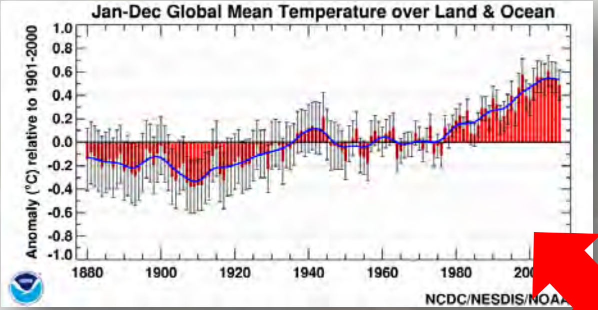
Development and Application of the NorWeST Regional Stream Temperature Model for Bull Trout Climate Assessments and Monitoring

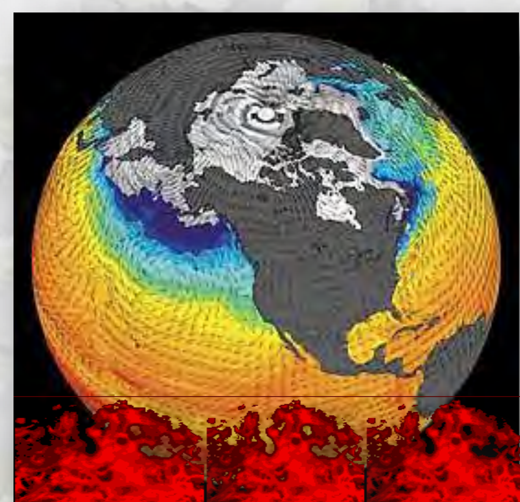
Dan Isaak, Seth Wenger[1], Erin Peterson[2], Jay Ver Hoef[3] Charlie Luce, Steve Hostetler[4], Jason Dunham[4], Jeff Kershner[4], Brett Roper, Dave Nagel, Dona Horan, Gwynne Chandler, Sharon Parkes, Sherry Wollrab

U.S. Forest Service
[1]Trout Unlimited
[2]CSIRO
[3]NOAA
[4]USGS

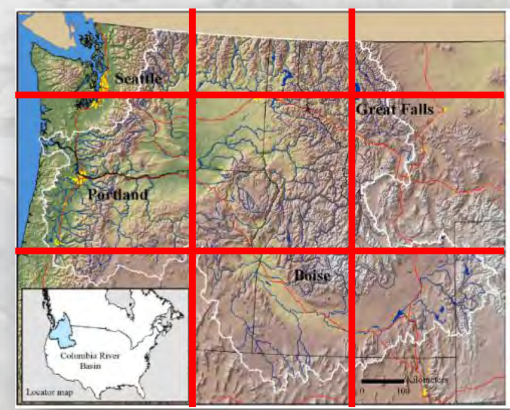


How Will Global Climate Change Affect My Streams & Favorite Fish?

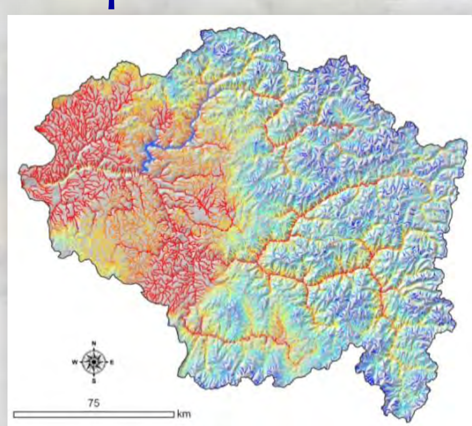
Global climate



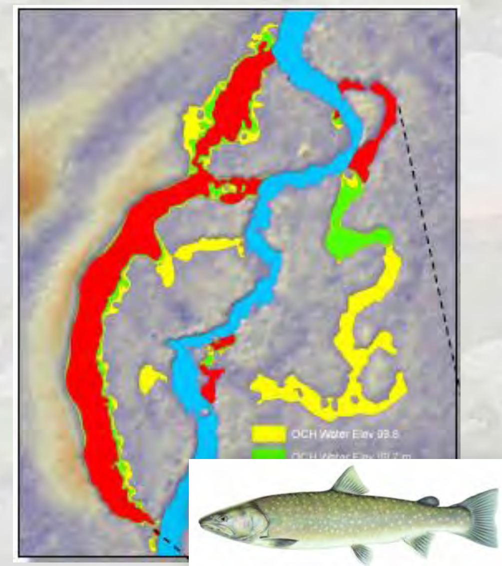
Regional climate



River network temperatures



Stream reach



General outline:

1) The Rieman et al. (2007) regional bull trout climate assessment

2) The NorWeST regional stream temperature database, model, and climate scenarios

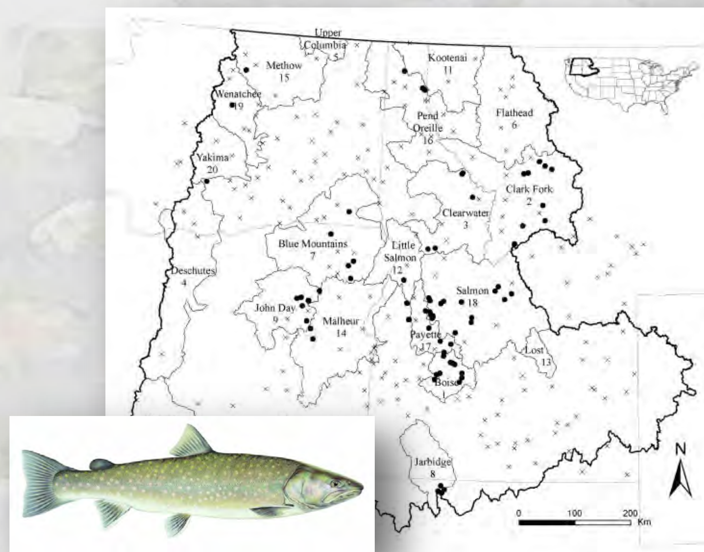
3) Uses of NorWeST products for bull trout conservation and management

4) Key uncertainties for bull trout in a warming world

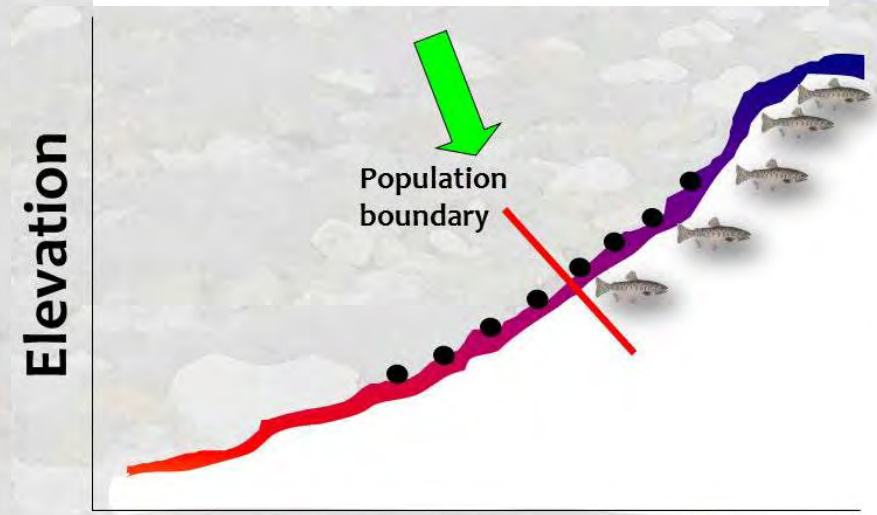
Bull Trout Climate Model:

What Are the Historical Patterns?

76 streams with longitudinal surveys



Bull trout elevation boundaries



Juvenile Bull Trout Lower Elevation Limit (R^2 = 0.74)

Y = 18693 - 191(latitude) + 73.6(longitude)

1° lat = -191 m; 1° long = 73.6 m change in bull trout elevation limit

Mean Annual Air Temperature (R^2 = 0.89)

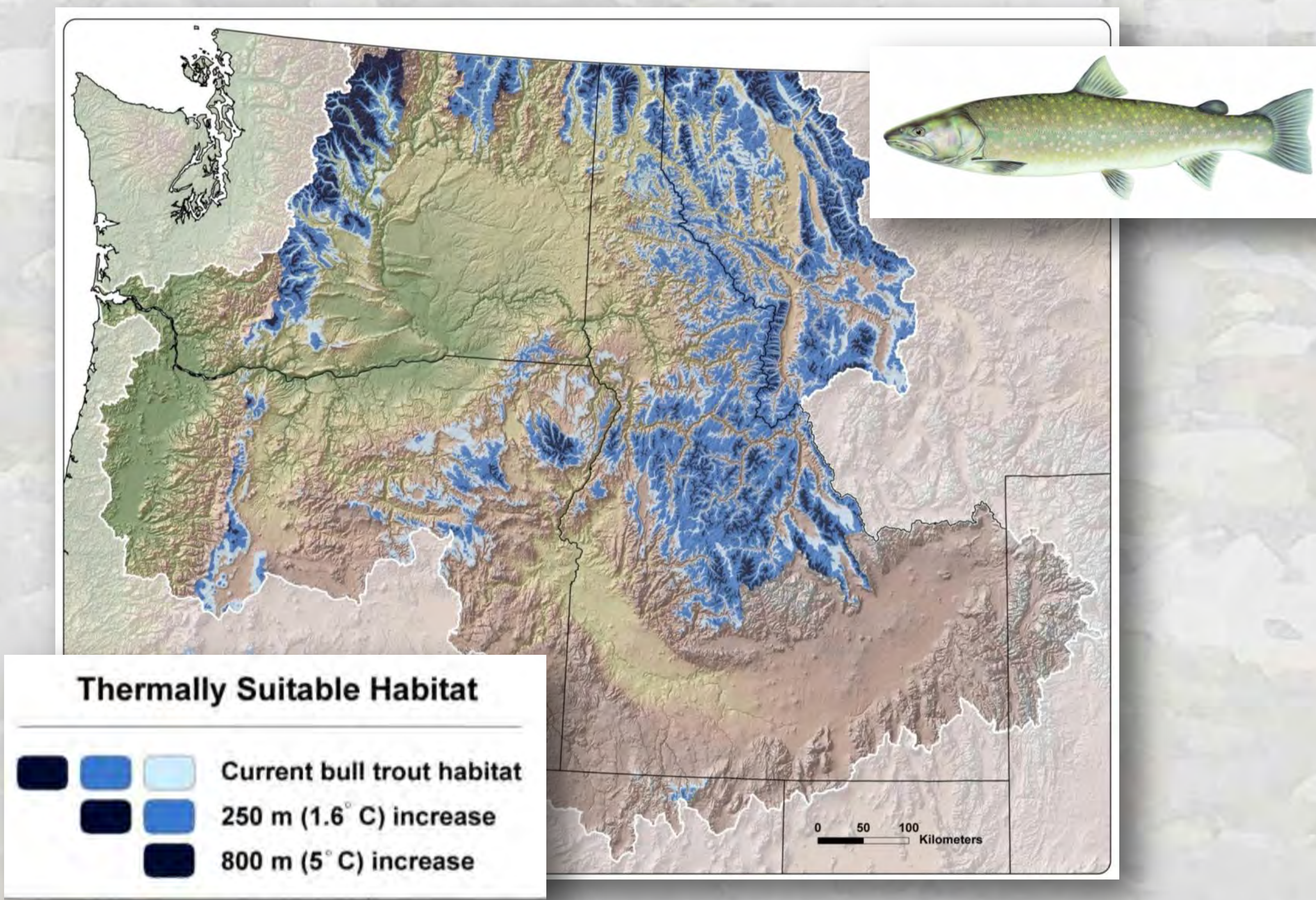
Y = 67 – 0.86(latitude) + 0.12(longitude) - 0.0062(elevation)

1° lat = - 138 m; 1° long = 88 m change in isotherm elevation

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

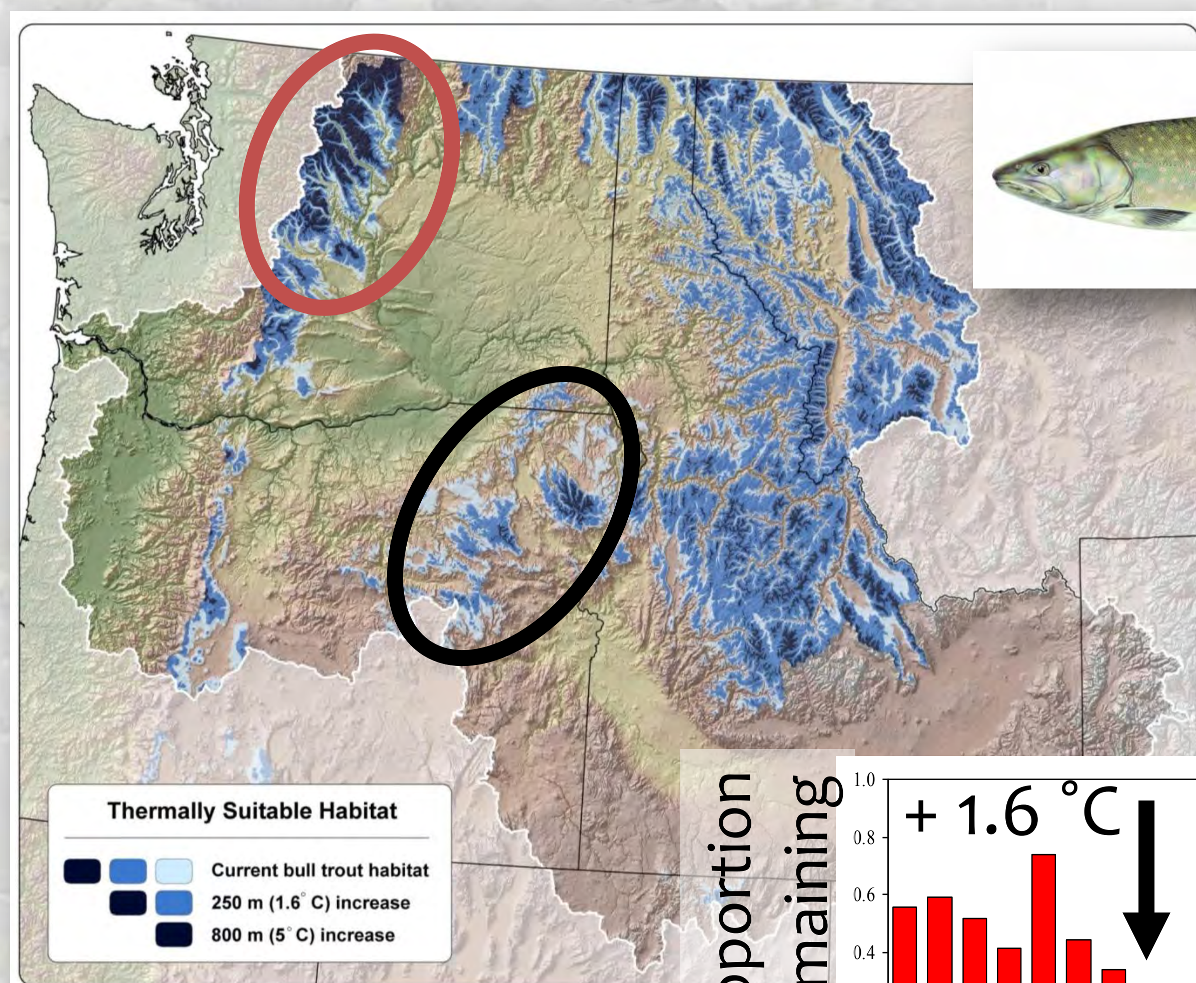
Bull Trout Climate Model:

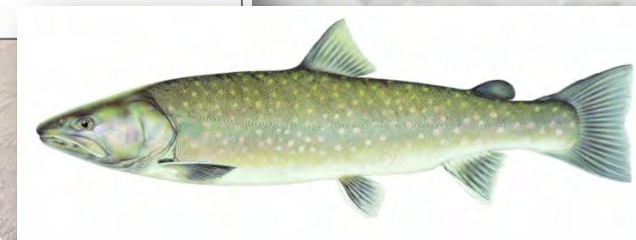
Lots of Habitat at Risk

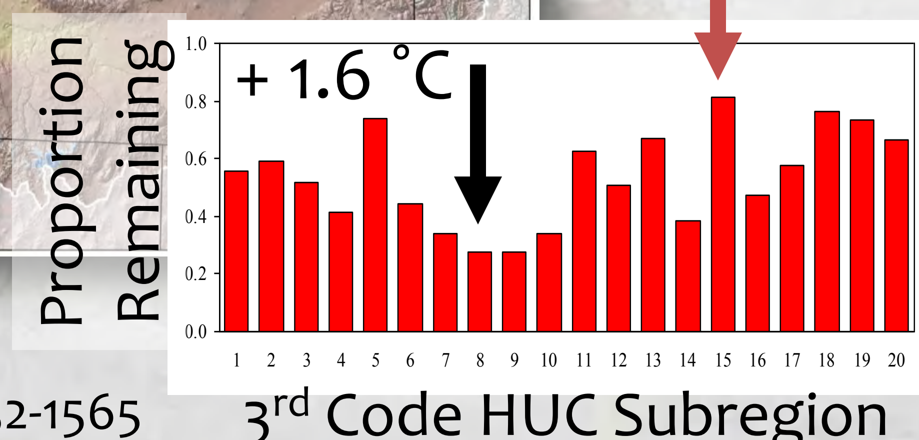


Rieman et al. 2007. *TAFS* **136**:1552-1565

Spatial Variation in Habitat Loss



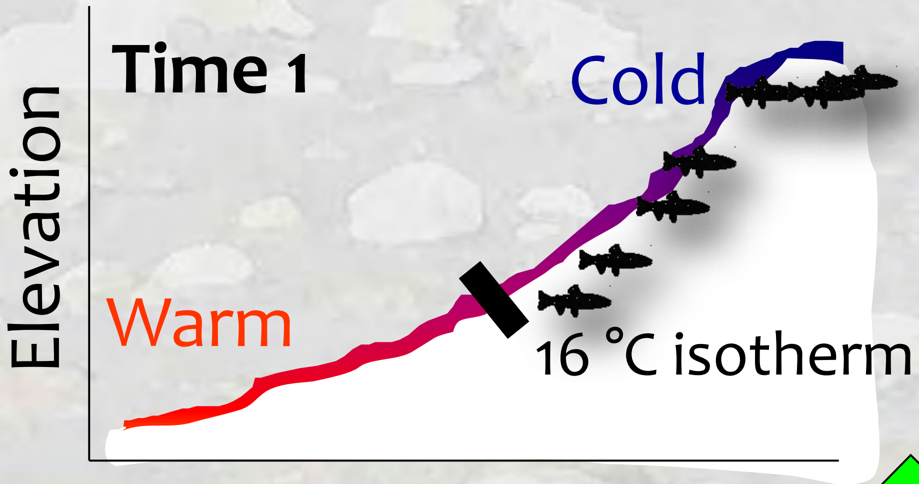




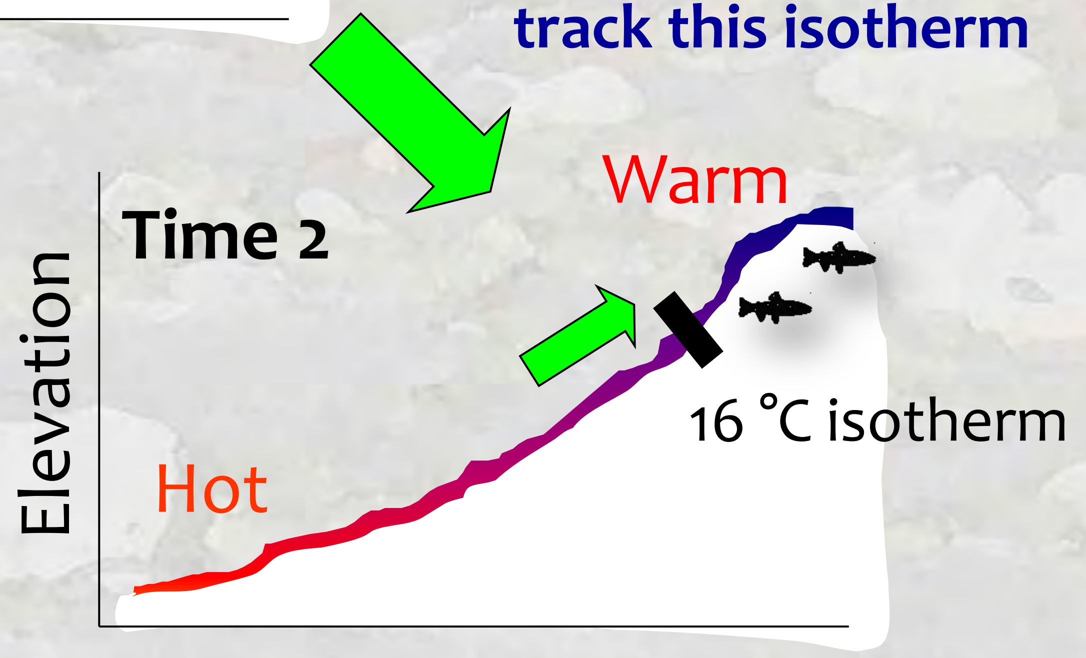
Rieman et al. 2007. *TAFS* **136**:1552-1565

Key BioClimate Model Assumption:

Critical isotherm delimits species/population boundary…

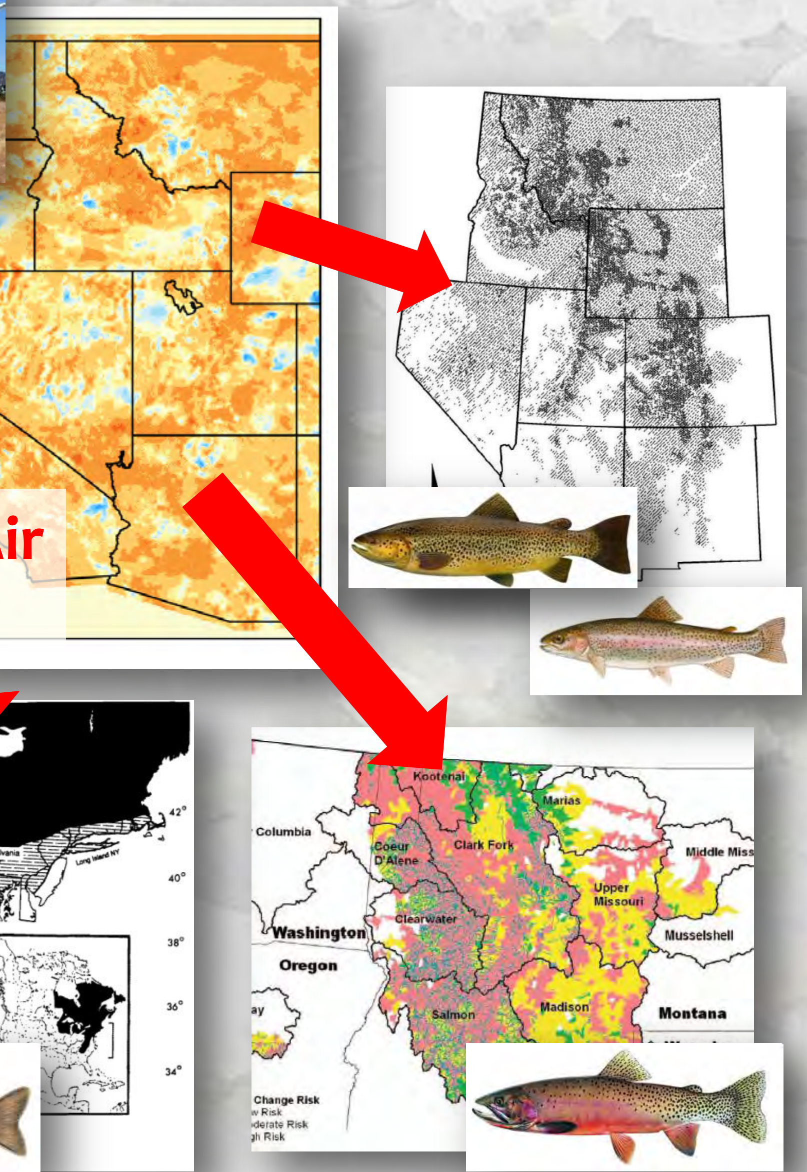



…& boundaries will track this isotherm

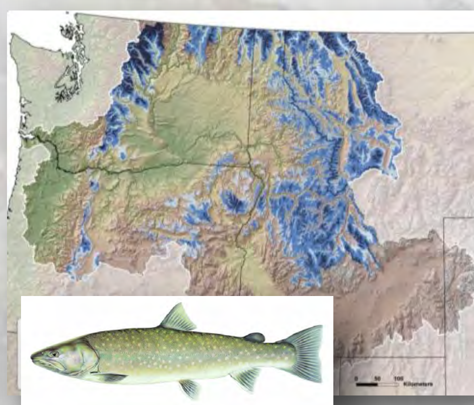


Existing Fish-Climate Models Are Coarse…

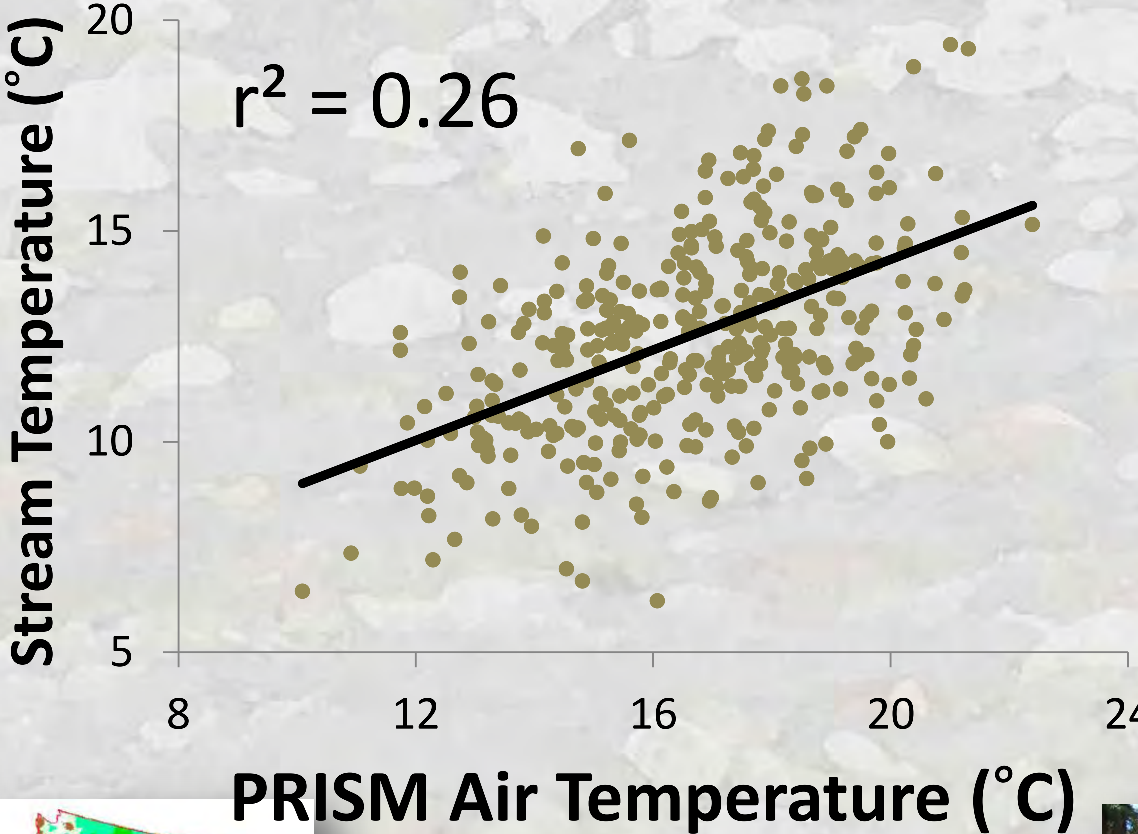
Based on air temperatures

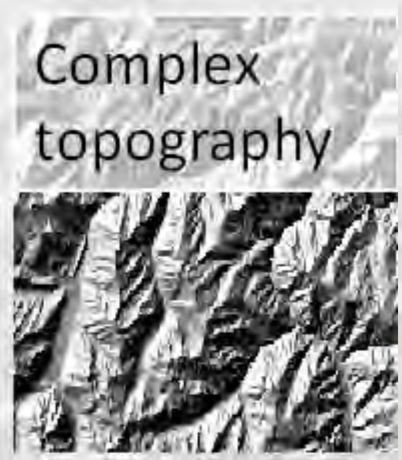


- •Meisner 1988, 1990
- •Eaton & Schaller 1996
- •Keleher & Rahel 1996
- •Rahel et al. 1996
- •Mohseni et al. 2003
- •Flebbe et al. 2006
- •Rieman et al. 2007
- •Kennedy et al. 2008
- •Williams et al. 2009
- •Wenger et al. 2011
- •Almodovar et al. 2011
- •Etc.

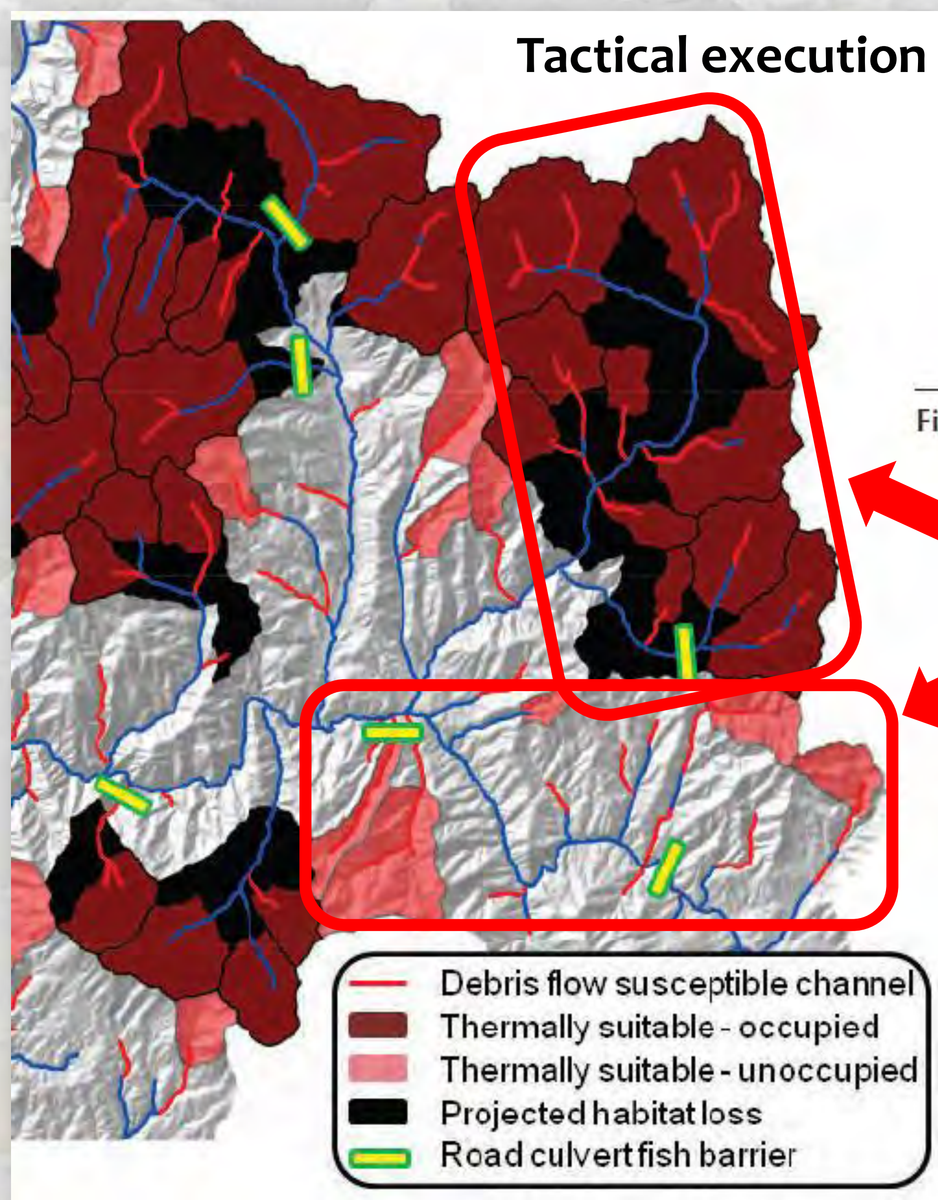


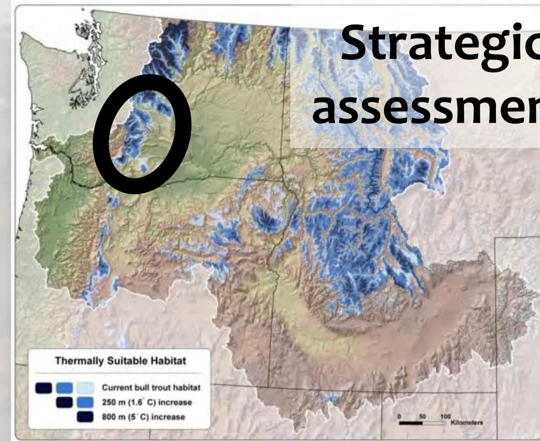
Air Temp ≠ Stream Temp





Accurate Landscape Level Information Needed to Empower Local Decision Makers





I'm going to invest here…

…instead of here

Developing a River Network Temperature Model from Application of Spatial Statistics to an Interagency Database

Dan Isaak, Charlie Luce, Bruce Rieman, Dave Nagel, Erin Peterson[1], Dona Horan, Sharon Parkes, and Gwynne Chandler

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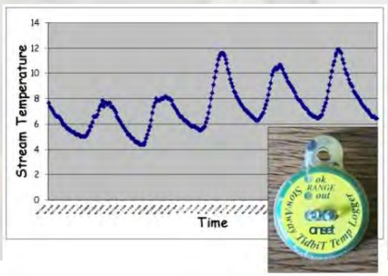
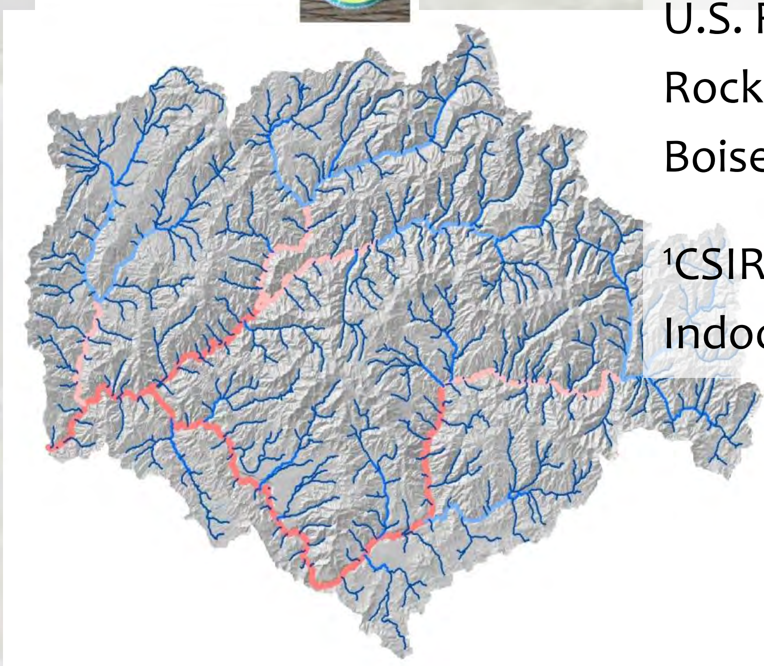
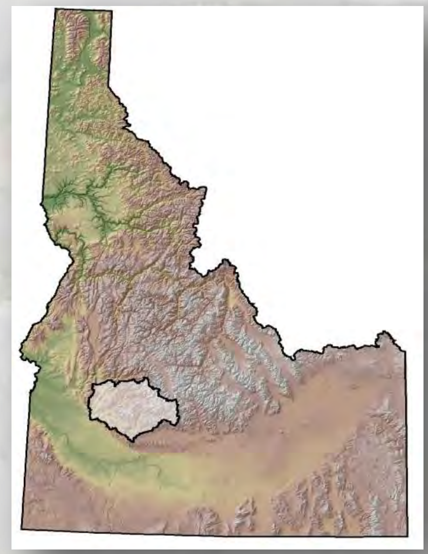
Indooroopilly, Queensland, Australia

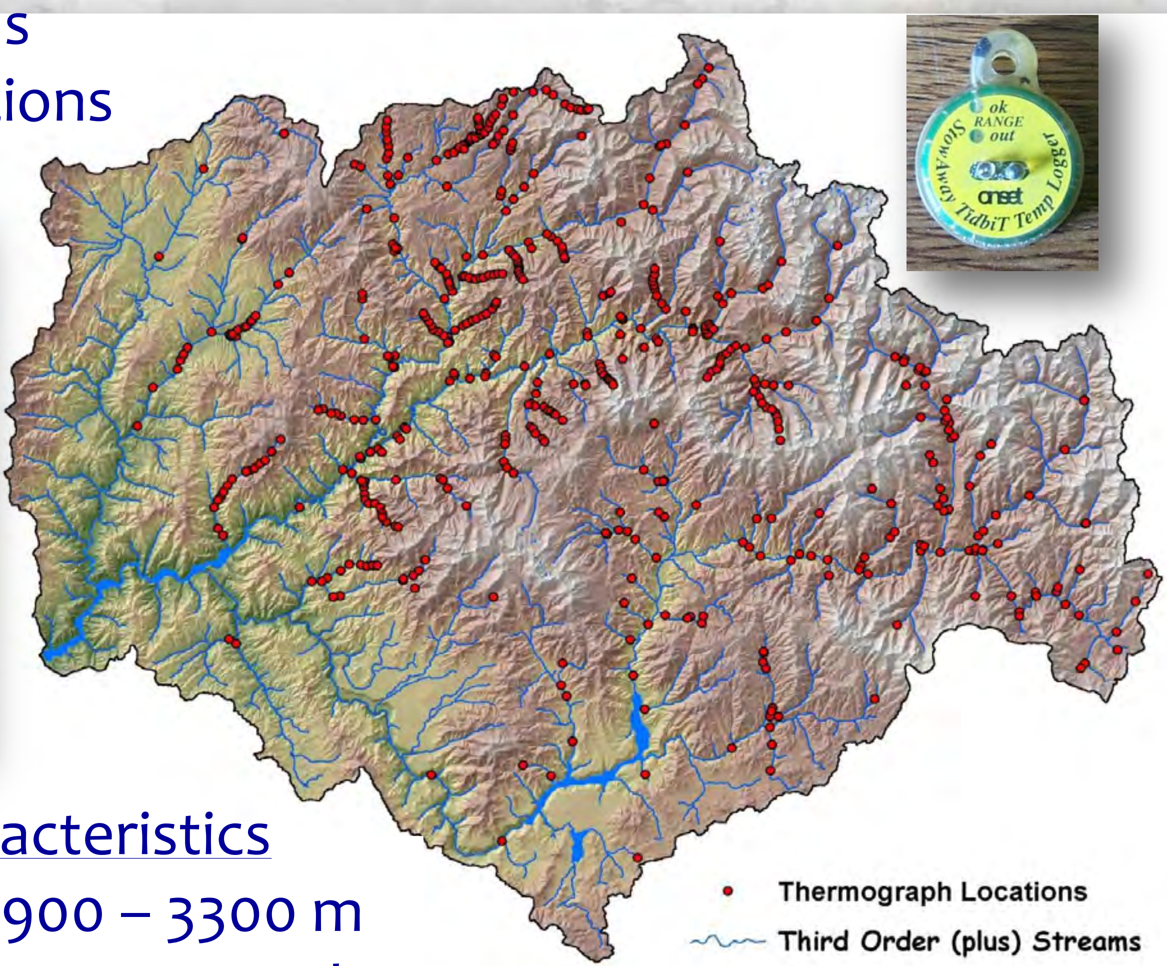




Boise River Temperature Database

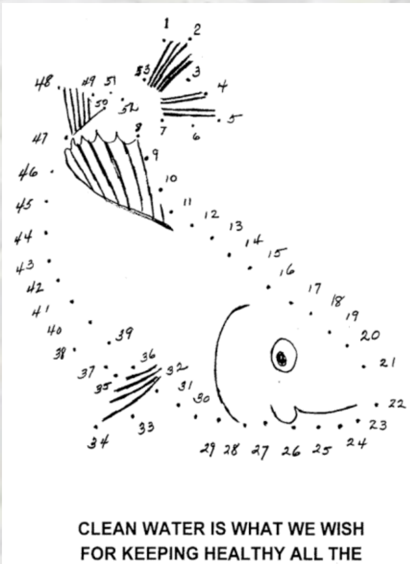
Stream Temperature Database
14 year period (1993 – 2006)
780 observations
518 unique locations



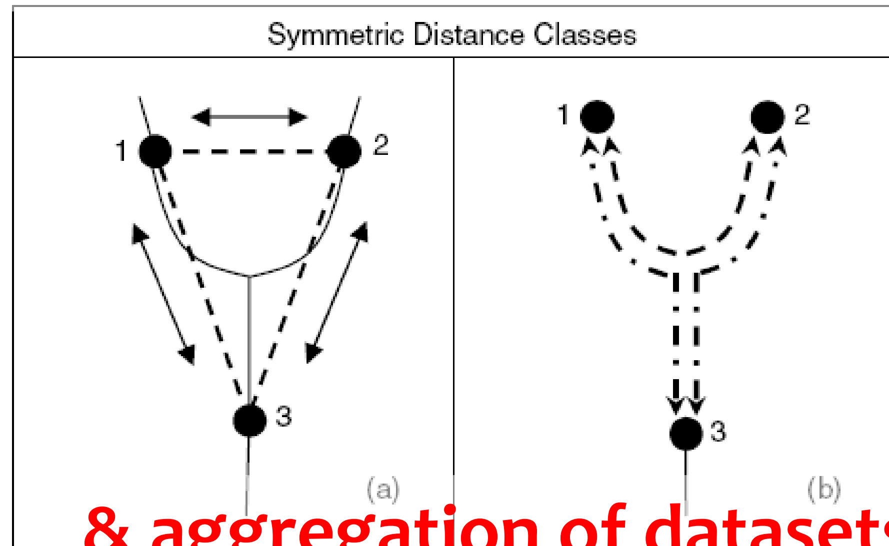


Watershed Characteristics
Elevation range 900 – 3300 m
Fish bearing streams ~2,500 km
Watershed area = 6,900 km²

Spatial Statistical Stream Models are Dot Connectors



Valid interpolation on networks



& aggregation of datasets

Advantages:

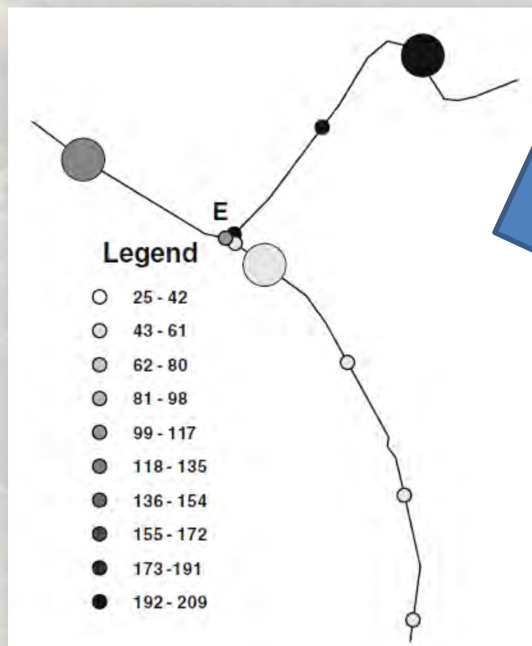
-flexible & valid covariance structures
by accommodating network topology
-weighting by stream size
-improved predictive ability & parameter
estimates relative to non spatial models

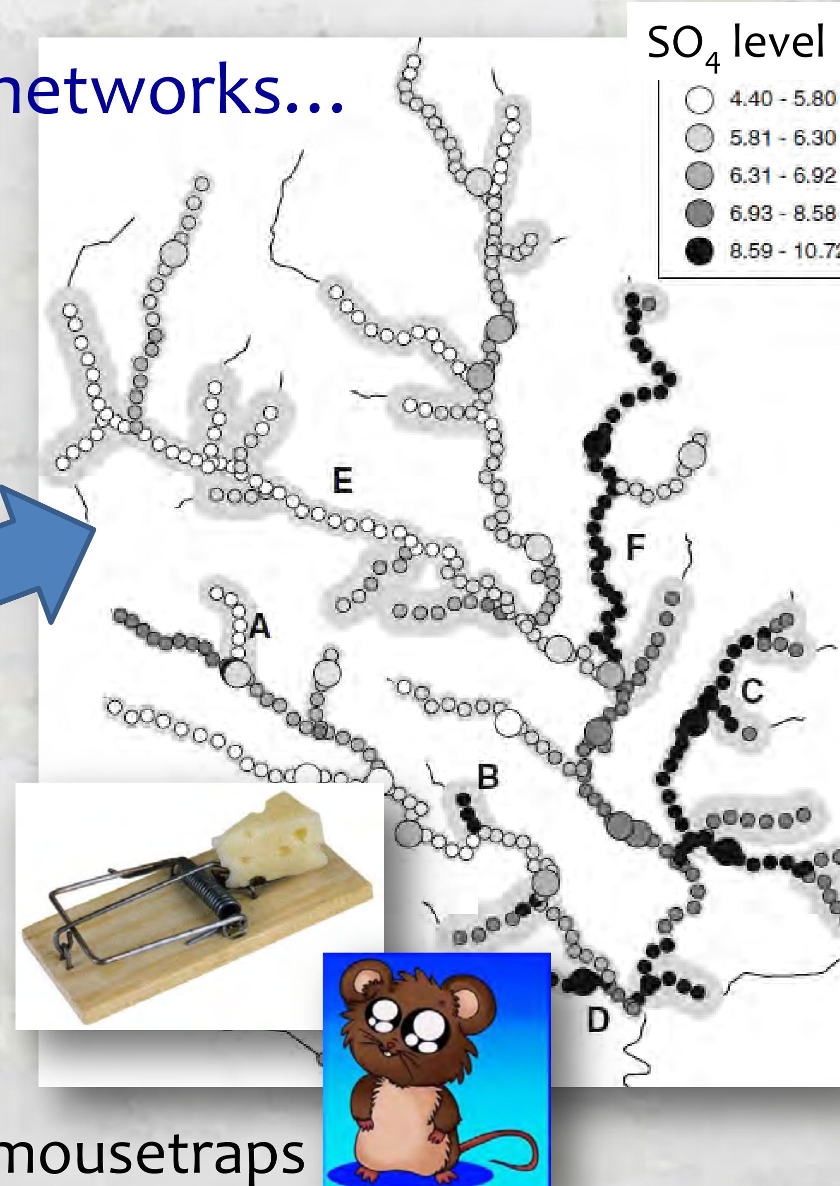
Ver Hoef et al. 2006; Peterson & Ver Hoef 2010; Ver Hoef & Peterson 2010

Spatial Statistical Network Models Work the Way that Streams Do…

Gradual trends within networks…

…but also changes at tributary confluences





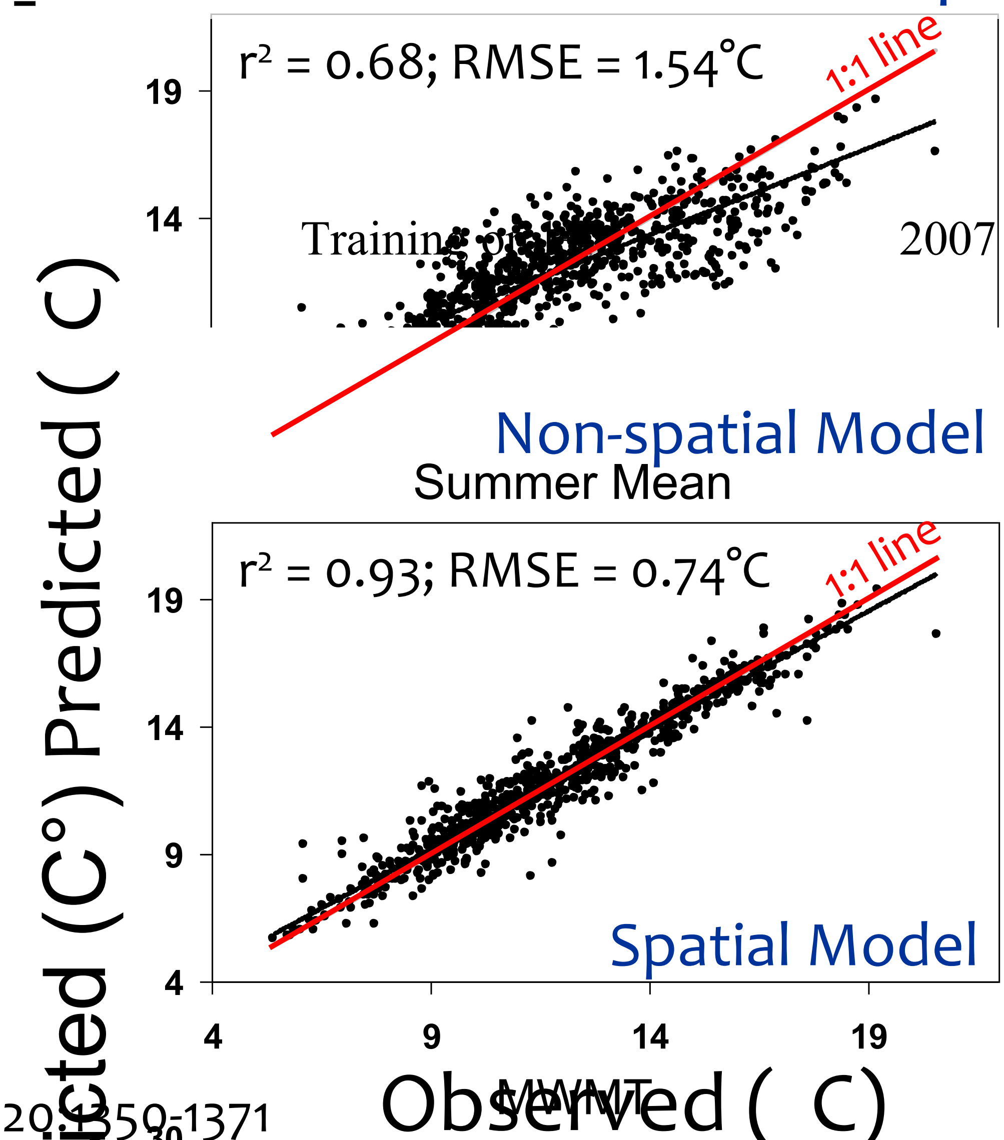
…& are significantly better mousetraps

Boise River Temperature Model

Non-spatial Stream Temp =
– 0.0064*Elevation (m)
+ 0.0104*Radiation
+ 0.39*AirTemp (°C)
– 0.17*Flow (m^3/s)

Parameter estimates are different because of autocorrelation in database

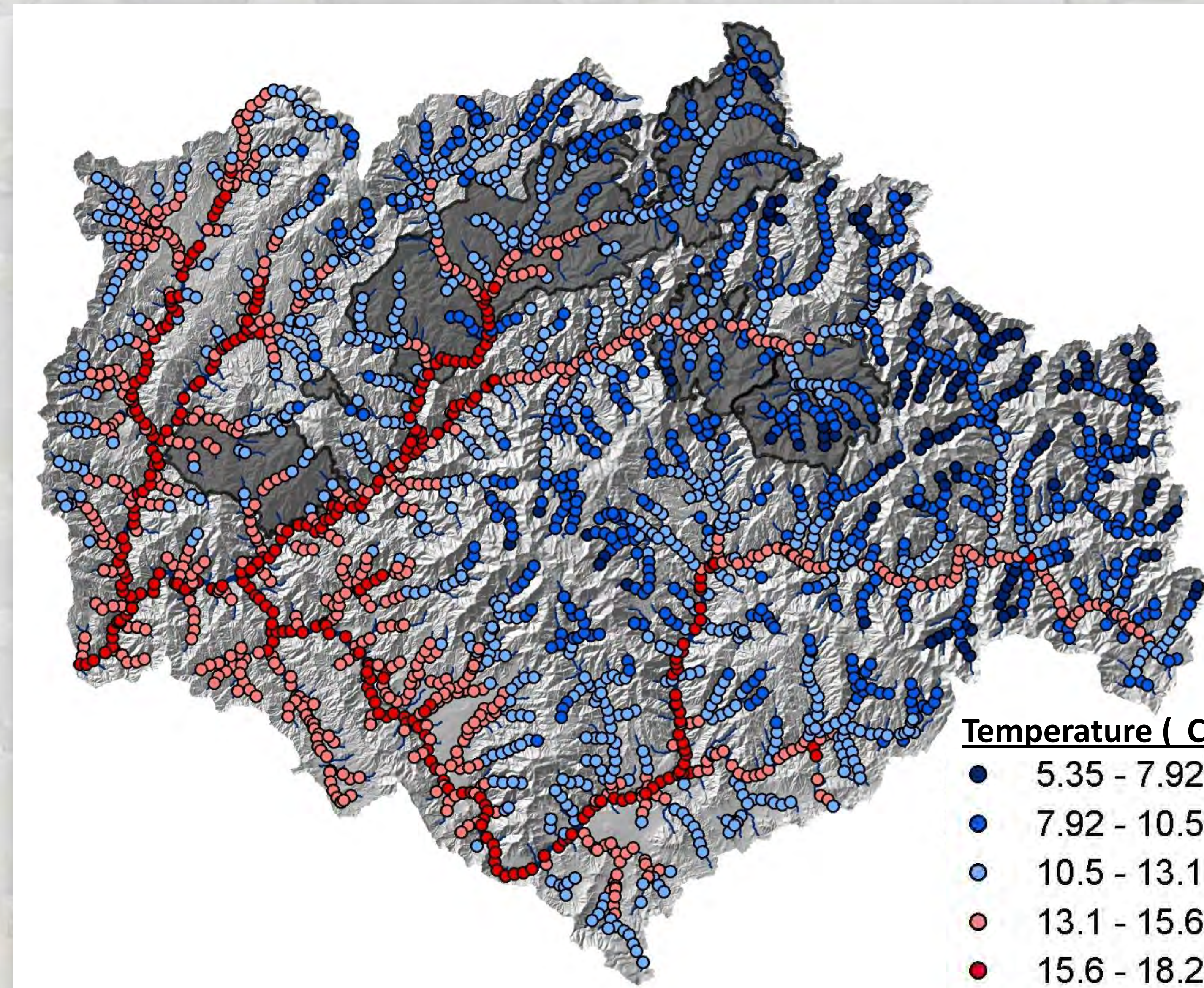
Spatial Stream Temp =
– 0.0045*Elevation (m)
+ 0.0085*Radiation
+ 0.48*AirTemp (°C)
– 0.11*Flow (m^3/s)



Isaak et al. 2010. *Ecol. Apps.* 20:1350-1371

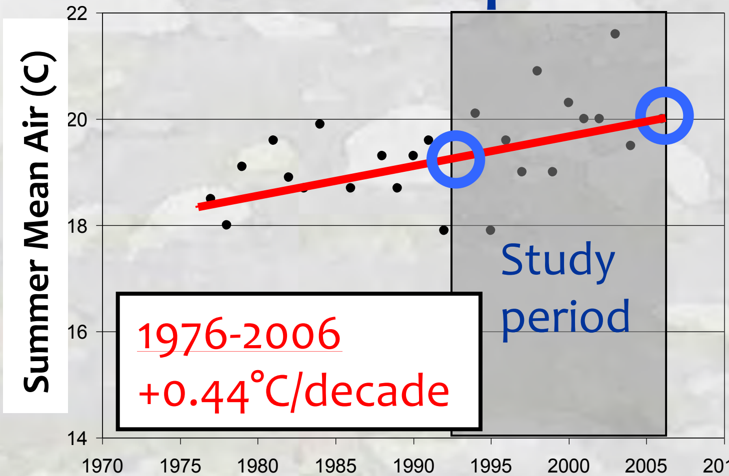
River Temperature Status Map

2006 Mean Summer Temperatures

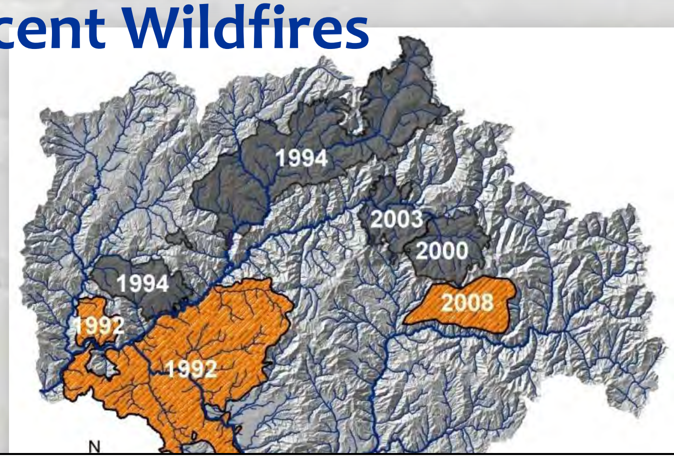


Trend Assessment = Change in Status Between Time 1 & Time 2

Summer Air Temperature

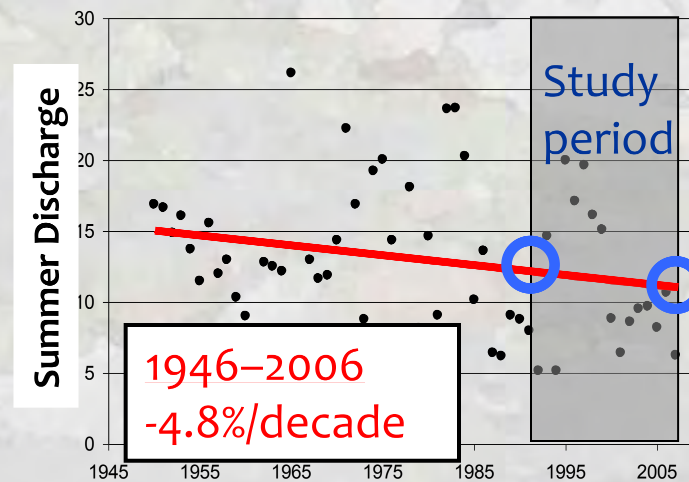


Recent Wildfires



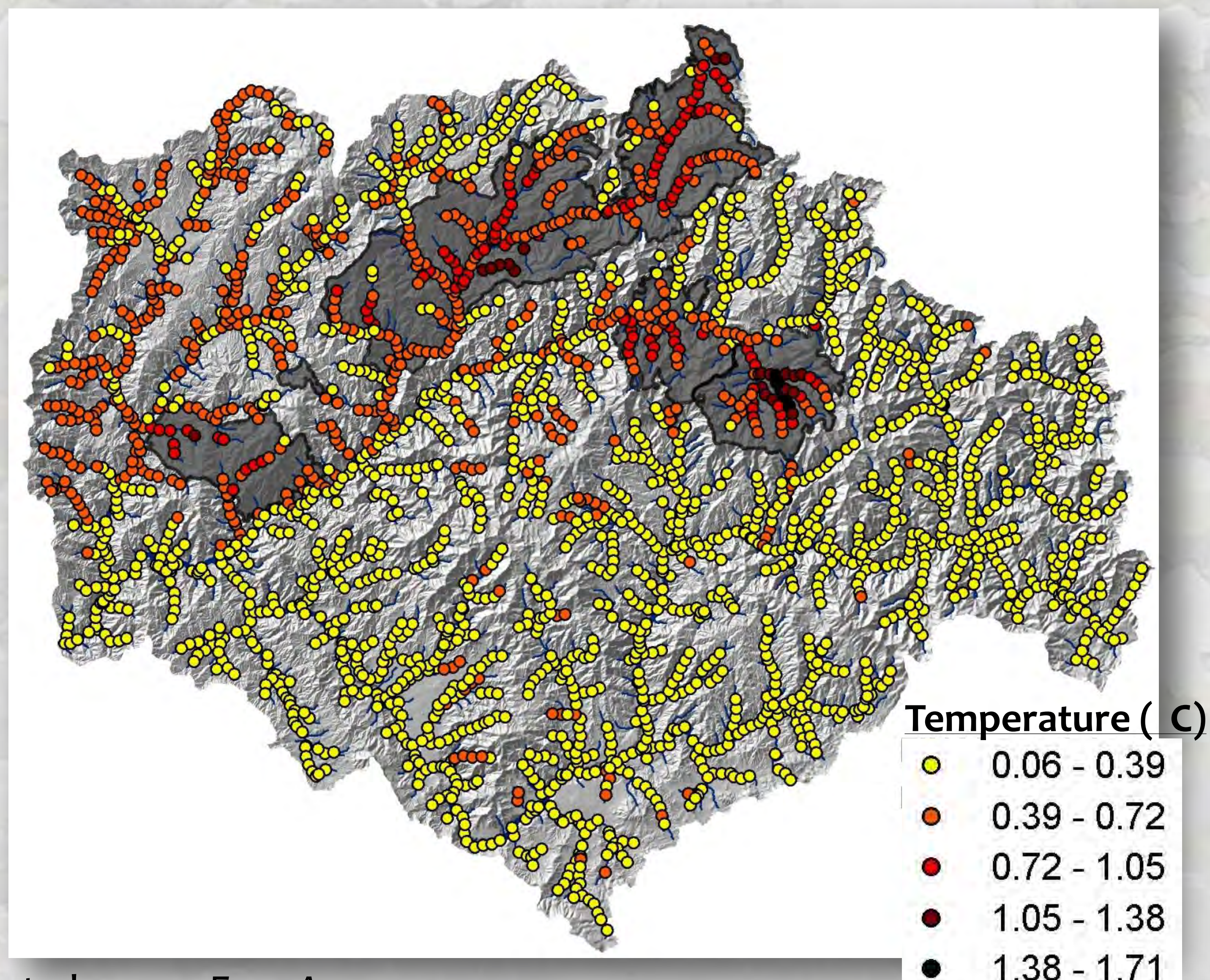
14% burned during 93–06 study period
30% burned from 92-08

Summer Stream Flow



Climate Change Map – Thermal Gains 93-06

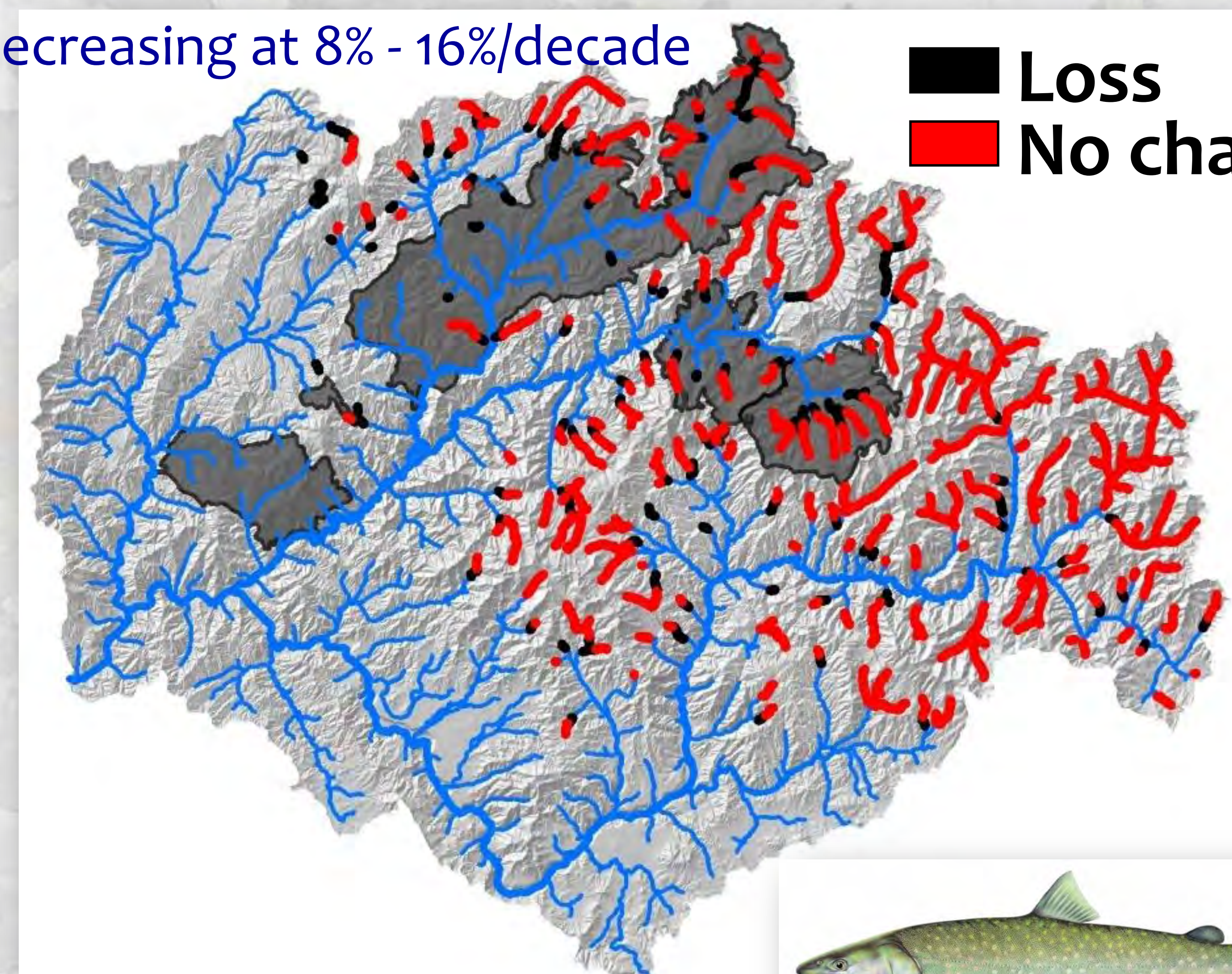
Change in Summer Temperature Status



Isaak et al. 2010. *Eco. Apps.* 20:1350-1371

Effects of Climate Change on Bull Trout Habitats (1993-2006)

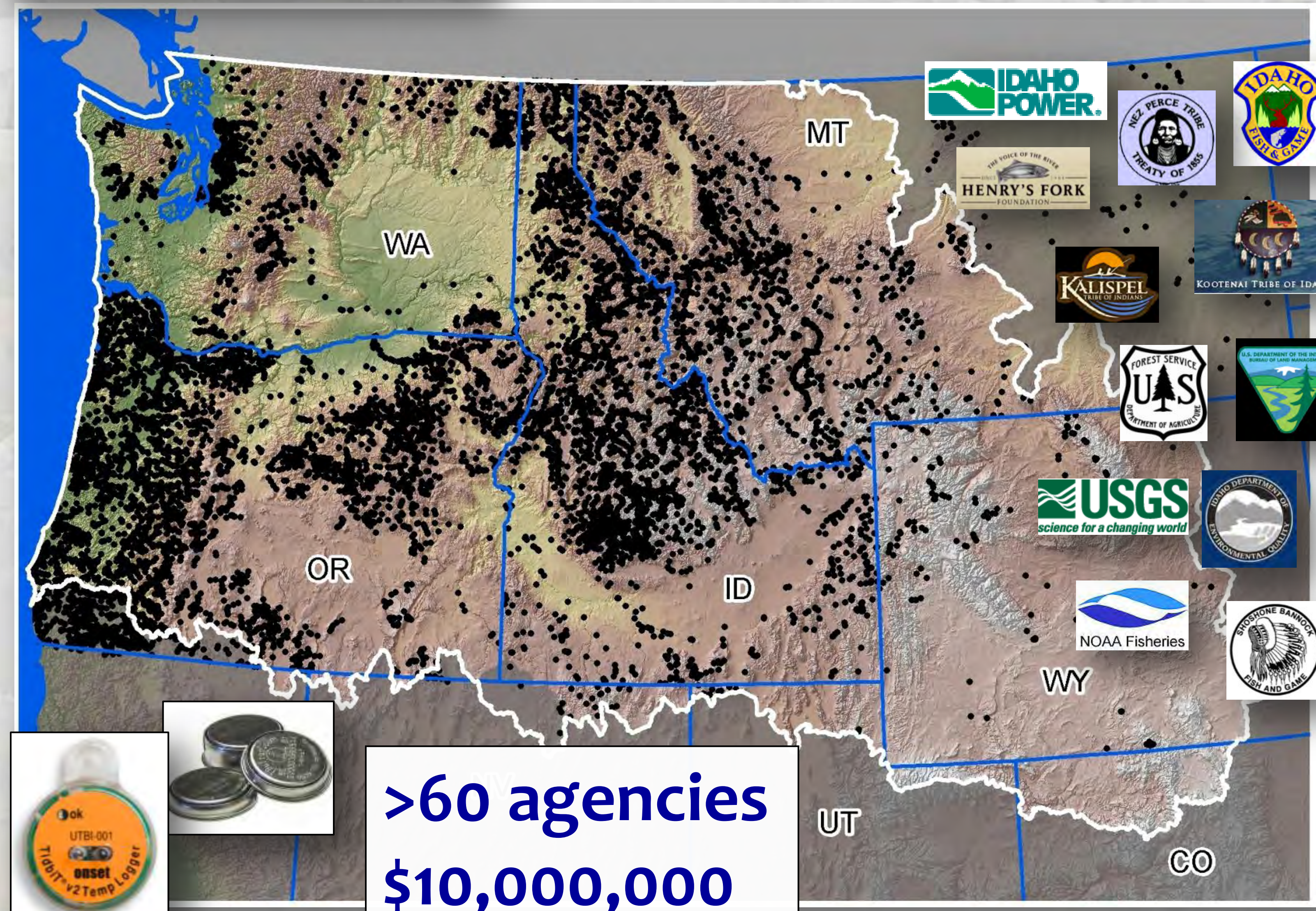
Decreasing at 8% - 16%/decade



Isaak et al. 2010. *Eco. Apps.* 20:1350-1371

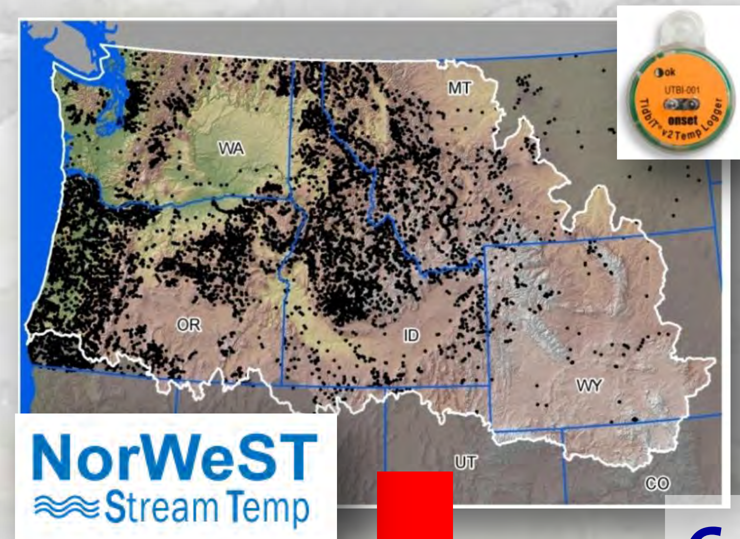
NorWeST Stream Temp

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



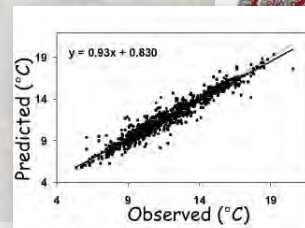
>60 agencies
$10,000,000

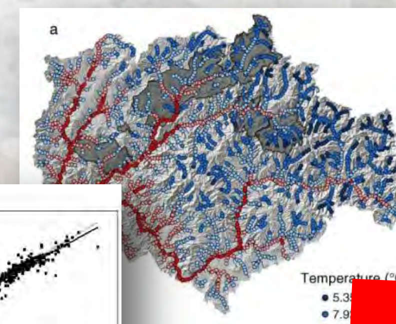
Regional Temperature Model



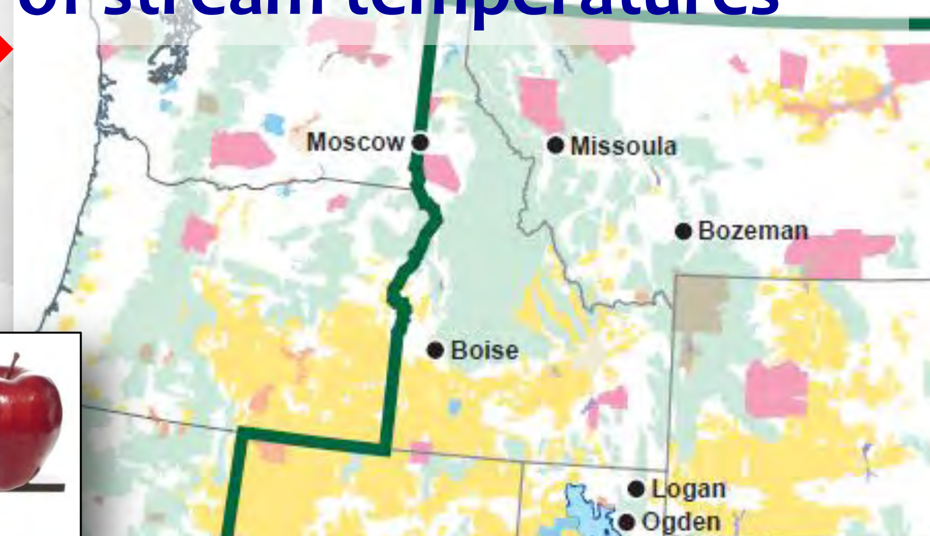
+

Accurate temperature models

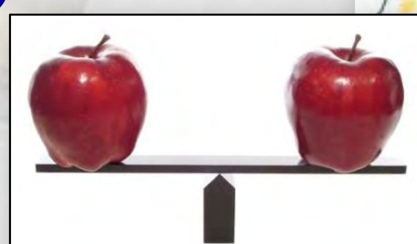




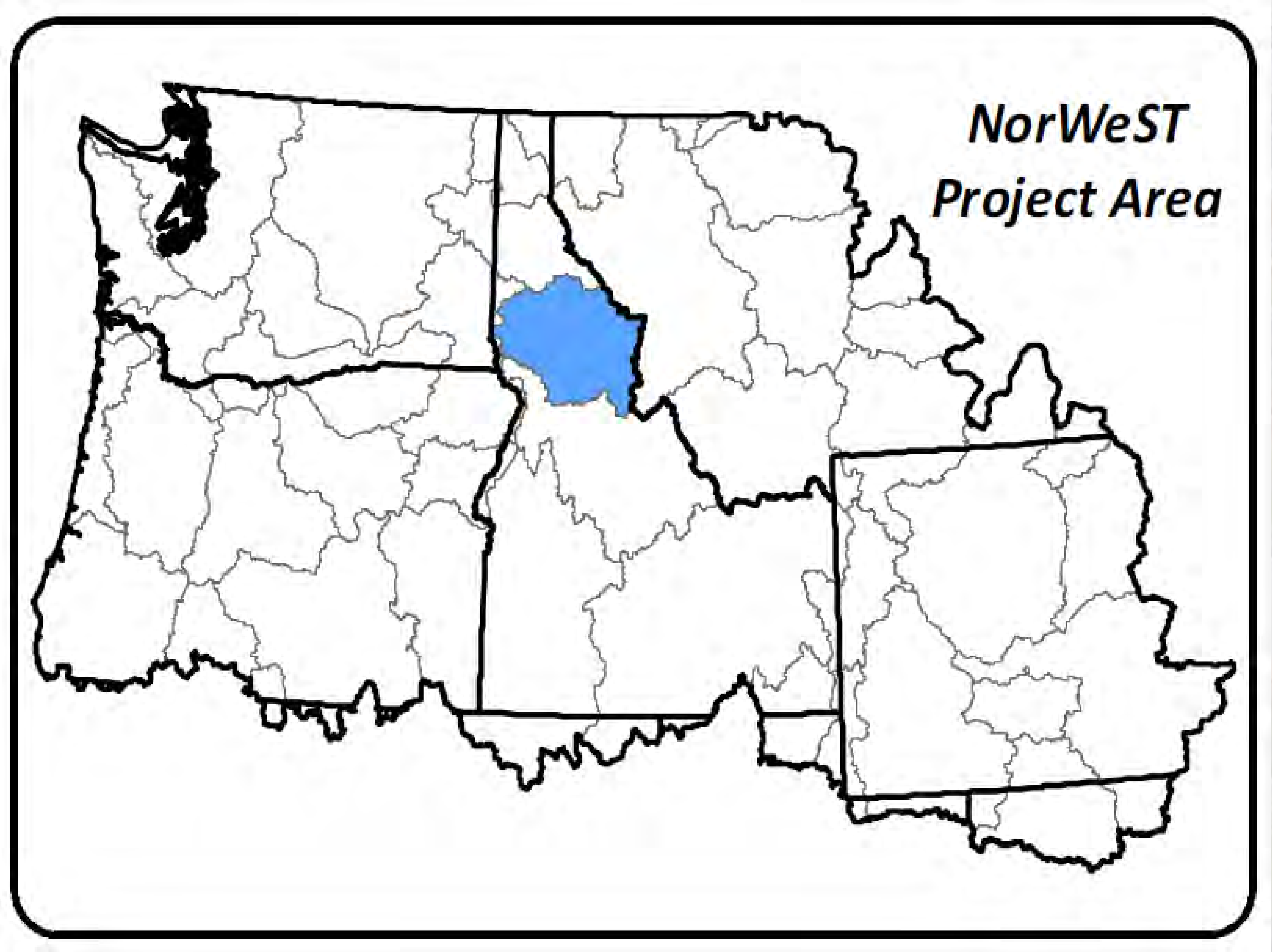
Cross-jurisdictional "maps" of stream temperatures



Consistent datum for strategic assessments across 400,000 stream kilometers



Example: Clearwater River Basin

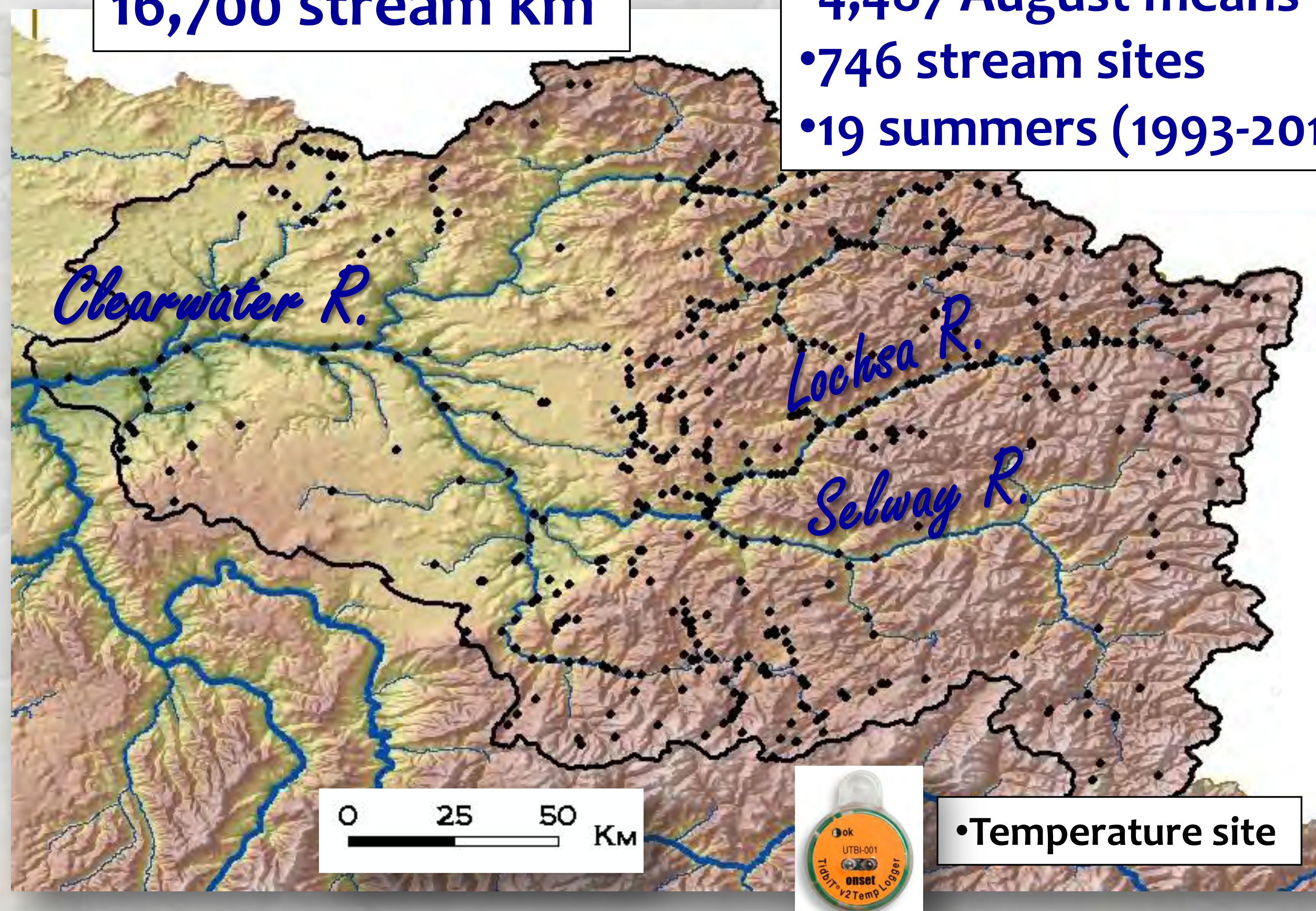


Example: Clearwater River Basin

Data extracted from NorWeST

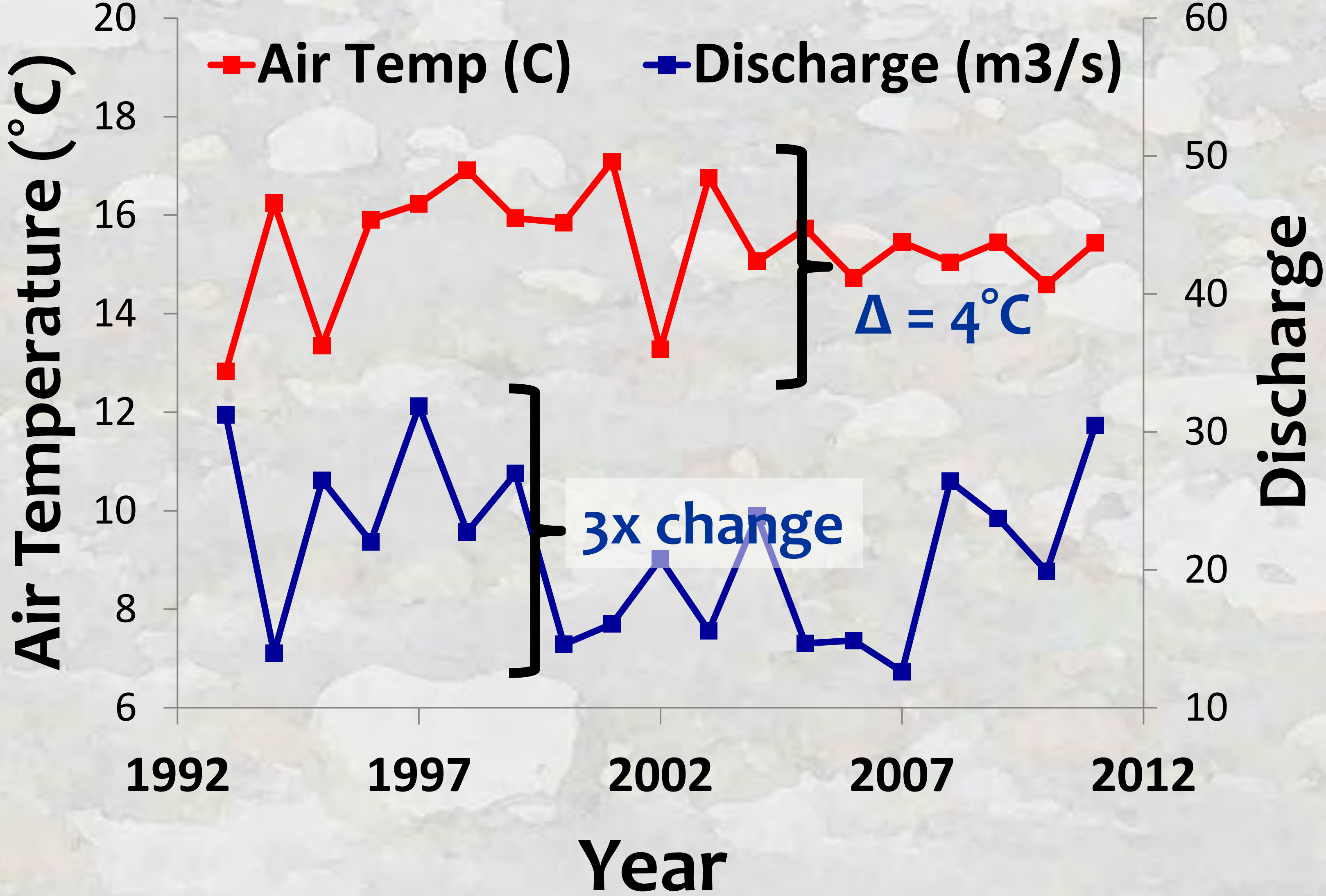
16,700 stream km

- 4,487 August means
- 746 stream sites
- 19 summers (1993-2011)



Climatic Variability in Historical Record

Extreme years include mid-21st-Century "averages"



Clearwater River Temp Model

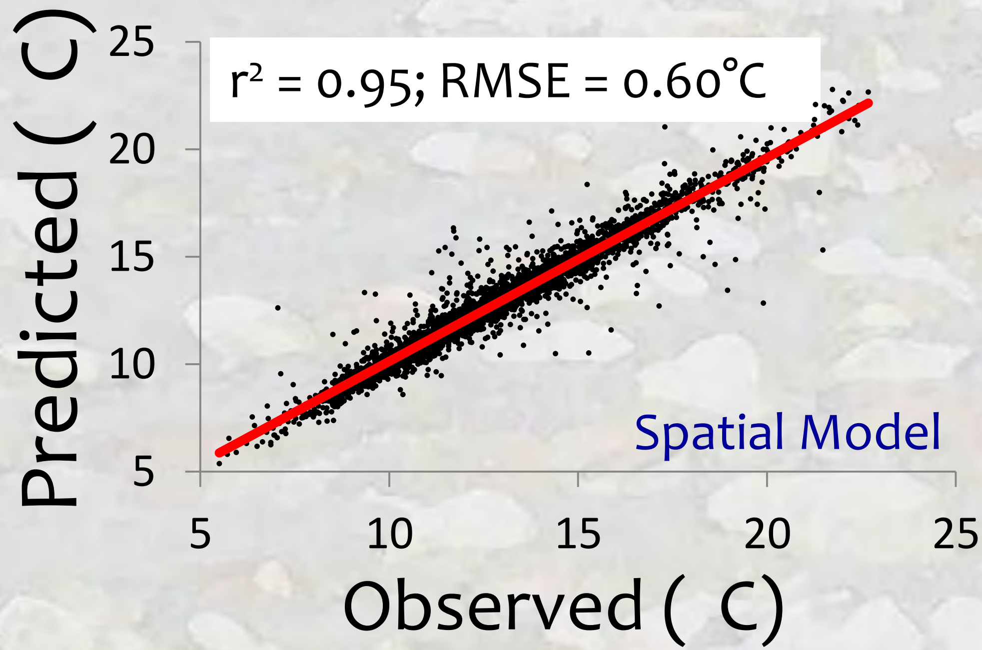
n = 4,487

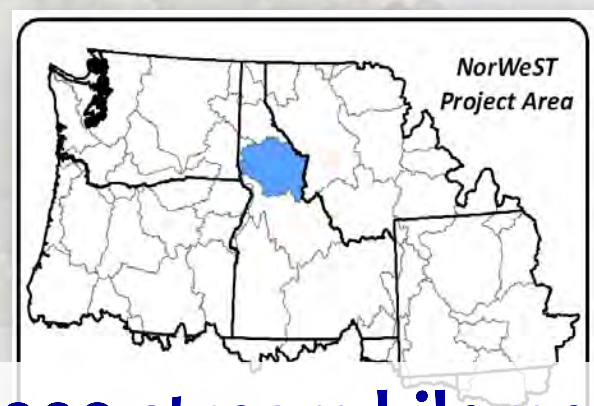
Covariate Predictors

1. Elevation (m)
2. Canopy (%)
3. Stream slope (%)
4. Ave Precipitation (mm)
5. Latitude (km)
6. Lakes upstream (%)
7. Baseflow Index
8. Watershed size (km²)

9. Discharge (m³/s)
   USGS gage data
10. Air Temperature (˚C)
    RegCM3 NCEP reanalysis
    Hostetler et al. 2011

Mean August Temperature





16,000 stream kilometers

Salmon River Temperature Model

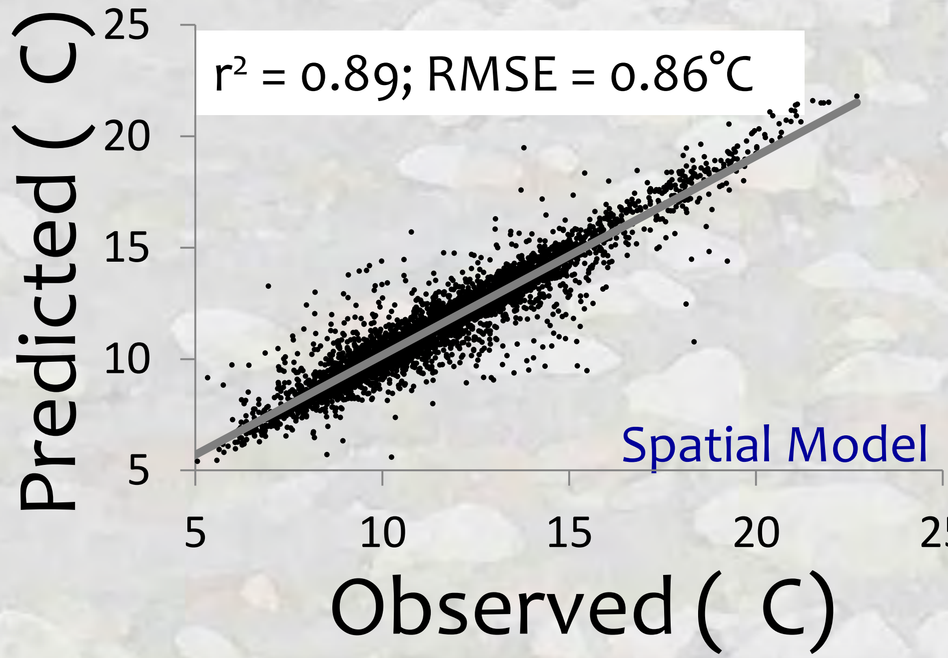
n = 4,401

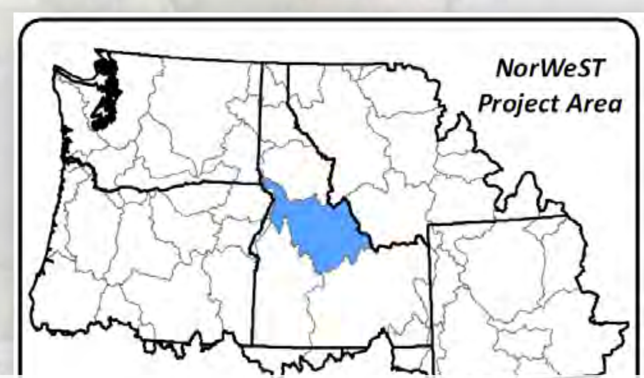
Covariate Predictors

1. Elevation (m)
2. Canopy (%)
3. Stream slope (%)
4. Ave Precipitation (mm)
5. Latitude (km)
6. Lakes upstream (%)
7. Baseflow Index
8. Watershed size (km²)

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

Mean August Temperature





21,000 stream kilometers

SpoKoot River Temp Model

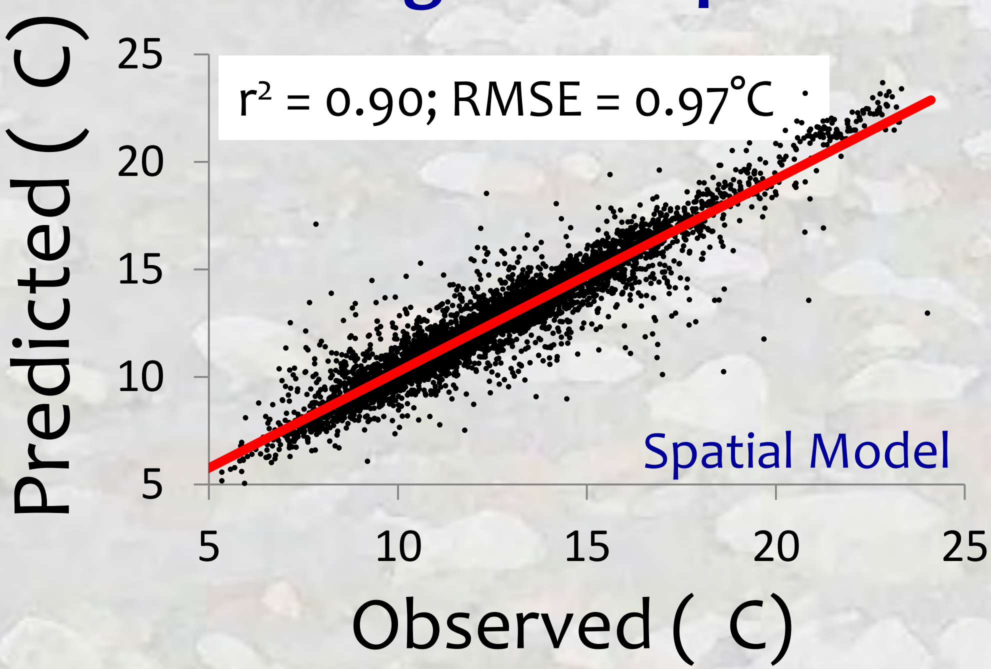
n = 5,482

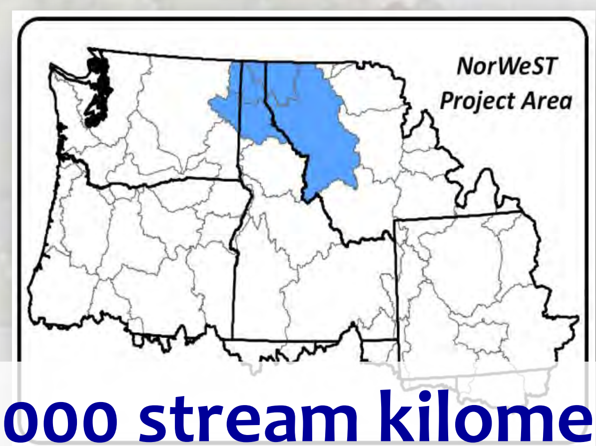
Covariate Predictors

1. Elevation (m)
2. Canopy (%)
3. Stream slope (%)
4. Ave Precipitation (mm)
5. Latitude (km)
6. Lakes upstream (%)
7. Baseflow Index
8. Watershed size (km²)

9. Discharge (m³/s)
   USGS gage data
10. Air Temperature (°C)
   RegCM3 NCEP reanalysis
   Hostetler et al. 2011

Mean August Temperature





55,000 stream kilometers

Upper Missouri River Temp Model

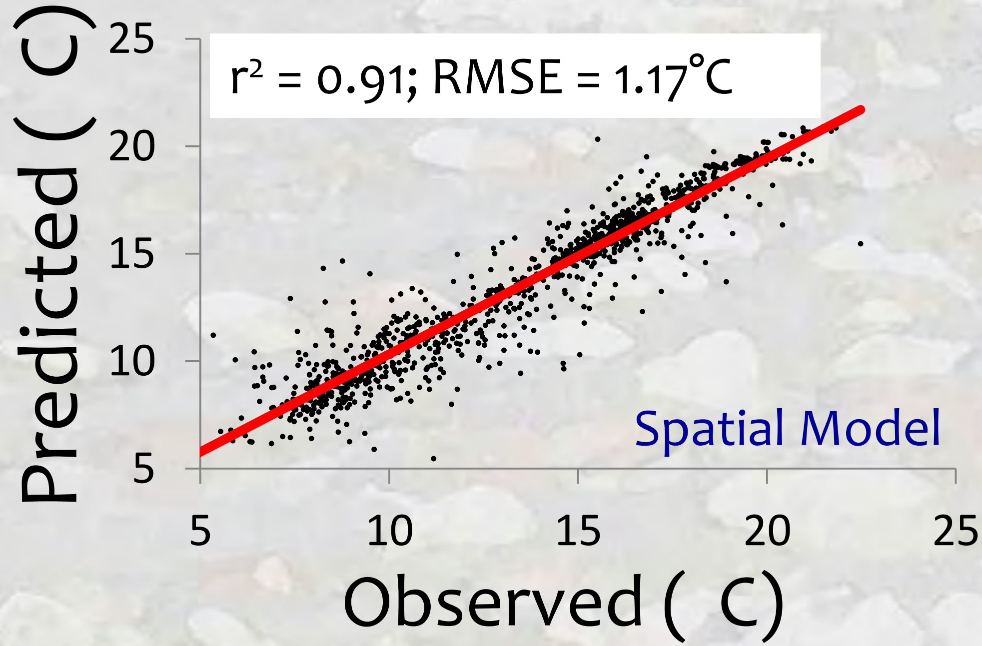
n = 1,145

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 (km²)

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

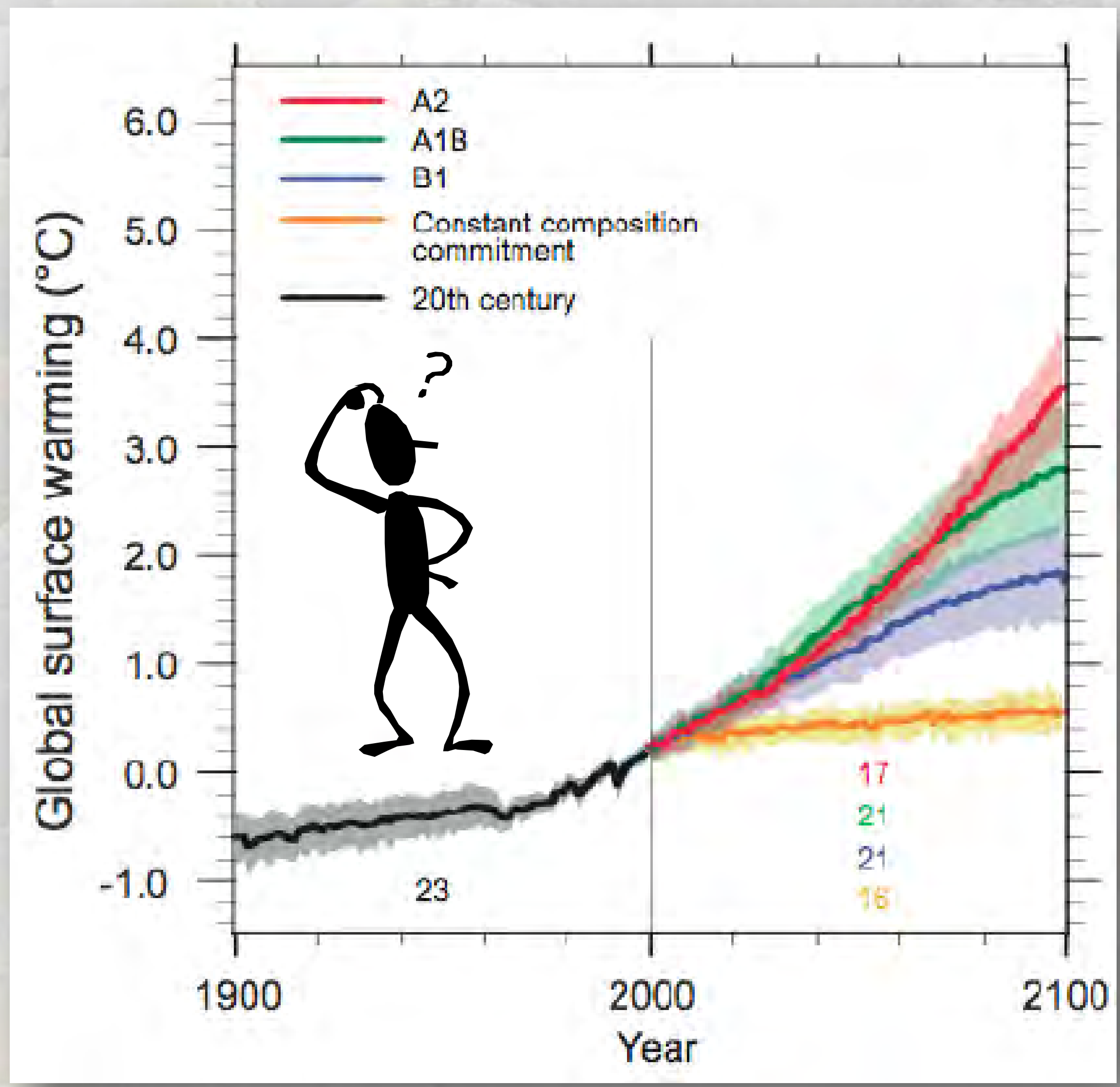
Mean August Temperature



25,000 stream kilometers

Models Enable Climate Scenario Mapping

Many possibilities exist…



Adjust…

- air temp
- discharge
- %canopy

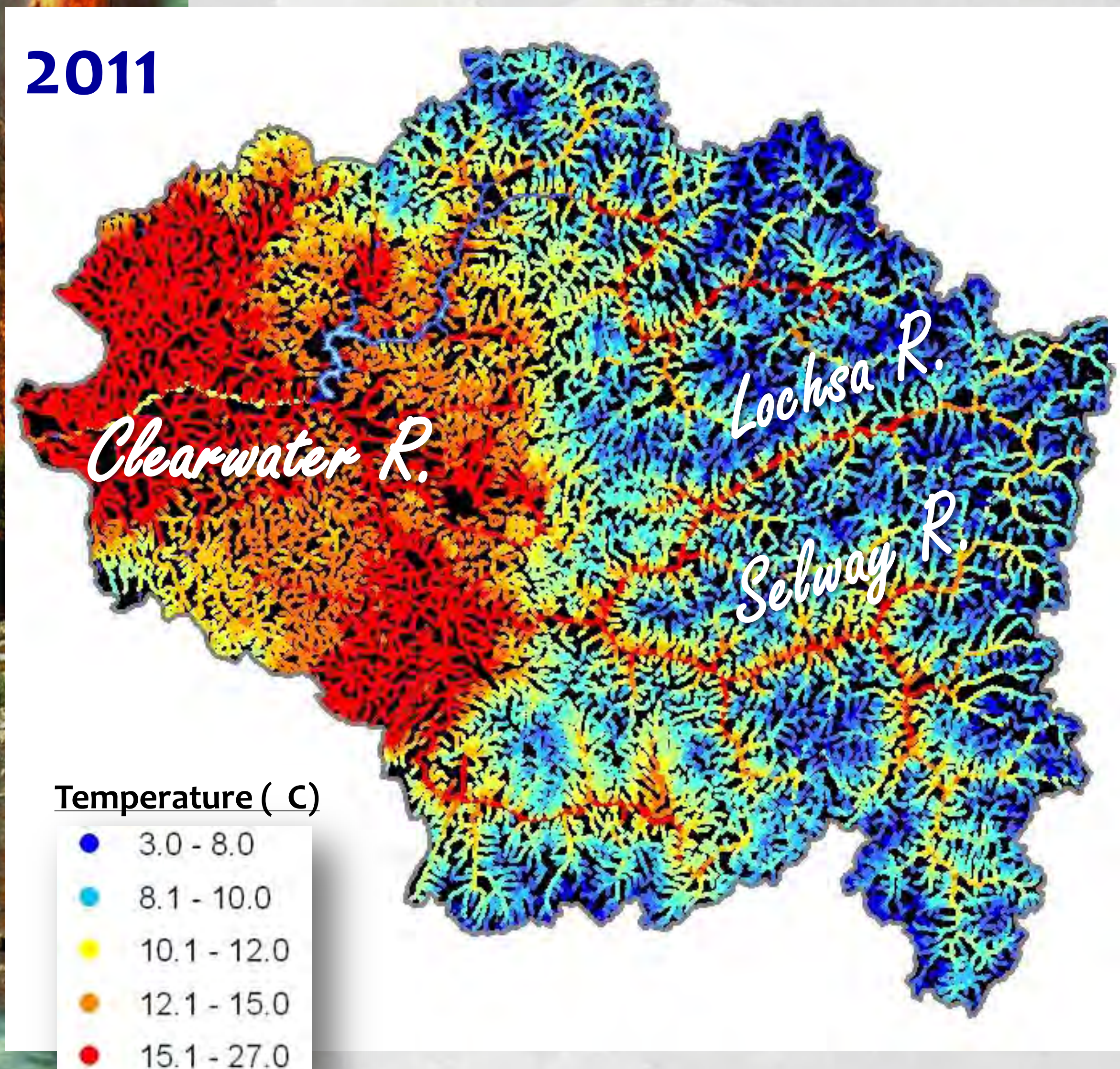
values to represent scenarios

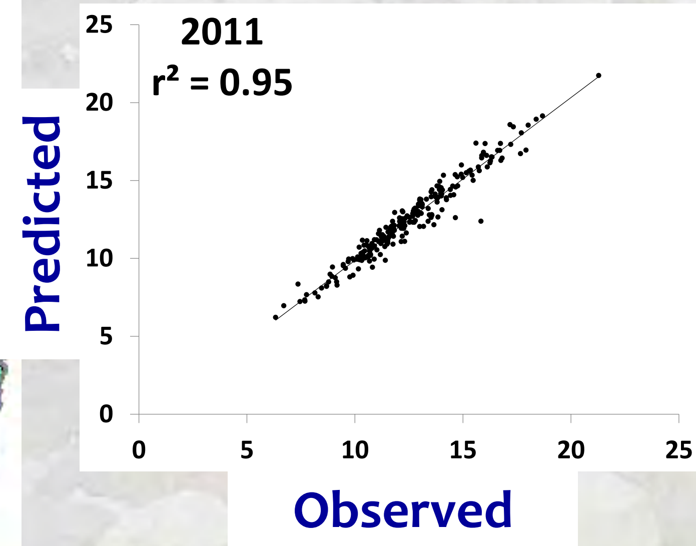
Climate Scenario Descriptions

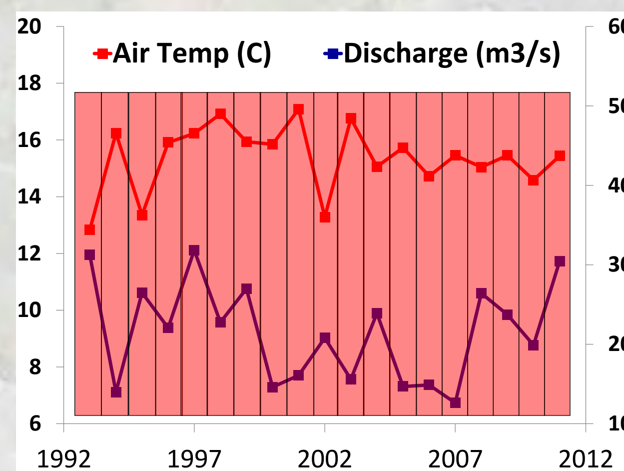
Scenario	Description
S1_93_11	Historical scenario representing 19 year average August mean stream temperatures for 1993-2011
S2_02_11	Historical scenario representing 10 year average August mean stream temperatures for 2002-2011
S3_1993	Historical scenario representing August mean stream temperatures 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
S22_025C	Future scenario adds 0.25˚C to S1_93-11
S23_050C	Future scenario adds 0.50˚C to S1_93-11
Etc…	
S33_300C	Future scenario adds 3.00˚C to S1_93-11
S34_PredSE	Standard errors of stream temperature predictions

Historical Year Sequence (1993-2011)

Mean August Temperature - Clearwater Basin

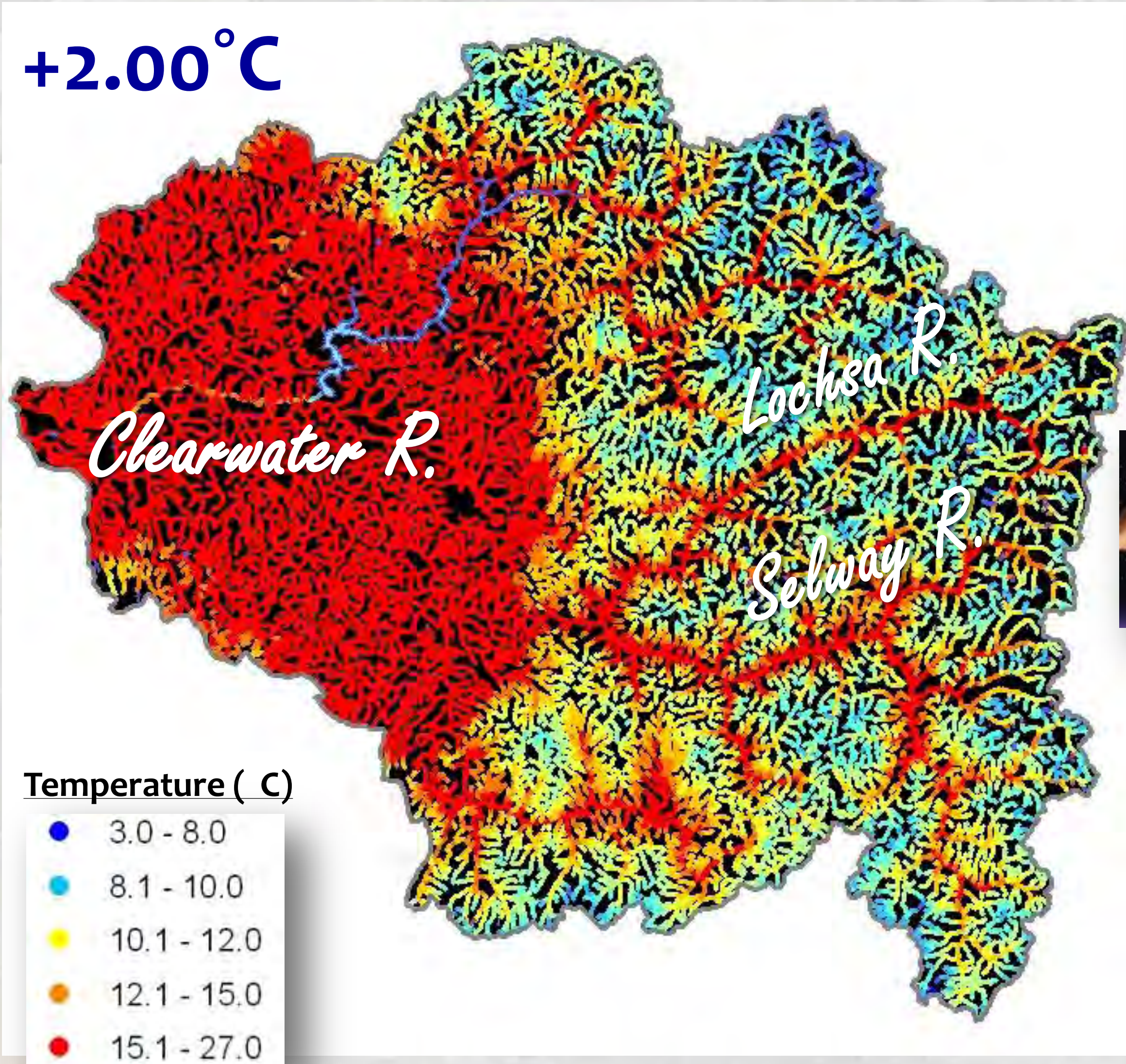


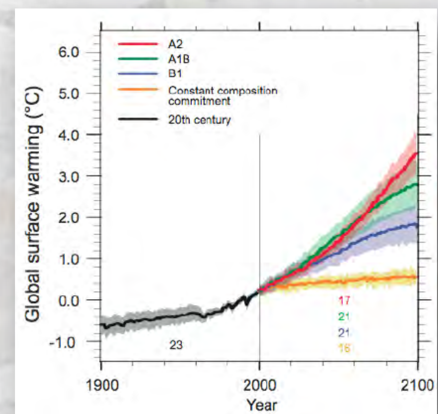




Future Scenarios (S1, S25, S29)

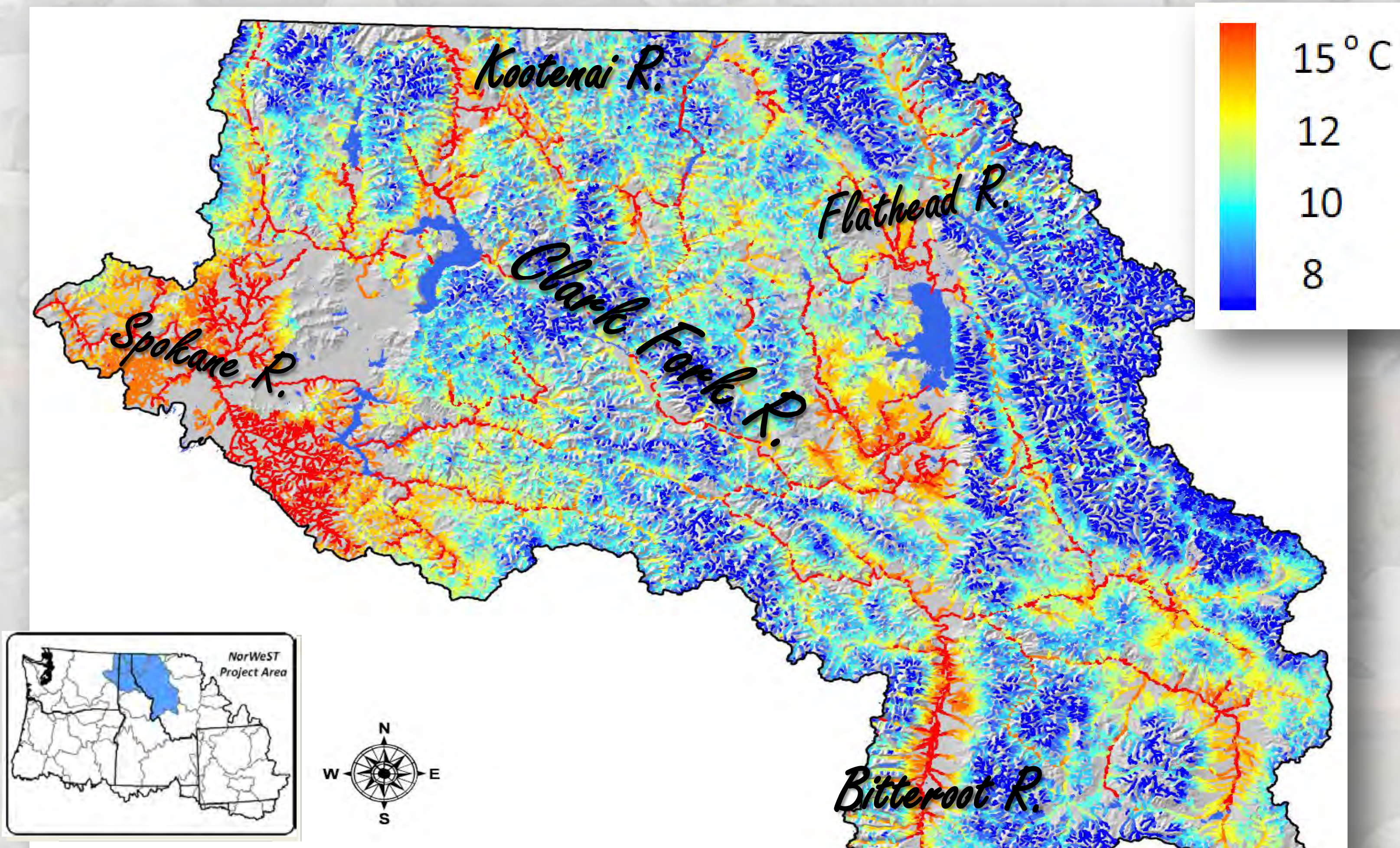
1993-2011, +1.0°C, +2.0°C





Historic Scenario: SpoKoot Unit (S1_93-11)

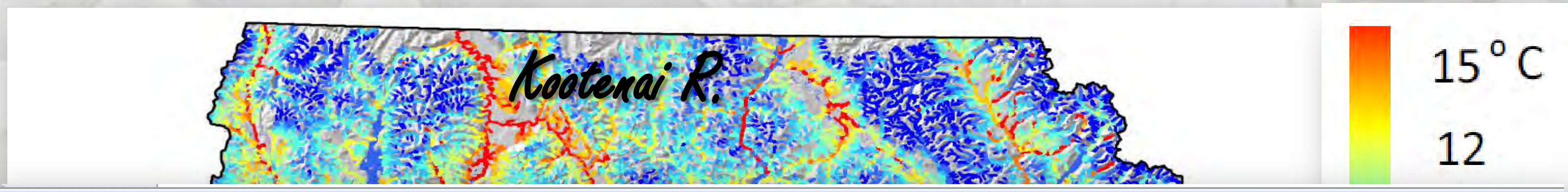
1993-2011 mean August stream temperatures



1 kilometer resolution
55,000 stream kilometers

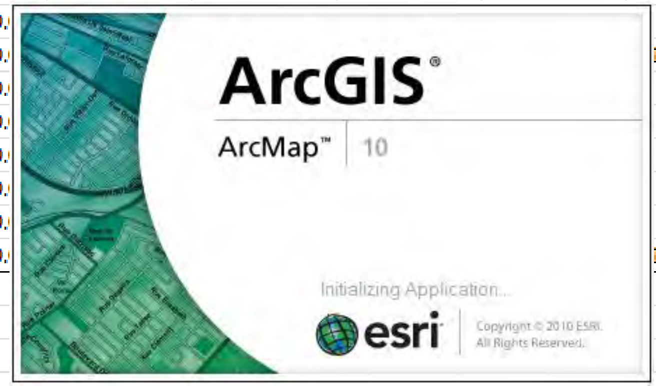
Historic Scenario: SpoKoot Unit (S1_93-11)

1993-2011 mean August stream temperatures



C	D	E	F	G	H	I	J	K	L	M
CANOPY	SLOPE	PRECIP	CUMDRAINAG	Y_COORD	NLCD11PC	NLCD12PC	BFI	Air_August	Flow_August	Stream_August
2.82	0.08857	299.6256	19.833	1623663.32	0	0	79	14.02	35.71	12.0812903
2.82	0.08857	299.6256	19.833	1623663.32	0	0	79	13.20	40.52	12.333771
2.82	0.08857	299.6256	19.833	1623663.32	0	0	79	13.00	38.99	11.4041581
12.23	0.03514	242.42	69.271	1620504.73	0.012	0	80	15.84	18.47	12.2216452
12.23										11.0053548
12.23										12.7445484
12.23										11.9685161
12.23										10.9931936
12.23										11.3862545
12.23										11.4452903
12.23										11.5266484
12.23										10.7834677
67.2										
62.89	0.12123	1040.365	3.544	1517651.14						
19.84	0.1333	1107.499	3.312	1516970.64						
61.45	0.1333	1107.499	3.312	1517620.51	0	0	75	13.59	32.75	
42.49	0.10194	984.29	3.36	1516791.23	0	0	75	13.59	32.75	
52.92	0.10194	984.29	3.36	1517620.42	0	0	75	13.59	32.75	

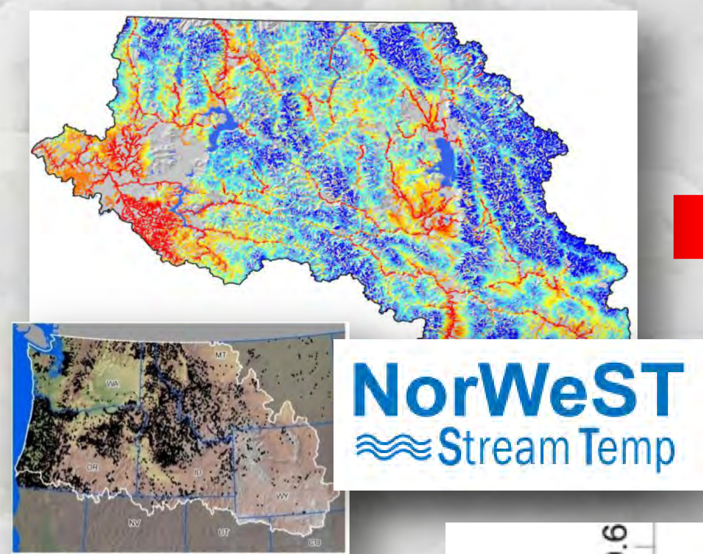
Scenarios are GIS layers for easy display & query



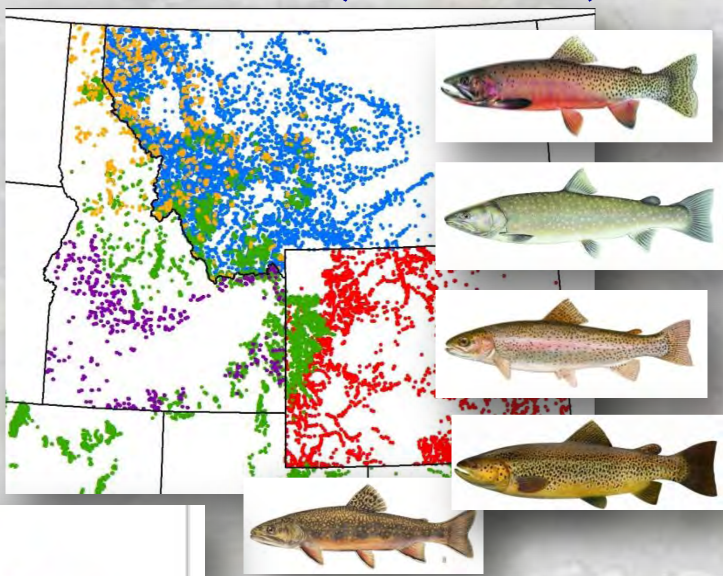
1 kilometer resolution
55,000 stream kilometers

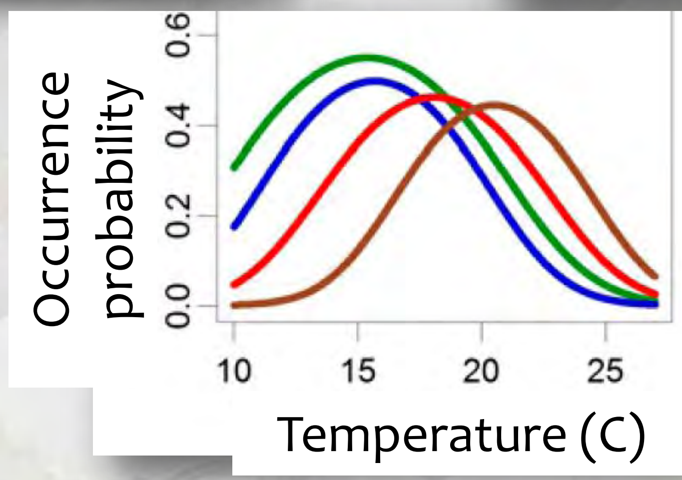
Regionally Consistent Thermal Niche Definitions

Stream temperature maps



Regional fish survey databases (n ~ 30,000)



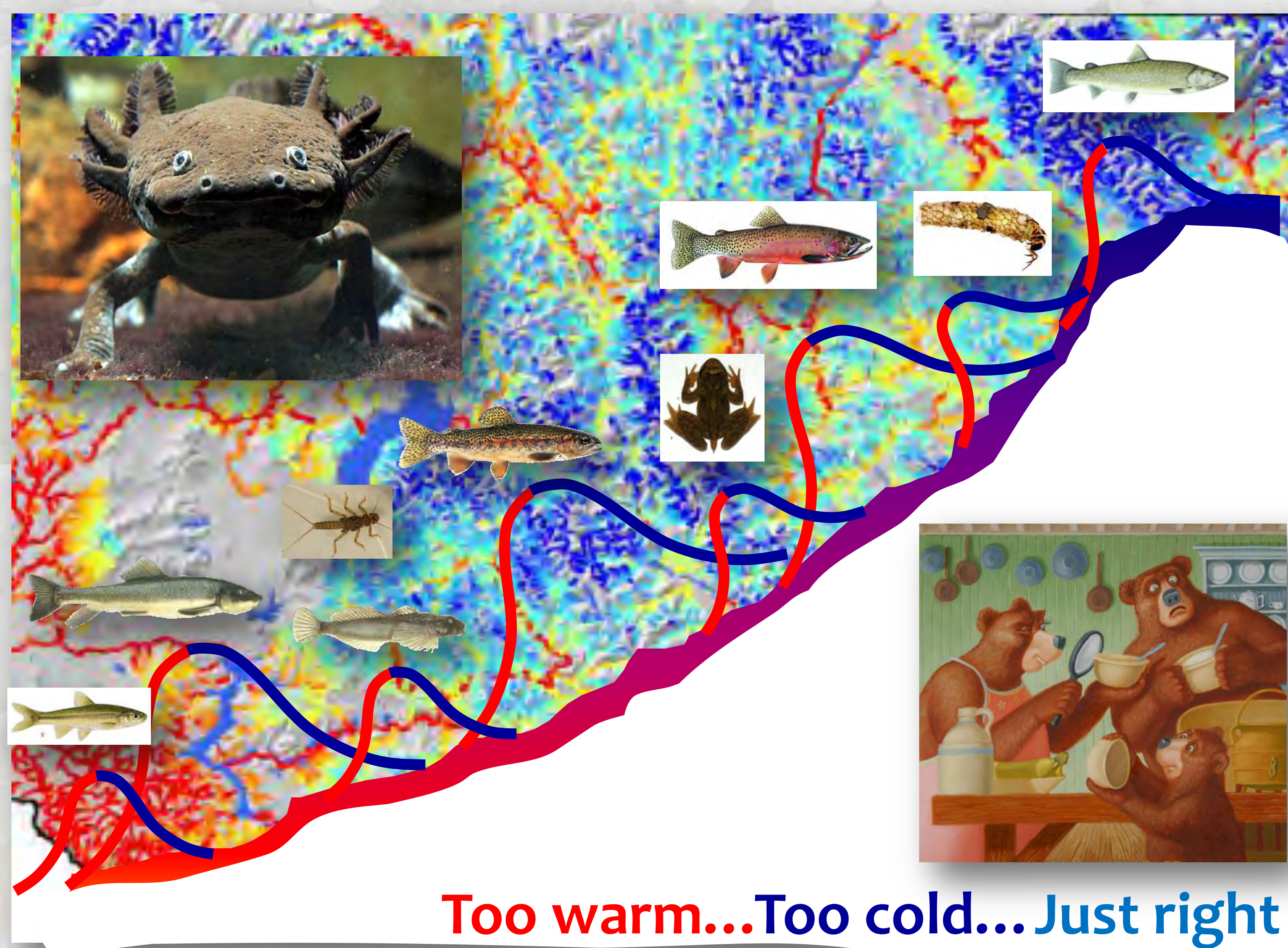


Wenger et al. 2011a. *PNAS* **108:**14175-14180

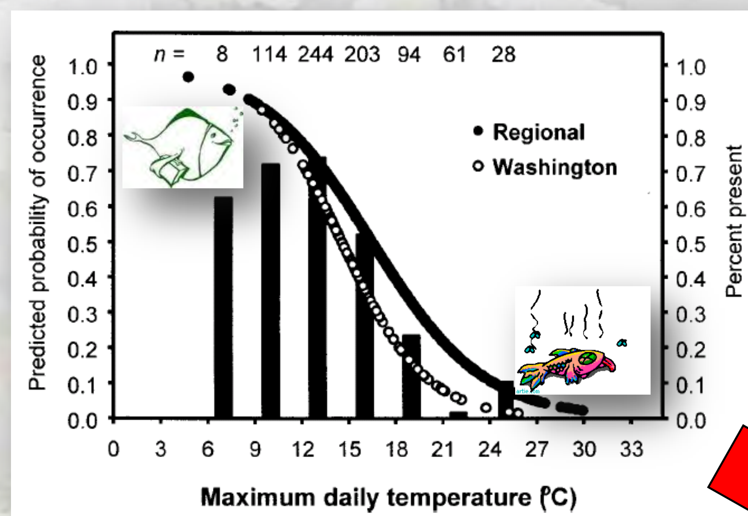
Wenger et al. 2011b. *CJFAS* **68**:988-1008; Wenger et al., *In Preparation*

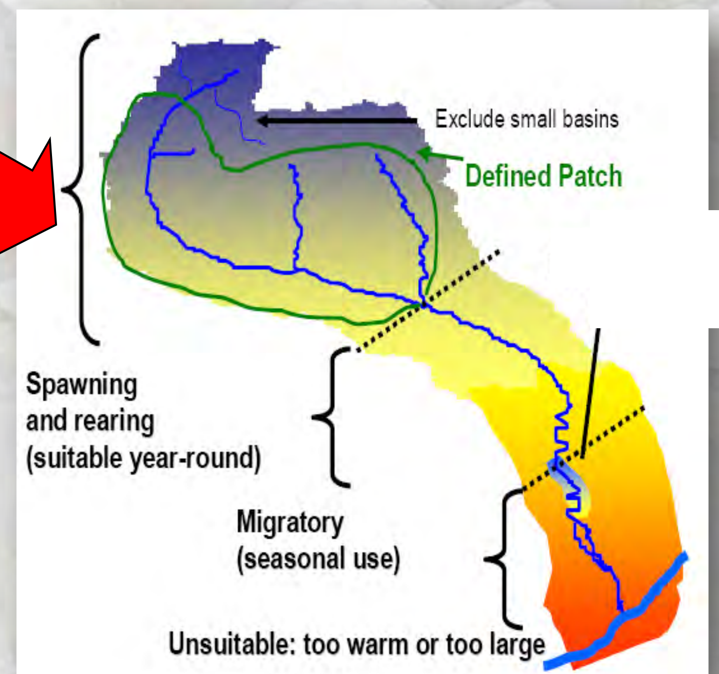
Thermal Niches For All Stream Critters

Just need georeferenced biological survey data



Bull Trout Thermal Criteria & Patches

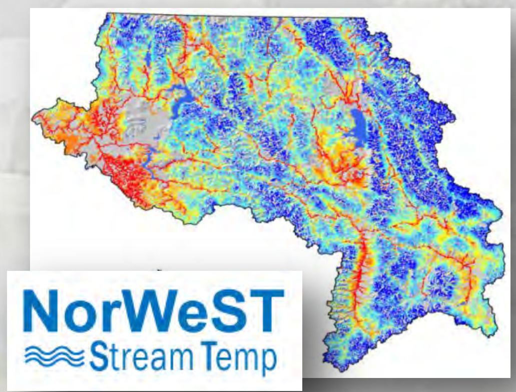




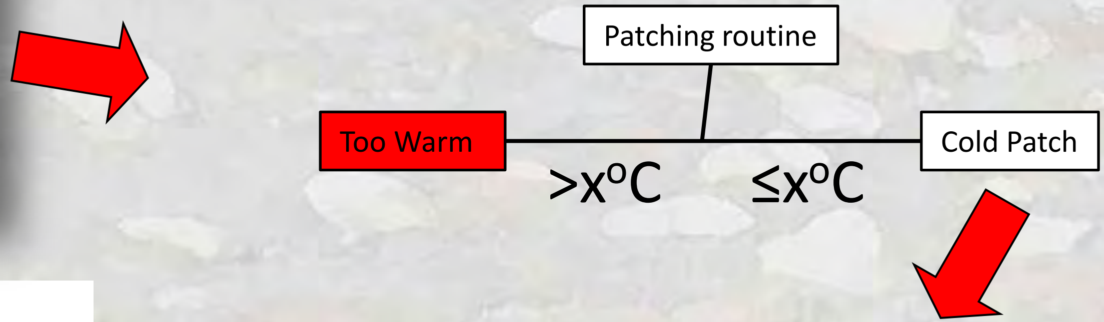
- Dunham et al. 2003
- Selong et al. 2001
- McMahon et al. 2007
- Mesa et al. 2012
- Many others…

- Dunham et al. 2002

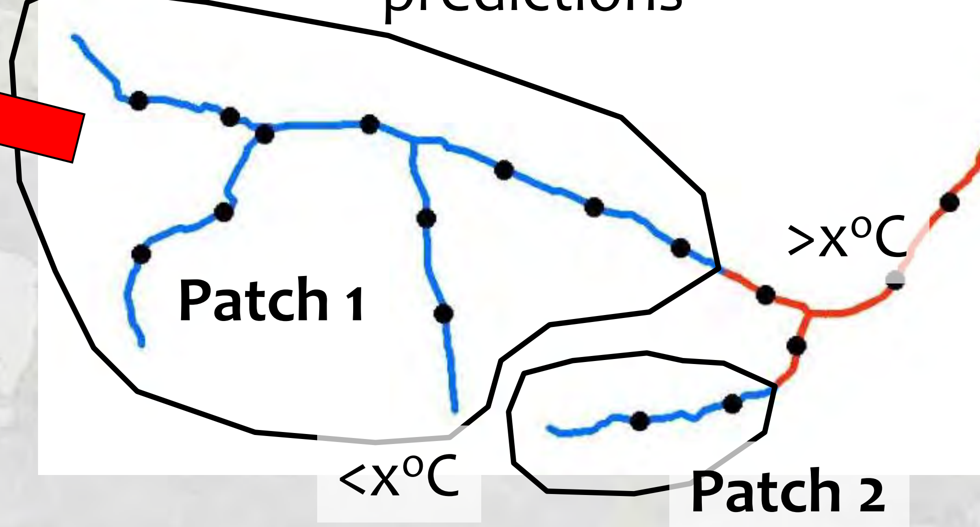
Range-wide bull trout vulnerability assessment (Dunham and co.)

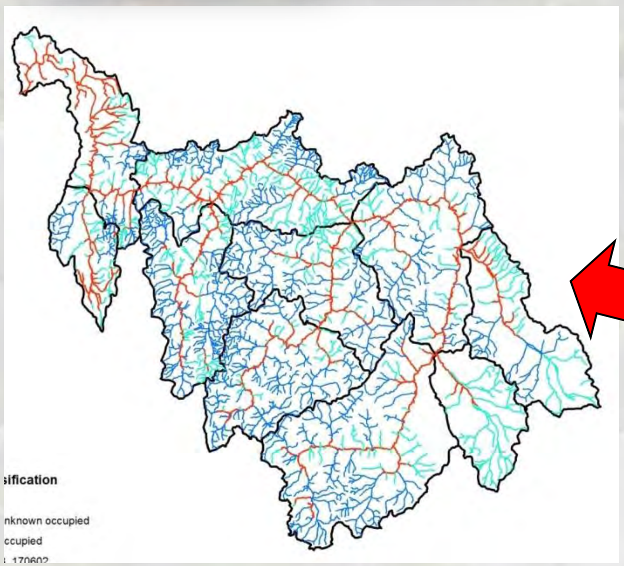


Computer algorithm delineates consistent set of patches based on thermal criteria



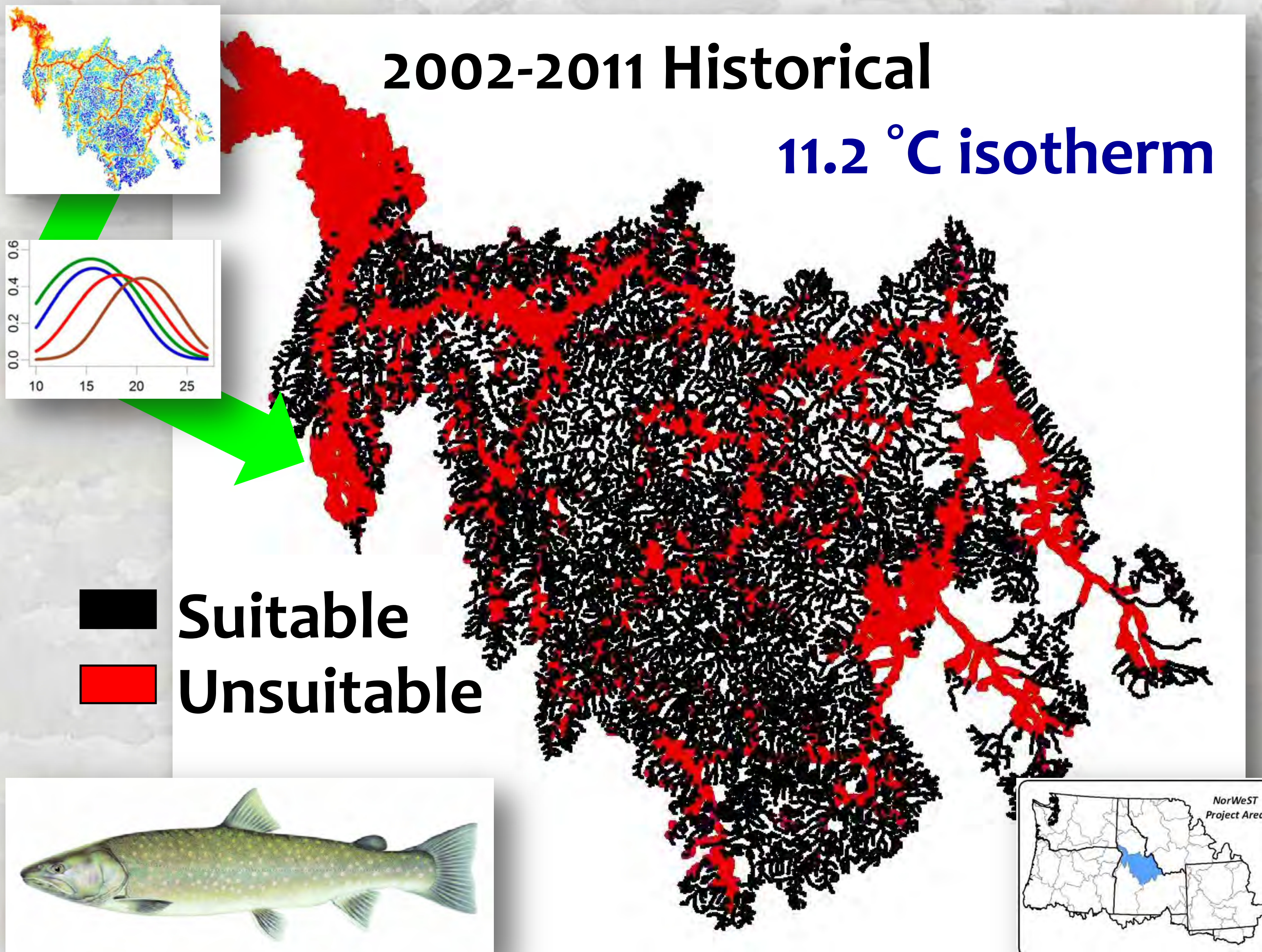
1 kilometer NorWeST predictions



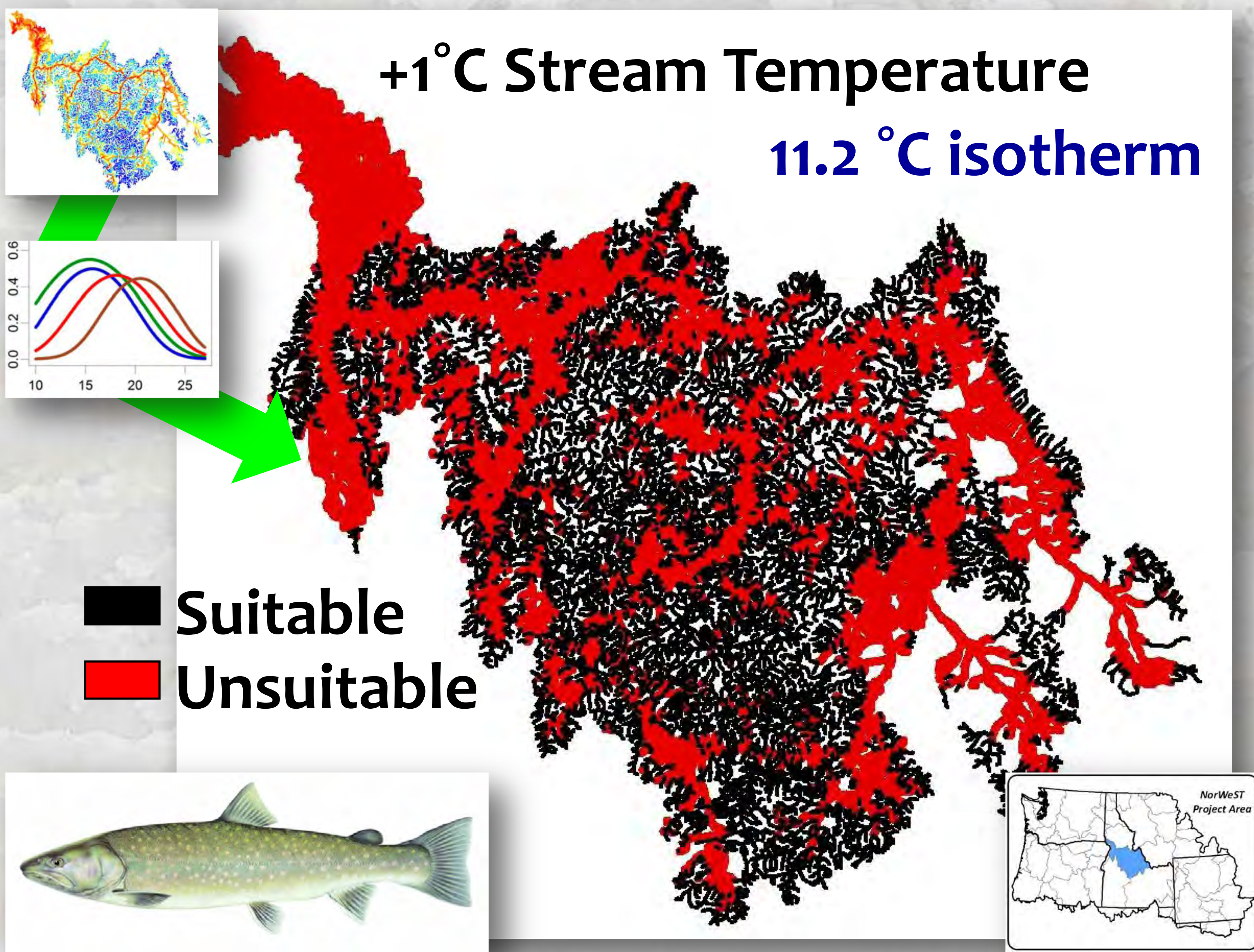


Accurate census of thermally suitable habitat

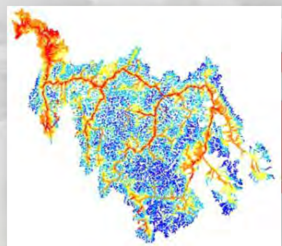
Simple Salmon River Example

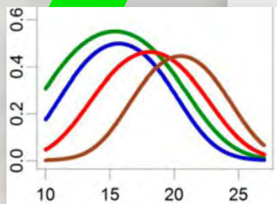


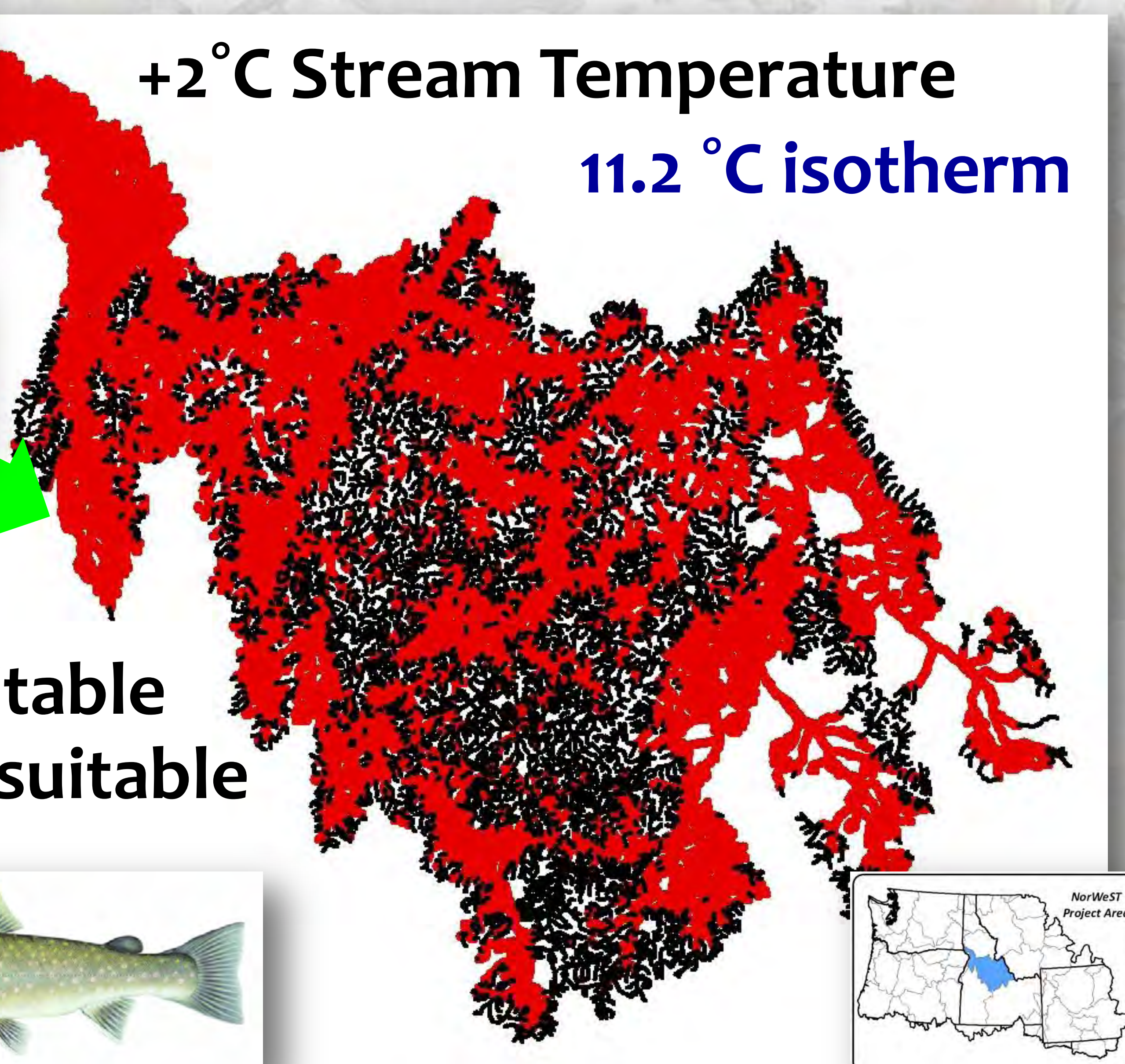
Simple Salmon River Example



Simple Salmon River Example

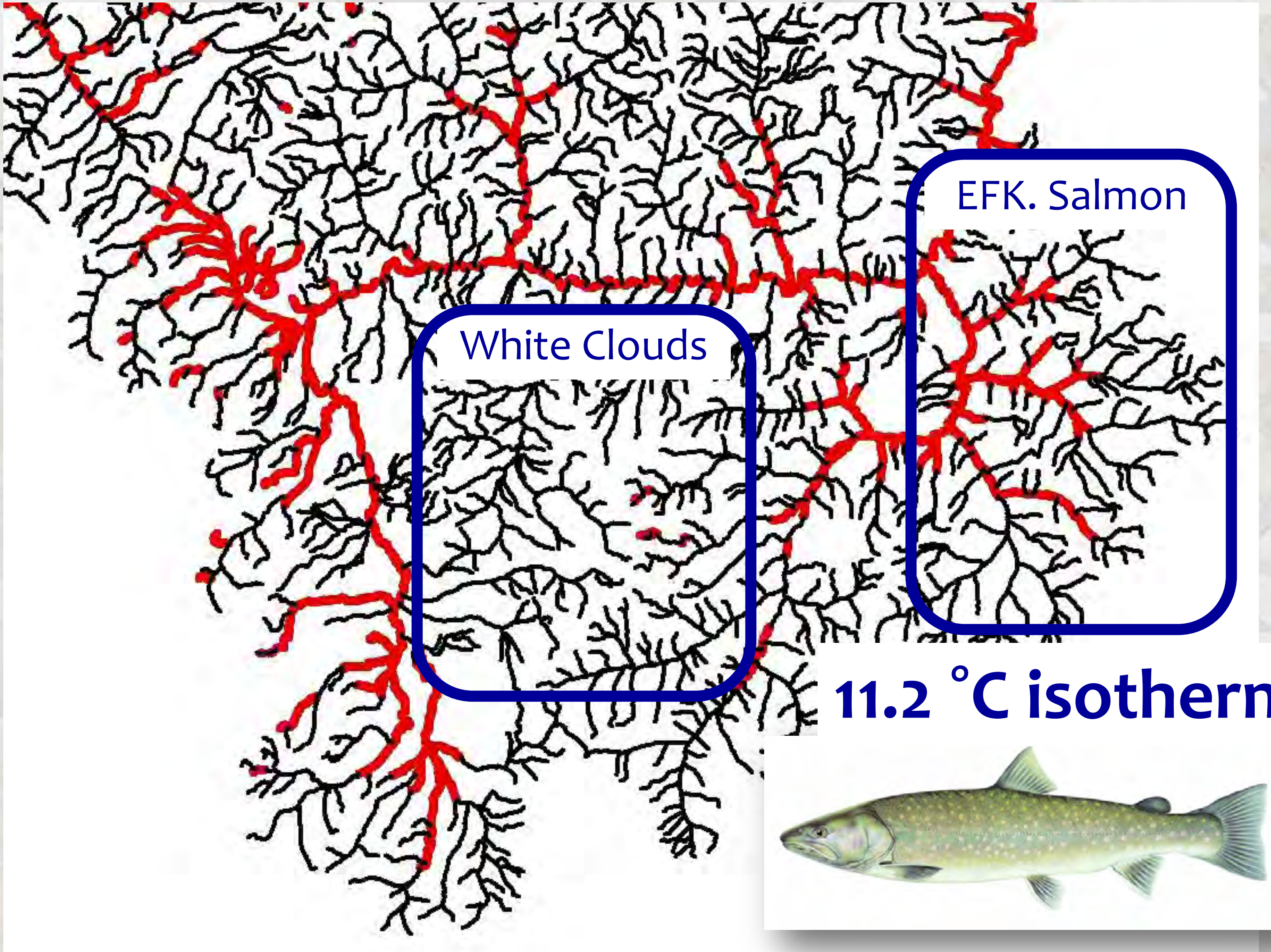






Spatial Variation in Habitat Loss

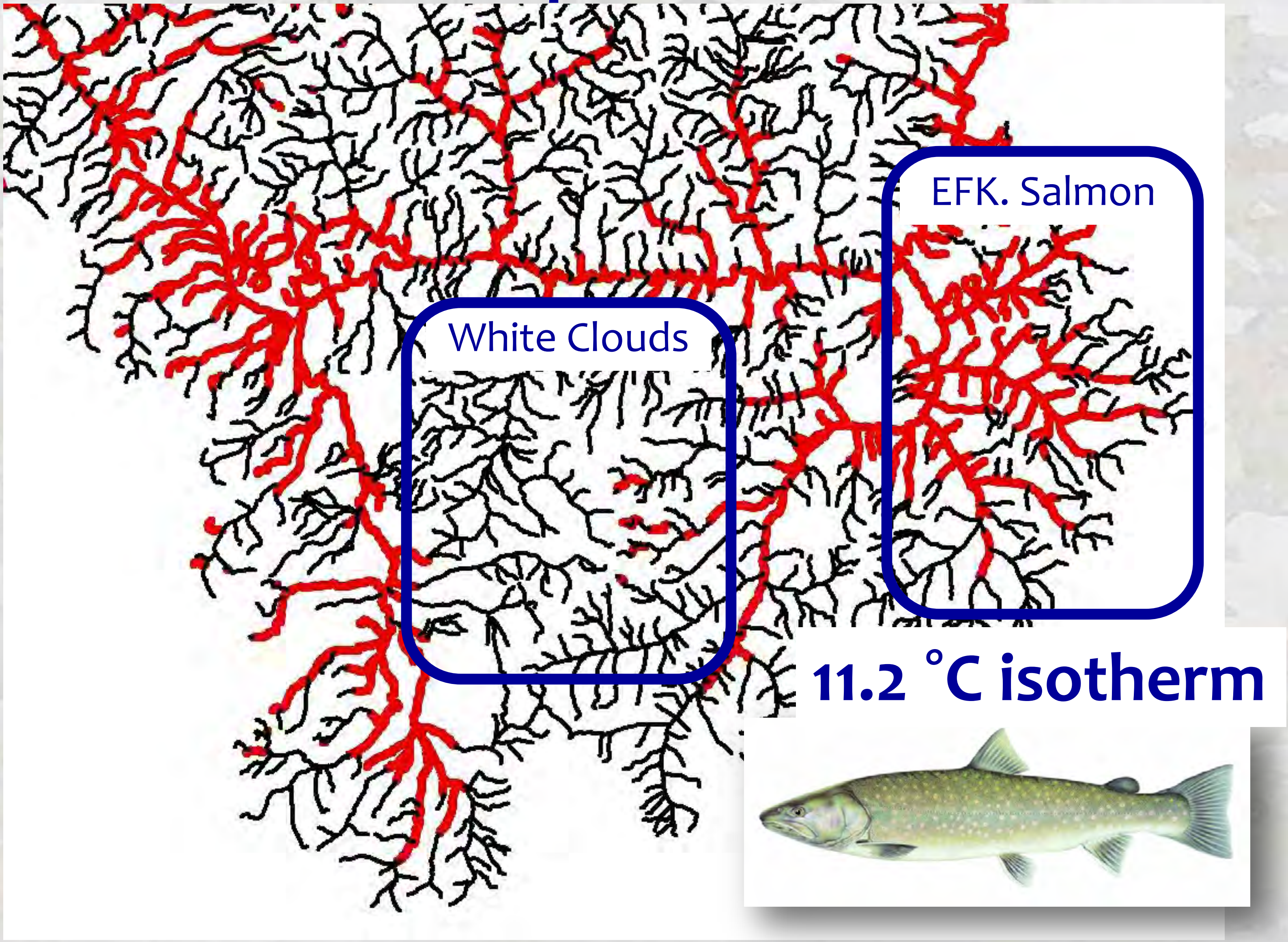
2002-2011 historical scenario



11.2 °C isotherm

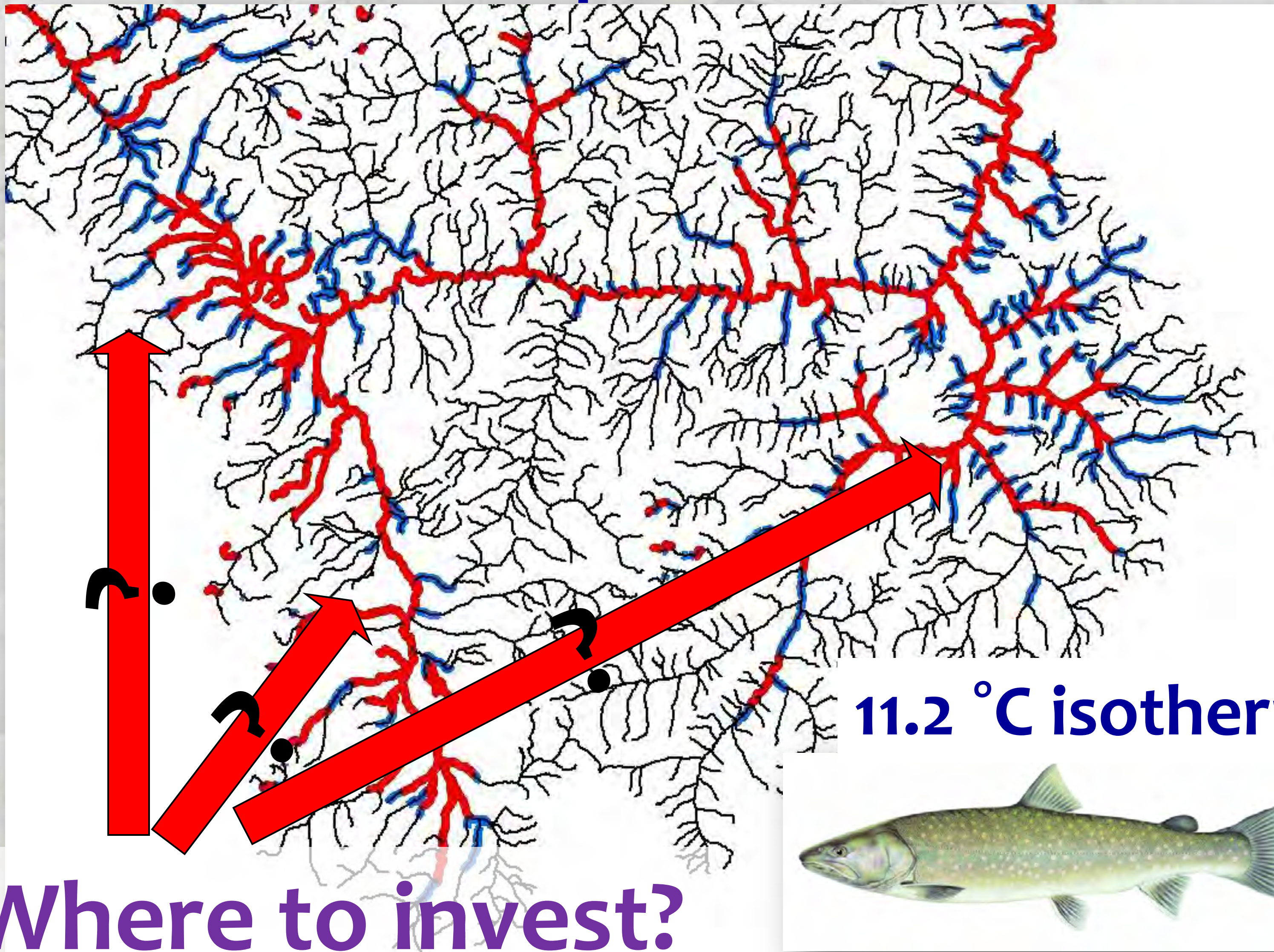
Spatial Variation in Habitat Loss

+1°C stream temperature scenario



Difference Map Shows Vulnerable Habitats

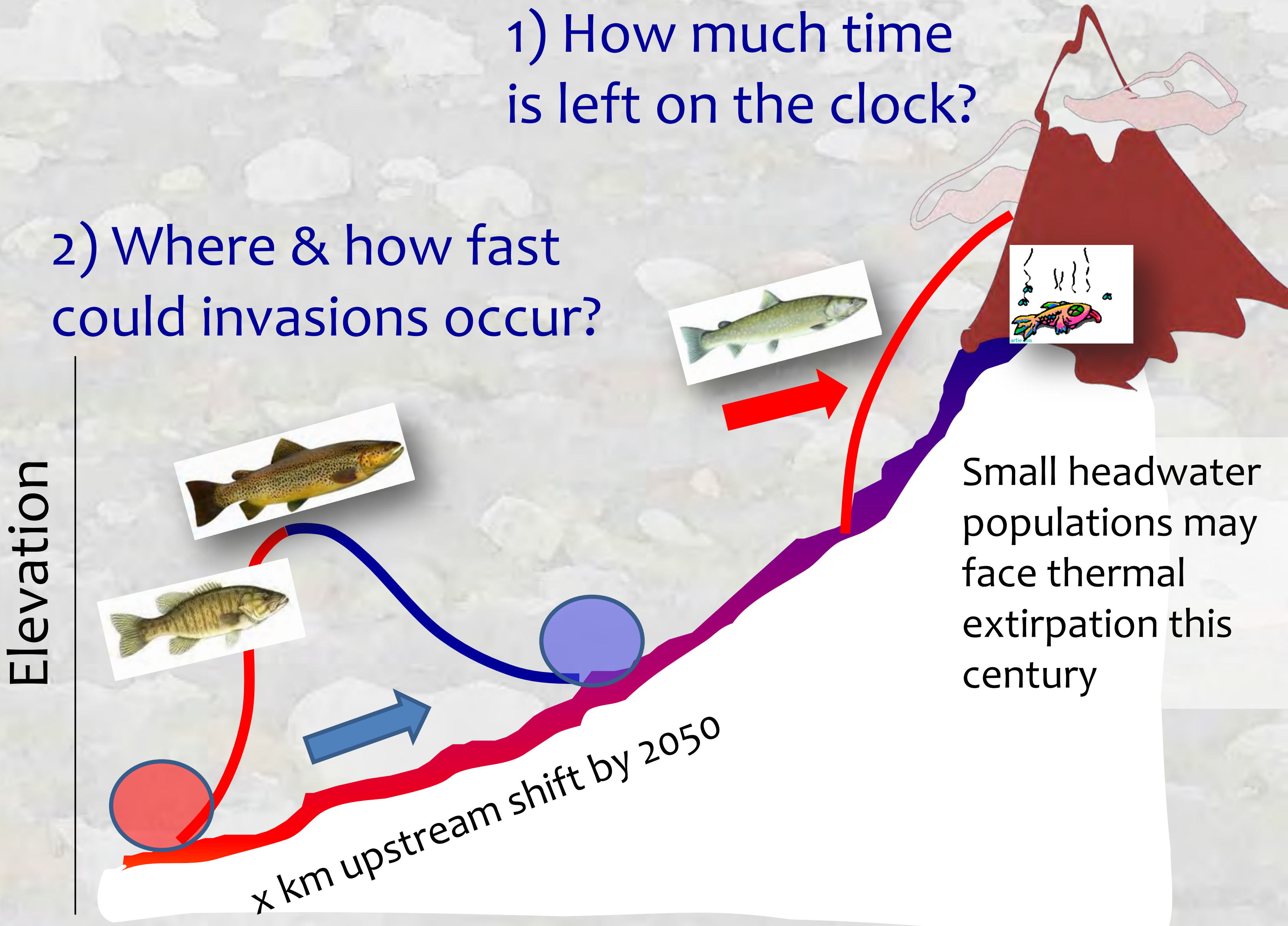
+1°C stream temperature scenario



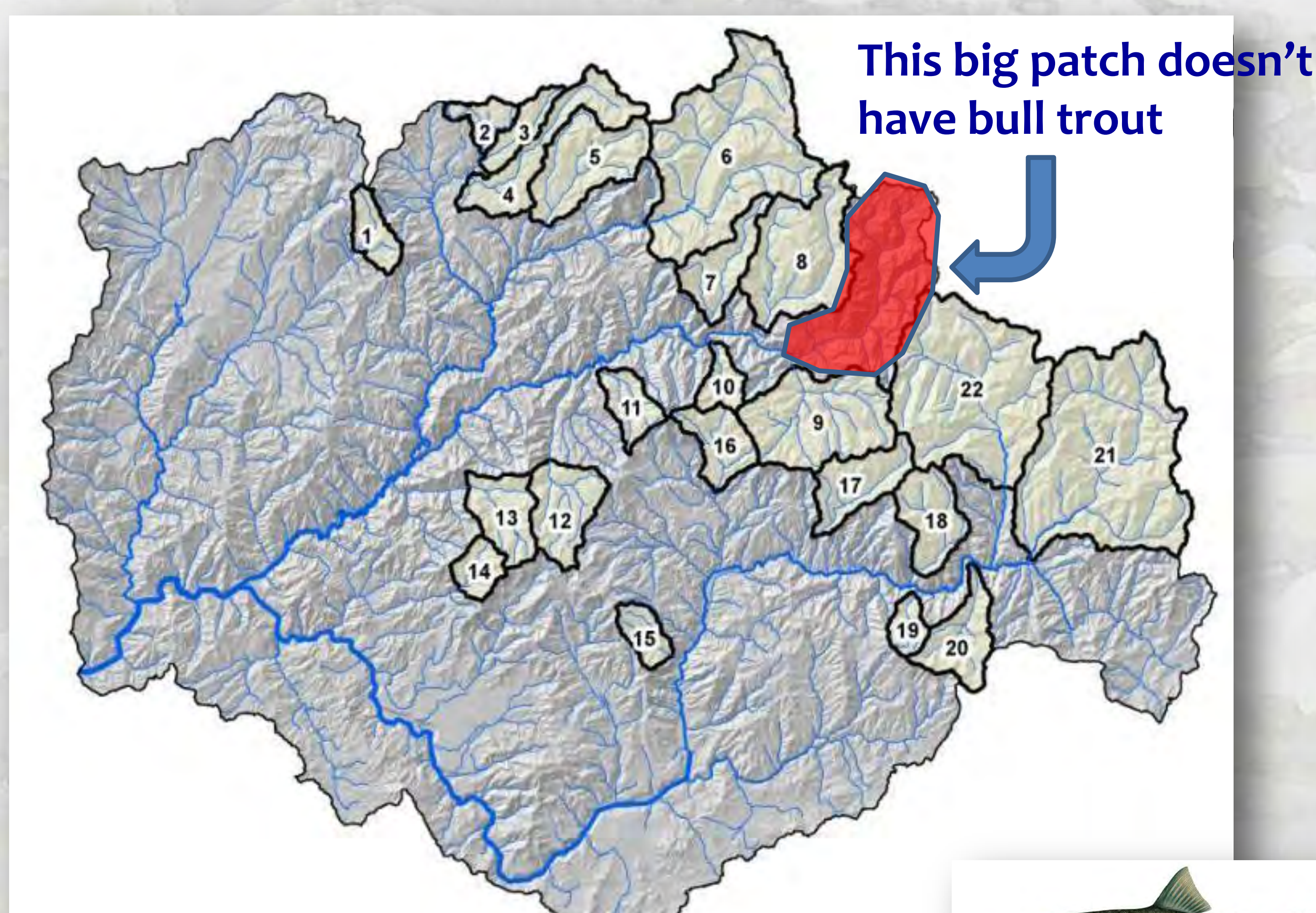
11.2 °C isotherm

Where to invest?

Precise Information Regarding Potential Species Invasions & Population Extirpations

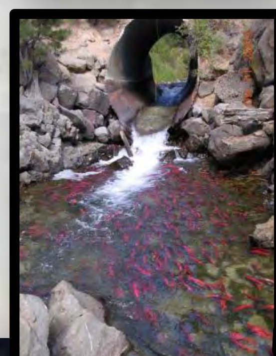


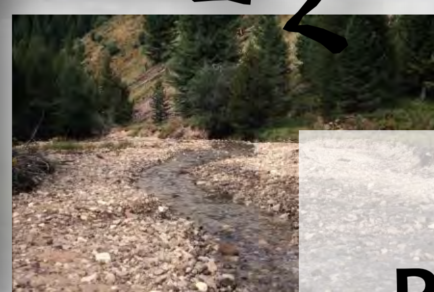
Precise Targeting of Assisted Migrations & Reintroduction Efforts

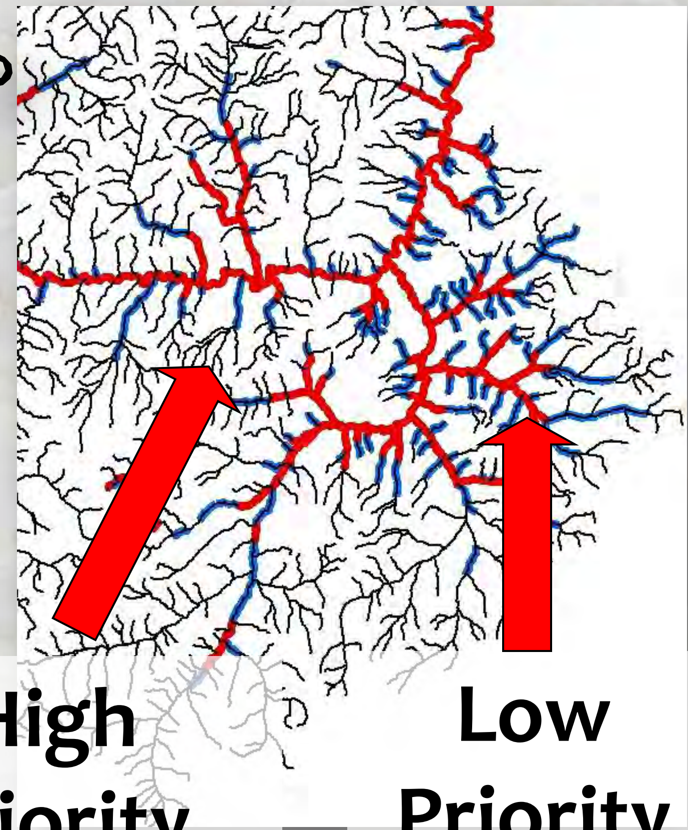


Climate-Smart Strategic Prioritization

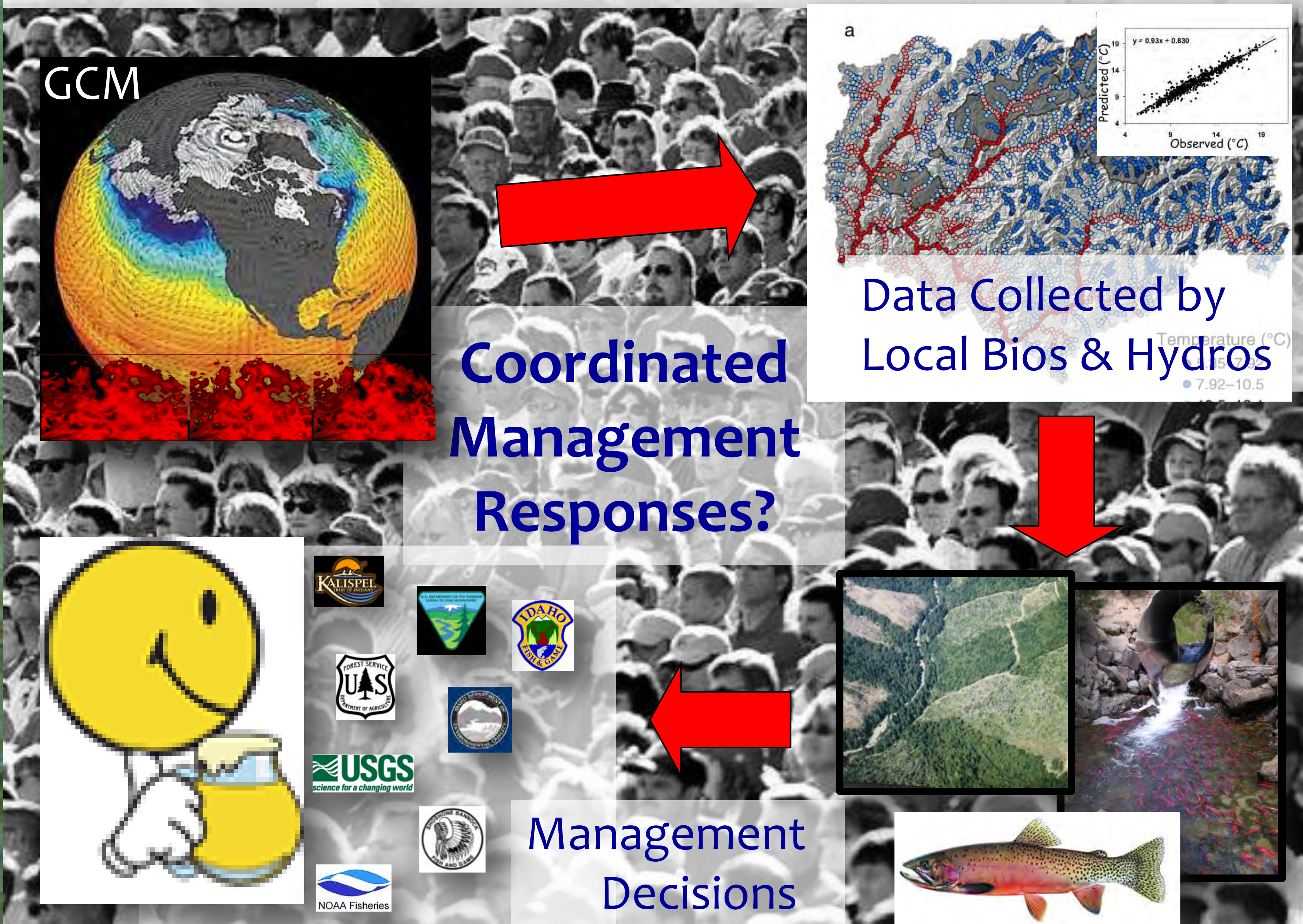
- Maintaining/restoring flow…
- Maintaining/restoring riparian…
- Restoring channel form/function…
- Prescribed burns limit wildfire risks…
- Non-native species control…
- Improve/impede fish passage…





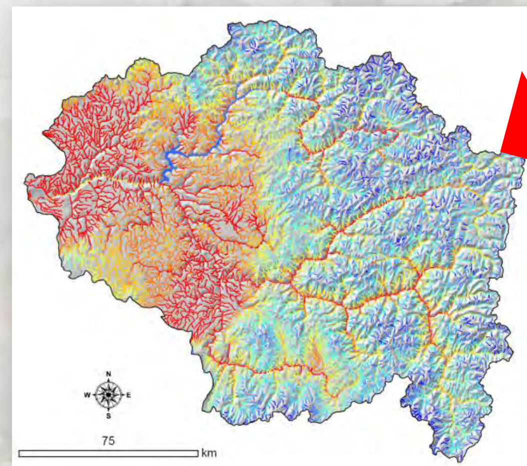


NorWeST is a "Crowd-Sourced" Model Developed from Everyone's Data

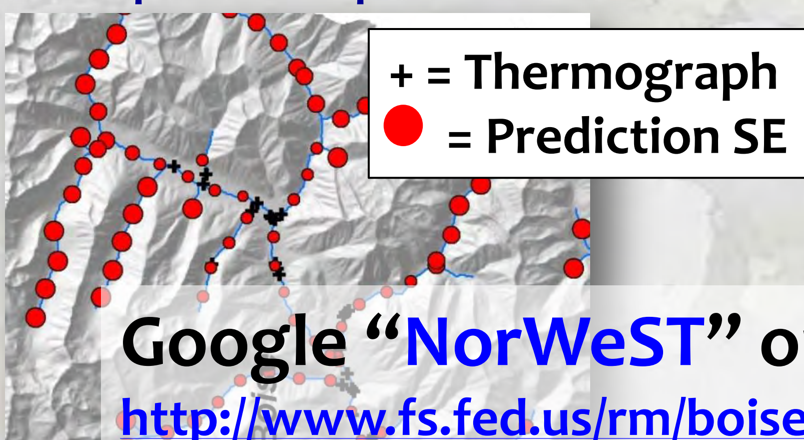


Website Distributes Scenarios & Temperature Data as GIS Layers

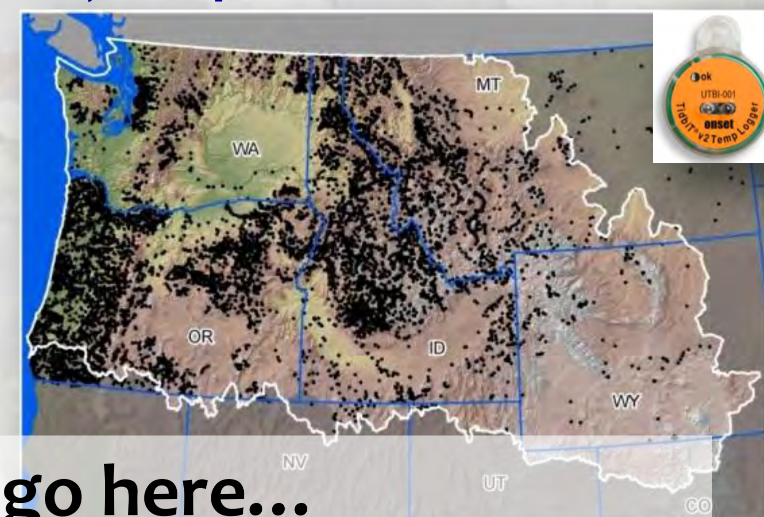
1) GIS shapefiles of stream temperature scenarios



2) GIS shapefiles of stream temperature model prediction precision



3) Temperature data summaries

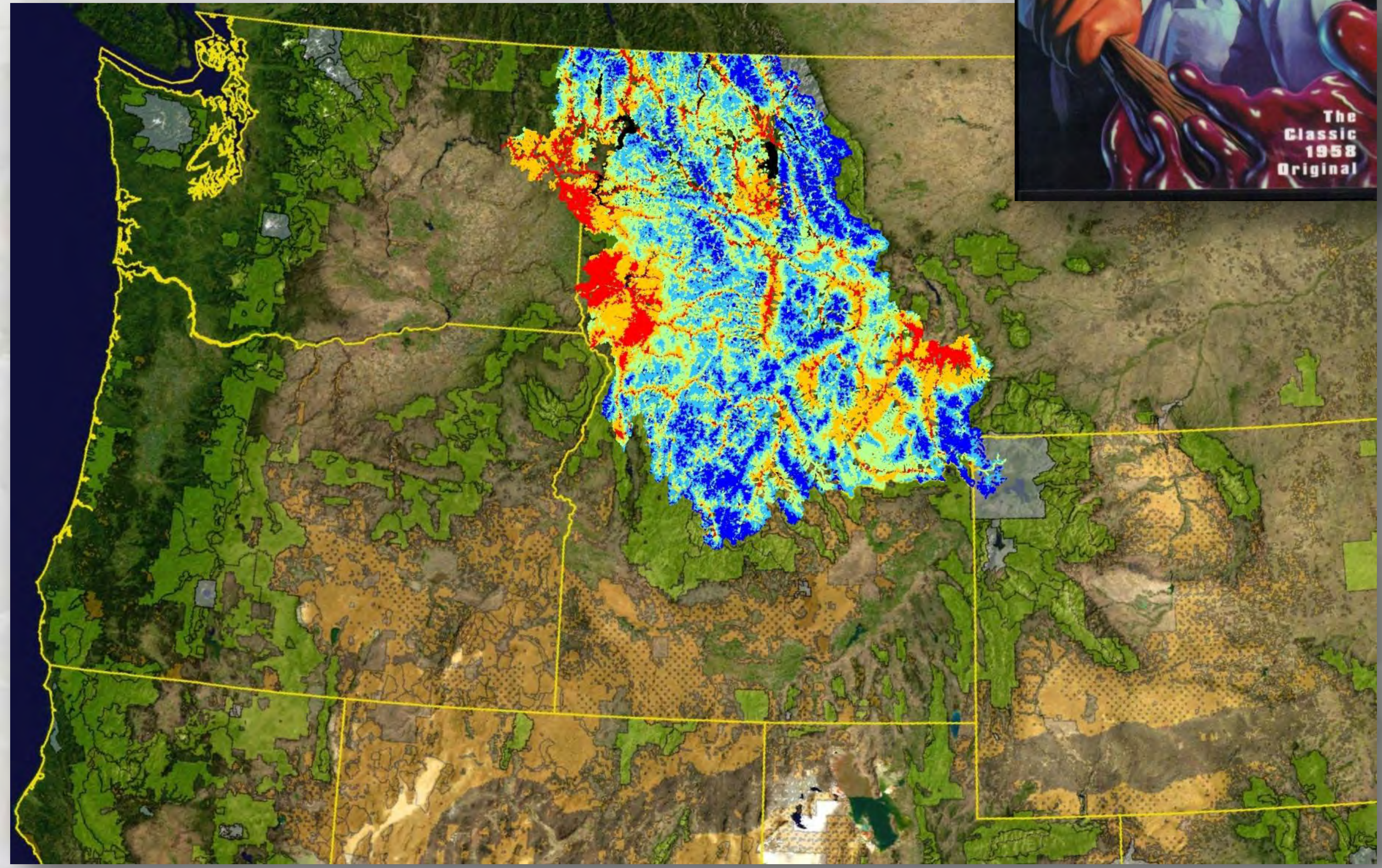


Google "NorWeST" or go here…

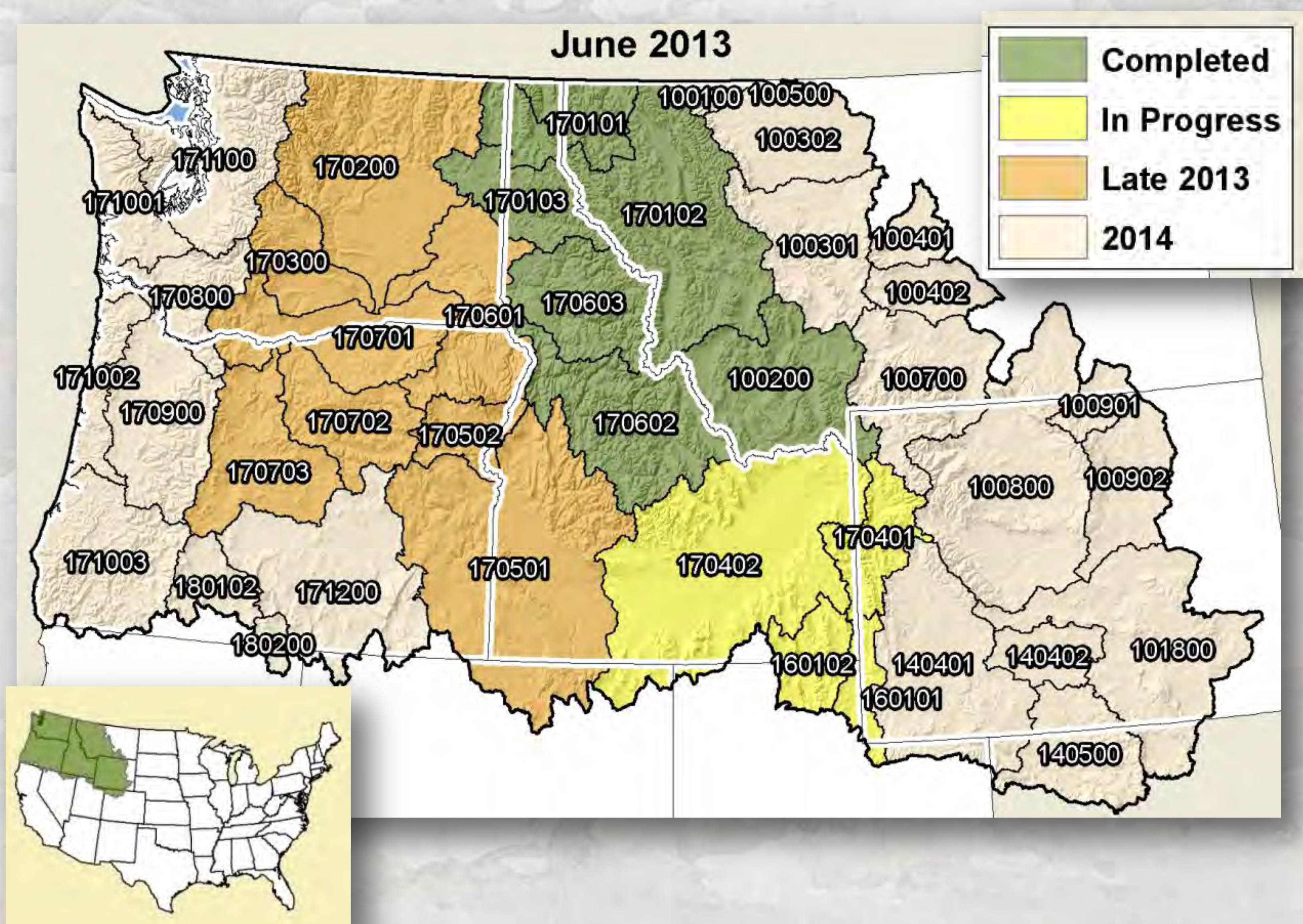
http://www.fs.fed.us/rm/boise/AWAE/projects/NorWeST.shtml

The Blob is Growing…

- 15,515 summers of data swallowed
- 117,000 stream kilometers of thermal ooze mapped

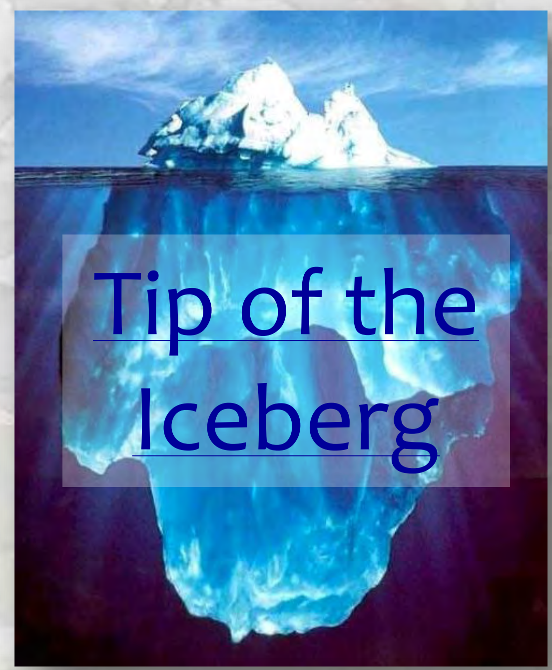


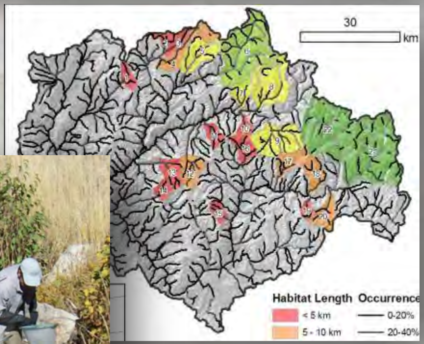
NorWeST Schedule

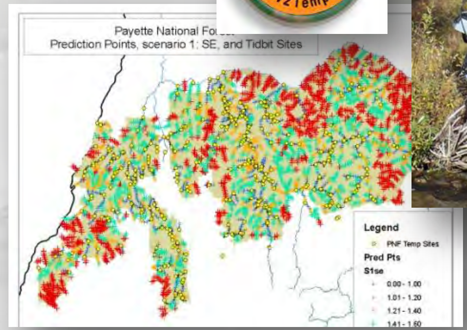


NorWeST Facilitating Related Projects

- 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

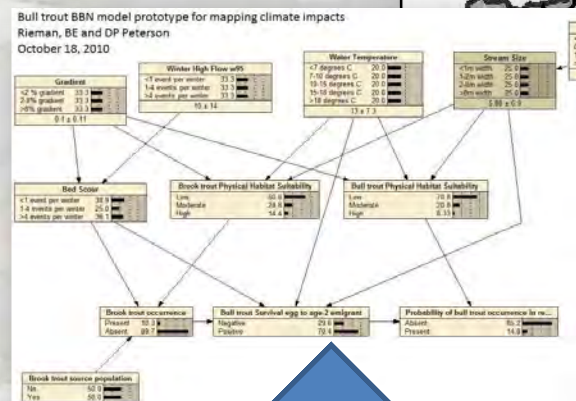


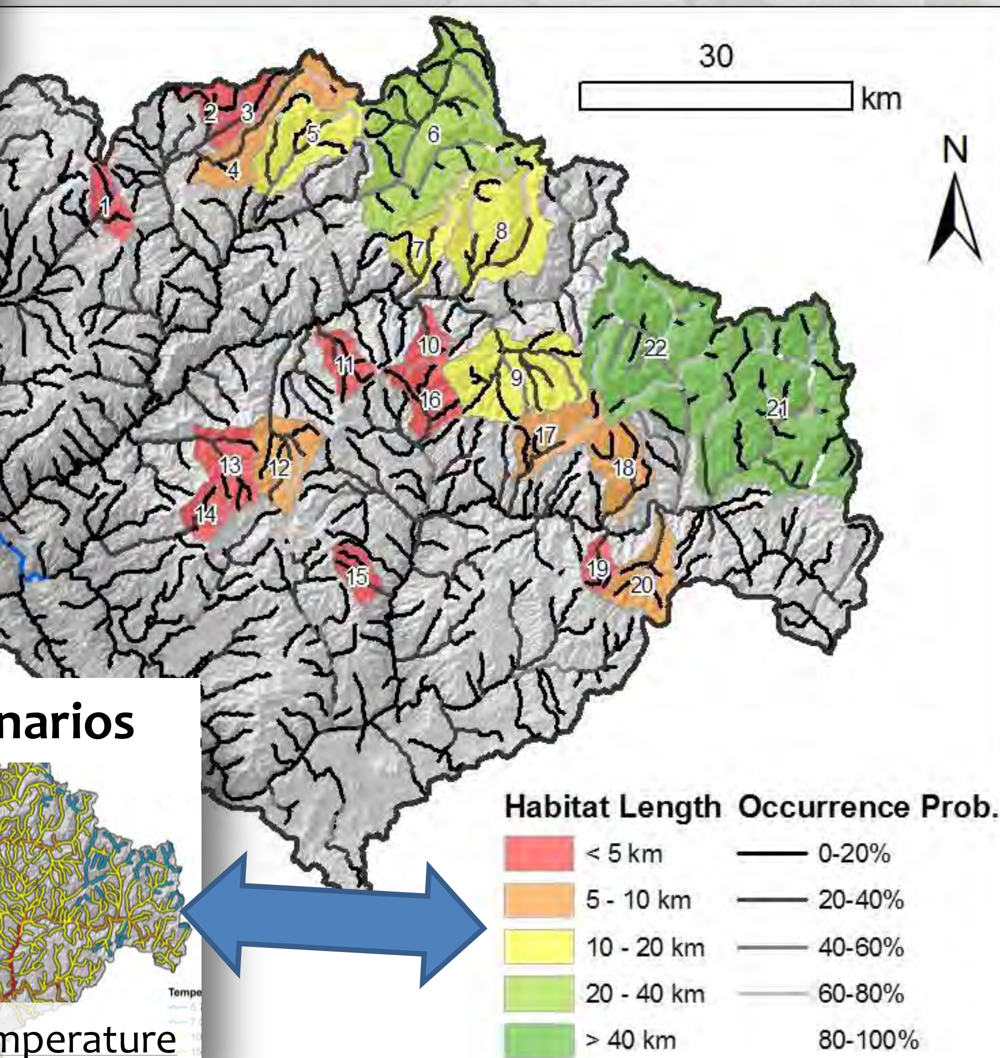




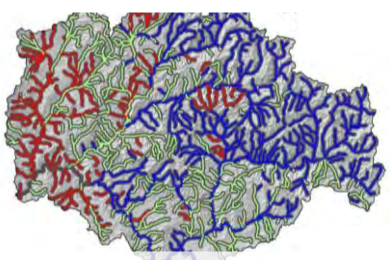
Bull Trout Climate Decision Support Tool

Tool runs on regionally consistent data layers

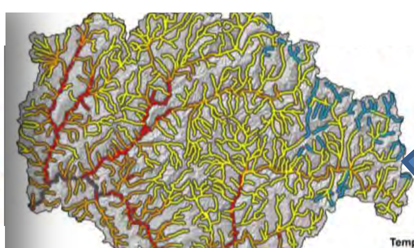




Downscaled Stream Scenarios



Streamflow

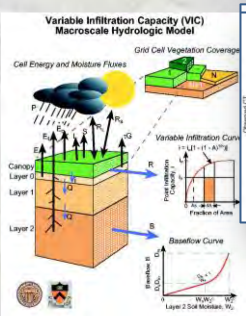


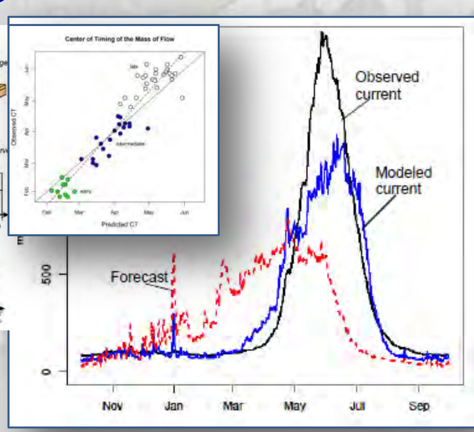
Stream Temperature

Peterson et al. 2013. *Fisheries* **38**:112-127.

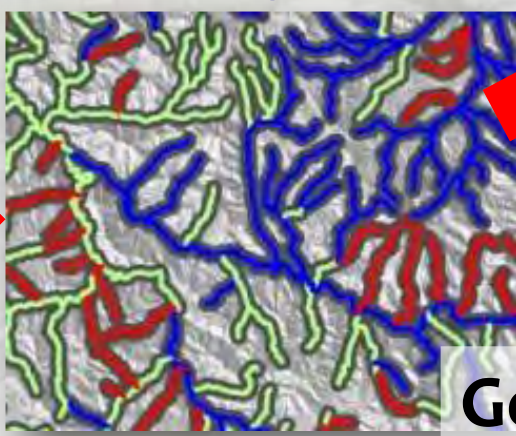
VIC Streamflow Scenarios

Ecological Flow Metrics





NHD+ stream segment resolution



A1B IPCC Scenarios for the western U.S.

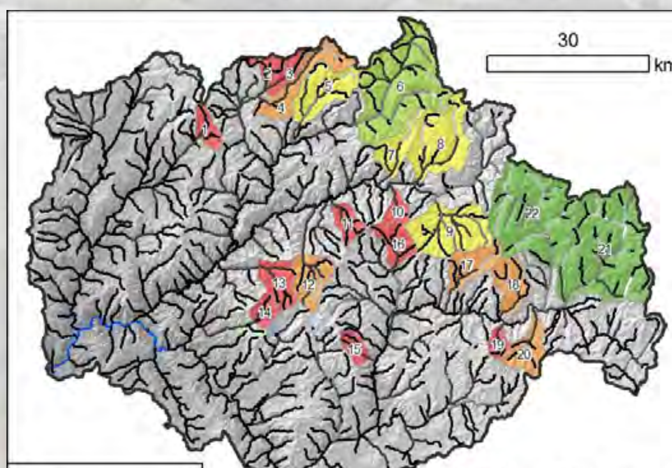
Google "**Stream flow Metrics**"

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

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

Efficient Biological Monitoring

Bull trout distributional status & trend

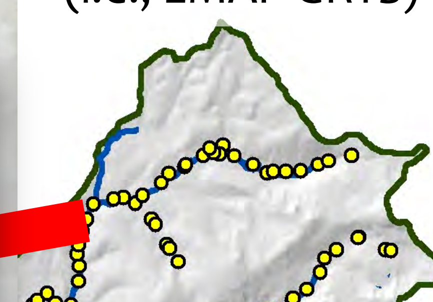


Accurate habitat maps from stream models

=

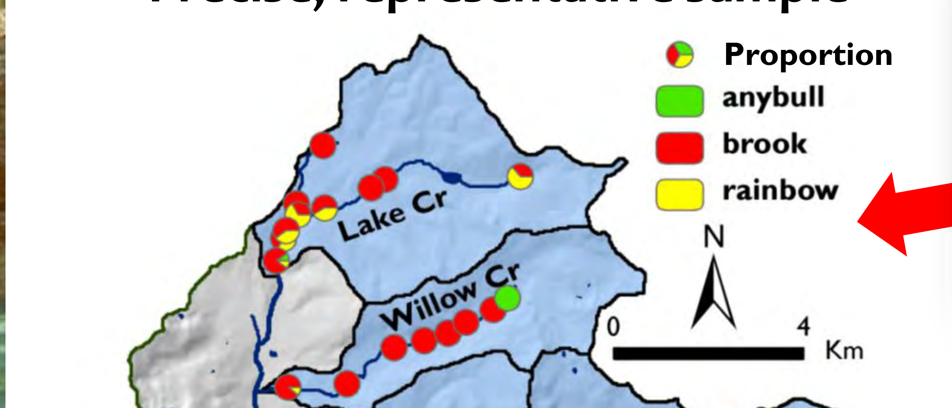
Map

Probabilistic sample (i.e., EMAP GRTS)



Biological survey

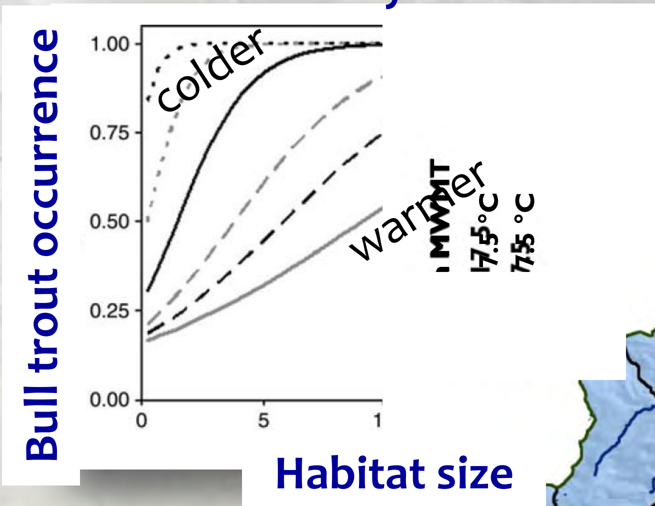
Precise, representative sample

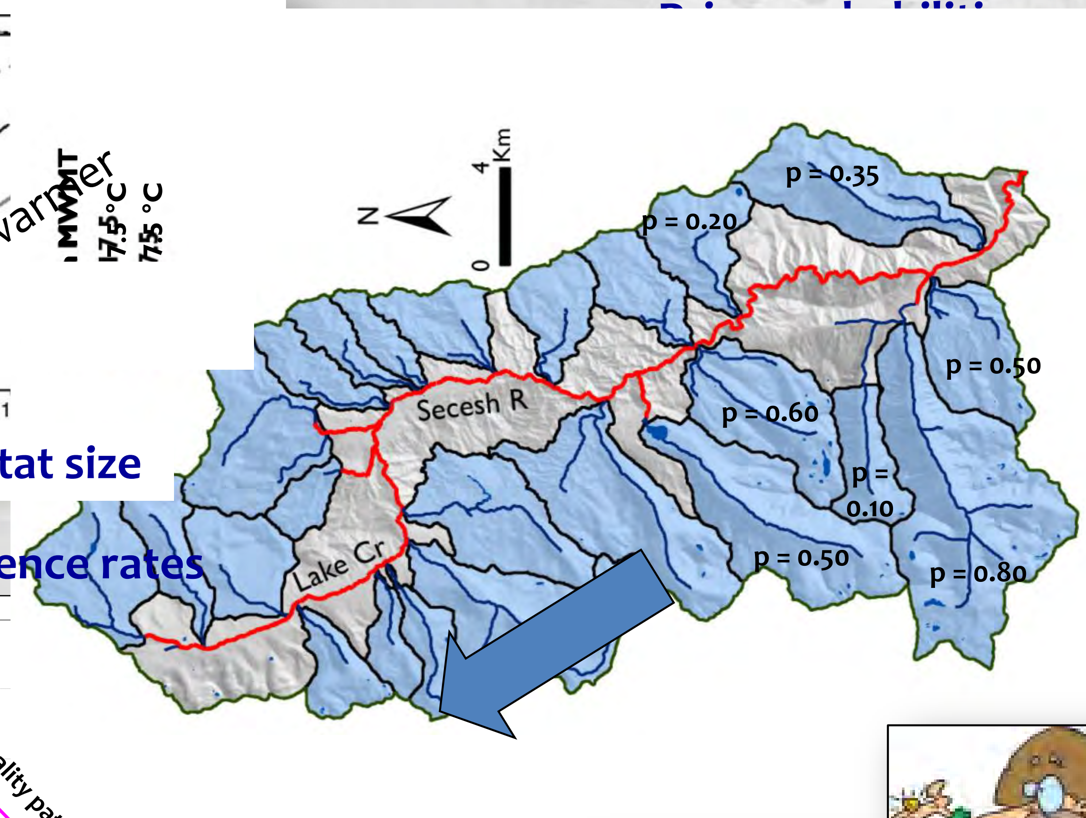


Optimizing Biological Monitoring:

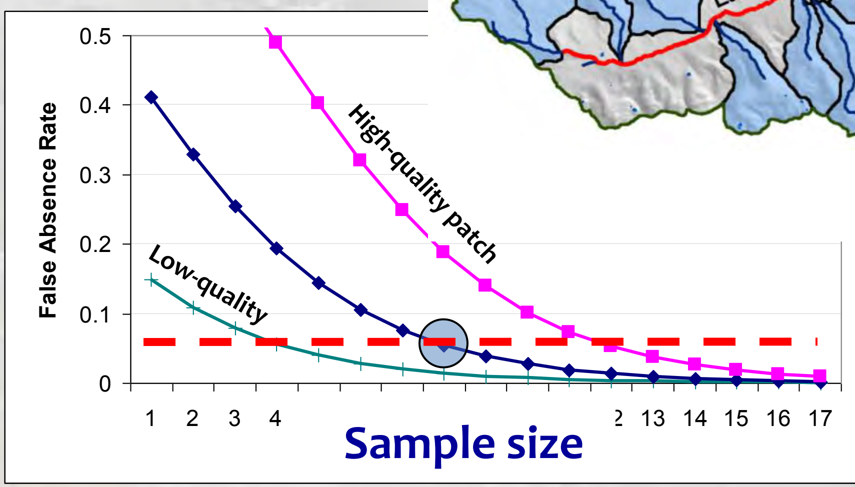
Covariate Effects on Detection Efficiencies

Habitat Suitability Curves

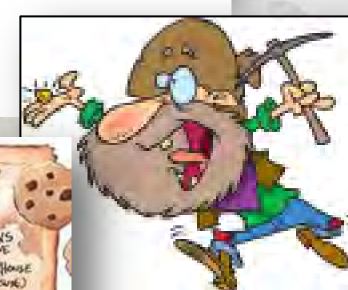




Modified false absence rates



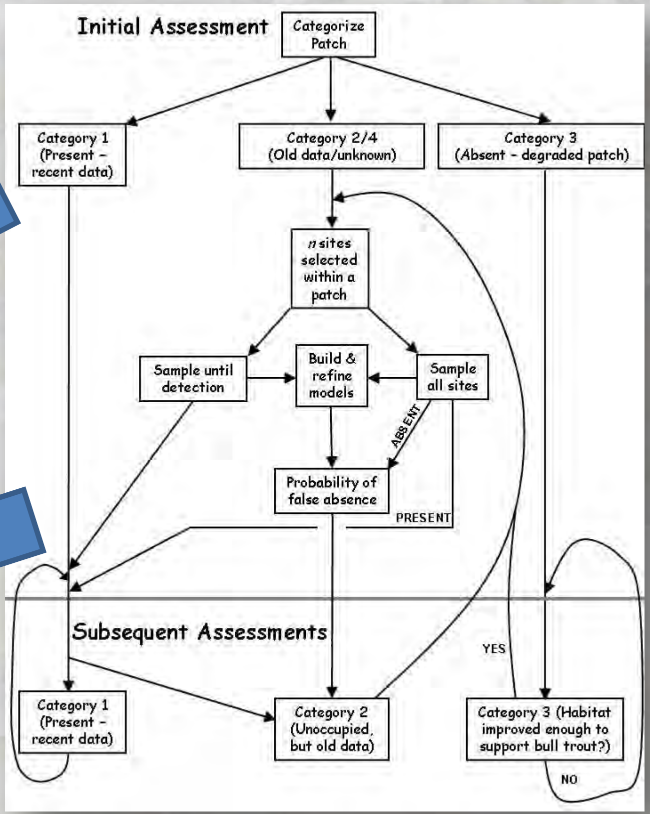
Peterson & Dunham 2003

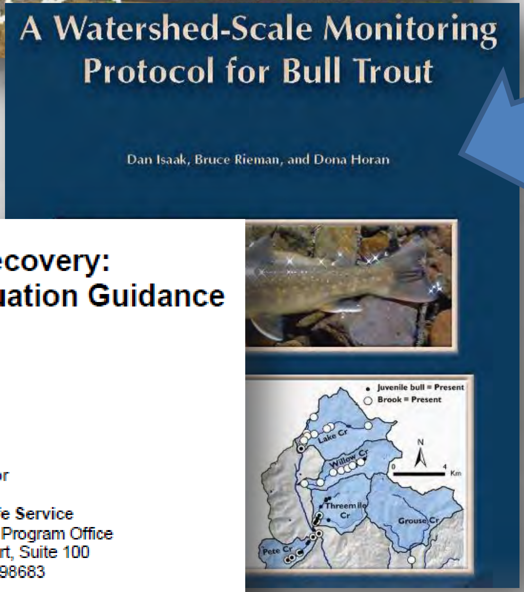


How many claims to stake?

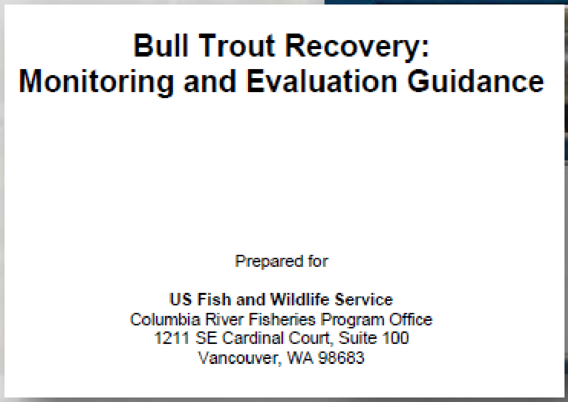
Regionally Consistent Framework

Bull trout status & trend monitoring




A Watershed-Scale Monitoring Protocol for Bull Trout

Dan Isaak, Bruce Rieman, and Dona Horan

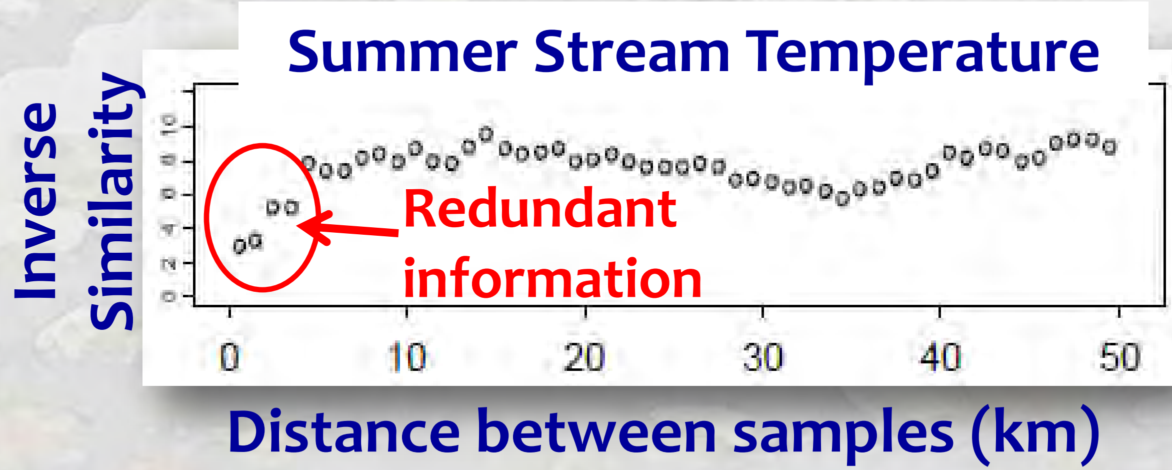

Bull Trout Recovery:
Monitoring and Evaluation Guidance

Prepared for

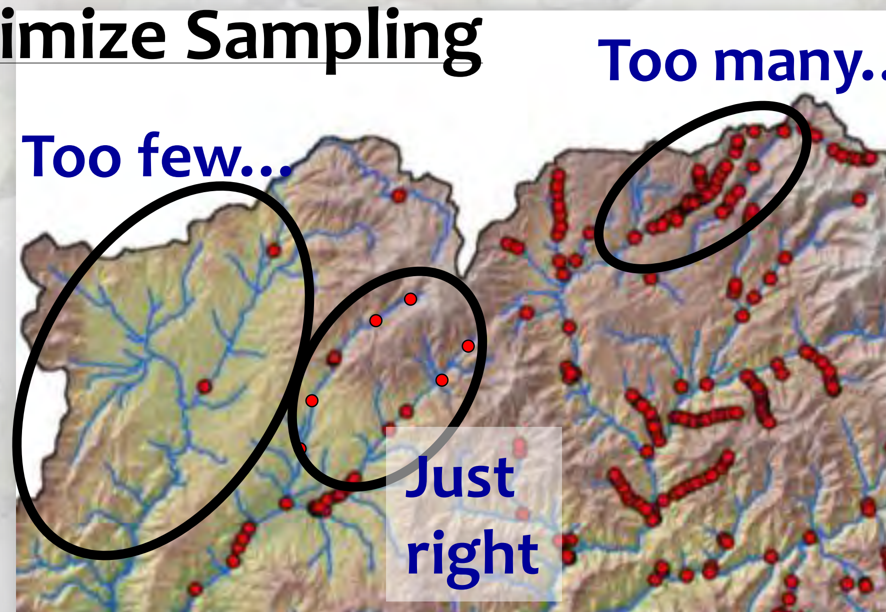
US Fish and Wildlife Service
Columbia River Fisheries Program Office
1211 SE Cardinal Court, Suite 100
Vancouver, WA 98683

USFWS 2008; Isaak et al. 2009

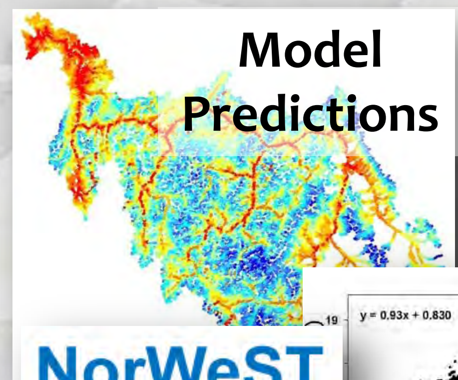
Efficient Temperature Monitoring



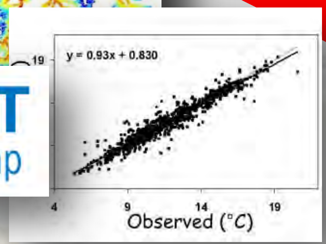
Optimize Sampling



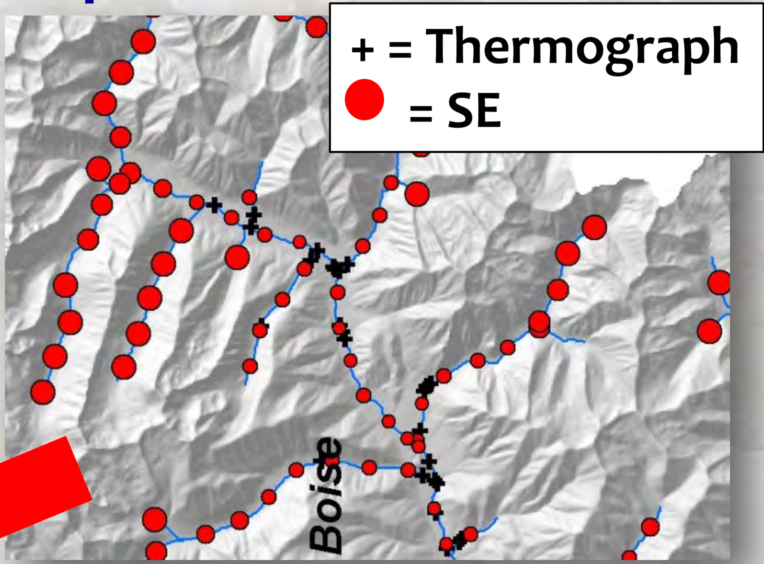
Spatially Explicit Maps of Prediction Uncertainty (S34_PredSE)



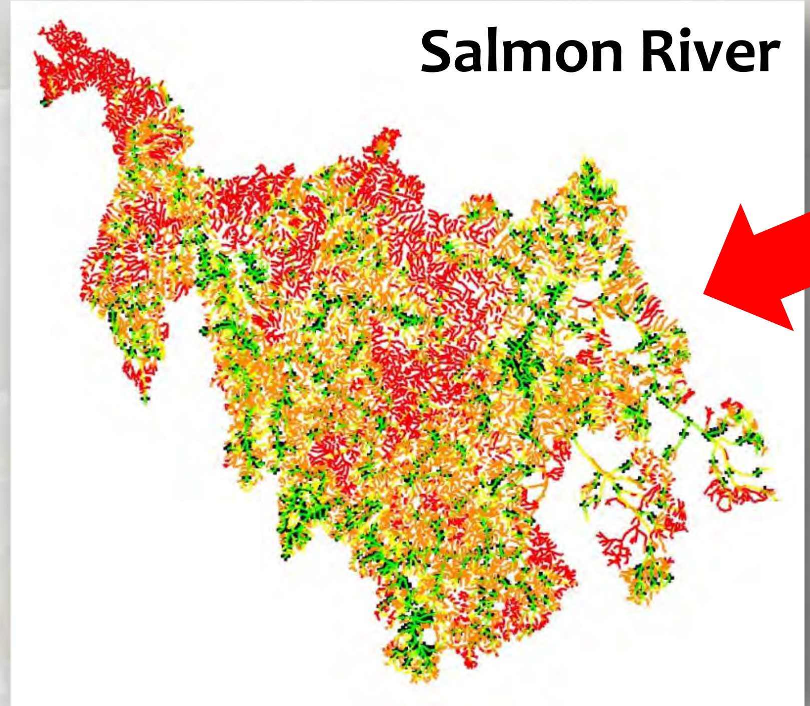
NorWeST Stream Temp



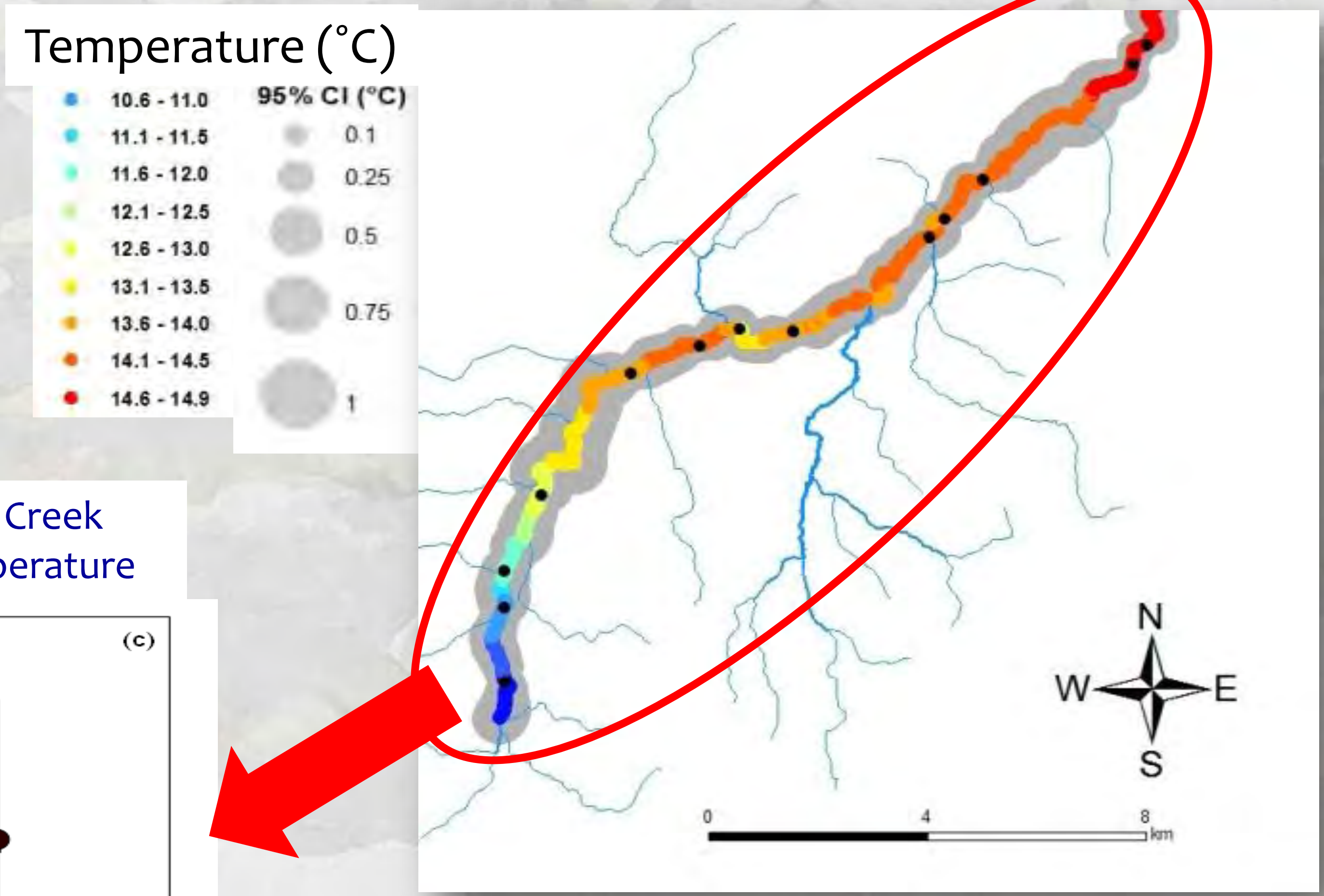
Temperature Prediction SE's



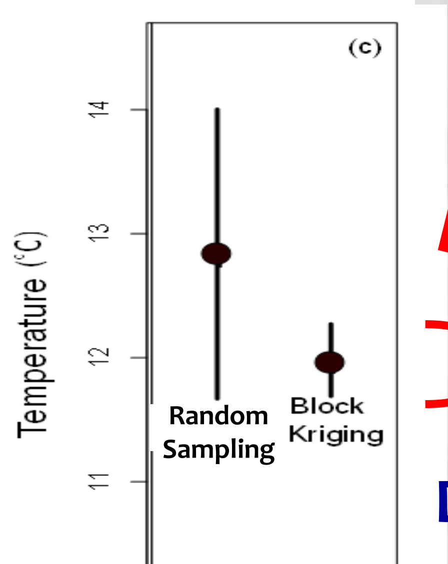
SE's are small near sites with temperature measurements



Block-krige Accurate Stream Temperature Estimates at User Defined Scales



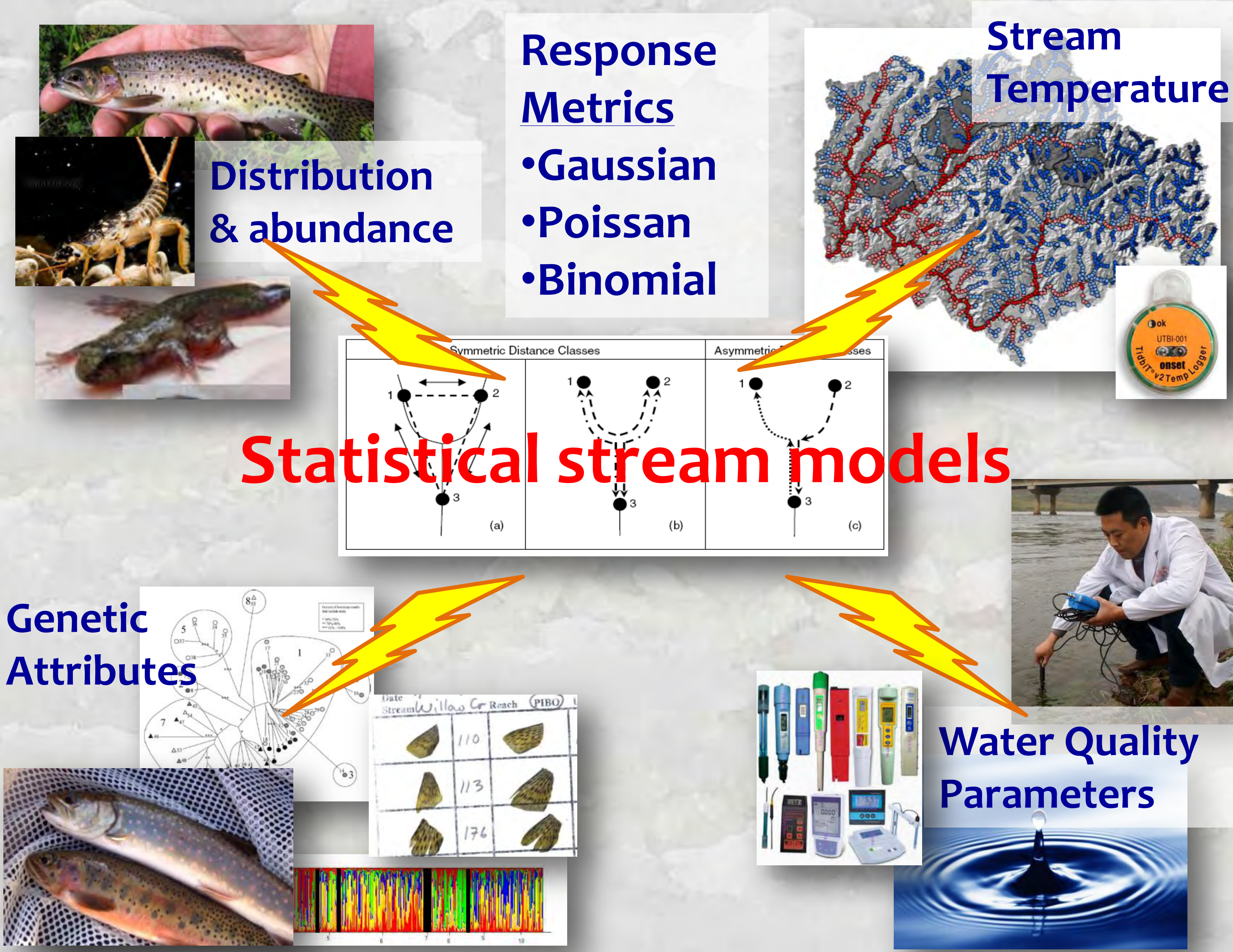
Bear Valley Creek
Mean Temperature



} Precise & unbiased estimates

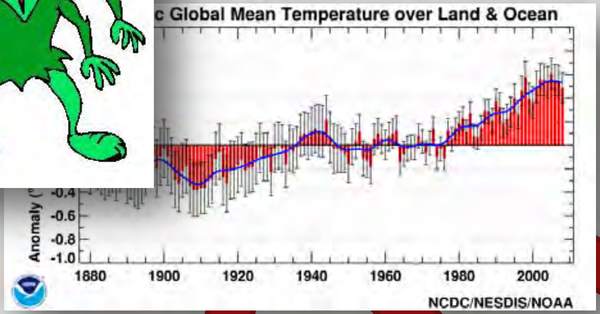
Does this reach exceed the TMDL standard?

Spatial Stream Models are Generalizable…



Climate Is Happening…

Distributions are Shifting in Many Species

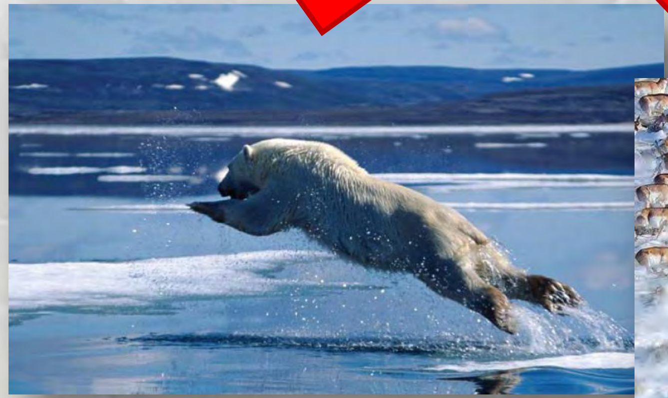


<u>Average distribution shift</u>

6.1 km/decade poleward

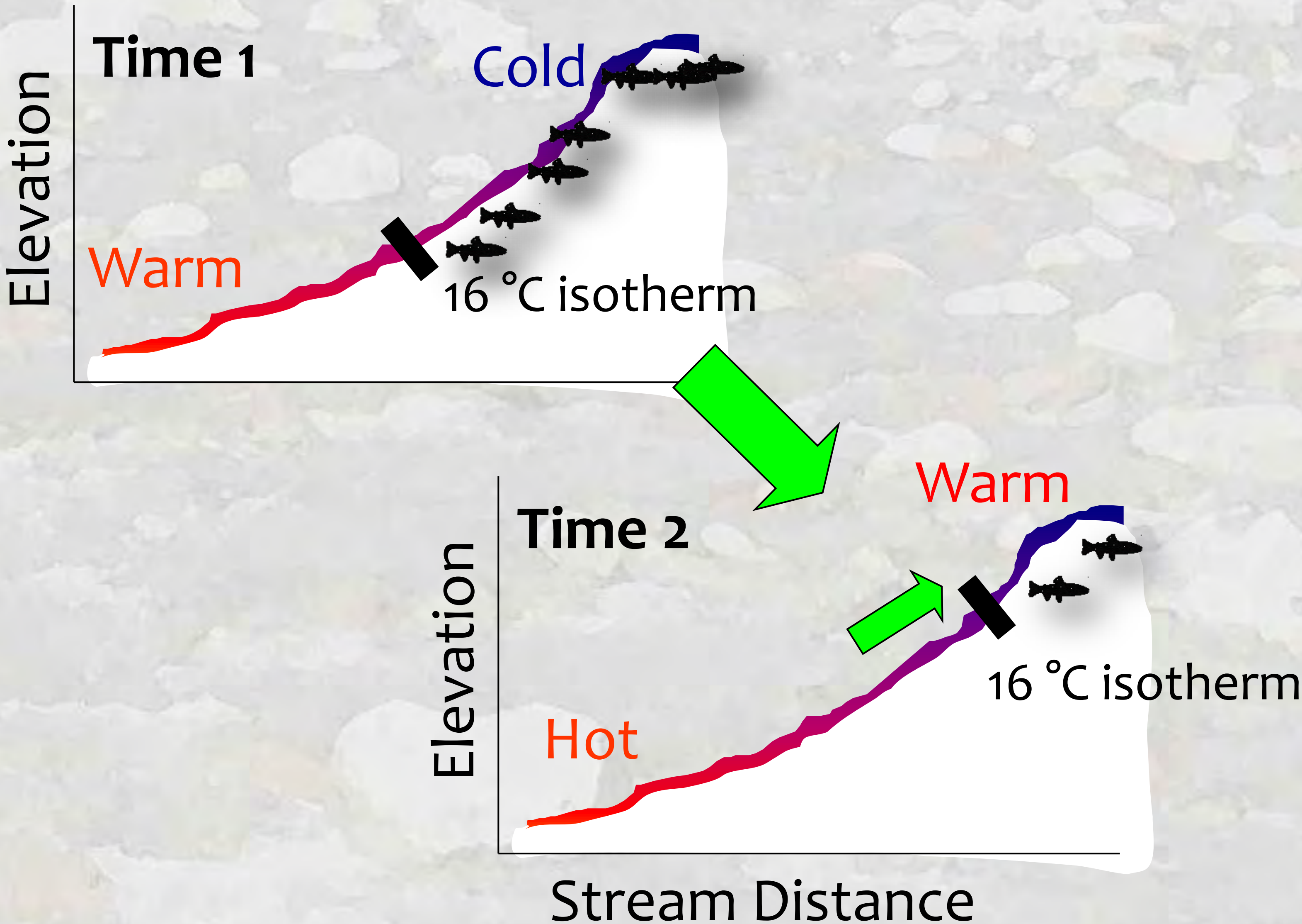
OR

6.1 m/decade higher elevation



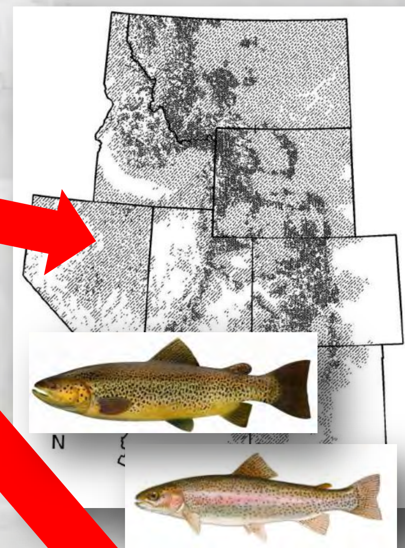
Parmesan and Yohe. 2003. *Nature* **421**:37-42.

…but how fast is it happening to fish?

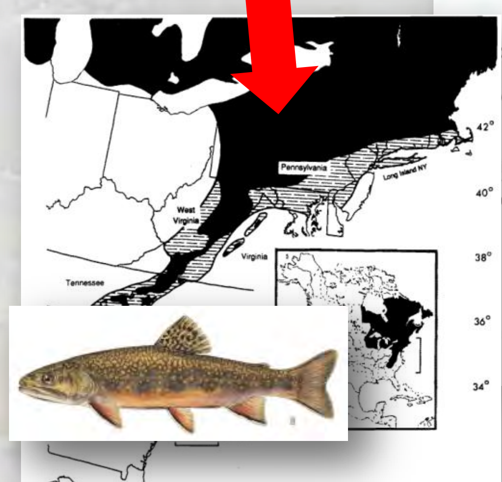


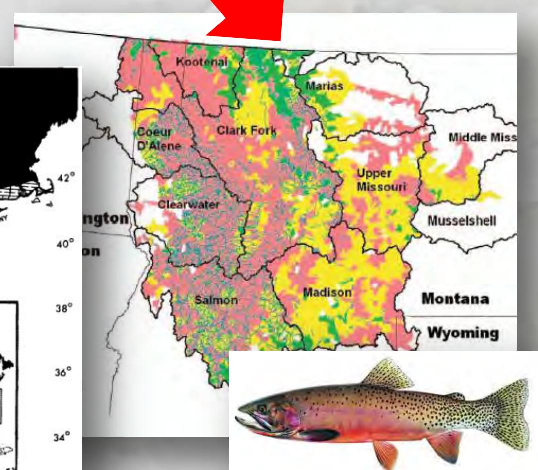
Evidence for Freshwater Fish Populations is Weak

- •Meisner 1988, 1990
- •Eaton & Schaller 1996
- •Keleher & Rahel 1996
- •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
- •Etc.

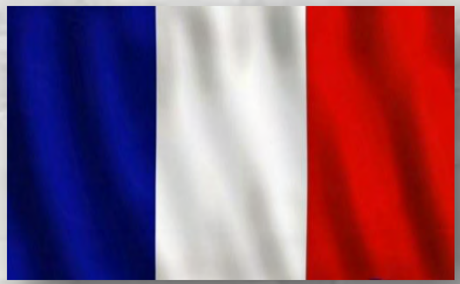


Lots of predicting, not much validating

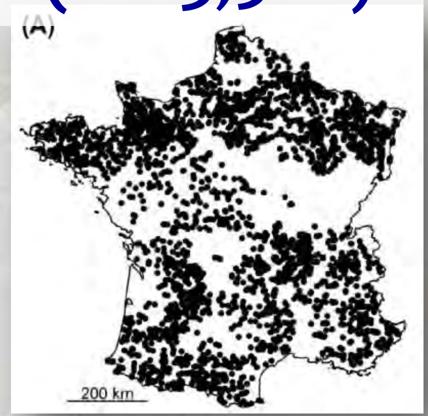




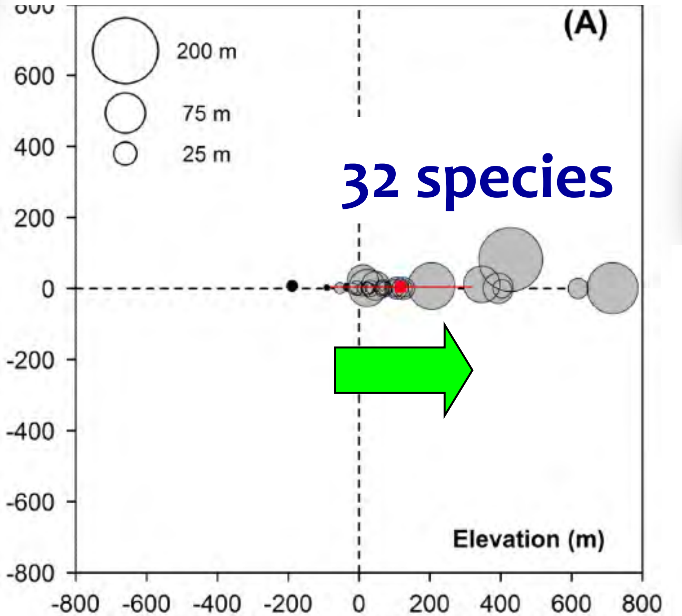
Distribution Shifts in French Streams



Survey sites (n = 3,500)



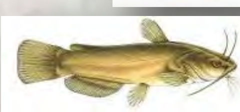
Difference in stream fish distributions (1980's vs 2000's)



32 species

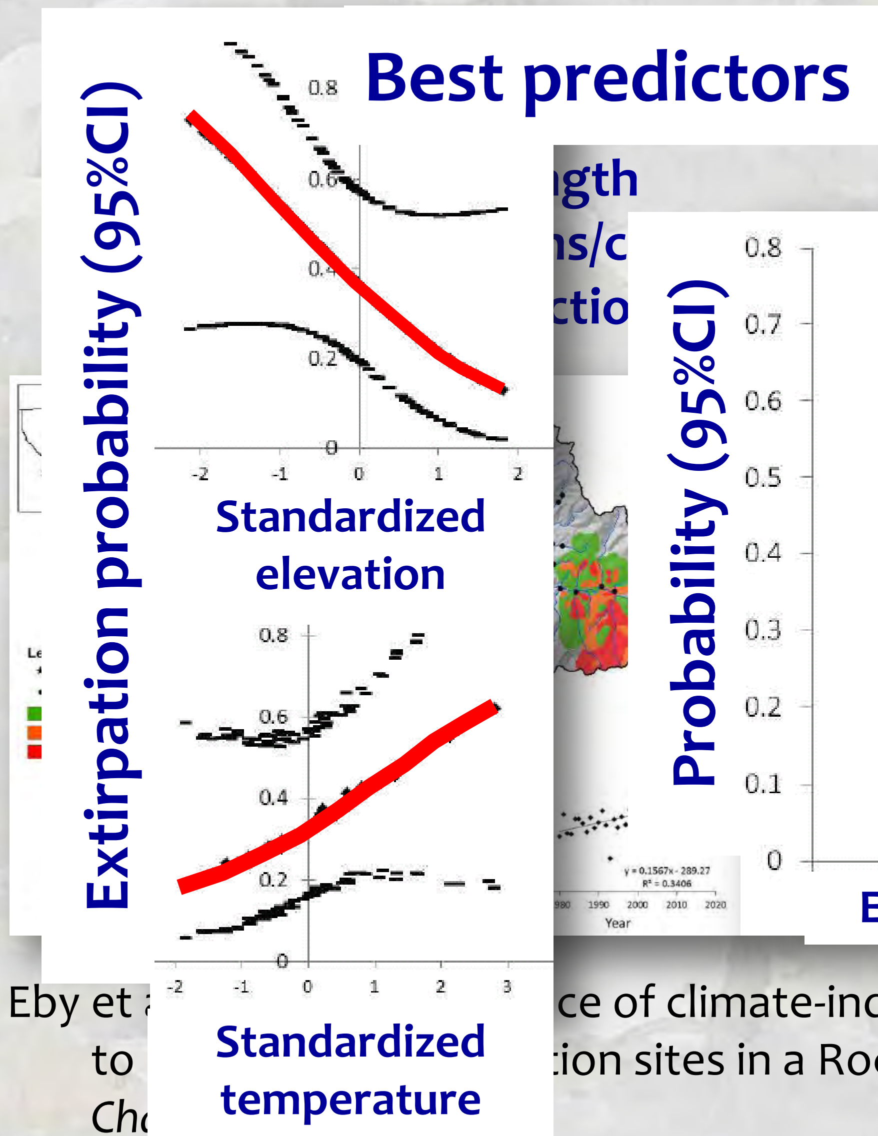
Change in Elevation (m)

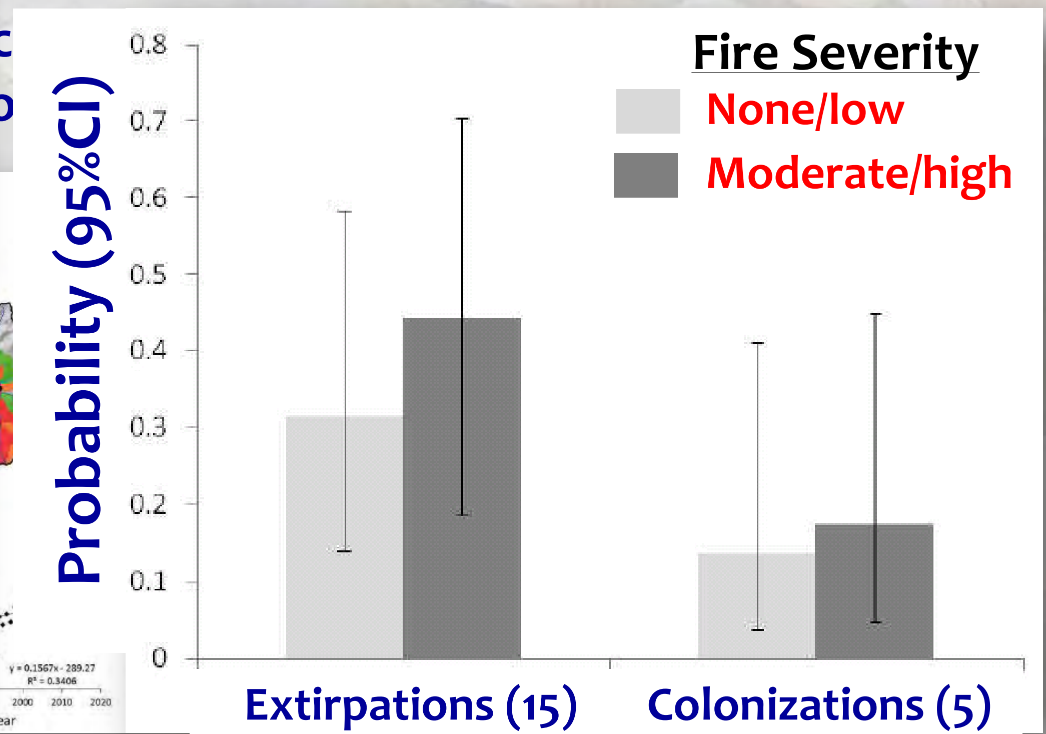
March of the fishes…



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

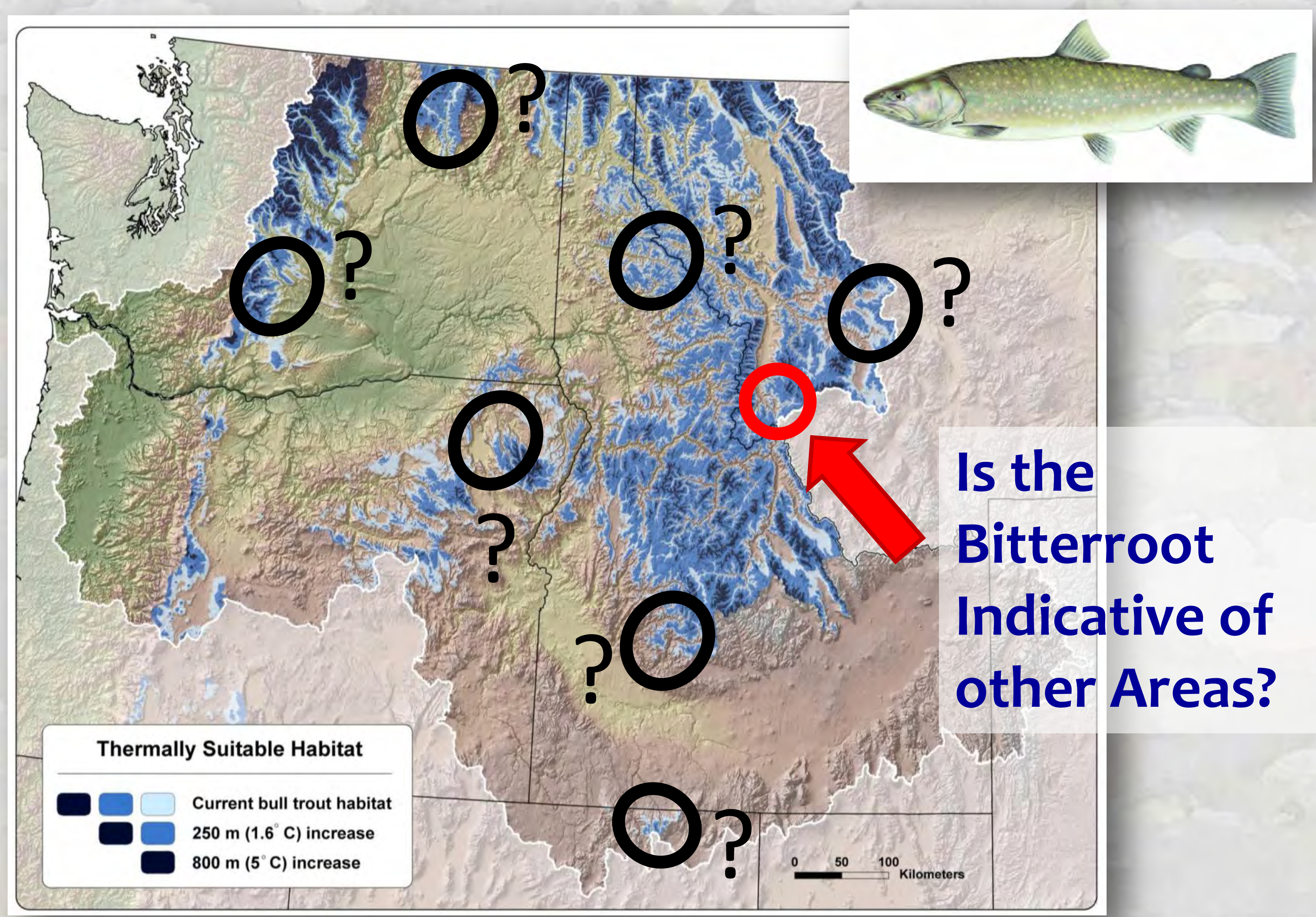
Distribution Shifts in Montana Bull Trout Populations





Eby et a ... ce of climate-induced range contractions for bull trout to ... tion sites in a Rocky Mountain watershed, U.S.A. *Global Ch...*

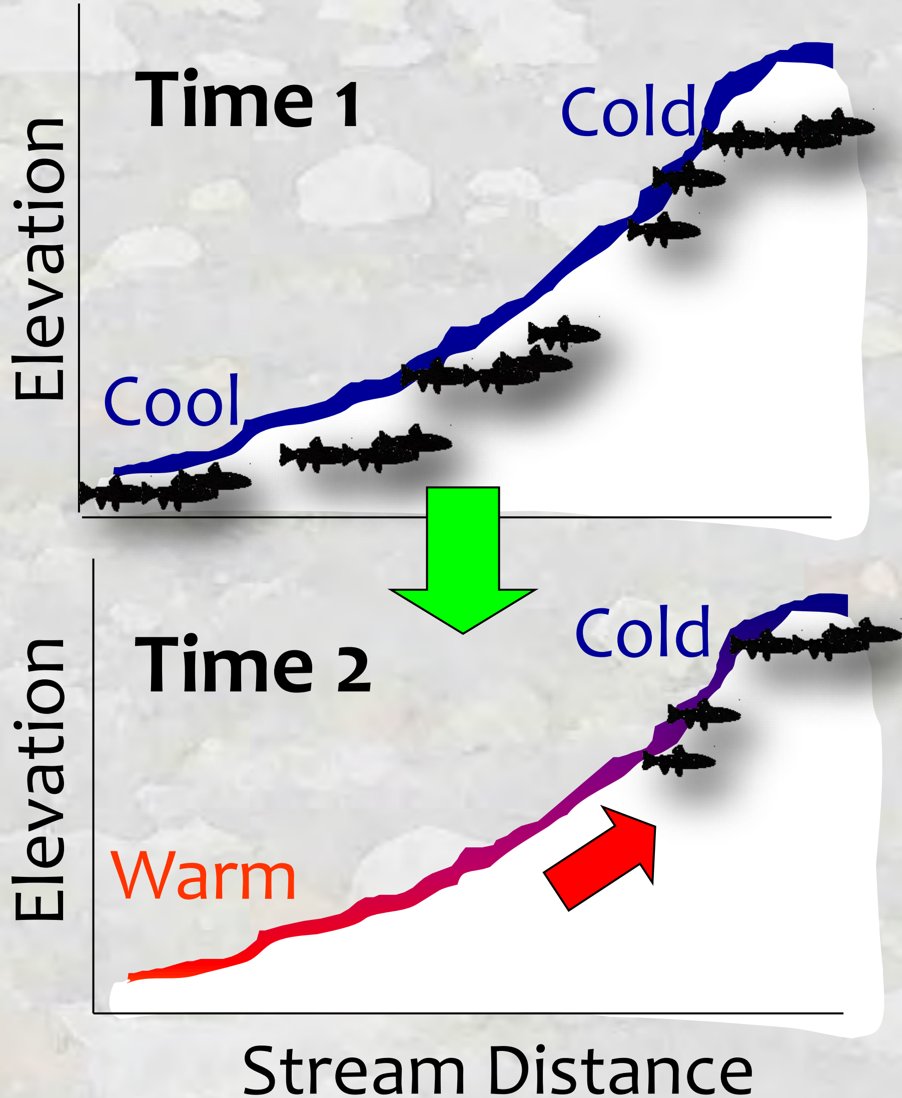
More Resurveys Needed to Understand Potential Breadth of Declines

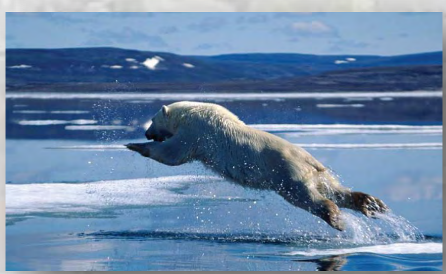


Is the Bitterroot Indicative of other Areas?

Additional Questions:

At what rate are bull trout distributions shifting?

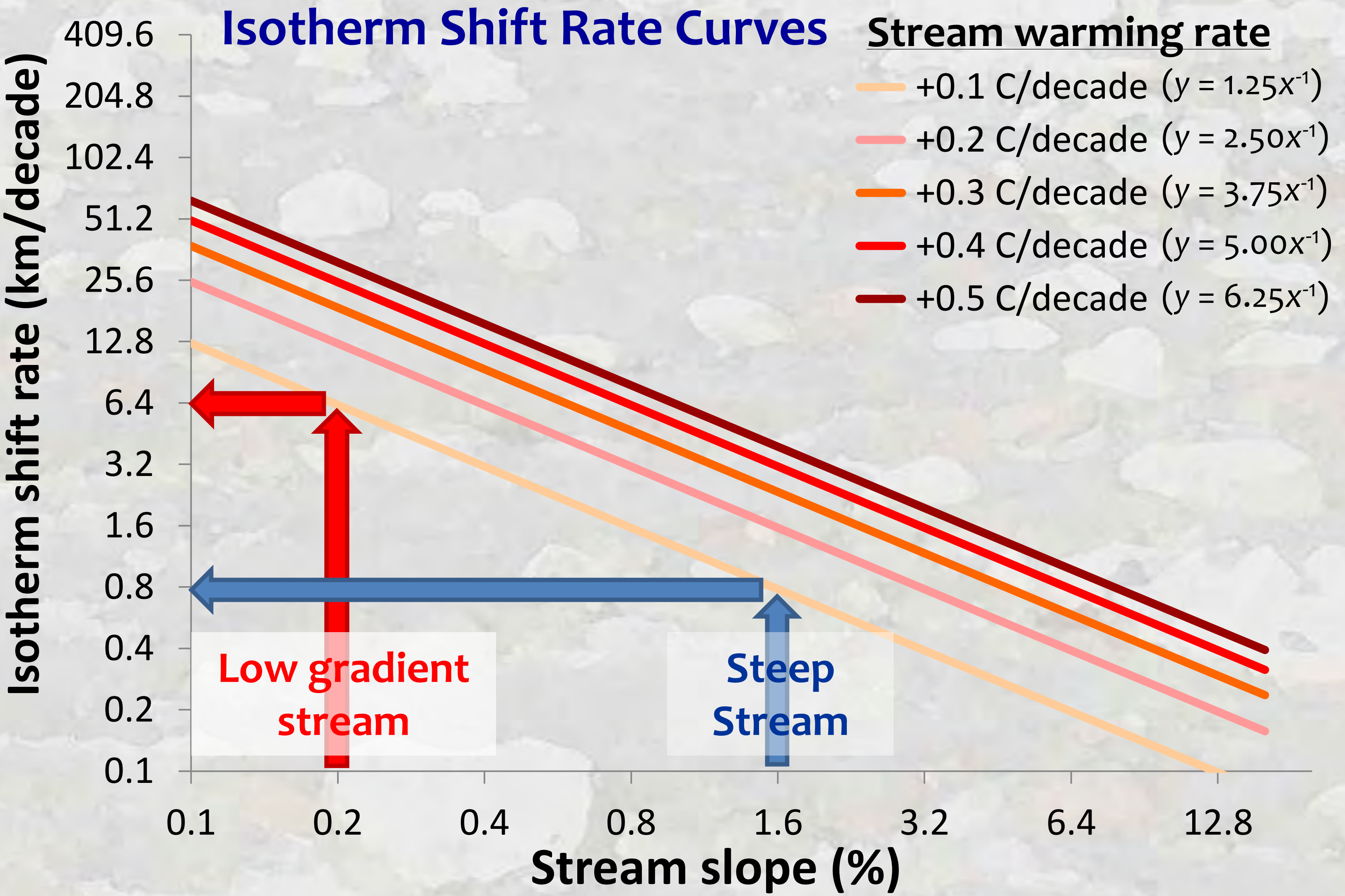




Average distribution shift across taxa =
6.1 km/decade poleward OR
6.1 m/decade higher

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

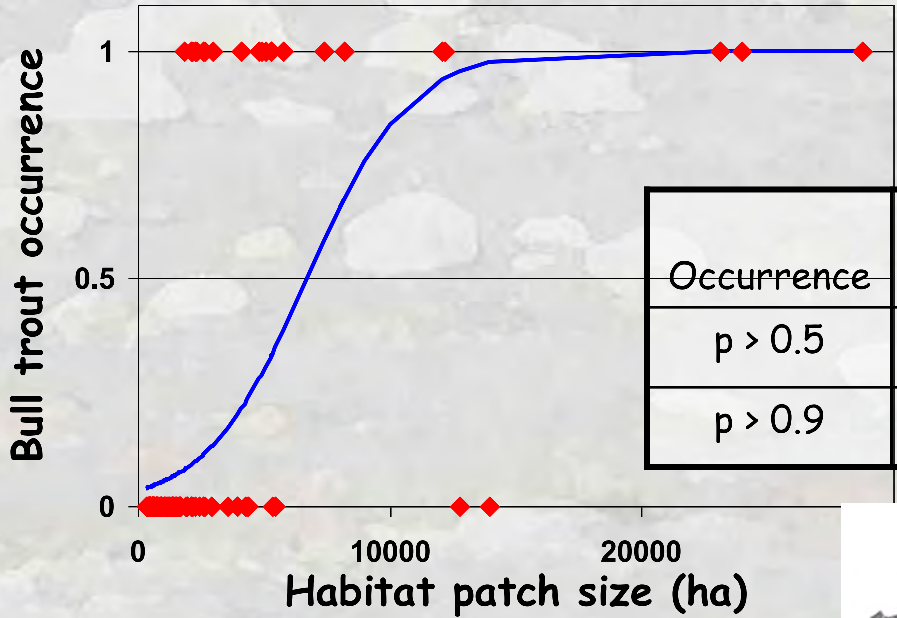
How do biological shifts relate to isotherm shifts?



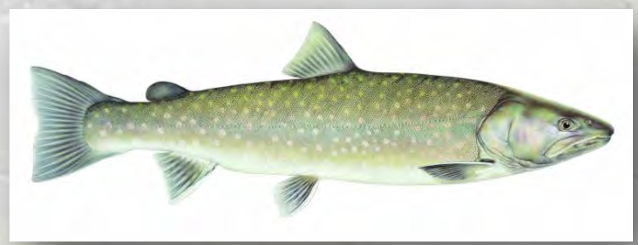
Isaak & Rieman. 2013. Stream isotherm shifts from climate change and implications for distributions of ectothermic organisms. *Global Change Biology* **19**:742-751.

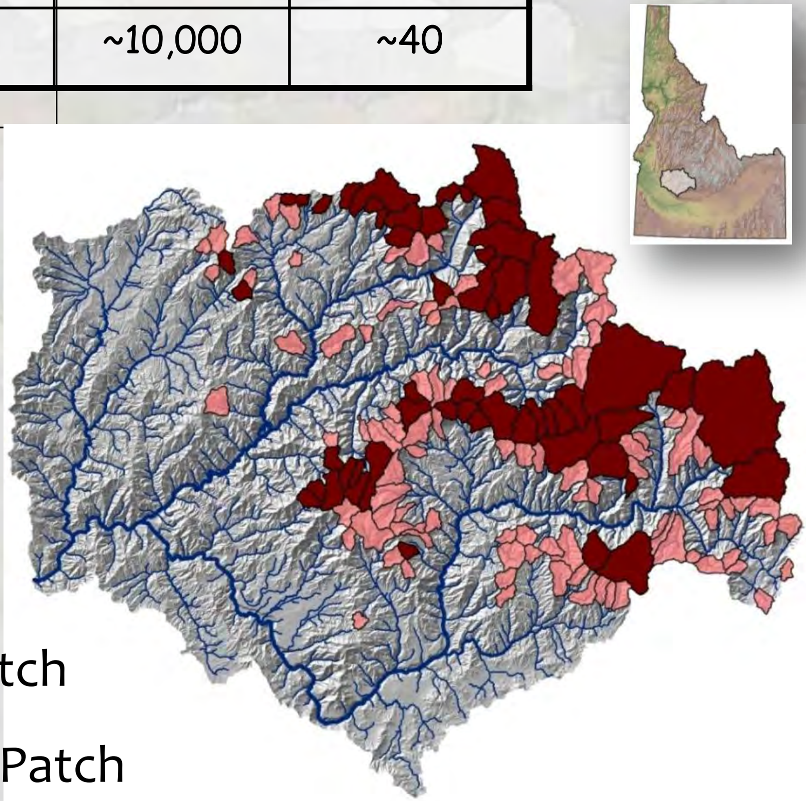
How Much Habitat is Needed to Persist?

Rieman & McIntyre 1995
Dunham and Rieman 1999
Dunham et al. 2002
Isaak et al. 2010



Occurrence	Watershed area (ha)	Stream length (km)
p > 0.5	~3,000	~13
p > 0.9	~10,000	~40



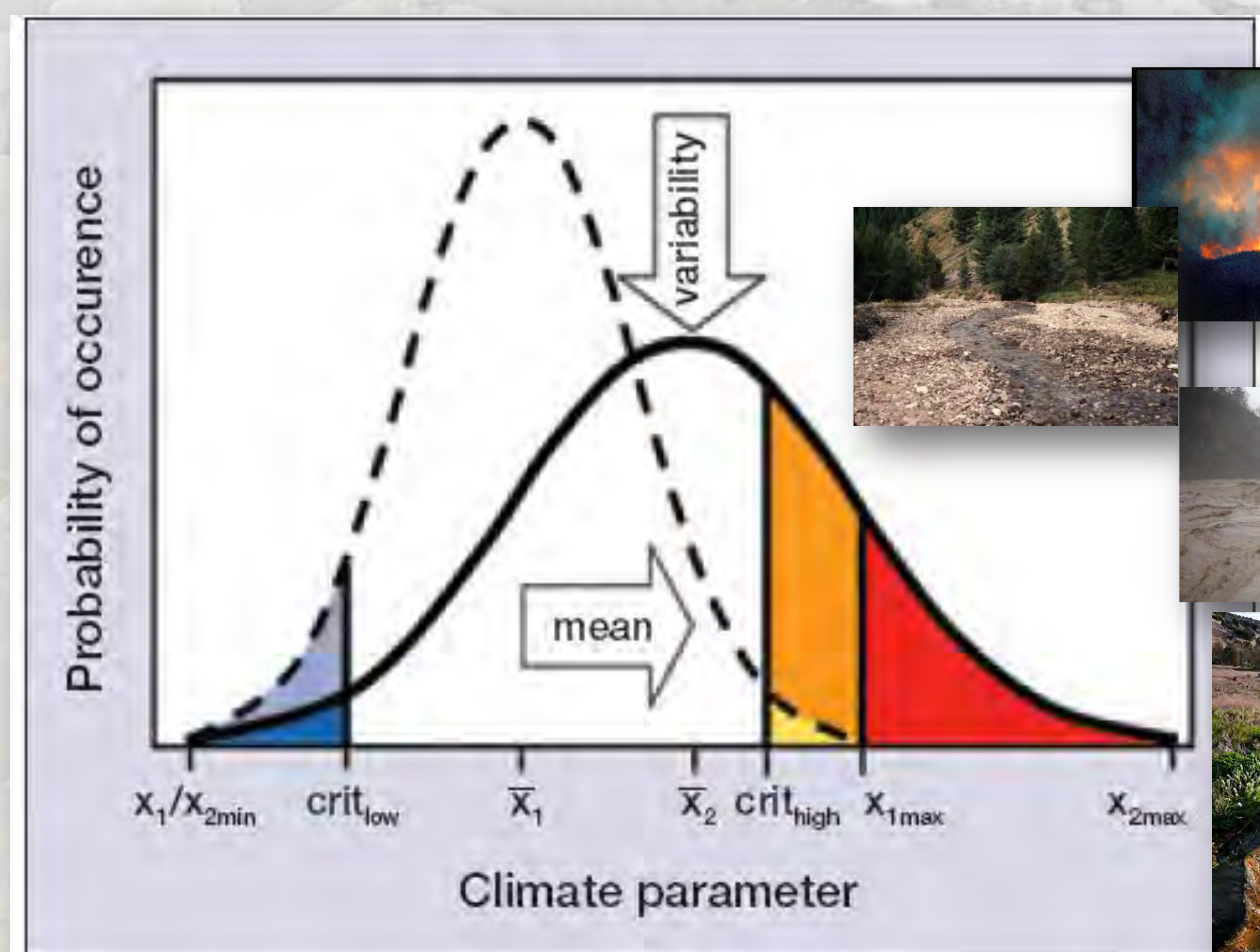


Occupied Patch

Unoccupied Patch

What's our Future Habitat Fudge Factor?

Larger Habitats Needed to Accommodate Larger Disturbances



Jentsch et al. 2007

How Will Climate Factors Interact?

- Warmer temperatures
- Reduced summer flows
- Fire & debris flows
- Winter flooding
- Non-native invasions

The Bull Trout Vise

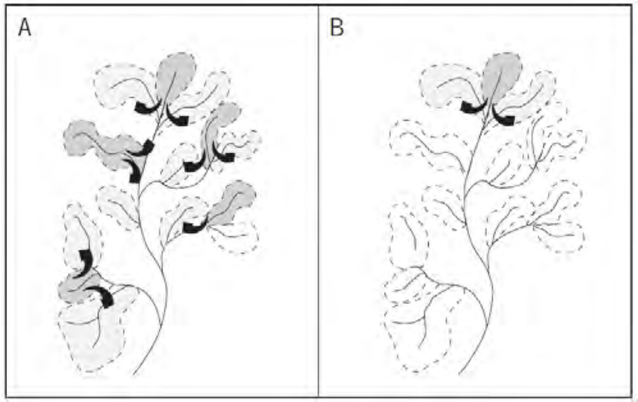
Where Are the "Bombproof" Habitats?

Should These Have Additional Protections to Provide a Foundation for a Bull Trout Reserve System?

Feature:
FISHERIES MANAGEMENT

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

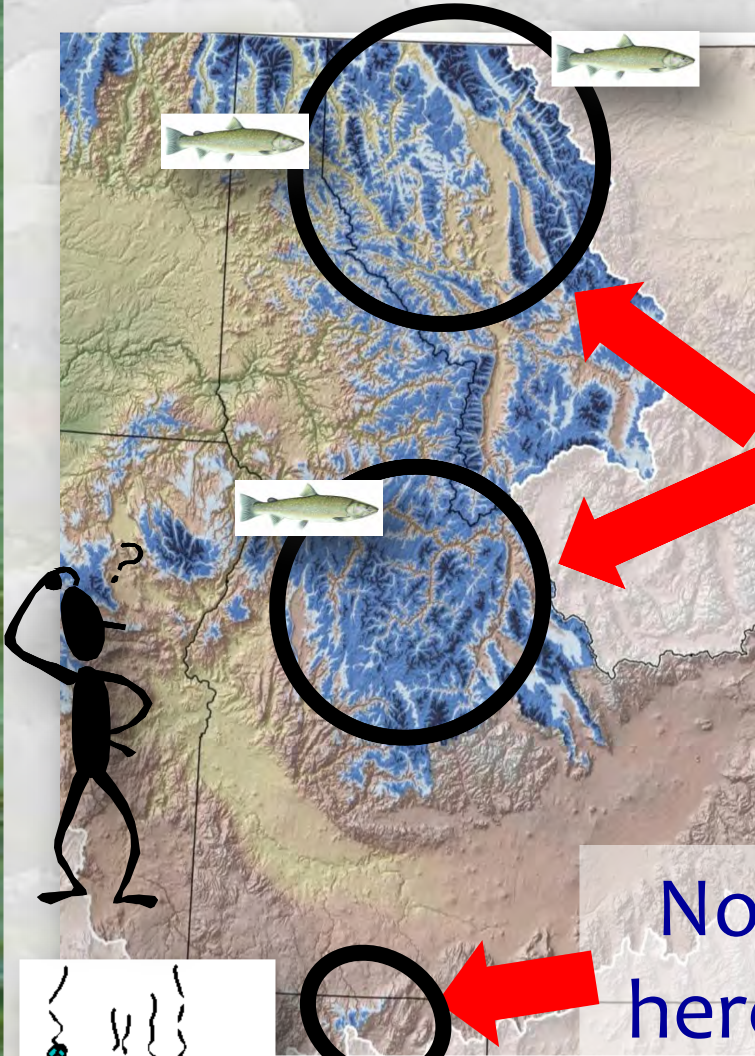
Jack E. Williams, Richard N. Williams, Russell F. Thurow, Leah Elwell, David P. Philipp, Fred A. Harris, Jeffrey L. Kershner, Patrick J. Martinez, Dirk Miller, Gordon H. Reeves, Christopher A. Frissell, and James R. Sedell



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.

We'll Soon Have The Necessary Information but…



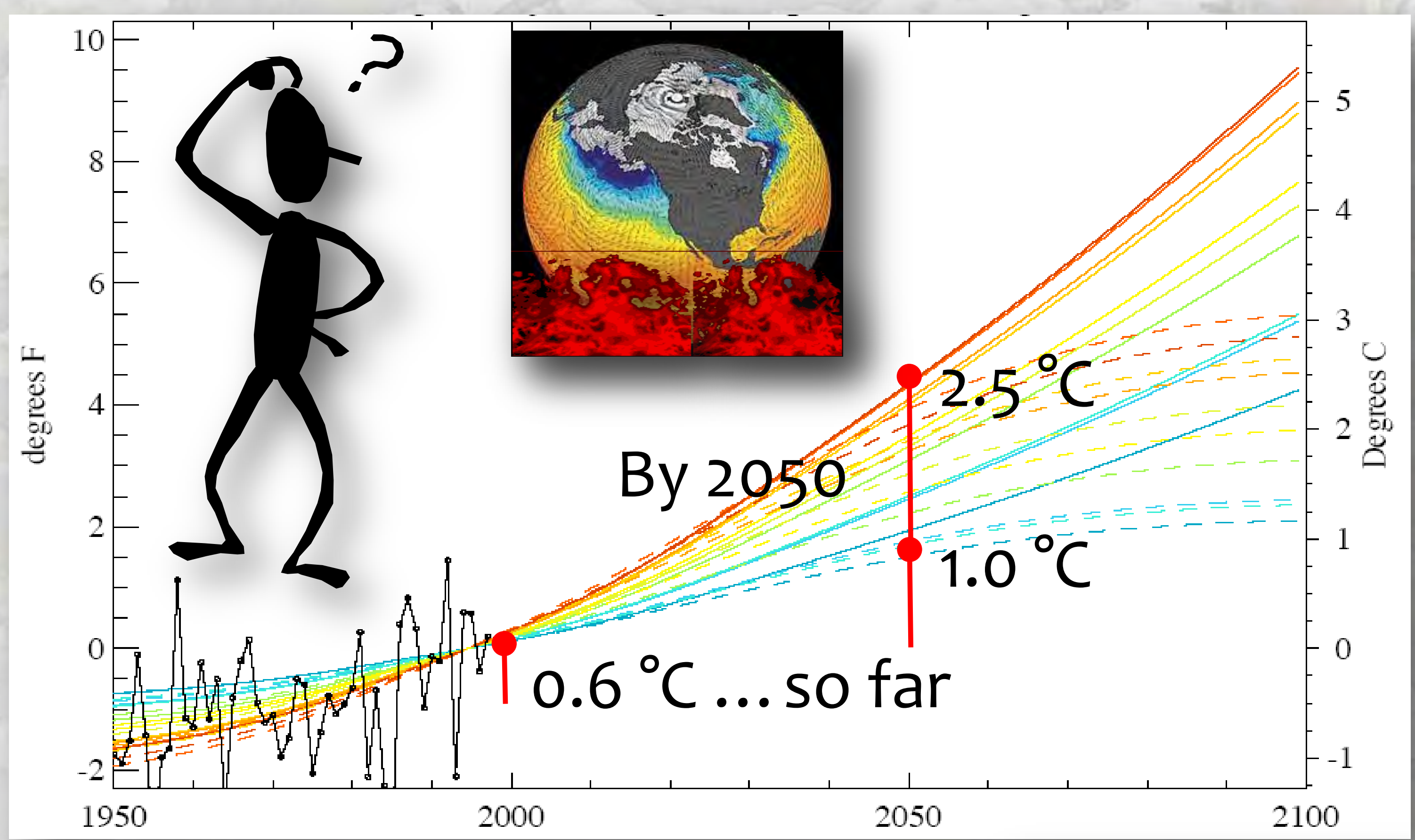
Invest Here

Not here?

Sorry Charlie

…no guarantees humans are rational creatures

& future uncertainties will be large…



We can't save everything, but the sooner (& smarter) we act, the bigger the long-term impact


Global Warming Is ...
NOT COOL!
The End