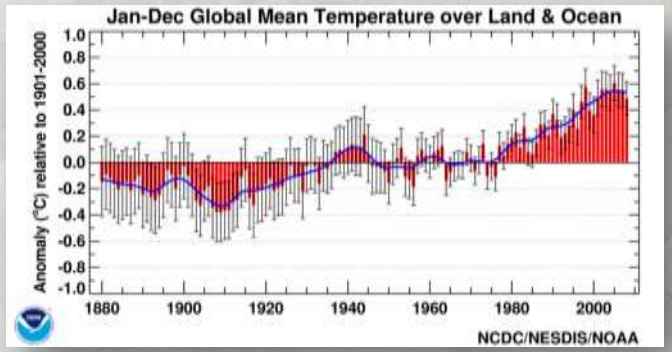
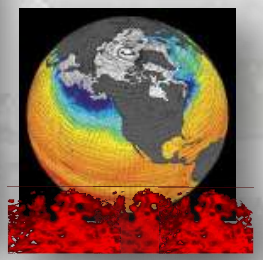
Climate Change, Crowd-Sourcing, BIG DATA & 21st-Century Conservation of Native Fishes in the Rocky Mountains

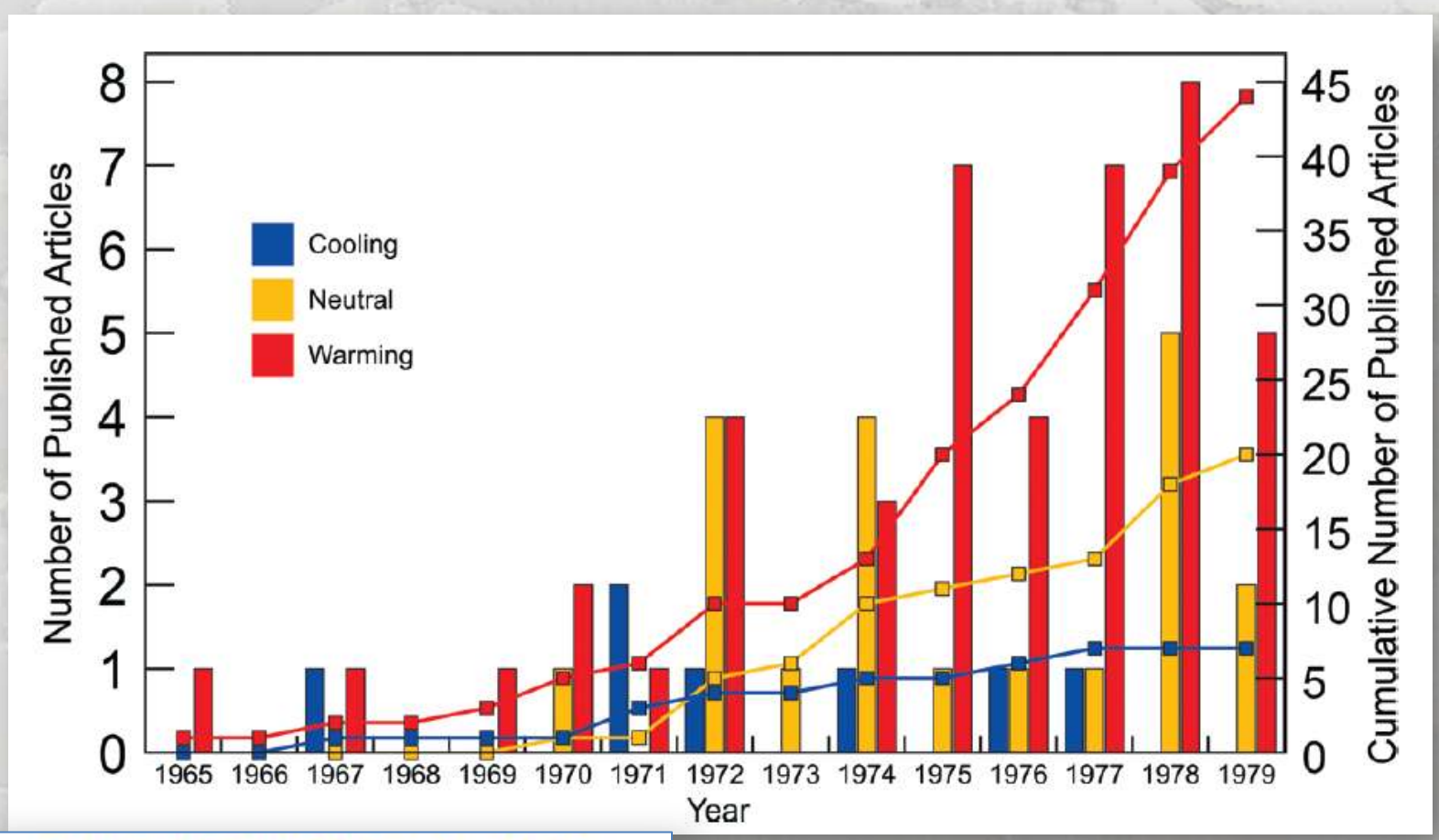
Dan Isaak, US Forest Service

Rocky Mountain Research Station





Predictions of Global Warming Emerged as the Scientific Consensus ~40 Years Ago…

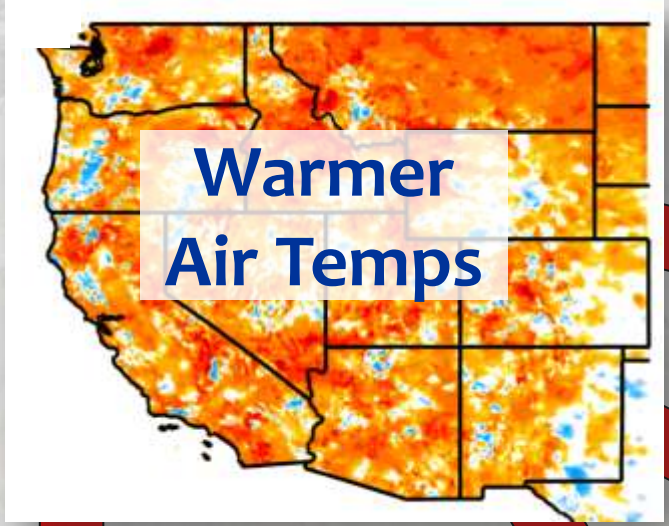


THE MYTH OF THE 1970s GLOBAL COOLING SCIENTIFIC CONSENSUS

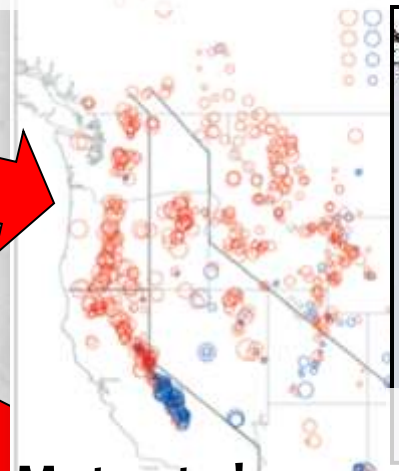
Peterson et al. 2008. *Bull. Amer. Metero. Soc.* **89**:1325-1337.

And GCM Predictions Have Been Accurate

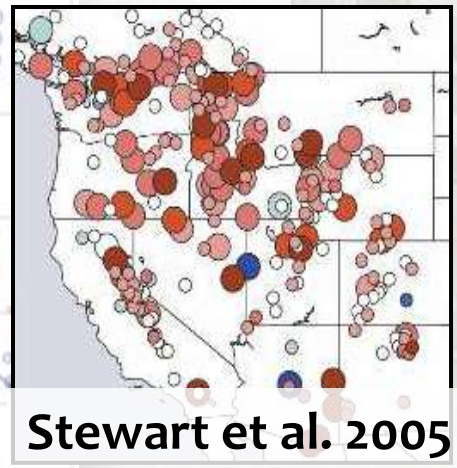
Climate Effects in Western U.S. (1950 – 2009)



Less Snow & Earlier Runoff

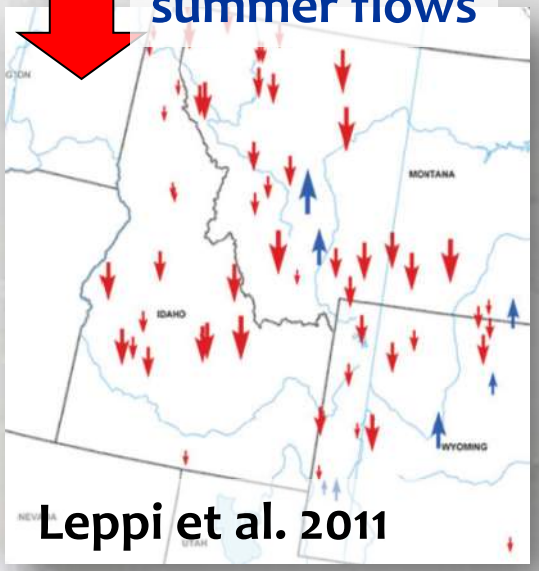


Mote et al. 2005



Stewart et al. 2005

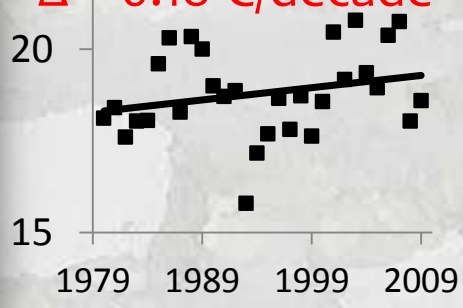
Decreasing summer flows



Leppi et al. 2011

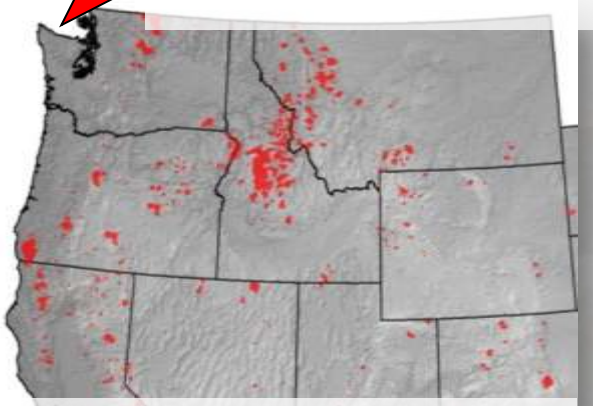
Stream Temp Increases

Δ = 0.18°C/decade



Isaak et al. 2012

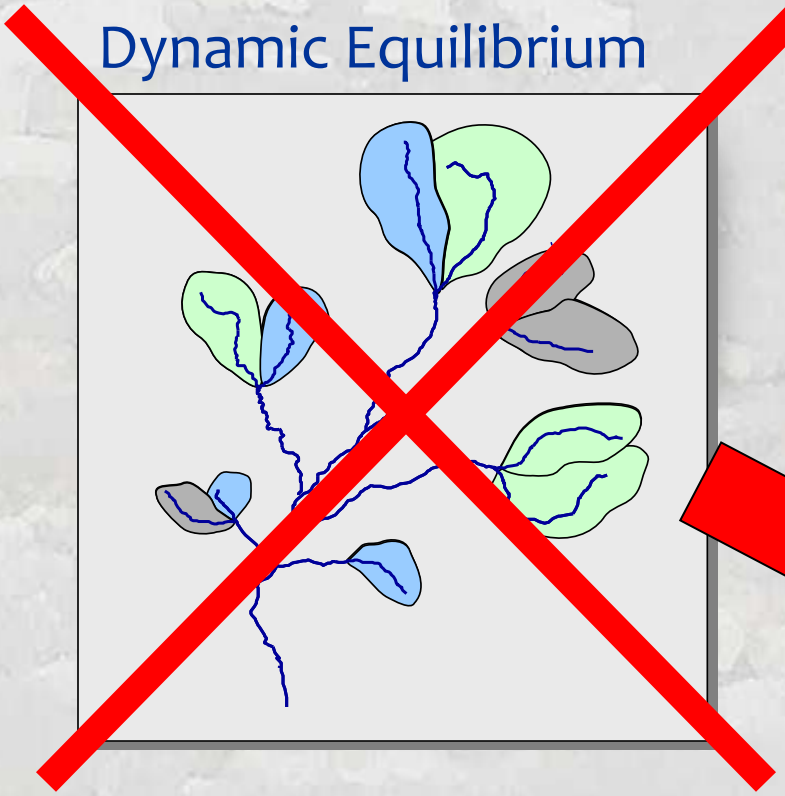
Wildfire Increases



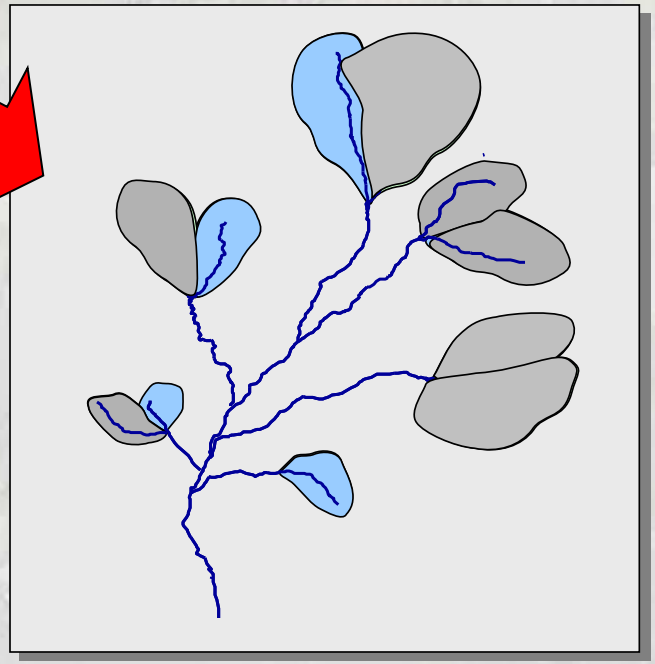
Westerling et al. 2006

“Balance of Nature” Paradigm no Longer Valid

Dynamic Equilibrium

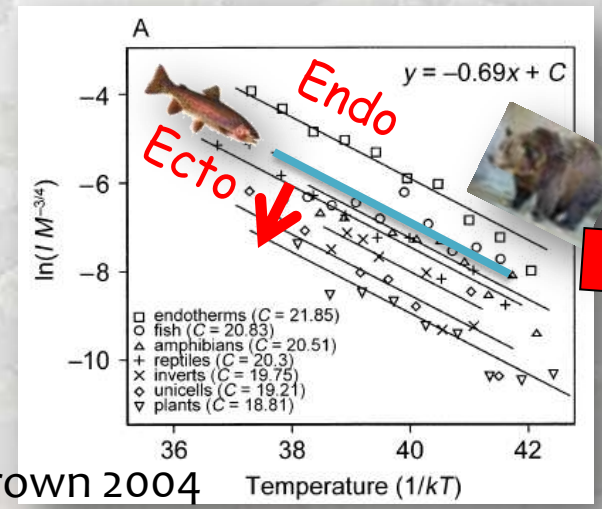


Dynamic Dis-Equilibrium



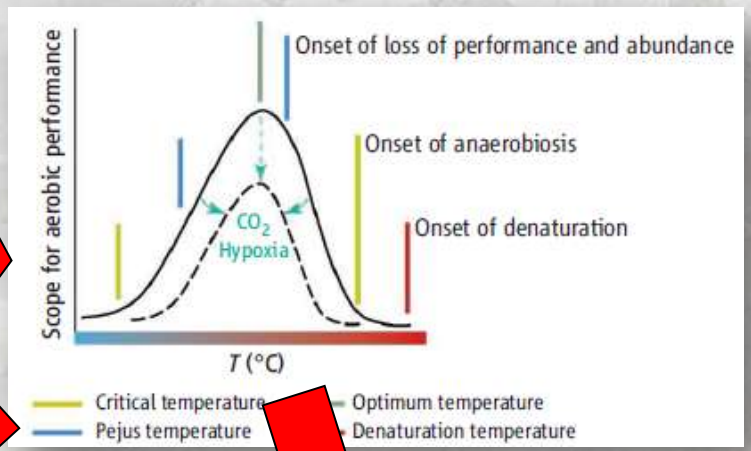
Temperature is Primary Control for Aquatic Ectotherms

Metabolism

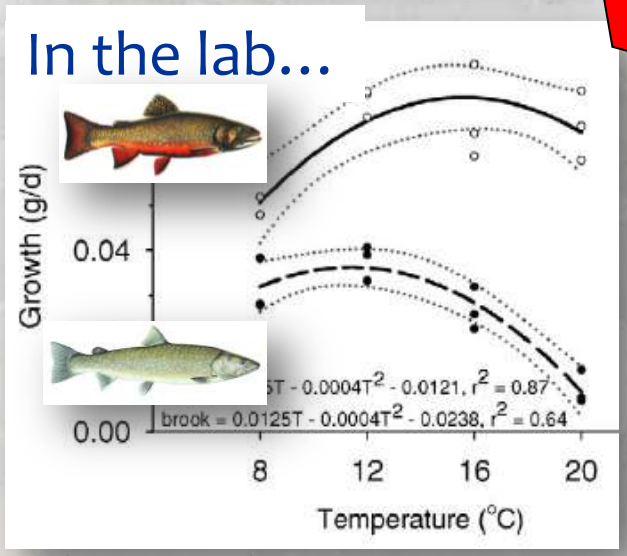


Brown 2004

Thermal Niche

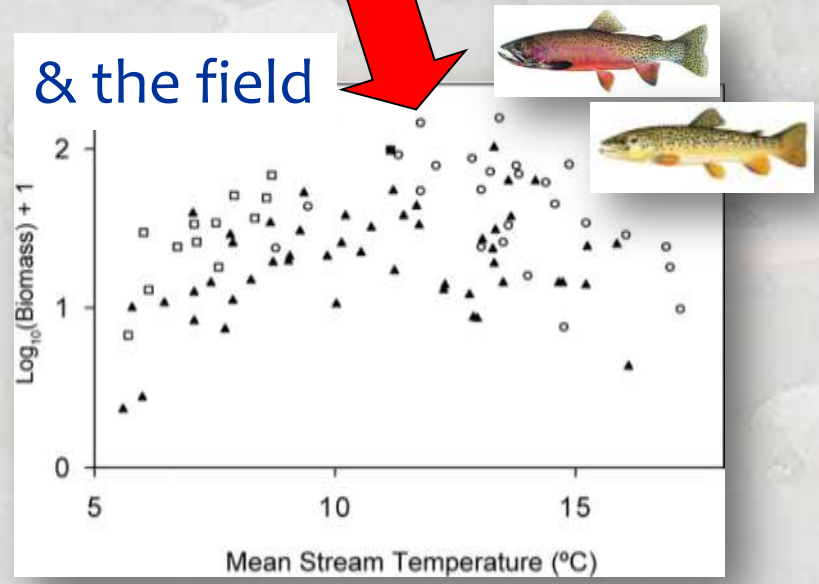


In the lab…



McMahon et al. 2007

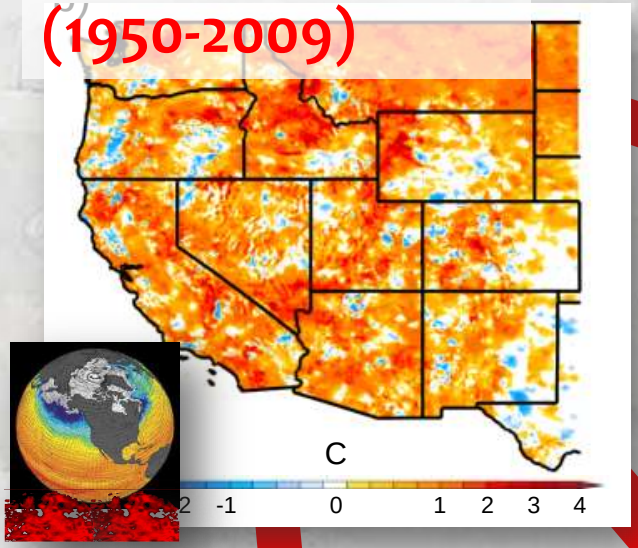
& the field

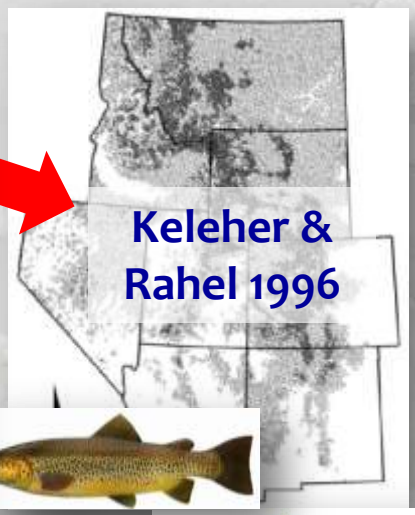


Isaak & Hubert 2004

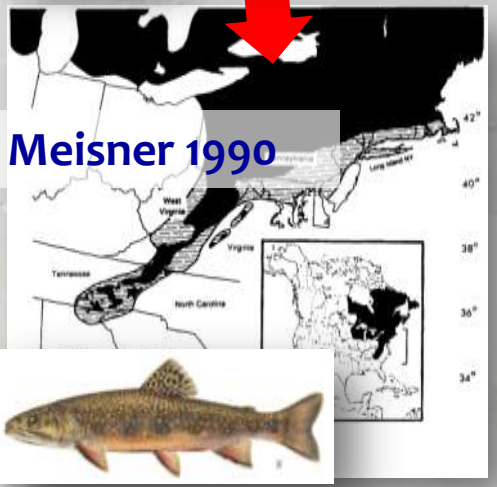
If You're a Coldwater Fish Like Trout, The Future Ain't so Pretty…

Air Temp trends (1950-2009)

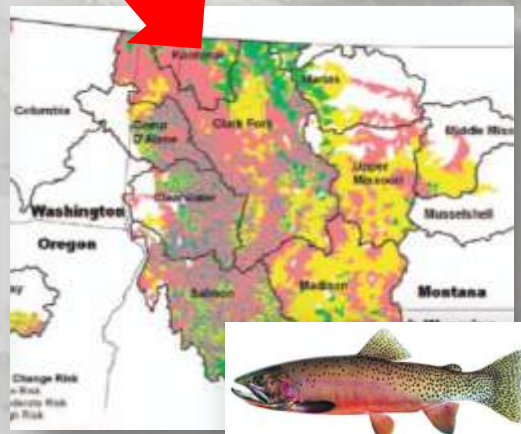


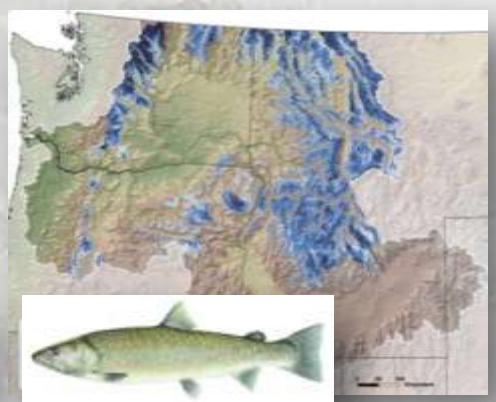


Keleher & Rahel 1996



Meisner 1990



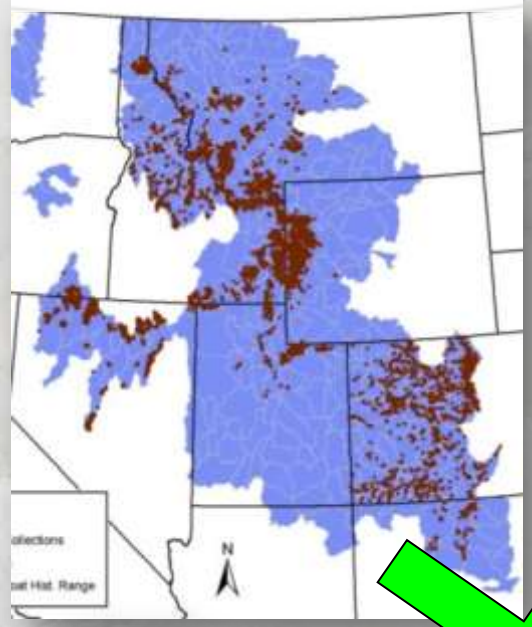


Many Others…

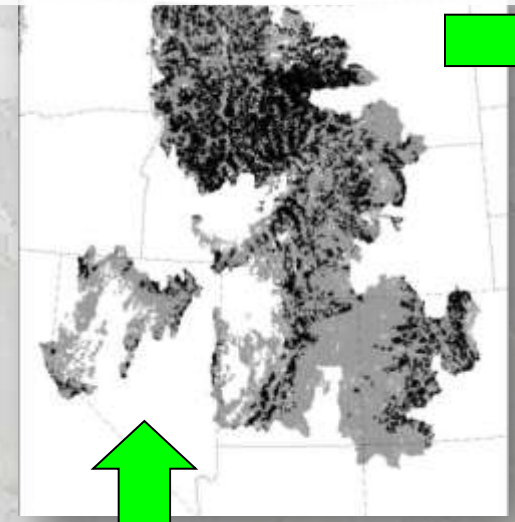
- Isaak et al. 2010
- Eaton & Schaller 1996
- Reusch et al. 2012
- Rahel et al. 1996
- Mohseni et al. 2003
- Flebbe et al. 2006
- Rieman et al. 2007
- Kennedy et al. 2008
- Williams et al. 2009
- Wenger et al. 2011
- Almodovar et al. 2011

Rocky Mountain Trout Climate Assessment

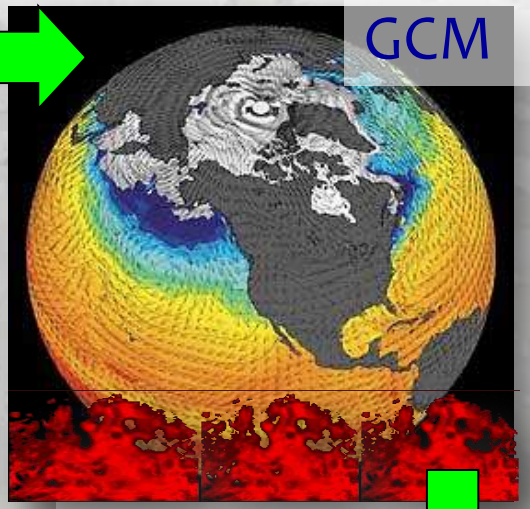
Fish survey database
~10,000 sites



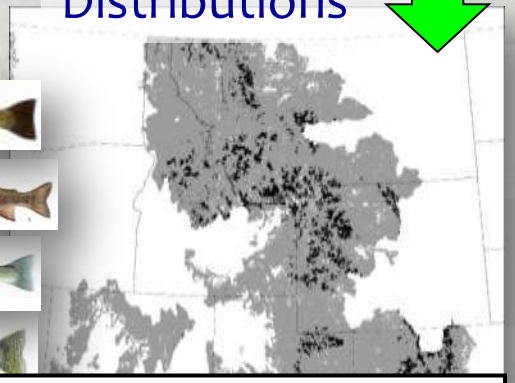
Historic Distributions



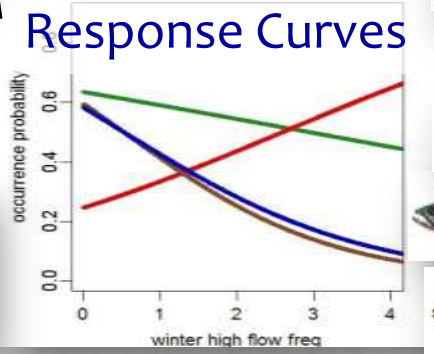
GCM



Future A1B Distributions



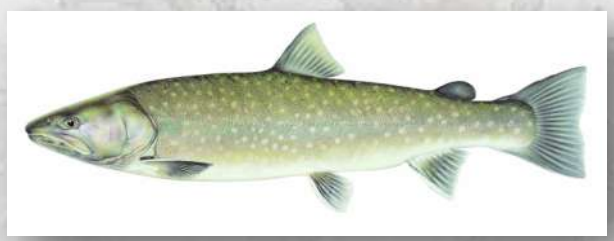
Species-Specific Habitat Response Curves



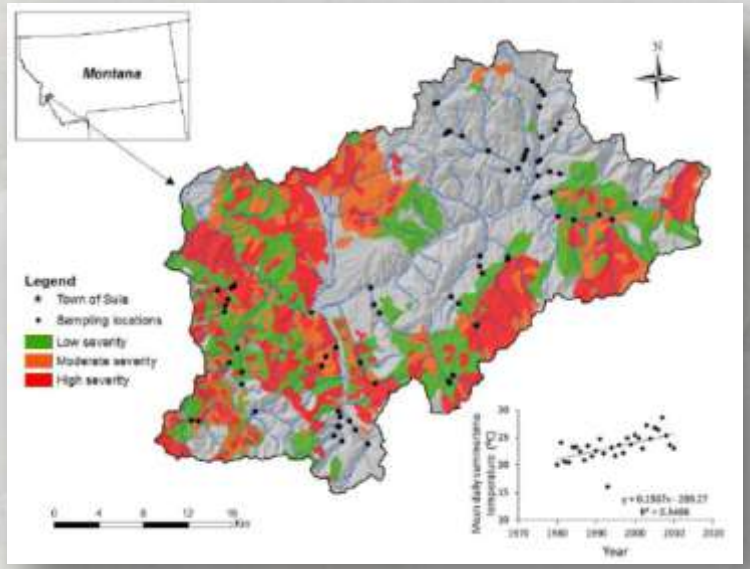
~50% reduction by 2080 under A1B

Wenger et al. 2011. *PNAS* **108**:14175-14180

Distribution Shifts in Montana Bull Trout Populations



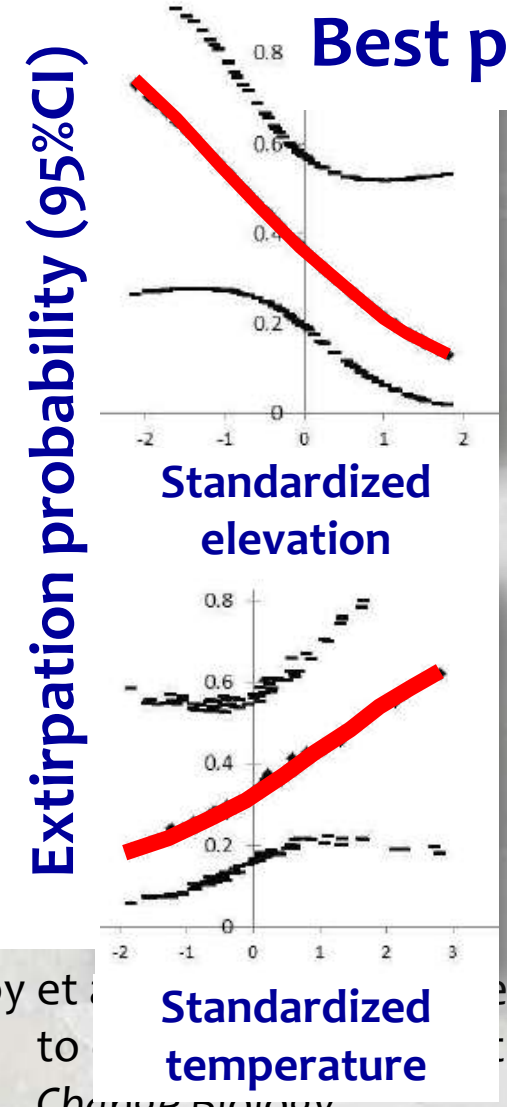
- Resurveyed Rich et al. 2003 sites 20 years later
- 77 sites, 500 m in length
- Modeled extirpations/colonizations accounting for detection efficiency

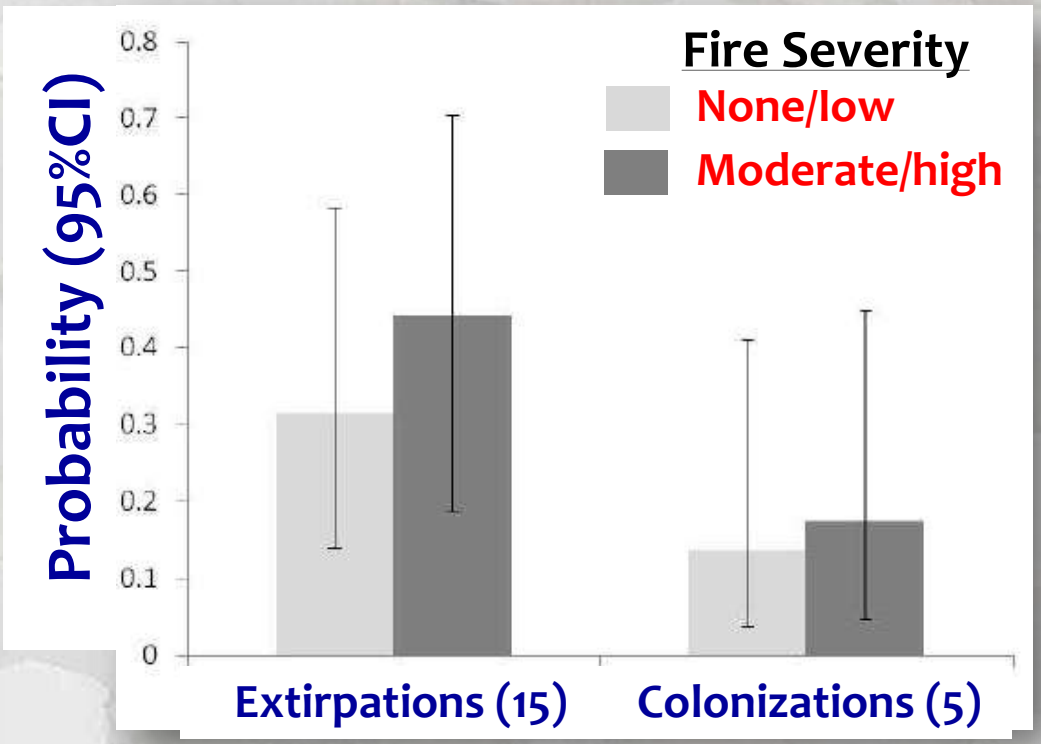


Eby et al. In Press. Evidence of climate-induced range contractions for bull trout to cooler, higher elevation sites in a Rocky Mountain watershed, U.S.A. *Global Change Biology*

Distribution Shifts in Montana Bull Trout Populations

Best predictors

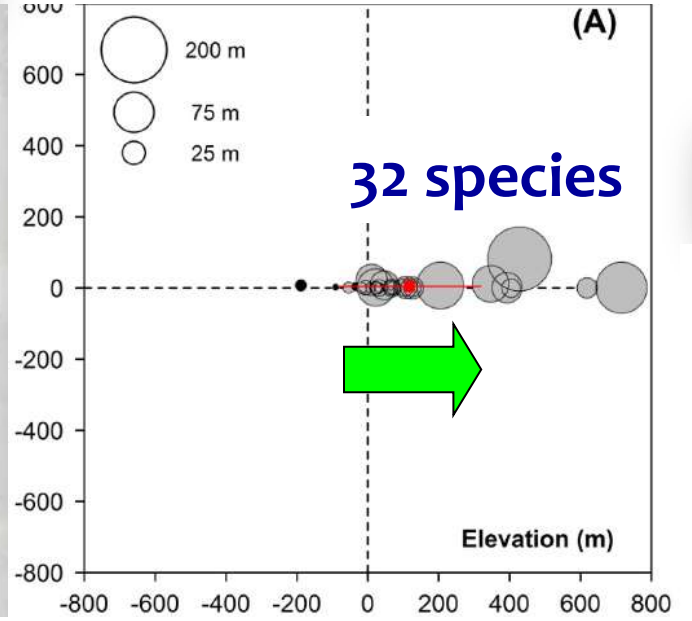




Eby et a[illegible] of climate-induced range contractions for bull trout to [illegible]tion sites in a Rocky Mountain watershed, U.S.A. *Global Change Biology*

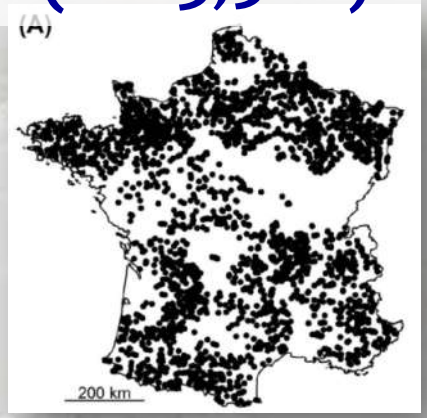
French Study Documents National Changes

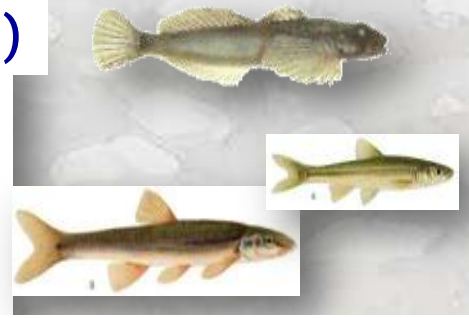
Difference in stream fish distributions (1980's vs 2000's)



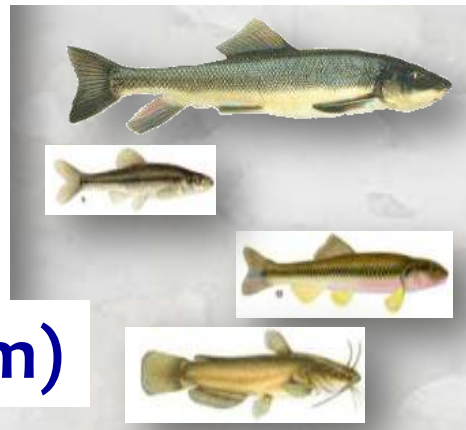
Change in Elevation (m)

Survey sites (n = 3,500)



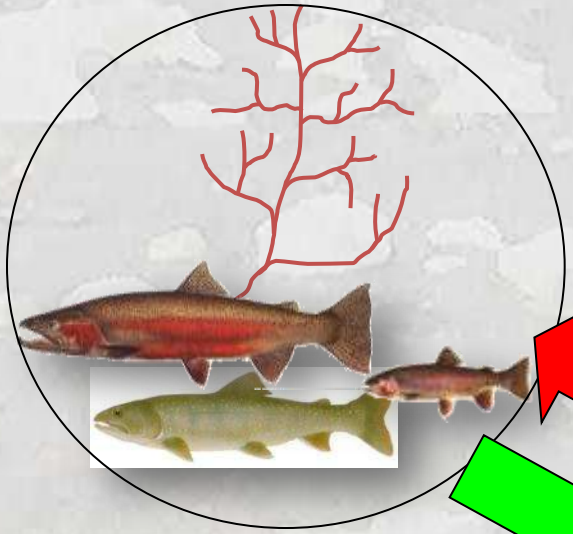


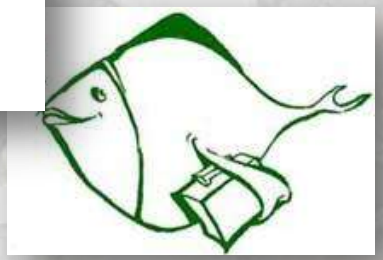
March of the fishes…

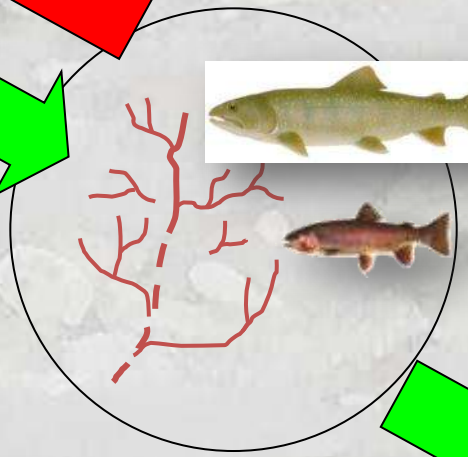


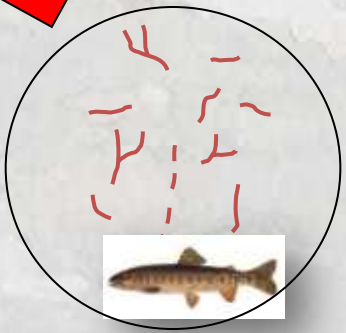
Comte & Grenouillet. 2013. Do stream fish track climate change? Assessing distribution shifts in recent decades. *Ecography* doi: 10.1111/j.1600-0587.2013.00282.x

Warm & Cool Water Fishes May Benefit

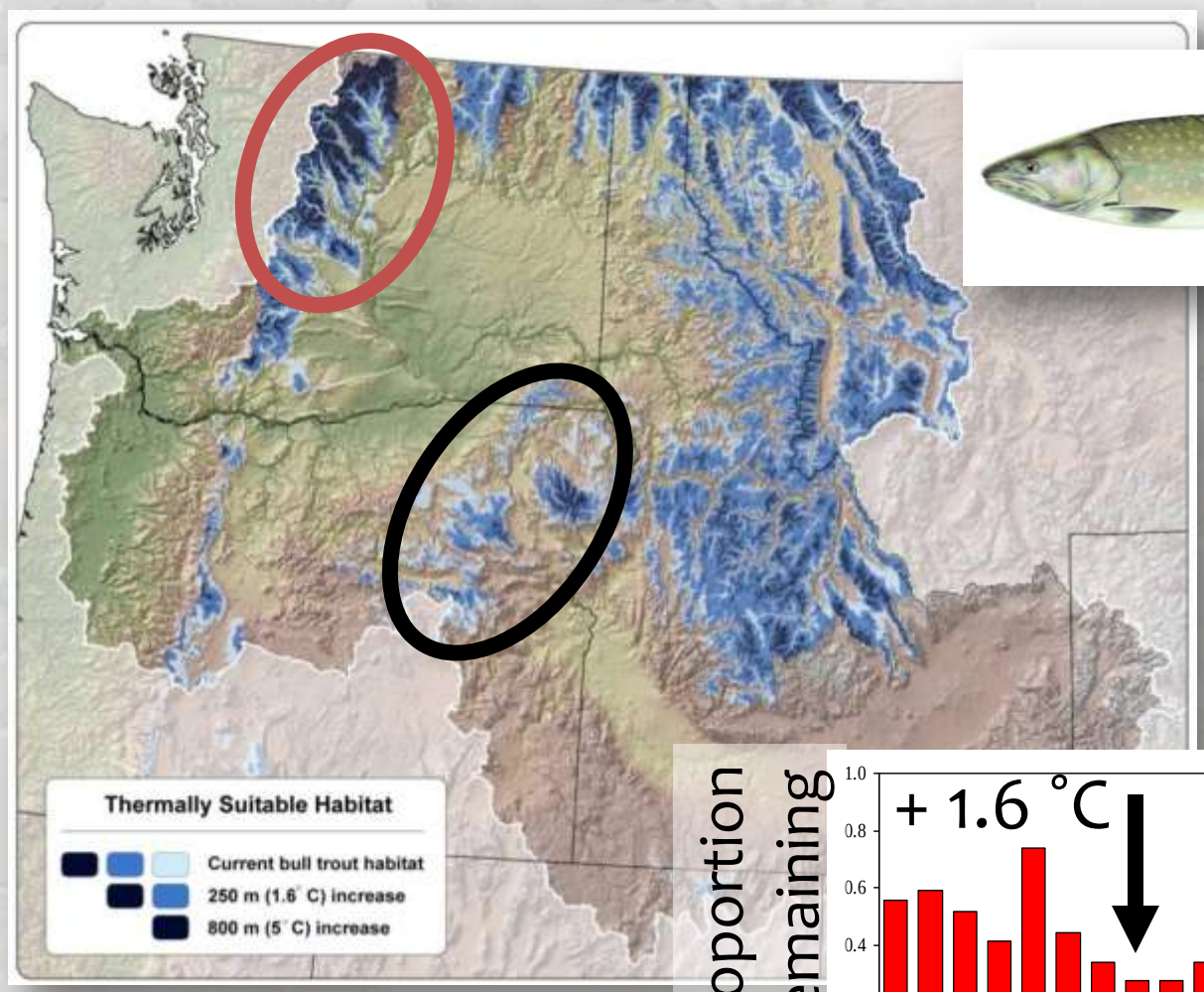


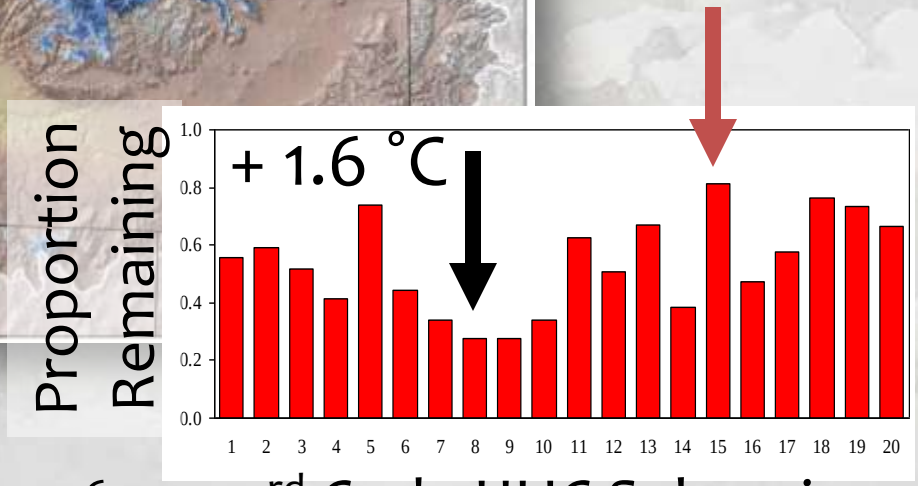






Rates of Change Will Vary Geographically

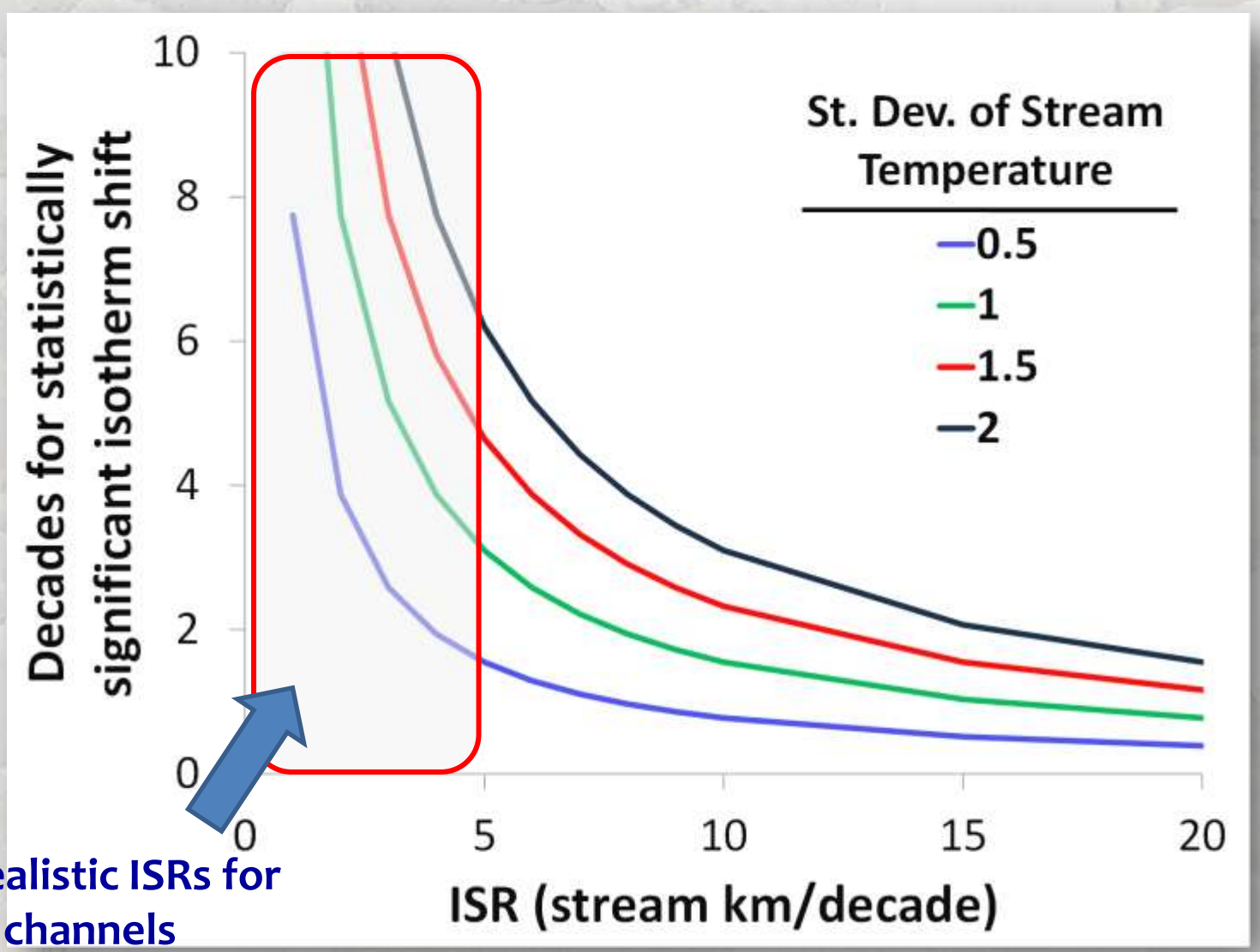




Rieman et al. 2007. *TAFS* **136**:1552-1565

Changes Will Happen Slowly

20 – 60 years for significant isotherm shifts



Isaak & Rieman. 2013. *Global Change Biology* **19**:742-751.

Changes Will Happen Slowly

20 – 60 years for significant isotherm shifts

Occur Over The Span of Careers

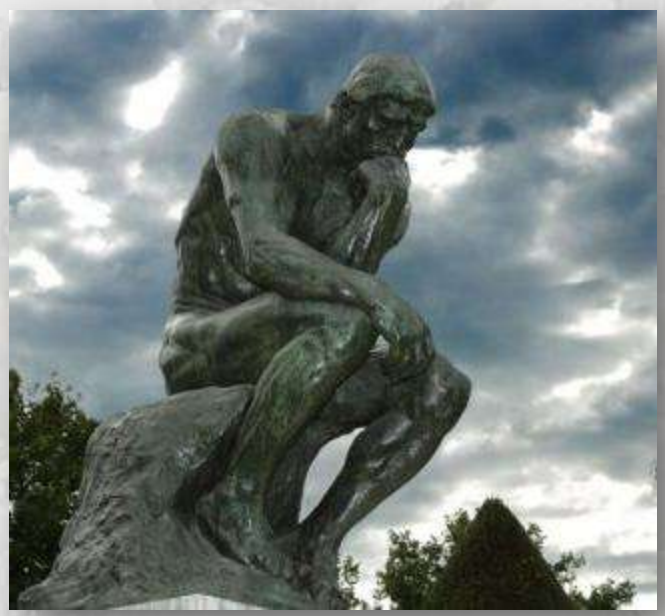
Future fish squeezer

Emeritus fish squeezer

Isaak & Rieman. 2013. *Global Change Biology* **19**:742-751.

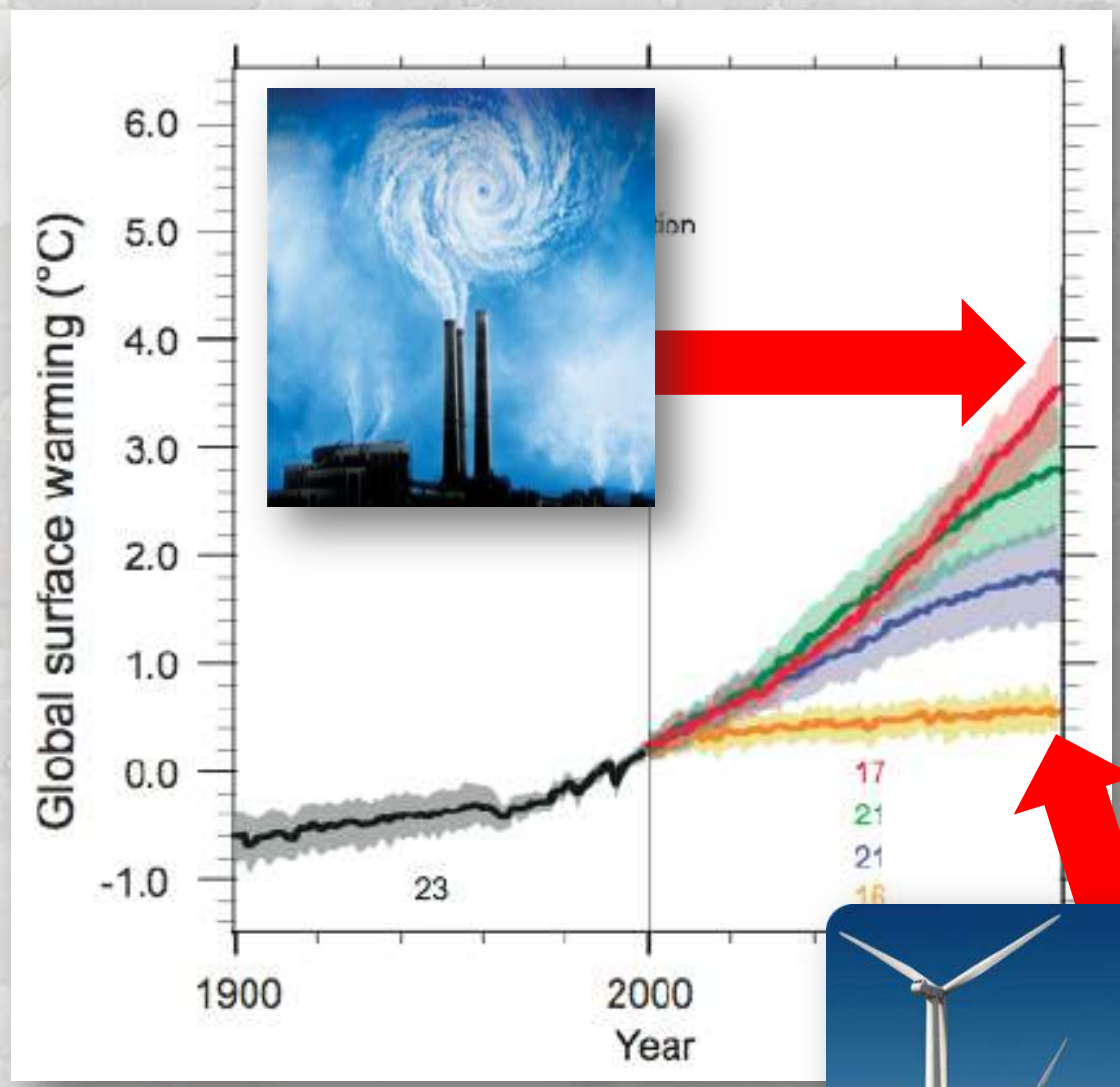
Time is a Double-Edged Sword

Strategic planning is possible, but…



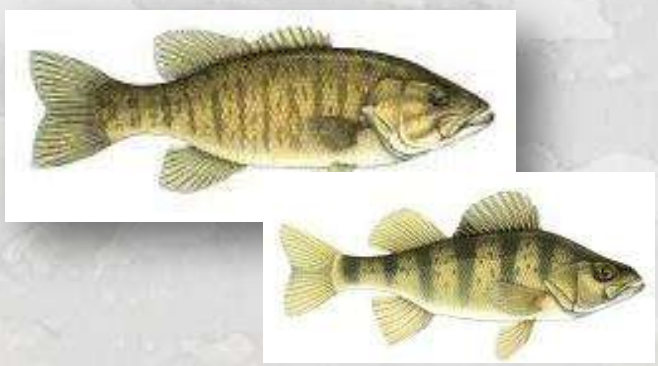
…urgency may be lacking

Current Choices Set Future Trajectories

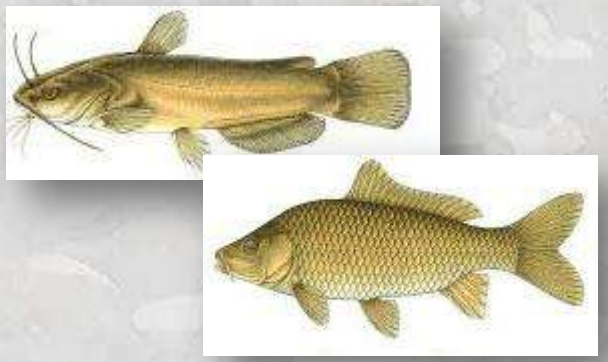


Current Choices Set Future Trajectories

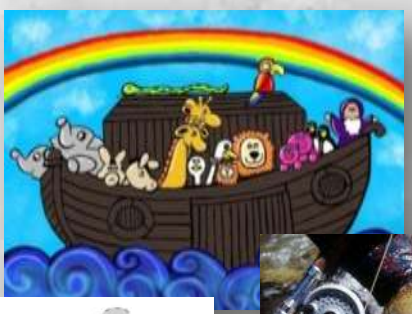
Choice A: Coexistence (accept change passively &/or shape transition to more desirable communities)



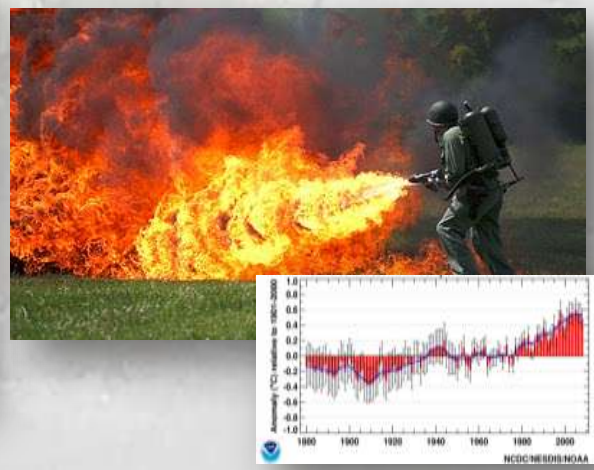
OR?



Choice B: Resistance (protect native biodiversity & other currently valued resources)

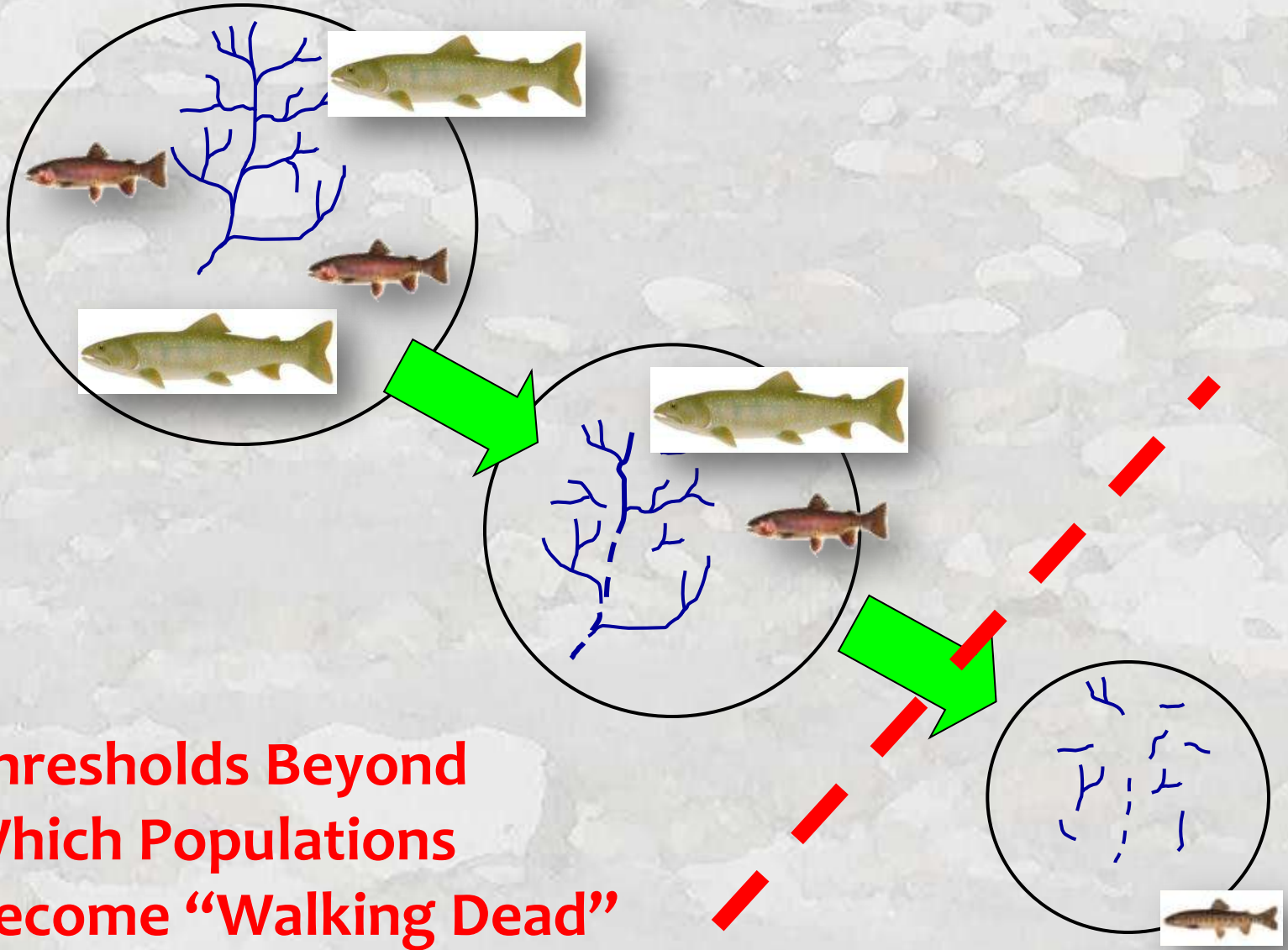


Conservation reserves, important fisheries



Resistance Will Be Futile Sometimes

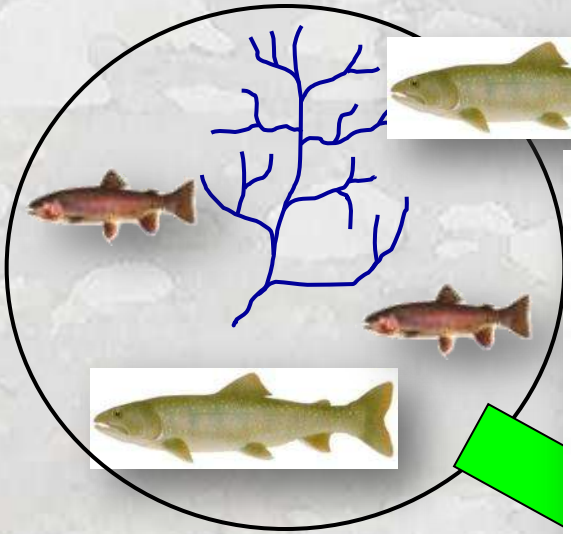
Not Everything Can be Saved



Thresholds Beyond Which Populations Become "Walking Dead"

Resistance Will Be Futile Sometimes

Not Everything Can be Saved



Sorry Charlie

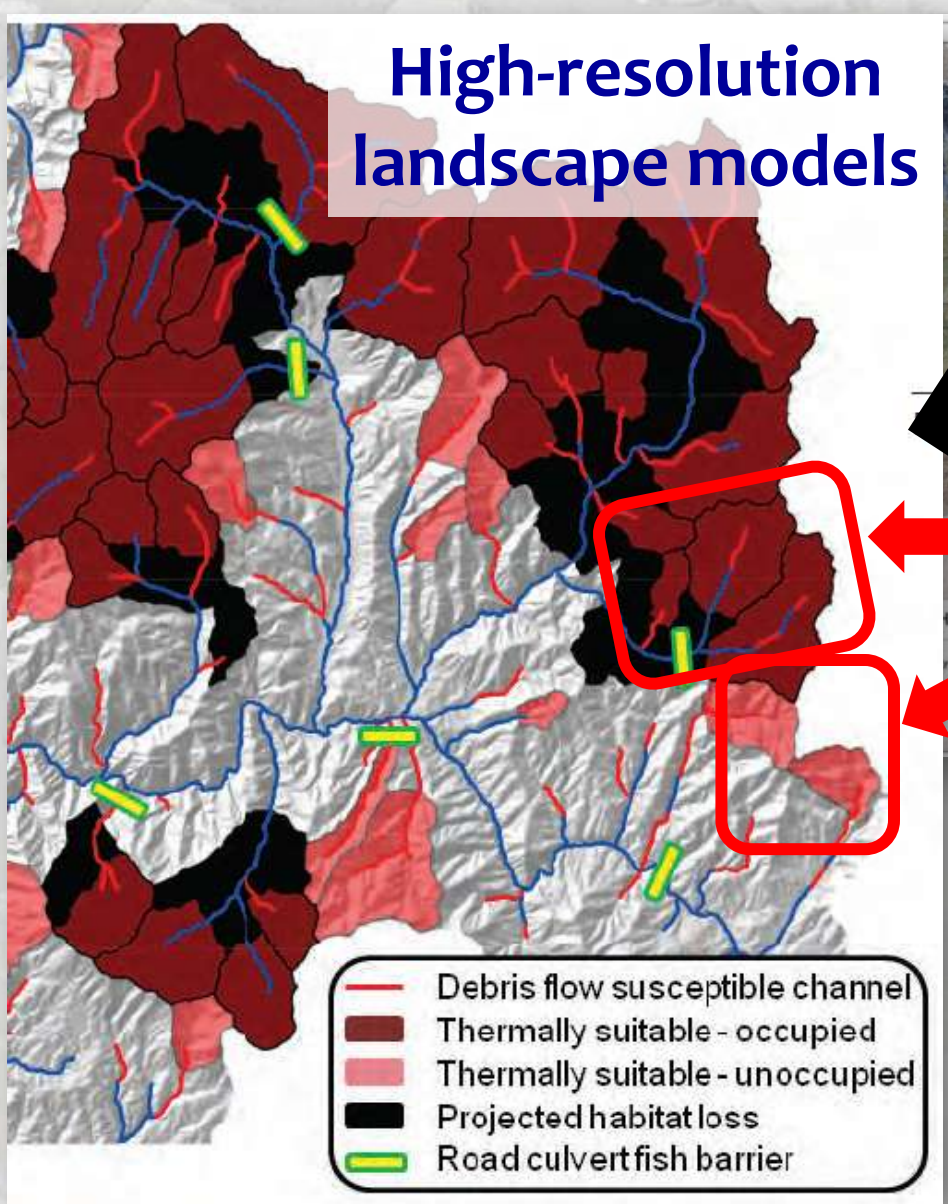
Thresholds Beyond Which Populations Become "Walking Dead"

Precise Information Needed for Efficient Local Decision Making

Regional models are too coarse

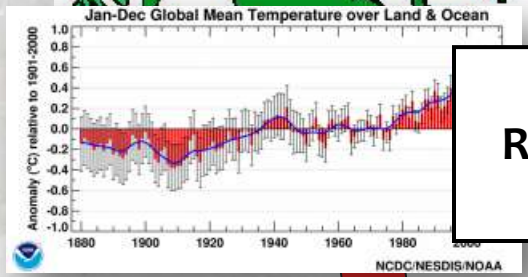
Not Good Enough for Zombie Detection

Precise Information Needed for Efficient Local Decision Making



There's A Lot on the Line…

Climate Boogeyman



Recreational/Commercial Fisheries

Low Flows Prompt Fishing Closure On Upper Beaverhead River And Reduced Limits On Clark Canyon Reservoir

Wednesday, September 29, 2004
Fishing

High Water Temperature In Grande Ronde Kills 239 Adult Spring Chinook

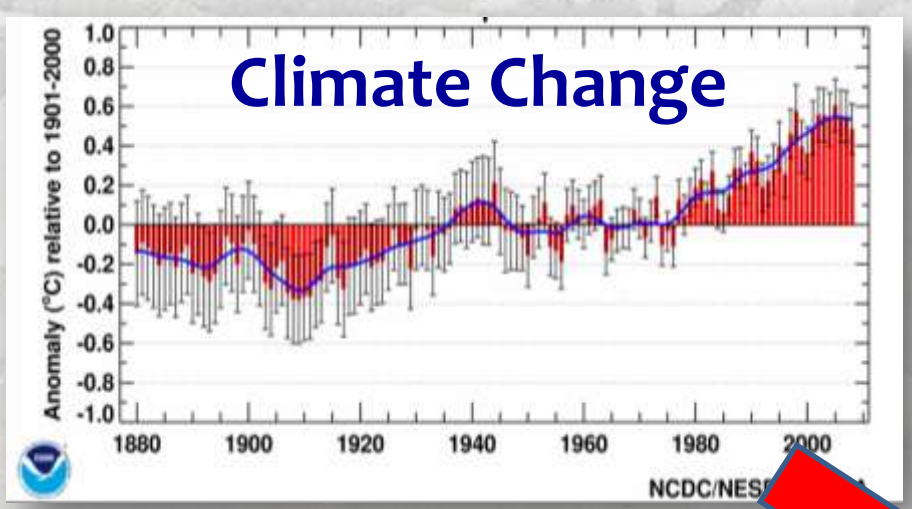
ulletin,
(PST)

$4 Billion on Fish & Wildlife Recovery Efforts in PNW Since 1980 (ISAB/ISRP 2007)

Land Use & Water Development

ESA Listed Species

More Pressure, Fewer Resources



Urbanization & Population Growth

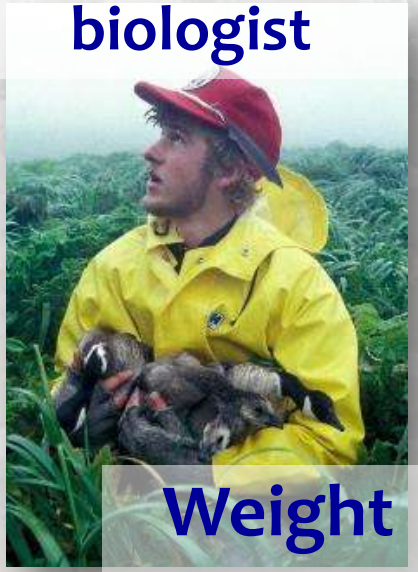
Shrinking Budgets

Need to do more with less

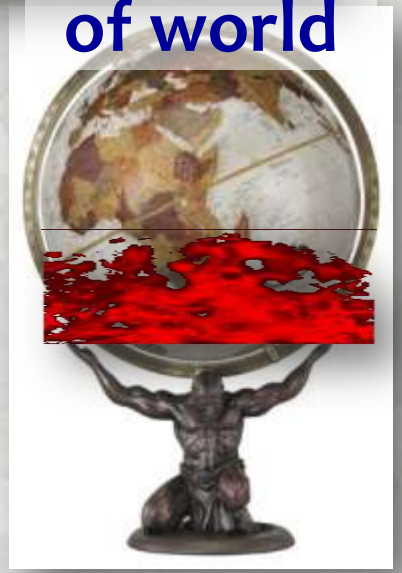
Climate Boogeyman

Onus?

Management biologist



Weight of world



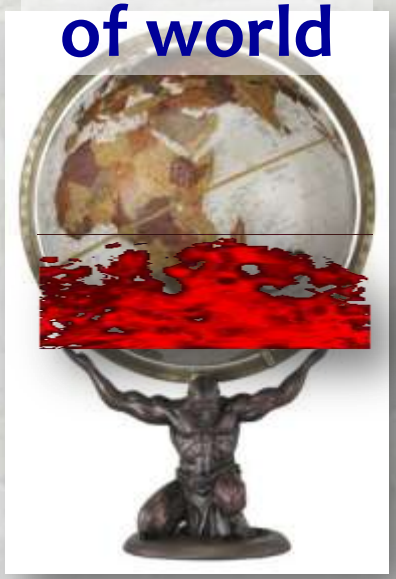
Climate Boogeyman

Analytical Capacity

- Remote sensing/GIS
- Georeferenced, corporate databases
- Computational capacity
- Spatial models

Opportunity?

Weight of world



Interagency Collaboration

IDAHO FISH & GAME

USGS science for a changing world

BONNEVILLE POWER ADMINISTRATION

FOREST SERVICE US DEPARTMENT OF AGRICULTURE

CLIMATE IMPACTS GROUP

U.S. FISH & WILDLIFE SERVICE

CENTER FOR ECOHYDRAULICS RESEARCH University of Idaho

TROUT UNLIMITED

NOAA Fisheries

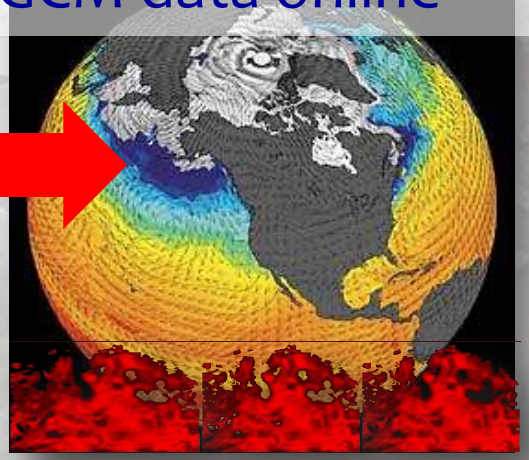
All agencies under pressure to "do something"…

Geospatial Technologies & Spatial Analyses Translate Science to "Real-World" Coordinates

Remote Sensing

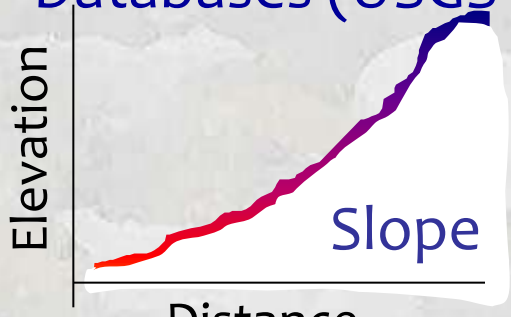
GIS / Computing Capacity

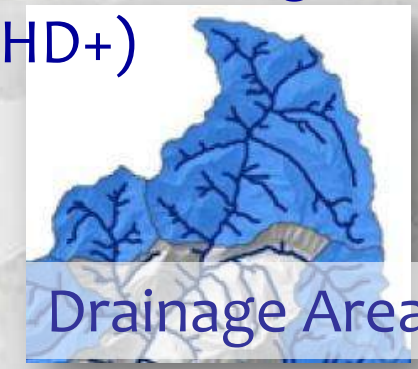
Climate, weather, GCM data online



Visualization

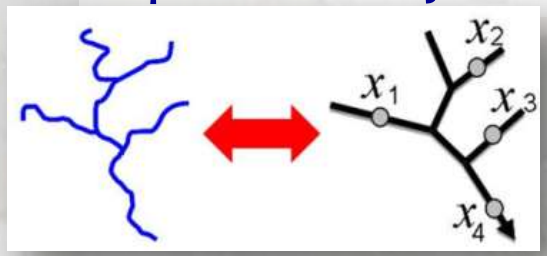
Nationally Consistent Hydrology Databases (USGS NHD+)





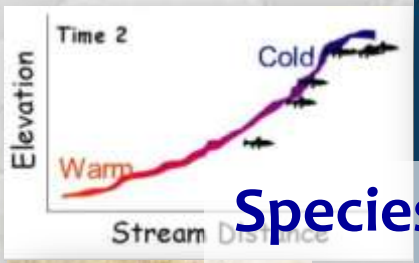
Drainage Area

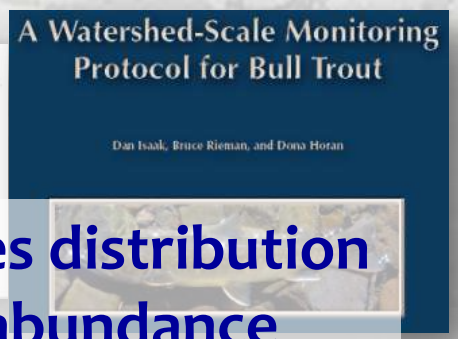
Spatial analyses



Local Measurements Provide Model Calibration

Standard Protocols, Inexpensive Sensors/Bioassays



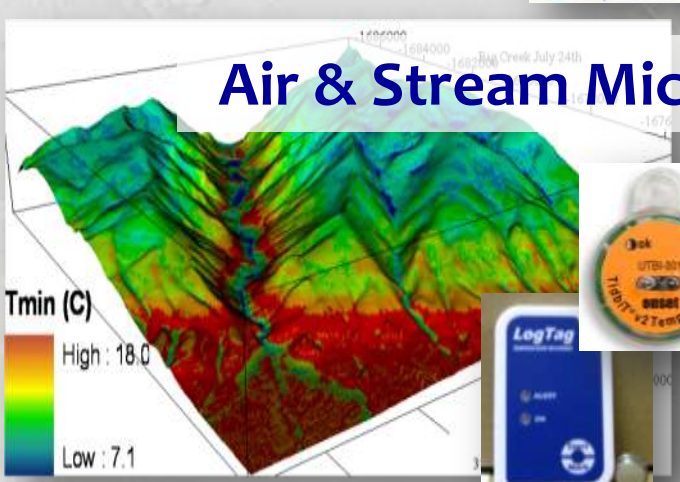


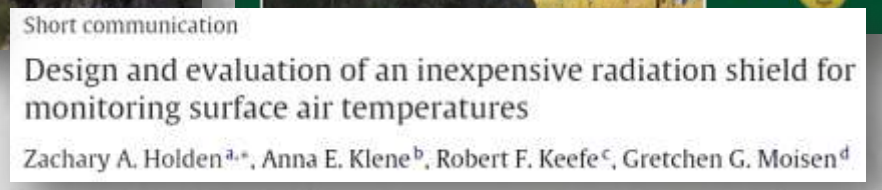
Species distribution & abundance

Stream discharge

Tissue Samples & DNA barcoding

Air & Stream Microclimates





Huge Potential Synergies Between Researchers, Managers, & the Public

Diverse stakeholders

NOAA Fisheries

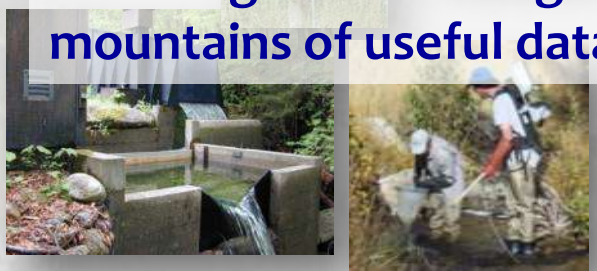
"Boots-on-the-Ground"

USFS has ~600 fish bios/hydros.
(That's an aquatics army!)

FOREST SERVICE U.S. DEPARTMENT OF AGRICULTURE

USGS science for a changing world

Managers collecting mountains of useful data

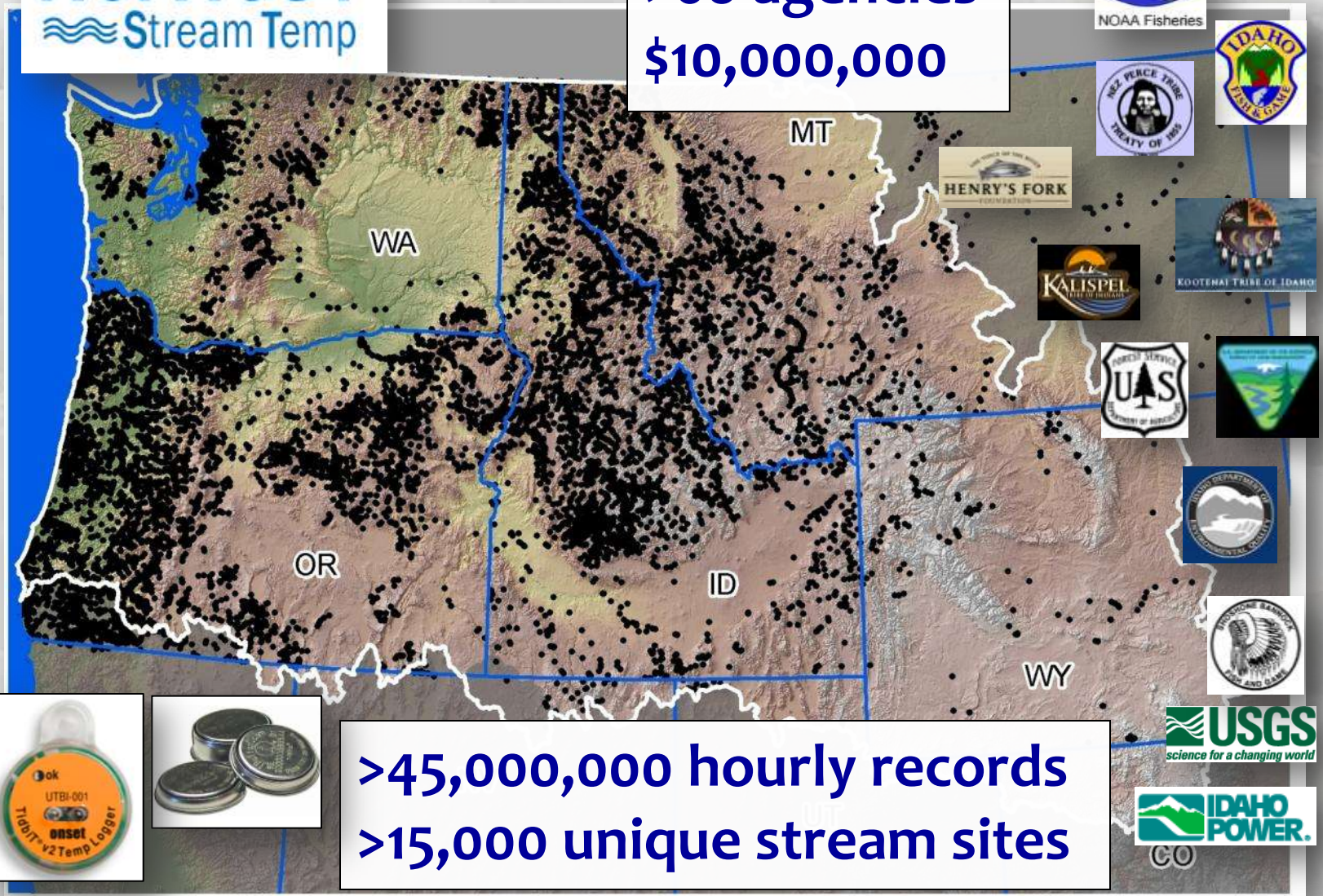


Researchers can develop information & connect people

An Example With a Crowd-Sourced, BIG DATA Temperature Database

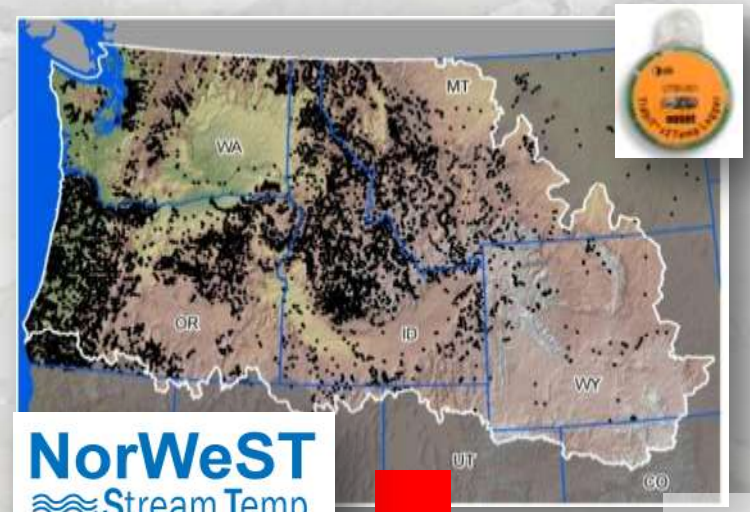
NorWeST Stream Temp

>60 agencies
$10,000,000



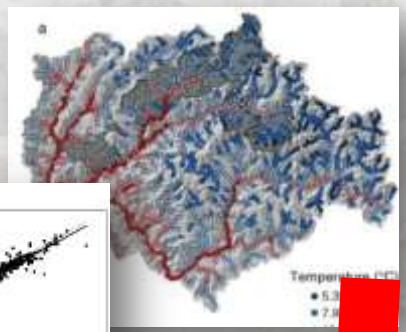
>45,000,000 hourly records
>15,000 unique stream sites

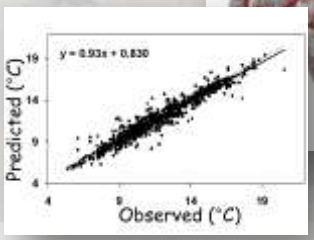
Stream Temp Model Application



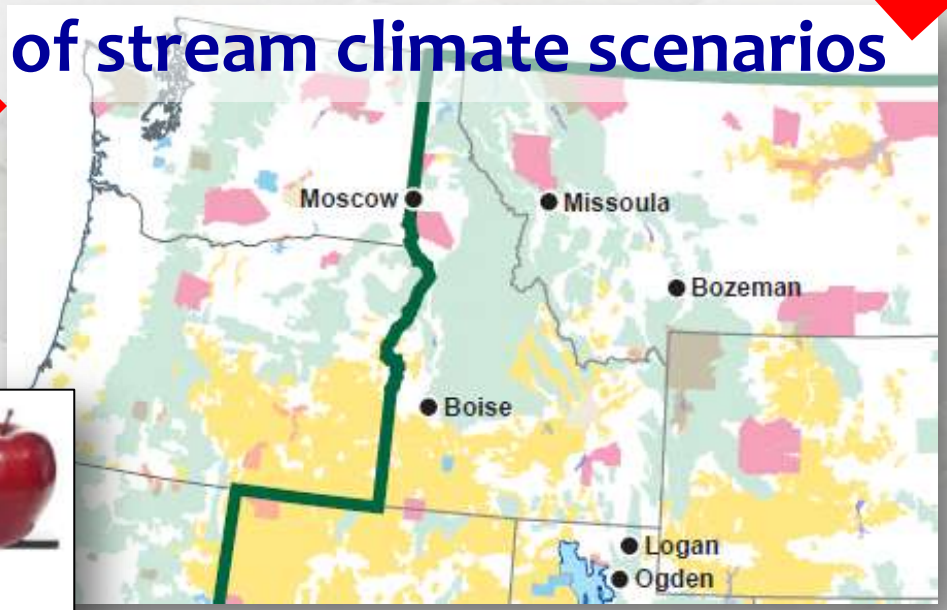
NorWeST
Stream Temp

Accurate stream temp model

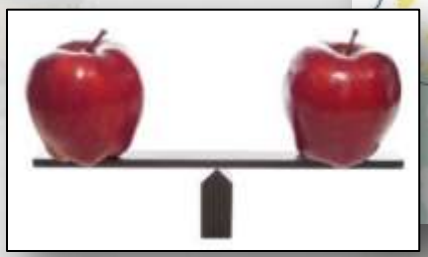




Cross-jurisdictional "maps" of stream climate scenarios

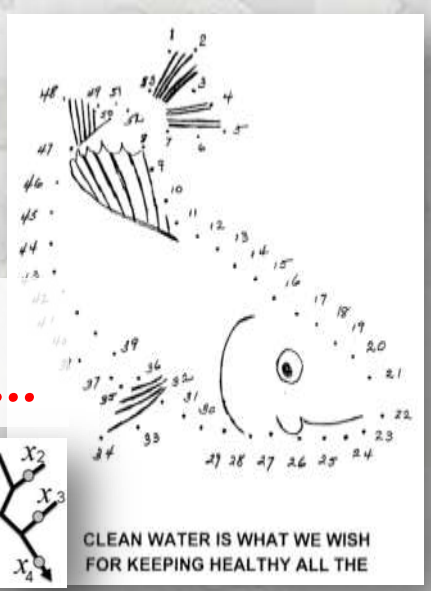


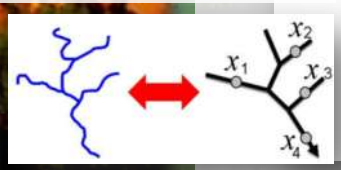
Consistent datum for strategic assessments across 400,000 stream kilometers



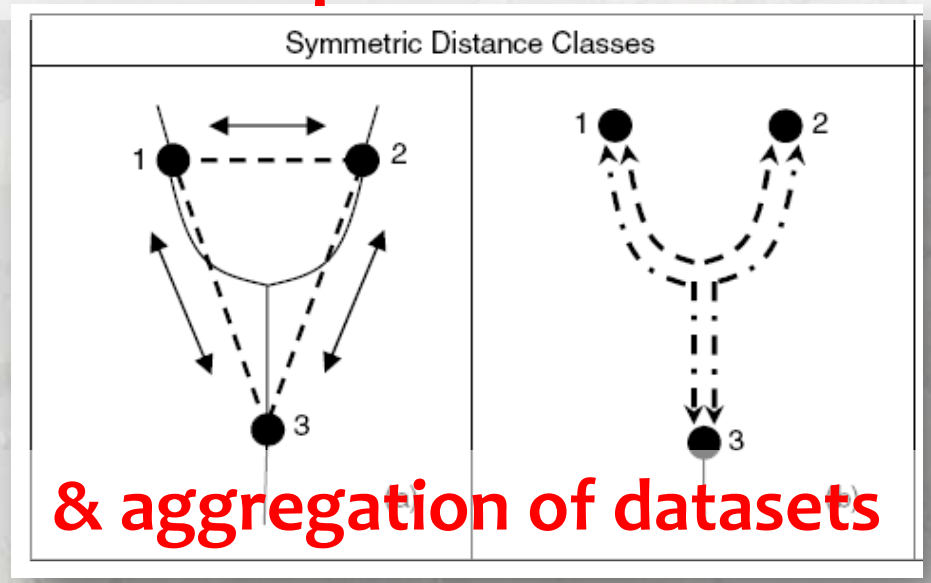
Spatial Statistical Network Models Provide Analytical Infrastructure

Fancy dot connectors…





Valid interpolation on networks



& aggregation of datasets

Advantages:

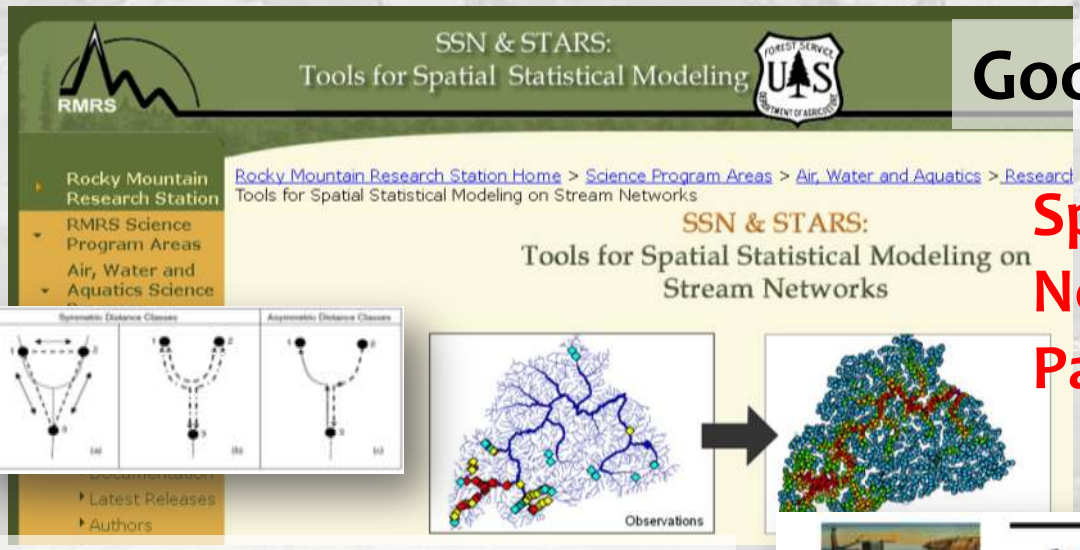
-flexible & valid autocovariance structures that accommodate network topology & non-independence among observations

-improved predictive ability & parameter estimates relative to non-spatial models

Ver Hoef et al. 2006; Ver Hoef & Peterson 2010; Peterson & Ver Hoef 2013

SSN/STARS Website

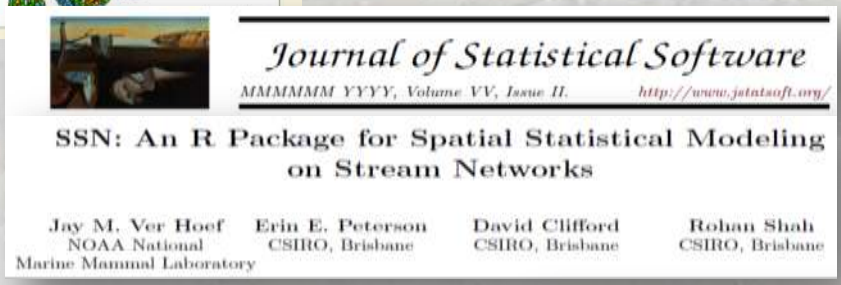
Tools For Statistical Analysis of Data on Stream Networks



Google "SSN/STARS"

Spatial Stream Networks Package for R

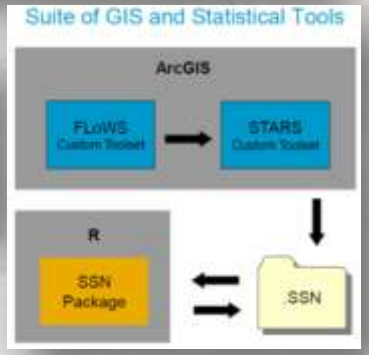
Open Source Statistical Stream Software, Example Datasets, & Applications



A Moving Average Approach for Spatial Statistical Models of Stream Networks

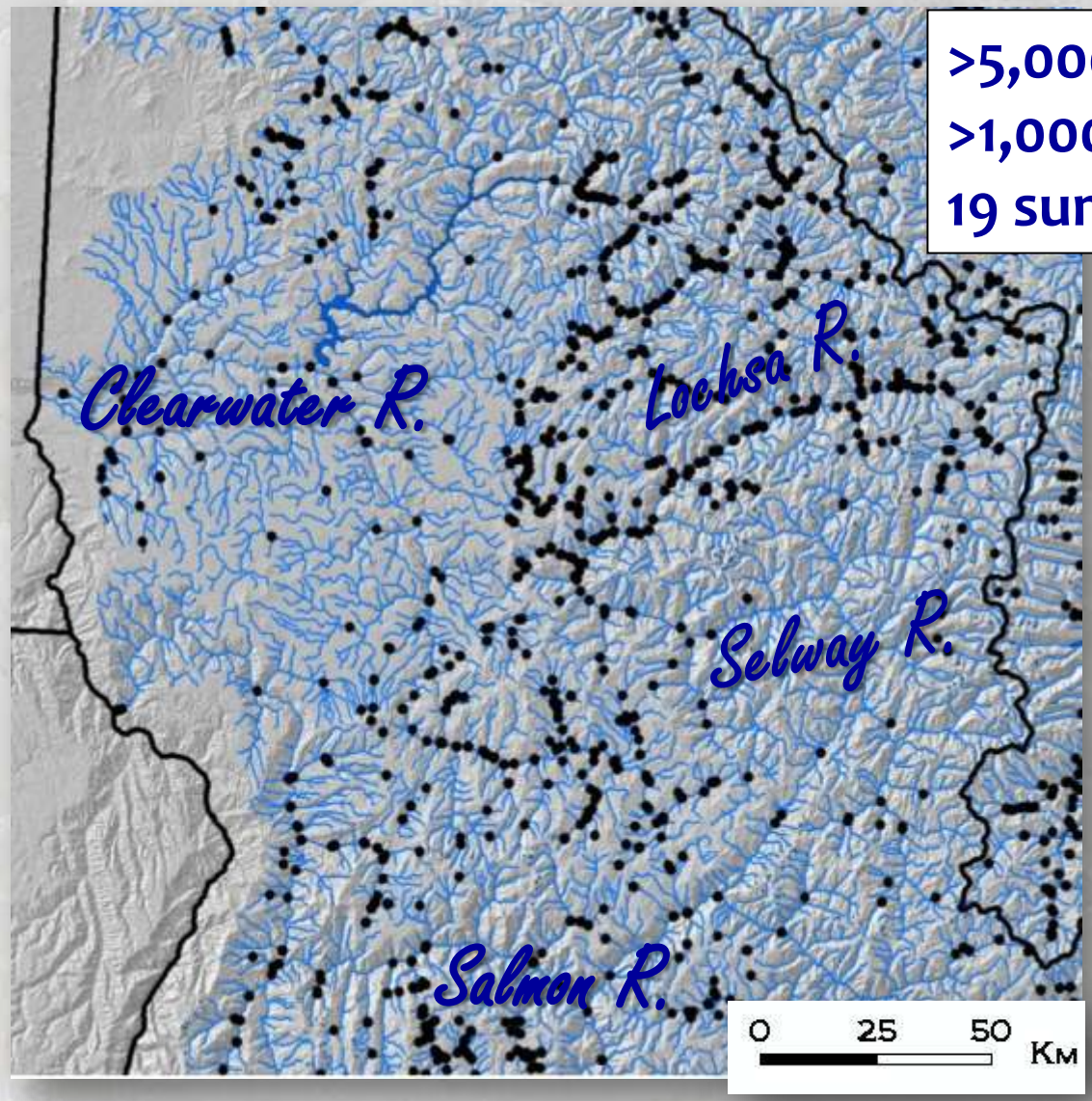
Jay M. VER HOEF and Erin E. PETERSON

STARS: An ArcGIS toolset used to calculate the spatial data needed to fit spatial statistical models to stream network data



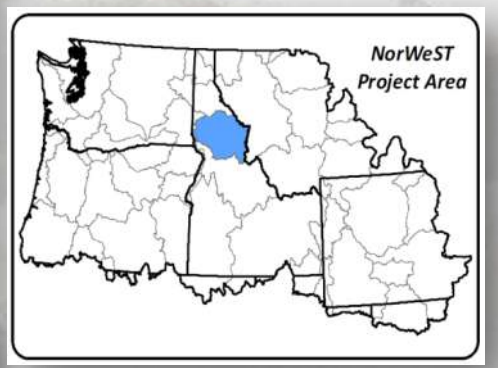
Example: Clearwater River Basin

Data extracted from NorWeST



>5,000 August means
>1,000 stream sites
19 summers (1993-2011)

•Temperature site



Clearwater River Temp Model

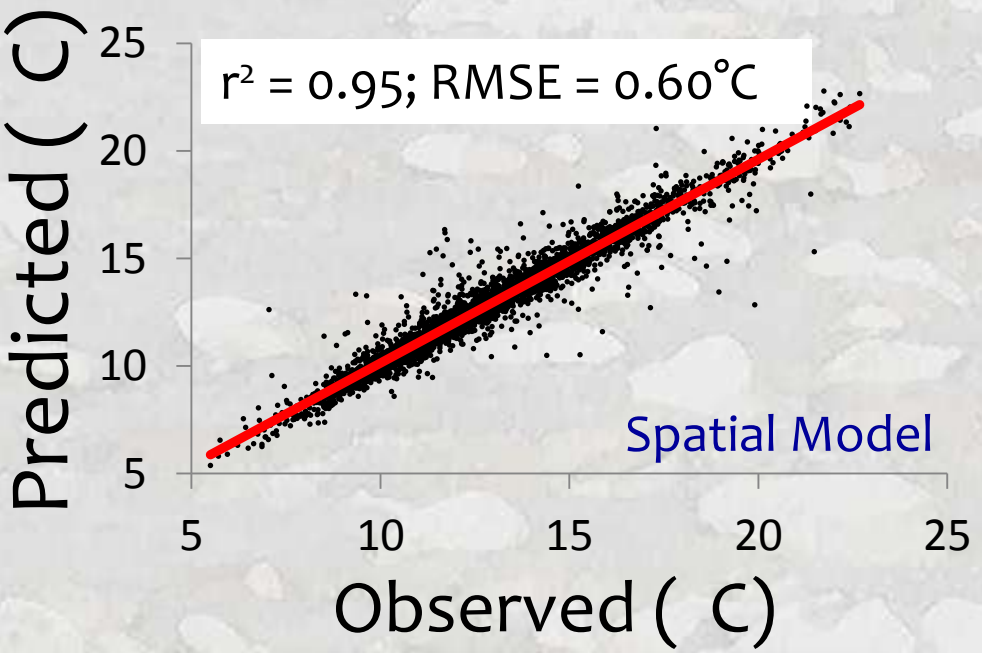
n = 4,487

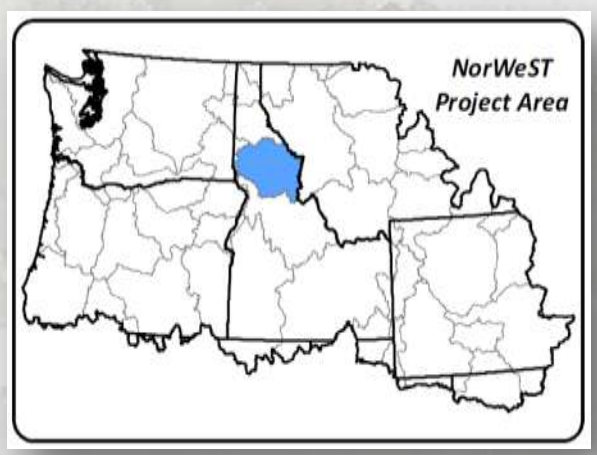
Covariate Predictors

1. Elevation (m)
2. Canopy (%)
3. Stream slope (%)
4. Ave Precipitation (mm)
5. Latitude (km)
6. Lakes upstream (%)
7. Baseflow Index
8. Watershed size (km^2)

9. Discharge (m^3/s)
   USGS gage data
10. Air Temperature (˚C)
    RegCM3 NCEP reanalysis
    Hostetler et al. 2011

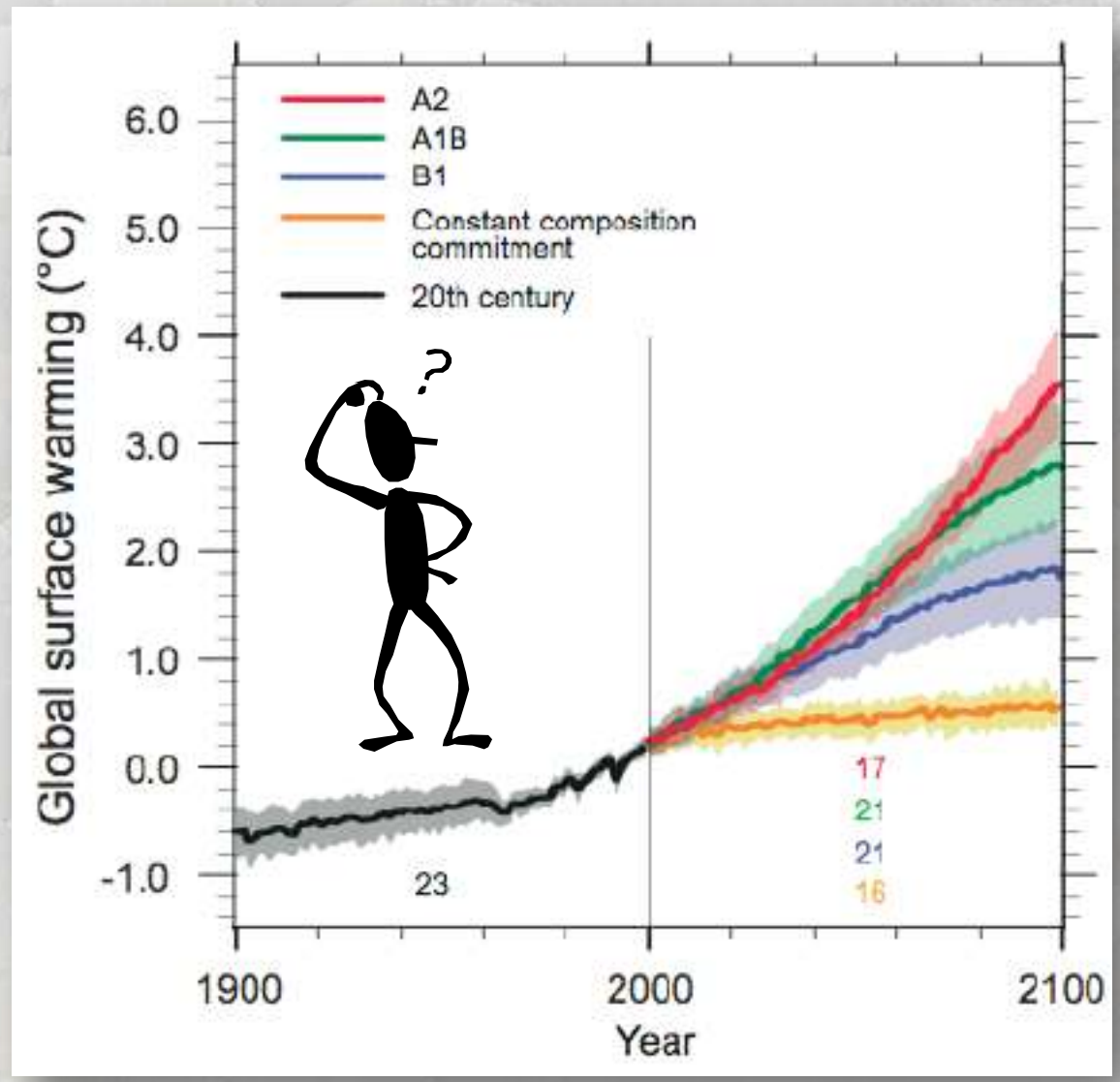
Mean August Temperature





Models Enable Climate Scenario Maps

Many possibilities exist…



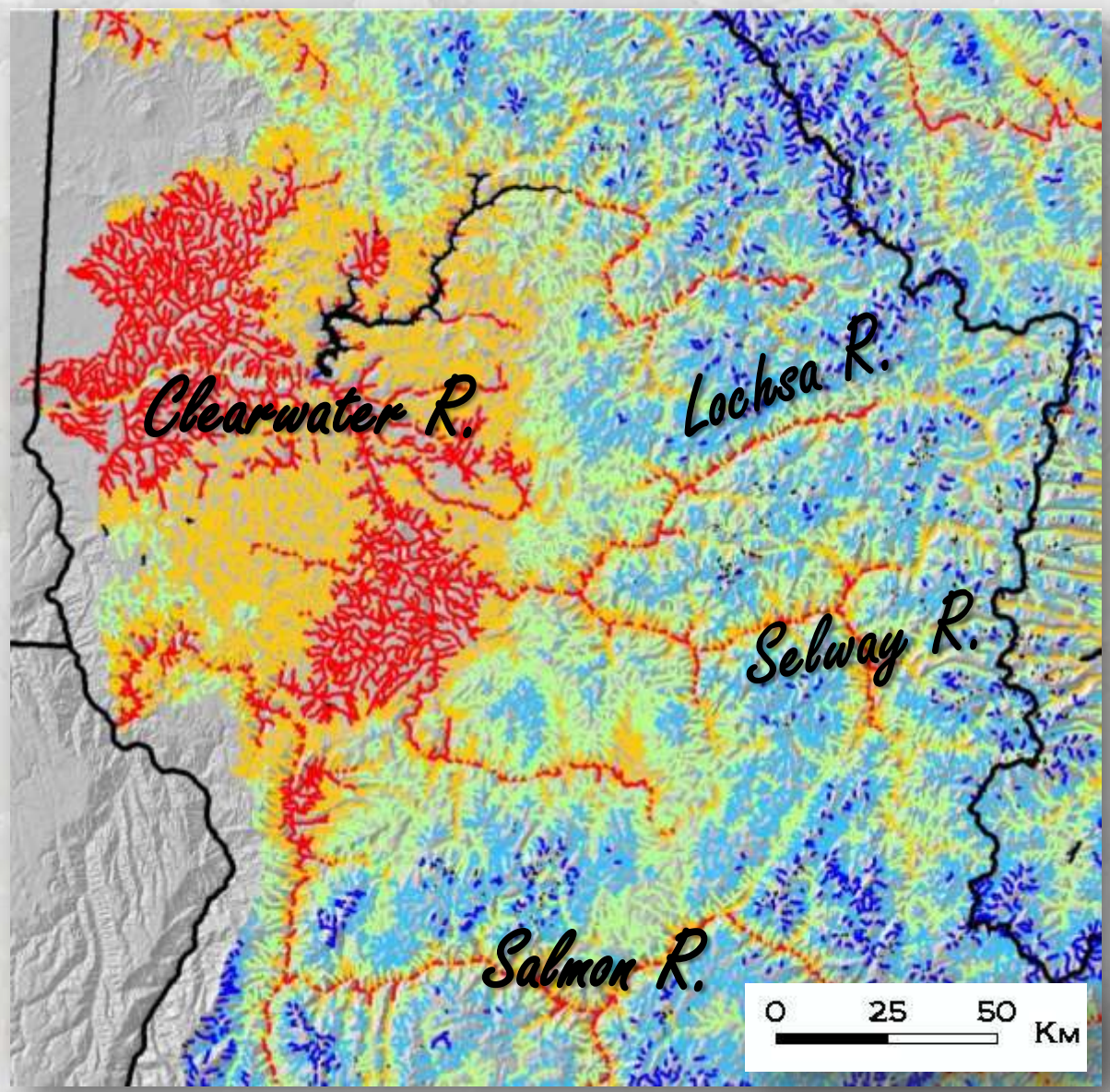
Adjust…

- Air
- Discharge
- %Canopy

…values to create scenarios

Clearwater Stream Temperature Scenario

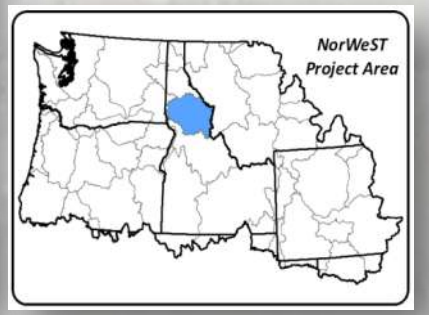
Historic (1993-2011 Average August)



Temperature (C)

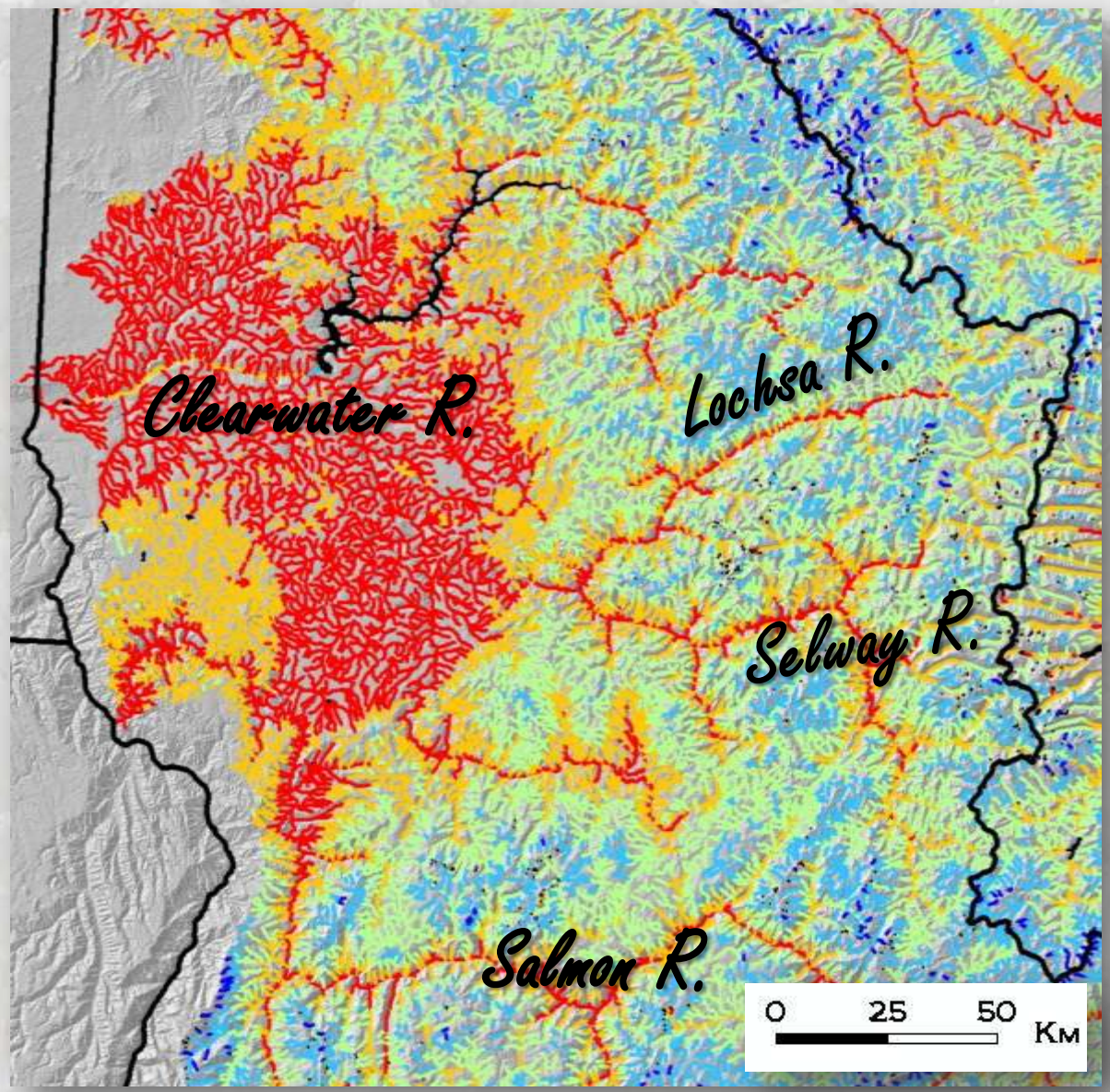
- 0.0 - 8.0
- 8.1 - 10.0
- 10.1 - 12.5
- 12.6 - 15.0
- > 15

1 kilometer resolution



Clearwater Stream Temperature Scenario

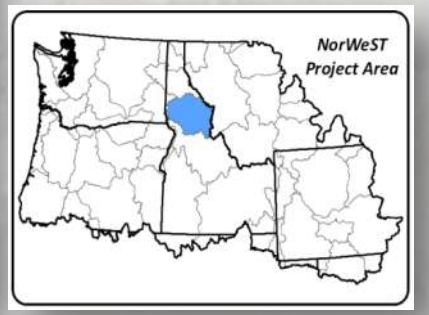
+1.00°C Stream Temp



Temperature (C)

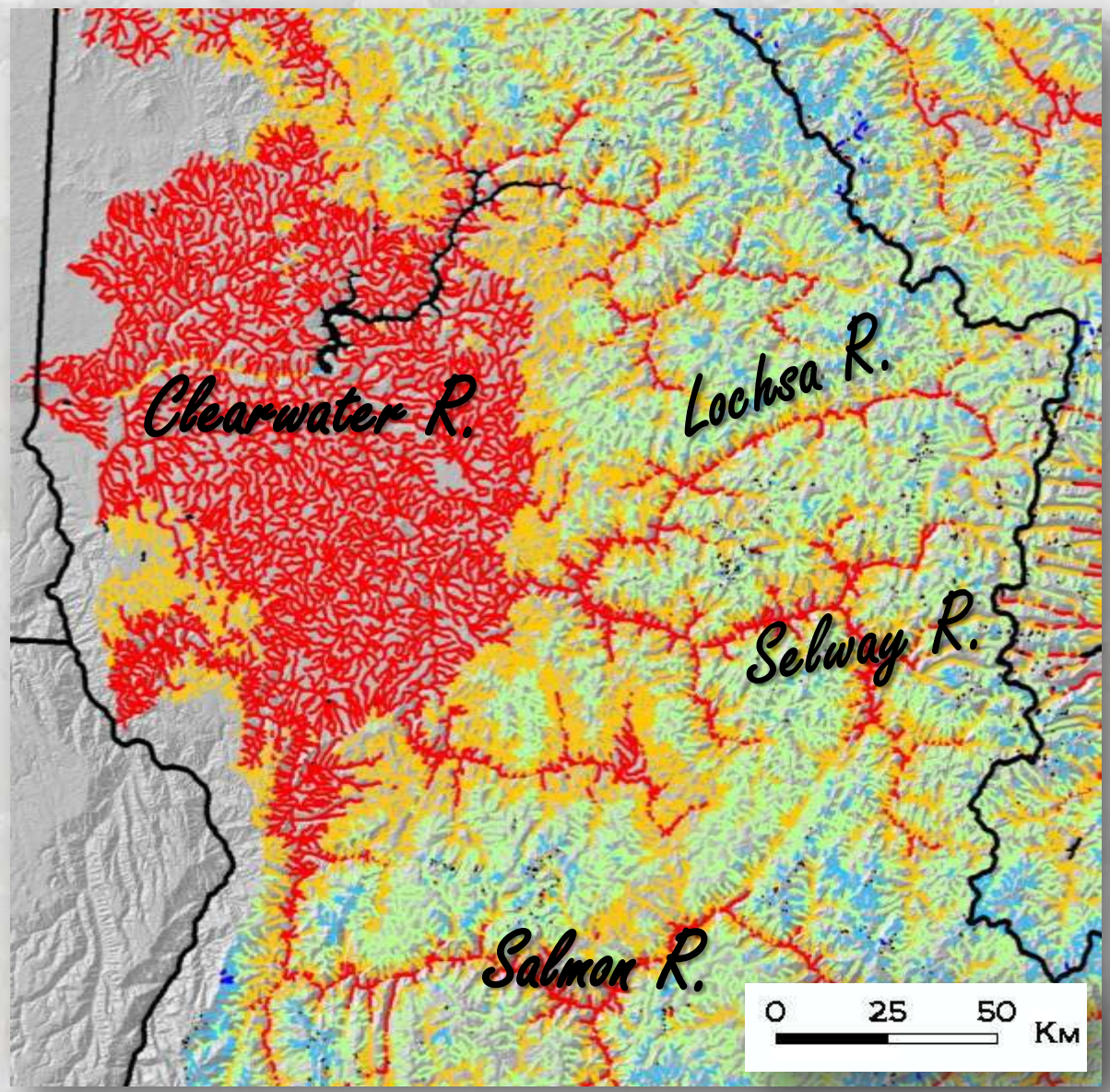
- 0.0 - 8.0
- 8.1 - 10.0
- 10.1 - 12.5
- 12.6 - 15.0
- > 15

1 kilometer resolution



Clearwater Stream Temperature Scenario

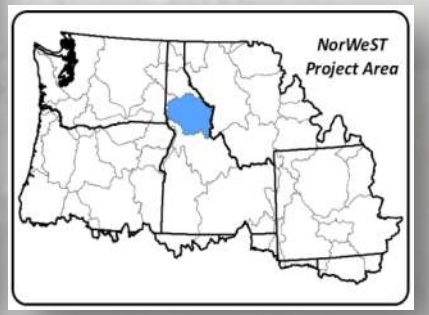
+2.00˚C Stream Temp



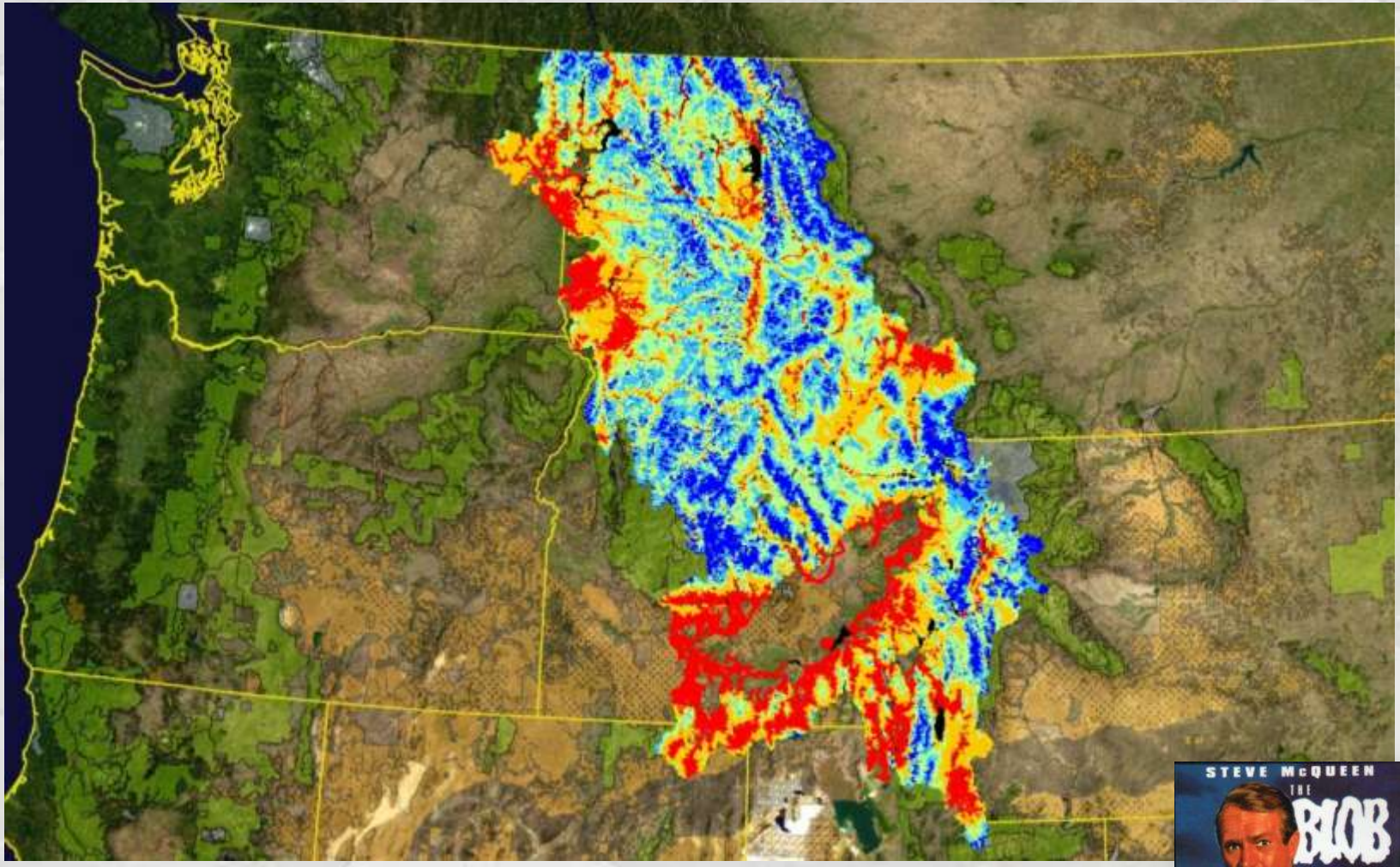
Temperature (C)

- 0.0 - 8.0
- 8.1 - 10.0
- 10.1 - 12.5
- 12.6 - 15.0
- > 15

1 kilometer resolution



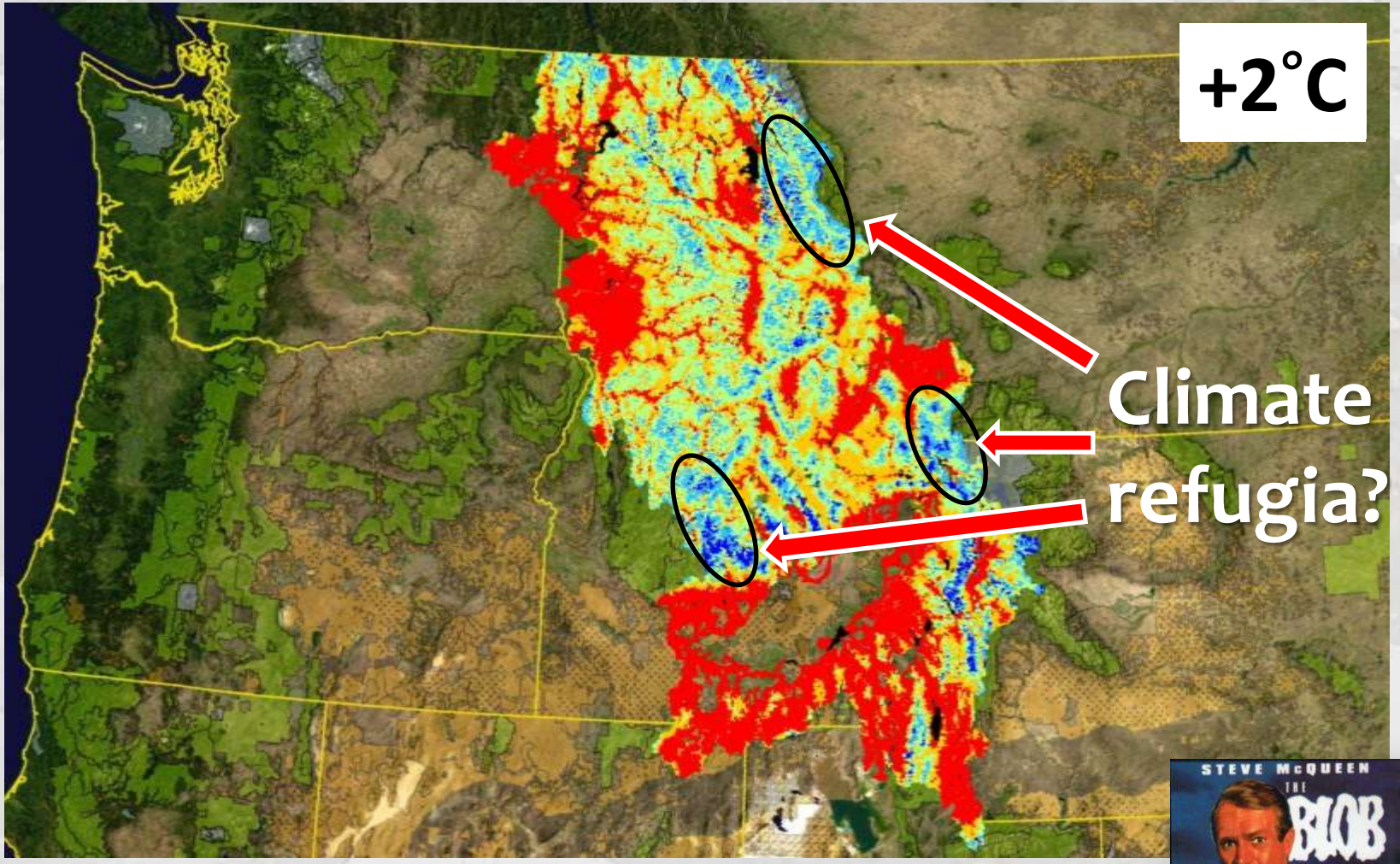
Stream Thermalscape so far…



The BLOB… it just keeps growing…

- 171,000 stream kilometers of thermal ooze
- 16,688 summers of data swallowed

Stream Thermalscape so far…

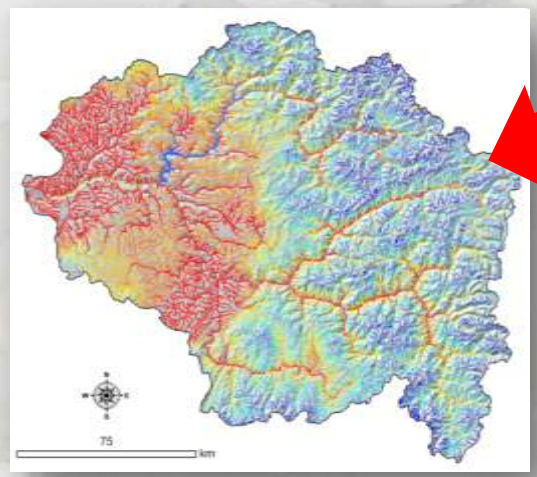


The BLOB… it just keeps growing…

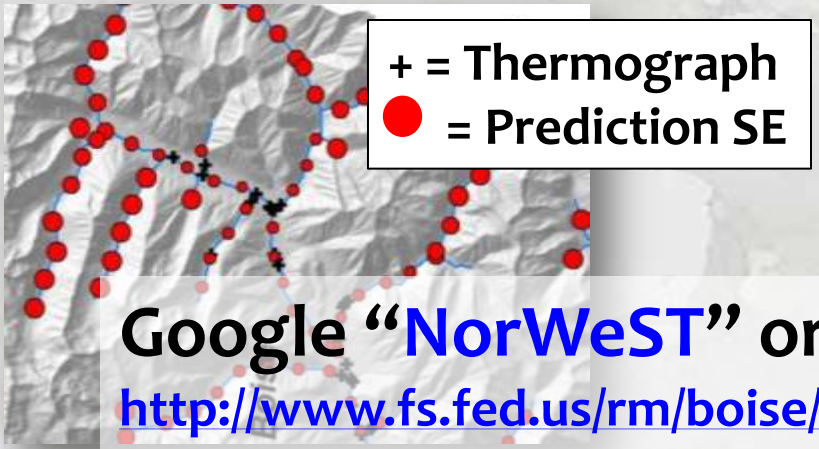
- 171,000 stream kilometers of thermal ooze
- 16,688 summers of data swallowed

Website Distributes Scenarios & Temperature Data as GIS Layers

1) GIS shapefiles of stream temperature scenarios



2) GIS shapefiles of stream temperature model prediction precision



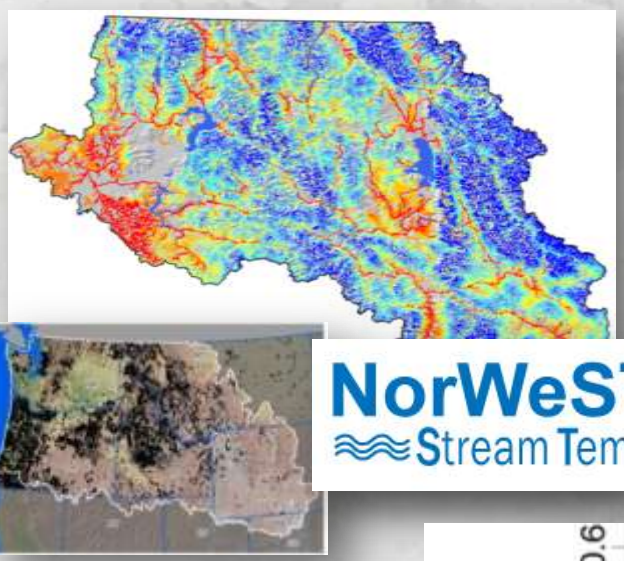
3) Temperature data summaries

Google "NorWeST" or go here…

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

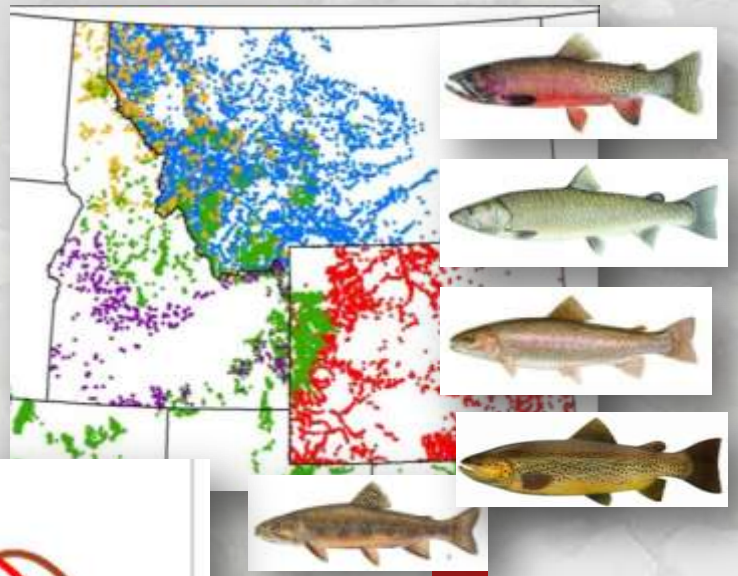
BIG fish DATA for Regionally Consistent Thermal Habitat Definitions

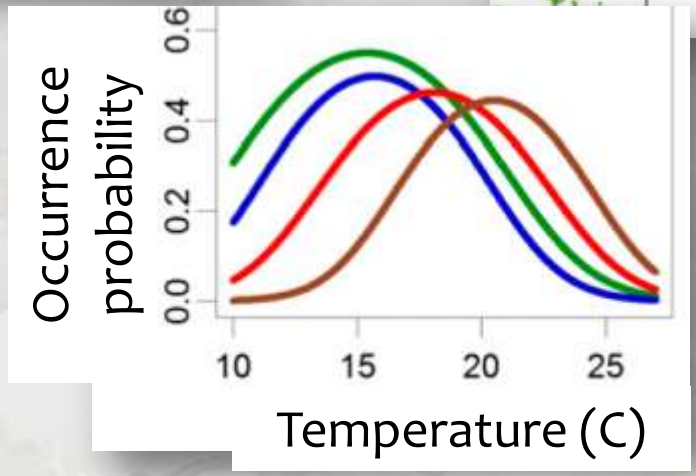
Stream temperature maps



NorWeST Stream Temp

Regional fish survey databases (n ~ 30,000)



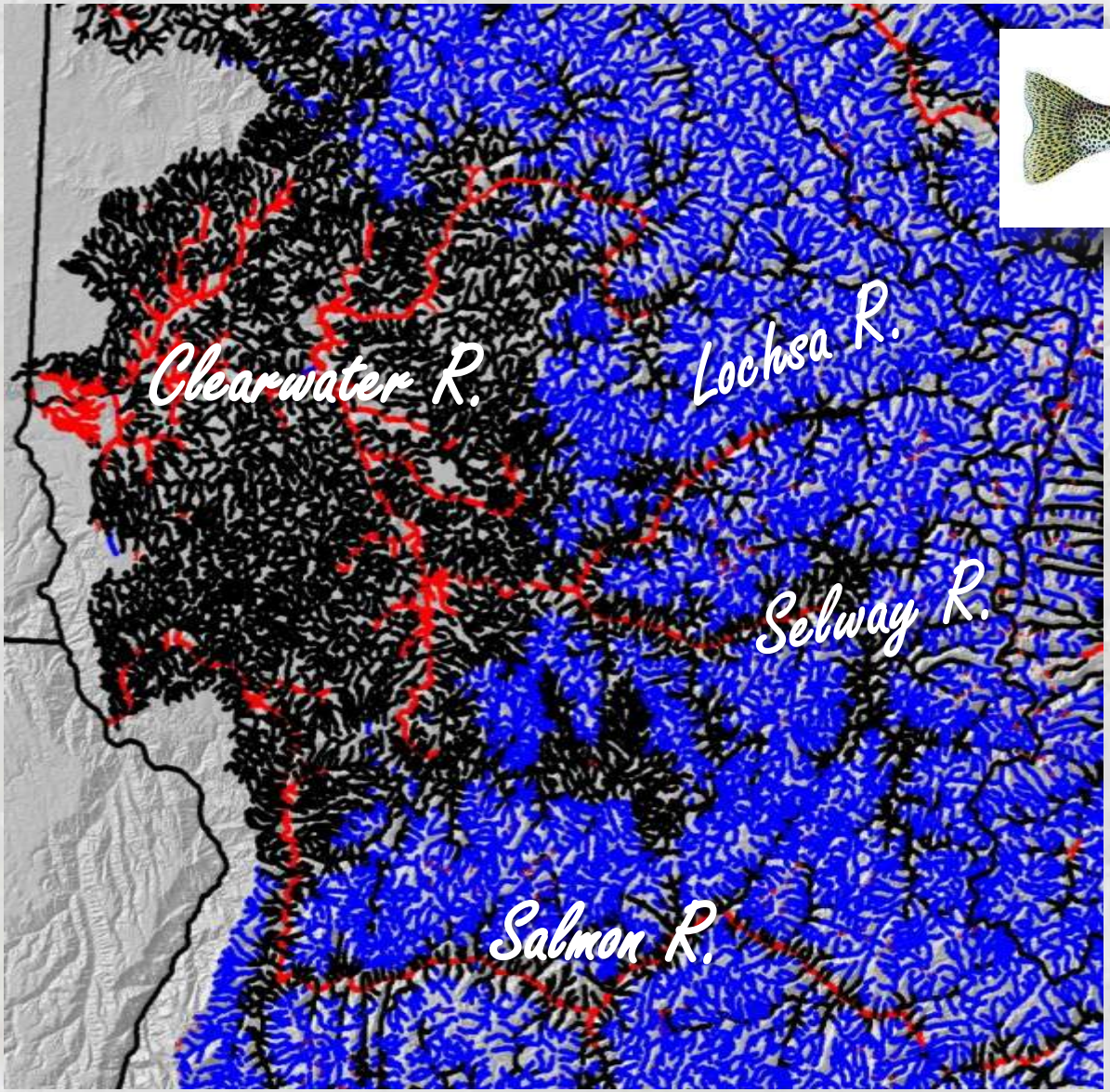


Wenger et al. 2011a. *PNAS* **108**:14175-14180

Wenger et al. 2011b. *CJFAS* **68**:988-1008; Wenger et al., *In Preparation*

Climate Effects on Cutthroat Thermal Habitat

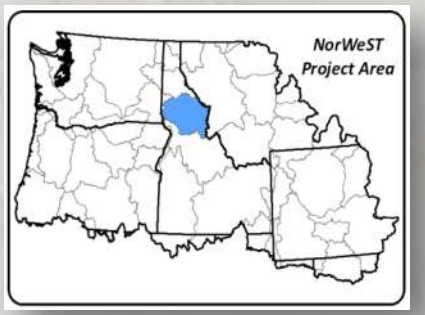
Historic (1993-2011 Average August)



Suitable

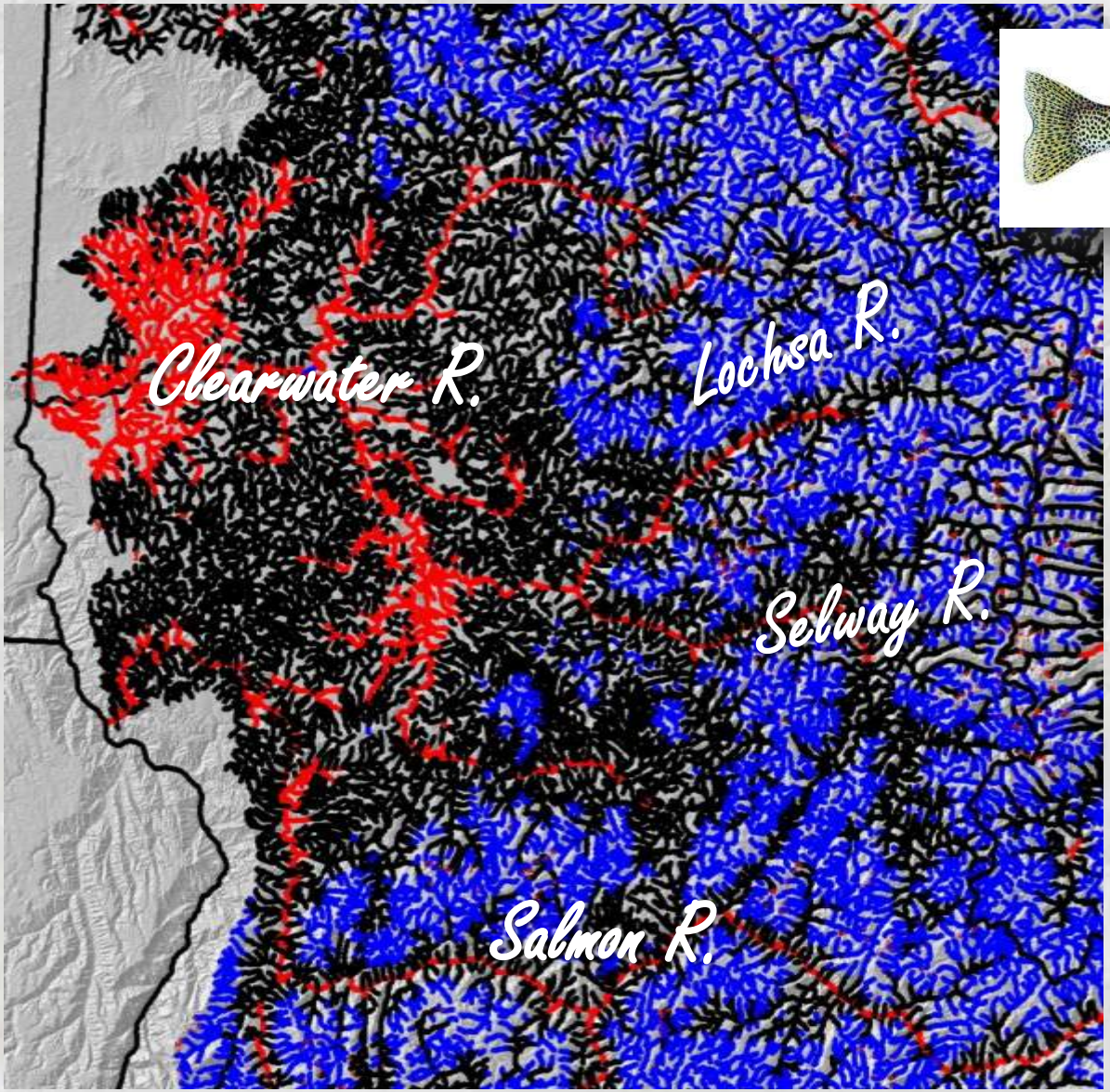
Too Hot

Too Cold



Climate Effects on Cutthroat Thermal Habitat

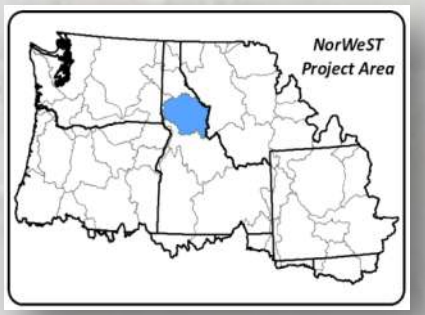
+1.00°C Stream Temp (~2040s)



Suitable

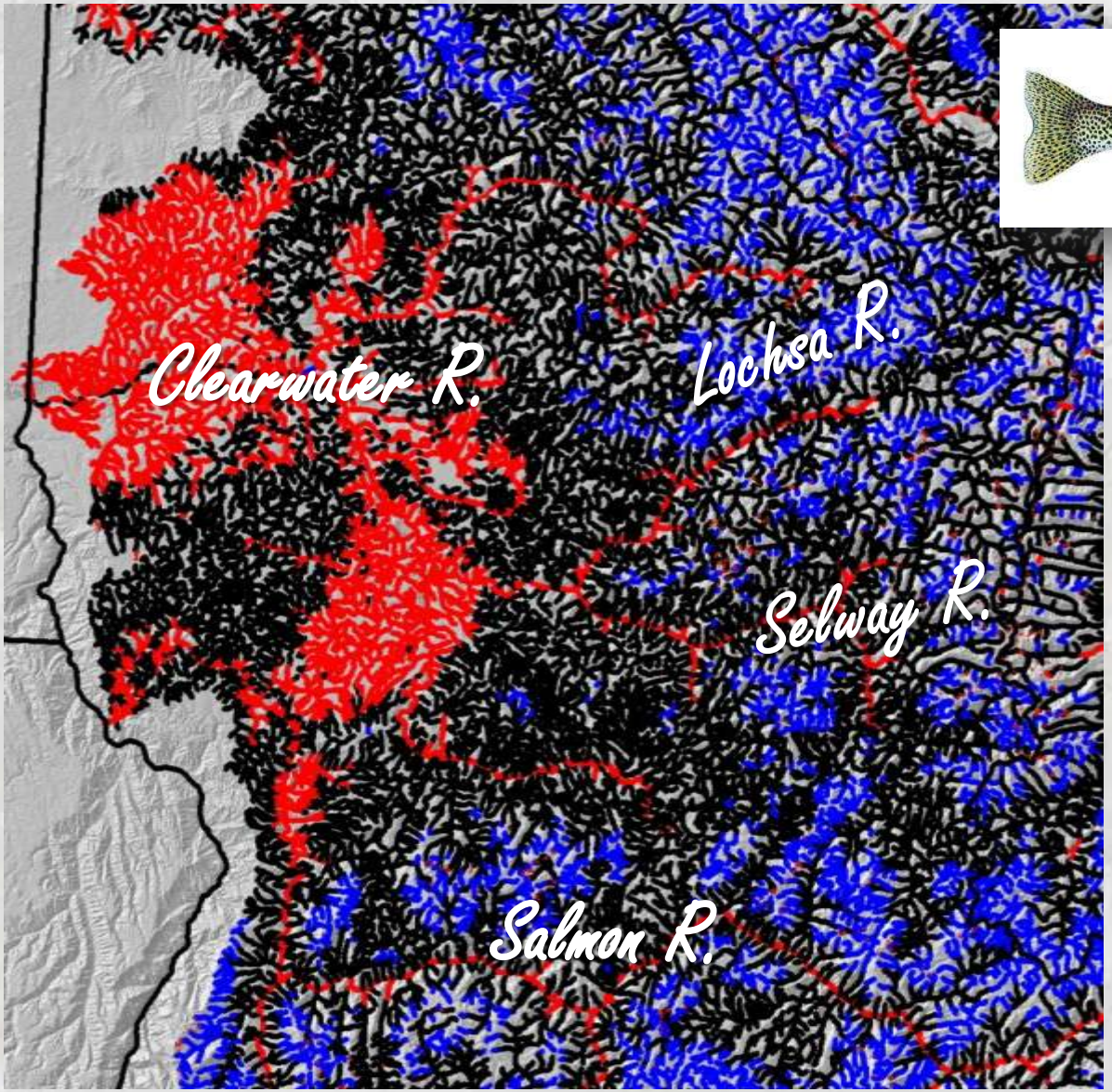
Too Hot

Too Cold



Climate Effects on Cutthroat Thermal Habitat

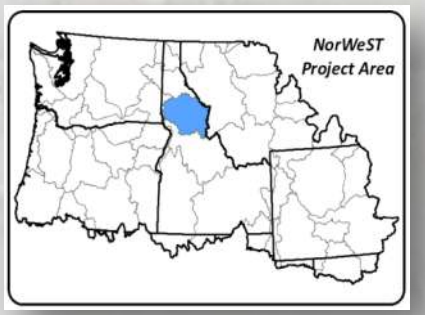
+2.00˚C Stream Temp (~2080s)



Suitable

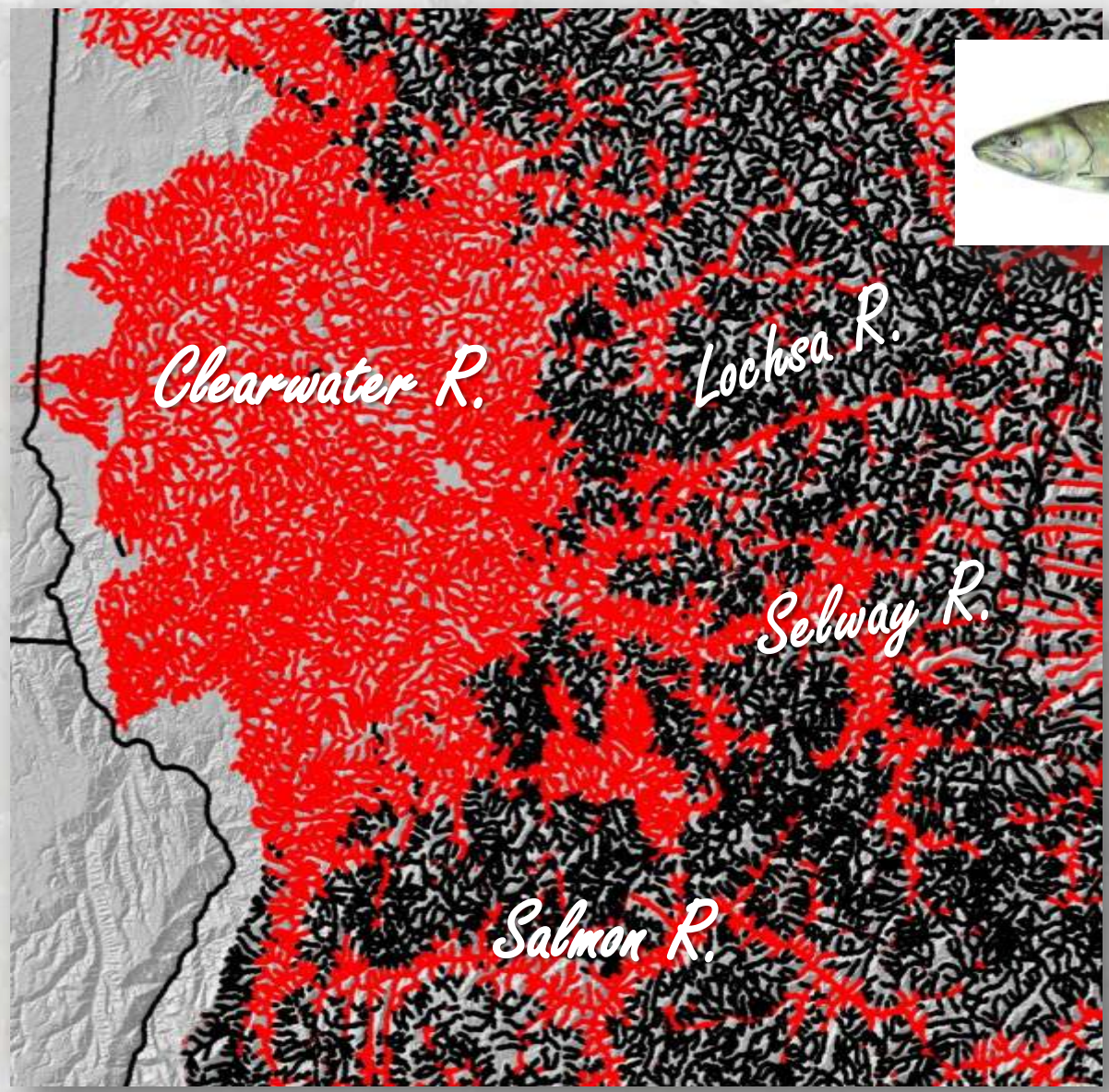
Too Hot

Too Cold



Climate Effects on Bull Trout Thermal Habitat

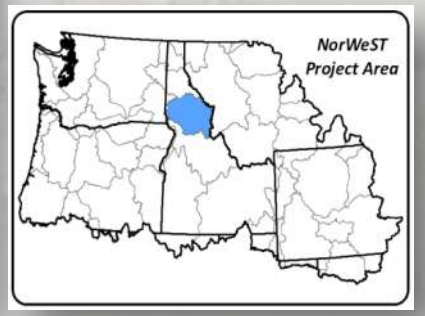
Historic (1993-2011 Average August)



11.0°C Isotherm

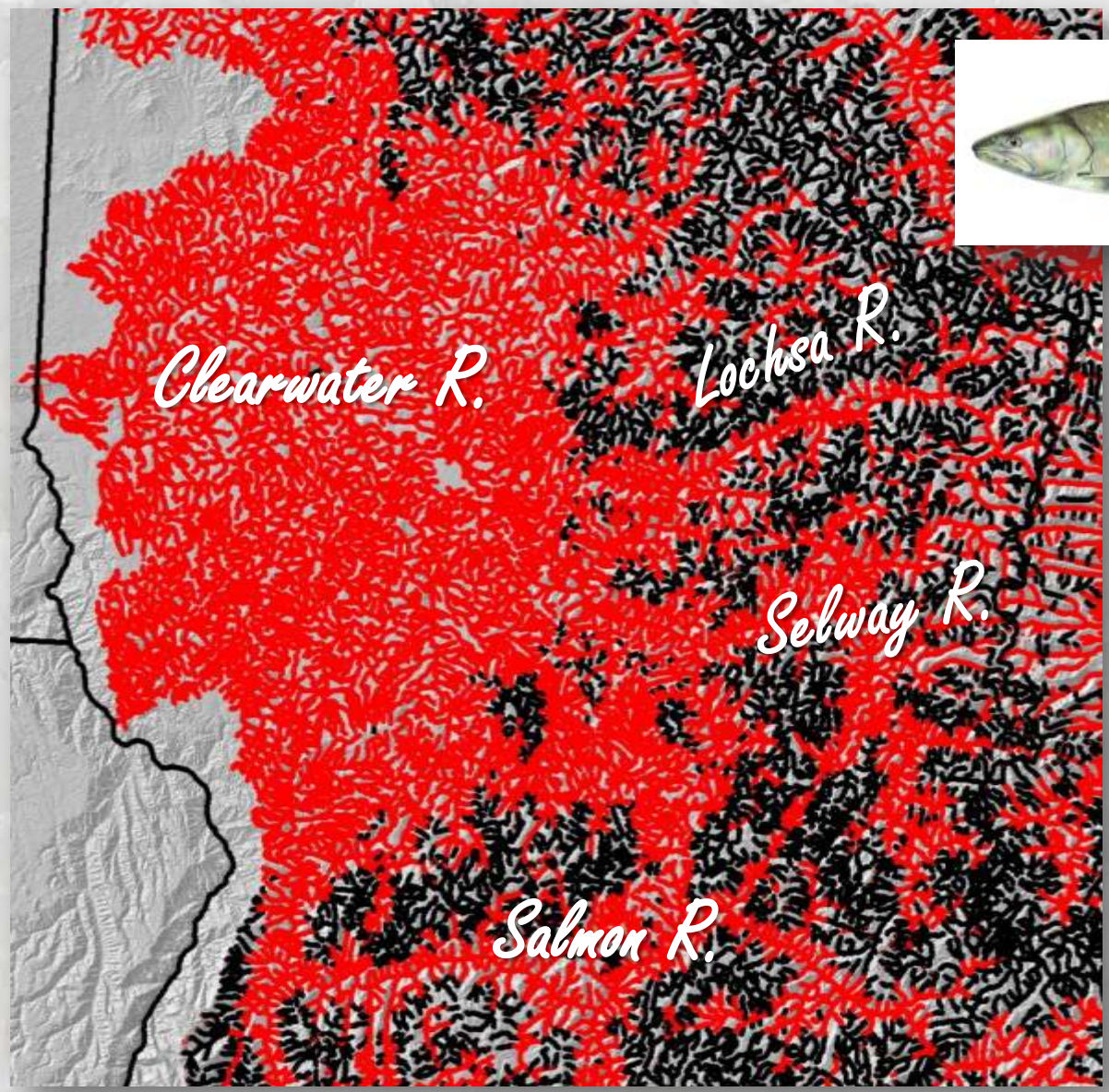
Suitable

Unsuitable



Climate Effects on Bull Trout Thermal Habitat

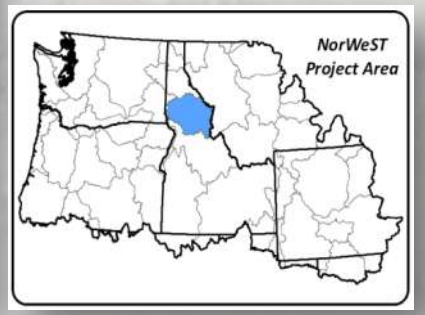
+1.00˚C Stream Temp (~2040s)



11.0˚C Isotherm

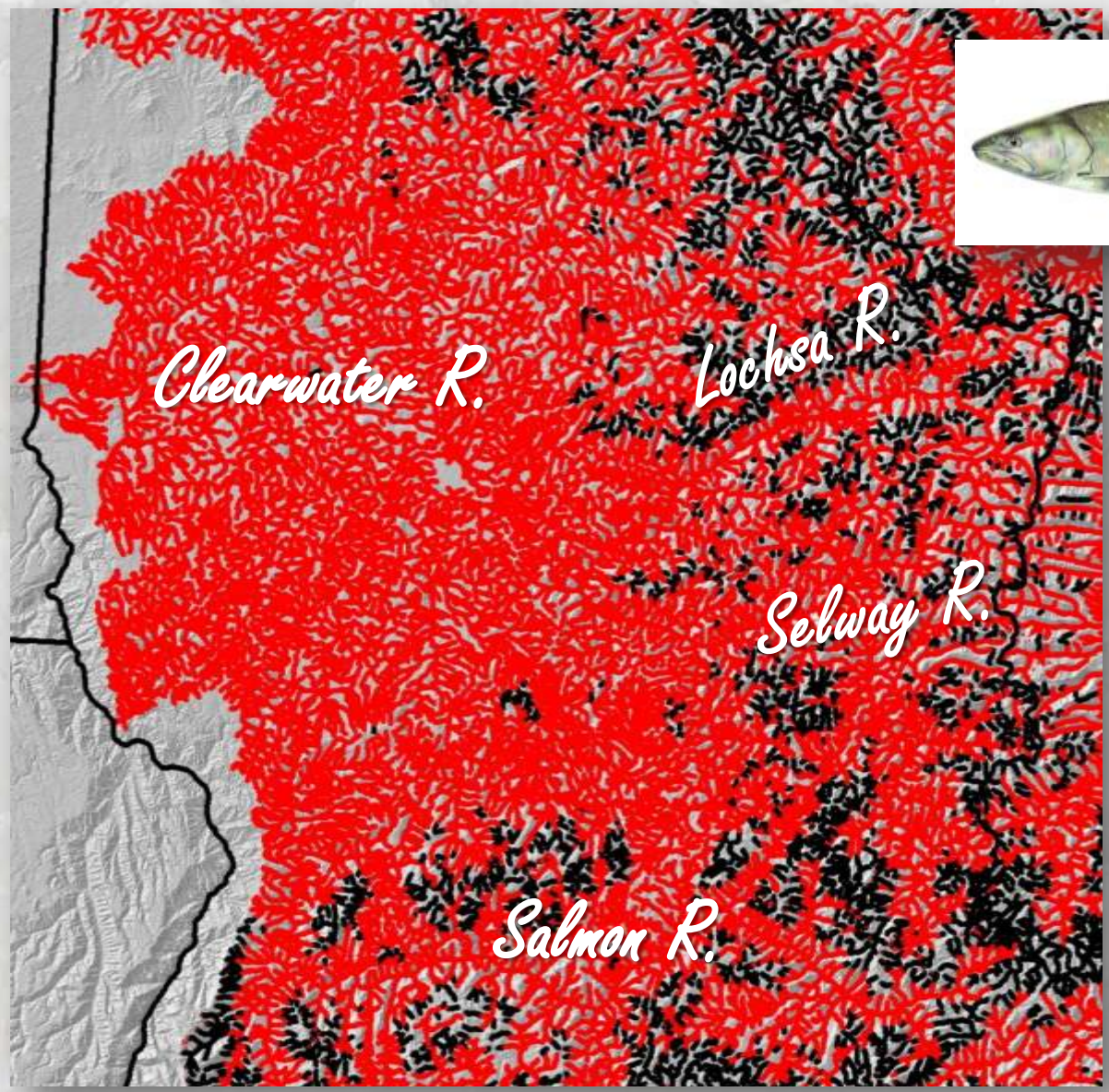
Suitable

Unsuitable



Climate Effects on Bull Trout Thermal Habitat

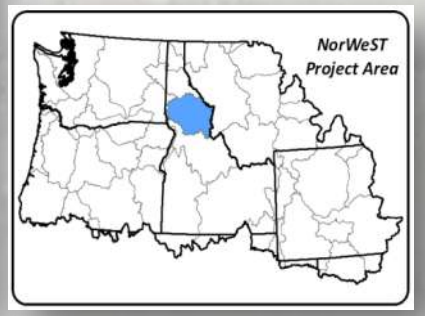
+2.00˚C Stream Temp (~2080s)



11.0˚C Isotherm

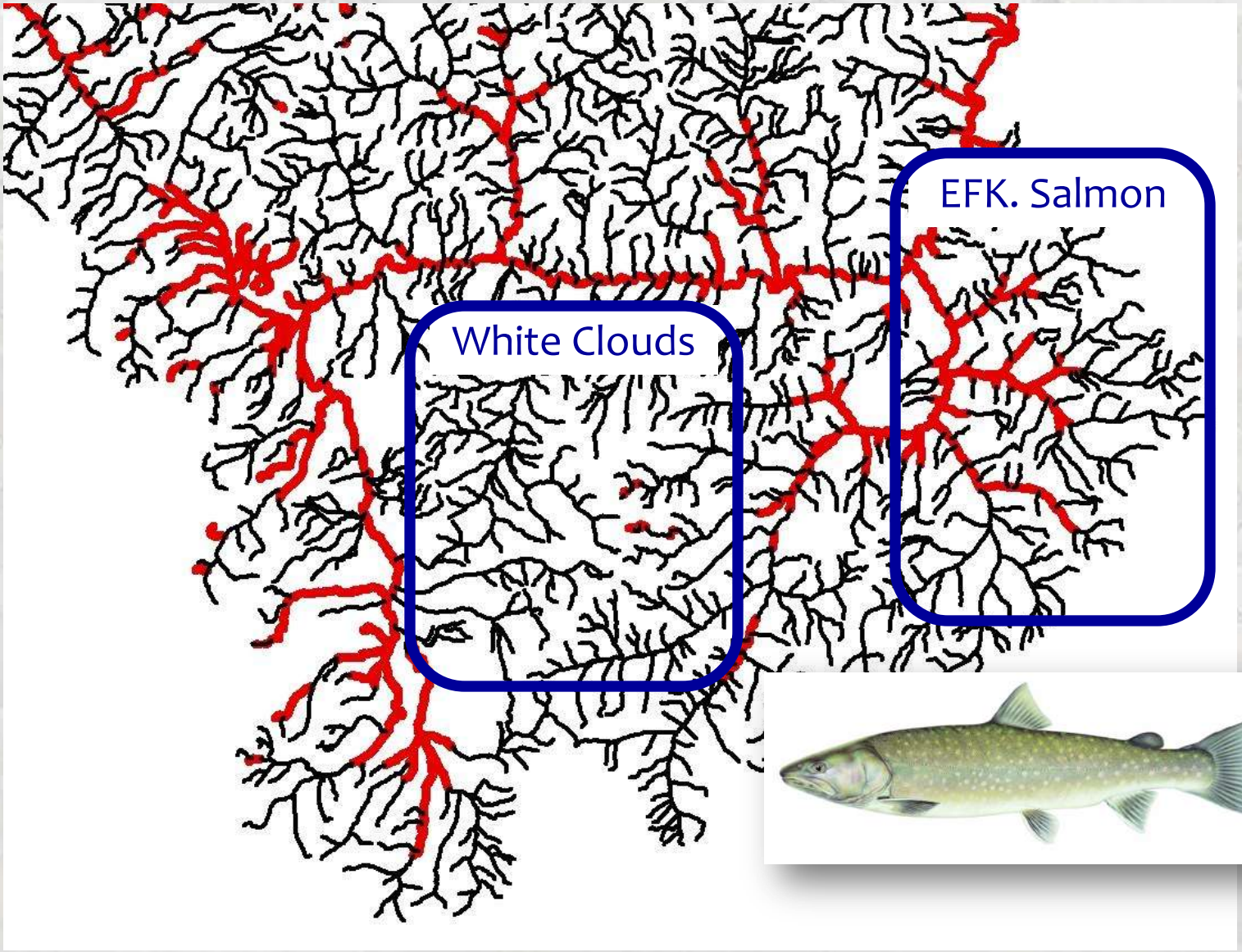
Suitable

Unsuitable



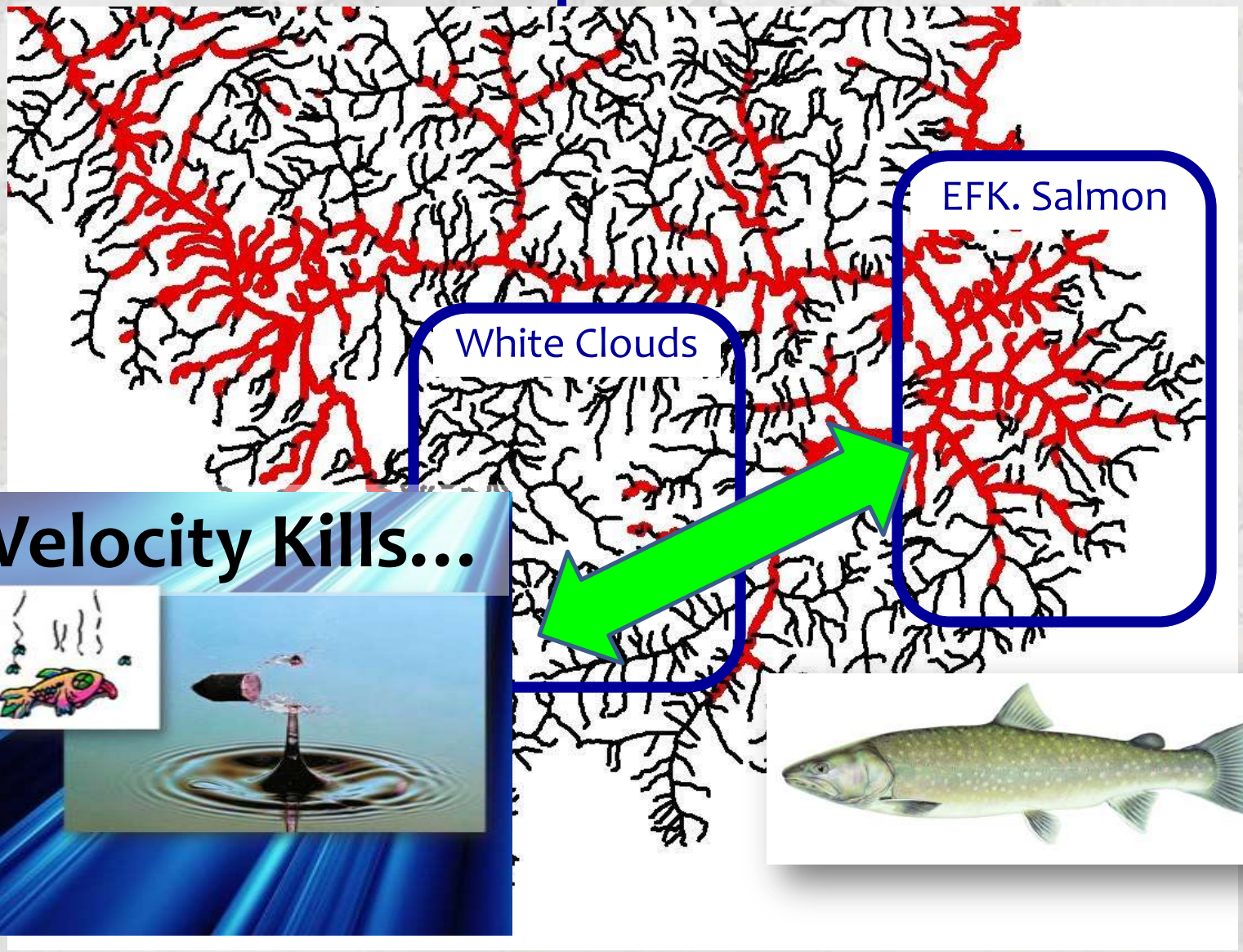
Spatial Variation in Habitat Loss

Historical scenario

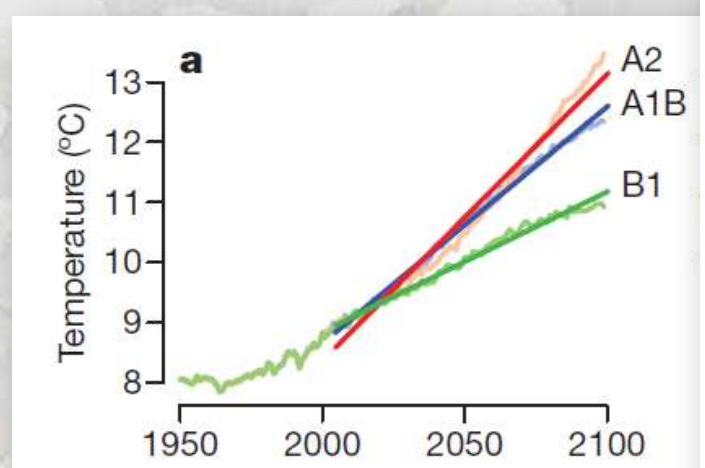


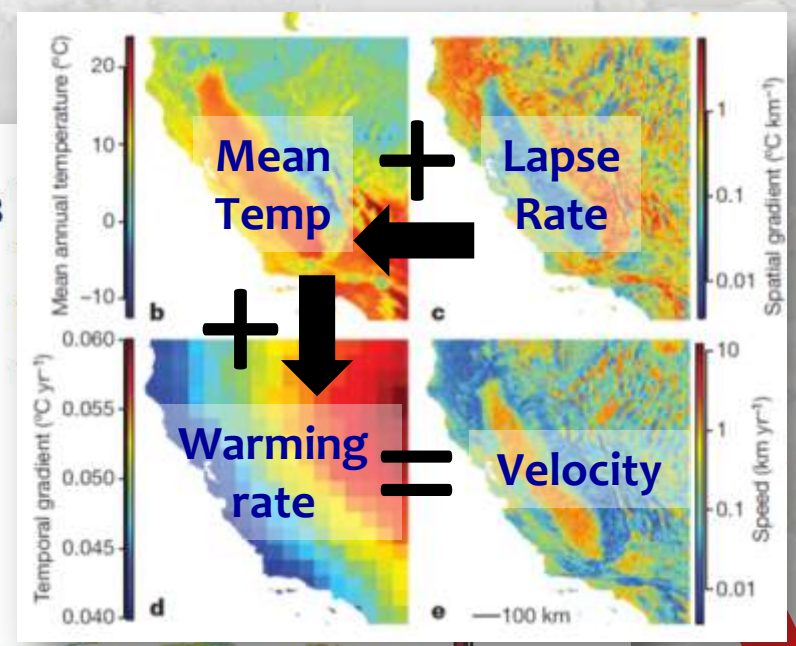
Spatial Variation in Habitat Loss

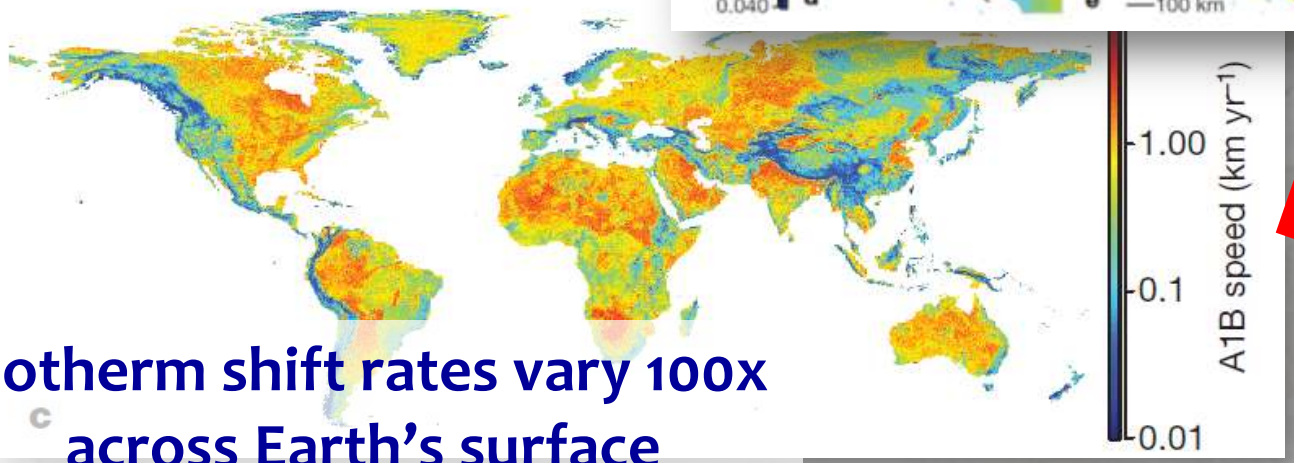
+1°C stream temperature scenario



Climate Velocity is Strongly Mediated by Topography…



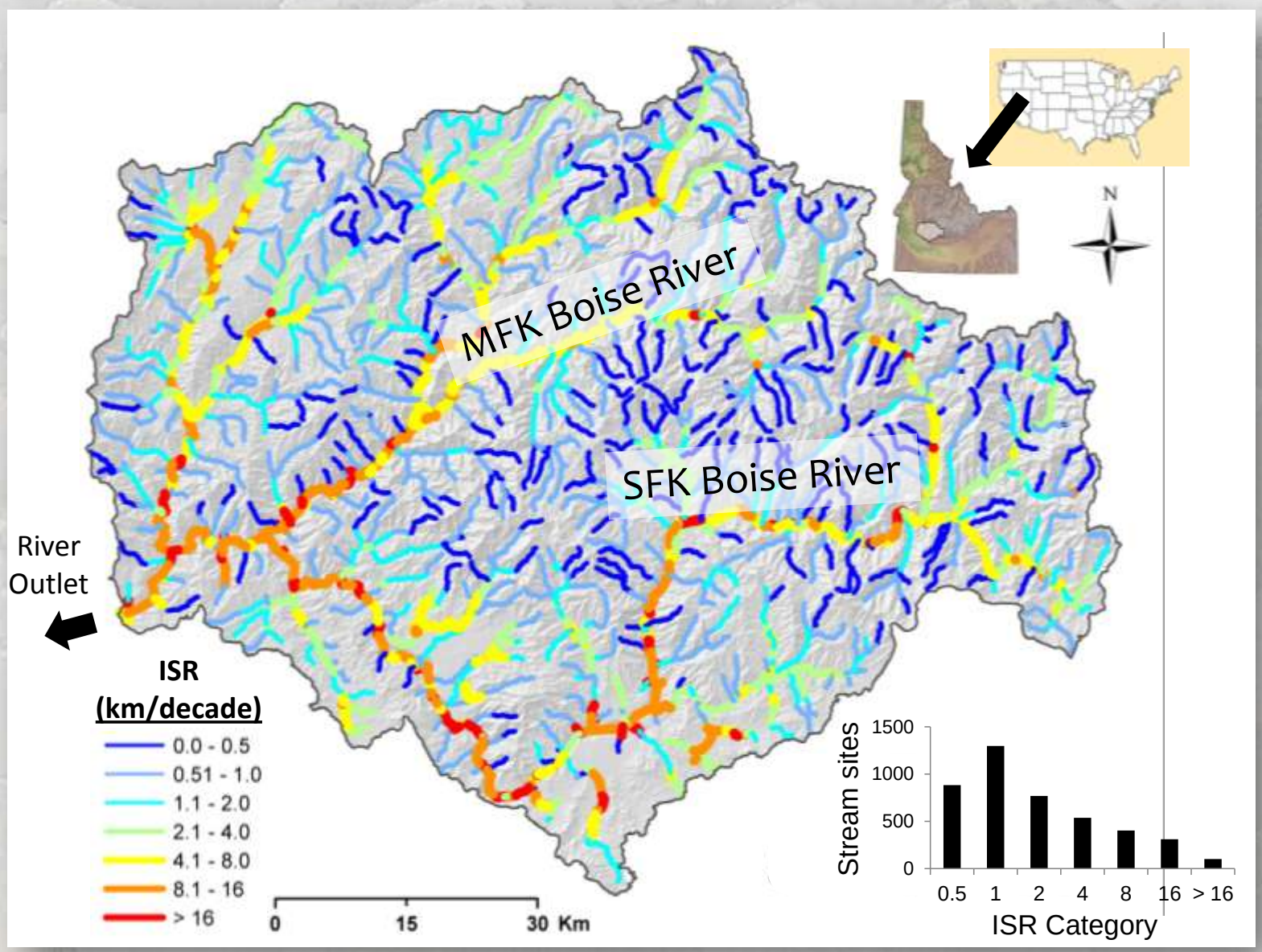




Isotherm shift rates vary 100x across Earth's surface

Loarie et al. 2009. *Nature* **462**:1052-1055.

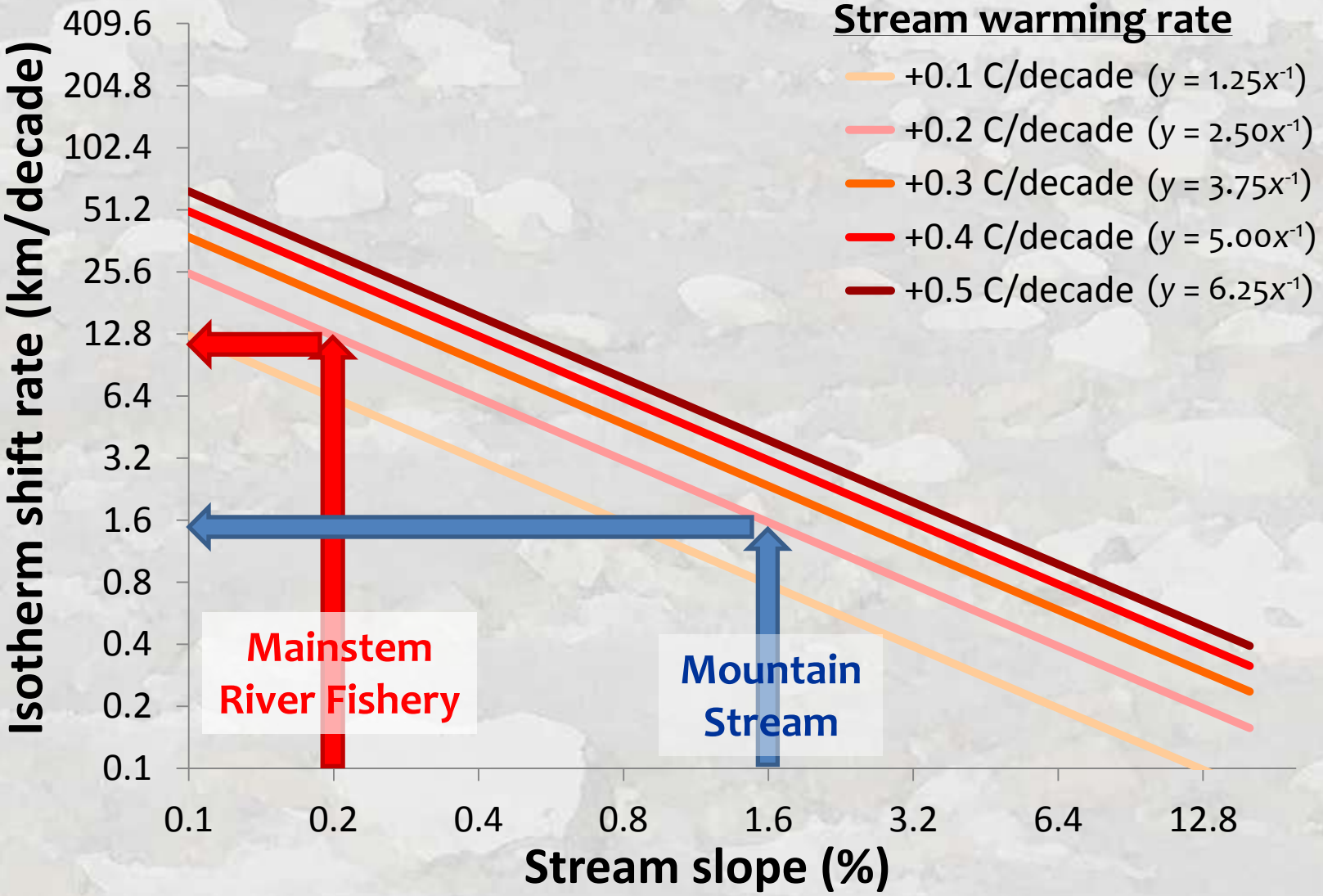
Climate Velocity Map for River Network



Isaak & Rieman. 2013. *Global Change Biology* **19**:742-751.

Isotherm Shift Rate Curves

Stream lapse rate = 0.8 °C / 100 m



Isaak & Rieman. 2013. *Global Change Biology* **19**:742-751.

Mainstem Rivers & Fisheries Will See First & Most Pronounced Thermal Impacts & Community Alterations

High Water Temperature In Grande Ronde Kills 239 Adult Spring Chinook

Columbia Basin Bulletin, August 14, 2009 (PST)

Low Flows Prompt Fishing Closure On Upper Beaverhead River And Reduced Limits On Clark Canyon Reservoir

Wednesday, September 29, 2004
Fishing

PRINT SHARE

denverpost.com

FISHING

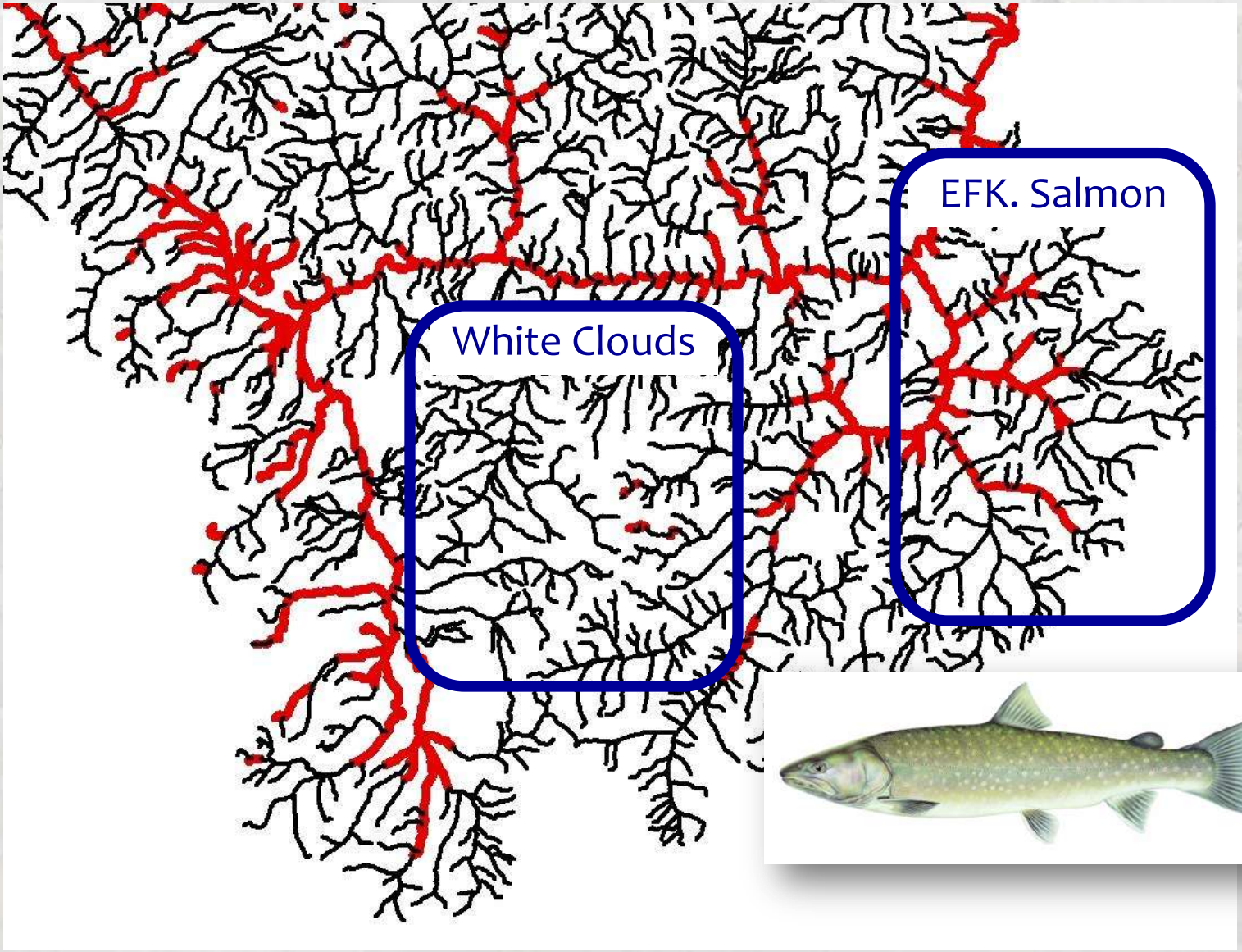
Heat causing fishing closures

PRINT EMAIL
0 COMMENTS

July 3, 2012

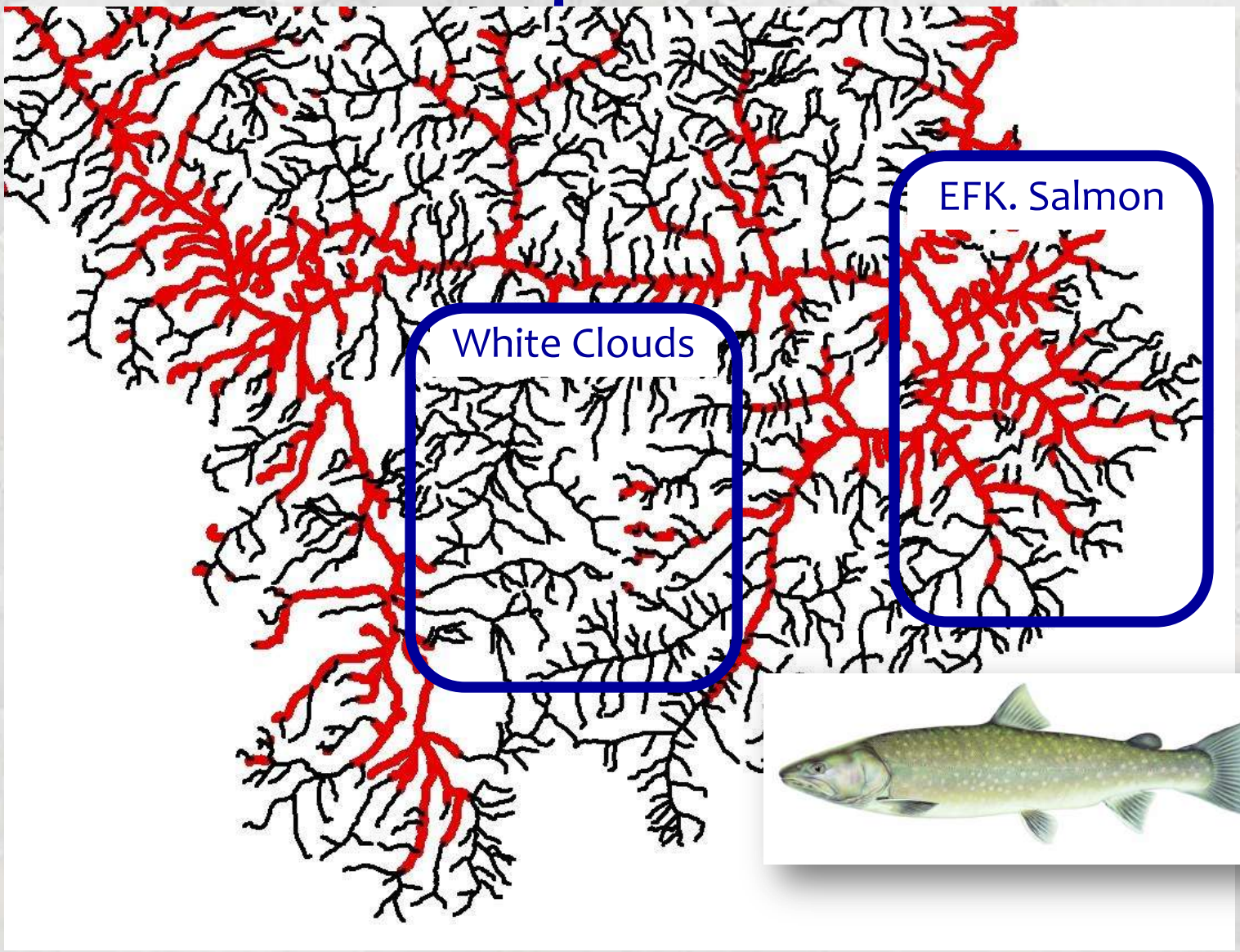
Spatial Variation in Habitat Loss

Historical scenario



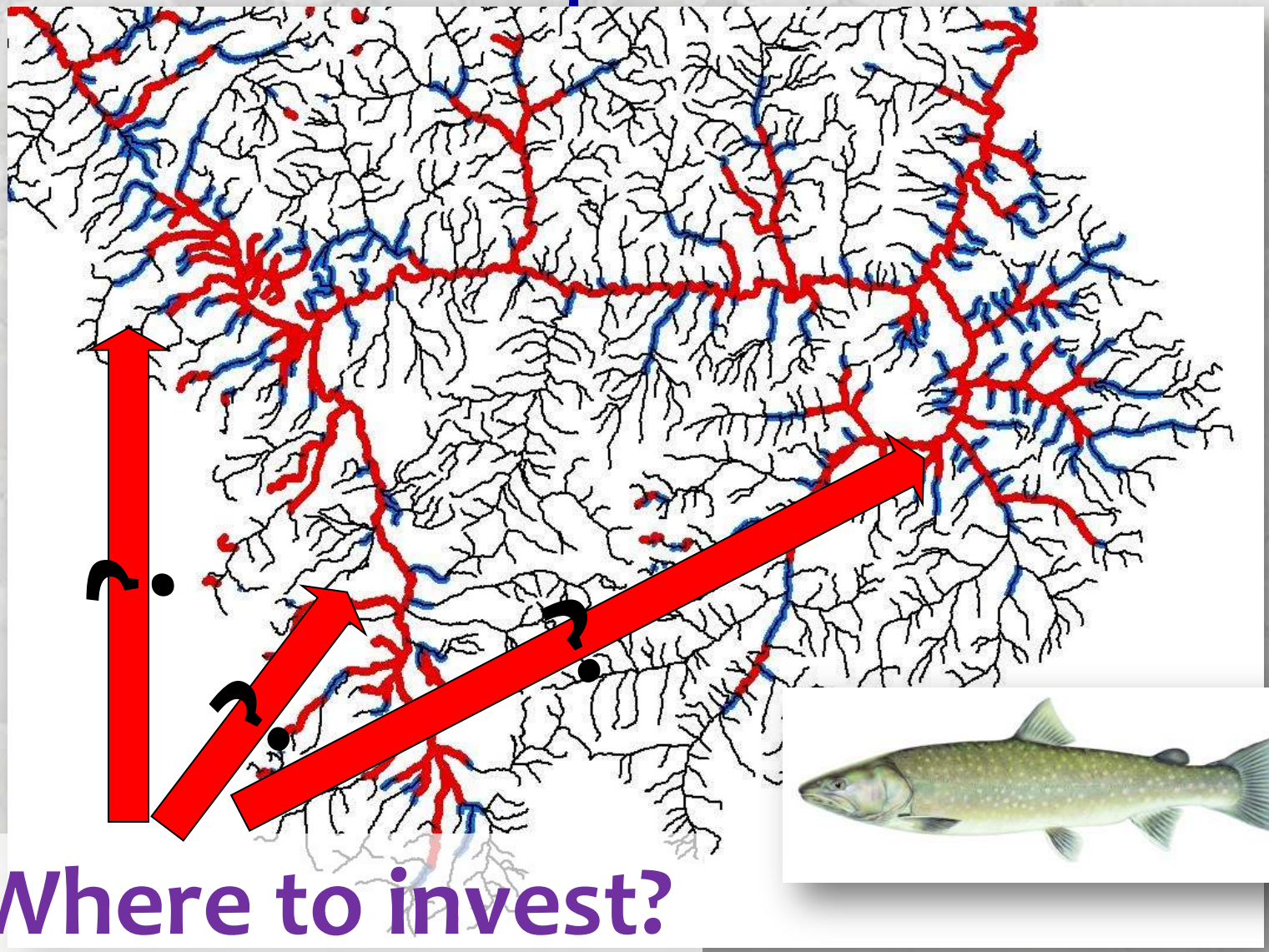
Spatial Variation in Habitat Loss

+1°C stream temperature scenario



Difference Map Shows Vulnerable Habitats

+1°C stream temperature scenario

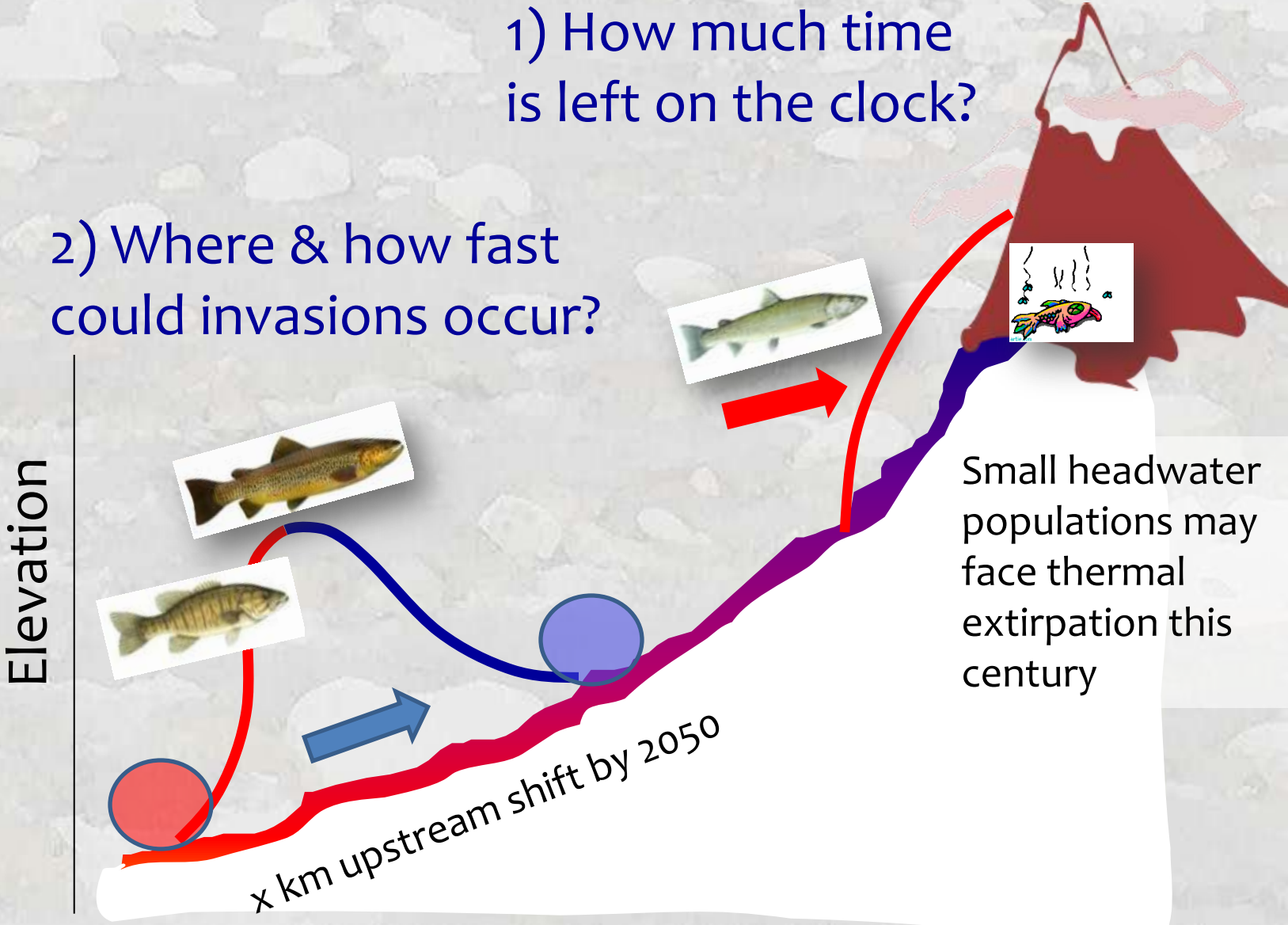


Where to invest?

Precise Information Regarding Potential Species Invasions & Population Extirpations

1) How much time is left on the clock?

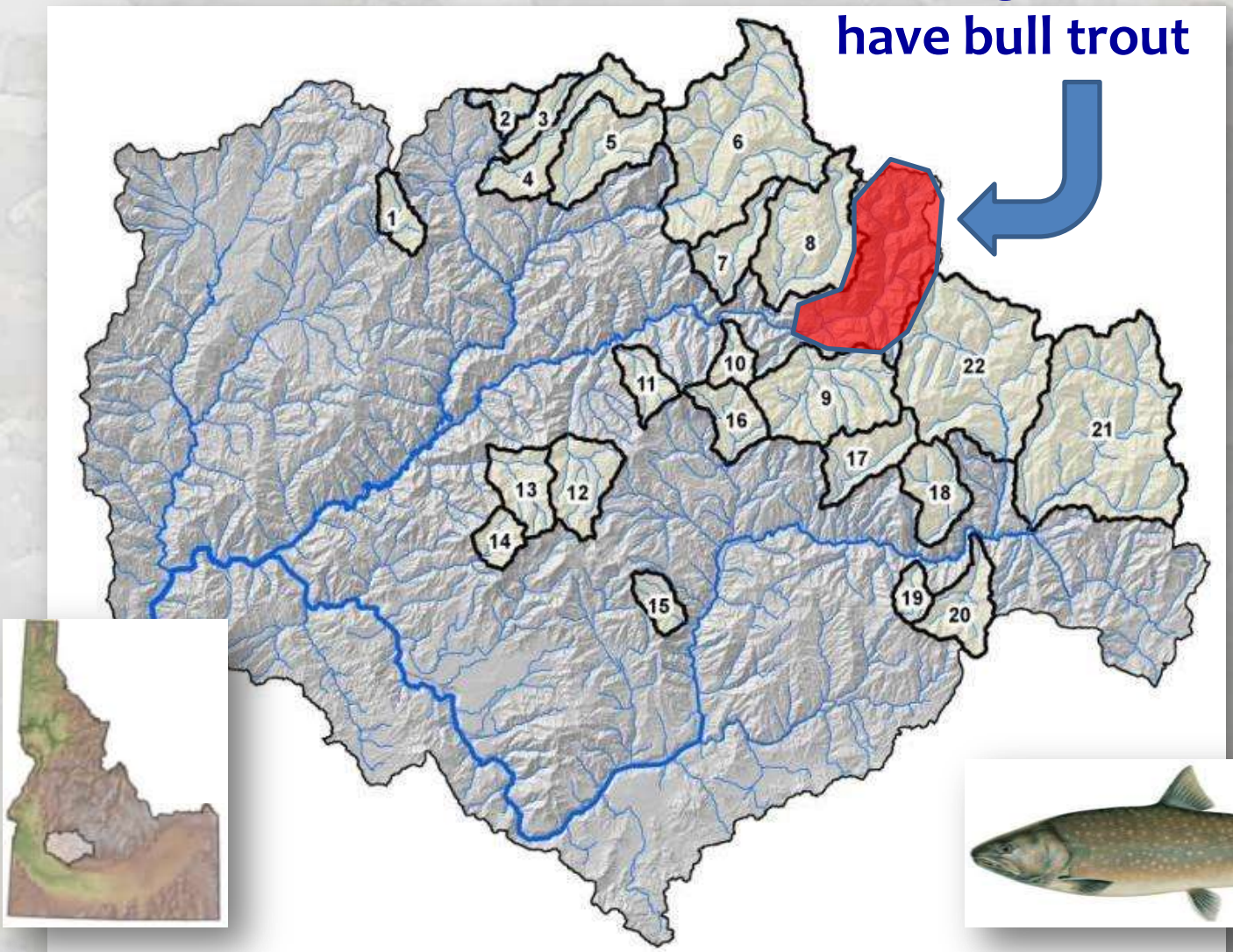
2) Where & how fast could invasions occur?



Small headwater populations may face thermal extirpation this century

Suitable Habitats for Assisted Migrations, Reintroductions, Barrier Construction

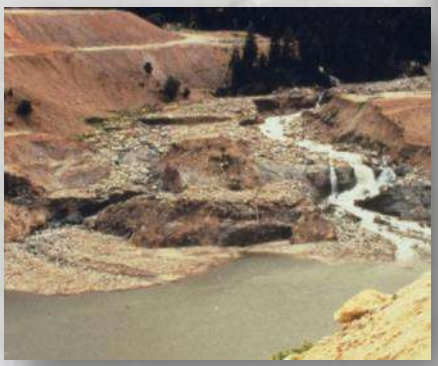
This big habitat doesn't have bull trout

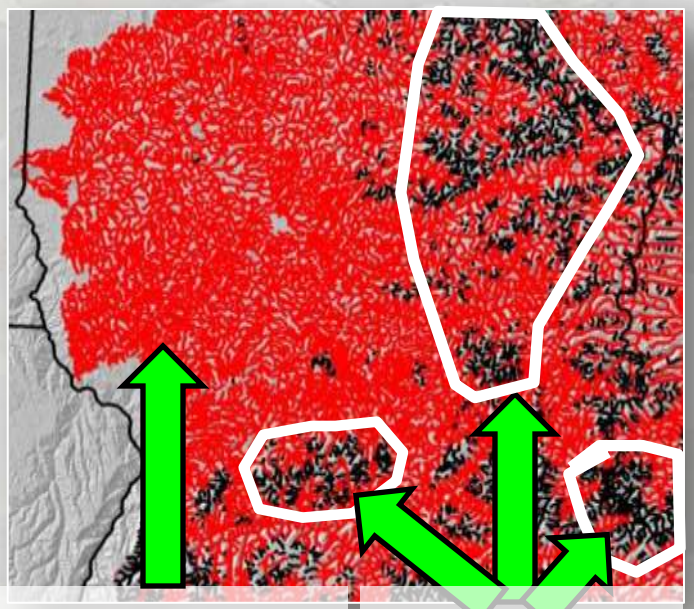


Climate-Smart Strategic Prioritization

Lots of things we can do…

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

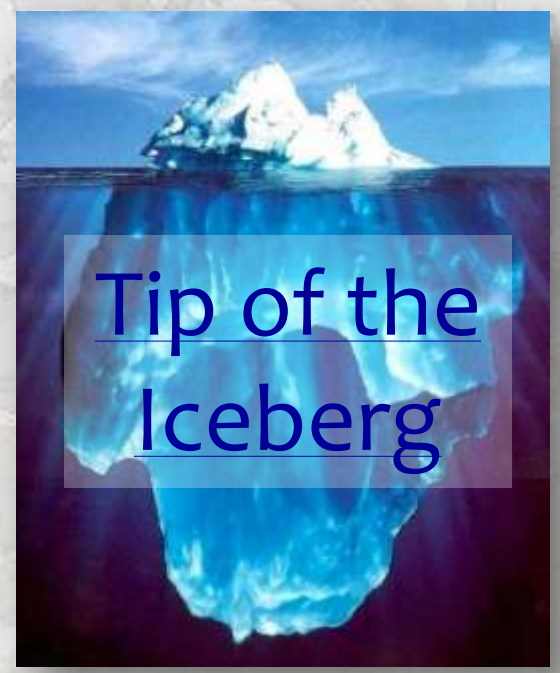


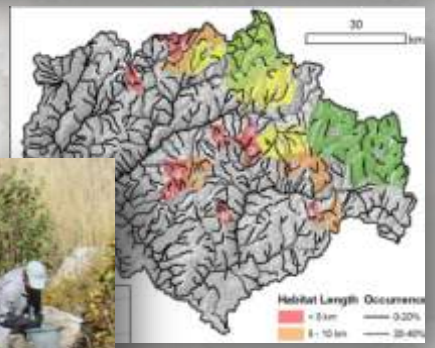


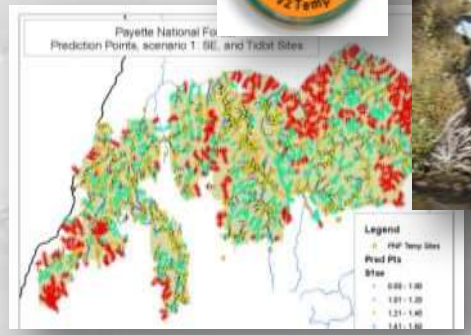
Low Priority | **High Priority**

NorWeST Facilitating Related Projects

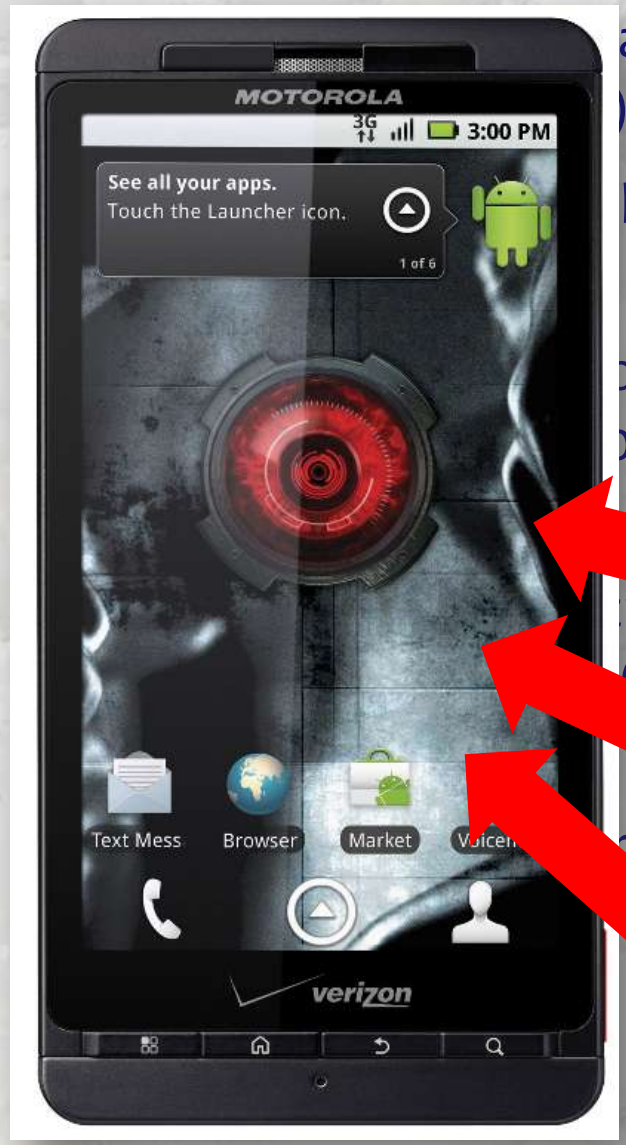
- Regional bull trout climate vulnerability assessment (J. Dunham)
- Cutthroat & bull trout climate decision support tools (Peterson et al., 2013)
- Landscape-scale bull trout monitoring protocol (Isaak et al. 2009)
- Consistent thermal niche definitions & more accurate bioclimatic models for trout & nongame fishes (S. Wenger, In Prep.)
- Efficient stream temperature monitoring designs



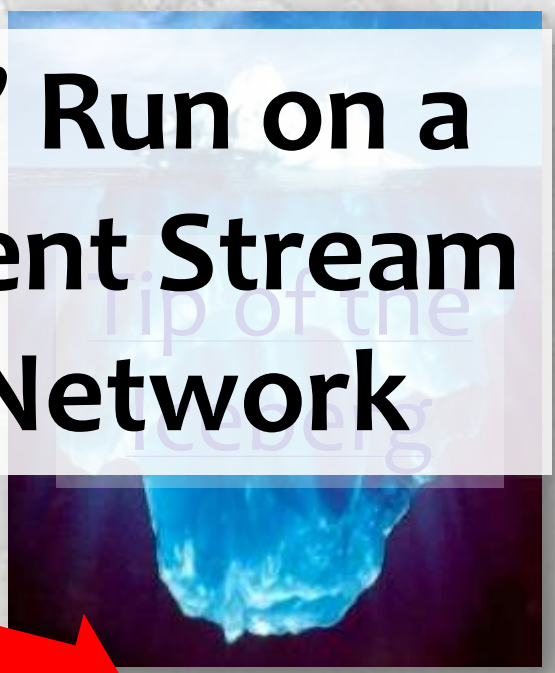


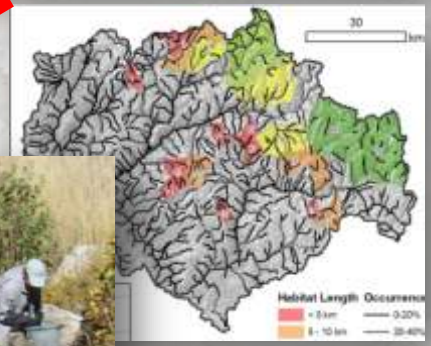


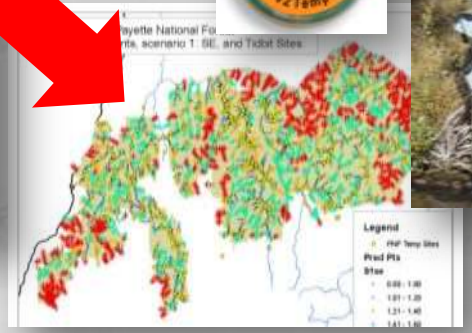
NorWeST Facilitating Related Projects



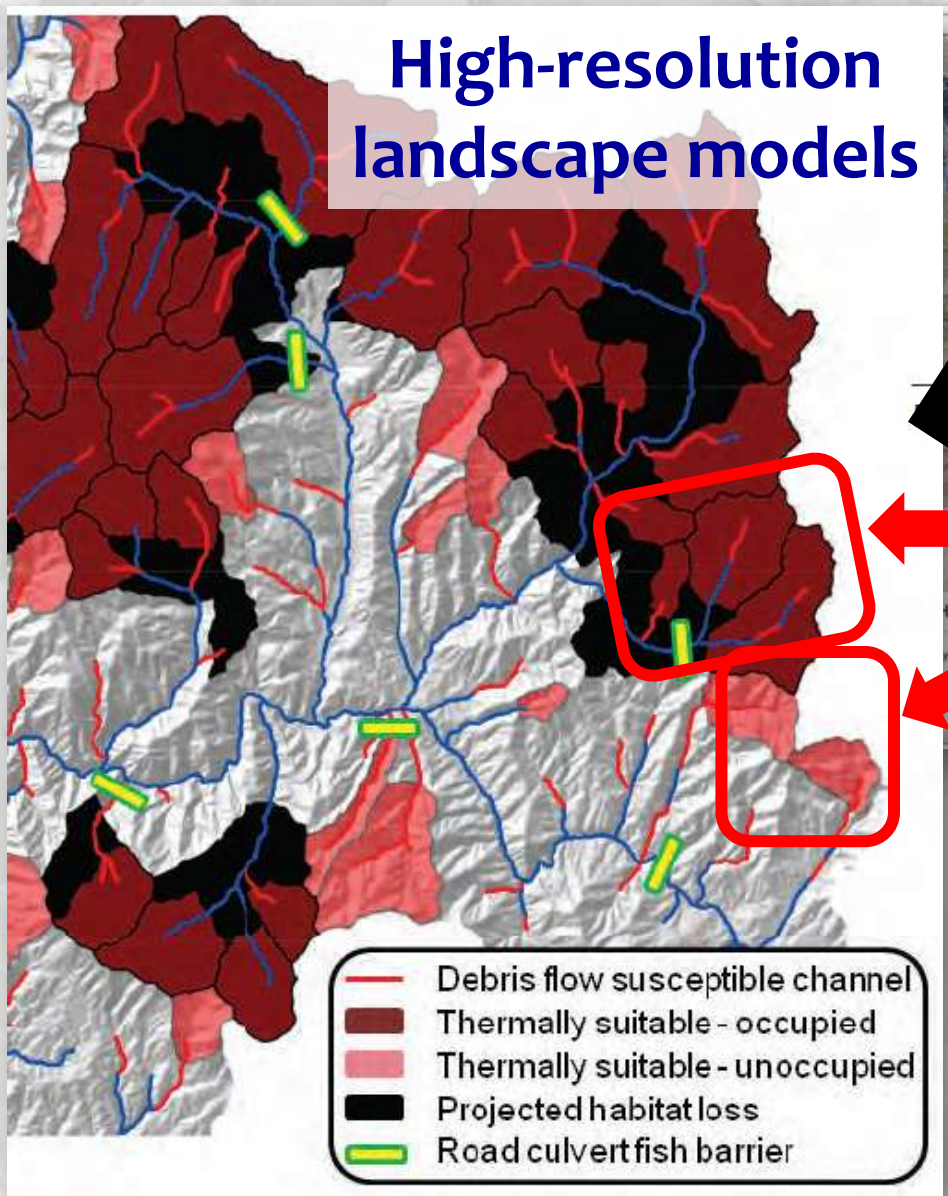
"Apps" Run on a Consistent Stream Data Network







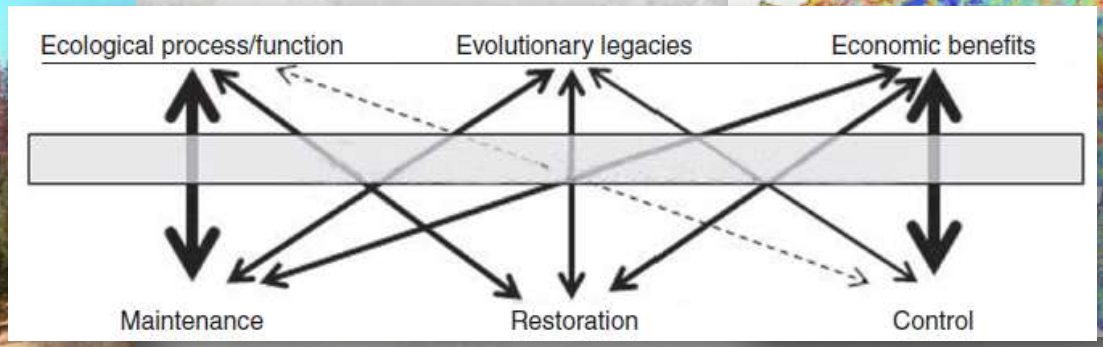
Lots of Precise Information for Decision Making Coming Online…

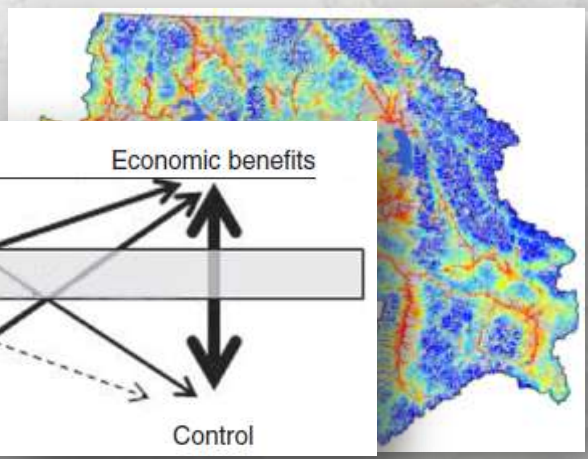


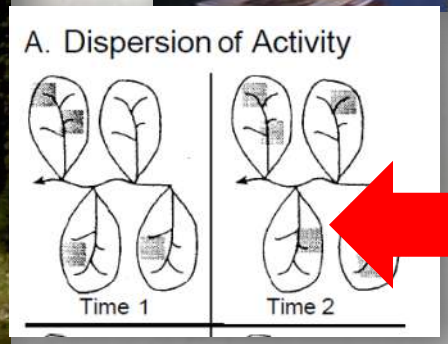
How do we Bring it All Together?

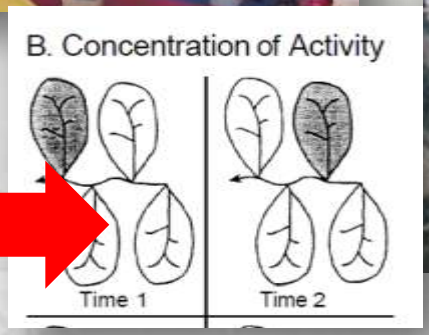
What is "Optimal" Management?

What are our Goals?









Reeves et al. 1995; Rieman et al. 2010.

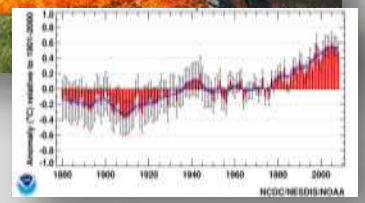
Current Choices Set Future Trajectories

Choice A: Coexistence (accept change passively &/or shape transition to more desirable communities)

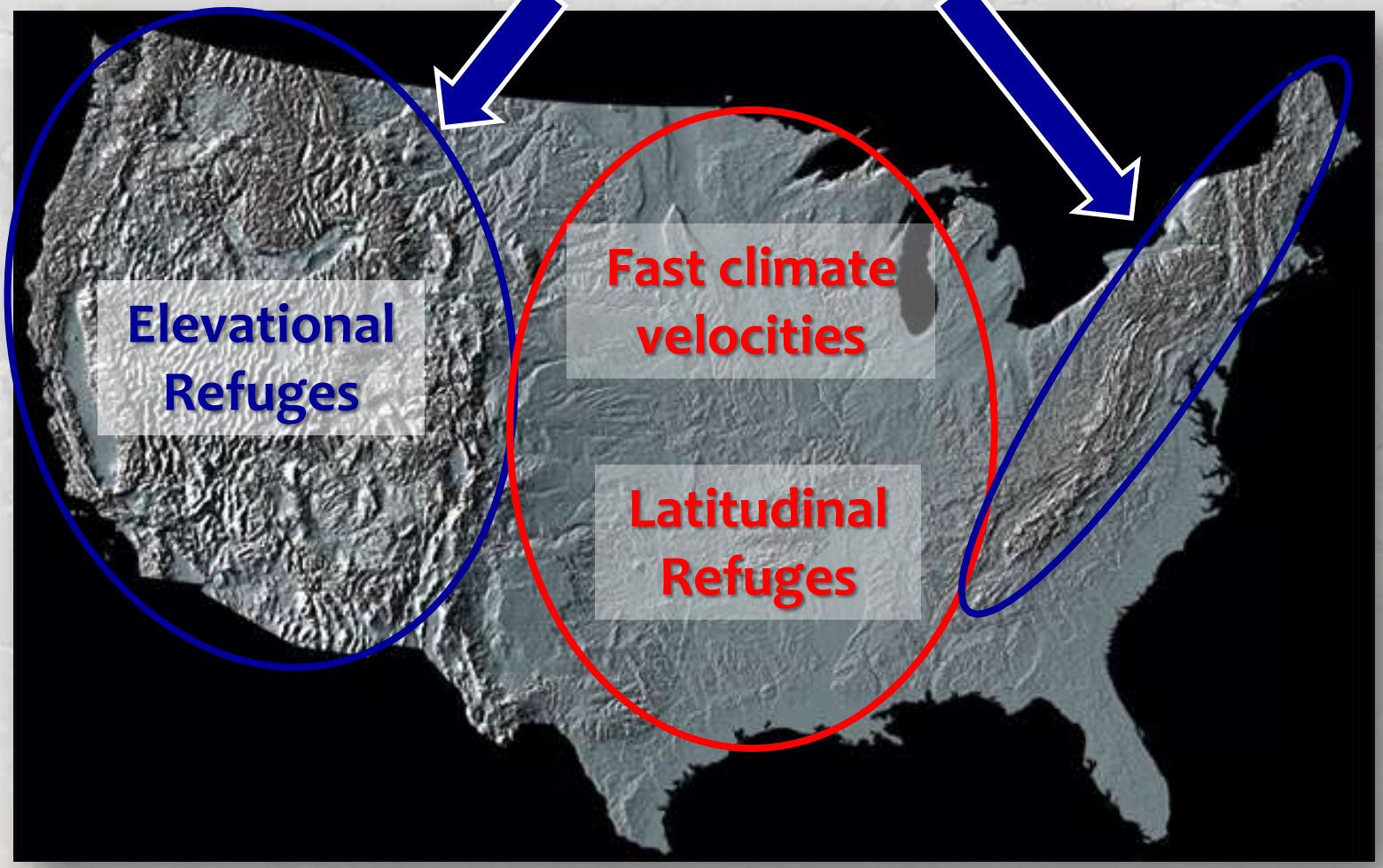
What Do We Choose?

Where Do We Choose It?

Conservation reserves, important fisheries



Steep Mountain Streams & Rivers Will Provide Important Climate Refugia



Where Are The "Bombproof" Habitats?

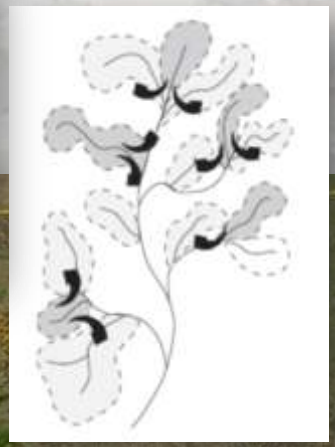
- Should These Have Additional Protections?
- Could the bomb-shelters provide a foundation for a fish conservation reserve system?

Feature:
FISHERIES MANAGEMENT

Native Fish Conservation Areas: A Vision for Large-Scale Conservation of Native Fish Communities

Jack E. Williams, Richard N. Williams, Russell F.

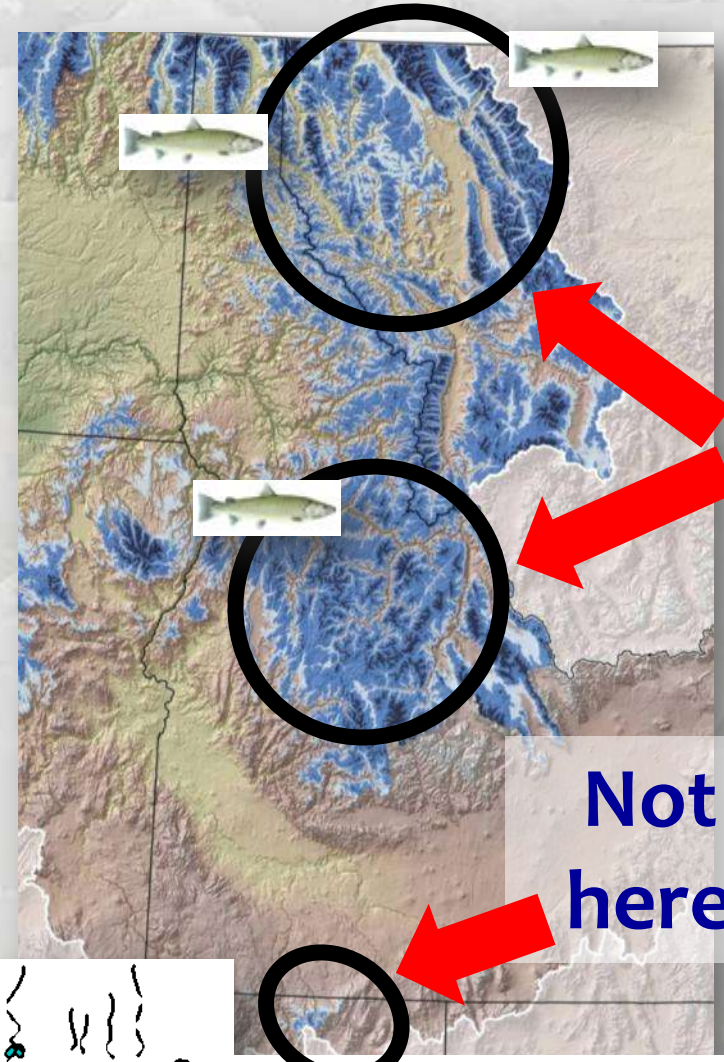
Áreas para la Conservación de Peces



The Past as Prelude to the Future for Understanding 21st-Century Climate Effects on Rocky Mountain Trout

Isaak et al. 2012. *Fisheries* **37**: 542-556.

Developing Good Scientific Information is the Easy Part, butt…

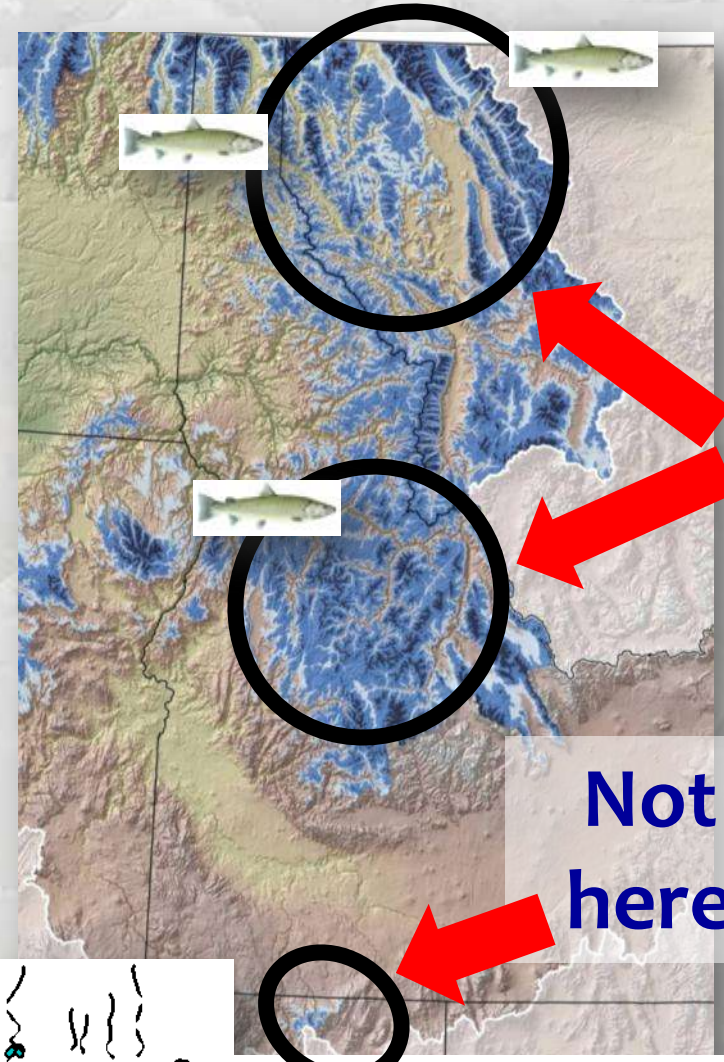


Invest Here

Not here

Sorry Charlie

Developing Good Scientific Information is the Easy Part, butt…



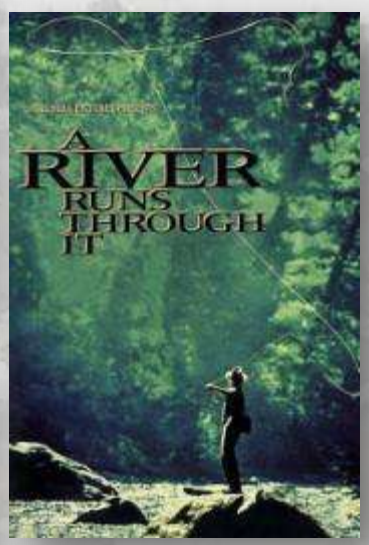
Invest Here

Not here

Sorry Charlie

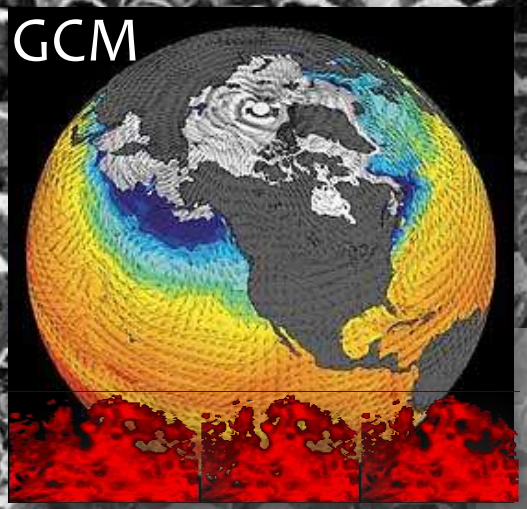
…we're not dealing with rational creatures here

People Love These Fish & Landscapes

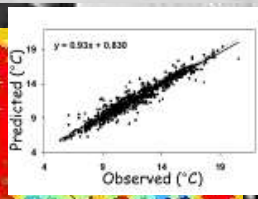


Building Consensus is Critical
"Crowd-Sourcing" is an Important Tool

GCM



Landscape/
Network



Data Collected by
Local Bios & Hydros

Coordinated Management Responses?

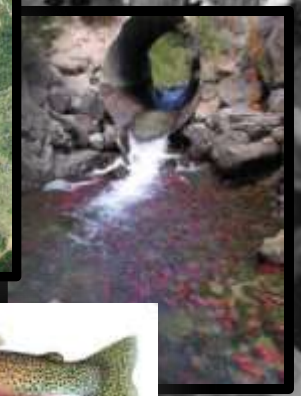
KALISPEL

IDAHO FISH & GAME

USFS

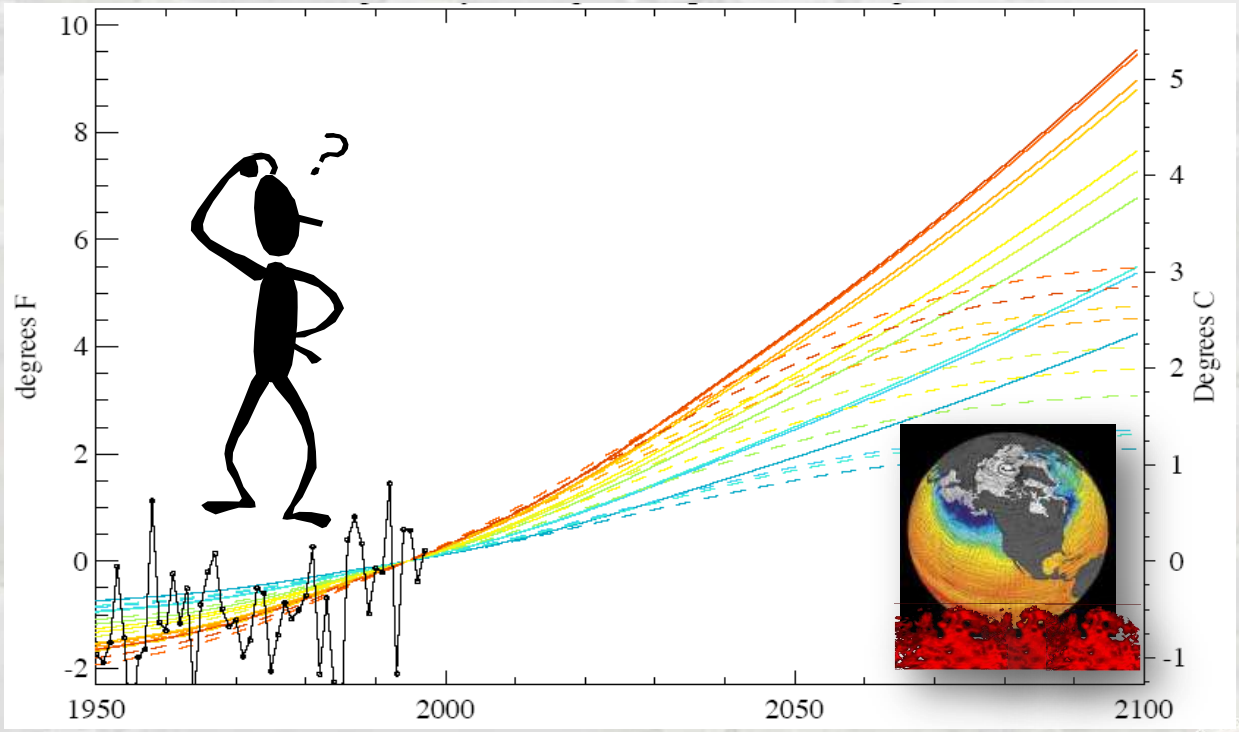
USGS
science for a changing world

NOAA Fisheries

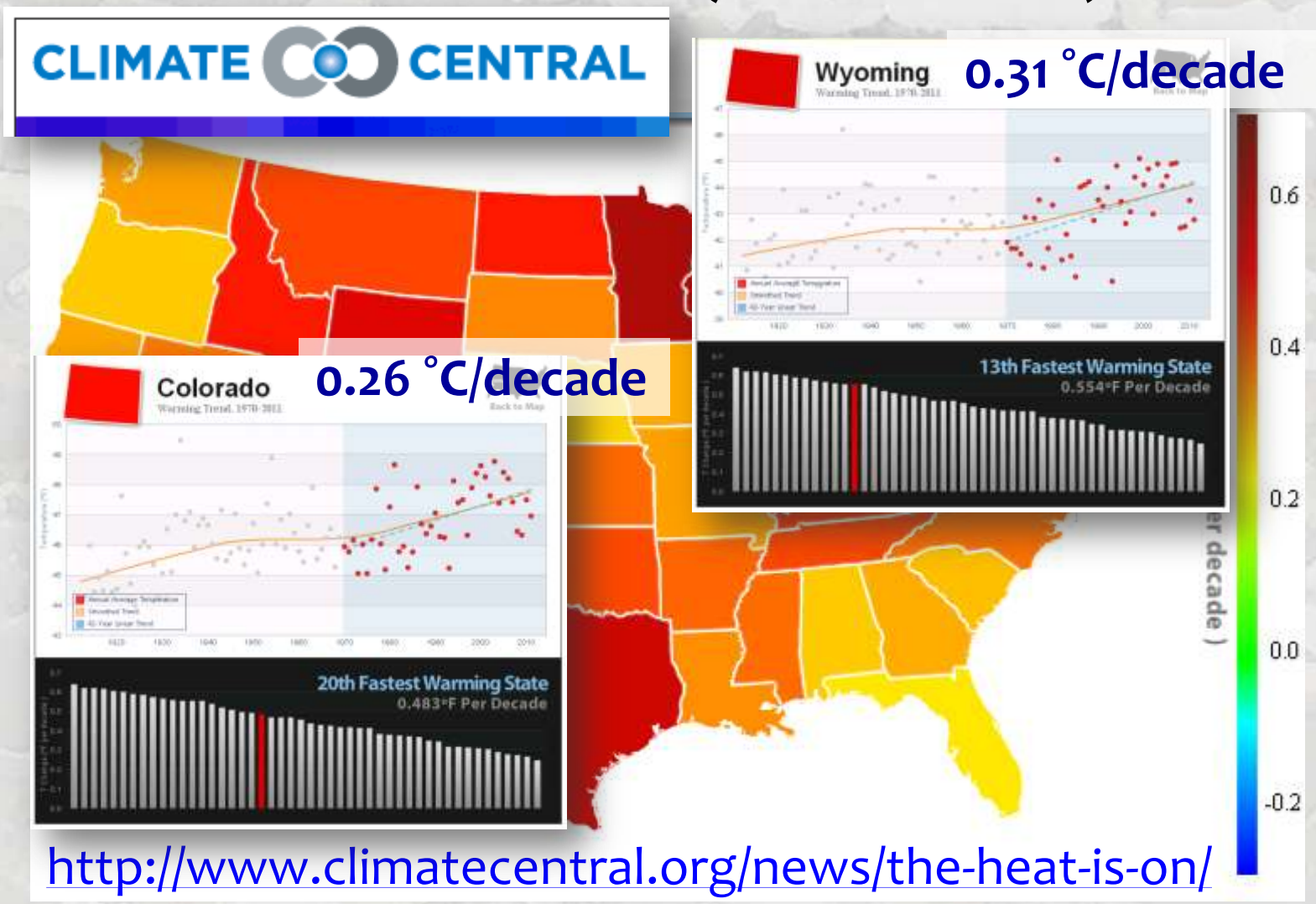


Management
Decisions

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



Air Temperature Warming Rates in WY/CO (1970 – 2011)…



"Heat is on report" Tebaldi 2012


Global Warming Is ...
NOT COOL!
The End