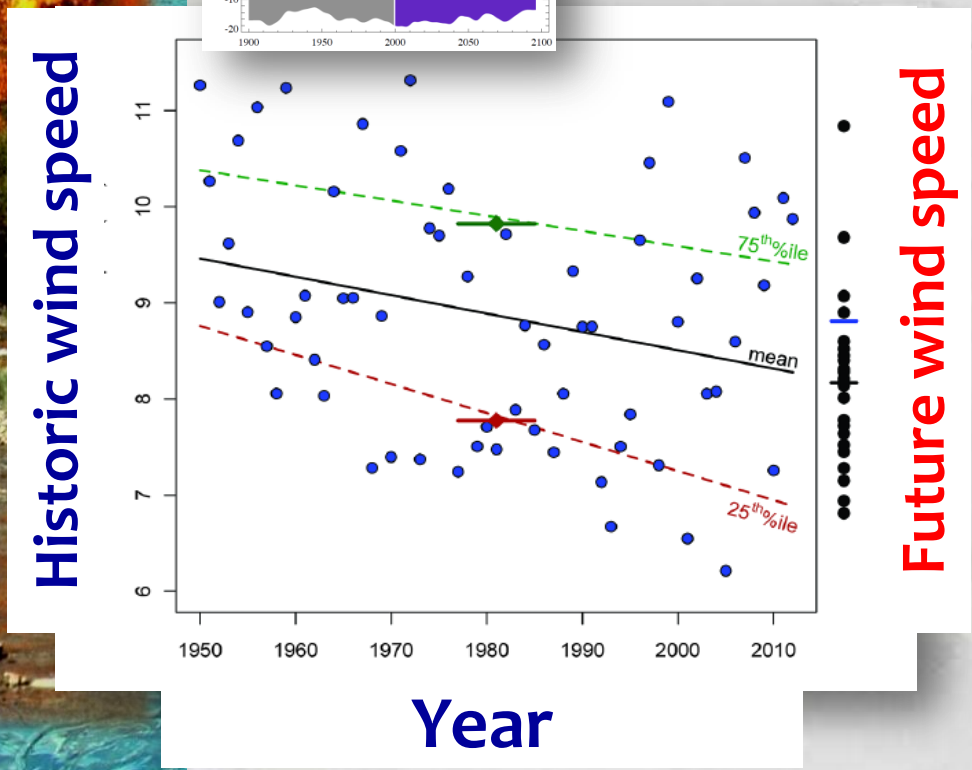
≠

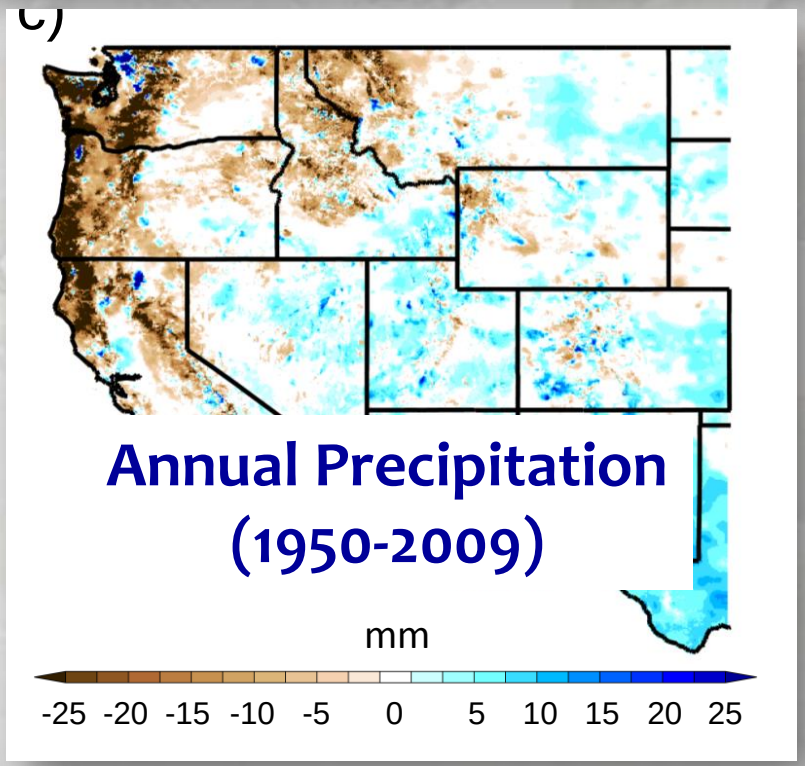



Sciencexpress

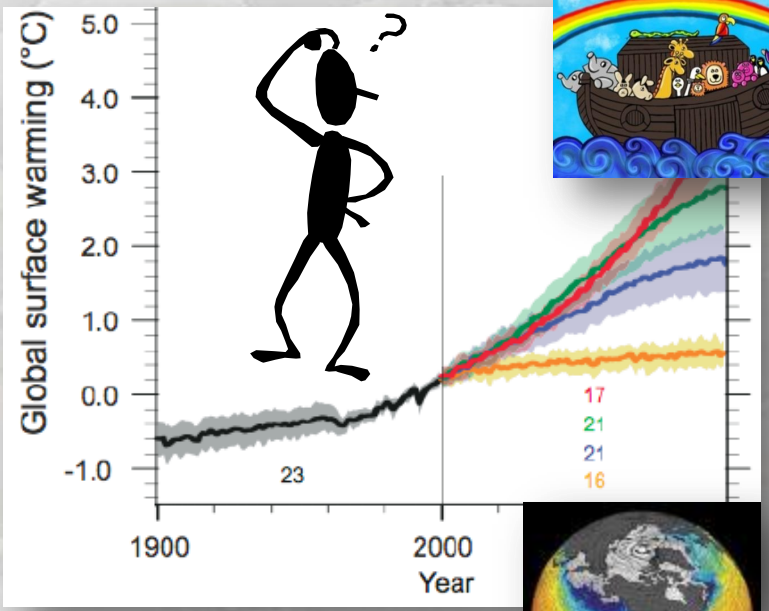
The Missing Mountain Water: Slower Westerlies Decrease Orographic Enhancement in the Pacific Northwest

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

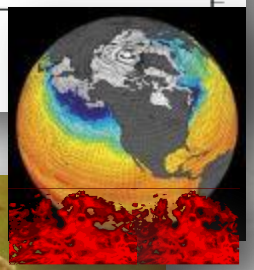


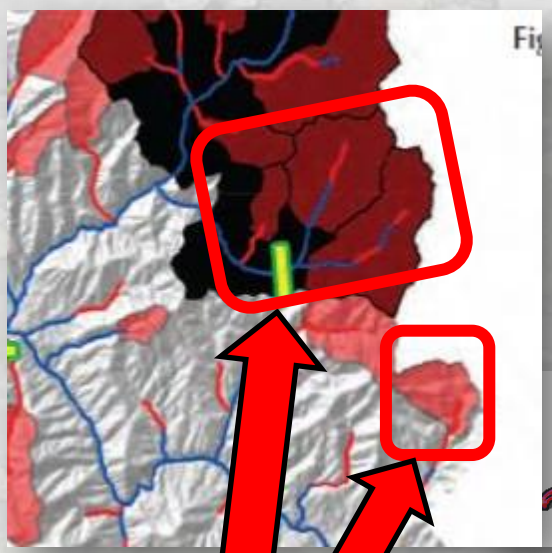
# Identifying & Protecting Climate Refuge Habitats Hedges Against Uncertainty





## Strategic Context for Investment Planning



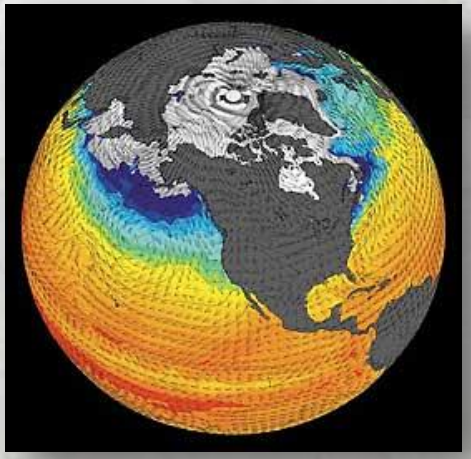
I'm going to invest here…

…not here

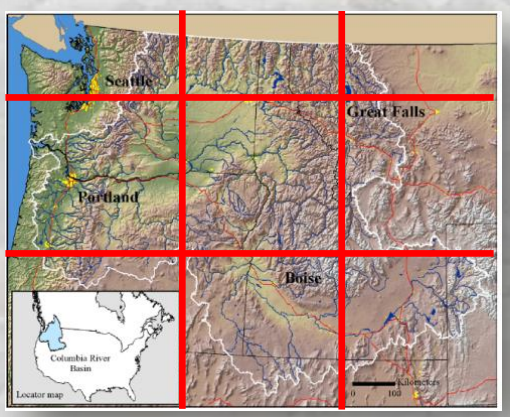
# Resolving Refugia Requires High-Resolution Climate Scenarios Where Fish Live

# Resolving Refugia Requires High-Resolution Climate Scenarios Where Fish Live

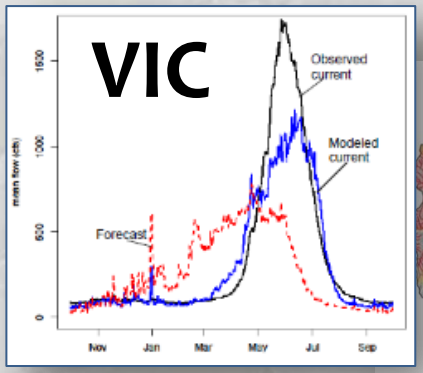
Climate model (air temp & precip)

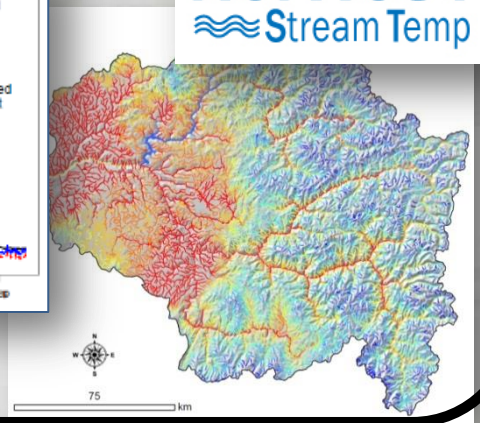


Regional patterns

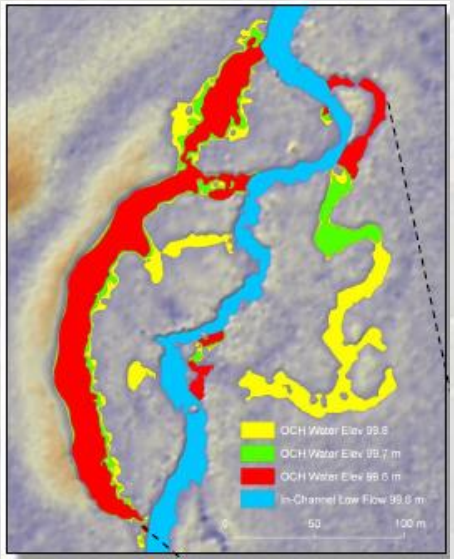



Stream temperatures & flow

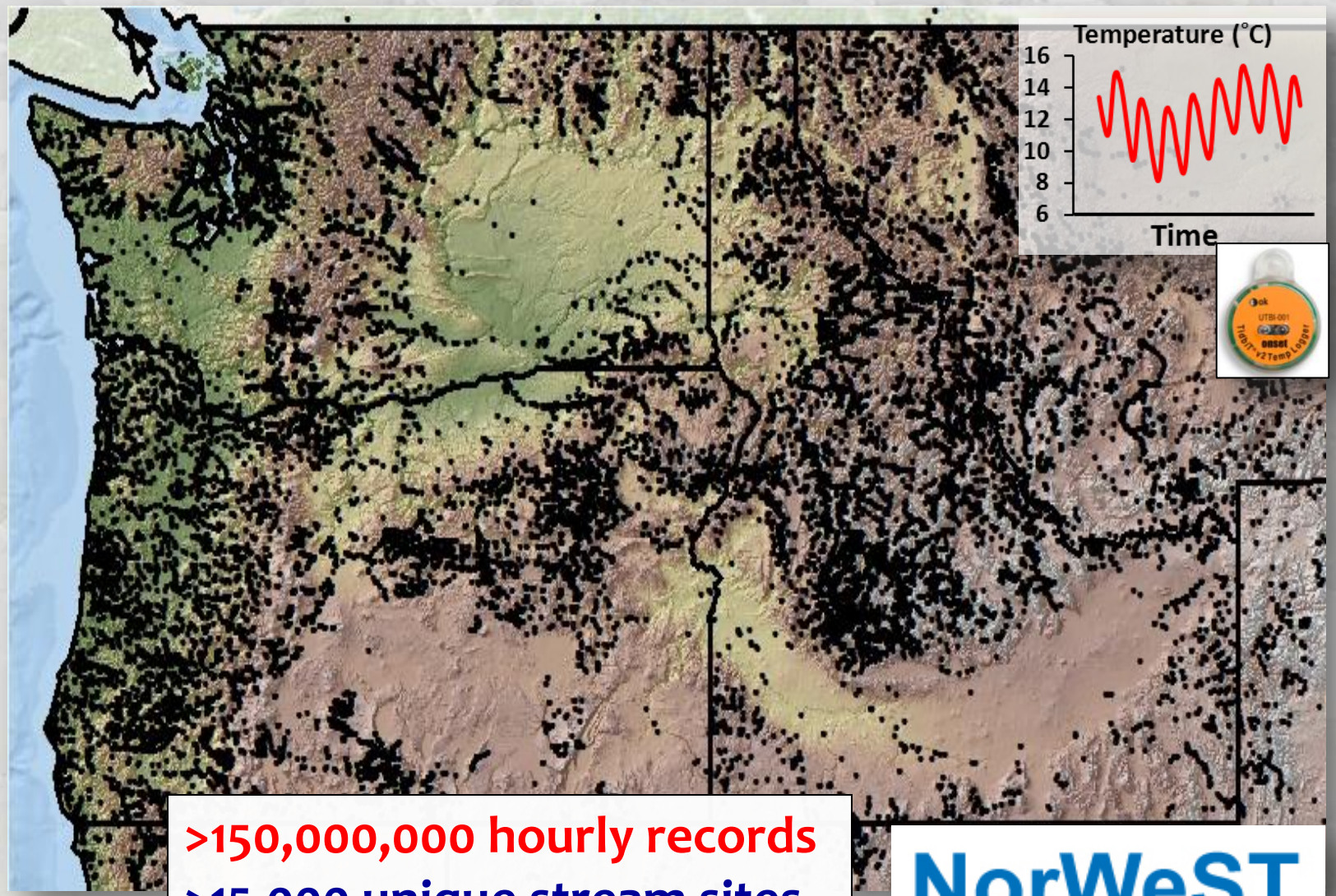



Stream reach patterns



# Lots of Stream Temp Data in the PNW



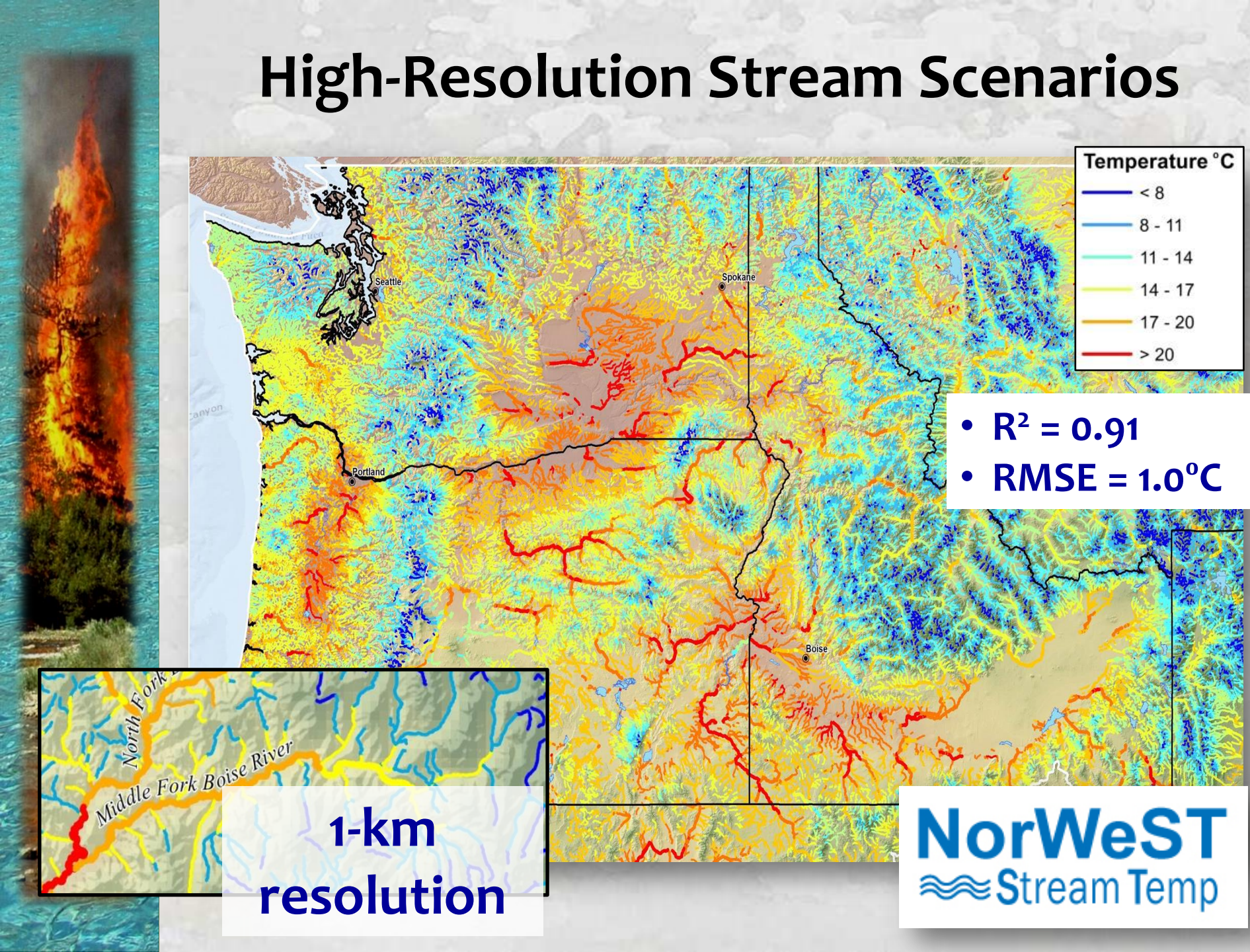

>150,000,000 hourly records

>15,000 unique stream sites

>100 resource agencies

NorWeST Stream Temp

# High-Resolution Stream Scenarios



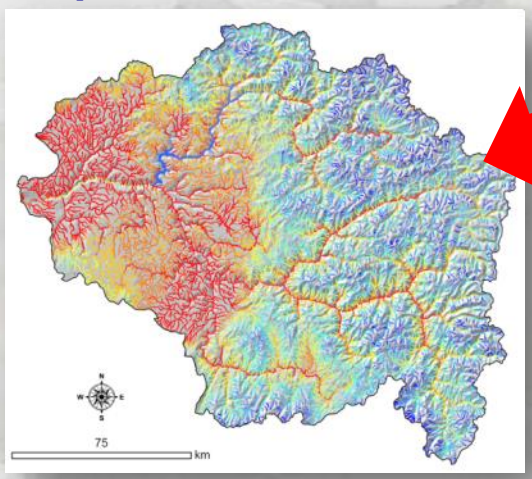

- $R^2$ = 0.91
- RMSE = 1.0°C

**1-km resolution**

NorWeST Stream Temp

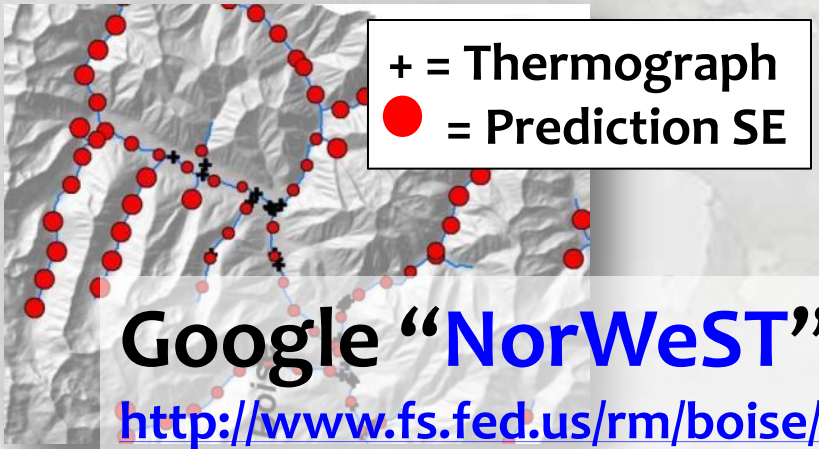
# Website Distributes Scenarios & Data in User-Friendly Formats

1) GIS shapefiles of stream temperature scenarios





2) GIS shapefiles of stream temperature model prediction precision



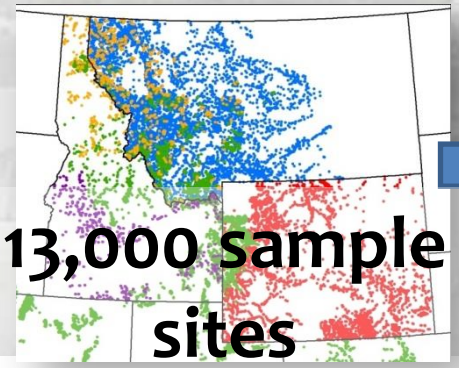

3) Temperature data summaries

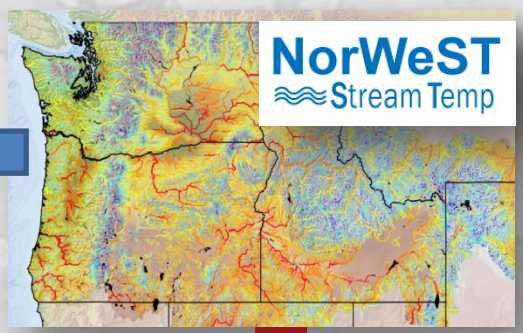

Google "NorWeST" or go here...

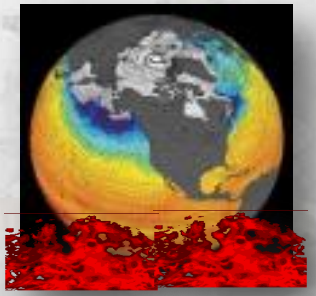
http://www.fs.fed.us/rm/boise/AWAE/projects/NorWeST.shtml

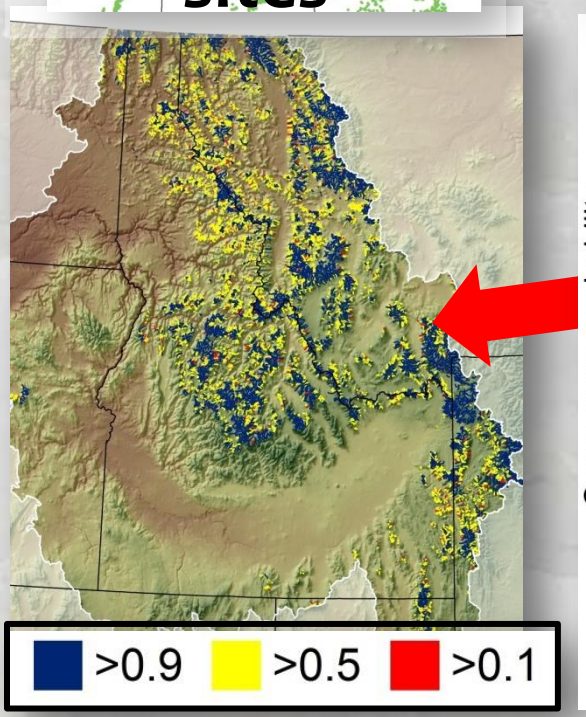
# Stream Scenarios Enable Accurate Fish Distribution Models

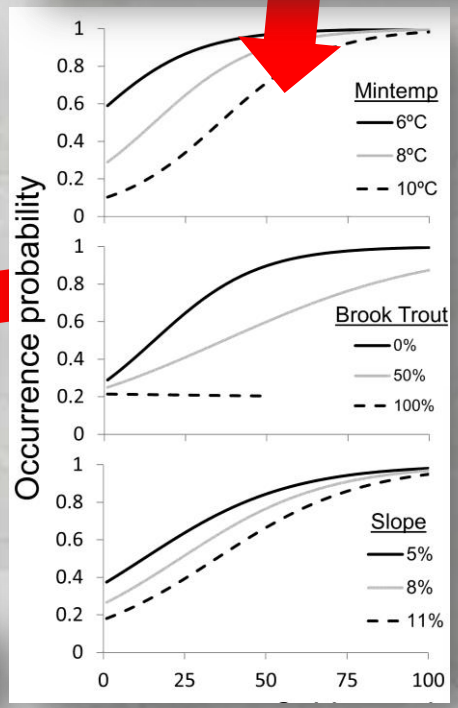
## BIG FISH DATA







Isaak et al. 2015. The cold-water climate shield: Delineating refugia for preserving native trout through the 21st Century. *Global Change Biology* **21:**2540-2553.

# Bull Trout Climate Probability Map 1980s

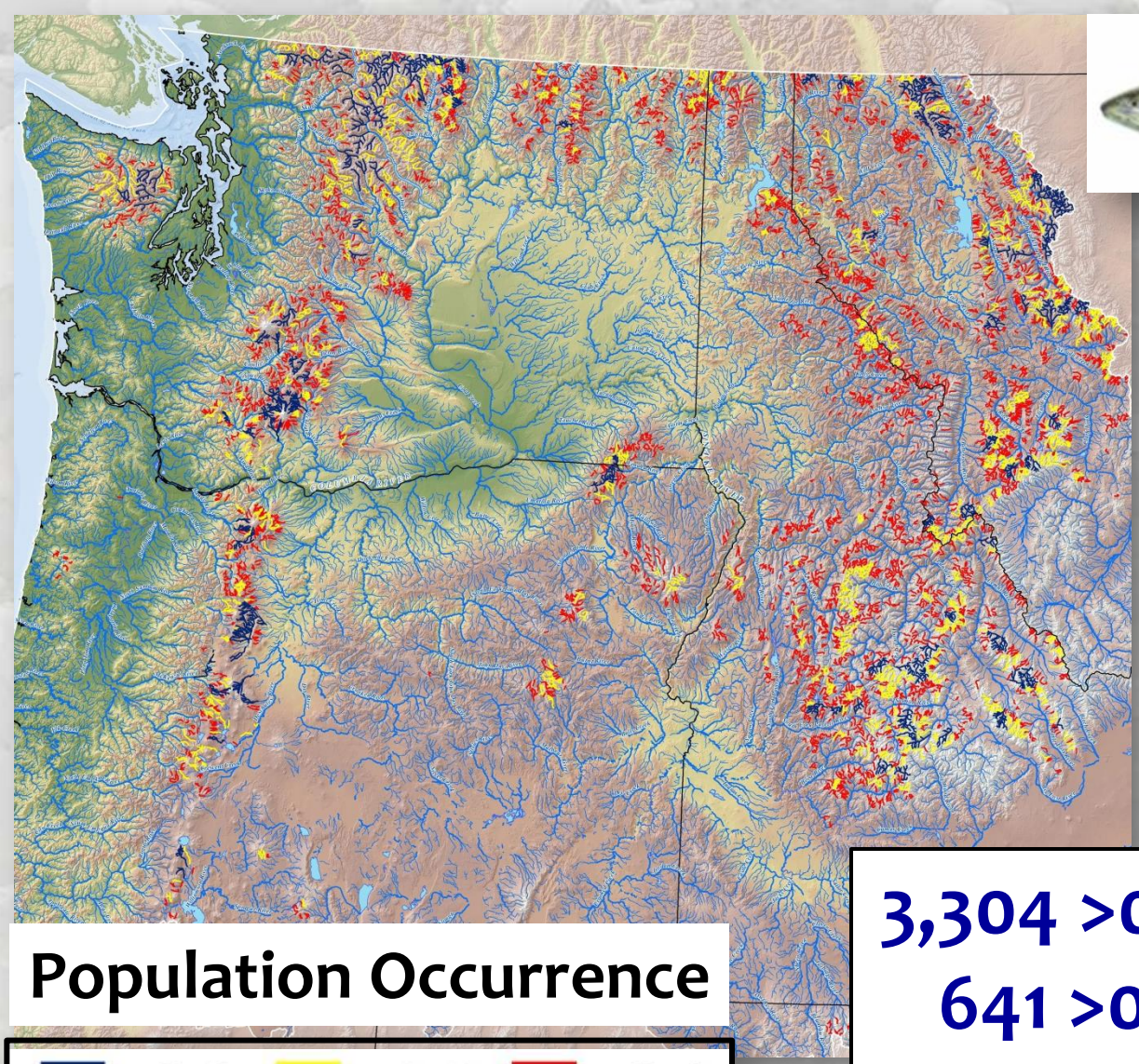
Stream scale predictions

Population Occurrence

>0.9 >0.5 >0.1

5,332 >0.1 habitats
1,325 >0.5 habitats
348 >0.9 habitats

# Bull Trout Climate Probability Map 2040s

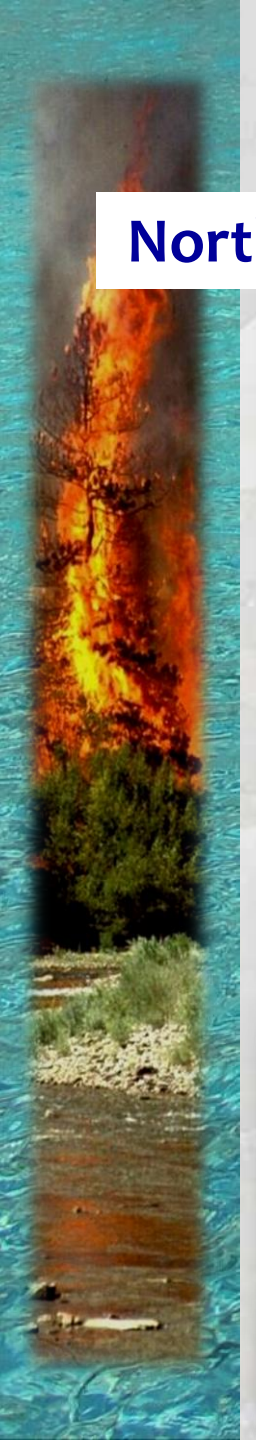


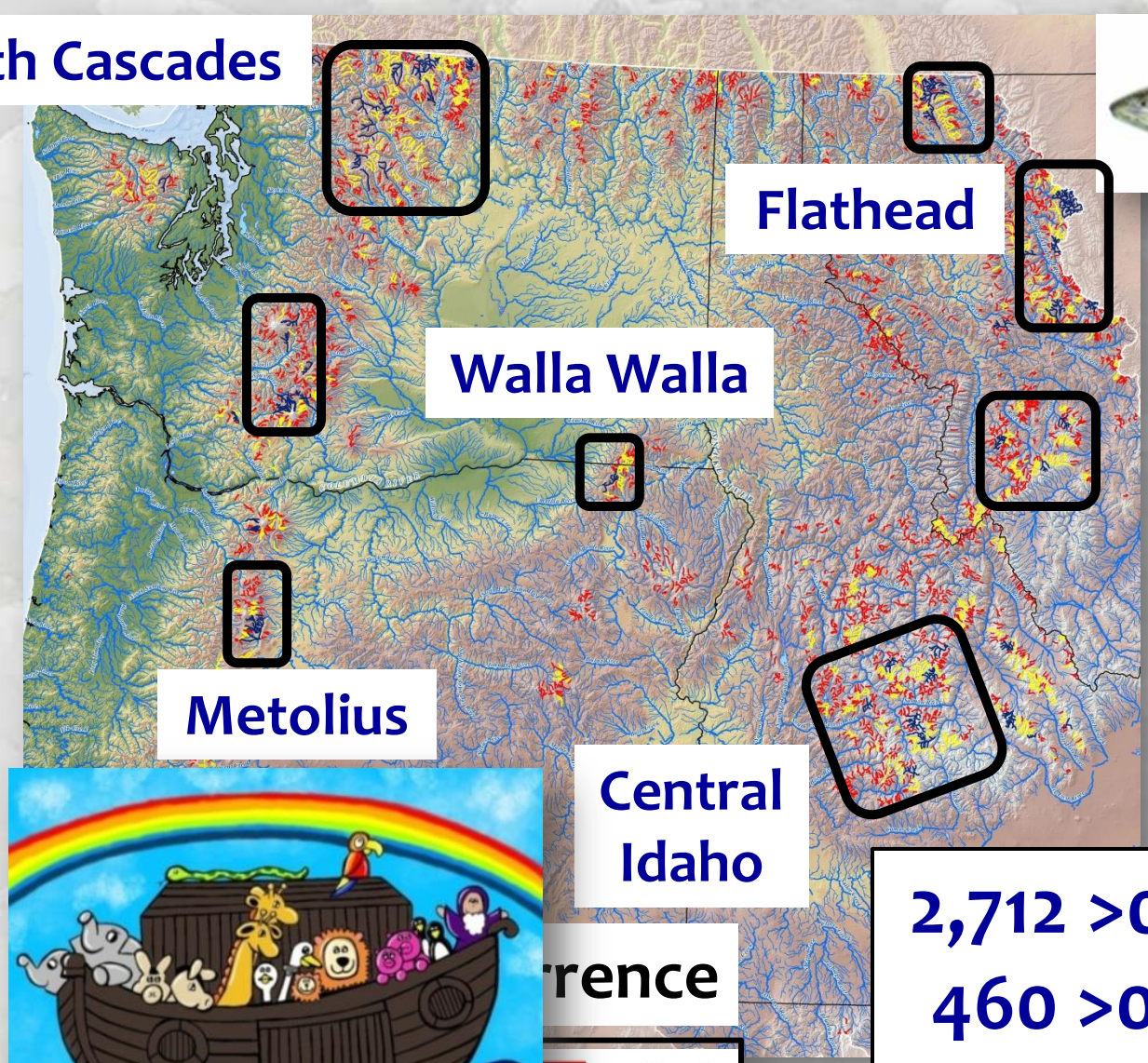
**Population Occurrence**

>0.9 >0.5 >0.1

3,304 >0.1 habitats
641 >0.5 habitats
130 >0.9 habitats

# Bull Trout Climate Probability Map 2080s






Worst case scenario!



2,712 >0.1 habitats
460 >0.5 habitats
62 >0.9 habitats

# Website Distributes Precise Digital Climate Habitat Maps…

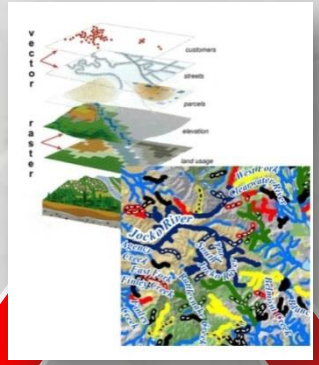
## Climate Shield website:

http://www.fs.fed.us/rm/boise/AWAE/projects/ClimateShield.html

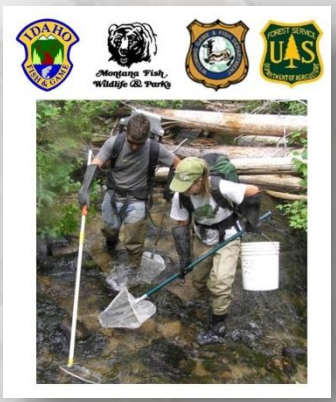
**Presentations & Publications**

COLDWATER AS A CLIMATE SHIELD TO PRESERVE NATIVE TROUT THROUGH THE 21ST CENTURY

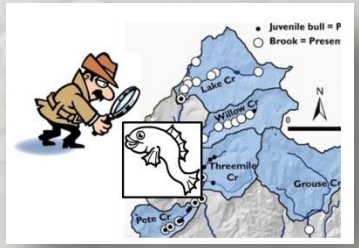
**Digital Maps & ArcGIS Shapefiles**




**Fish Data Sources**




**Distribution Monitoring**




## File formats:

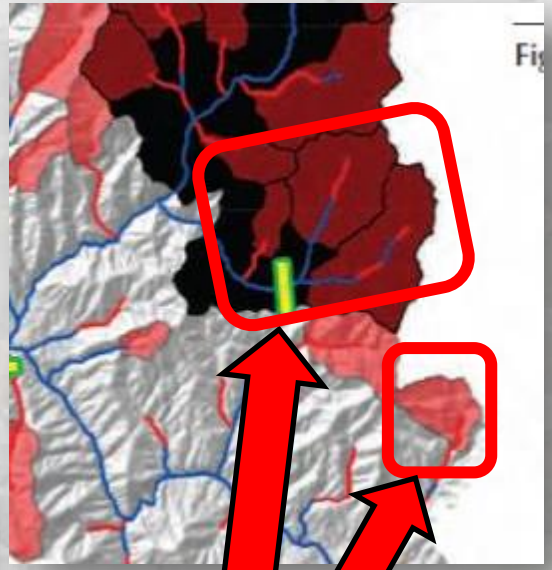
- ArcGIS files
- pdf files

## 15 Scenarios:

- 3 climate periods
- 5 Brook invasion levels

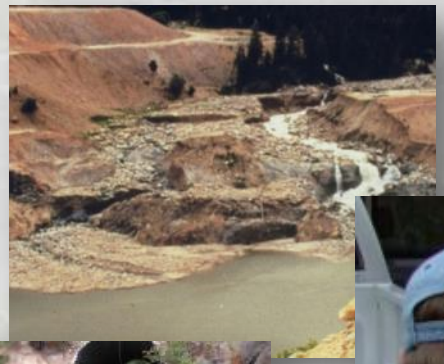
# Many Conservation Investment Options Once we Know "Where"

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

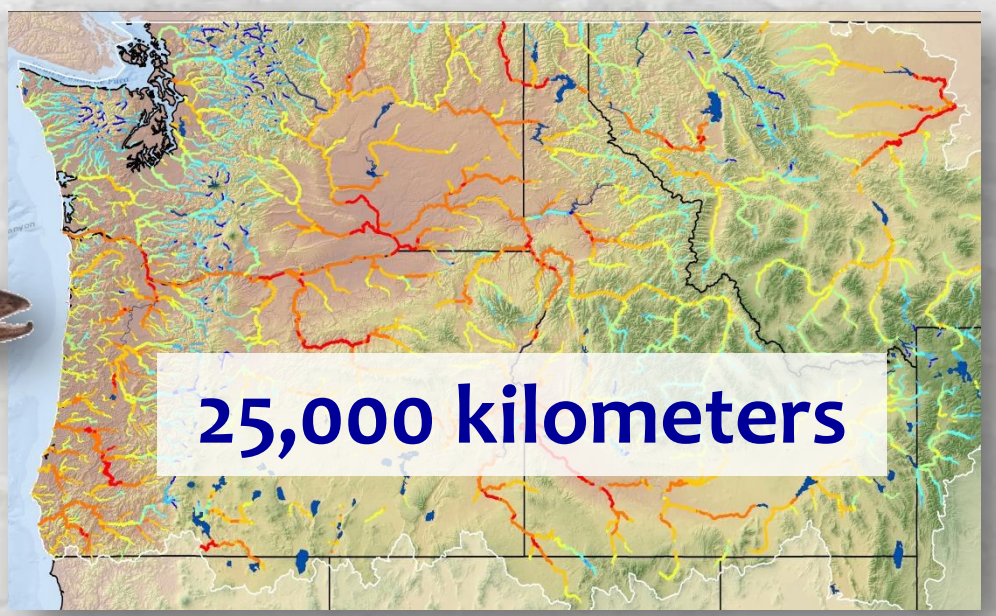


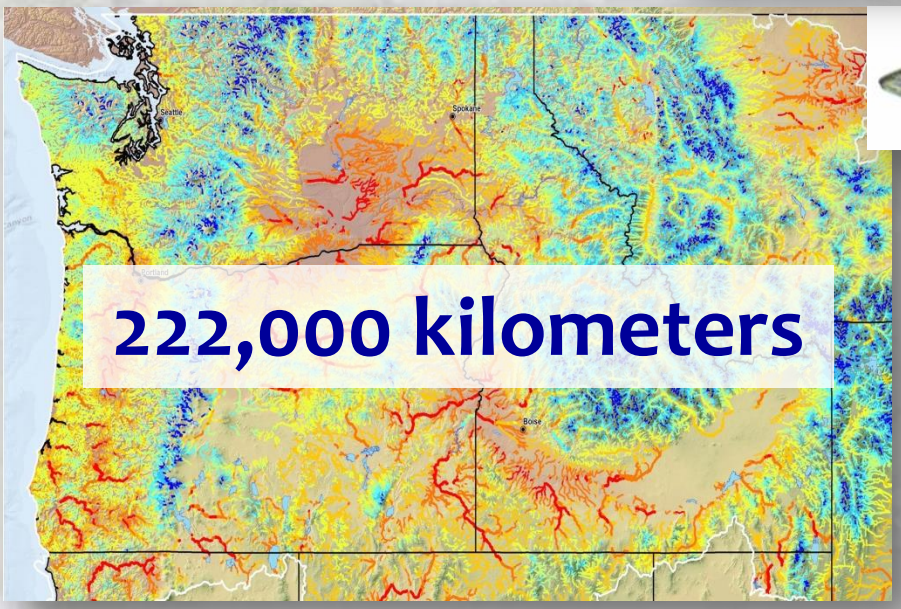
I'm going to invest here…

…not here



# Refuge Concept for Big Fish in Big Rivers

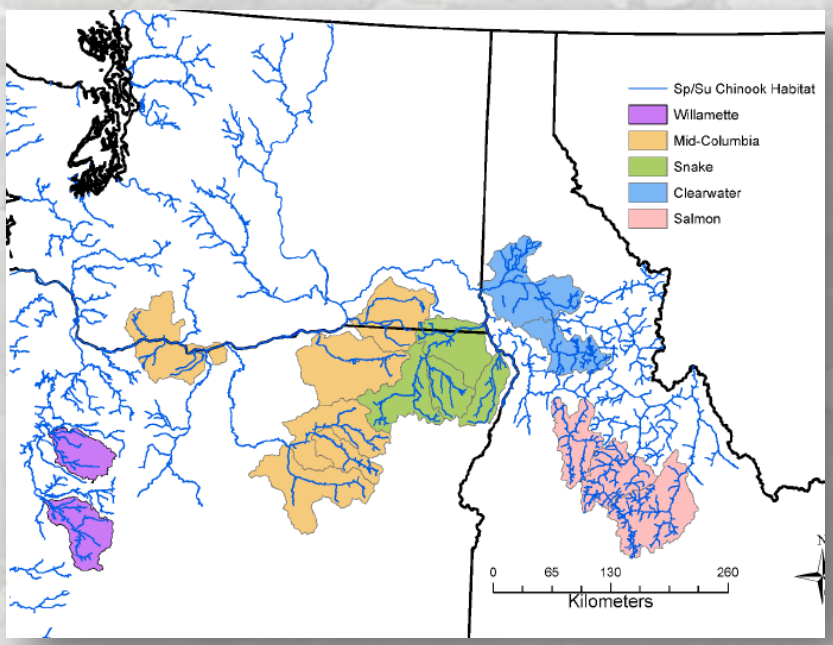


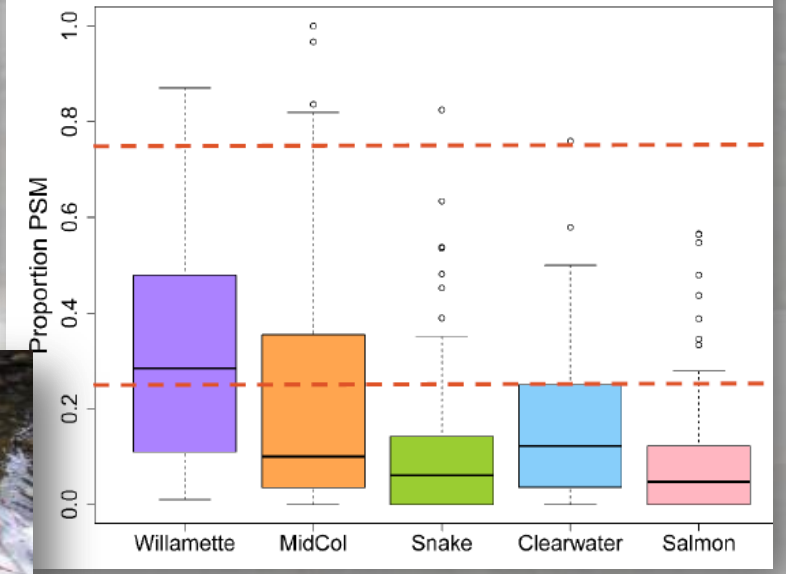

- Abundant high elevation refuges
- Body size not limiting
- Life cycle includes small areas

# An Application with Salmon

## Spatial variation in pre-spawn mortality



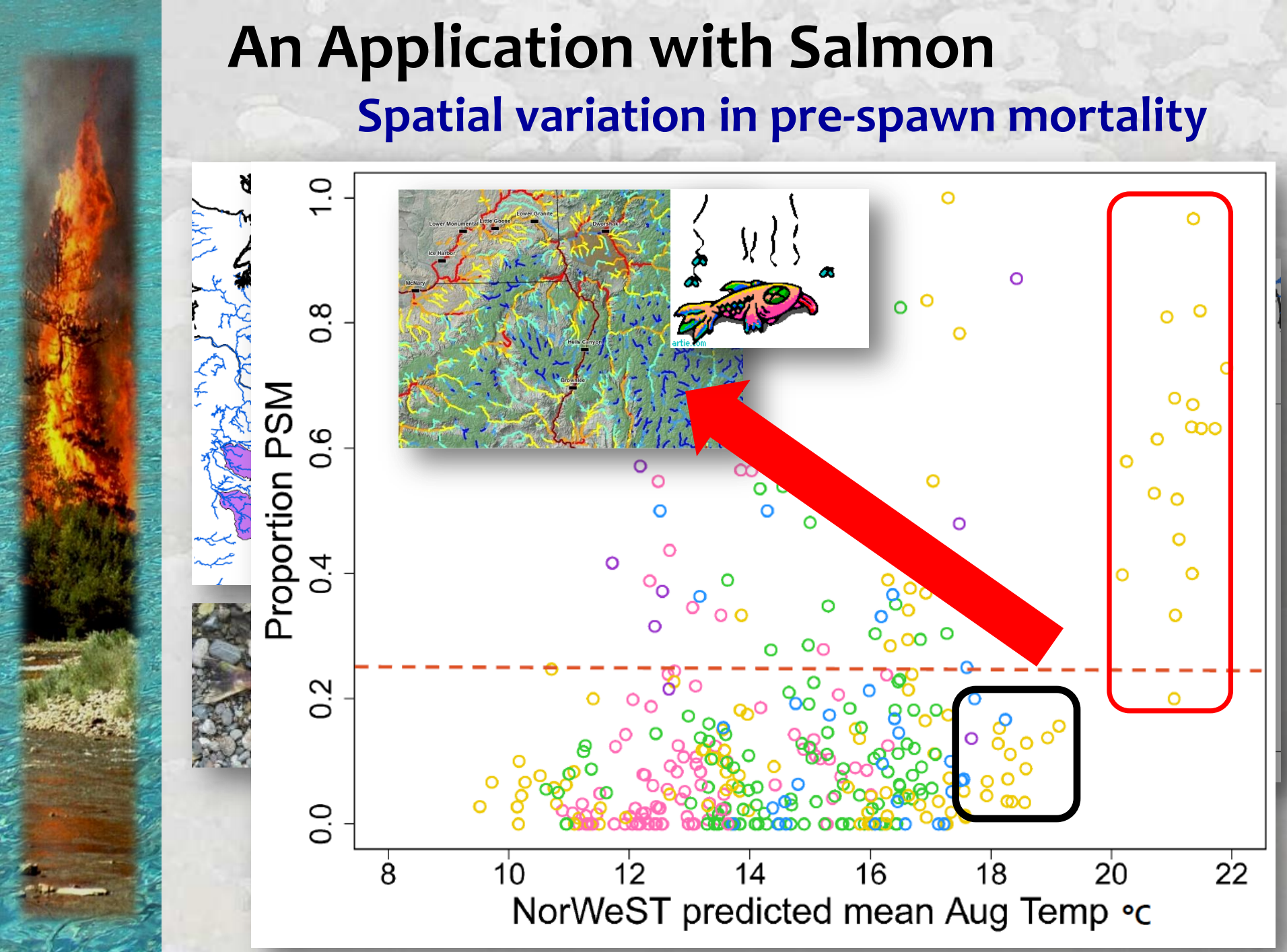

450 site years of PSM data
8 different agencies
3 ESUs




Bowerman, Keefer, & Caudill (U. Idaho)

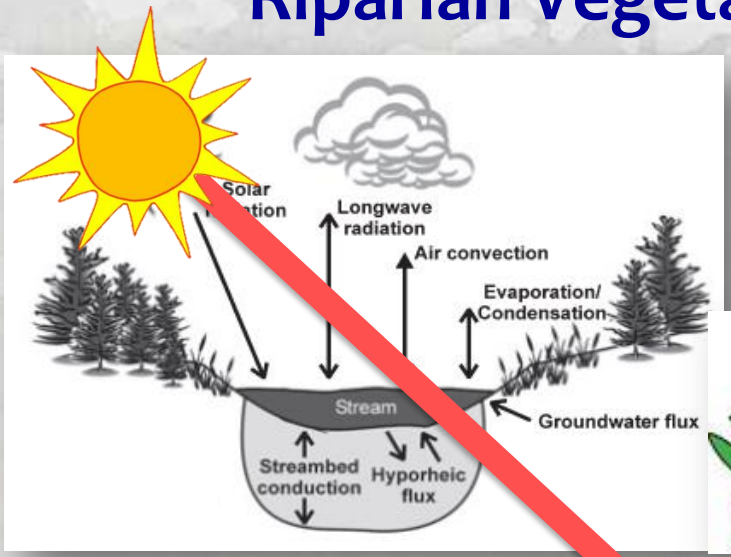
# An Application with Salmon

## Spatial variation in pre-spawn mortality

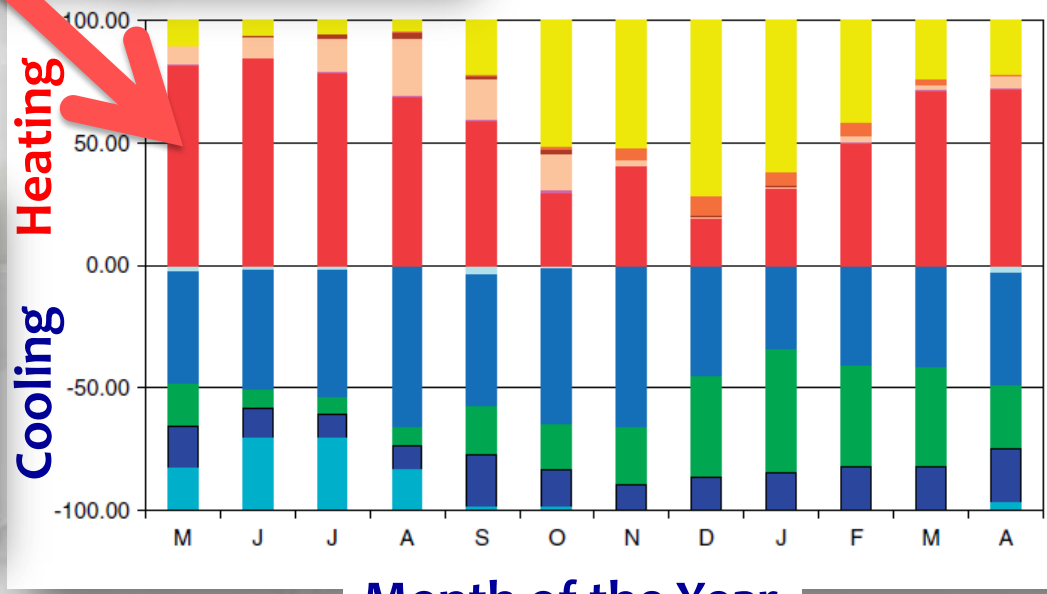


# Small & Medium Size Rivers

## Riparian Vegetation Restoration Can Help



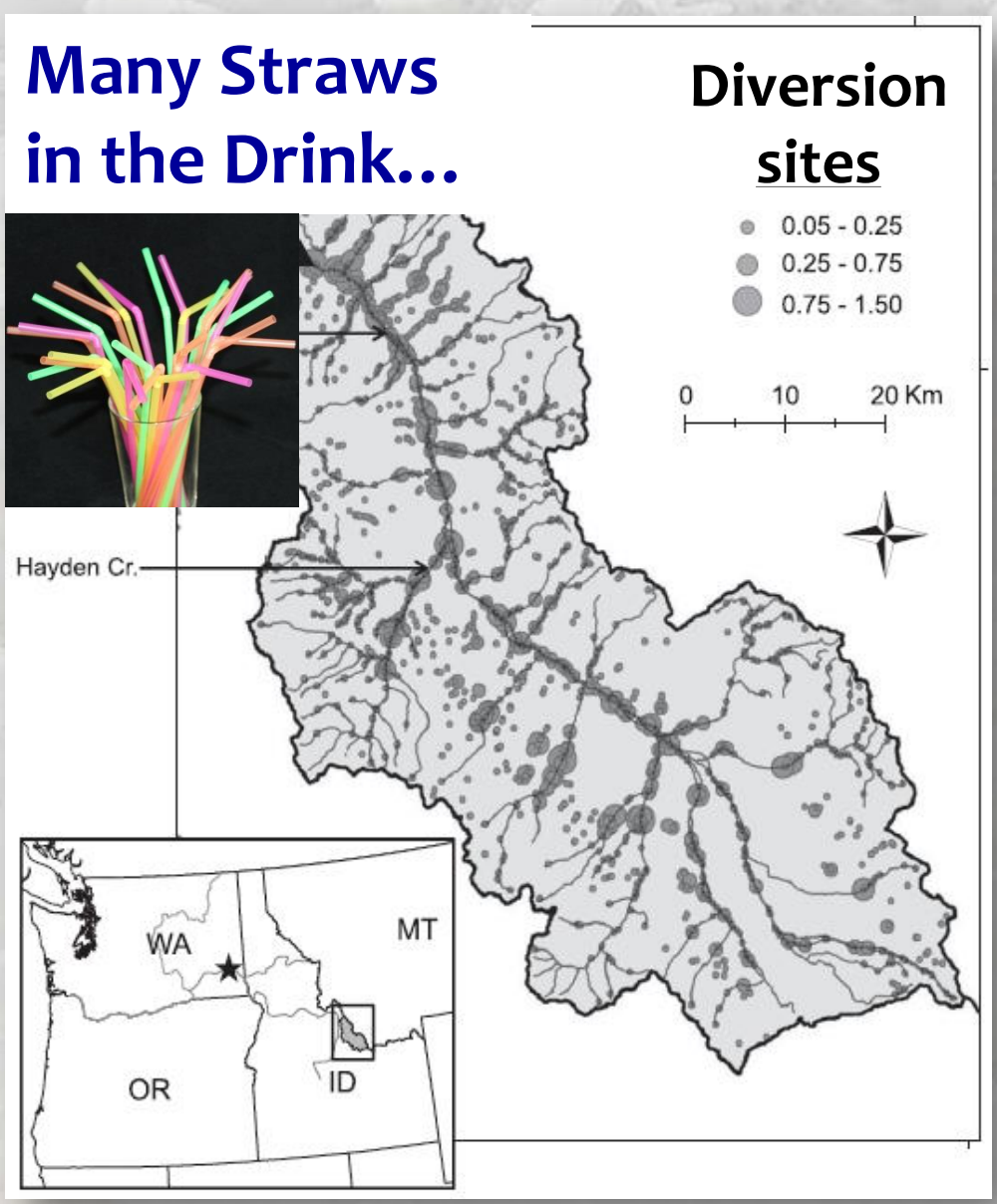

**Shading is THE most important factor…**




Webb et al. 2008

# More Summer Water Keeps Streams Cooler

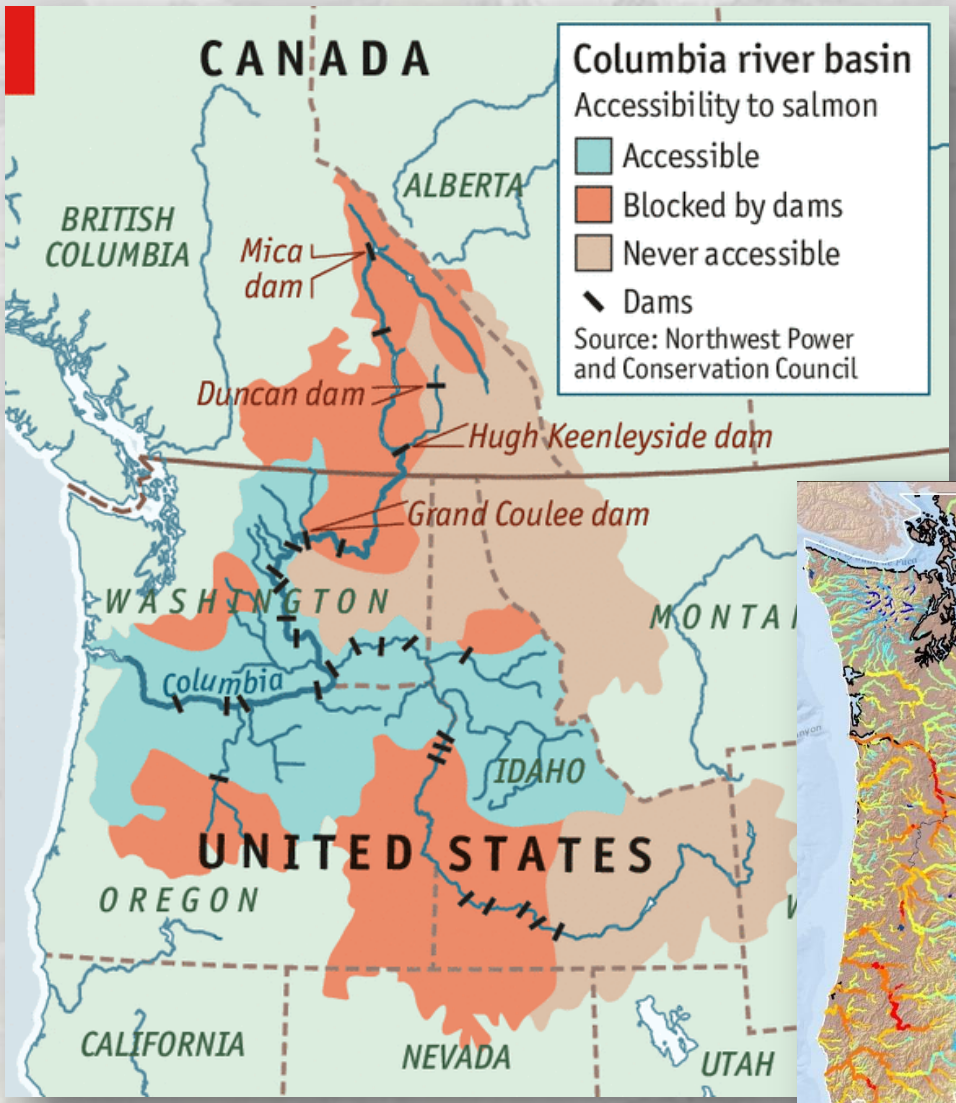
## Many Straws in the Drink…

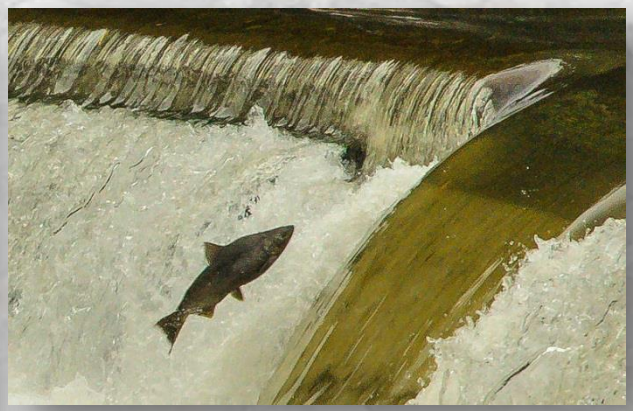


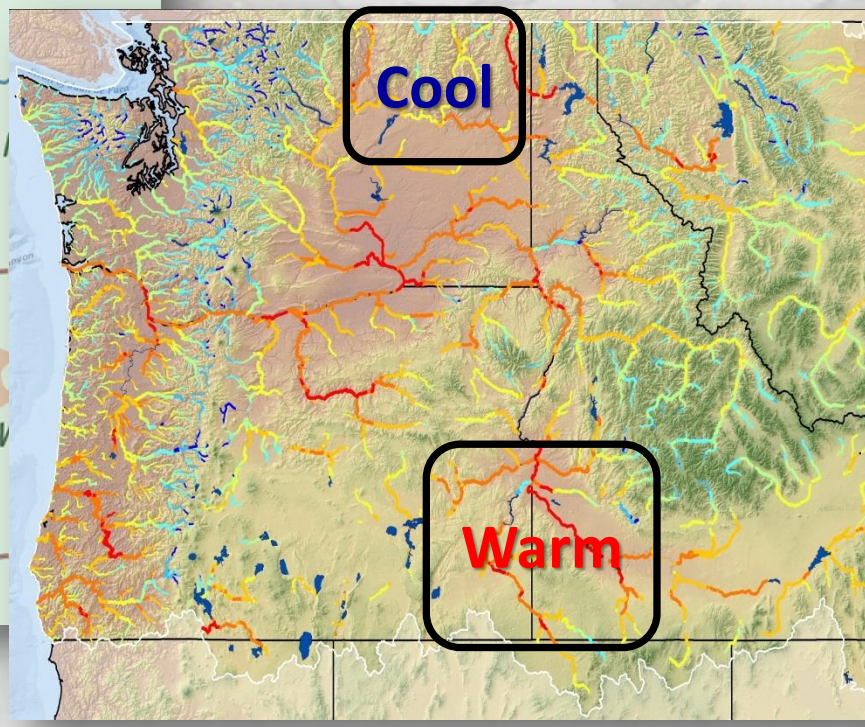

## Modernize Water Systems for Efficiency…

## Purchase Water Rights

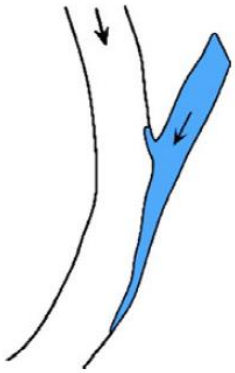
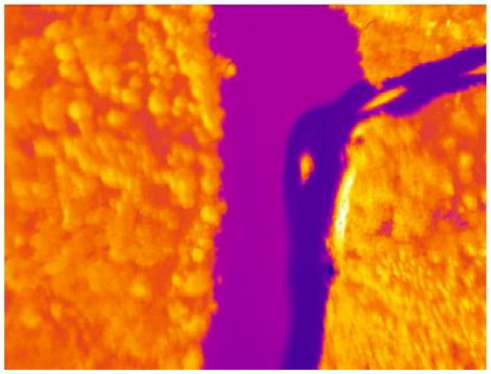
# Some Cool Salmon Rivers Blocked





# Cold Micro-refugia are Important Migration Waypoints Why Not Map Them all in PNW Rivers?

| Schematic | Optical image example | TIR image example |
|---|---|---|
|  |  |  |

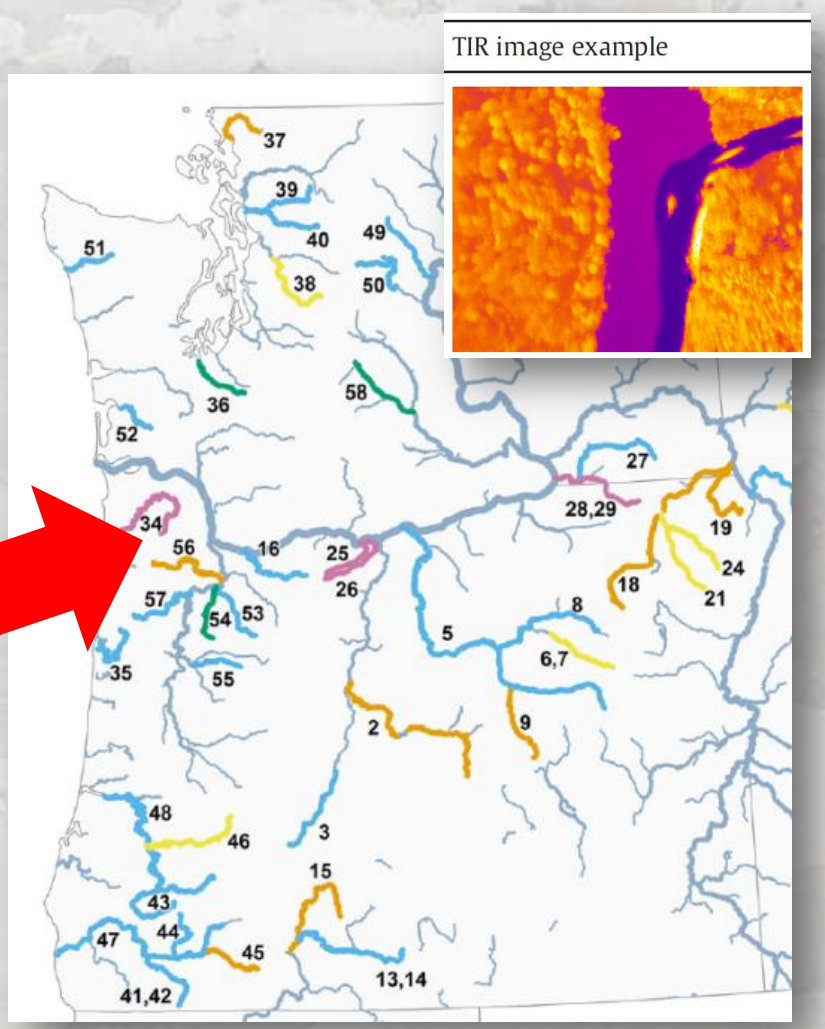
**Technology exists & becoming cheaper…**

**Drone mounted cameras**

Torgersen et al. 1999; 2012

# Some Rivers Already Have Thermal Imagery

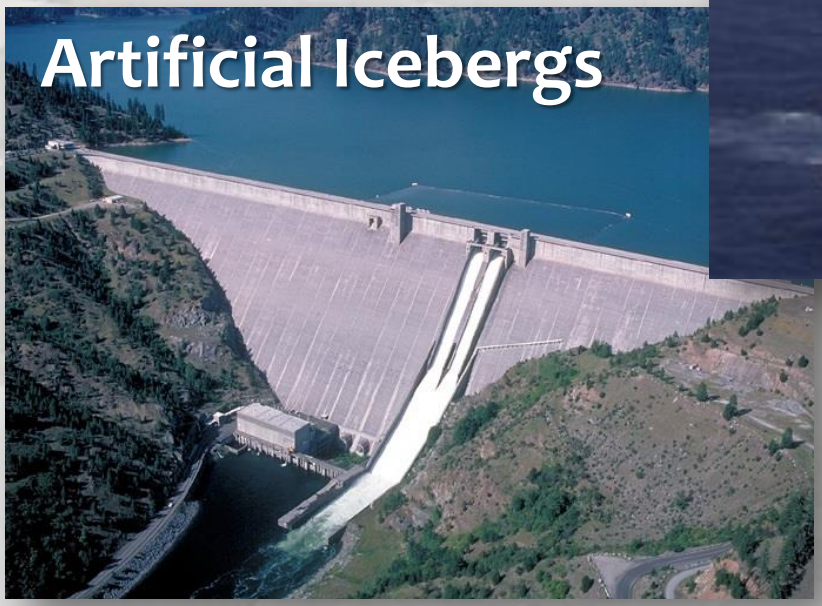
## Website & User-Friendly Digital Formats Needed to Provide Access…

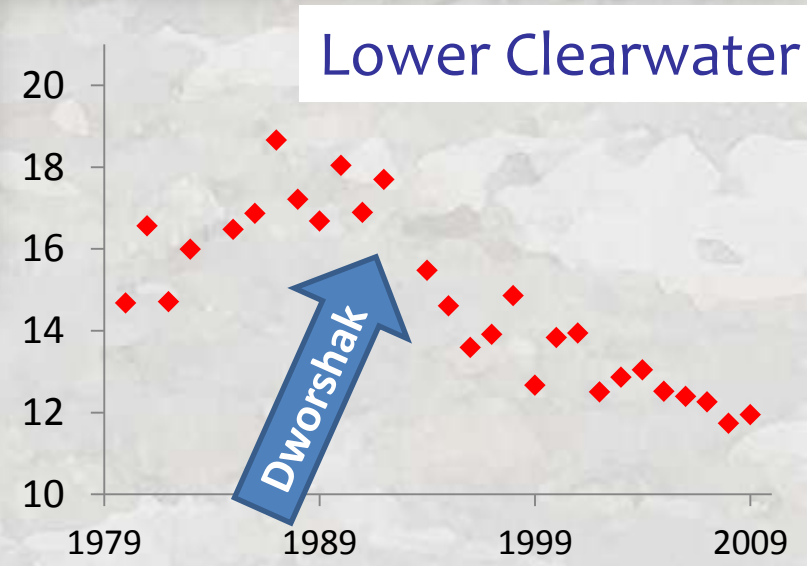




Fullerton et al. 2015

## Protecting Something Requires Knowing Where it Is…

# Options for Cooling Largest Rivers are Limited…

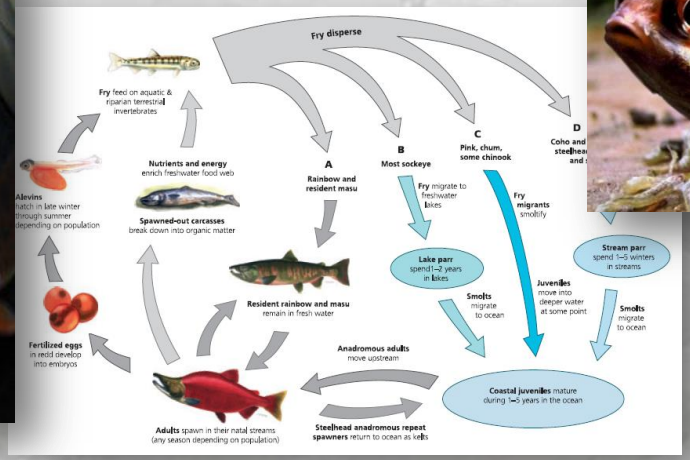




- Deep reservoir needed for cold water creation

# Accelerate Evolution?

## Hatchery selection of migration timing

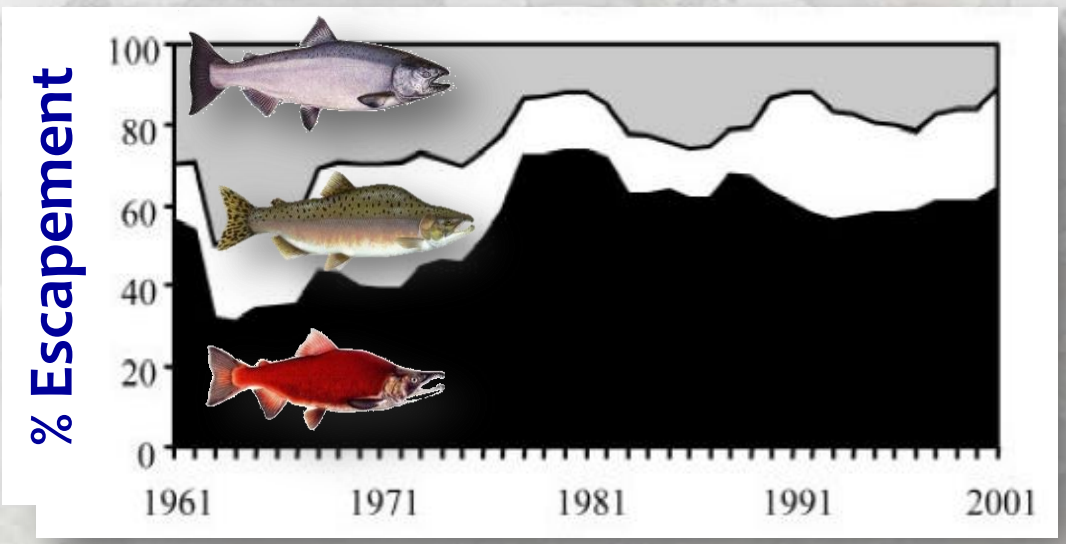



| Trait | Evolutionary Potential |
|---|---|
| Heat tolerance | Low |
| Disease resistance | Low to moderate |
| Upstream migration timing | High |
| Spawning date | High |
| Emergence date | Low |
| Juvenile growth | Low |
| Downstream migration timing | ? |
| Ocean residence | ? |

Crozier et al. 2008

# Biocomplexity Will Buffer Future Changes

Extinction not happening

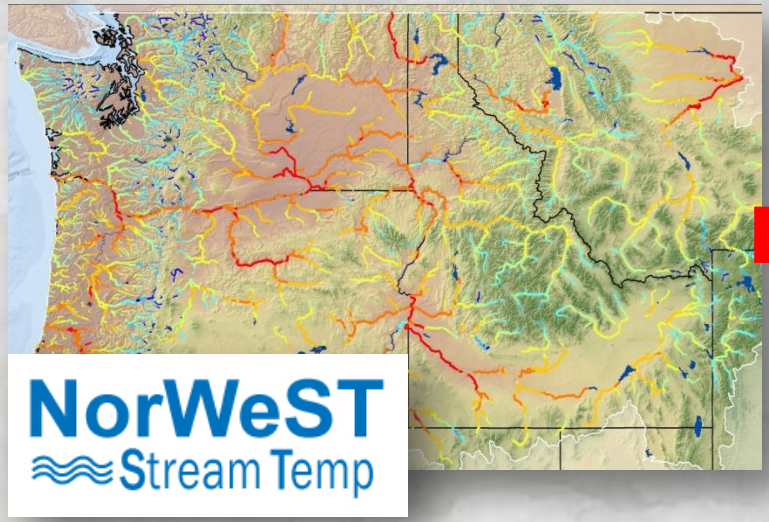


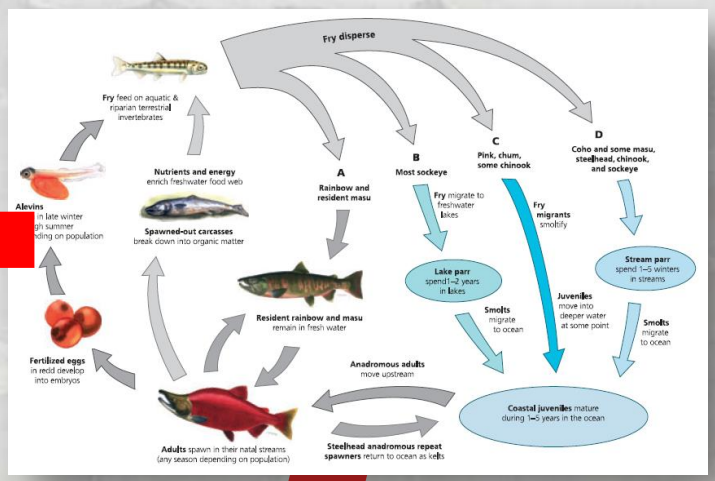

…But some species (or runs) will experience long-term declines in abundance

Summer runs

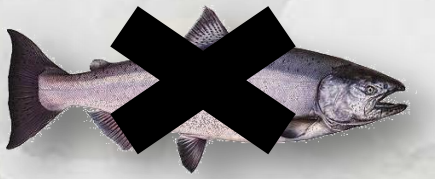
Fall/winter runs

# Integrate Salmon Life Cycle Models & Stream Climate Scenarios




Yes

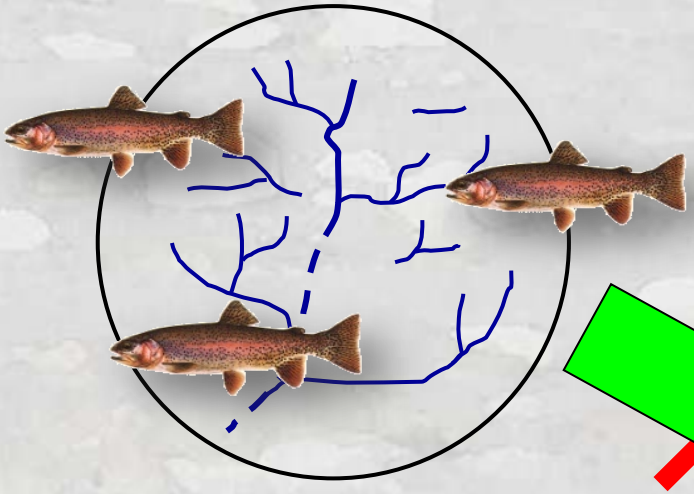


NO

**Spatially explicit predictions for investment planning…**

# A Different Mindset is Required…

## We can't save everything

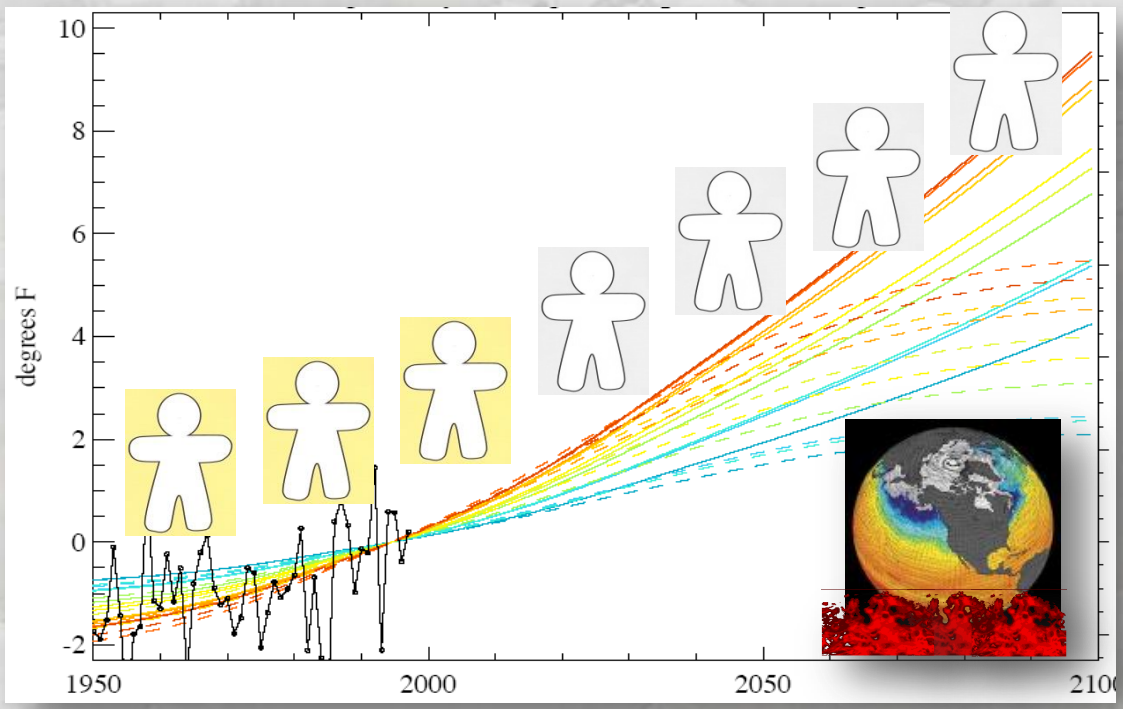


Sorry Charlie

# Inter-Disciplinary, Inter-Agency Spirit will Be Needed…

## PNW is a World Leader

# Inter-Generational Commitment




**This can be our Finest Century**



Global Warming Is ...
NOT COOL!
The End

# Identifying, protecting, and enhancing climate refugia for salmonids

Dan Isaak and Mike Young, US Forest Service

Climate change in the PNW has been gradually warming rivers and reducing snowpacks and runoff for several decades. Those trends are likely to continue for the next several decades and maybe longer depending on the evolution of human energy economies and future greenhouse gas emissions. Climate cycles associated with the Pacific Decadal Oscillation and El Nino will periodically dampen or exacerbate environmental trends, but populations of salmon and trout that require cold water to survive will be subject to increasing amounts of thermal stress for the foreseeable future. Many populations of resident salmonid species like bull trout or cutthroat trout that live in steep, cold headwater streams can persist simply by shifting their distributions towards higher elevation refuge habitats. But adaptation is more challenging for populations of anadromous fish that migrate through large rivers during warm periods. Warming trends of those rivers are difficult or impossible to stop so shifts in migration timing by natural and hatchery selection are needed. Near spawning grounds, habitat restoration strategies that maximize riparian vegetation shade or instream flows may be beneficial. Facilitating access of anadromous fish to cooler river habitats that are blocked by dams or natural barriers could also be a viable option in a few instances. High-resolution stream temperature and flow scenarios are