Use of NorWeST for Regionally Consistent Status & Trend Assessments of Stream Temperature

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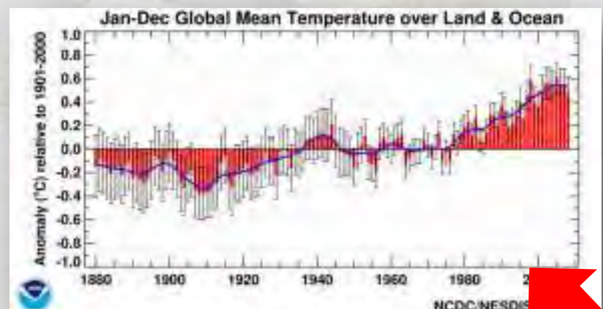
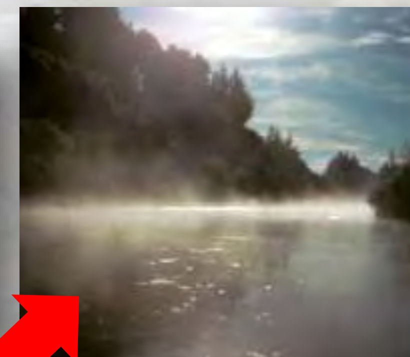
U.S. Forest Service
[1]Trout Unlimited
[2]CSIRO
[3]NOAA
[4]USGS

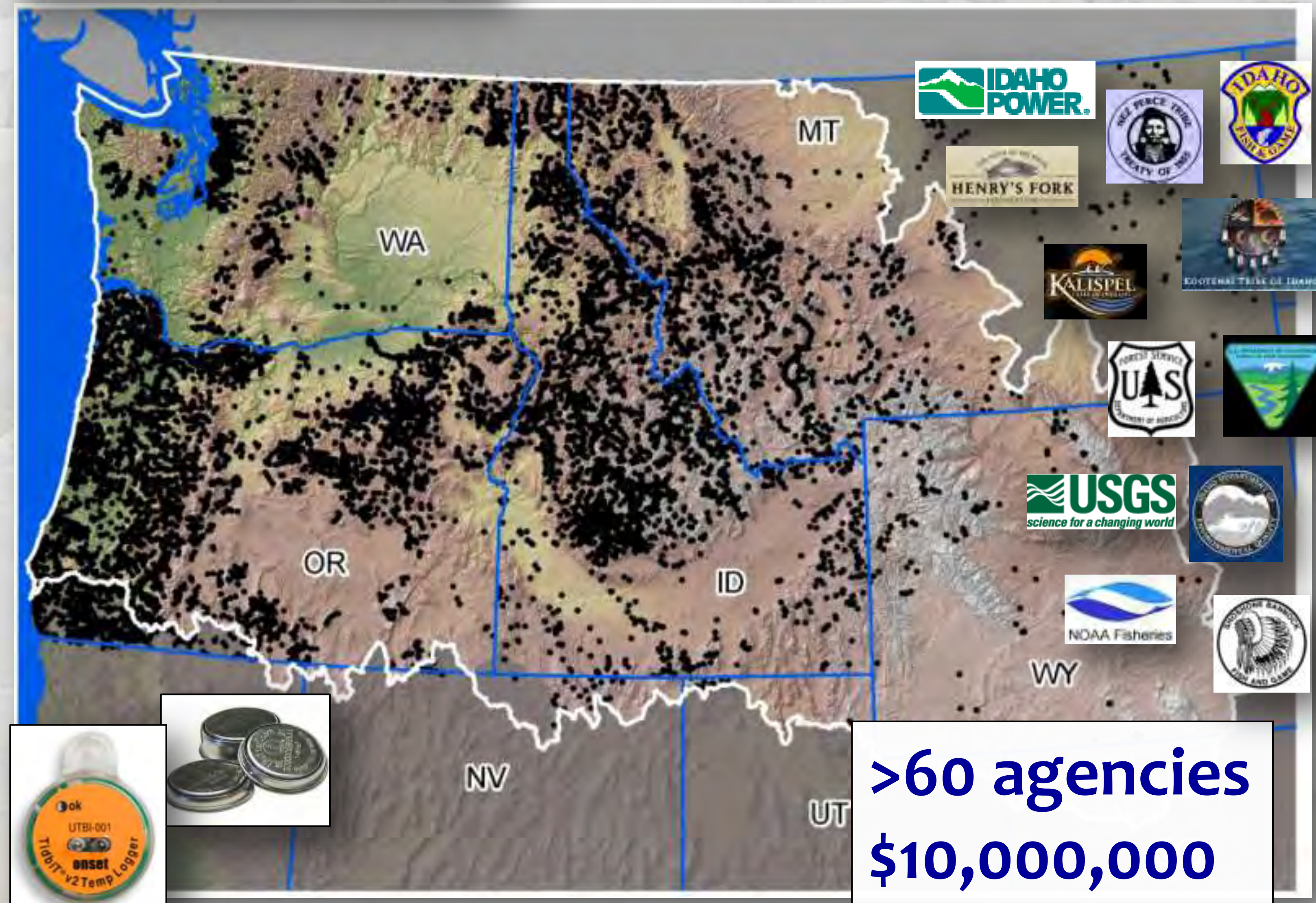




Great Northern
LANDSCAPE CONSERVATION COOPERATIVE

NorWeST Stream Temp

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



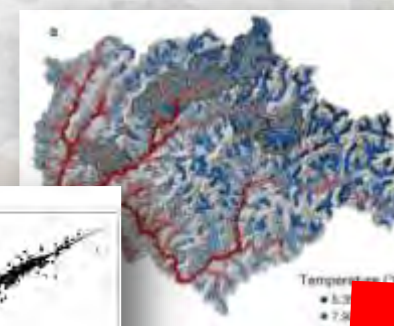
>60 agencies
$10,000,000

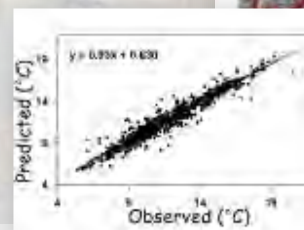
Regional Temperature Model

NorWeST
Stream Temp

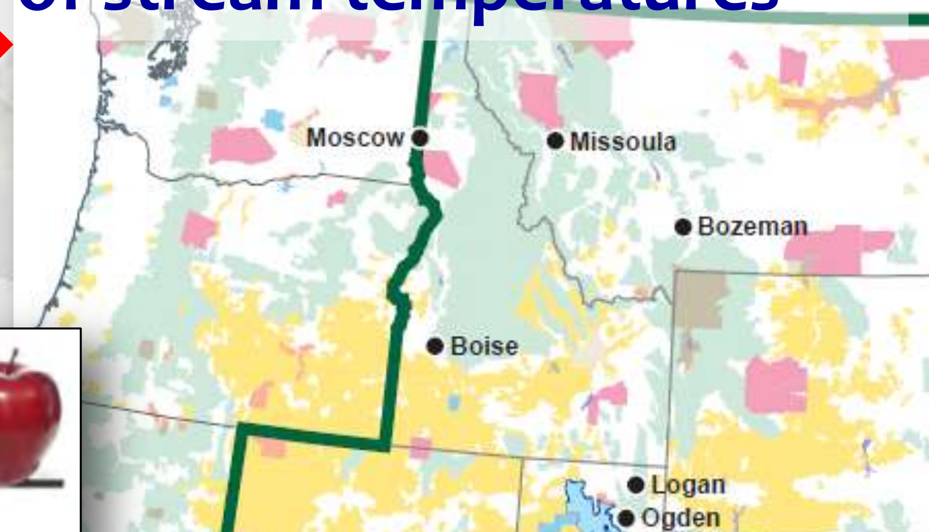
+

Accurate temperature models

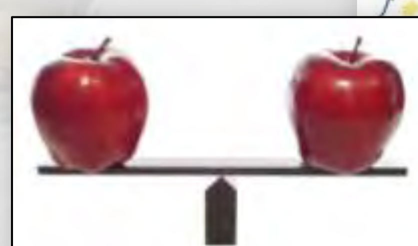




Cross-jurisdictional "maps" of stream temperatures

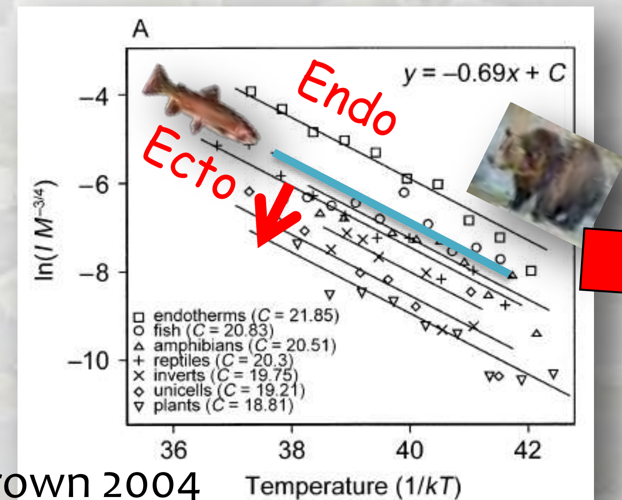


Consistent information across 350,000 stream kilometers



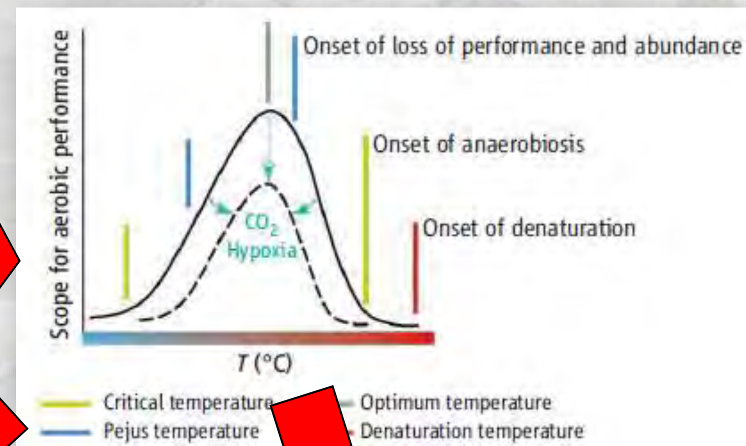
Temperature is Important for Aquatic Critters

Metabolism

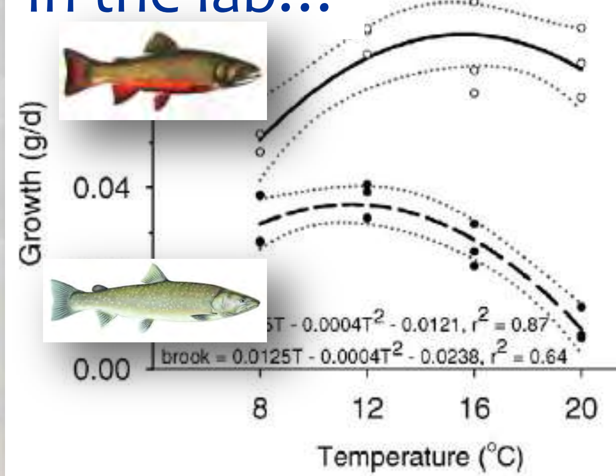


Brown 2004

Thermal Niche

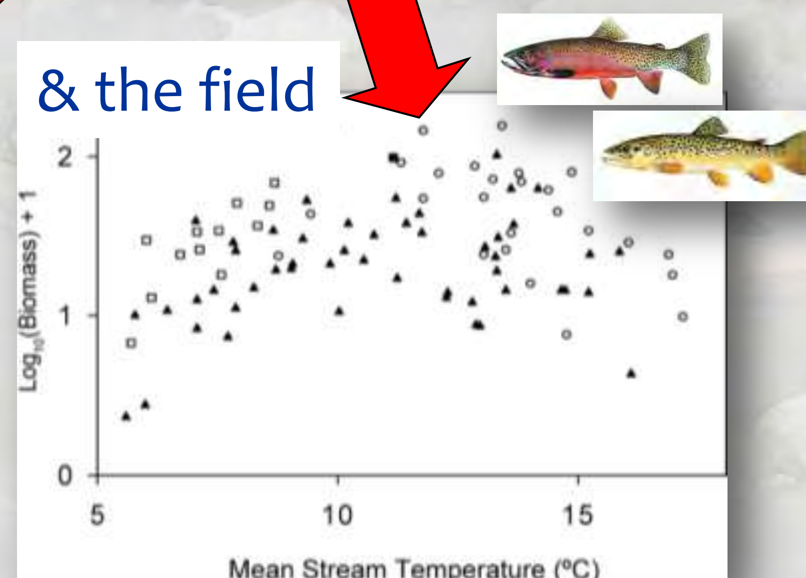


In the lab…



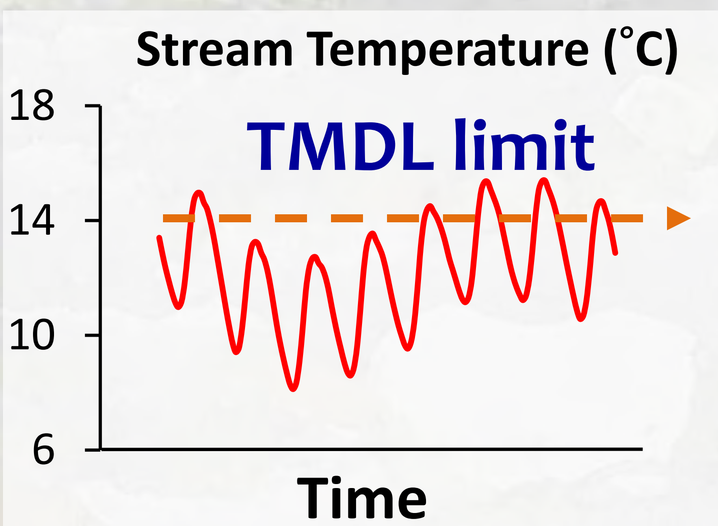
McMahon et al. 2007

& the field

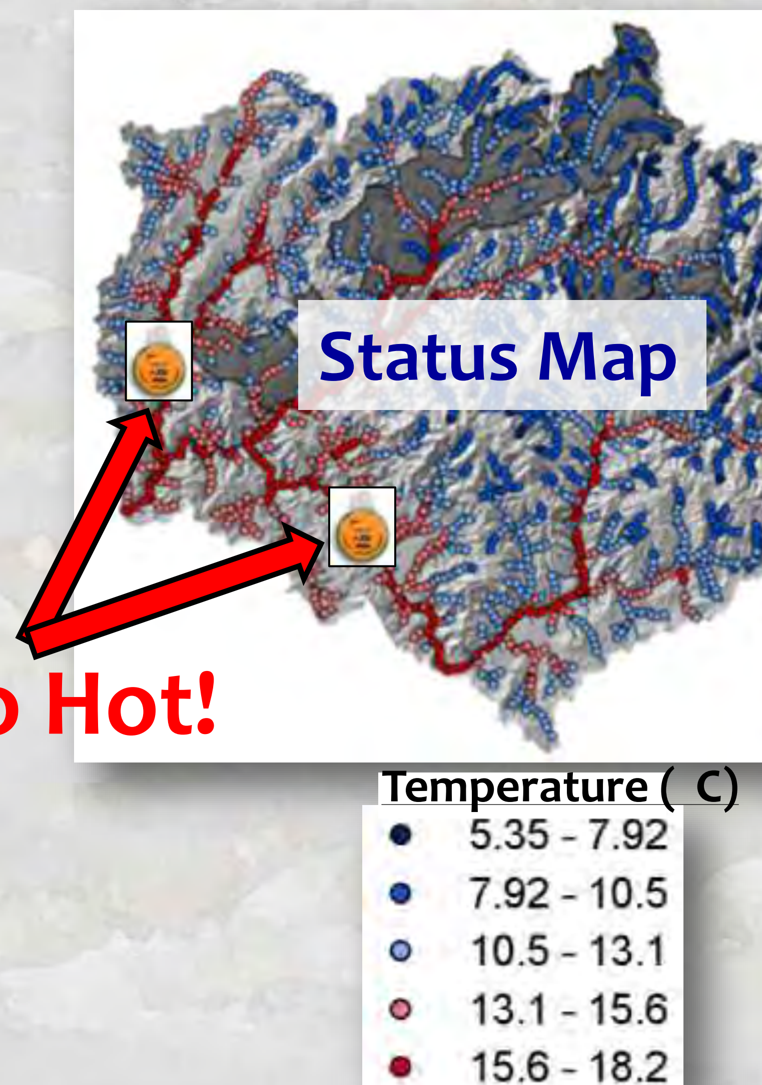


Isaak & Hubert 2004

Thermal Status is Important Within Regulatory Contexts



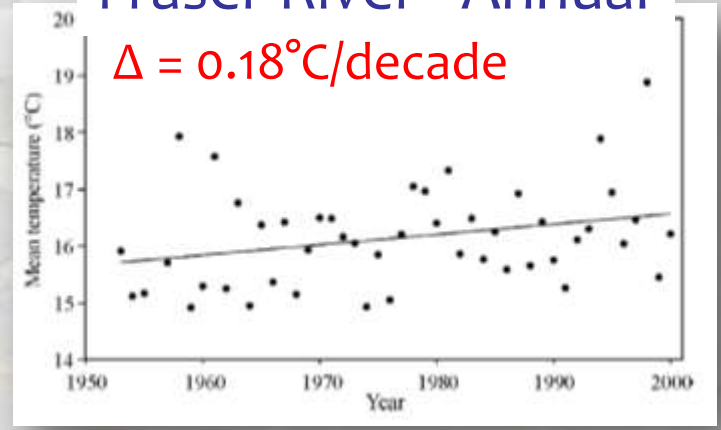
Too Hot!



Thermal Status is Changing

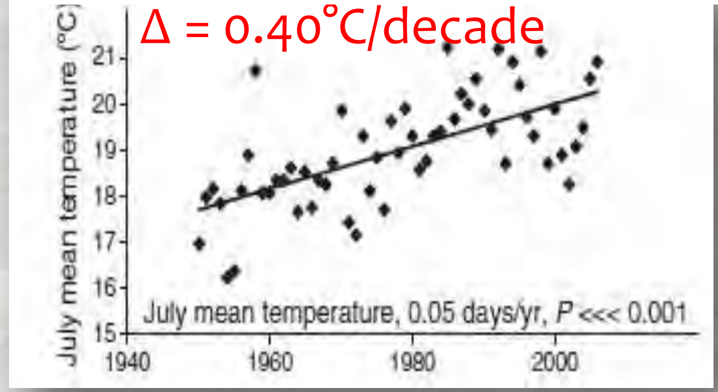
Regional Trends In Northwest Rivers

Fraser River - Annual



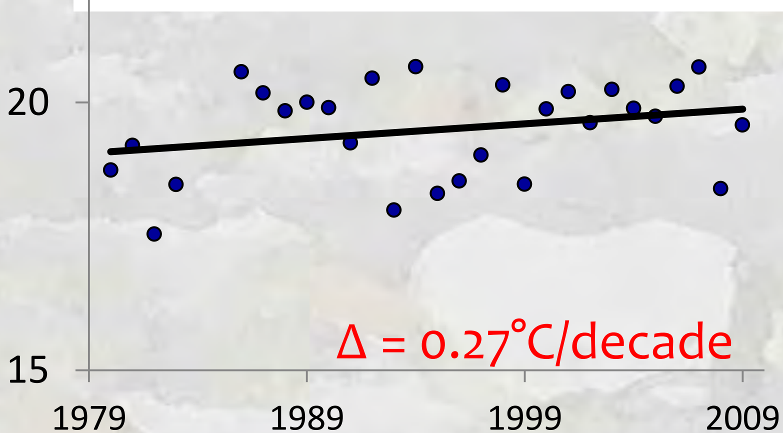
Morrison et al. 2002

Columbia River - Summer

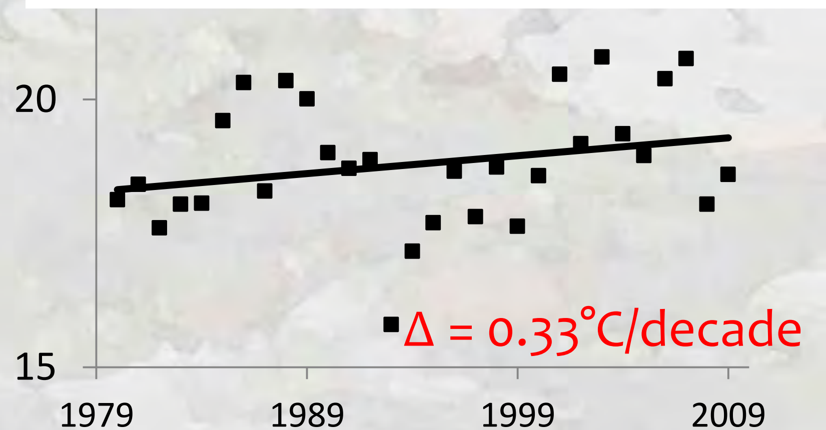


Crozier et al. 2008

Snake River, ID - Summer

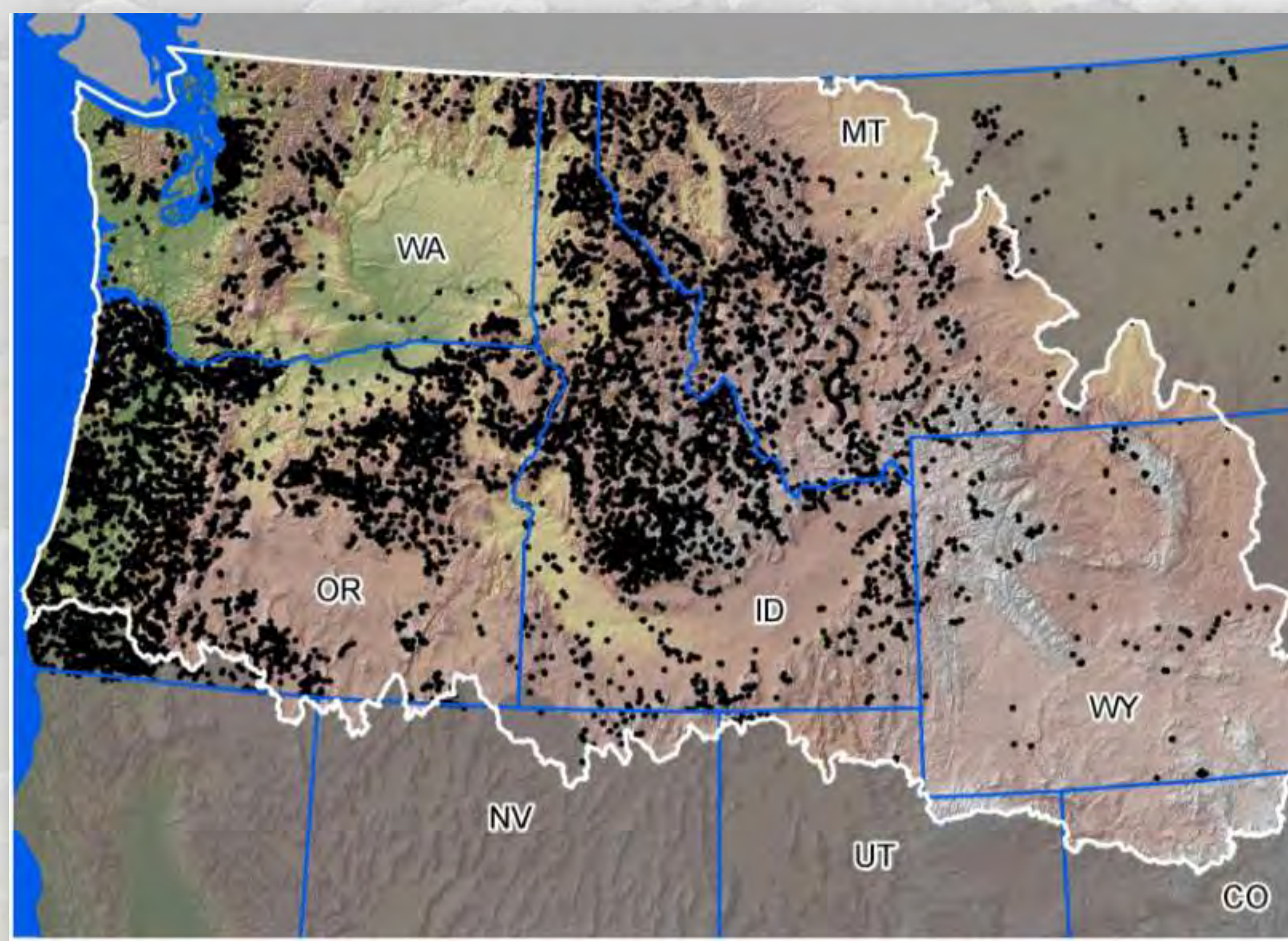


Missouri River, MT - Summer



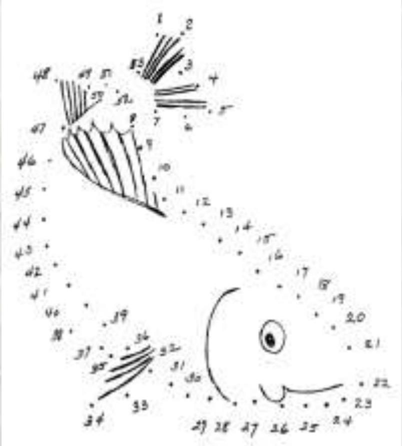
Isaak et al. 2012. *Climatic Change* **113**:499-524.

Information From Data?



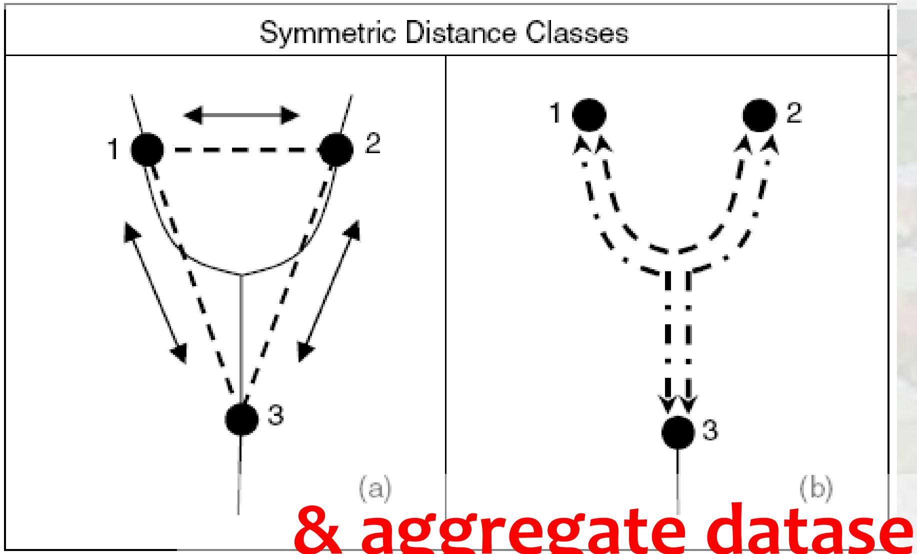
Information From Data?

Spatial Statistical Models for Stream Networks



…so we can connect the dots

…let us interpolate on networks



& aggregate datasets

Advantages:

- valid covariance structures account for network topology
- account for spatial autocorrelation among sites
- improved predictive power & less bias

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

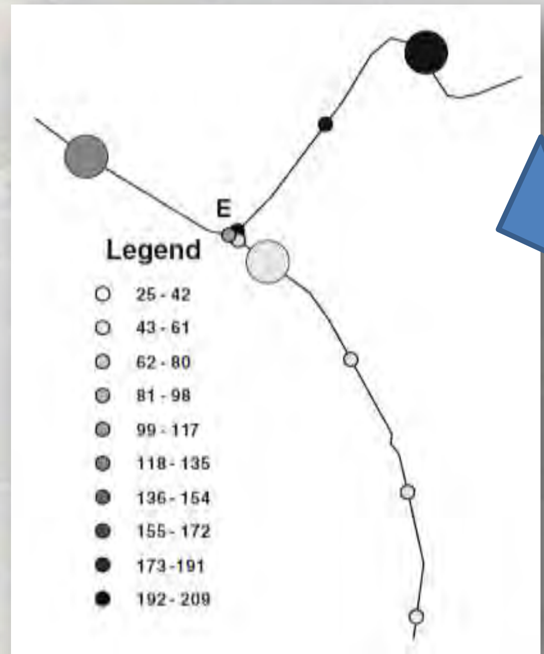
“Smart” Maps Developed from Lots of Data to Show Resource Status

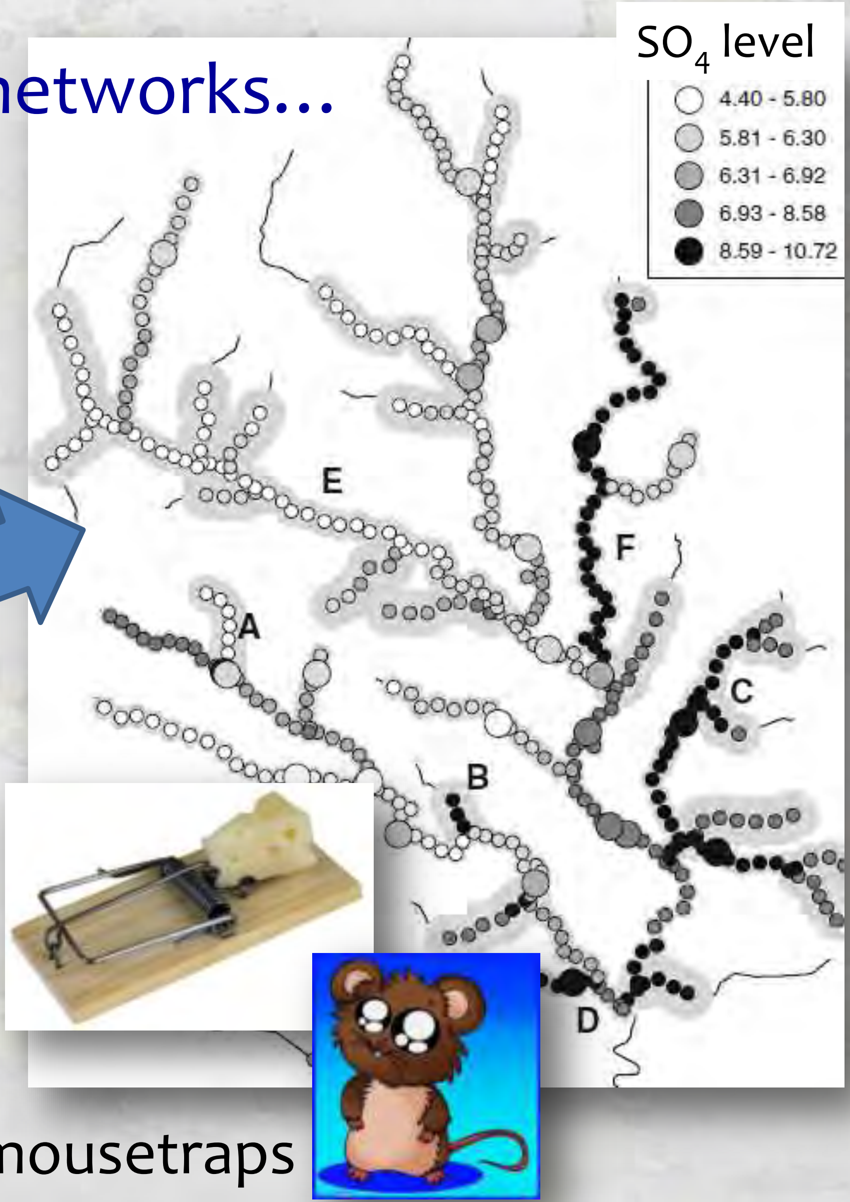
Maps are useful… even when imperfect

Spatial Statistical Network Models Work the Way that Streams Do…

Gradual trends within networks…

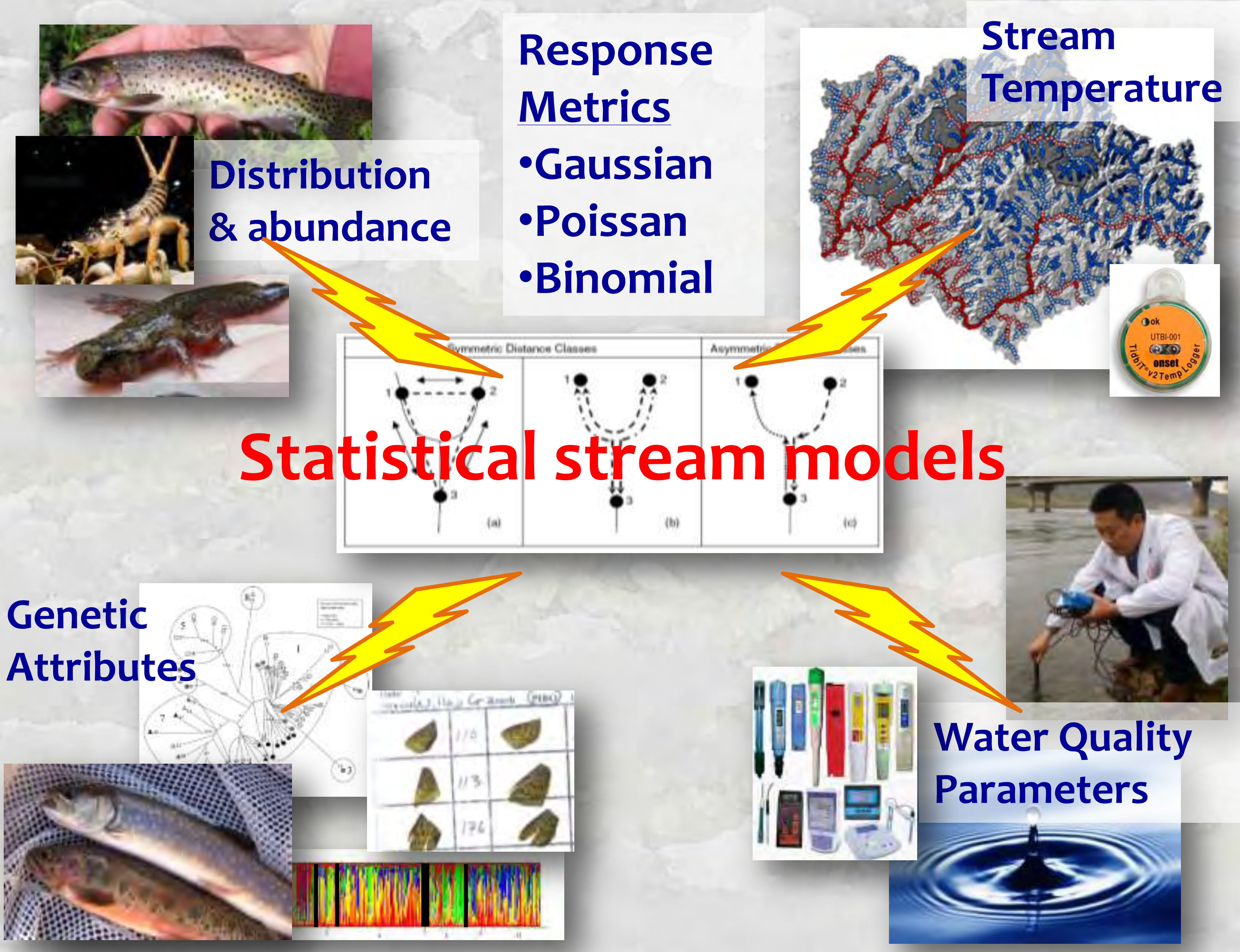
…but also changes at tributary confluences





…& are significantly better mousetraps

Stream Models are Generalizable…

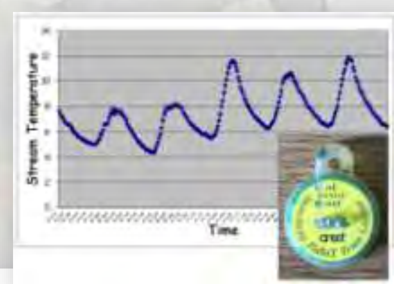


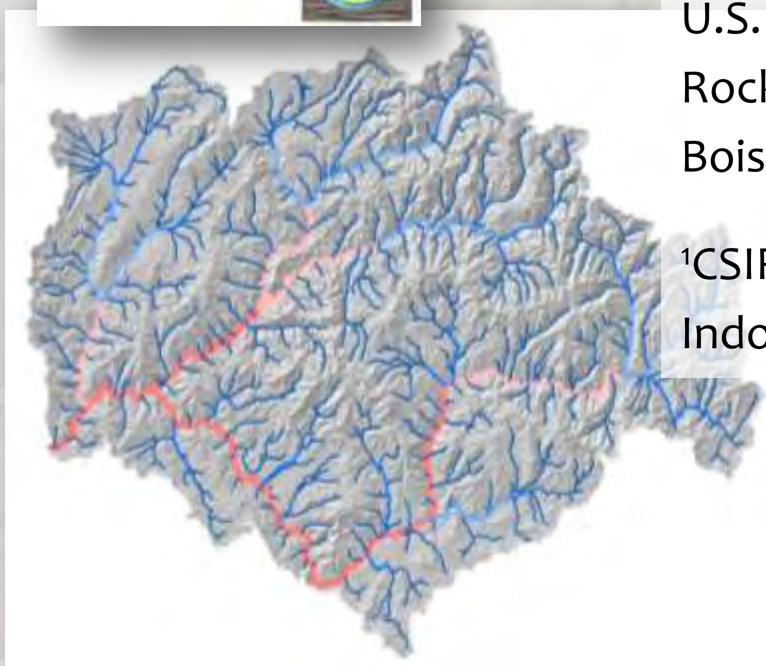
An Example: Boise River Network Stream Temperature Model & Climate Assessment

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

Boise Aquatic Sciences Lab
U.S. Forest Service
Rocky Mountain Research Station
Boise, ID 83702

[1]CSIRO Mathematical and Information Sciences
Indooroopilly, Queensland, Australia





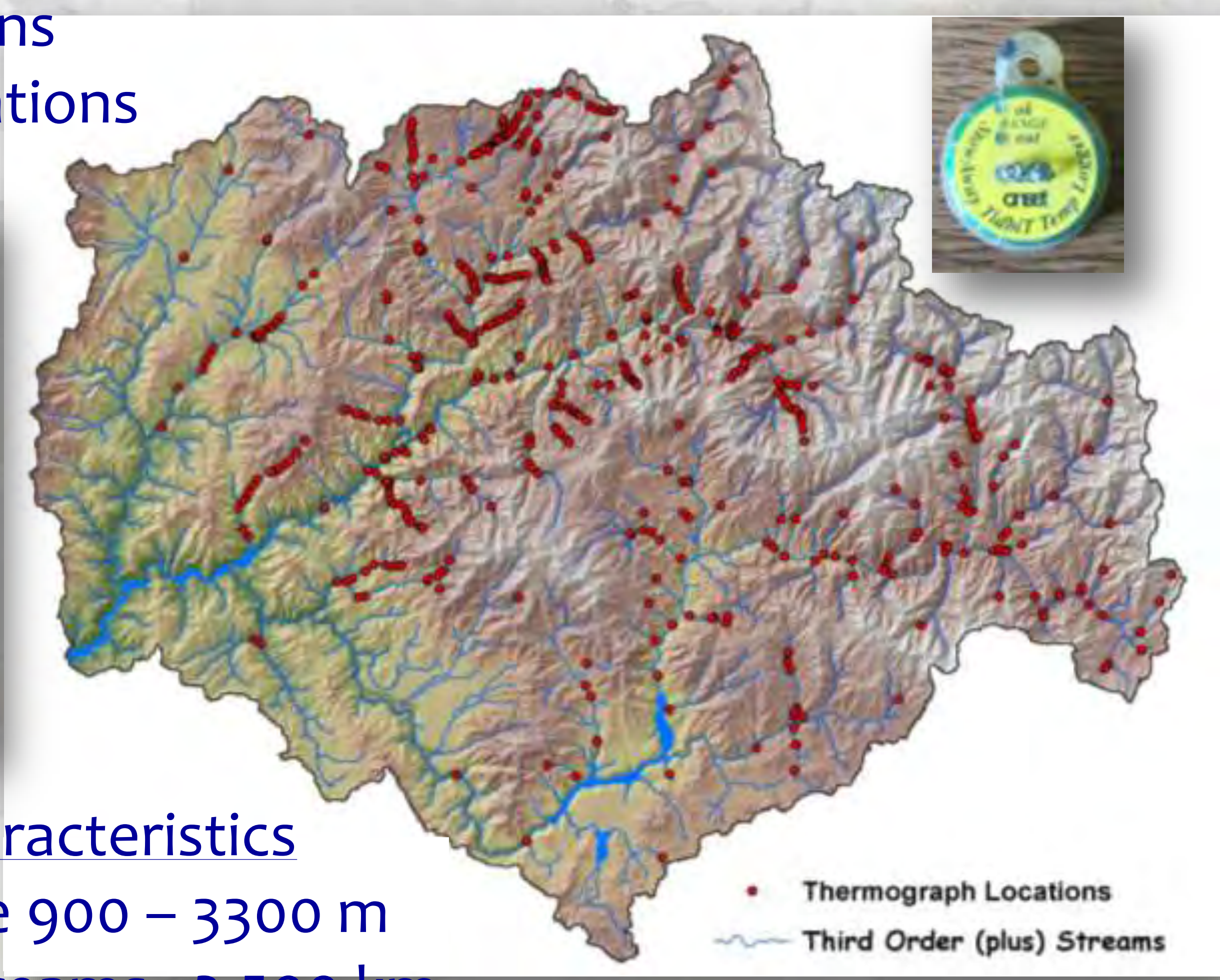
Boise River Temperature Database

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

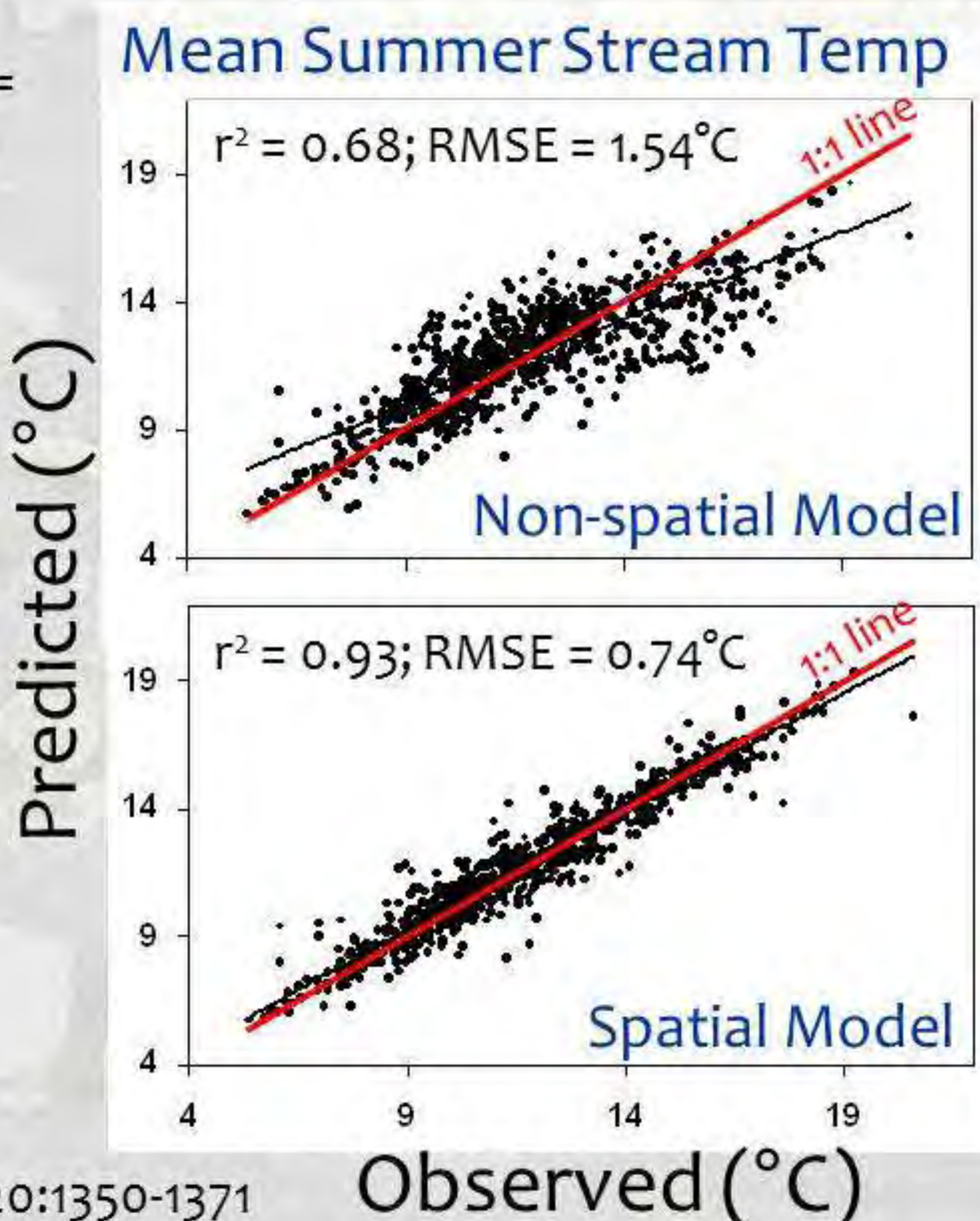
Watershed area = 6,900 km^2

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

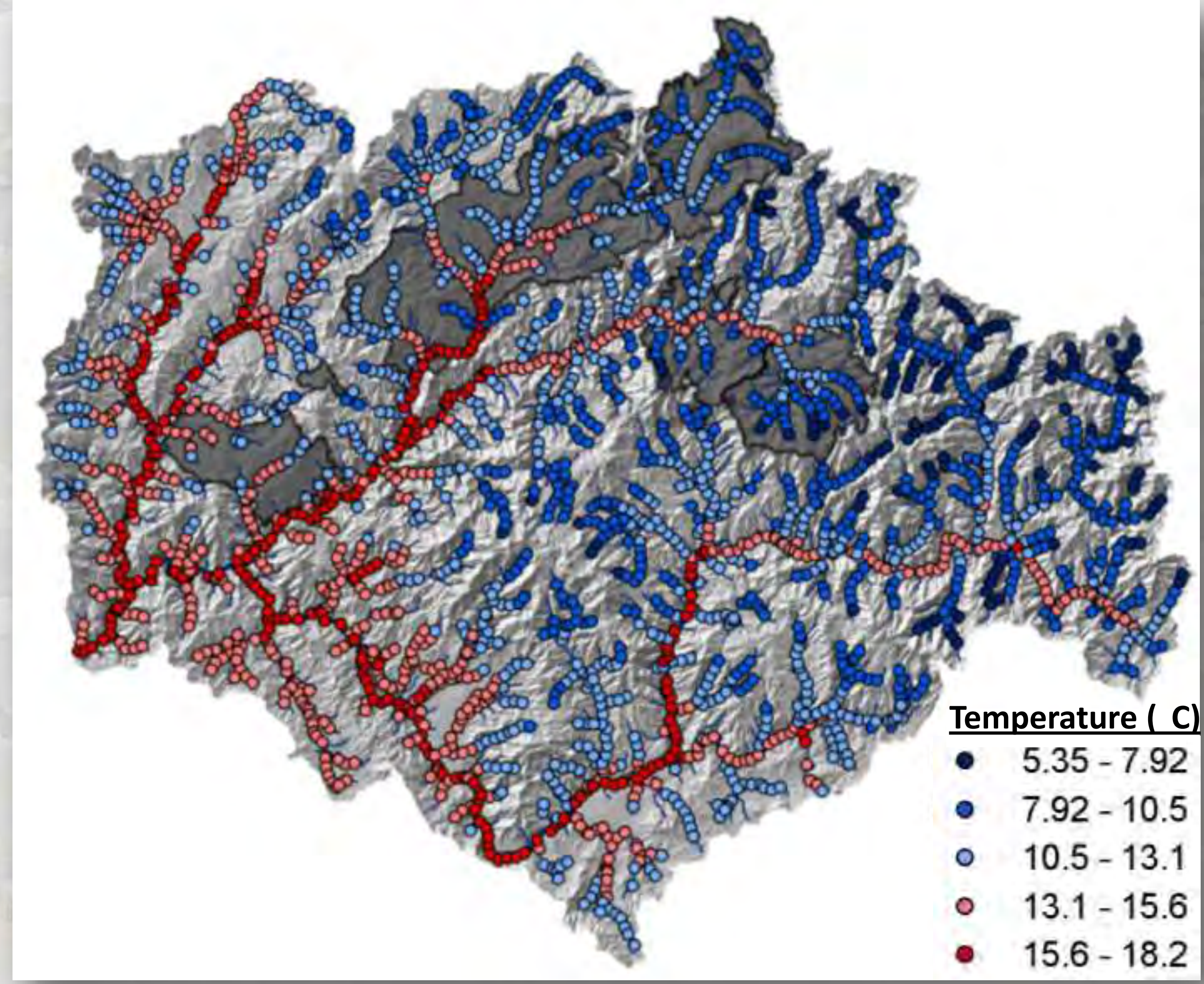
Spatial Stream Temp =
– 0.0045*Elevation (m)
+ 0.0085*Radiation
+ 0.48*AirTemp (°C)
– 0.11*Flow (m^3/s)



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

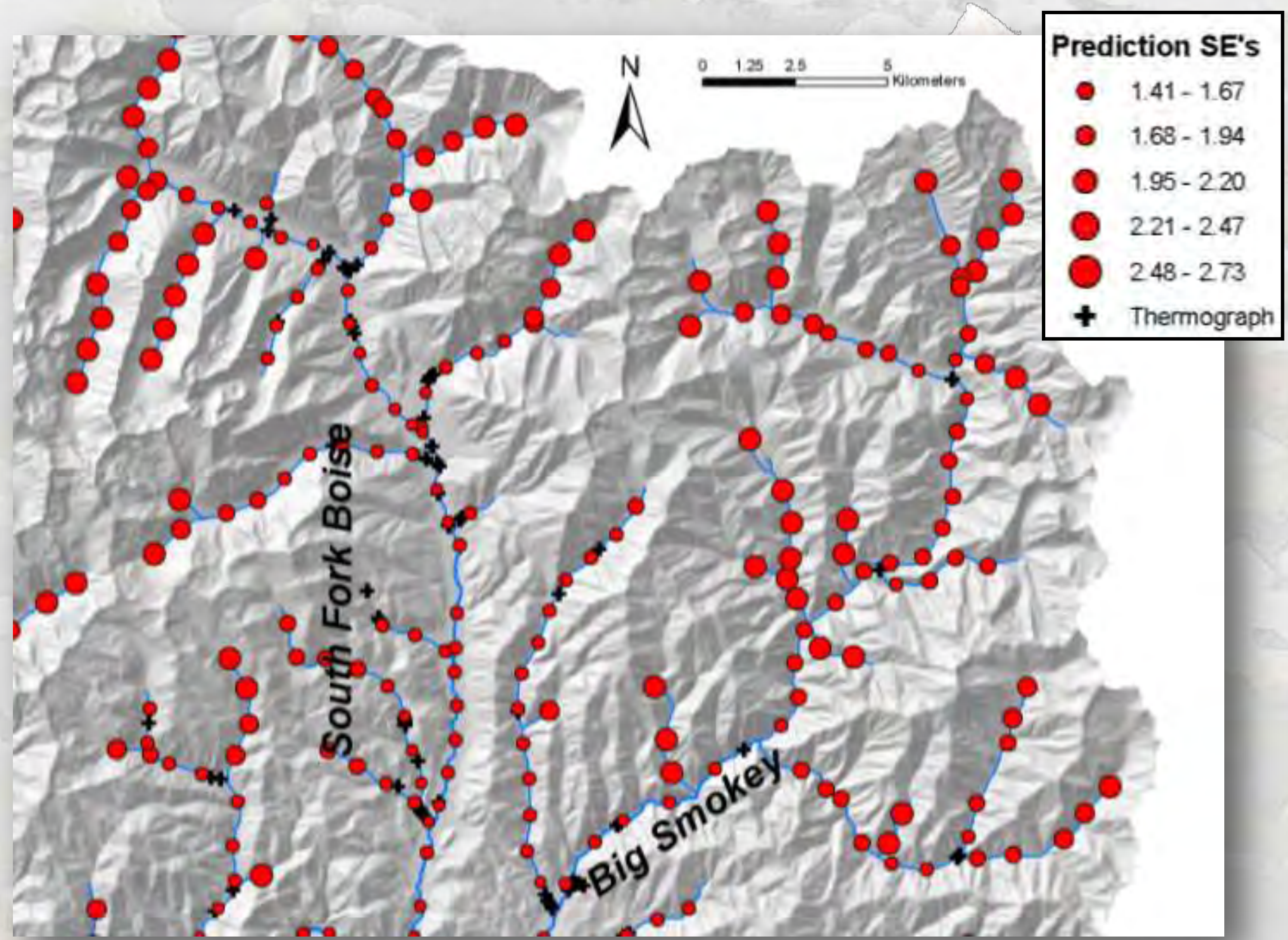
Application: River Temperature Status Map

2006 Mean Summer Temperatures

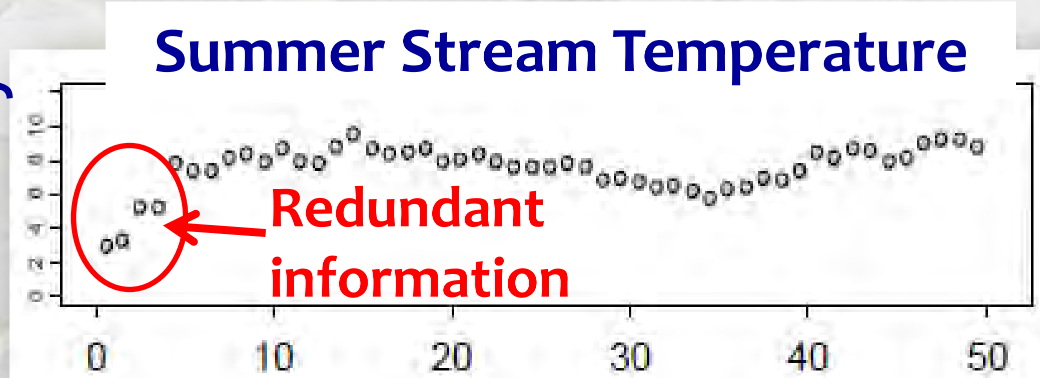


Mapping Uncertainty

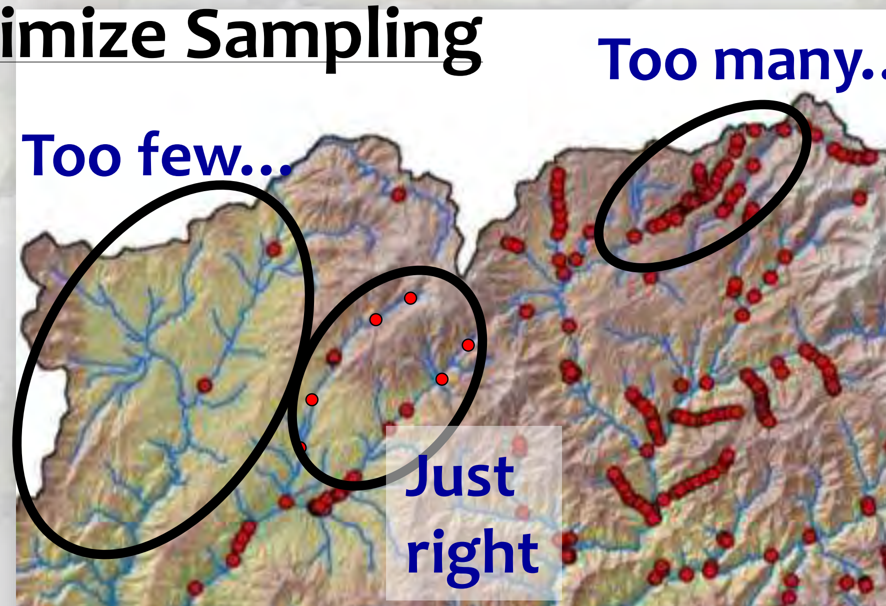
Temperature Prediction Precision



Application: Efficient Monitoring Designs

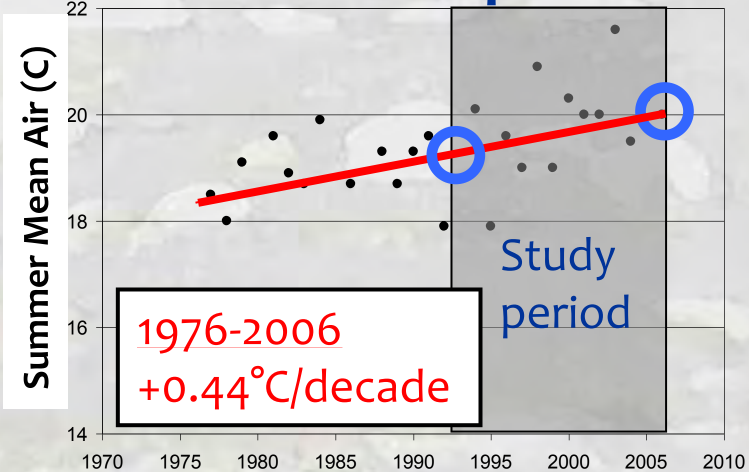


Optimize Sampling

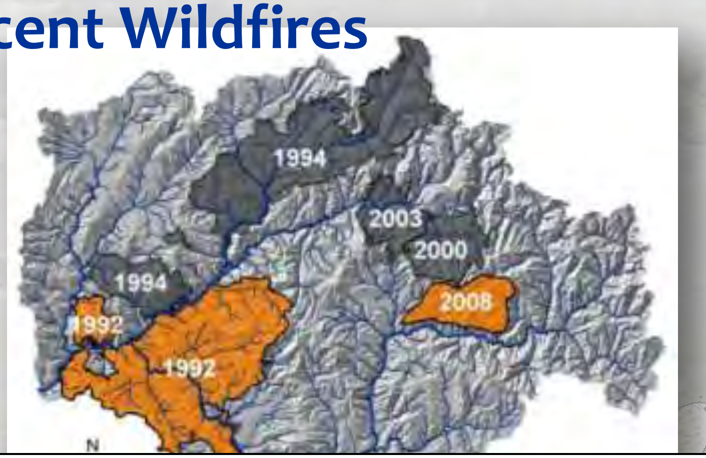


Trend Assessment = Change in Status Between Time 1 & Time 2

Summer Air Temperature

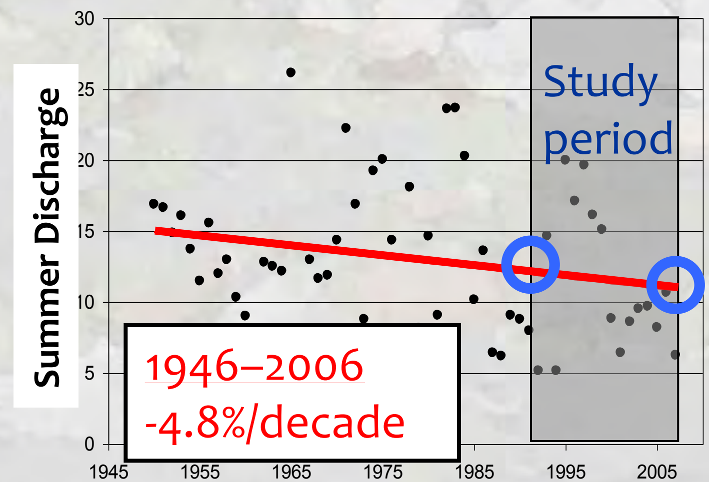


Recent Wildfires



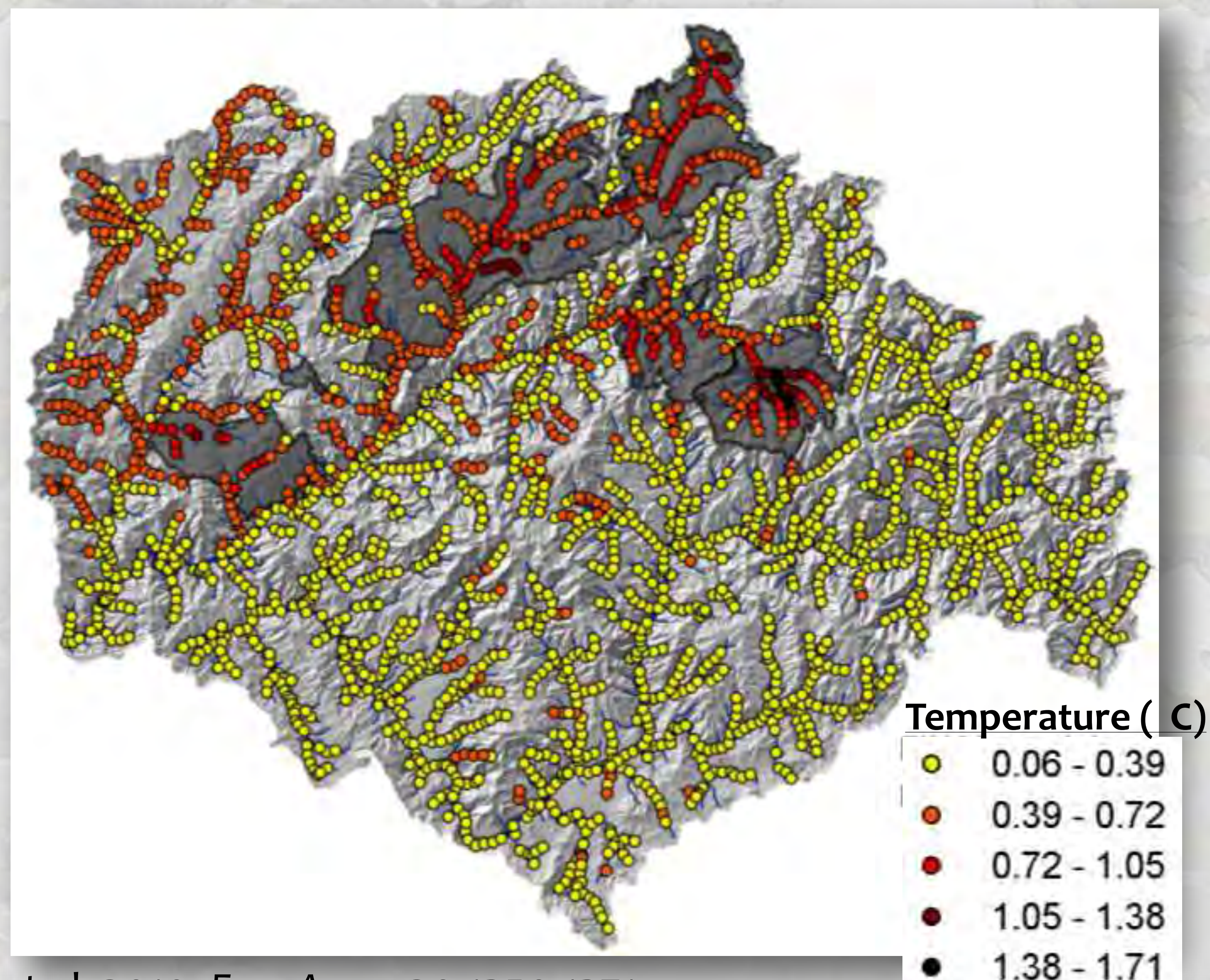
14% burned during 93–06 study period
30% burned from 92-08

Summer Stream Flow



Climate Change Map – Thermal Gains 93-06

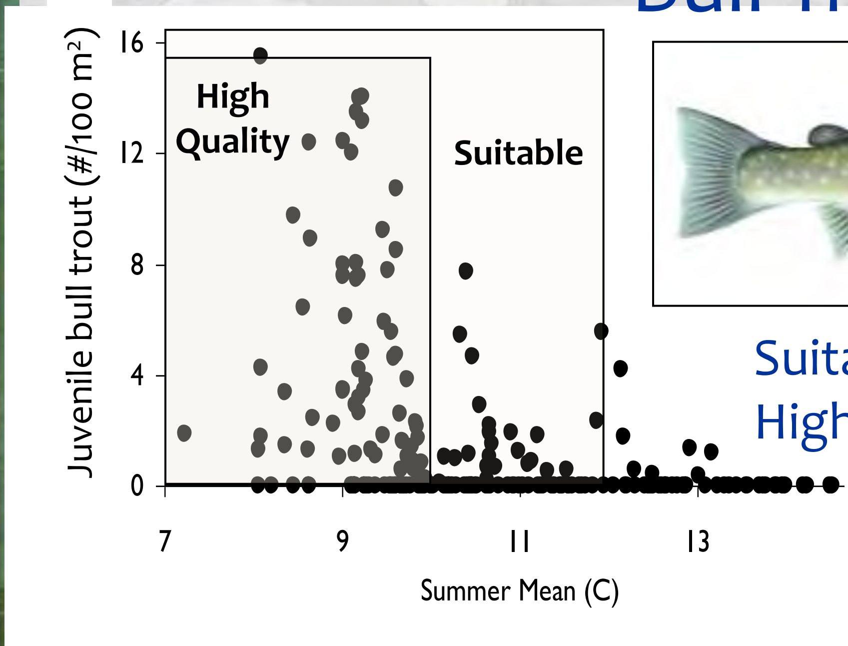
Change in Summer Temperature Status



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

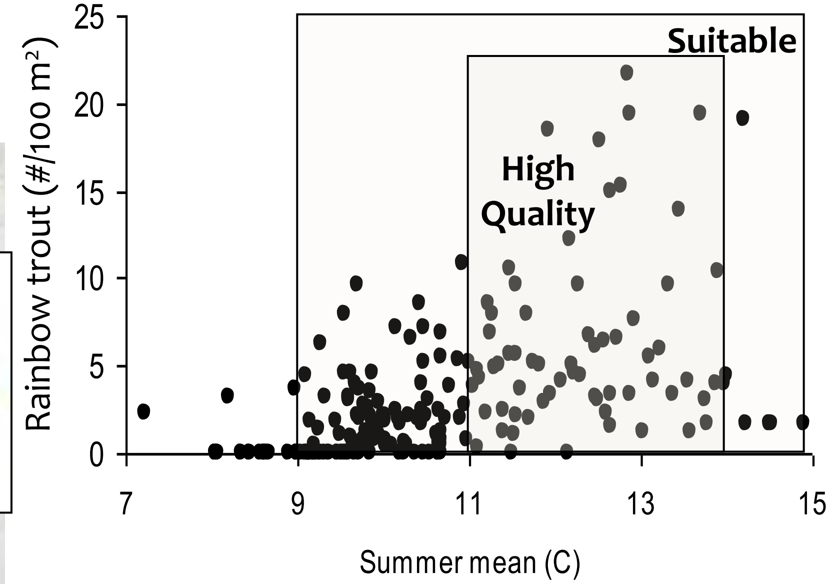
Application: Effects on Thermal Habitats

Bull Trout



Suitable habitat < 12.0°C
High-quality habitat < 10.0°C

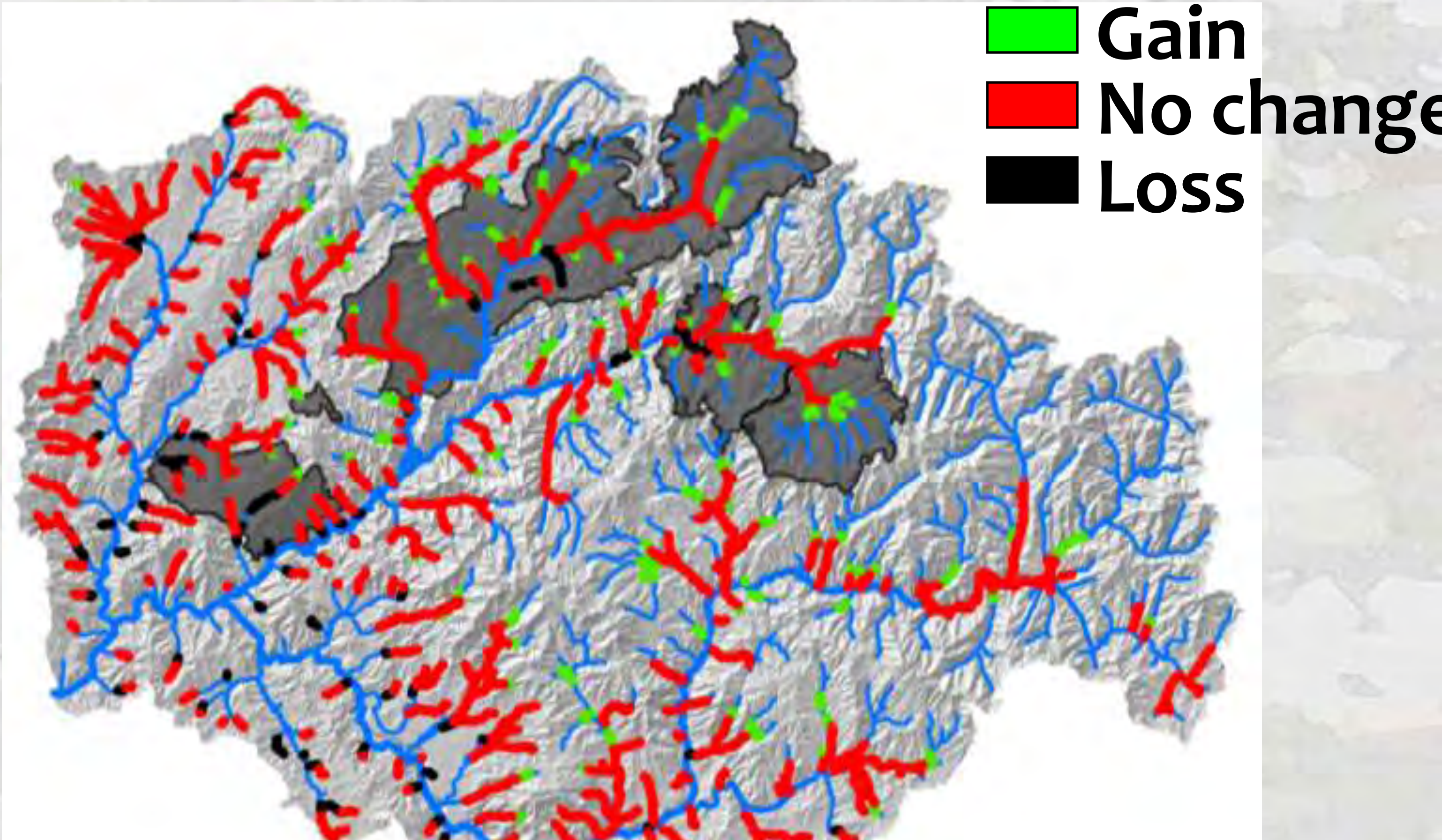
Rainbow Trout



Suitable habitat = > 9.0°C
High-quality habitat = 11.0-14.0°C

93'-06' Rainbow Trout Habitat Changes

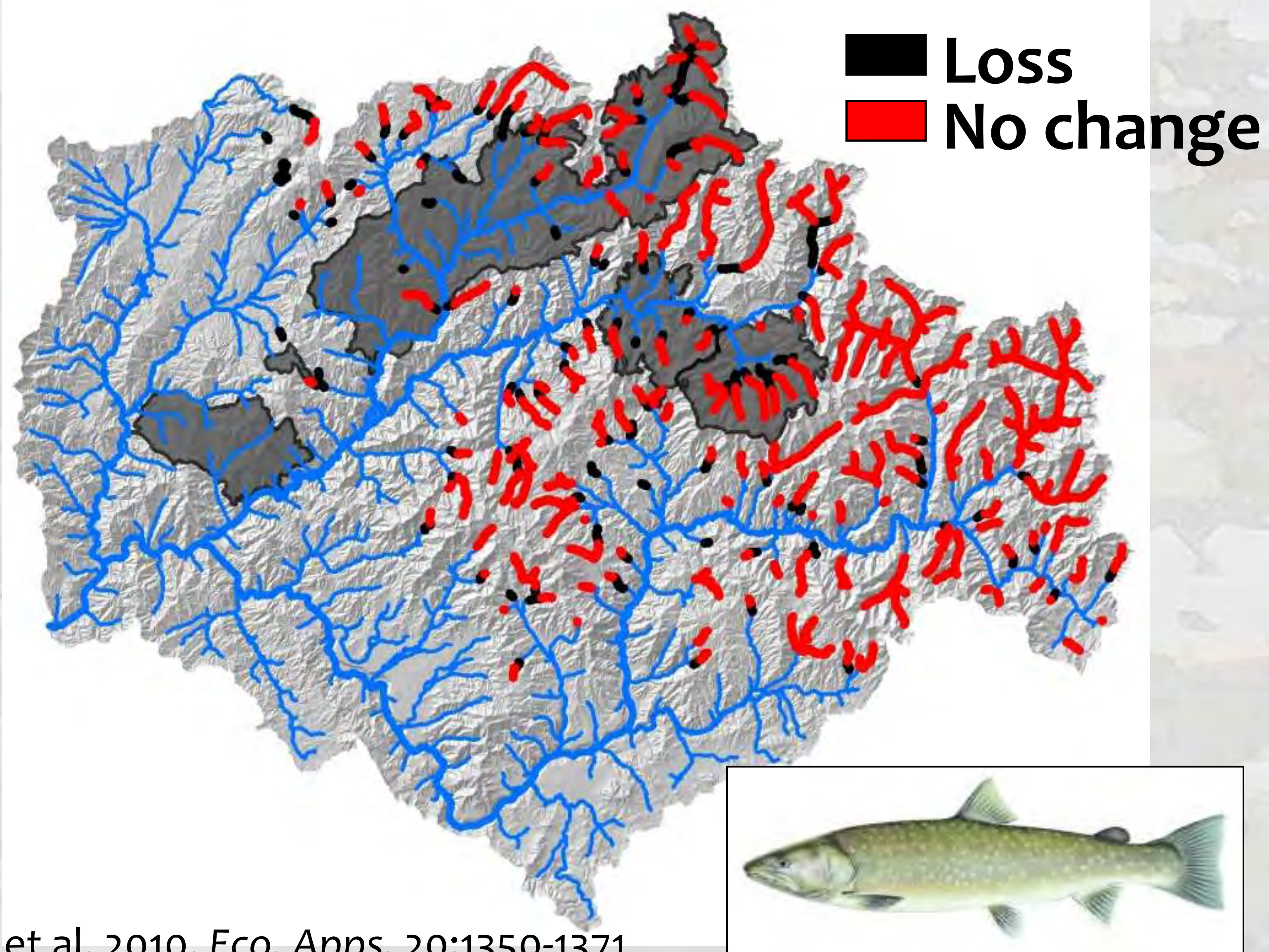
Habitat is shifting, but no net gain or loss



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

93’-06’ Bull Trout Habitat Changes

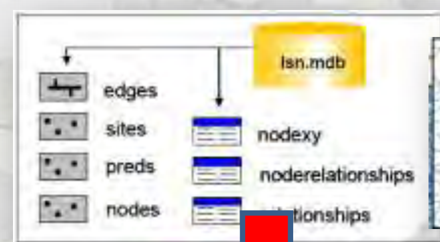
Habitat is decreasing 8%-16% / decade

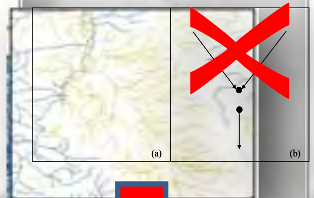


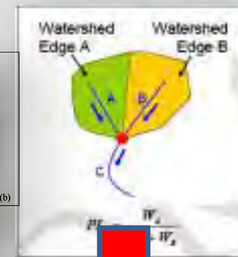
Isaak et al. 2010. *Eco. Apps.* 20:1350-1371

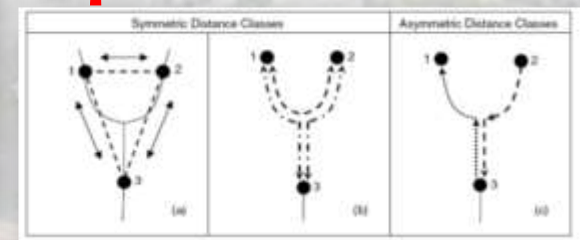
Infrastructure for Regional Analysis Developed Through NorWeST

Spatial models

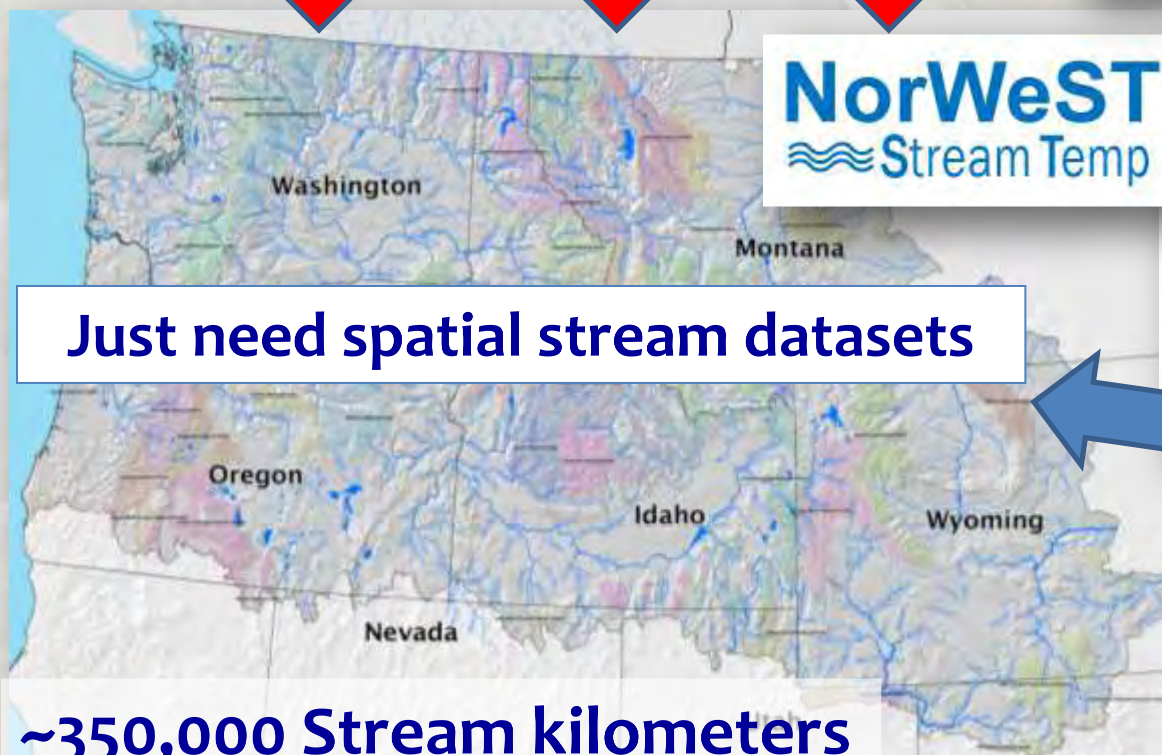






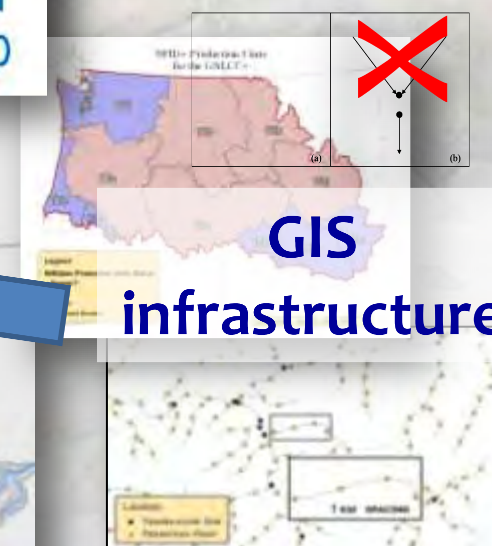


NorWeST Stream Temp



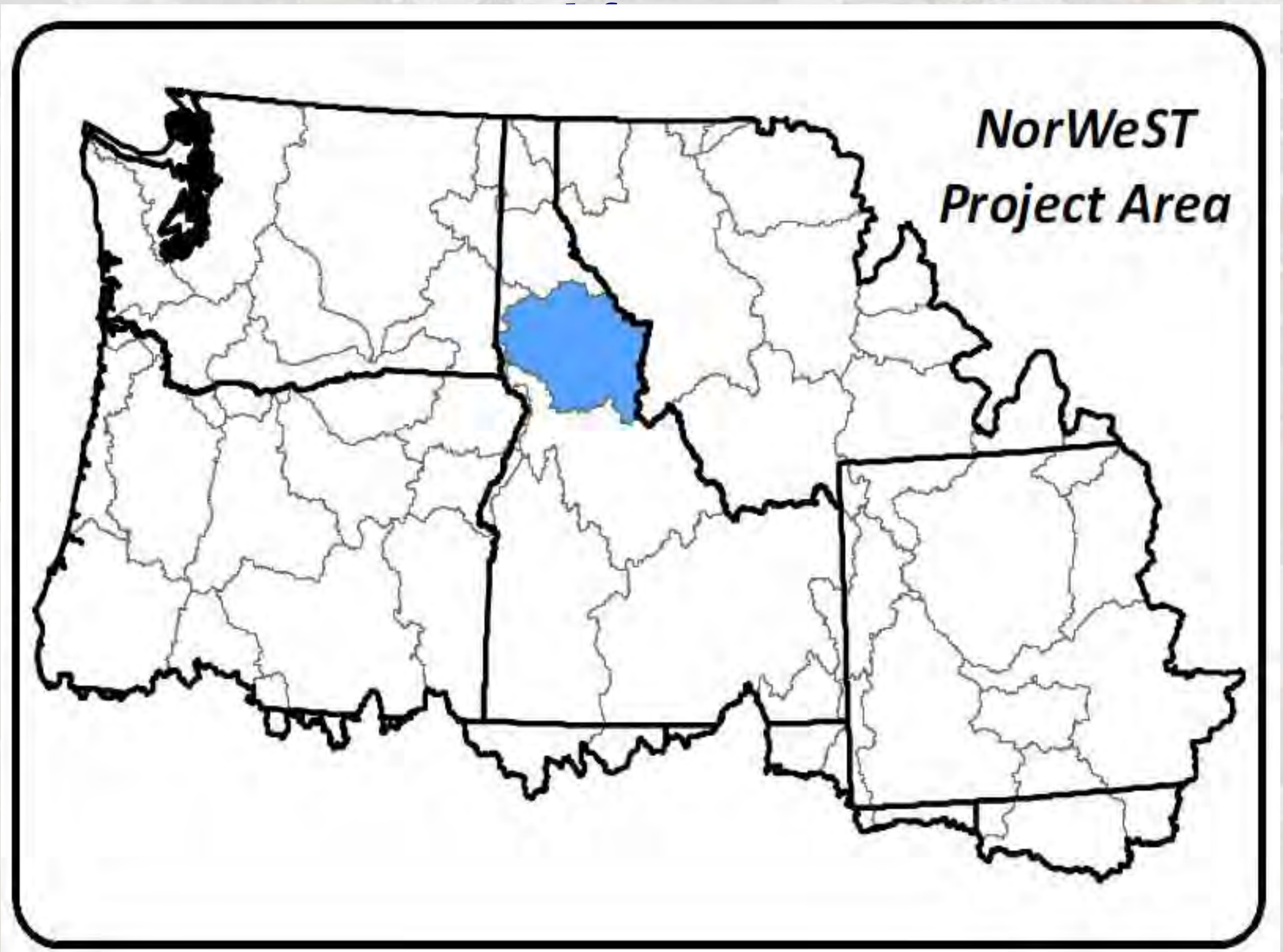
Just need spatial stream datasets

~350,000 Stream kilometers



GIS infrastructure

Example: Clearwater River Basin

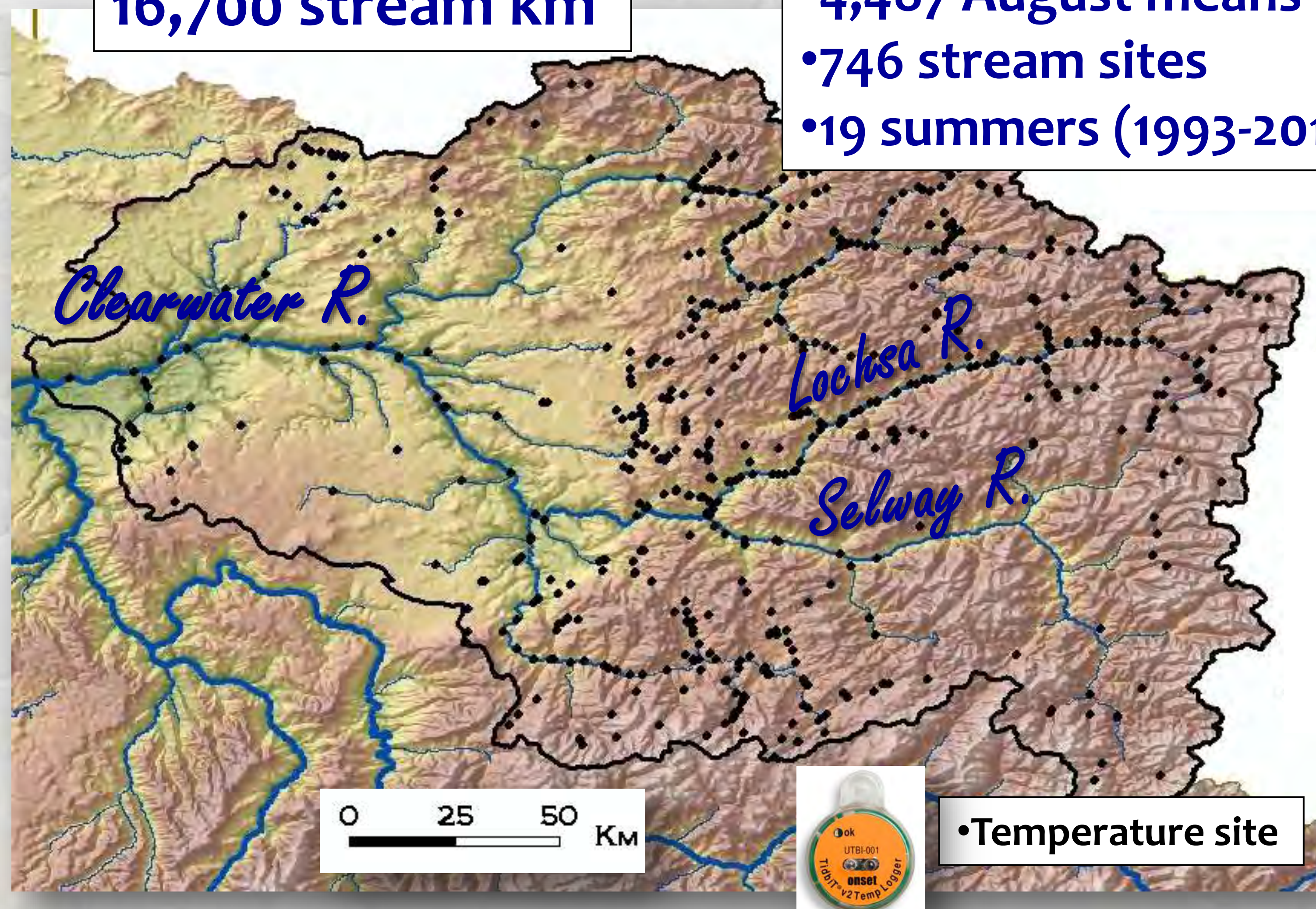


Example: Clearwater River Basin

Data extracted from NorWeST

16,700 stream km

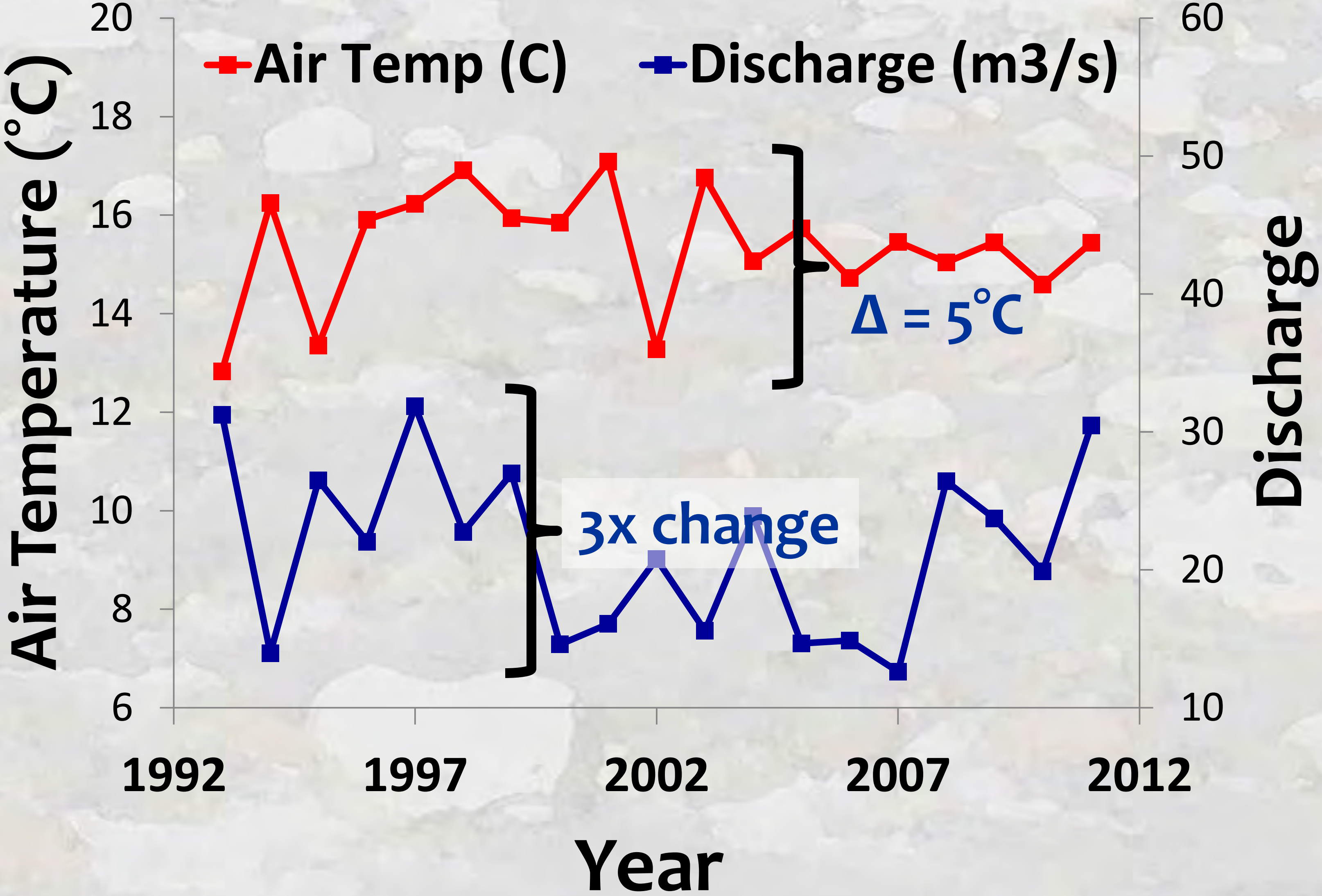
- 4,487 August means
- 746 stream sites
- 19 summers (1993-2011)



•Temperature site

Climatic Variability in Historical Record

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



Clearwater River Temp Model

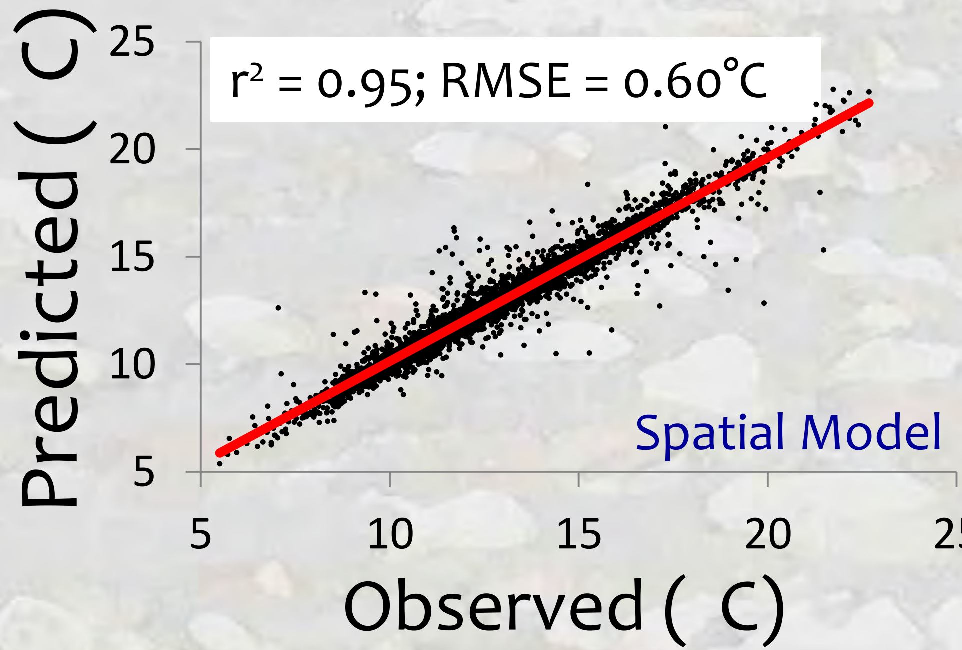
n = 4,487

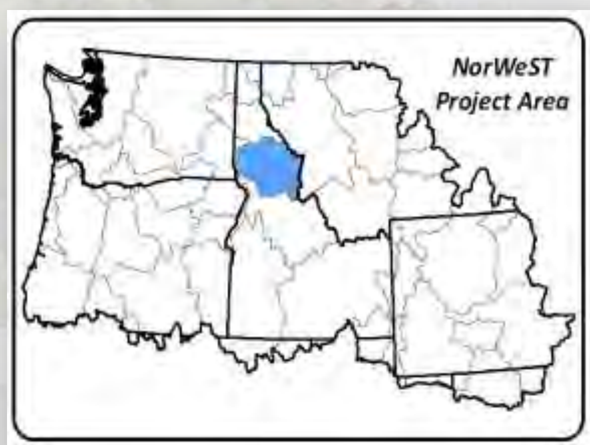
Covariate Predictors

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

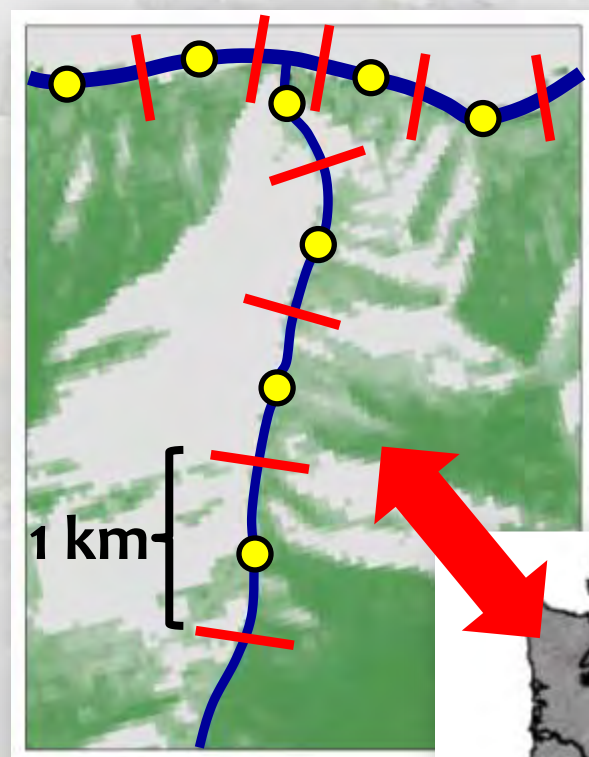
Mean August Temperature



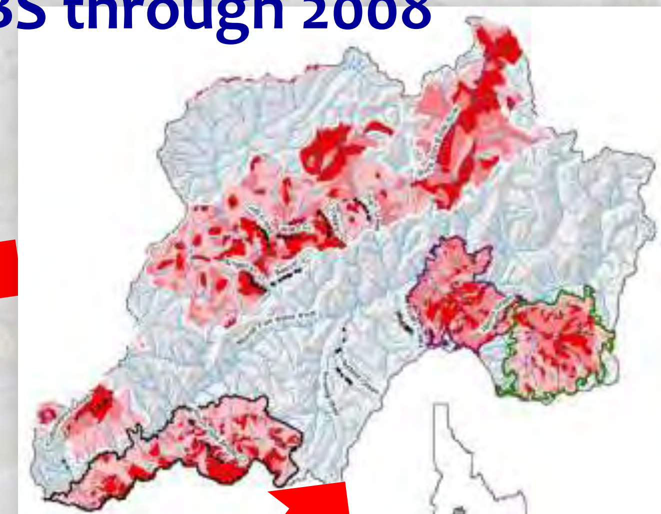


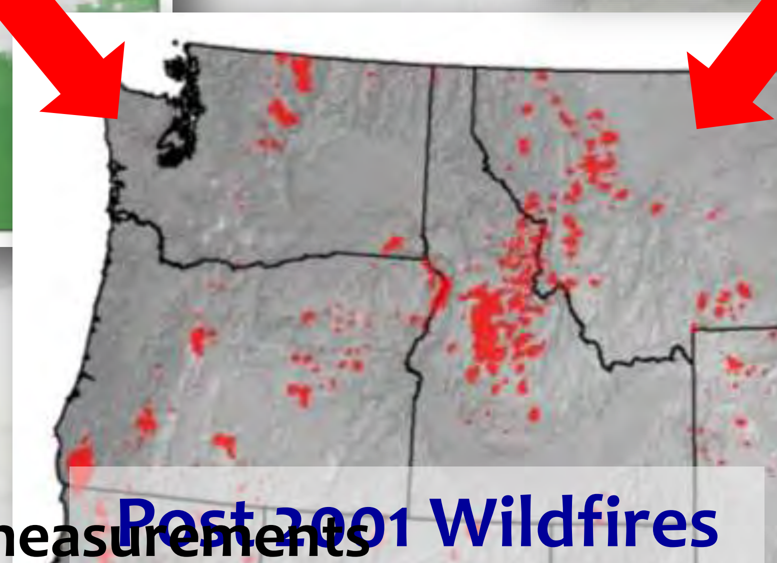
Riparian Canopy Predictor

%Canopy variable from 2001 NLCD



%Canopy adjusted by MTBS through 2008





Also tested:

- LandFire
- TreeFrac
- Radiation measurements

Why August Mean Temperature?

1) 95% of temperature data are summer only
2) All summer metrics are strongly correlated
3) Monthly mean is easily linked to regional climate model

MWAT ~ **Maximum** ~ **Minimum**

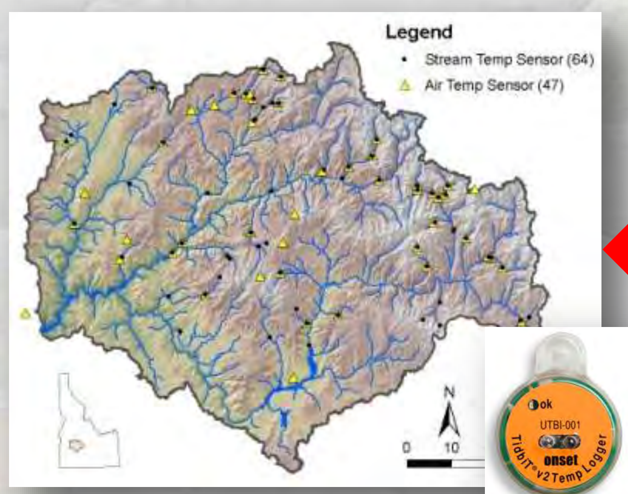
MDAT ~ **AWAT** ~ **Degree-days** ~ Mean

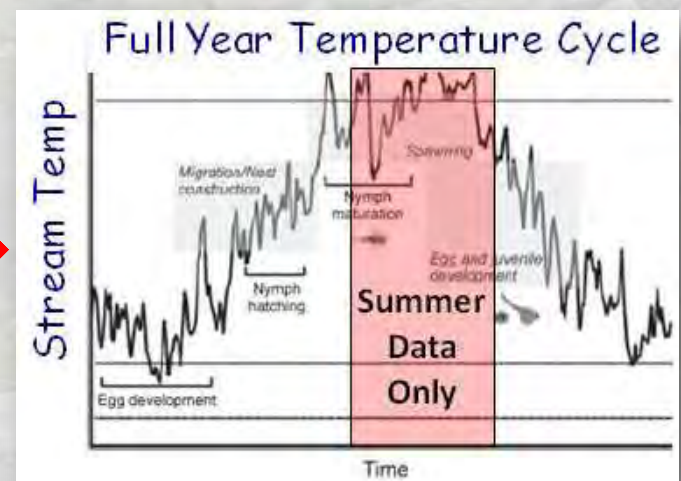
	Summer_mn	*Mwmt*	*Mwat*	*awat_mn*	*awmt_mn*	***August Mean***
Summer_mn						
Mwmt	0.93					
Mwat	0.98	0.94				
awat_mn	1.00	0.93	0.97			
awmt_mn	0.96	0.98	0.94	0.96		
August Mean	**0.99**	**0.92**	**0.96**	**0.99**	**0.95**	
August MWMT	0.92	0.99	0.92	0.92	0.98	**0.92**

***Modeling each additional metric doubles computational time**
***Conversion factors can facilitate metric translation**

Summer Temperatures ~ Other Seasons

	Fall mean	Fall SD	Winter Mean	Winter SD	Spring mean	Spring SD	Summer Mean
Fall SD	0.87	---					
Winter Mean	0.50	0.02	---				
Winter SD	0.70	0.35	0.83	---			
Spring mean	0.95	0.76	0.51	0.78	---		
Spring SD	0.69	0.77	-0.05	0.29	0.74	---	
Summer Mean	**0.91**	**0.92**	**0.23**	**0.45**	**0.88**	**0.87**	---
Summer SD	0.62	0.77	-0.02	0.15	0.48	0.49	**0.65**





Salmon River Temperature Model

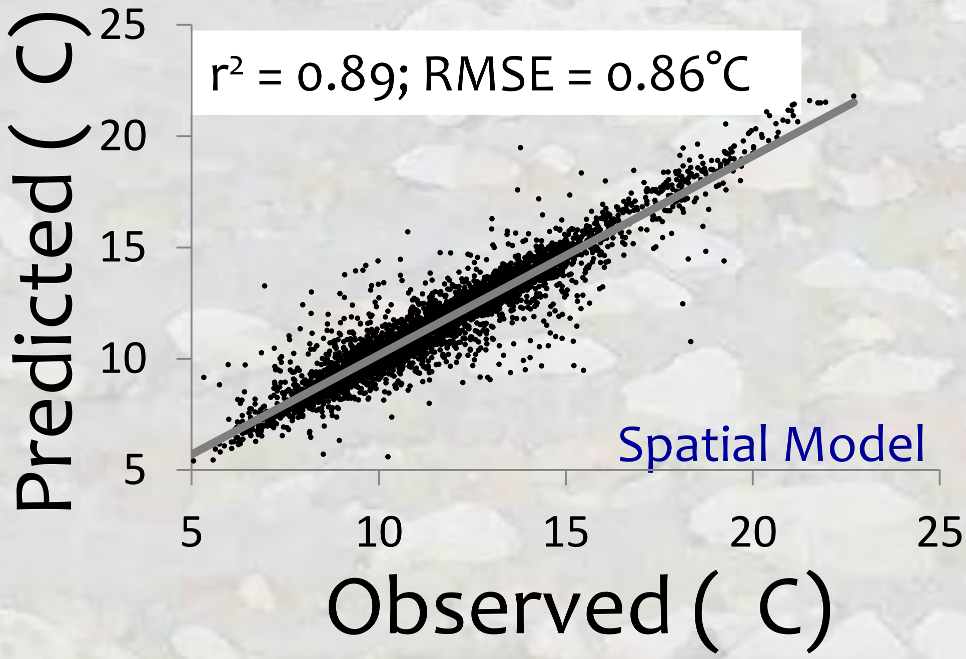
n = 4,401

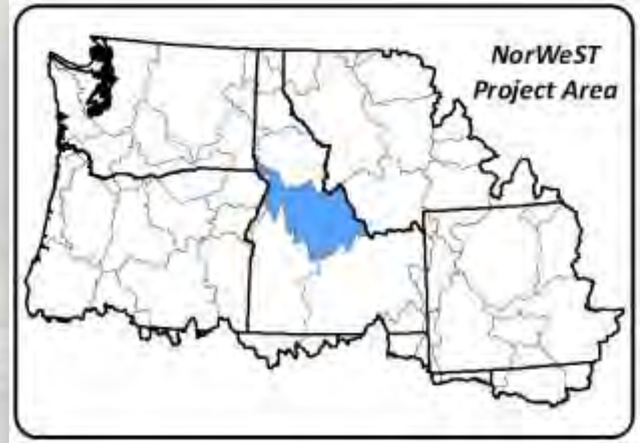
<u>Covariate Predictors</u>

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





SpoKoot River Temp Model

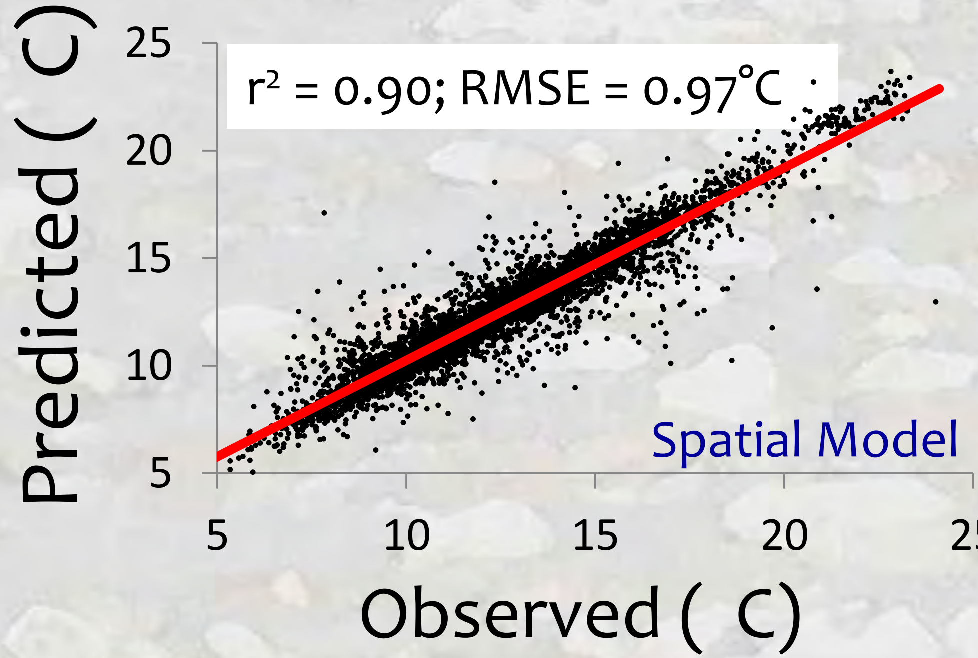
n = 5,482

Covariate Predictors

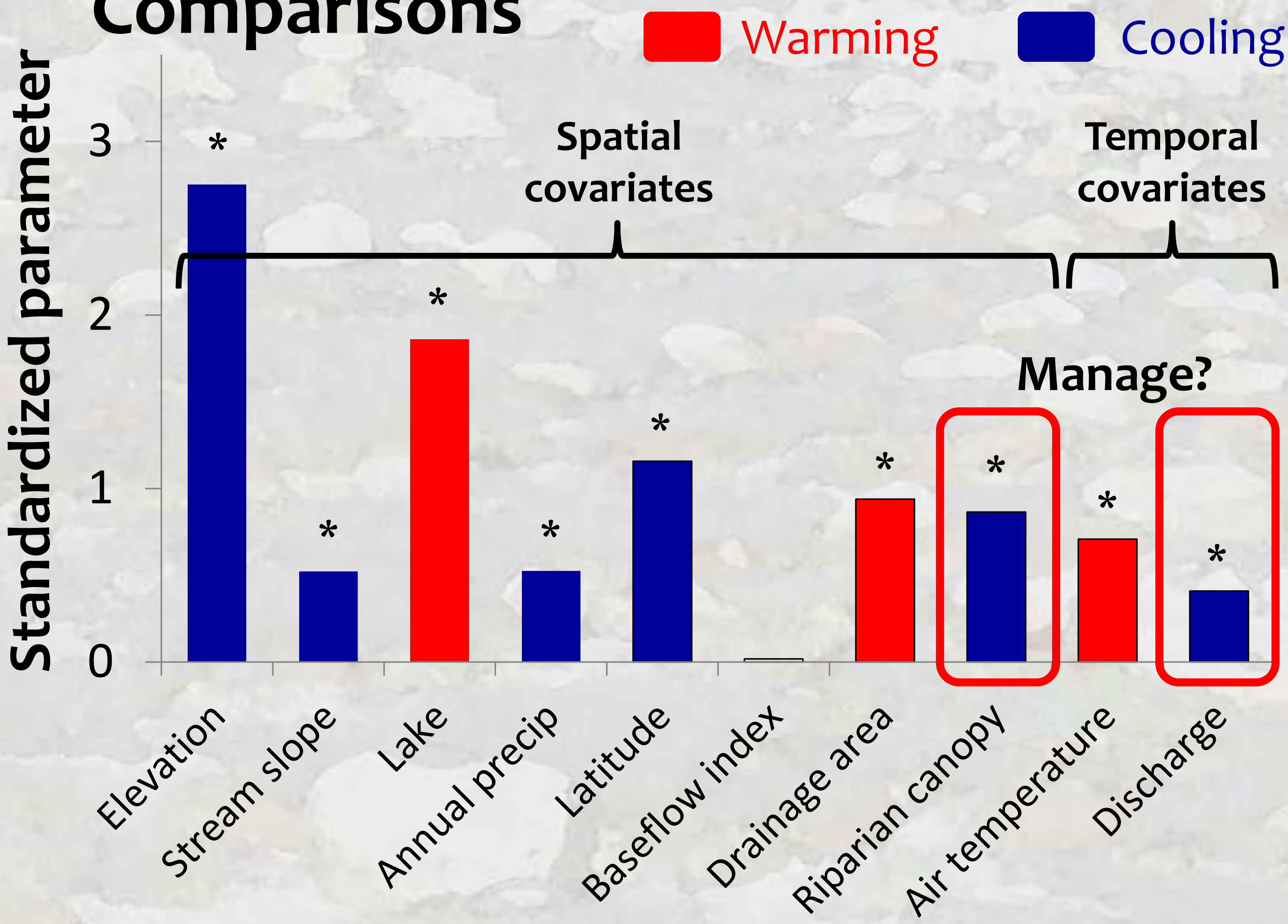
1. Elevation (m)
2. Canopy (%)
3. Stream slope (%)
4. Ave Precipitation (mm)
5. Latitude (km)
6. Lakes upstream (%)
7. Baseflow Index
8. Watershed size (km^2)

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

Mean August Temperature



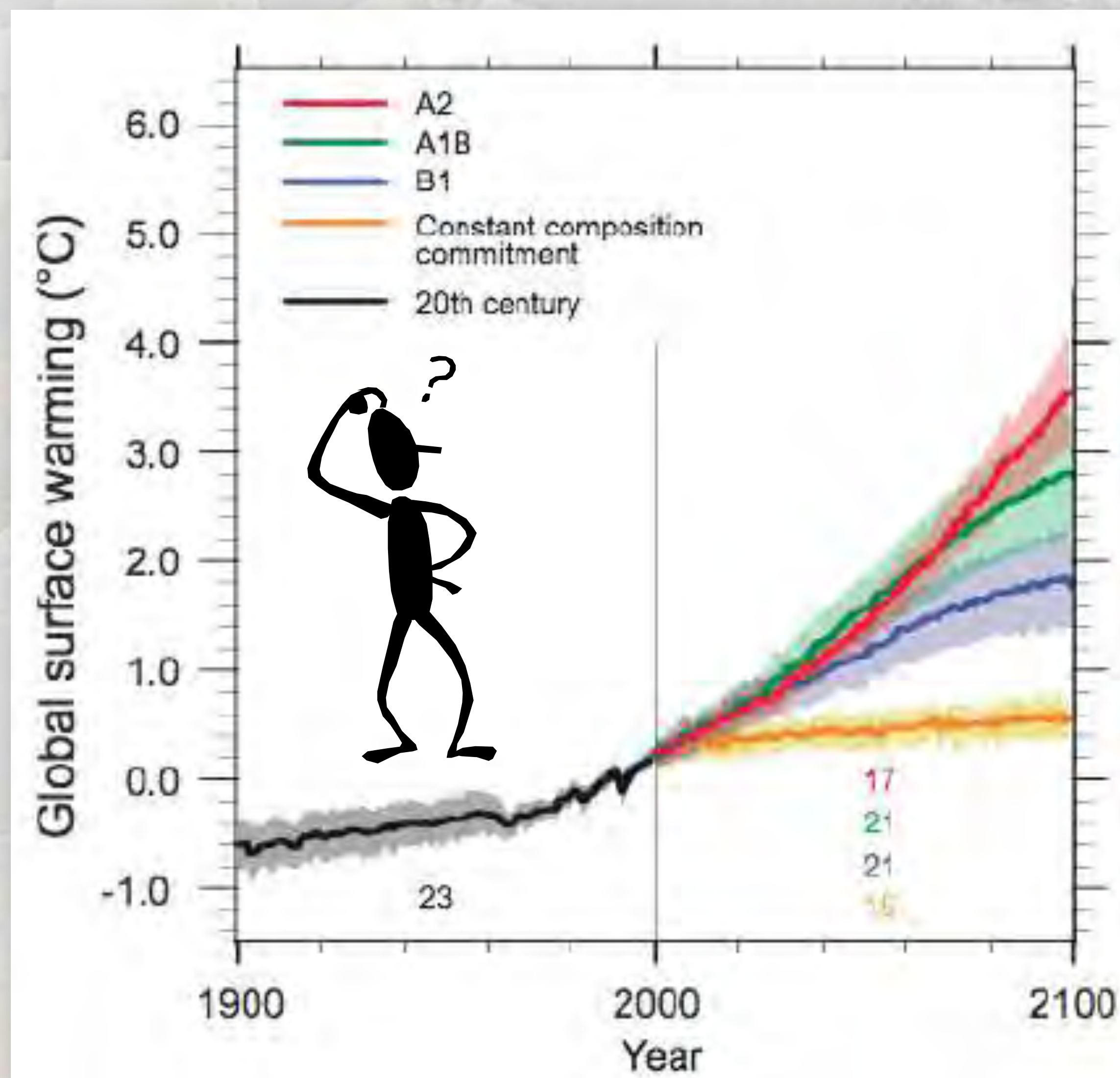
SpoKoot Temp Model Parameter Comparisons



* = significant at $p < 0.05$

Models Enable Climate Scenario Maps

Many possibilities exist…



Adjust…

- Air
- Discharge
- %Canopy

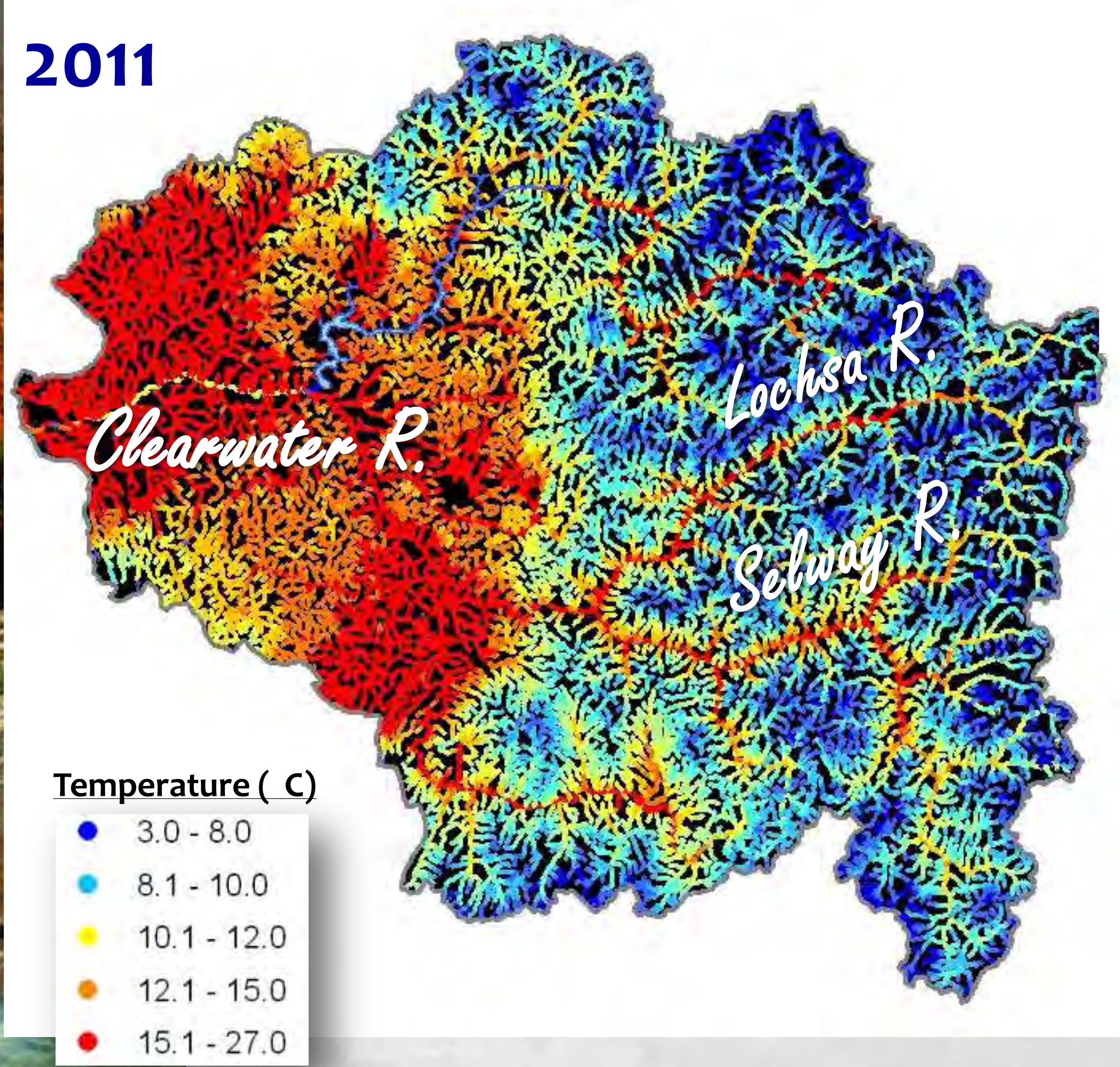
…values to create scenarios

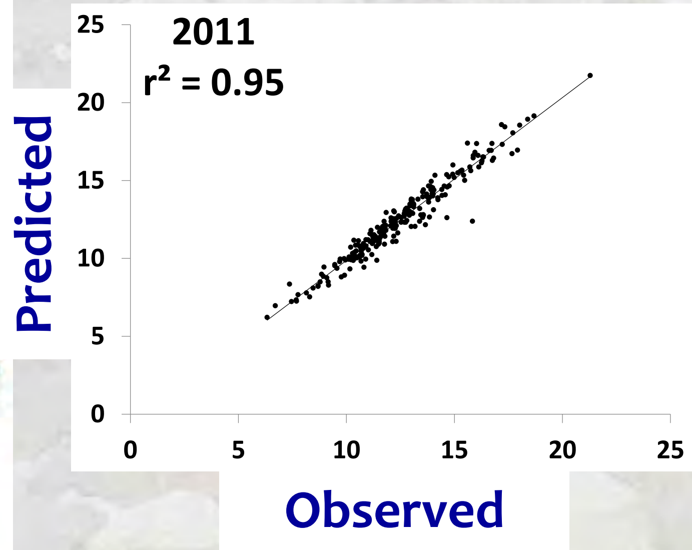
Climate Scenario Descriptions

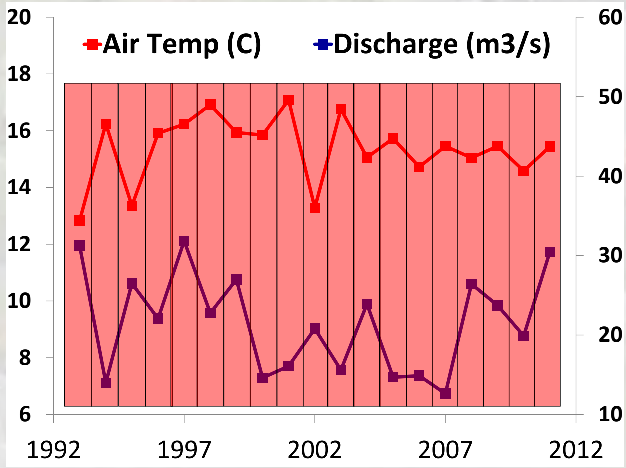
Scenario	Description
S1_93_11	Historical scenario representing 19 year average August mean stream temperatures for 1993-2011
S2_02_11	Historical scenario representing 10 year average August mean stream temperatures for 2002-2011
S3_1993	Historical scenario representing August mean stream temperatures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

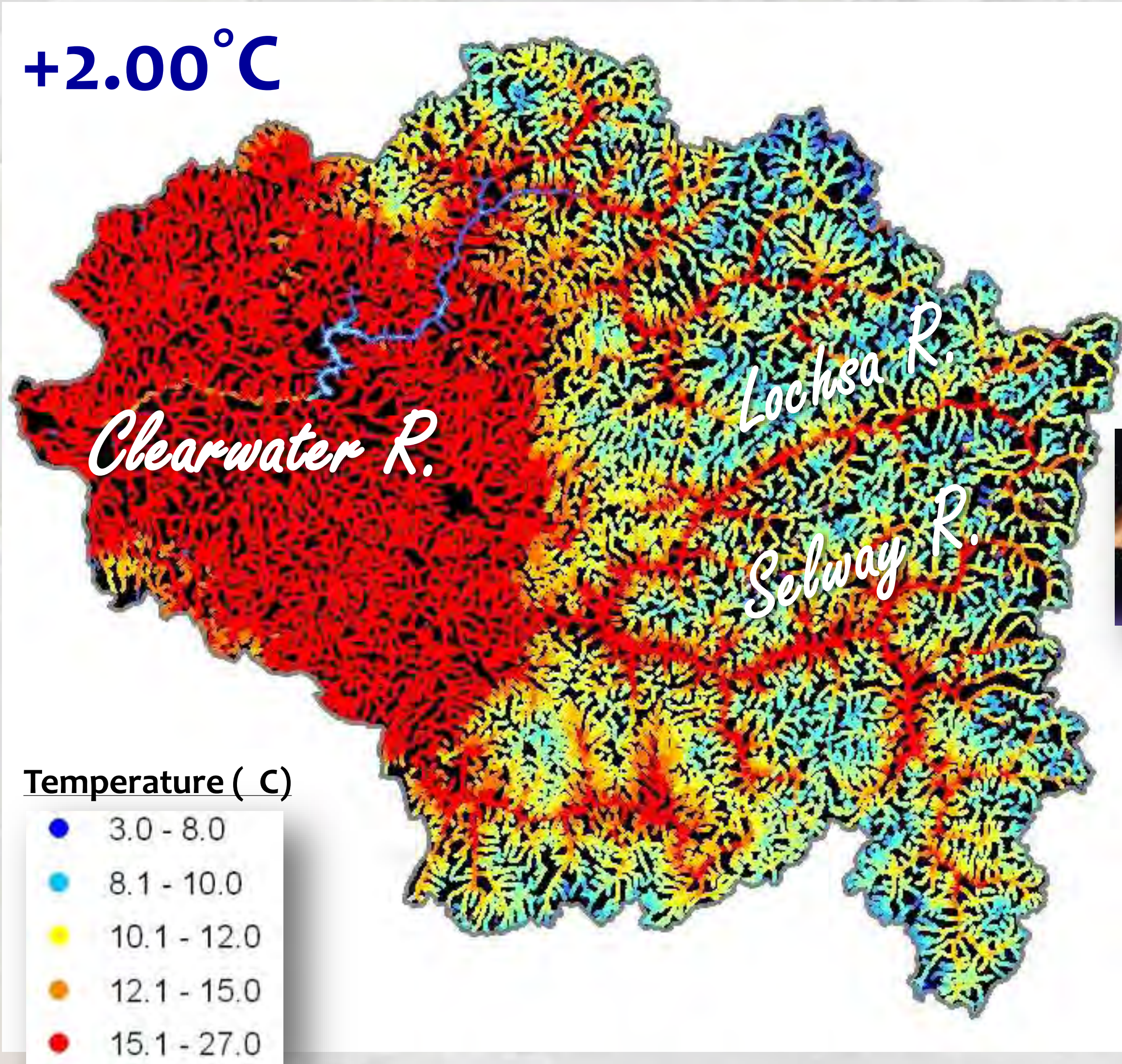


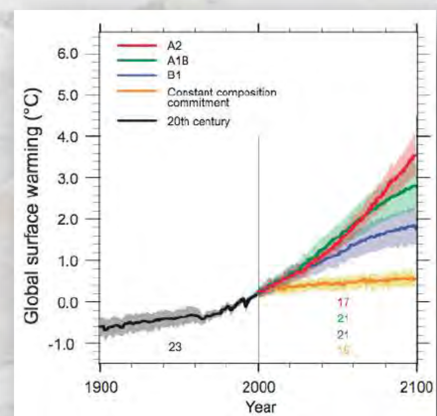




Future Scenarios (S1, S25, S29)

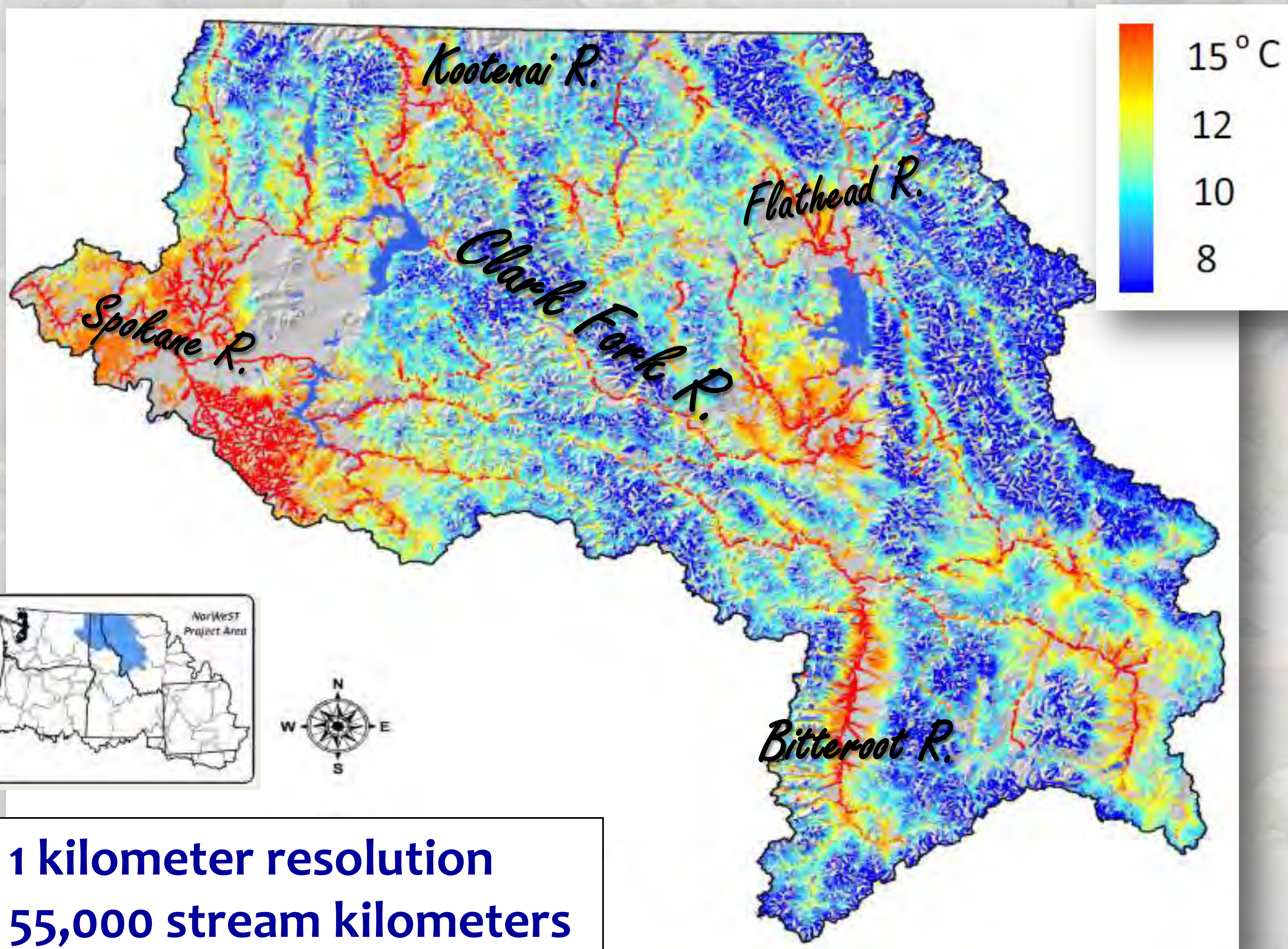
1993-2011, +1.0°C, +2.0°C





Historic Scenario: SpoKoot Unit (S1_93-11)

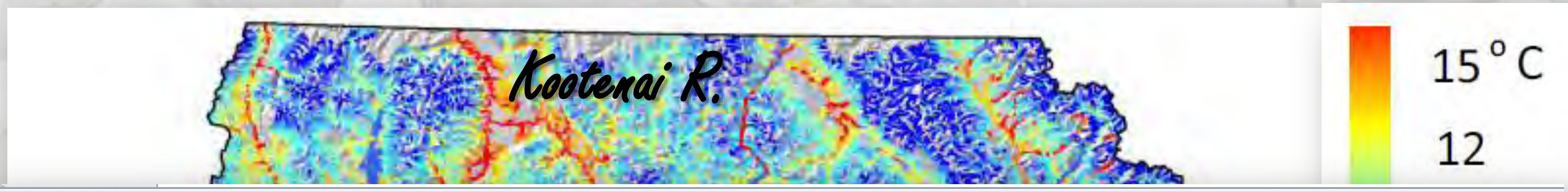
1993-2011 mean August stream temperatures



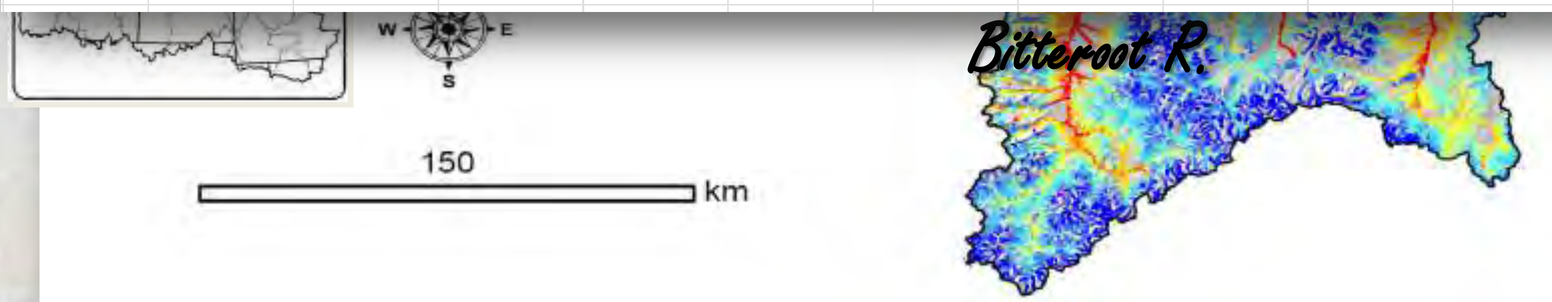
1 kilometer resolution
55,000 stream kilometers

Historic Scenario: SpoKoot Unit (S1_93-11)

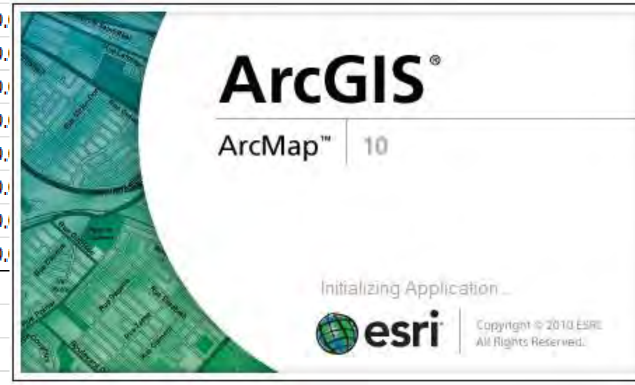
1993-2011 mean August stream temperatures



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										
19.84										
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	



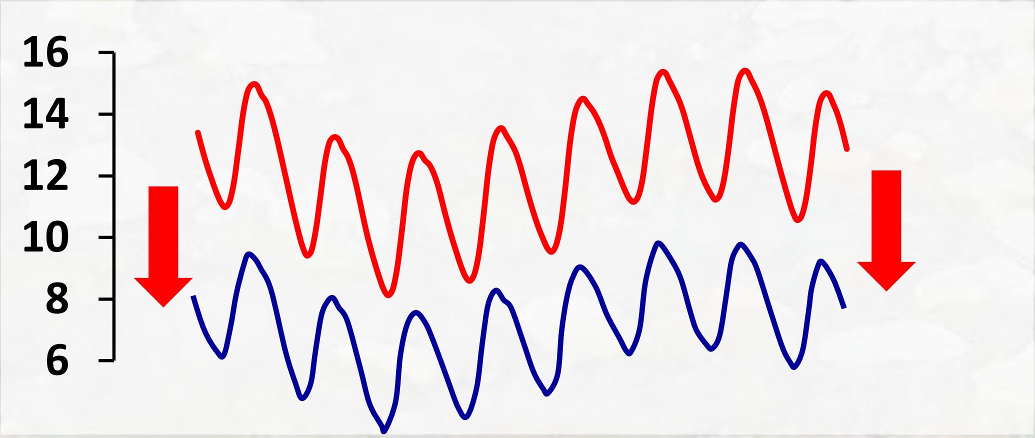
Scenarios are Shapefile Tables Easily Displayed & Queried in ArcMap



Application: Quantify Thermal Degradation

What is the thermal "intrinsic potential" of a stream?

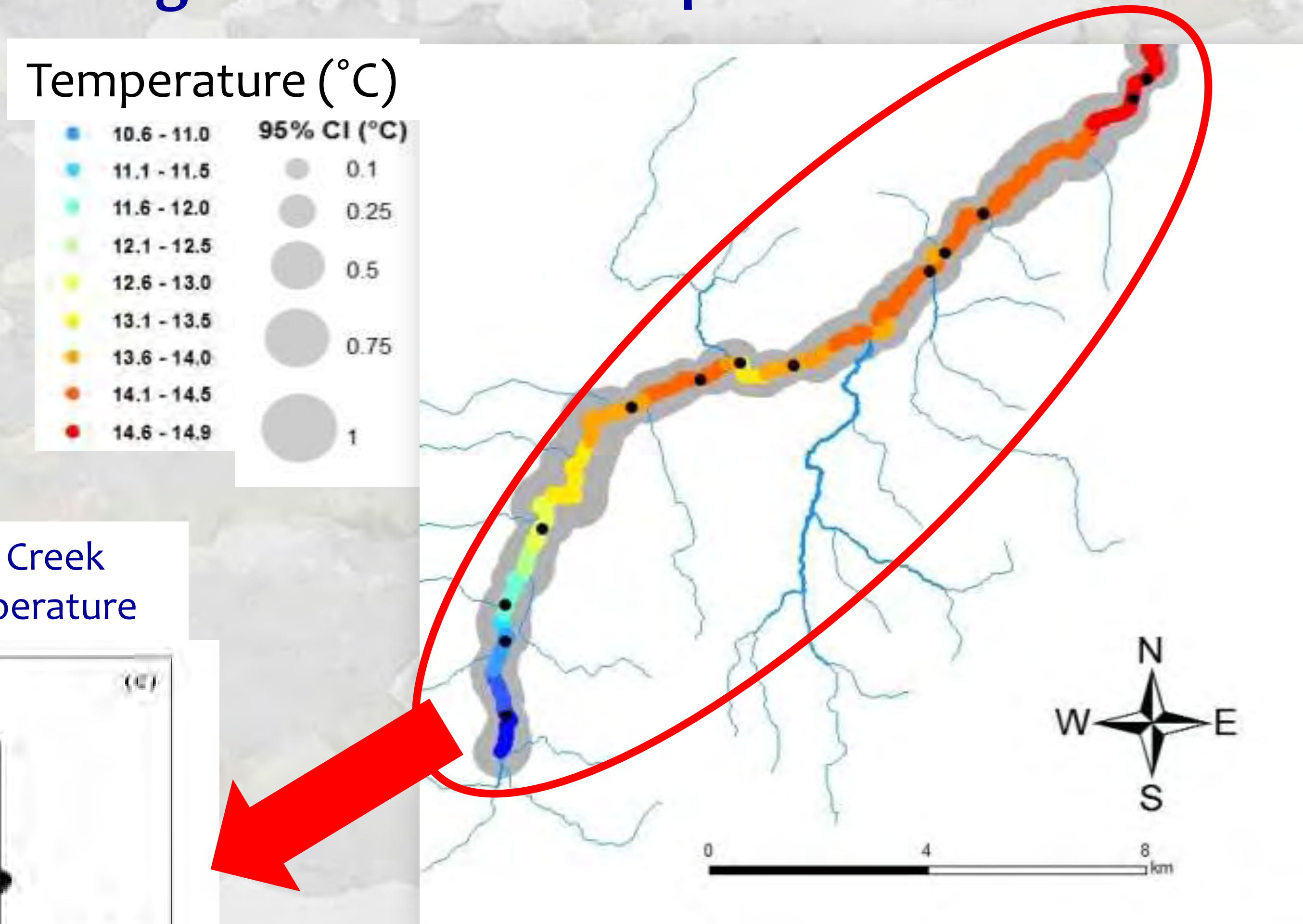
"How much cooler could we make this stream?"

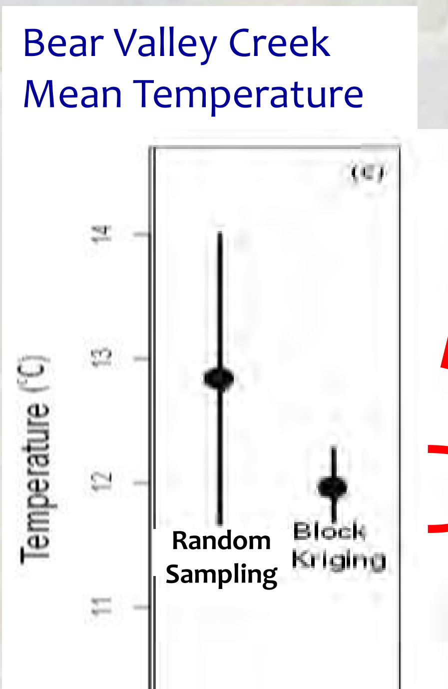


1) Pick "degraded" and "healthy" streams to compare

Application: Quantify Thermal Degradation

2) Block-krige estimates of temperature at desired scale

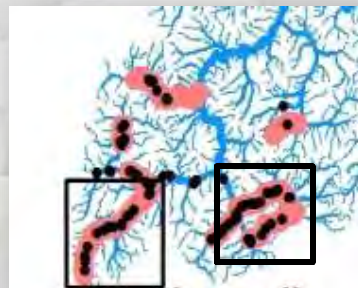


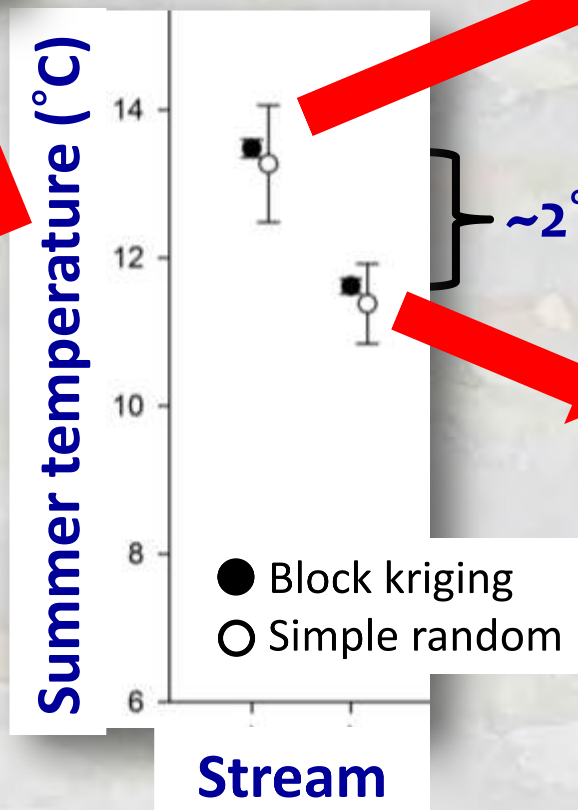


Precise & unbiased estimates

Application: Quantify Thermal Degradation

3) Compare estimates among streams

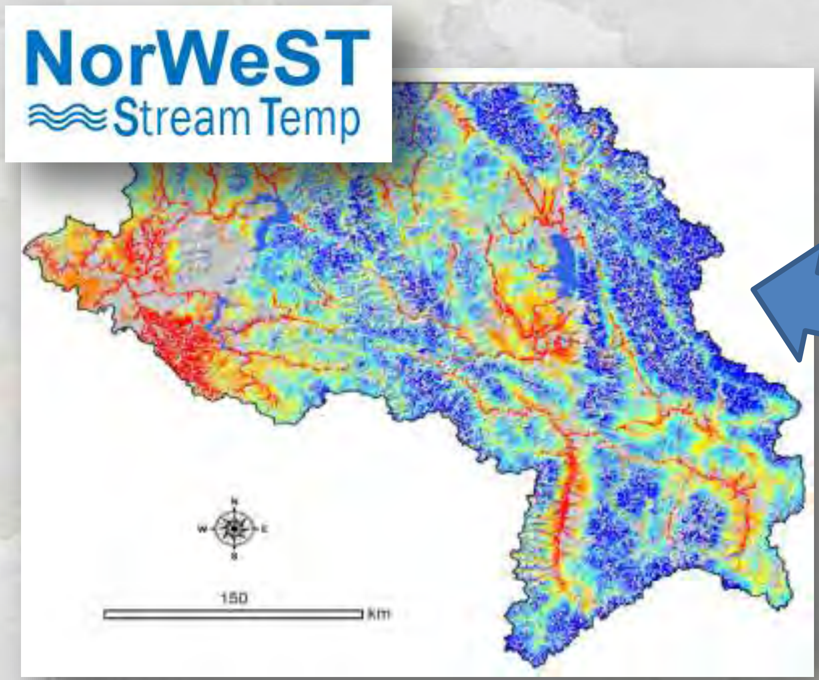




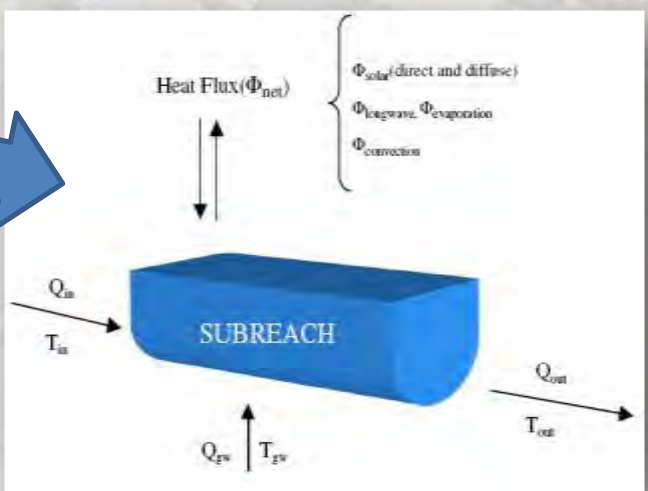
~2°C cooling is possible

Complimentary Model Information

Strategic & Tactical Information



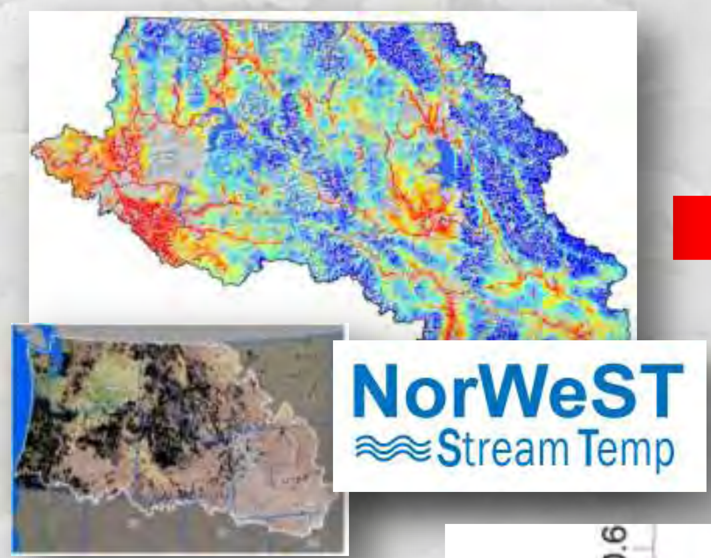
Mechanistic models…



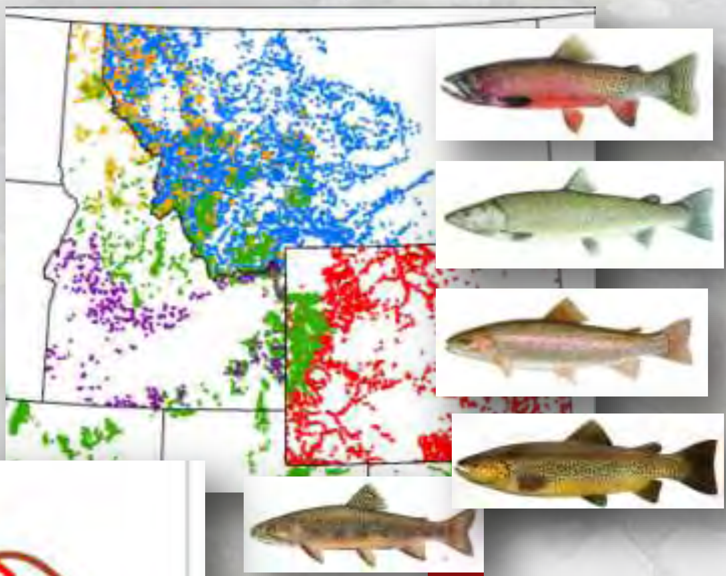
- QUAL2Kw
- SSTEMP/SNTEMP
- BasinTemp
- Heat Source
- WET-Temp

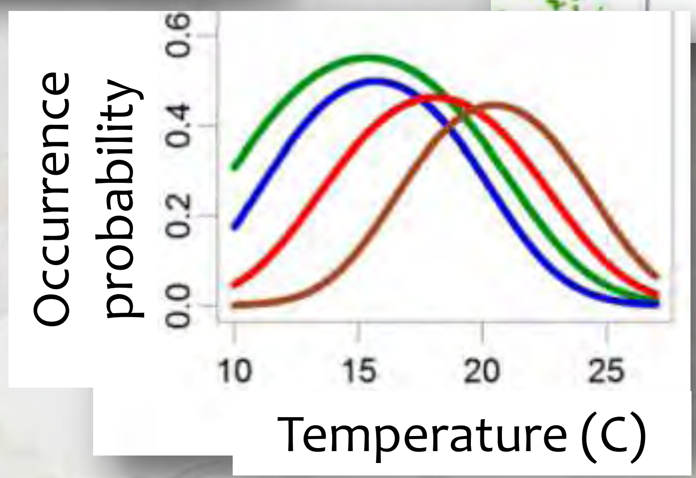
Application: Regionally Consistent Thermal Niche Definitions

Stream temperature maps



Regional fish survey databases (n ~ 30,000)



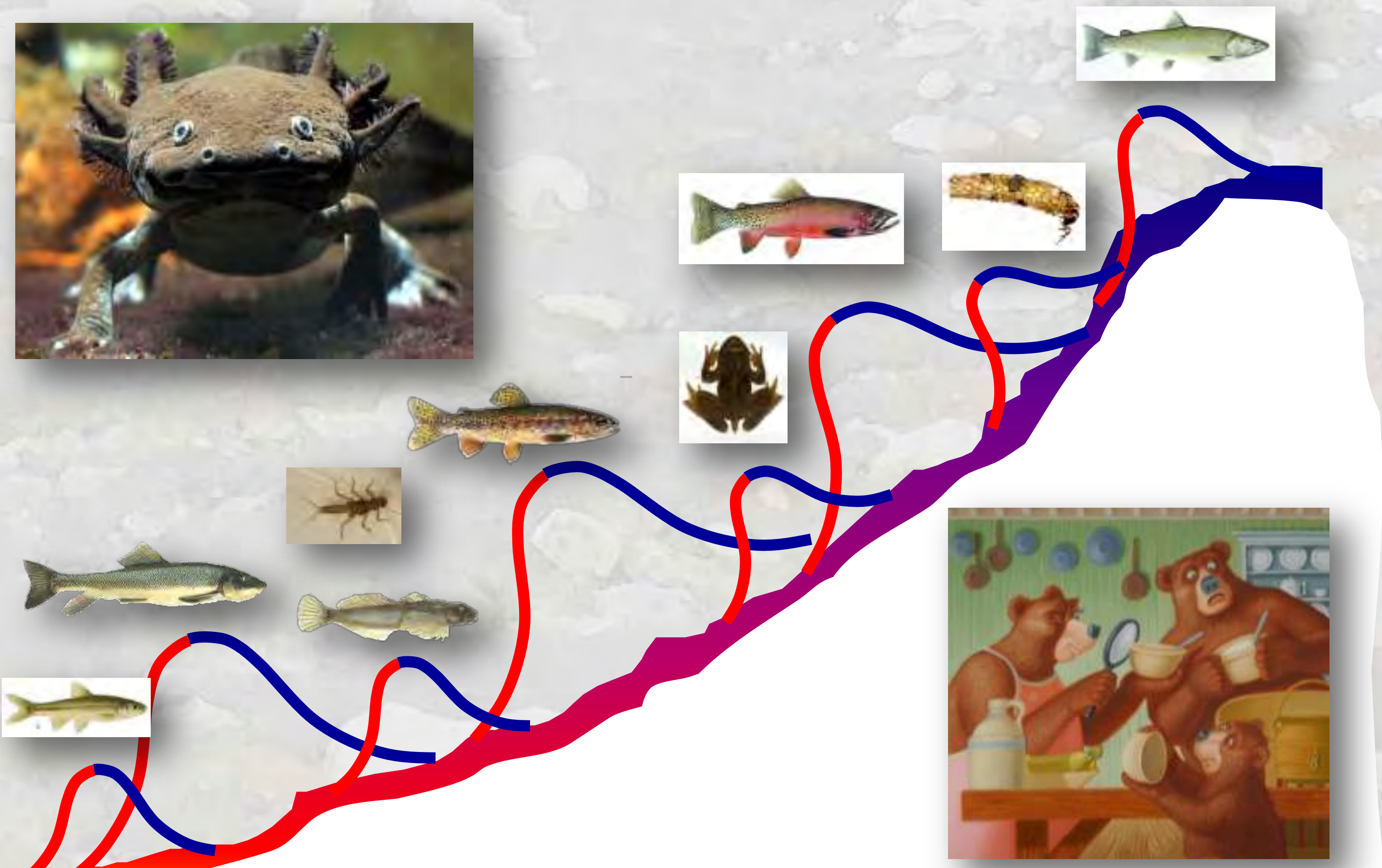


Wenger et al. 2011a. *PNAS* **108:**14175-14180

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

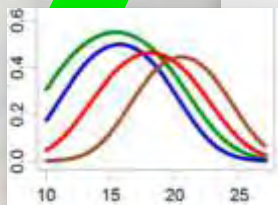
Thermal Niches For All Stream Critters

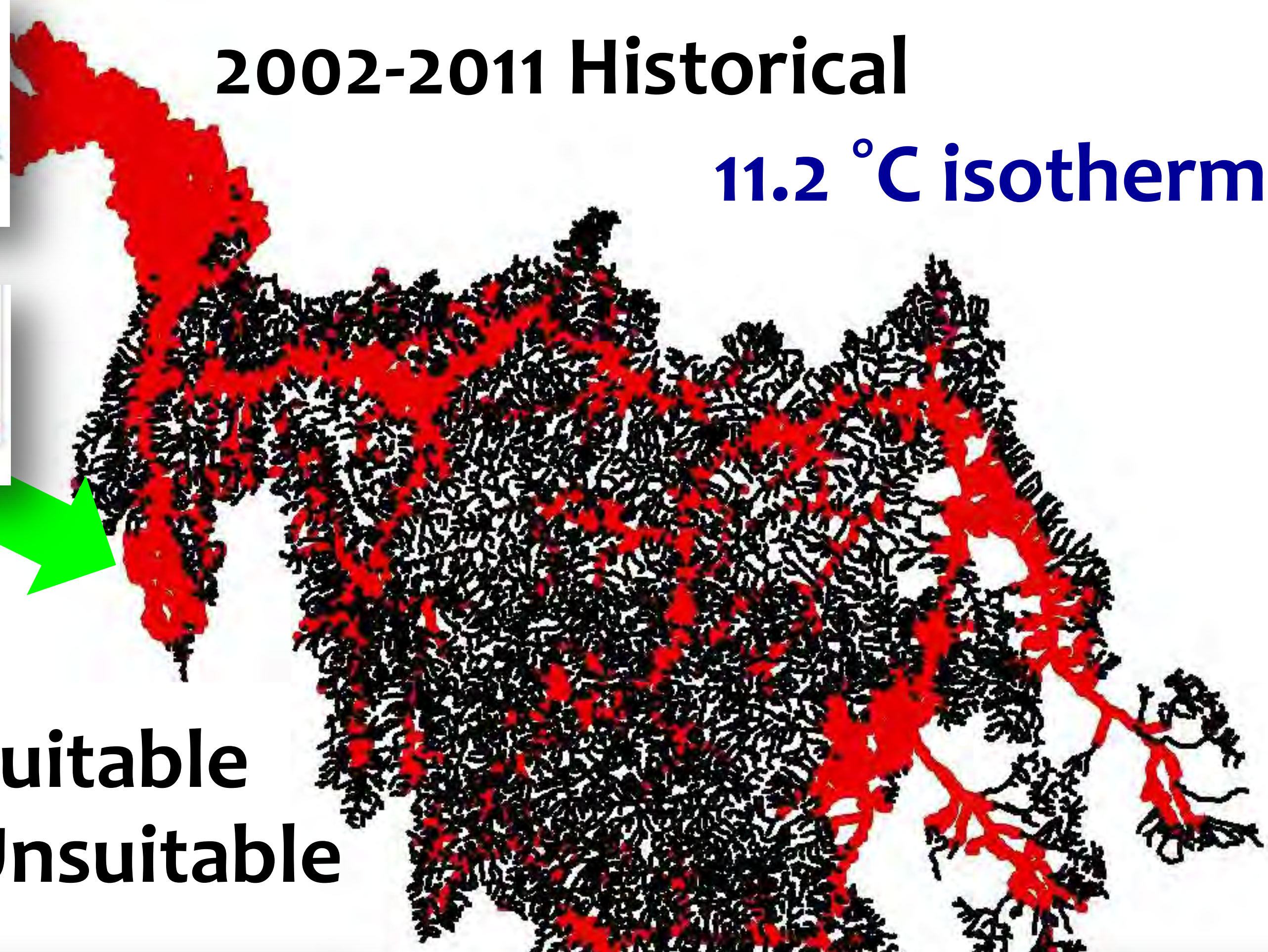
Just need georeferenced biological survey data



Too warm…Too cold…Just right

Salmon River Bull Trout Habitats



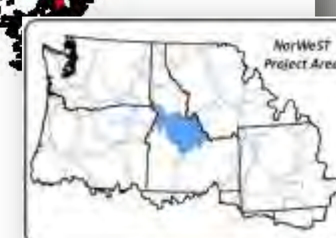


2002-2011 Historical

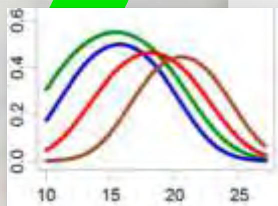
11.2 °C isotherm

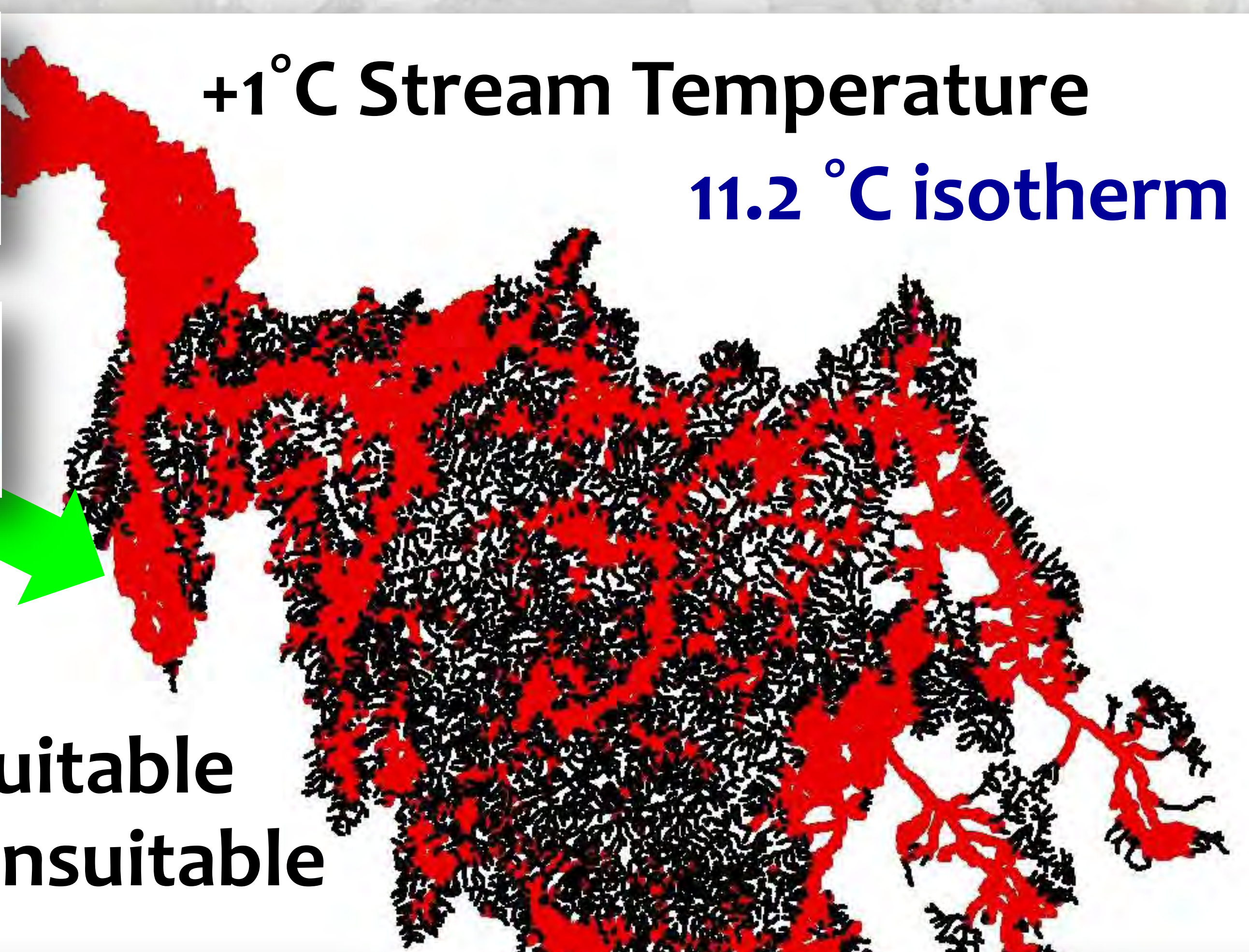
Suitable

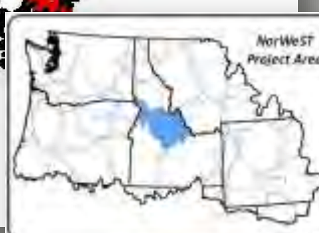
Unsuitable



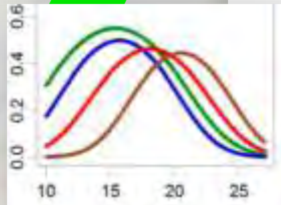
Salmon River Bull Trout Habitats

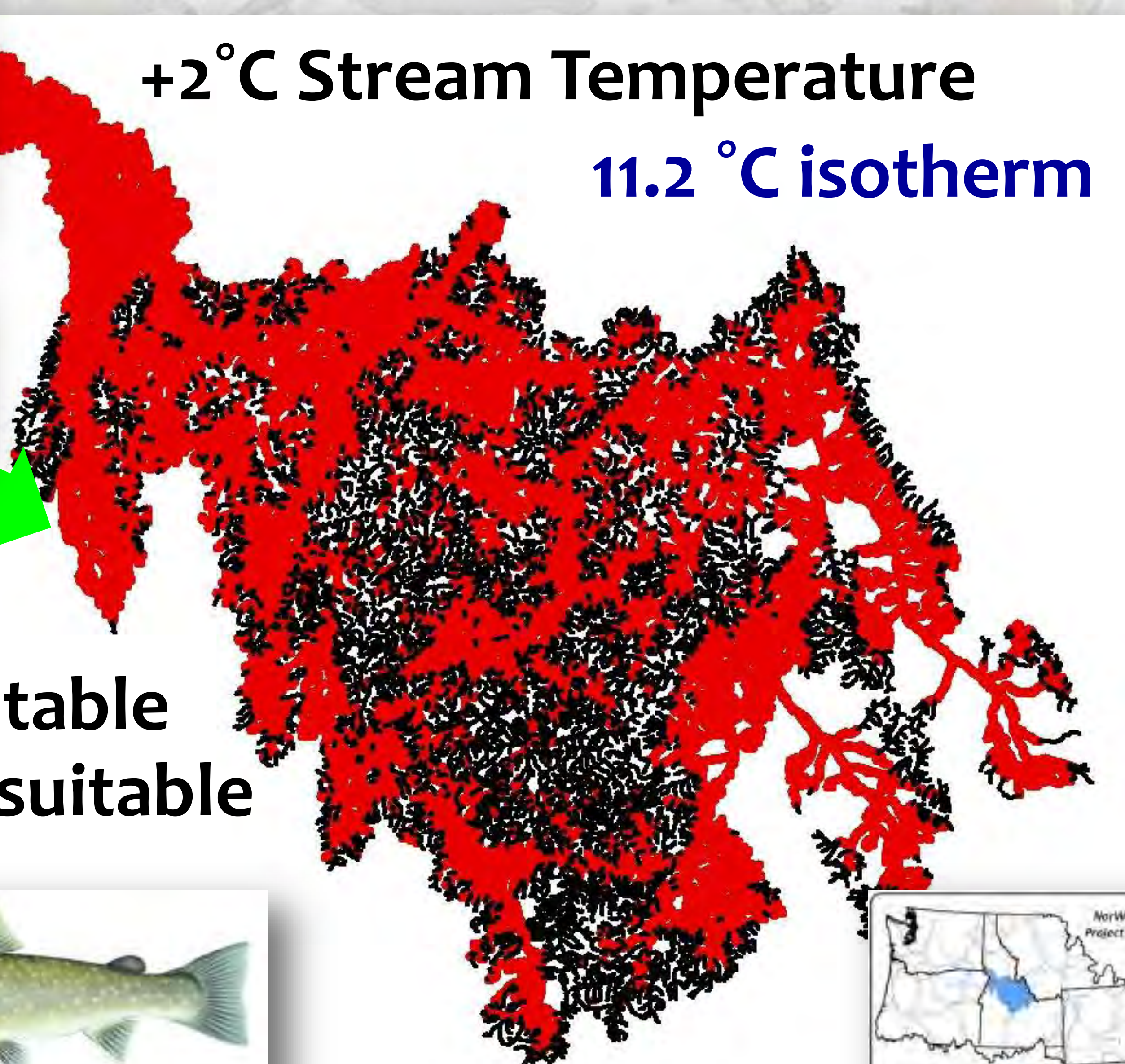






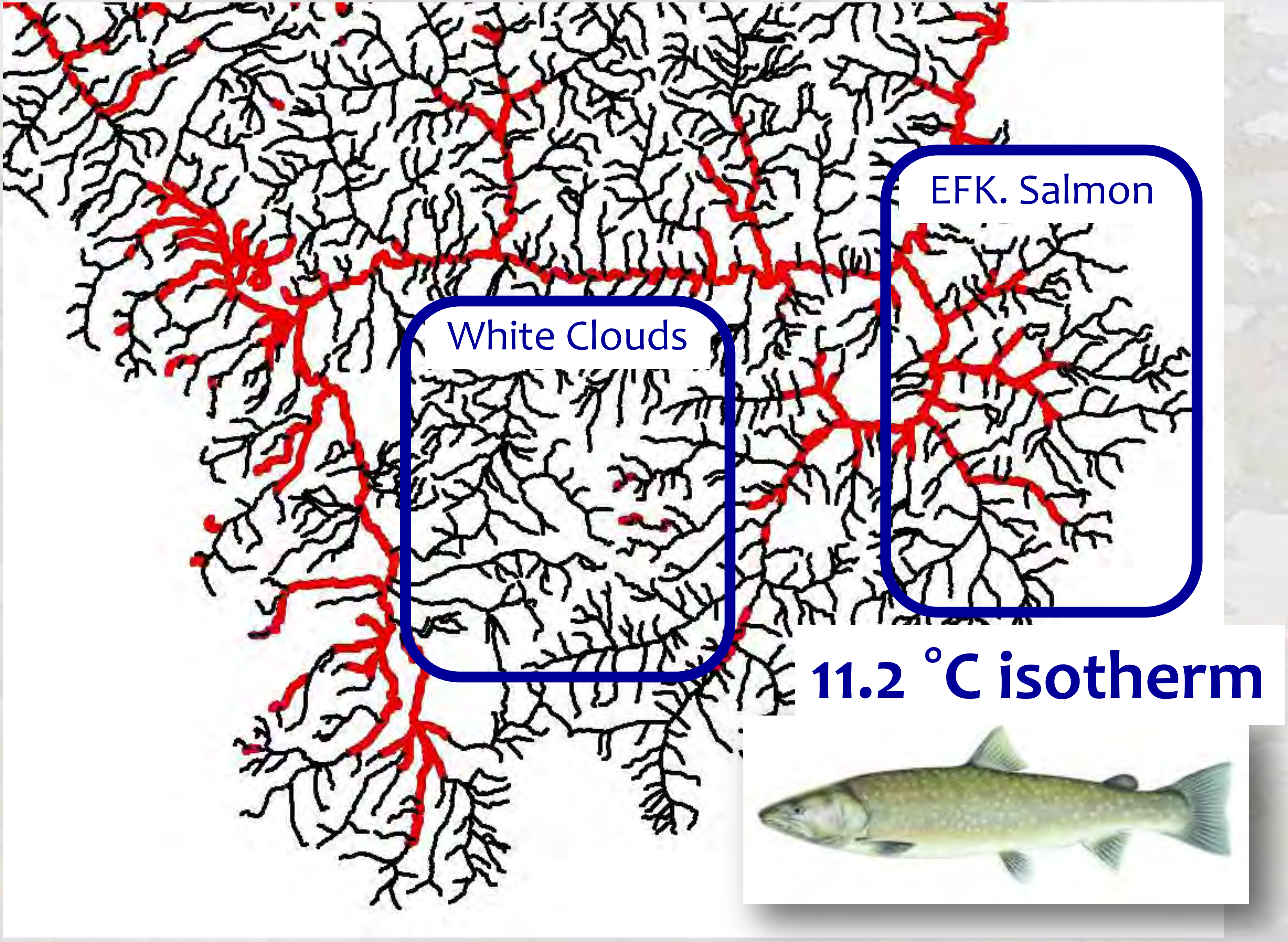
Salmon River Bull Trout Habitats





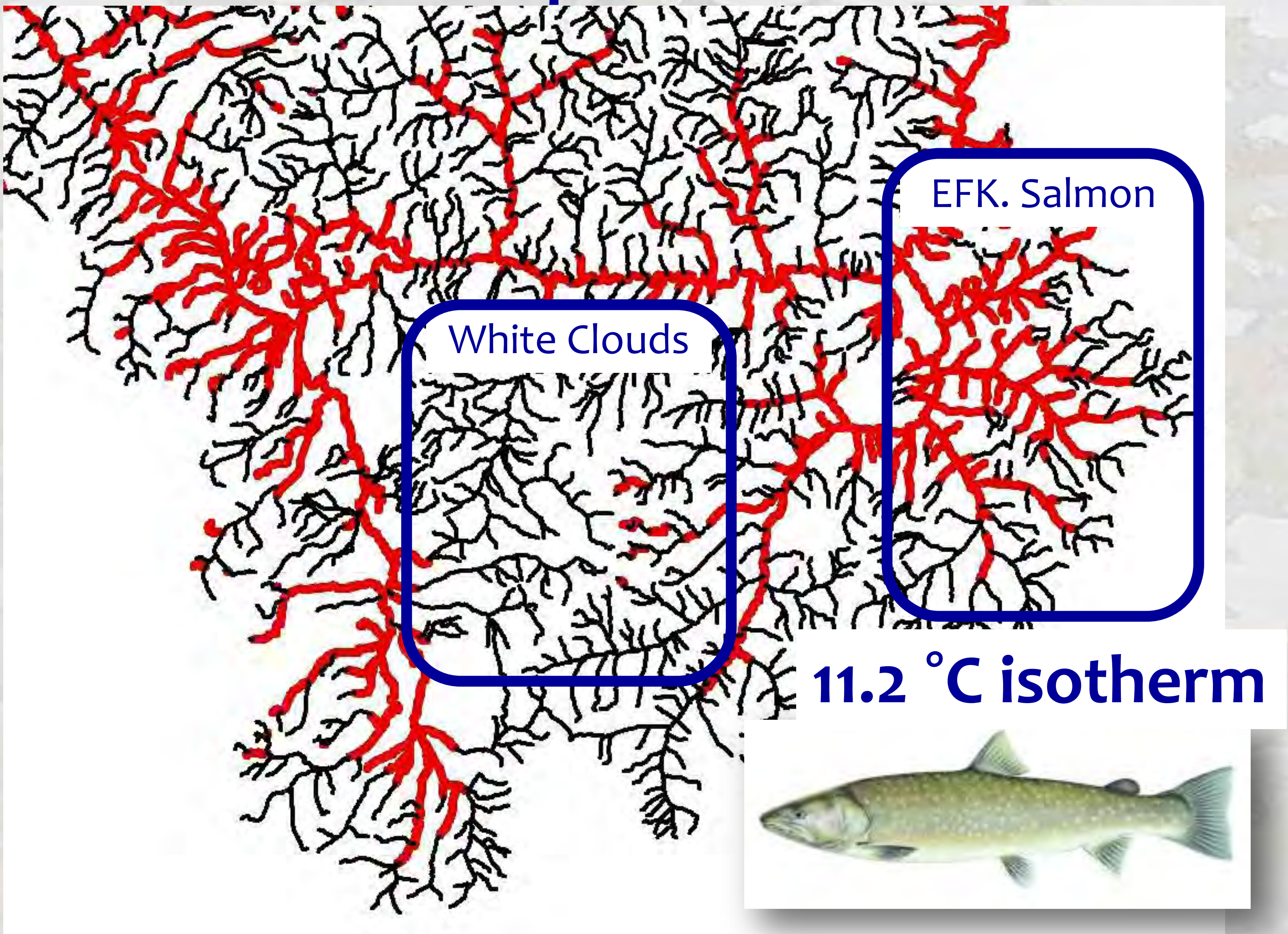
Spatial Variation in Habitat Loss

2002-2011 historical scenario



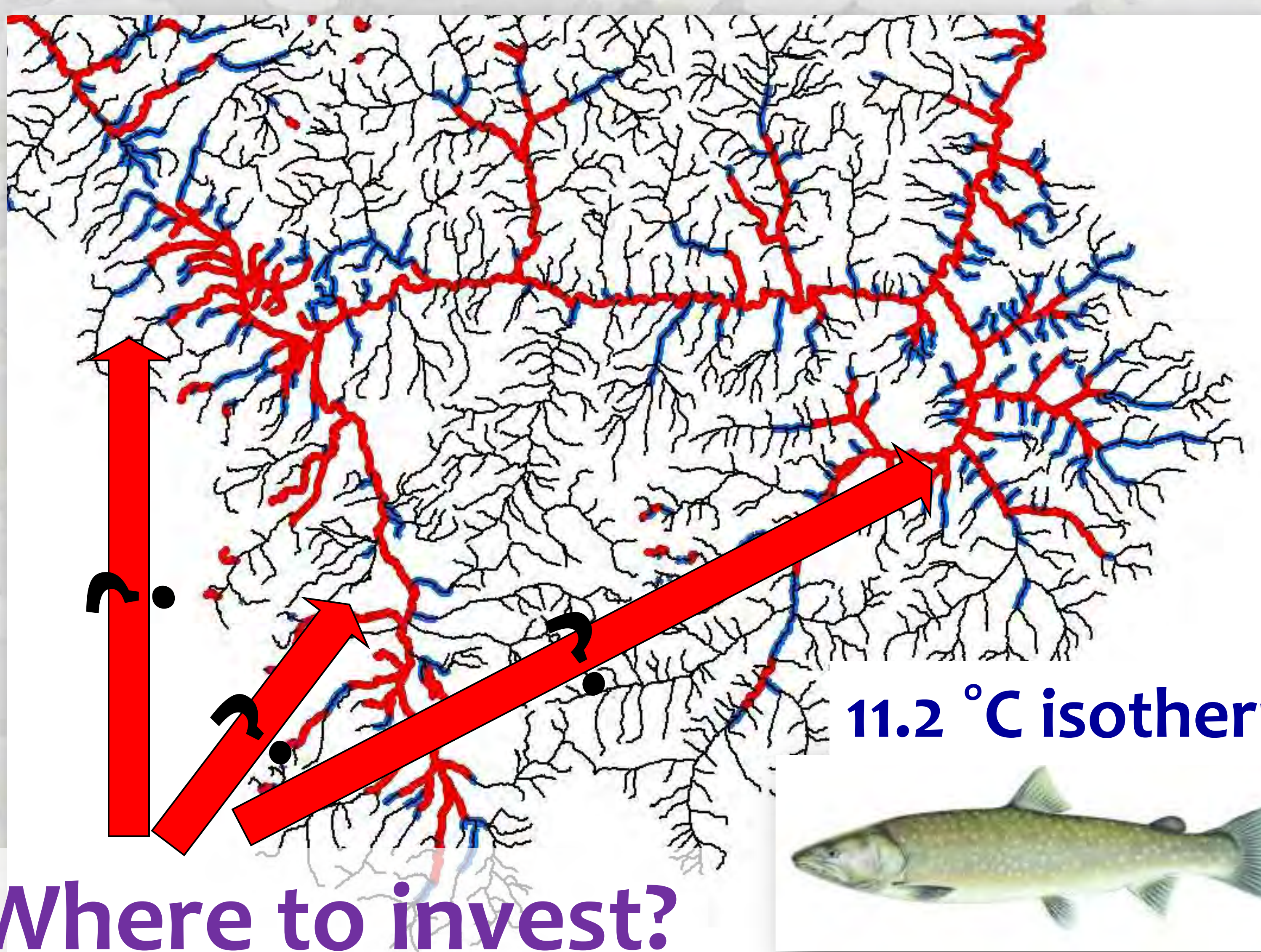
Spatial Variation in Habitat Loss

+1°C stream temperature scenario



Difference Map Shows Vulnerable Habitats

+1°C stream temperature scenario



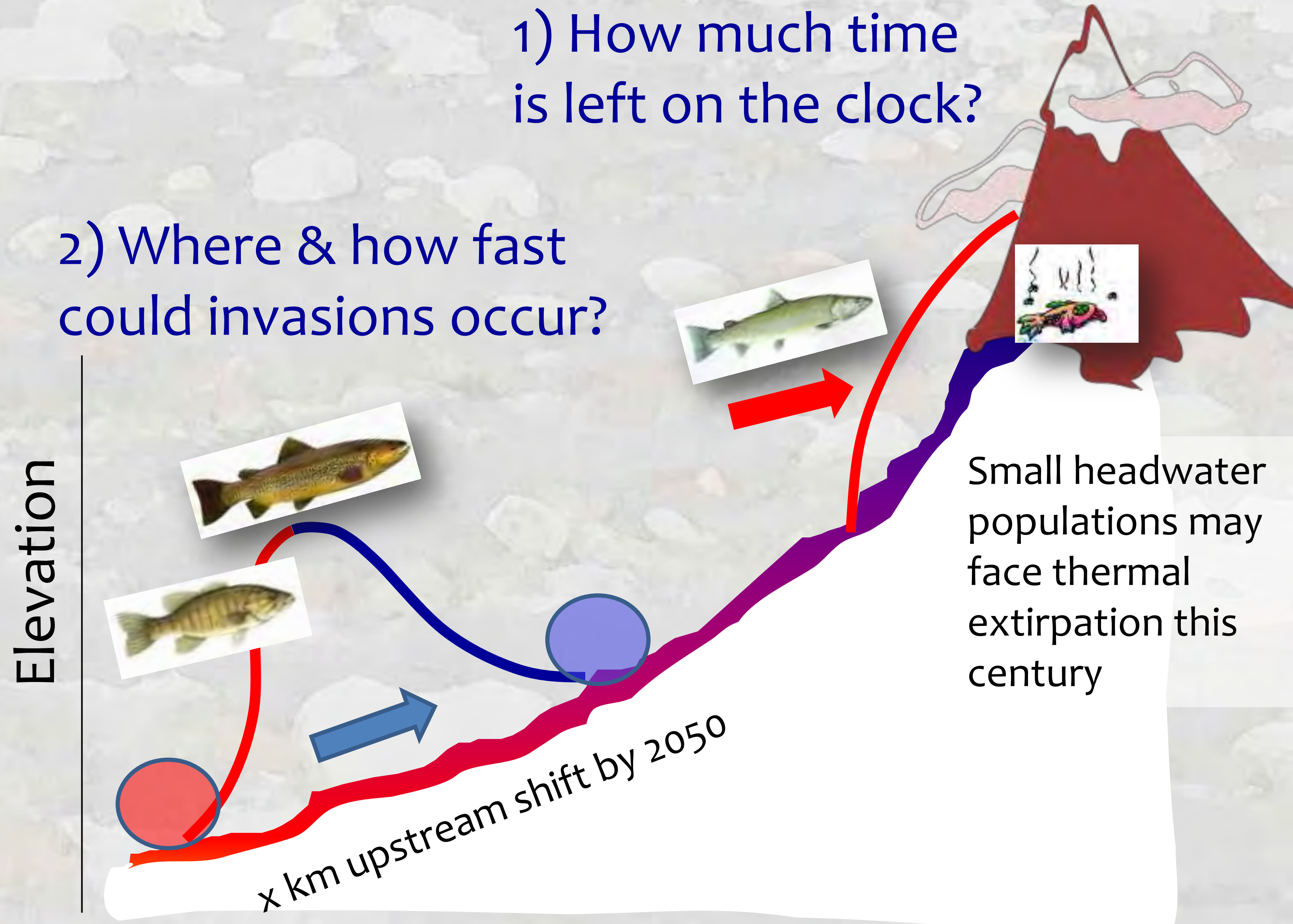
Where to invest?

11.2 °C isotherm

Precise Information Regarding Potential Species Invasions & Population Extirpations

1) How much time is left on the clock?

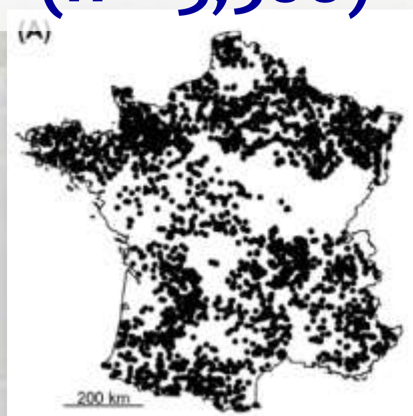
2) Where & how fast could invasions occur?



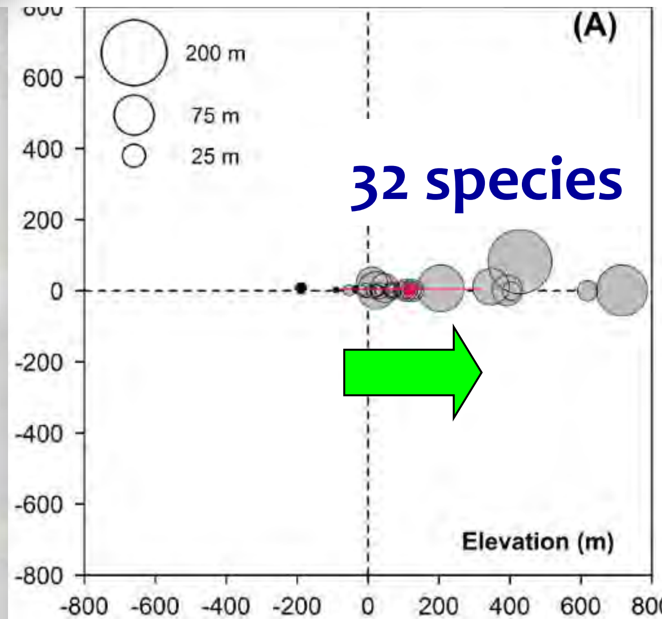
Small headwater populations may face thermal extirpation this century

Climate Change is Causing Stream Fish Distributions to Shift…

French Fish survey sites (n = 3,500)

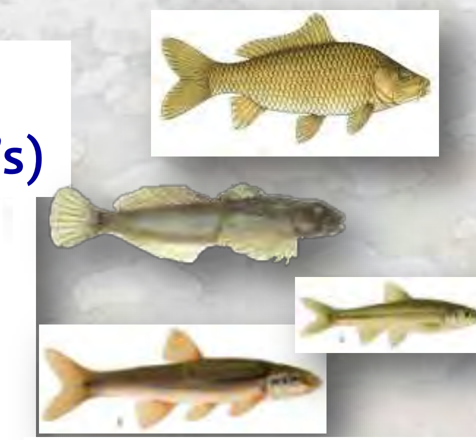


Difference in stream fish distributions (1980's vs 2000's)

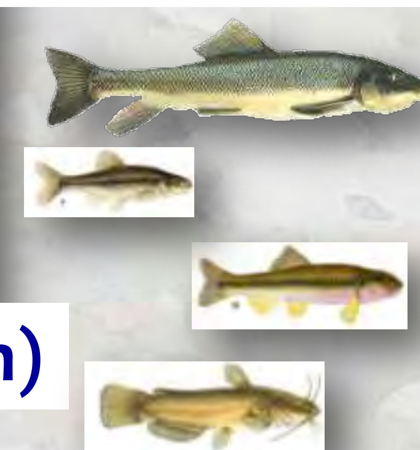


32 species

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

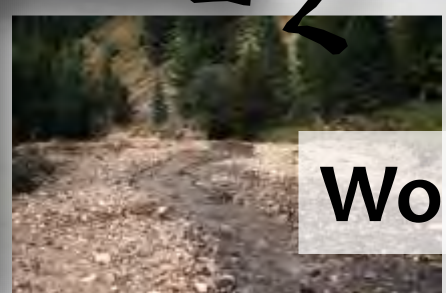
Strategic Prioritization of Restoration Actions is Possible

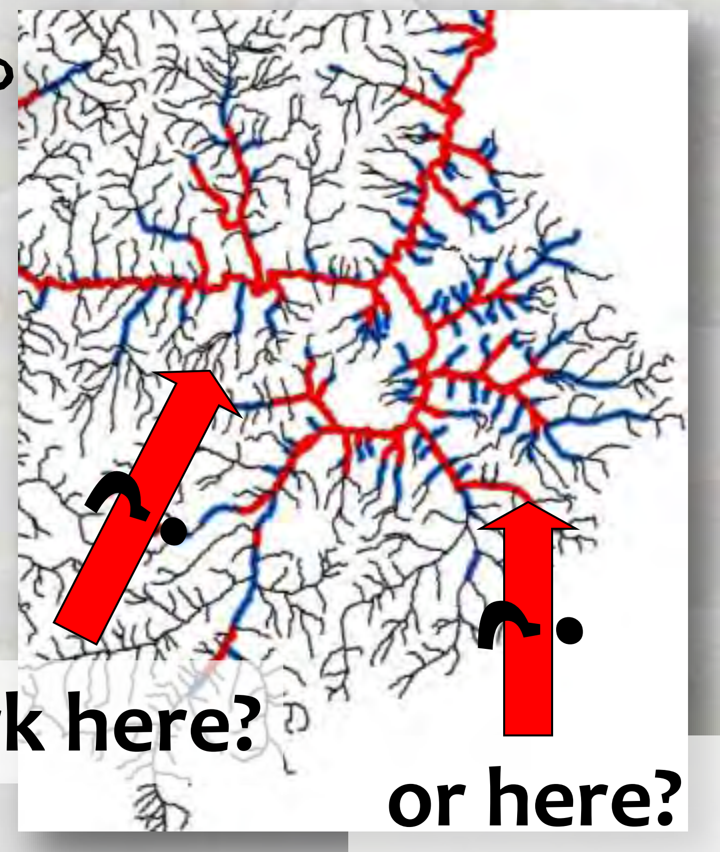
- •Maintaining/restoring flow…
- •Maintaining/restoring riparian…
- •Restoring channel form/function…
- •Prescribed burns limit wildfire risks…
- •Non-native species control…
- •Improve/impede fish passage…









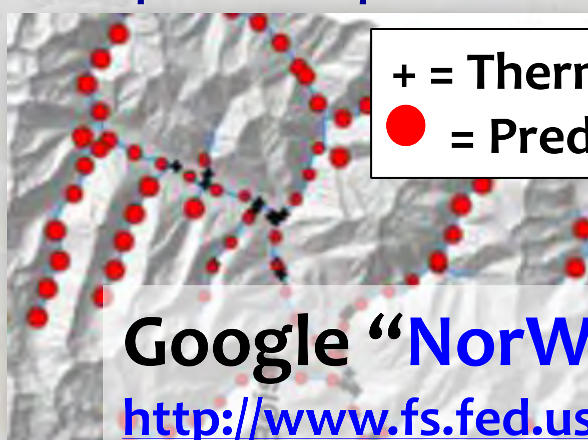


NorWeST is a “Crowd-Sourced” Model Developed from Everyone’s Data

NorWeST Website Distributes Temperature Products GIS Data

1) GIS shapefiles of stream temperature scenarios

2) GIS shapefiles of stream temperature model prediction precision

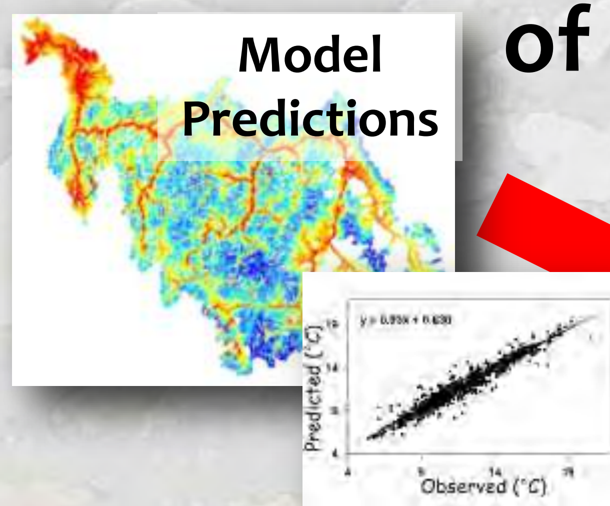


3) Temperature data summaries

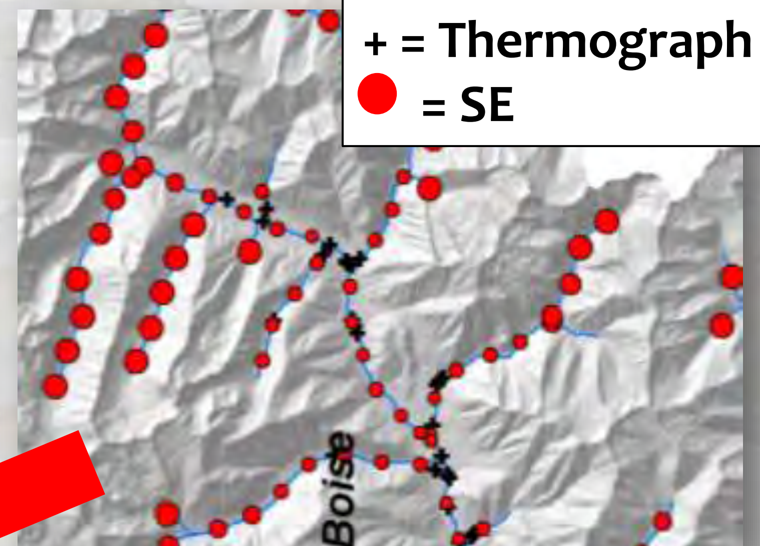
Google "**NorWeST**" or go here…

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

S34_PredSE = Spatially Explicit Maps of Prediction Uncertainty

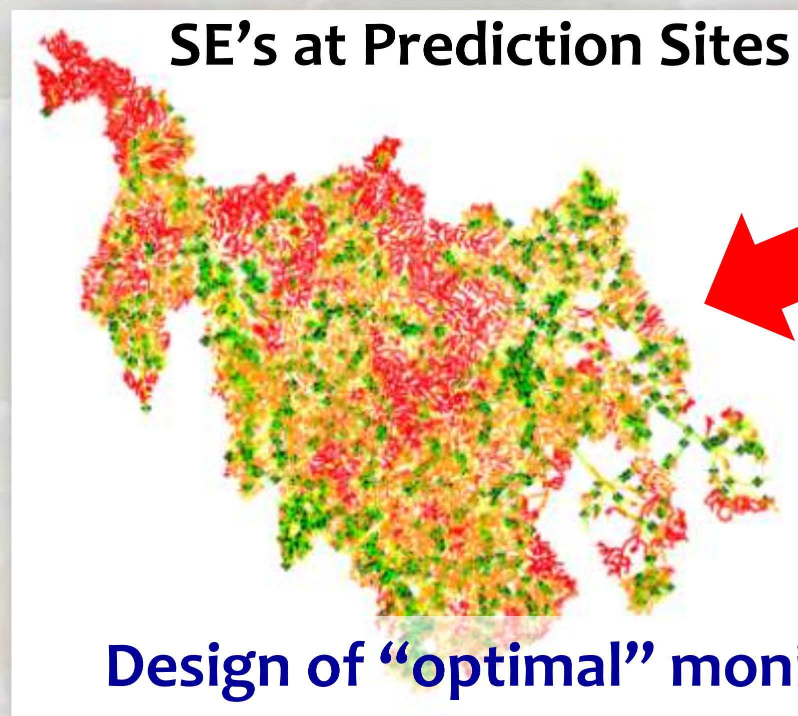


Temperature Prediction SE's



SE's are small near sites with temperature measurements

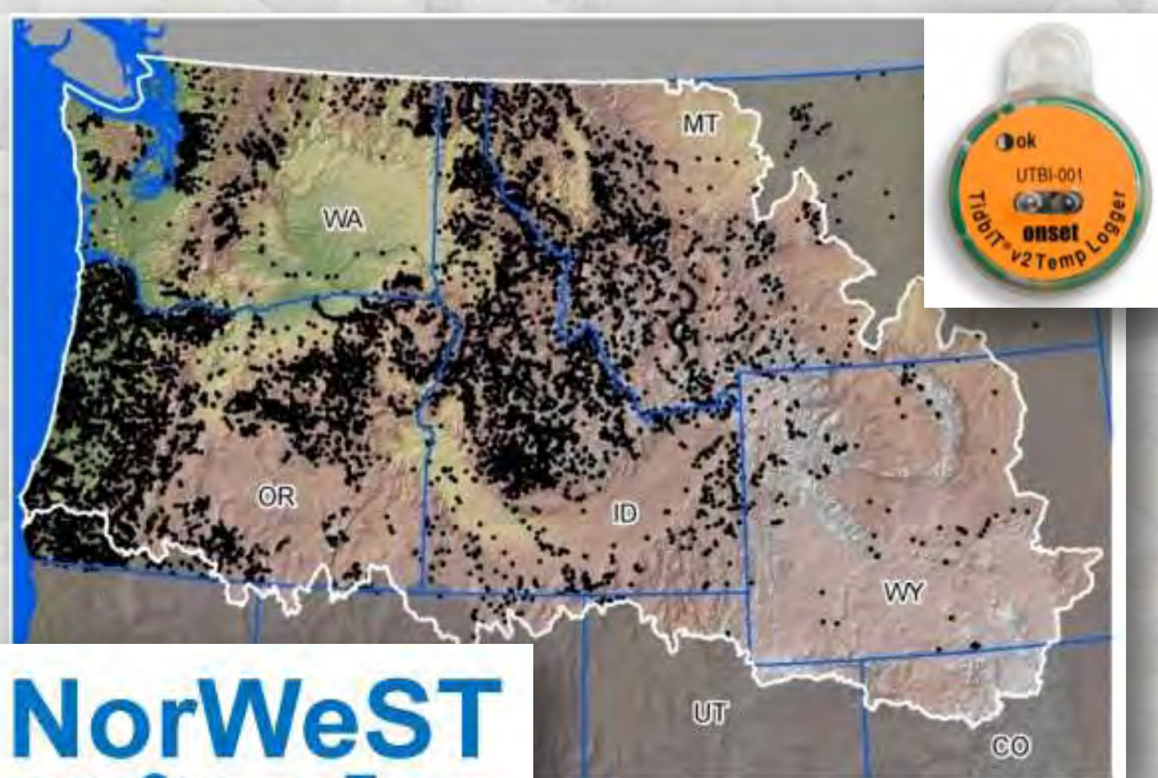
SE's at Prediction Sites



Design of "optimal" monitoring networks now possible

Data Availability Provides Flexibility

Daily Data Summaries (Min/Max/Mean)



- **Calculate other metrics**
- **Fit other models**

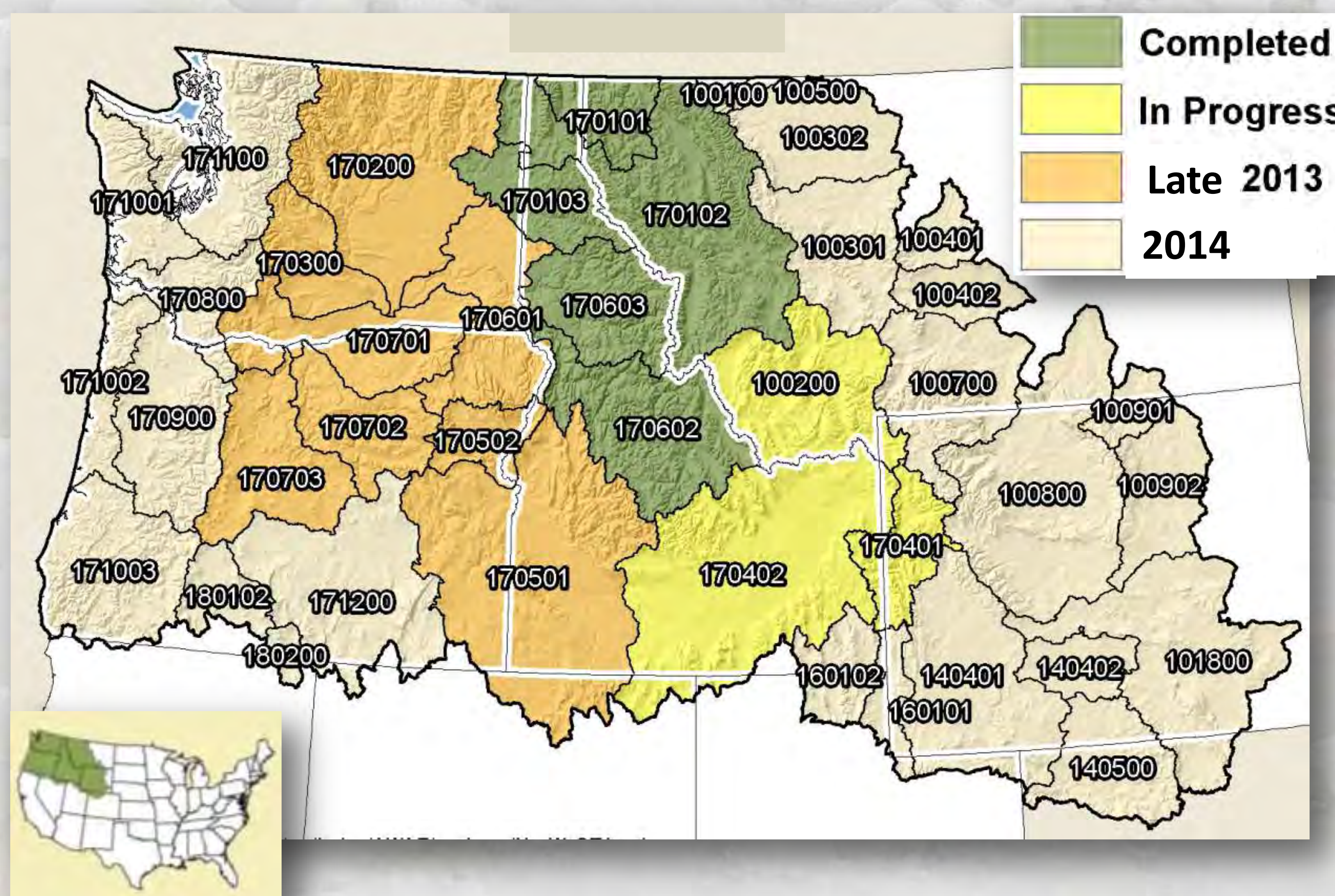
NorWeST
Stream Temp

MWAT ~ **Maximum** ~ **Minimum**

MDAT ~ **AWAT** ~ **Degree-days** ~ Mean

NorWeST Schedule

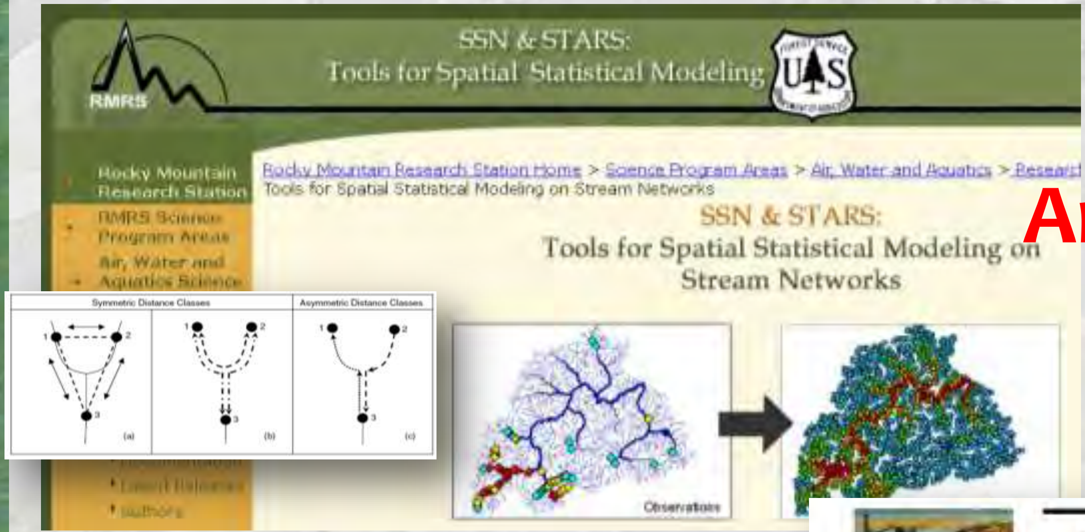
Interior Columbia Done by end of 2013



SSN/STARS Website

Google "SSN/STARS"

Open Source SoftWare Tools, Example Datasets, & Documentation



Analytical Stream Ecosystem is Growing

ECOLOGY LETTERS

Ecology Letters, (2013)

Modelling dendritic ecological networks in space: an integrated network perspective

Journal of Statistical Software

SSN: An R Package for Spatial Statistical Modeling on Stream Networks

Jay M. Ver Hoef, Erin E. Peterson, David Clifford, Rohan Shah

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

Supporting Research…

Regional Stream Temperature Modeling Approach…

Ecological Applications, 20(5), 2010, pp. 1350–1371
© 2010 by the Ecological Society of America

Effects of climate change and wildfire on stream temperatures and salmonid thermal habitat in a mountain river network

DANIEL J. ISAAK,[1,3] CHARLES H. LUCE,[1] BRUCE E. RIEMAN,[1] DAVID E. NAGEL,[1] ERIN E. PETERSON,[2] DONA L. HORAN,[1] SHARON PARKES,[1] AND GWYNNE L. CHANDLER[1]

[1]*U.S. Forest Service, Rocky Mountain Research Station, Boise Aquatic Sciences Laboratory, 322 E. Front Street, Suite 401, Boise, Idaho 83702 USA*
[2]*Commonwealth Scientific and Industrial Research Organization (CSIRO), Division of Mathematical and Information Sciences, Indooroopilly, Queensland, Australia*

A Moving Average Approach for Spatial Statistical Models of Stream Networks

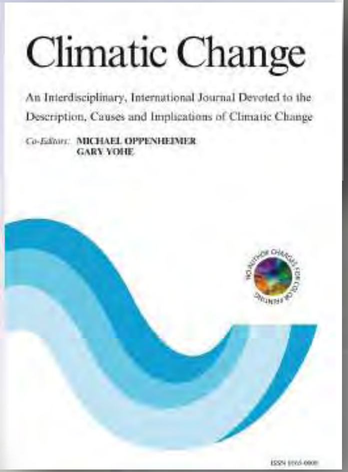
Jay M. VER HOEF and Erin E. PETERSON

Journal of the American Statistical Association
March 2010, Vol. 105, No. 489, Applications and Case Studies
DOI: 10.1198/jasa.2009.ap08248

Regional Stream Temperature Trend Assessment…

Climate change effects on stream and river temperatures across the northwest U.S. from 1980–2009 and implications for salmonid fishes

D. J. Isaak, S. Wollrab, G. Chandler



Climate "Velocity" in streams…

Global Change Biology

Global Change Biology (2012), doi: 10.1111/gcb.12073 (Online at http://onlinelibrary.wiley.com/journal/10.1111/%28ISSN%291365-2486/accepted)

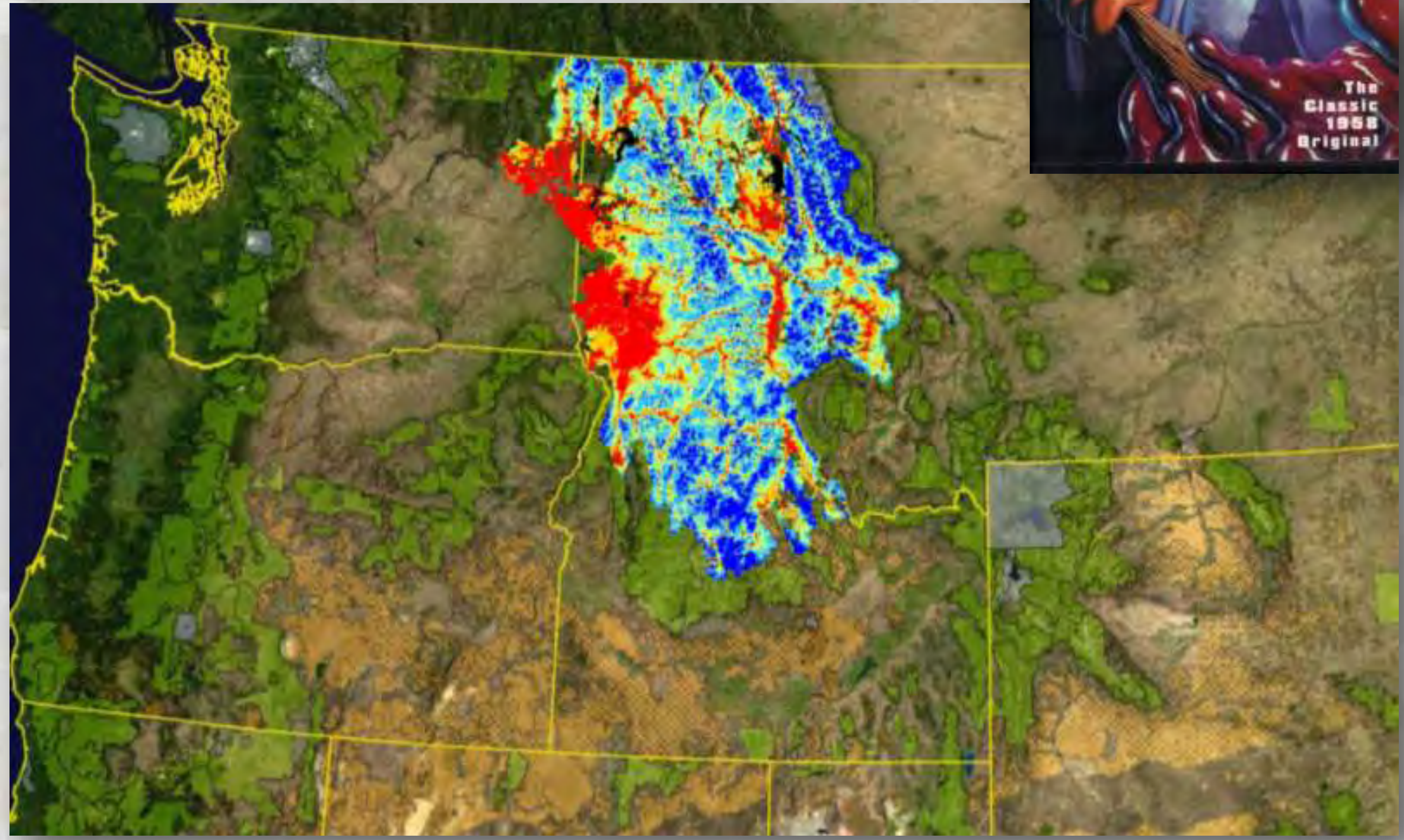
Stream isotherm shifts from climate change and implications for distributions of ectothermic organisms

DANIEL J. ISAAK* AND BRUCE E. RIEMAN†
**U.S. Forest Service, Rocky Mountain Research Station, Boise Aquatic Sciences Laboratory, 322 E. Front St., Suite 401, Boise, Idaho †U.S. Forest Service, Rocky Mountain Research Station (retired), P.O. Box 1541, Seeley Lake, MT*

Isaak & Rieman. 2012. *Global Change Biology* **19**, doi: 12073

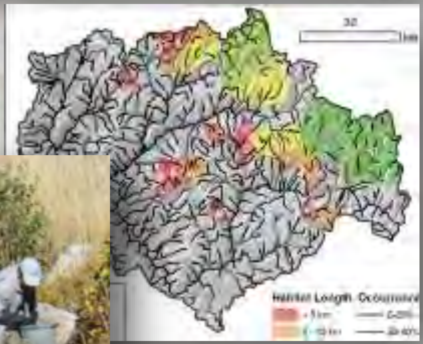
The Blob is Growing…

- 14,370 summers of data swallowed
- 92,000 stream kilometers of thermal ooze mapped

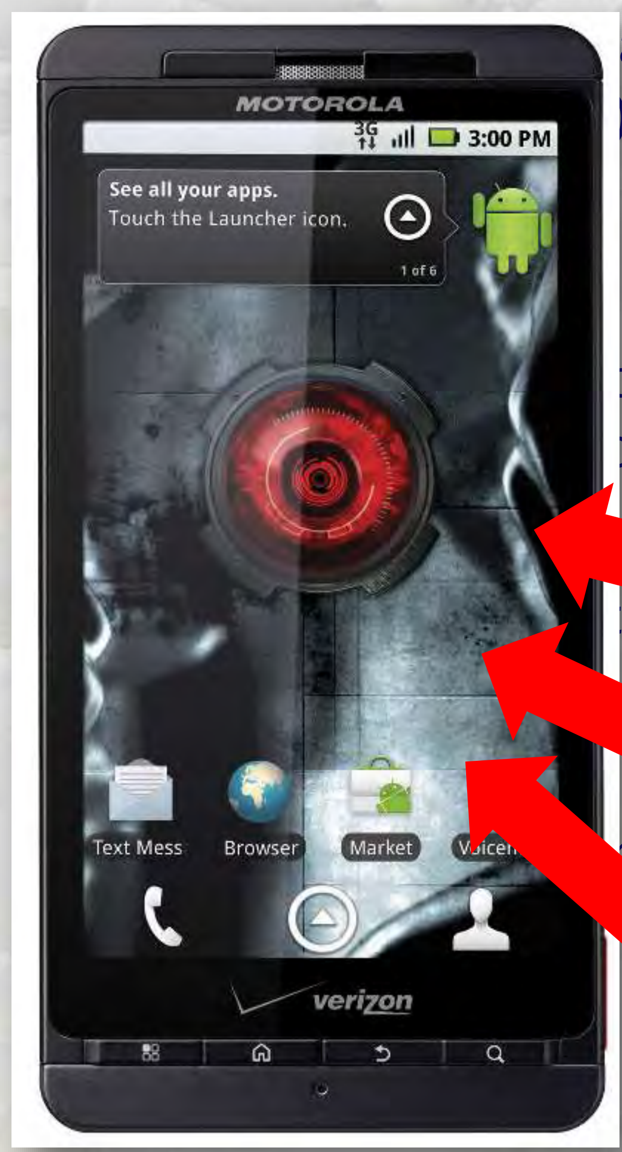


NorWeST Facilitating Related Projects

- 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 Data Network

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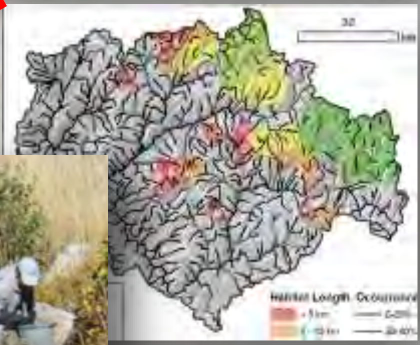
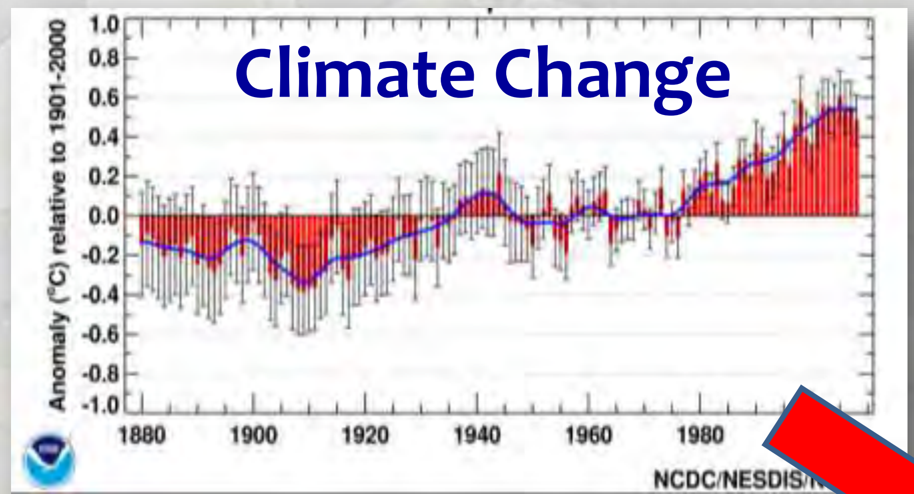


Need to Do More With Less, but What If… We Did Much More?

Climate Change



Urbanization & Population Growth

Shrinking Budgets

A Special Thanks to The 60+ Data Contributors and Partner Agencies…

Great Northern
LANDSCAPE CONSERVATION COOPERATIVE


The End