Applications of the NorWeST regional stream temperature model to improve conservation and monitoring of aquatic resources

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

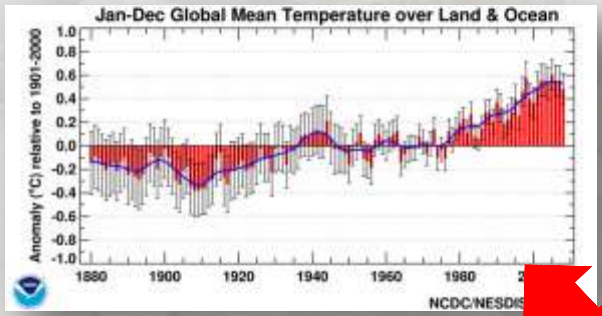
U.S. Forest Service

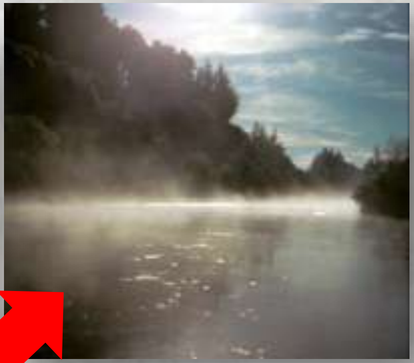
[1]Trout Unlimited

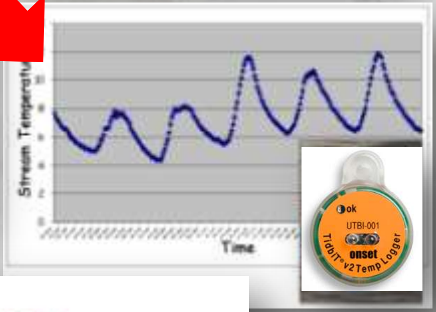
[2]CSIRO

[3]NOAA

[4]USGS

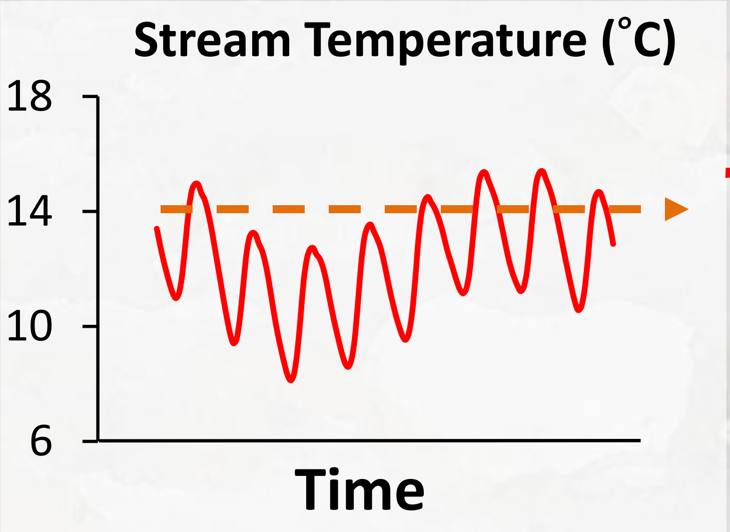




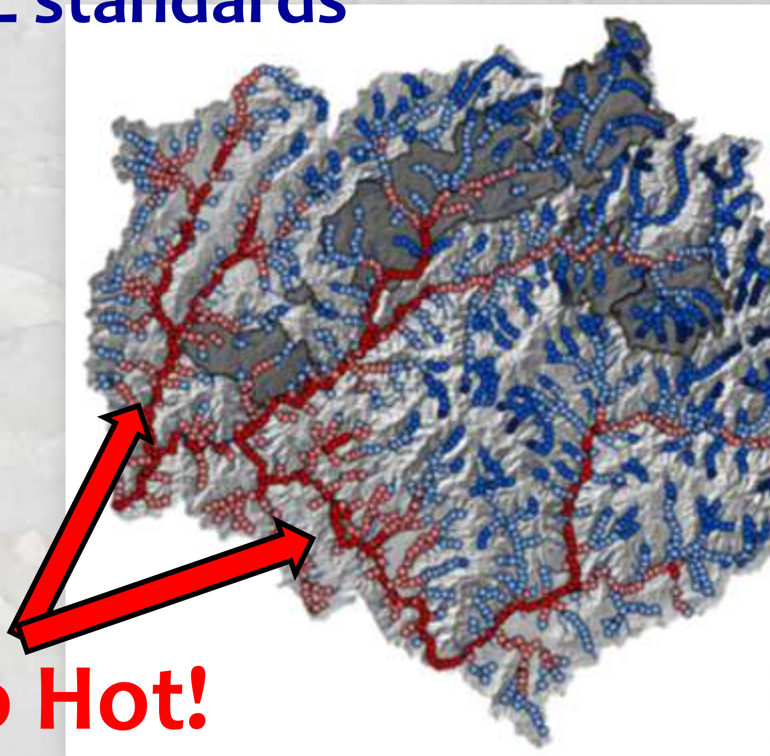


Great Northern
LANDSCAPE CONSERVATION COOPERATIVE

Temperature is Important Within Regulatory Contexts



TMDL standards



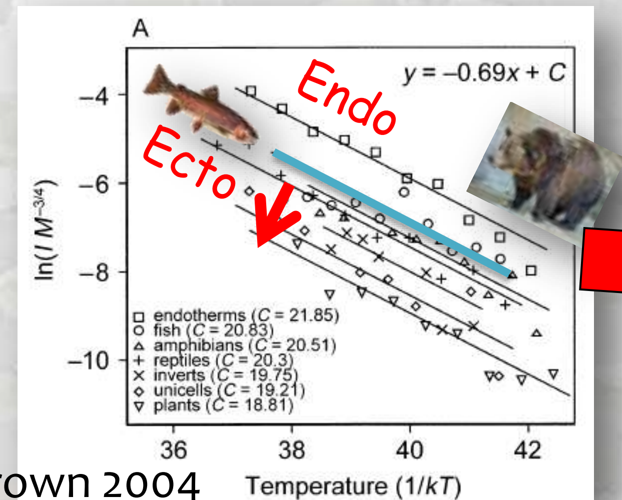
Too Hot!

Temperature (C)

- 5.35 - 7.92
- 7.92 - 10.5
- 10.5 - 13.1
- 13.1 - 15.6
- 15.6 - 18.2

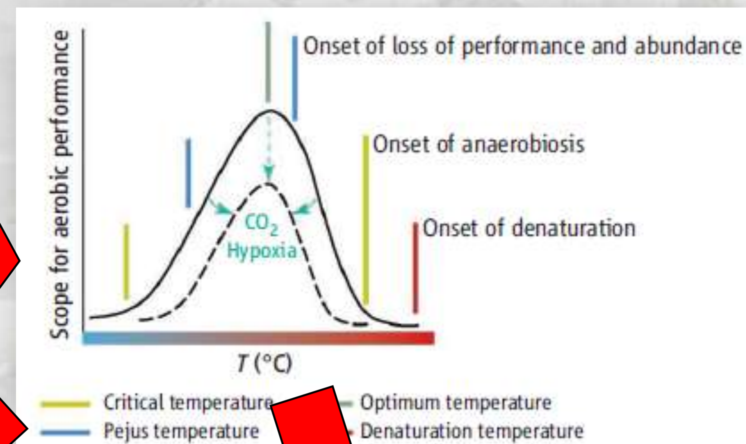
Temperature is Primary Control for Aquatic Ectotherms

Metabolism

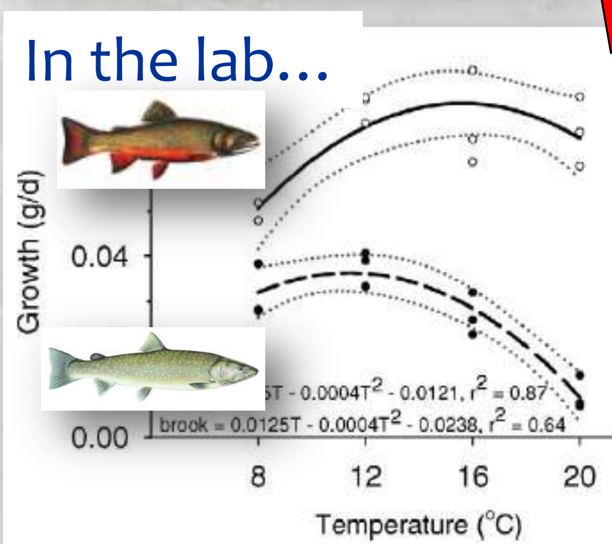


Brown 2004

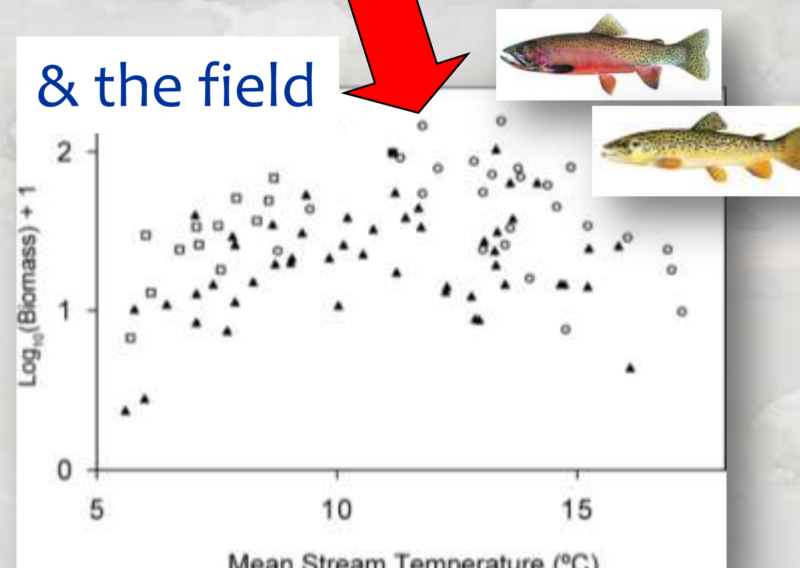
Thermal Niche



In the lab…



& the field



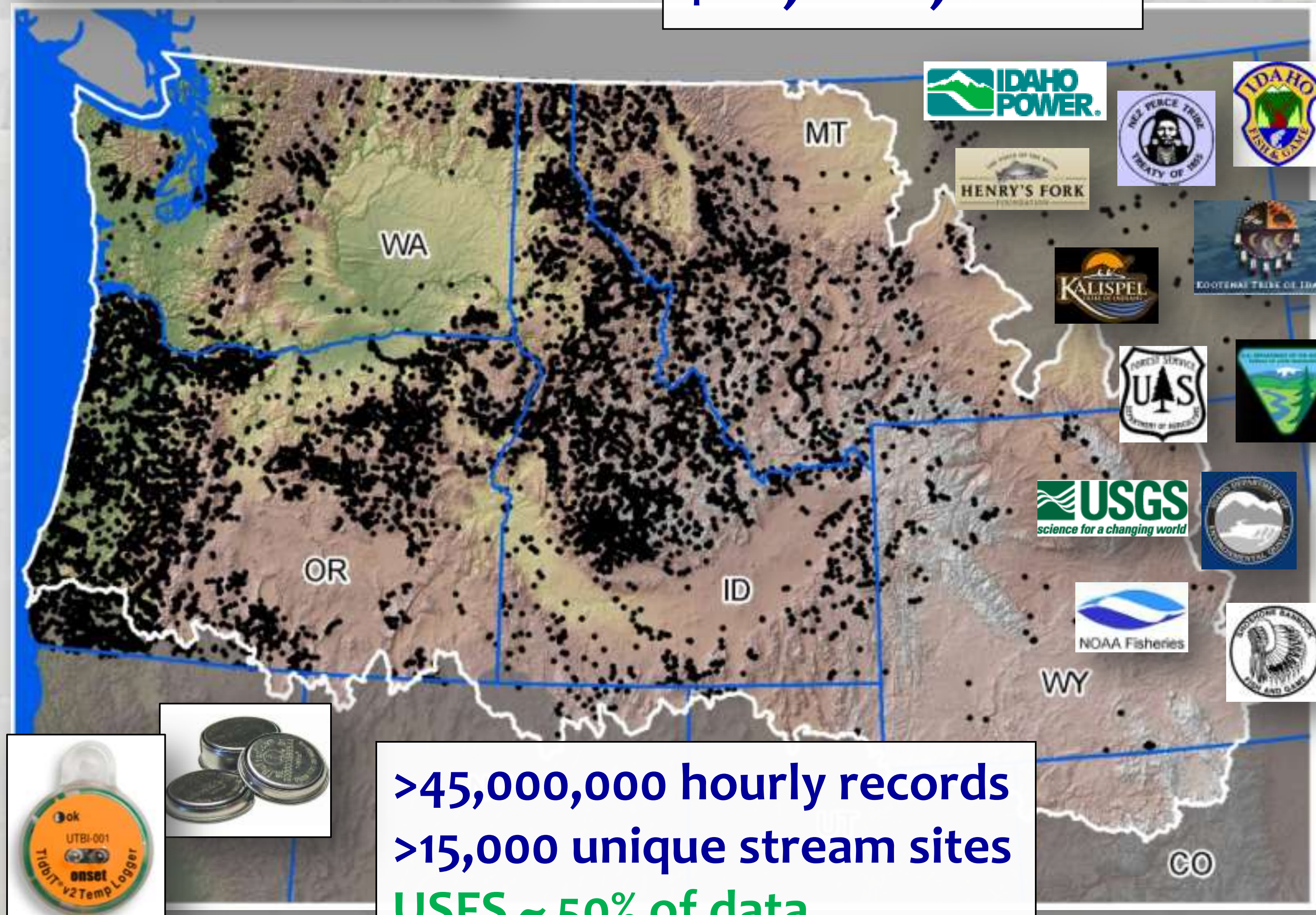
McMahon et al. 2007

Isaak & Hubert 2004

NorWeST Stream Temp

>60 agencies

$10,000,000

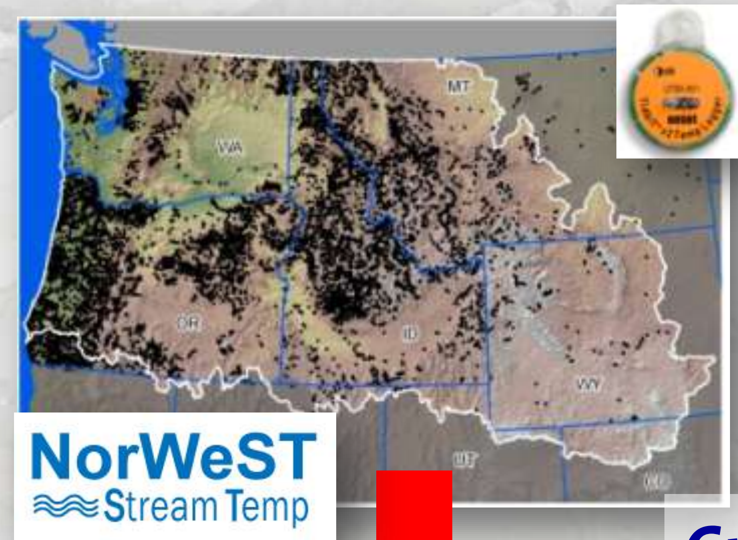


>45,000,000 hourly records

>15,000 unique stream sites

USFS ~ 50% of data

Regional Temperature Model



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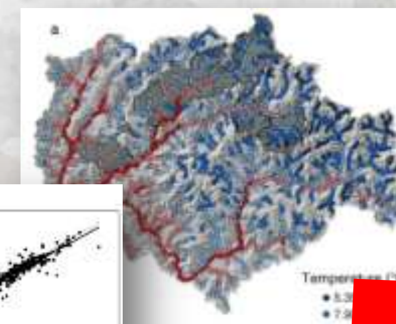
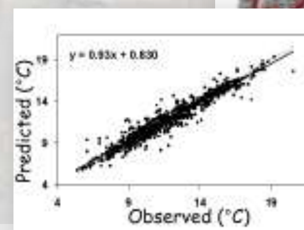
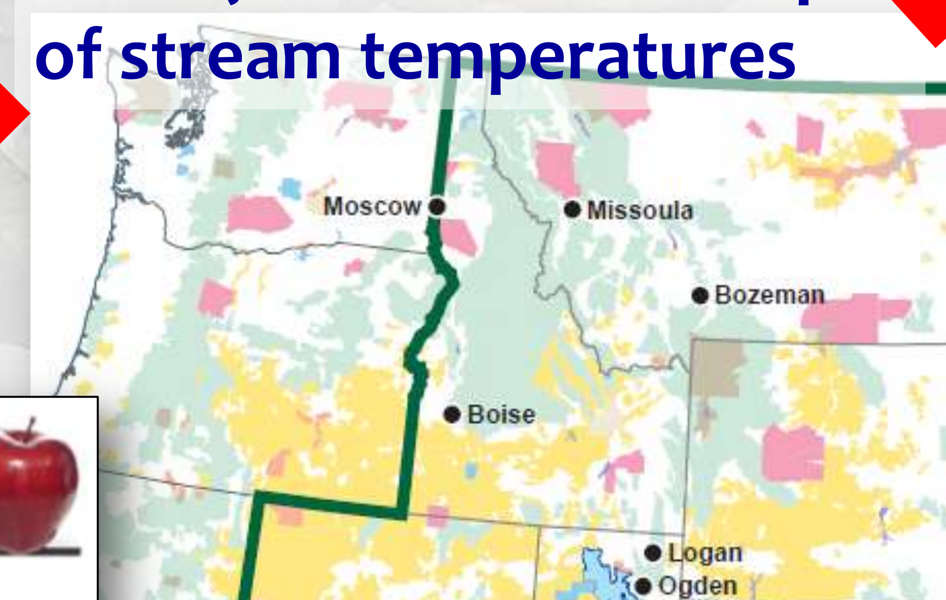
Accurate temperature models

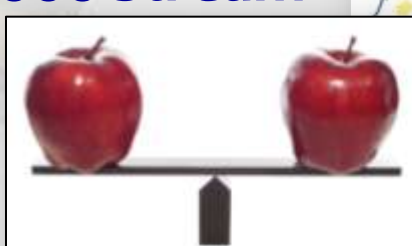




Cross-jurisdictional "maps" of stream temperatures

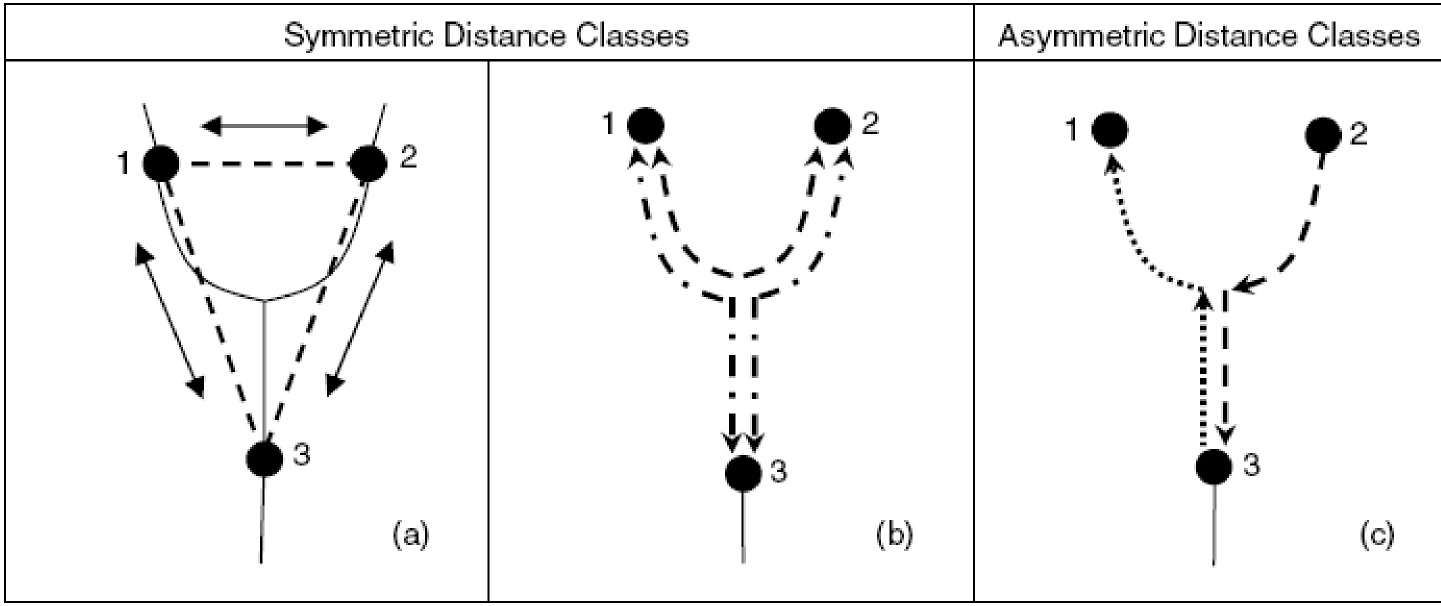


Consistent datum for strategic assessments across 350,000 stream kilometers



Spatial Statistical Stream Models

Valid means of data interpolation on networks



Advantages:

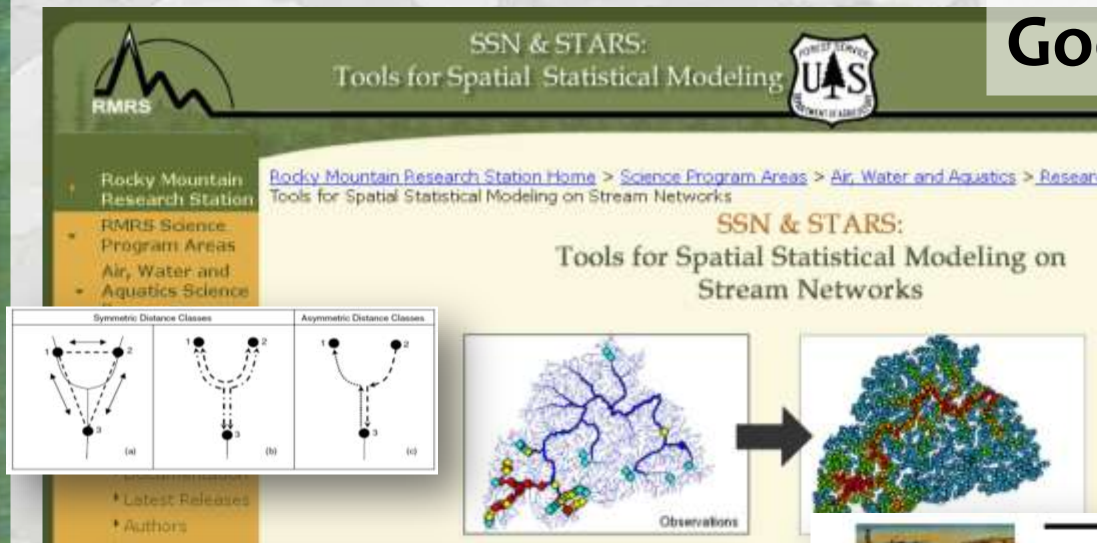
- Flexible & valid covariance structures that accommodate network topology & autocorrelation
- Much improved predictive ability & parameter estimates relative to non spatial models

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

Spatial Statistical Stream Models

SSN & STARS Website – FreeWare Tools & R package

Google "SSN/STARS"



Journal of Statistical Software

MMMMMM YYYY, Volume VV, Issue II. http://www.jstatsoft.org/

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

Clifford ... Brisbane — Rohan Shah, CSIRO, Brisbane

Environ Ecol Stat (2006) 13:449–464
DOI 10.1007/s10651-006-0022-8

ORIGINAL ARTICLE

Spatial statistical models that use flow and distance

Jay M. Ver Hoef · Erin Peterson · David Theobald

Functional Linkage of Water basins and Streams (FLoWS) v1 User's Guide:
ArcGIS tools for Network-based analysis of freshwater ecosystems

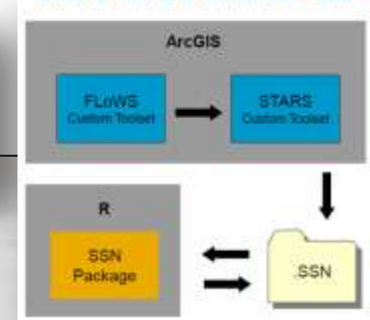
Authors:

A Moving Average Approach for Spatial Statistical Models of Stream Networks

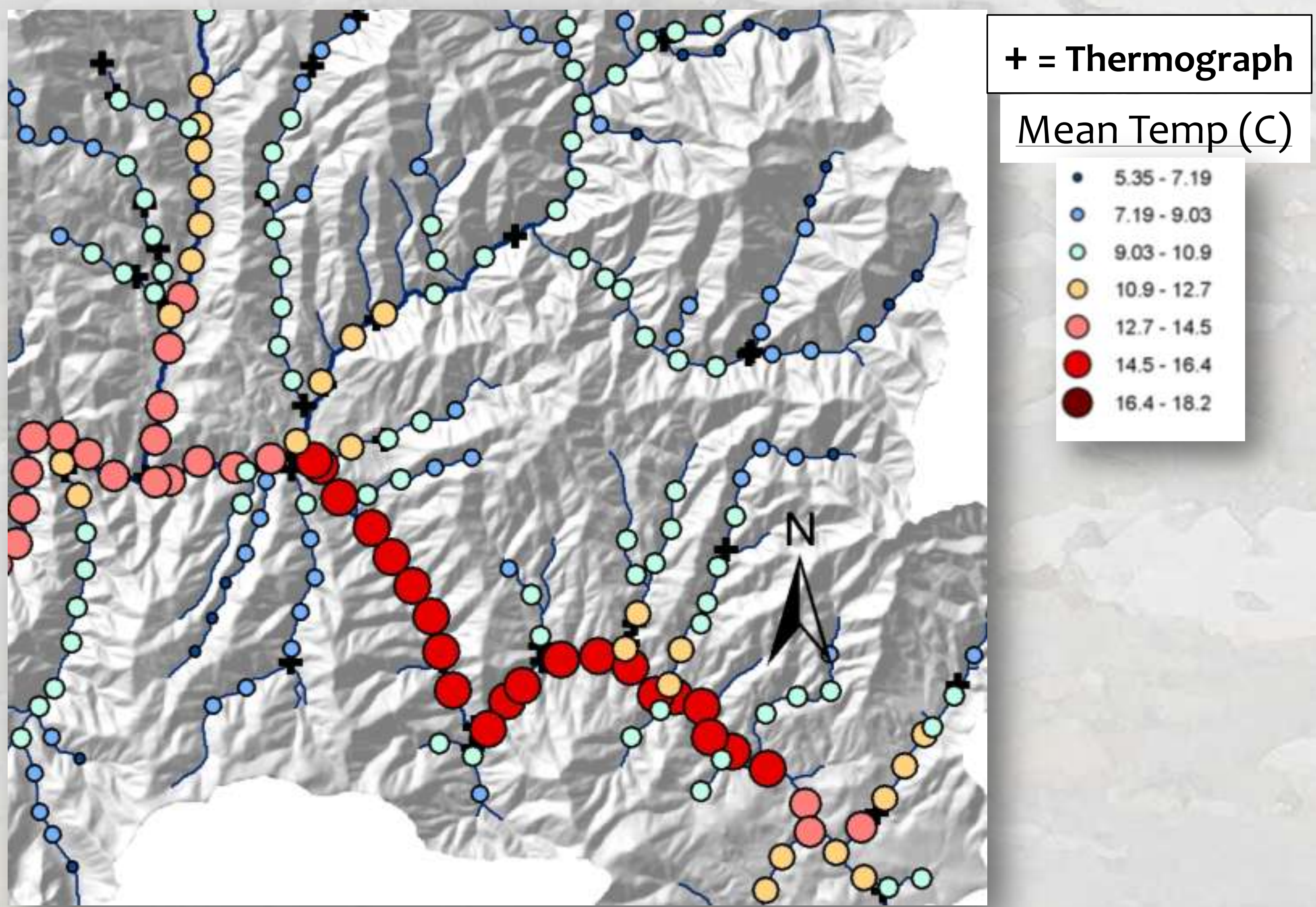
Jay M. Ver Hoef and Erin E. Peterson

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

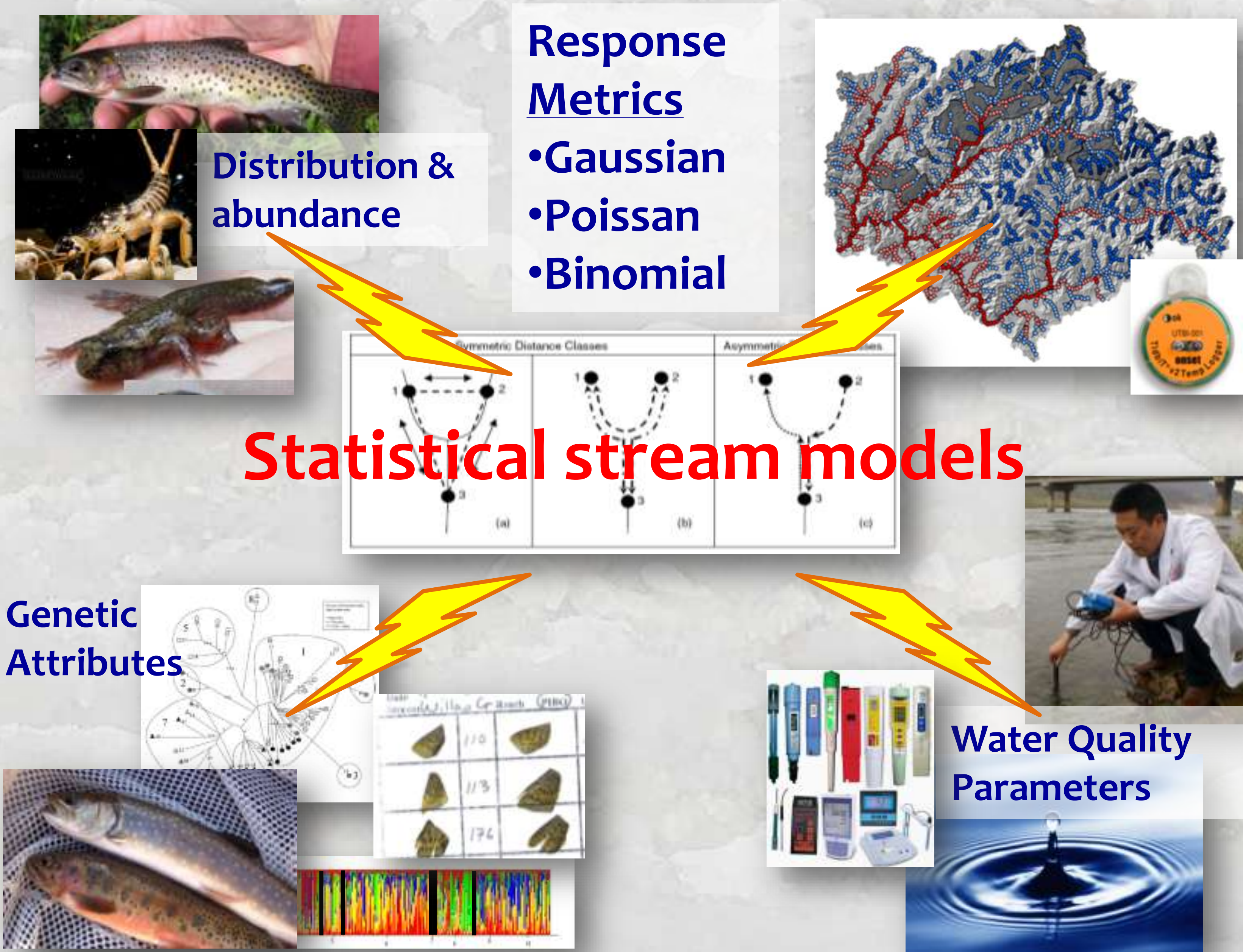
Suite of GIS and Statistical Tools



Spatial Network Models Work the Way that Streams Do…

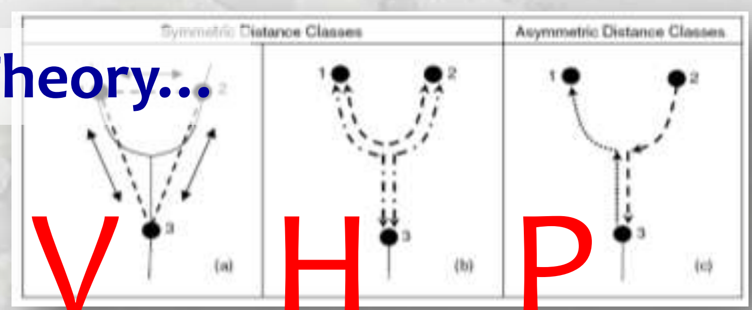


Temperature Data, but also…

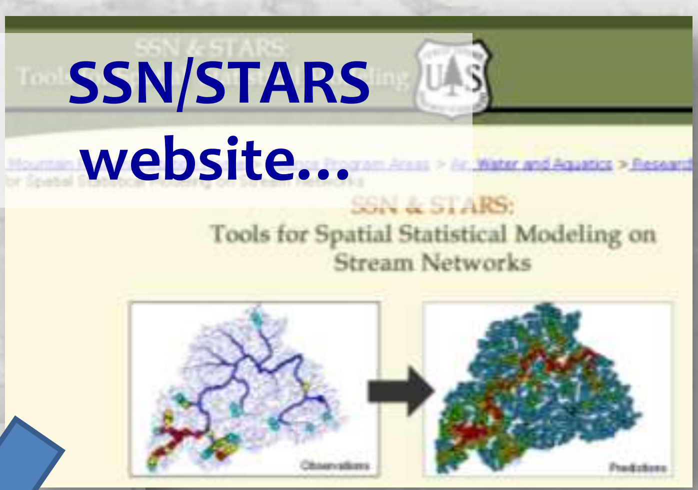


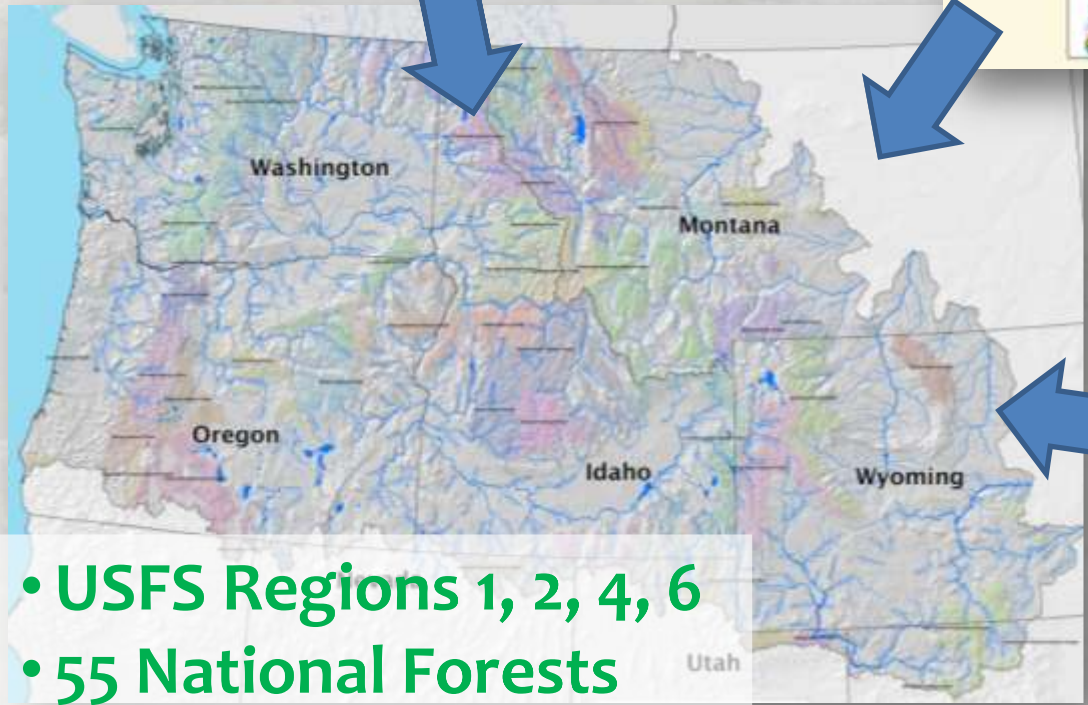
Regional Infrastructure for Spatial Analysis of Stream Data

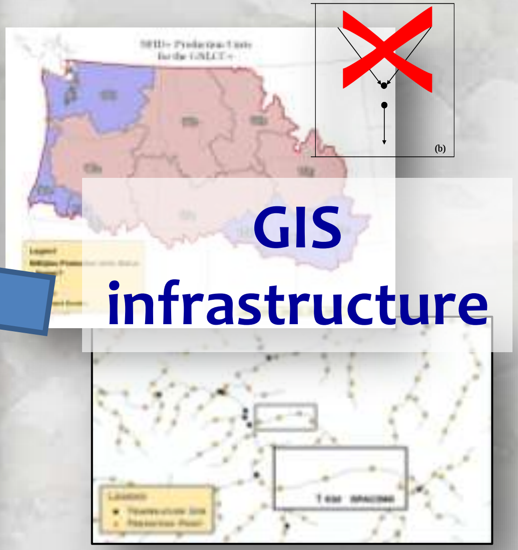
Theory…



SSN/STARS website…



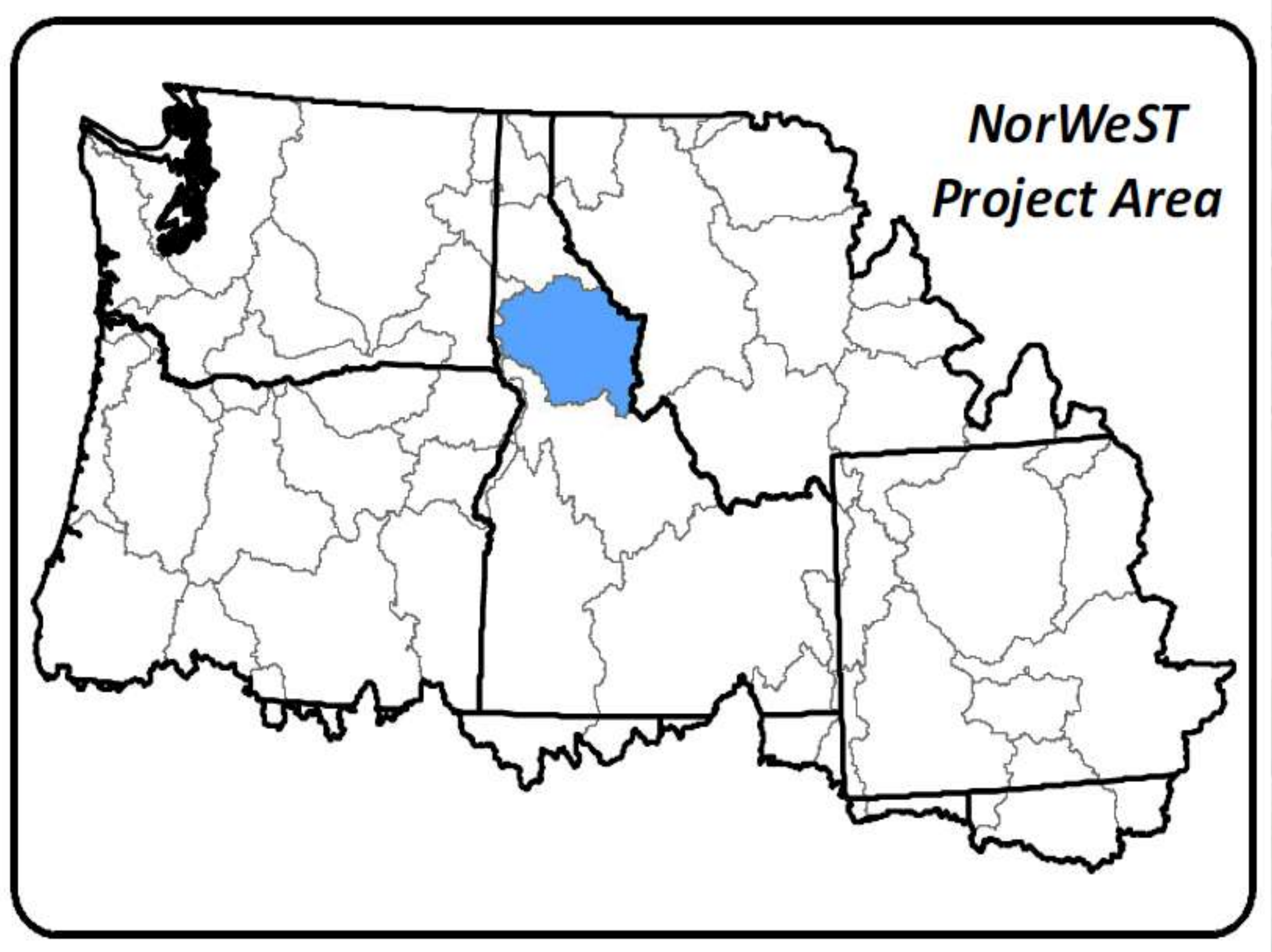




GIS infrastructure

- USFS Regions 1, 2, 4, 6
- 55 National Forests

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

Clearwater River Temp Model

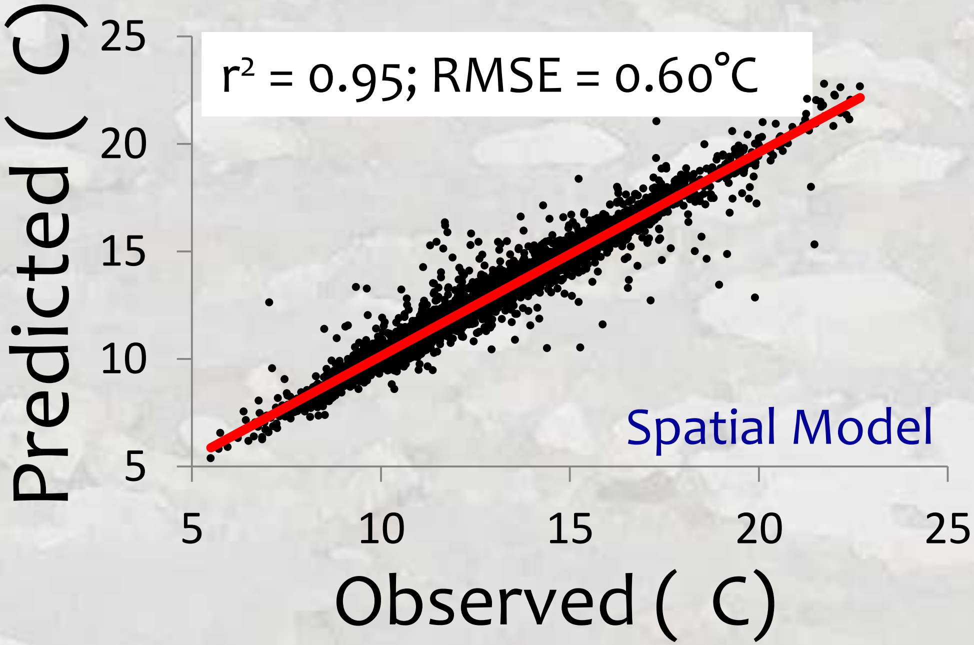
n = 4,487

Covariate Predictors

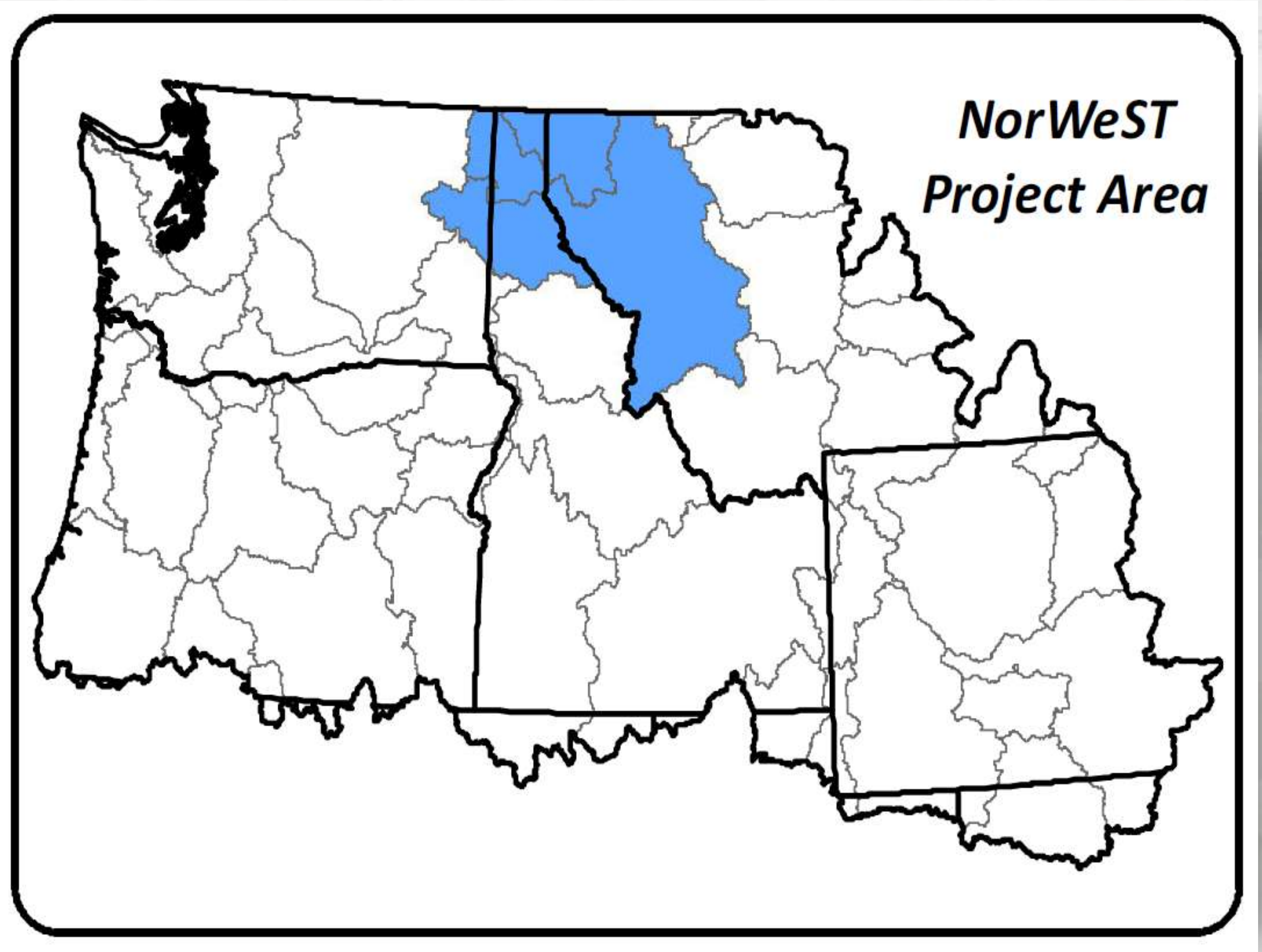
1. Elevation (m)
2. Canopy (%)
3. Stream slope (%)
4. Ave Precipitation (mm)
5. Latitude (km)
6. Lakes upstream (%)
7. Baseflow Index
8. Watershed size (km²)

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

Mean August Temperature

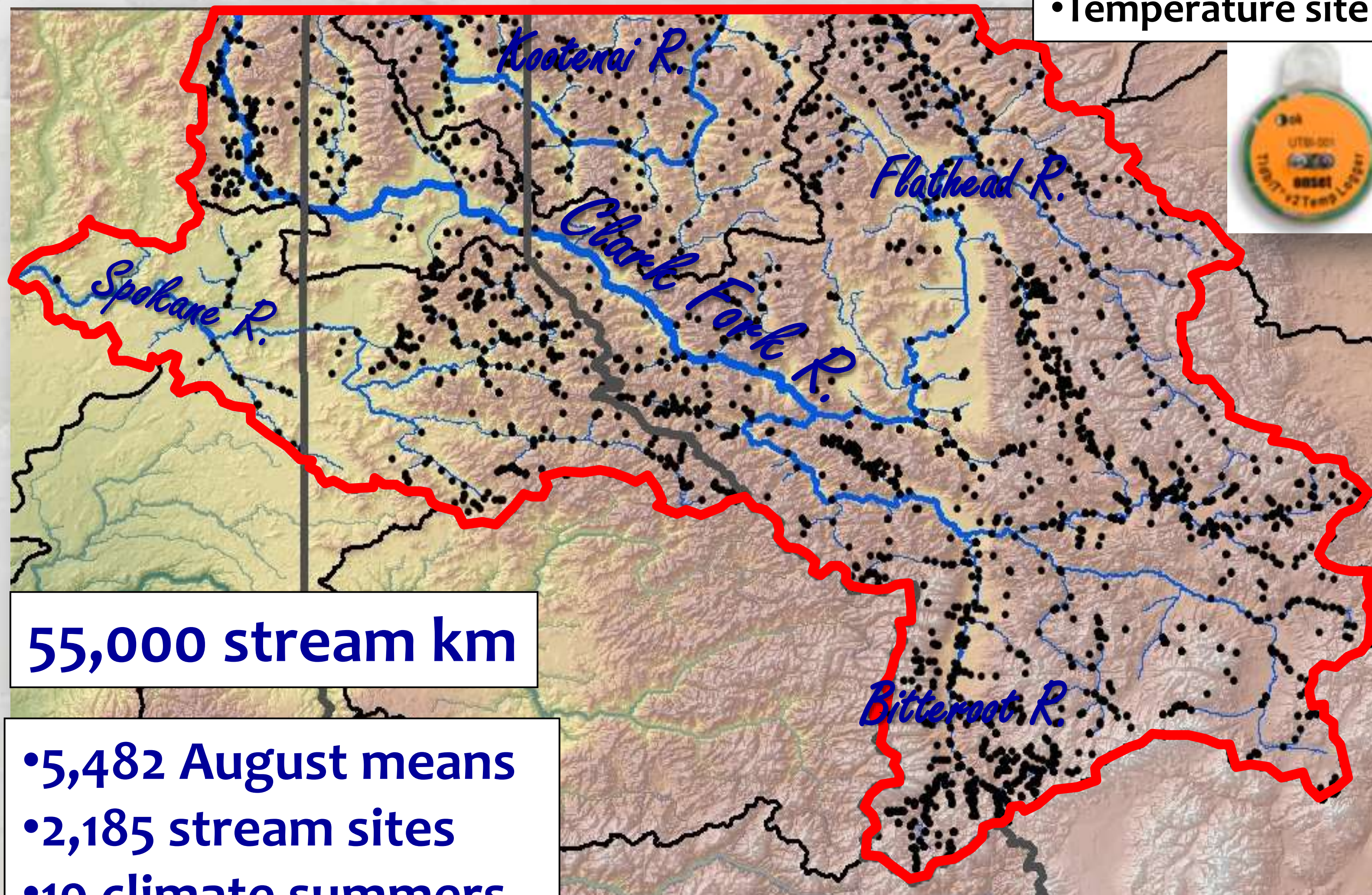


Example: SpoKoot River Basins



Example: SpoKoot River Basins

Data extracted from NorWeST



55,000 stream km

- 5,482 August means
- 2,185 stream sites
- 19 climate summers

SpoKoot River Temp Model

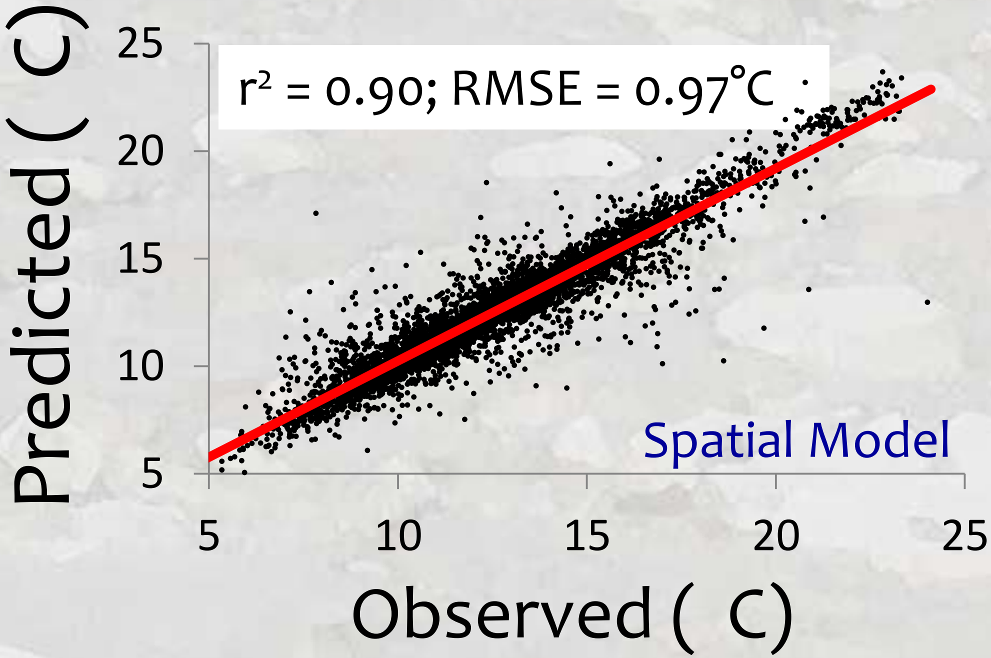
n = 5,482

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

Mean August Temperature



Why August Mean Temperature?

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

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

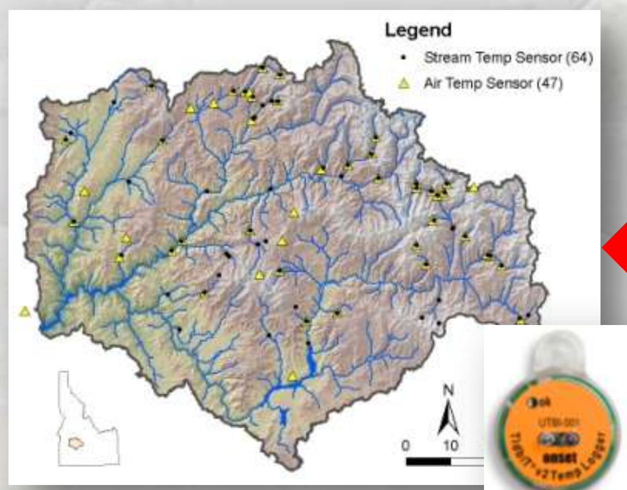
MDAT ~ **AWAT** ~ **Degree-days** ~ Mean

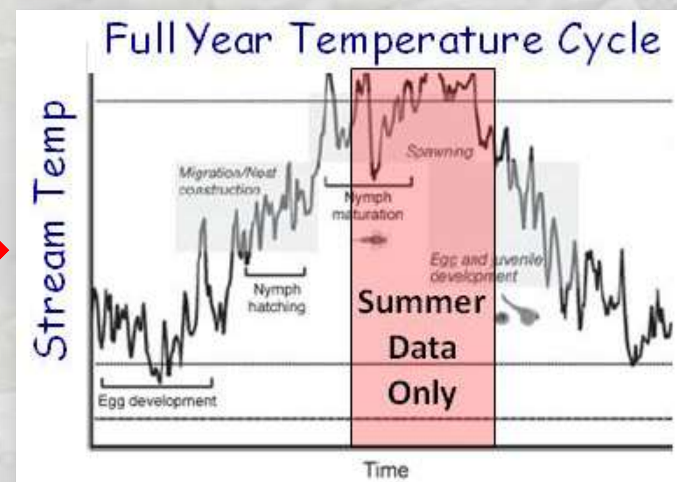
	Summer_mn	*Mwmt*	*Mwat*	*awat_mn*	*awmt_mn*	***August Mean***
Summer_mn						
Mwmt	0.93					
Mwat	0.98	0.94				
awat_mn	1.00	0.93	0.97			
awmt_mn	0.96	0.98	0.94	0.96		
August Mean	**0.99**	**0.92**	**0.96**	**0.99**	**0.95**	
August MWMT	0.92	0.99	0.92	0.92	0.98	**0.92**

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

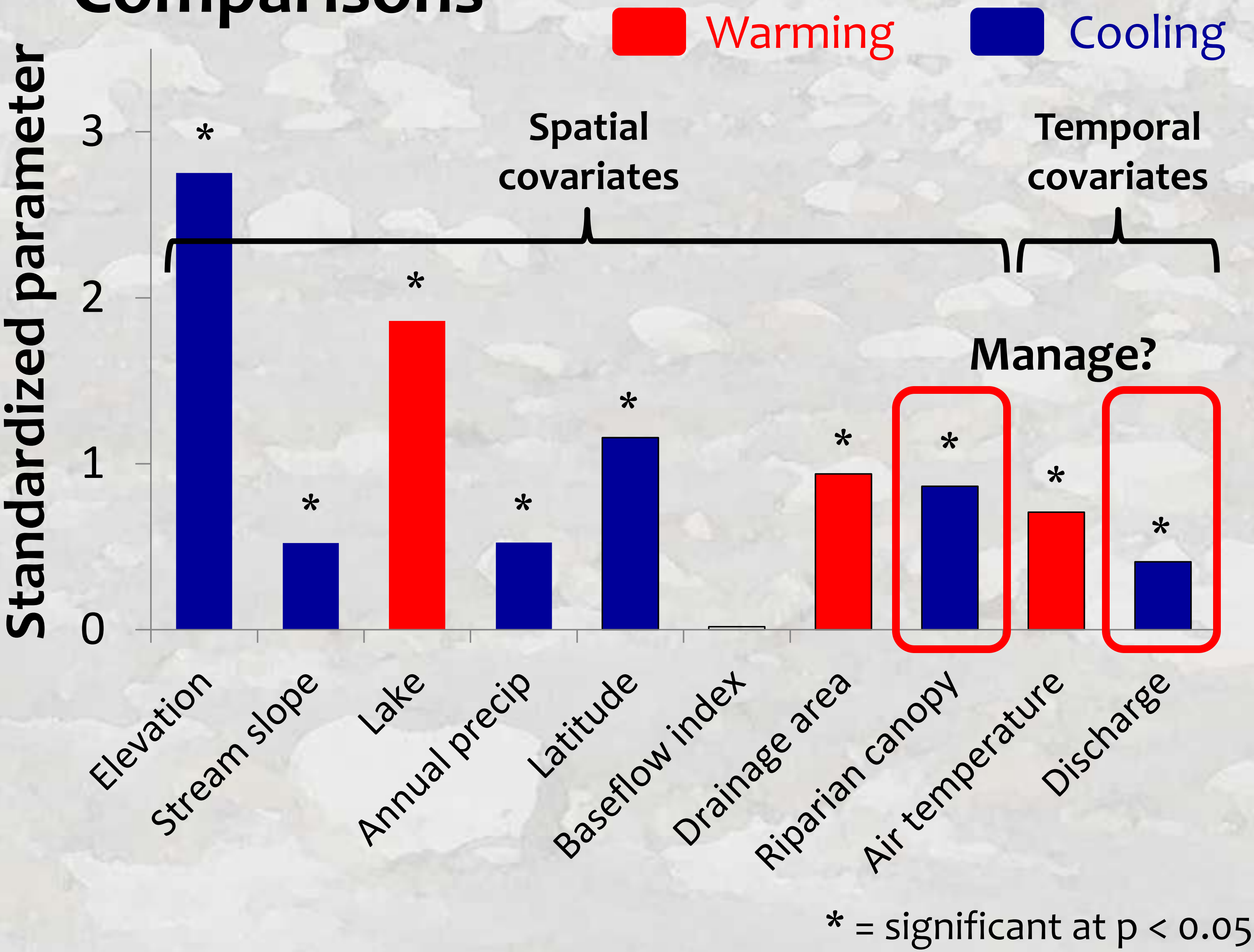
Summer Temperatures ~ Other Seasons

	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**



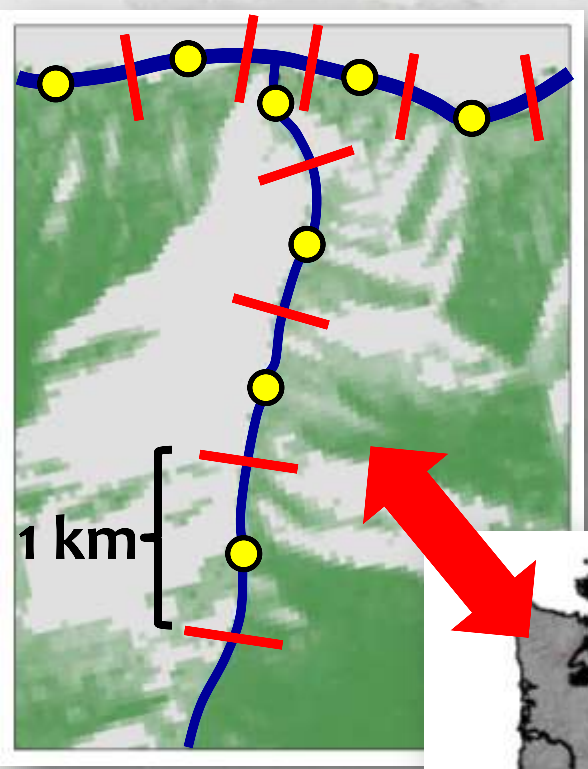


SpoKoot Temp Model Parameter Comparisons

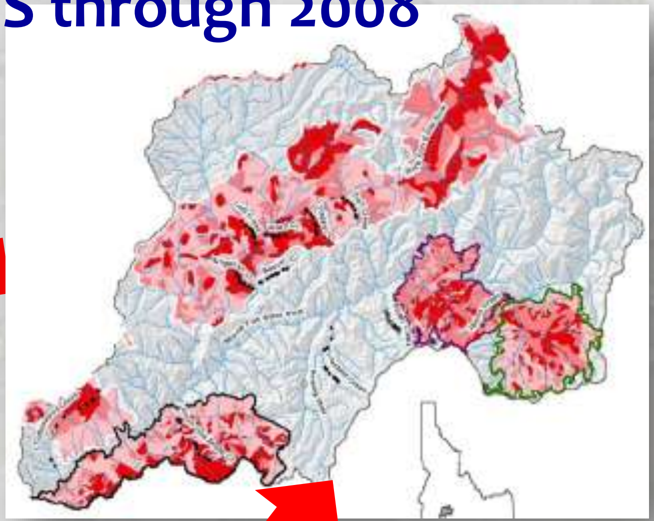


Riparian Canopy Predictor

%Canopy variable from 2001 NLCD



%Canopy adjusted by MTBS through 2008



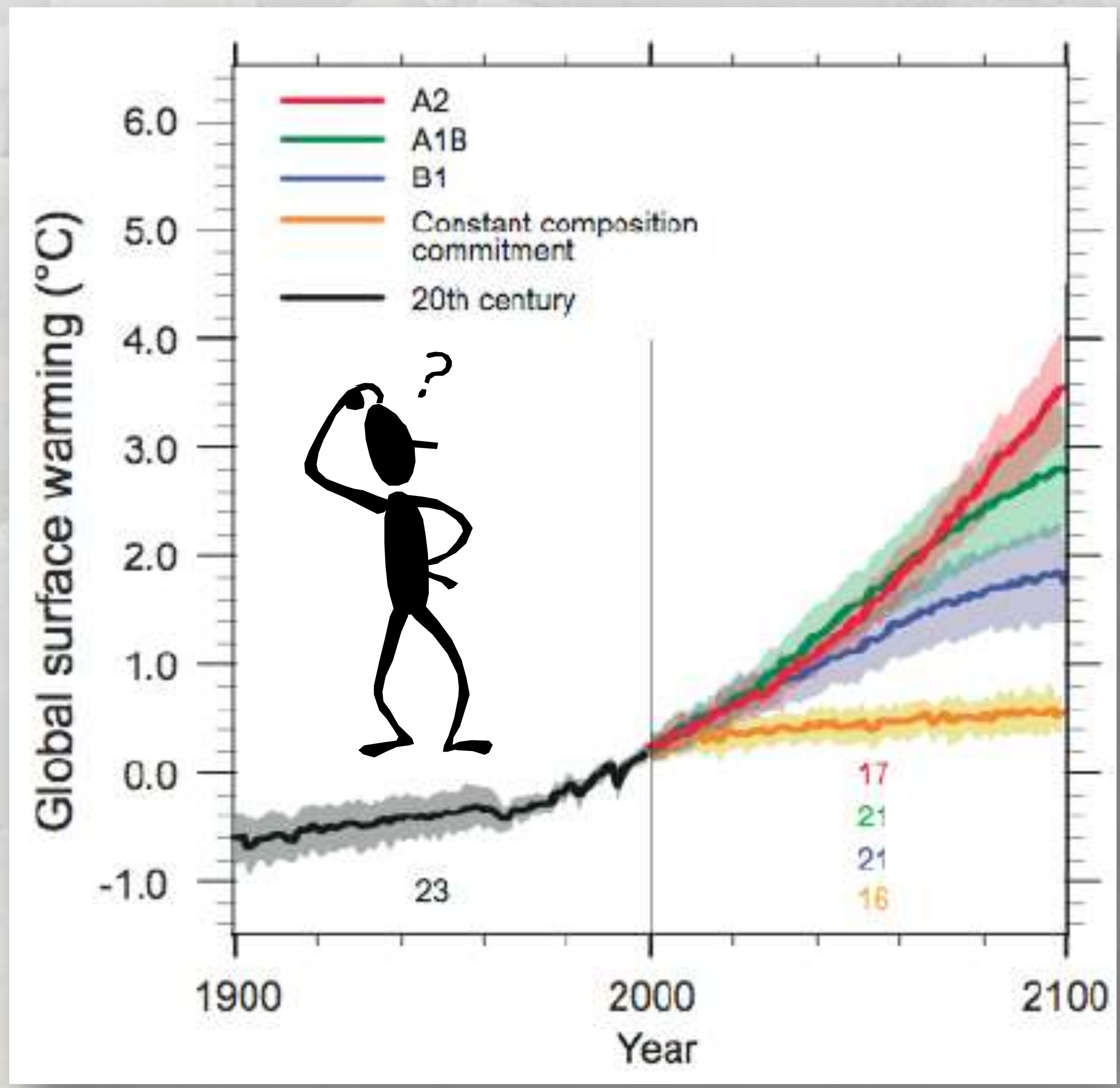
Post 2001 Wildfires

Also tested:

- LandFire
- TreeFrac
- Radiation measurements

Models Enable Climate Scenario Maps

Many possibilities exist…



Adjust…

- Air
- Discharge
- %Canopy

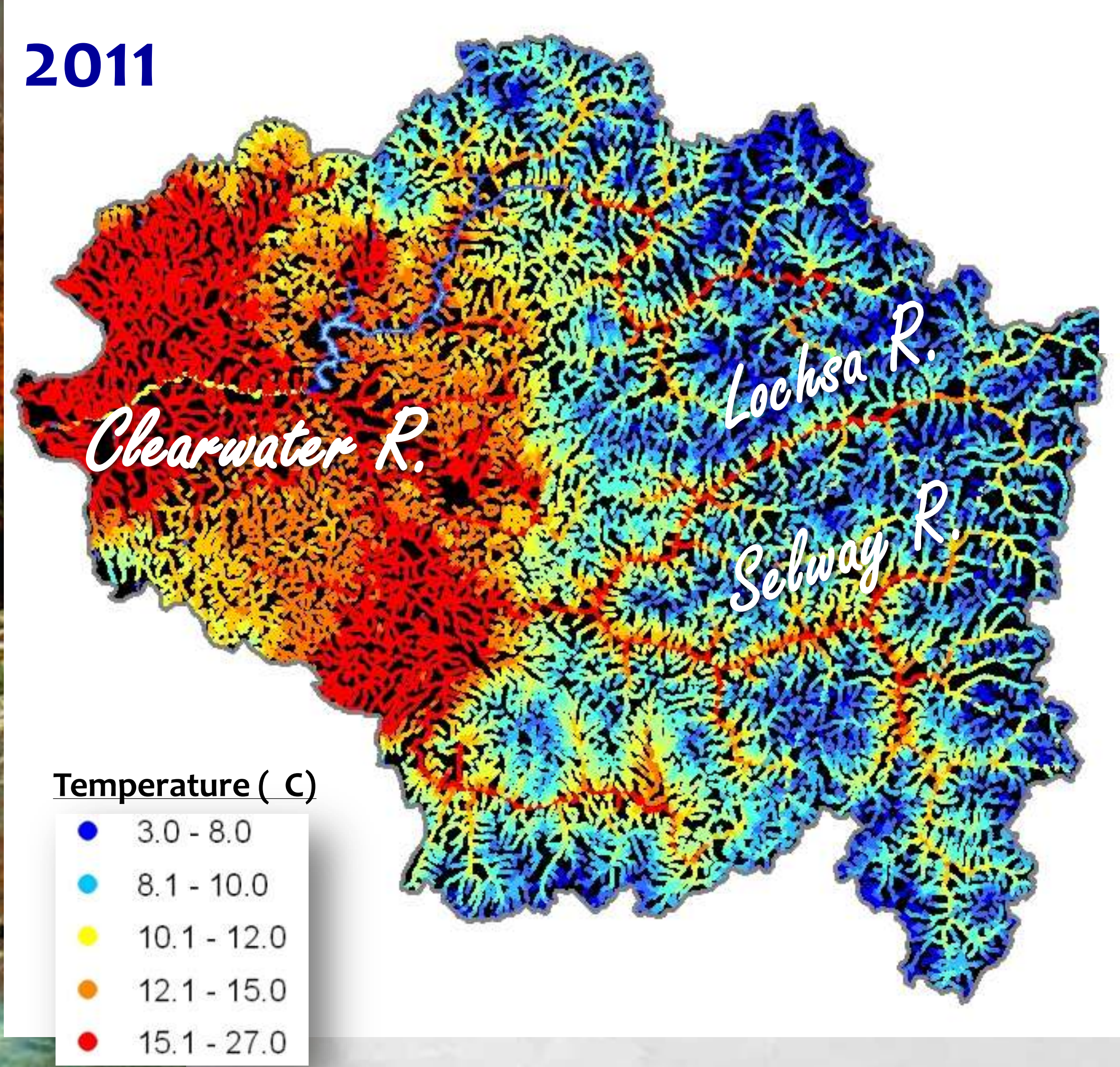
…values to create scenarios

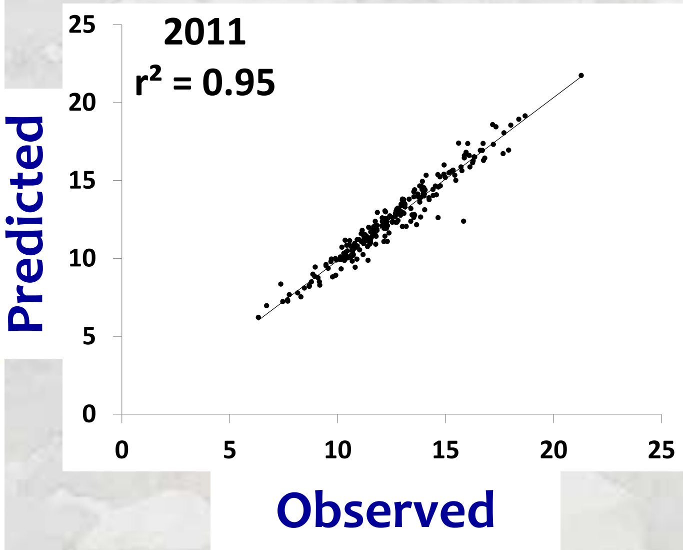
Climate Scenario Descriptions

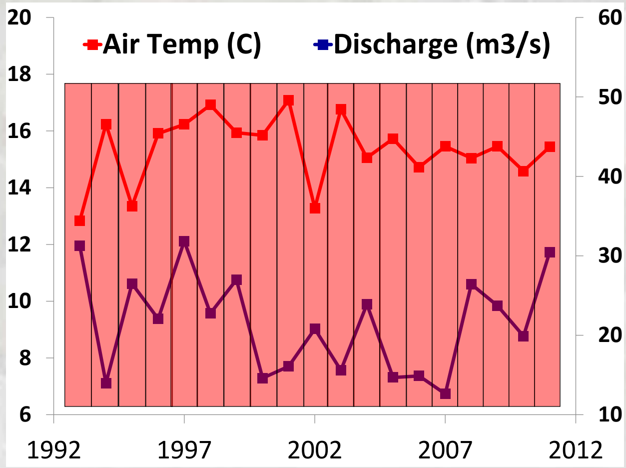
Scenario	**Description**
S1_93_11	Historical scenario representing 19 year average August mean stream temperatures for 1993-2011
S2_02_11	Historical scenario representing 10 year average August mean stream temperatures for 2002-2011
S3_1993	Historical scenario representing August mean stream temperatures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

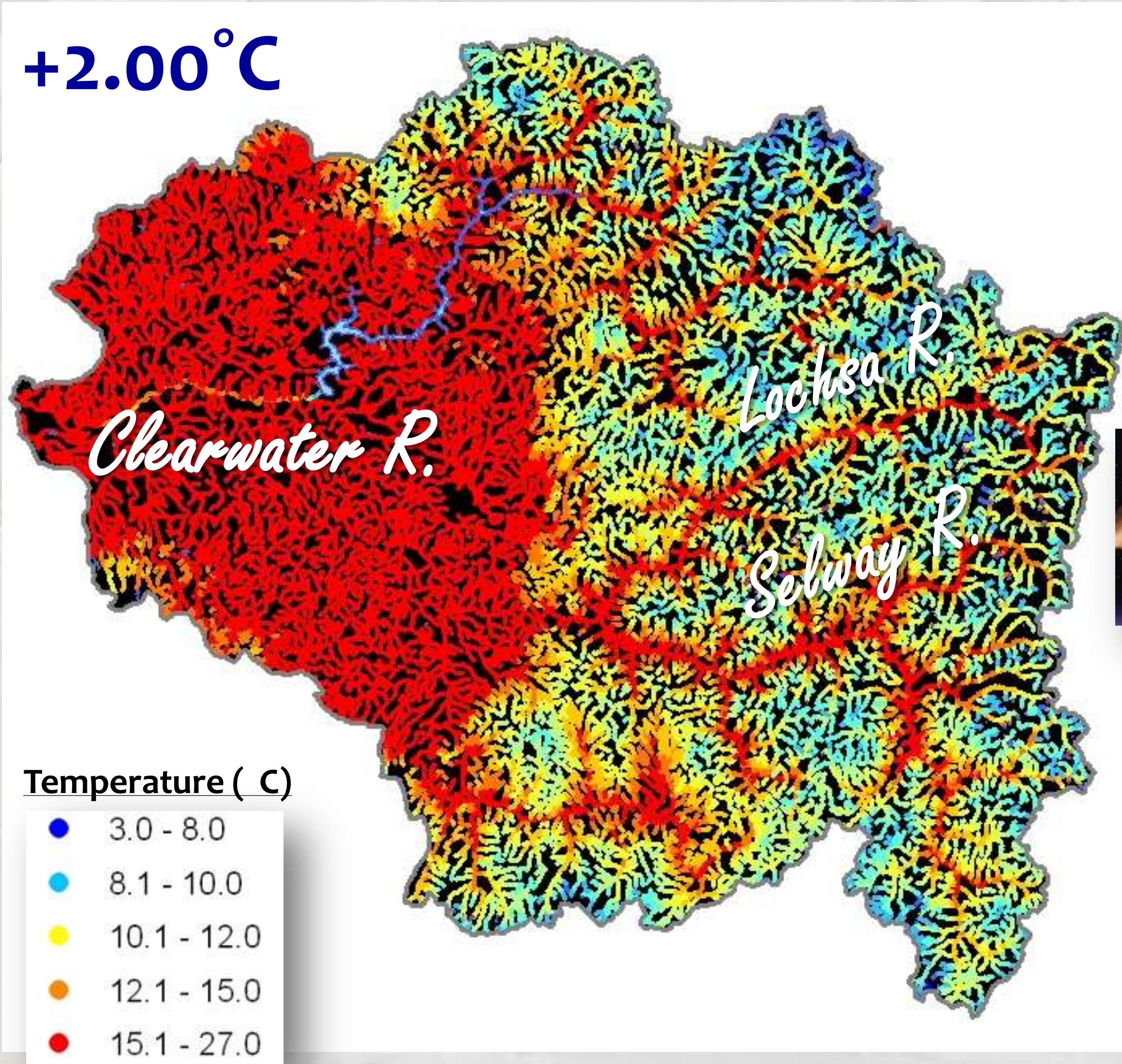


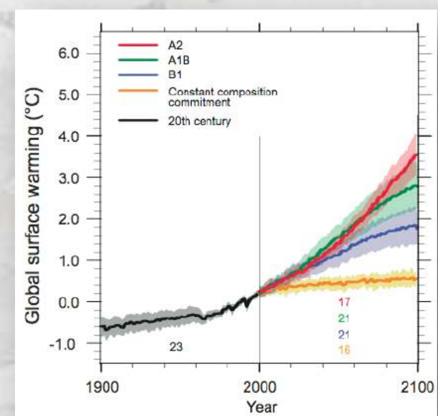




Future Scenarios (S1, S25, S29)

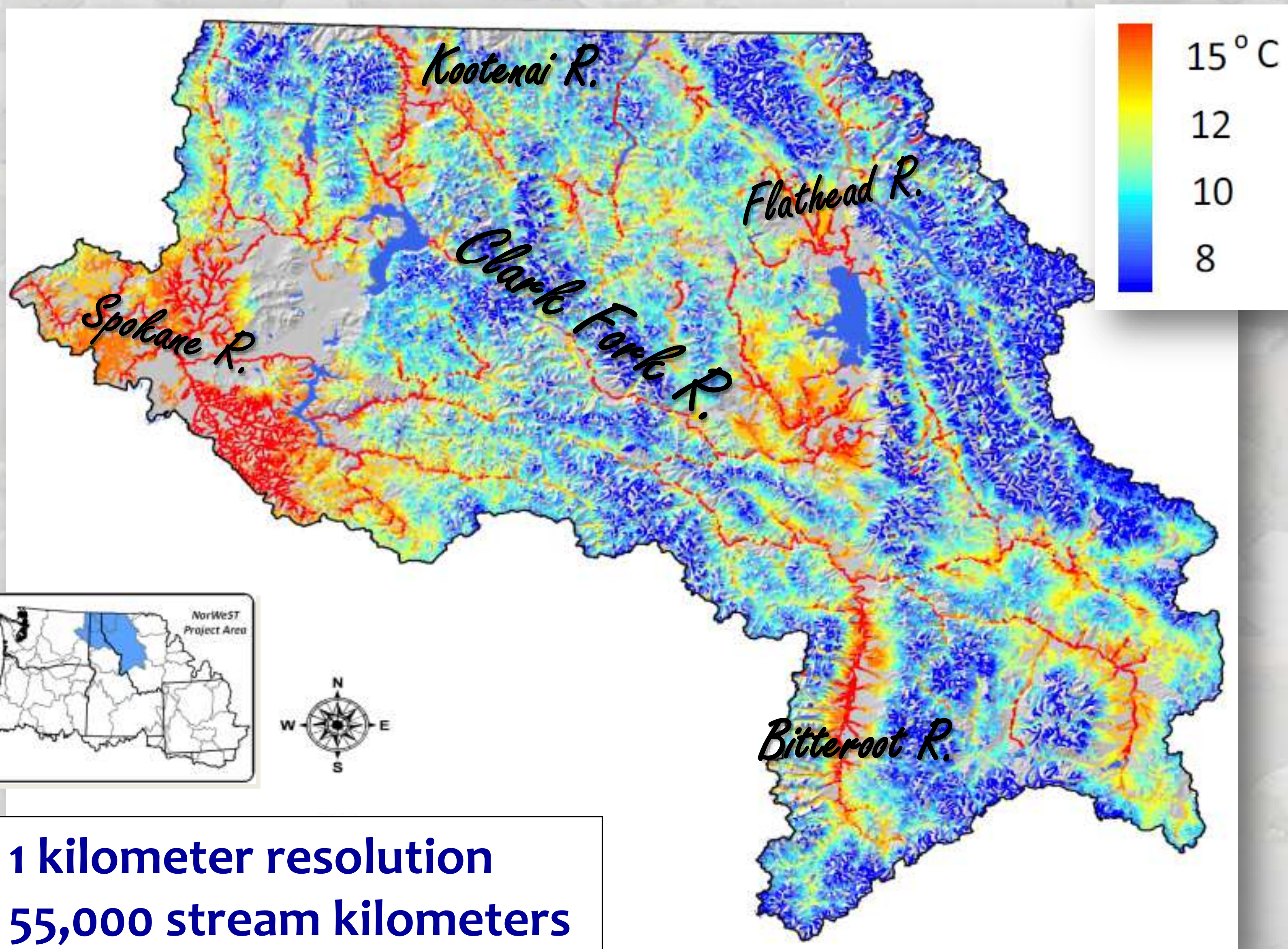
1993-2011, +1.0°C, +2.0°C





Historic Scenario: SpoKoot Unit (S1_93-11)

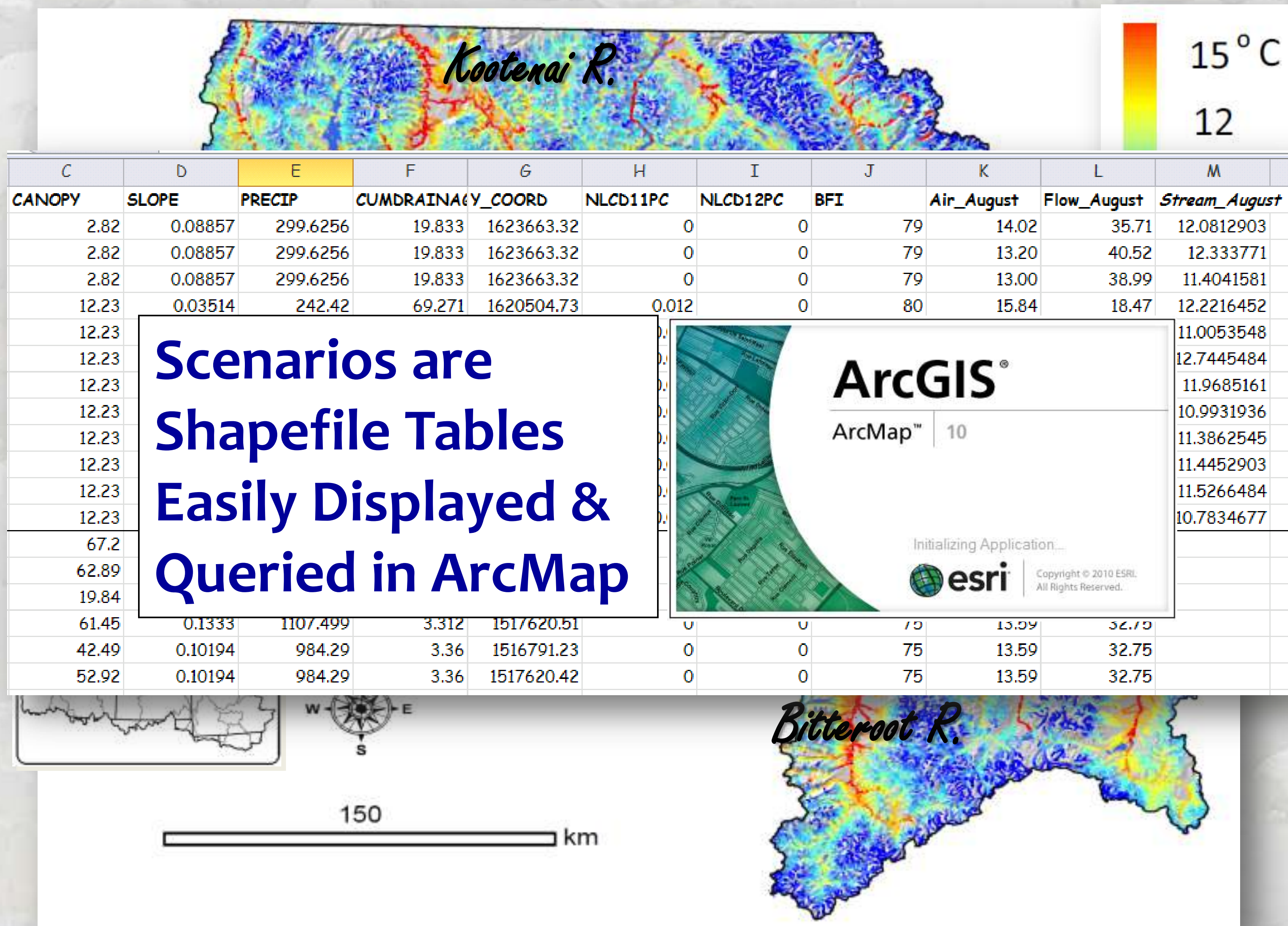
1993-2011 mean August stream temperatures



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	CUMDRAINA(	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

ArcGIS
ArcMap™ 10
Initializing Application...
esri
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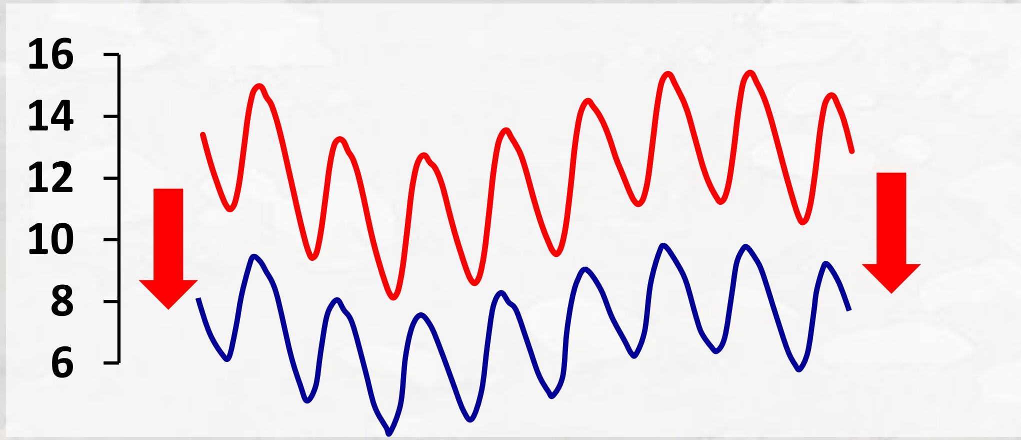
Application: Quantify Thermal Degradation

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

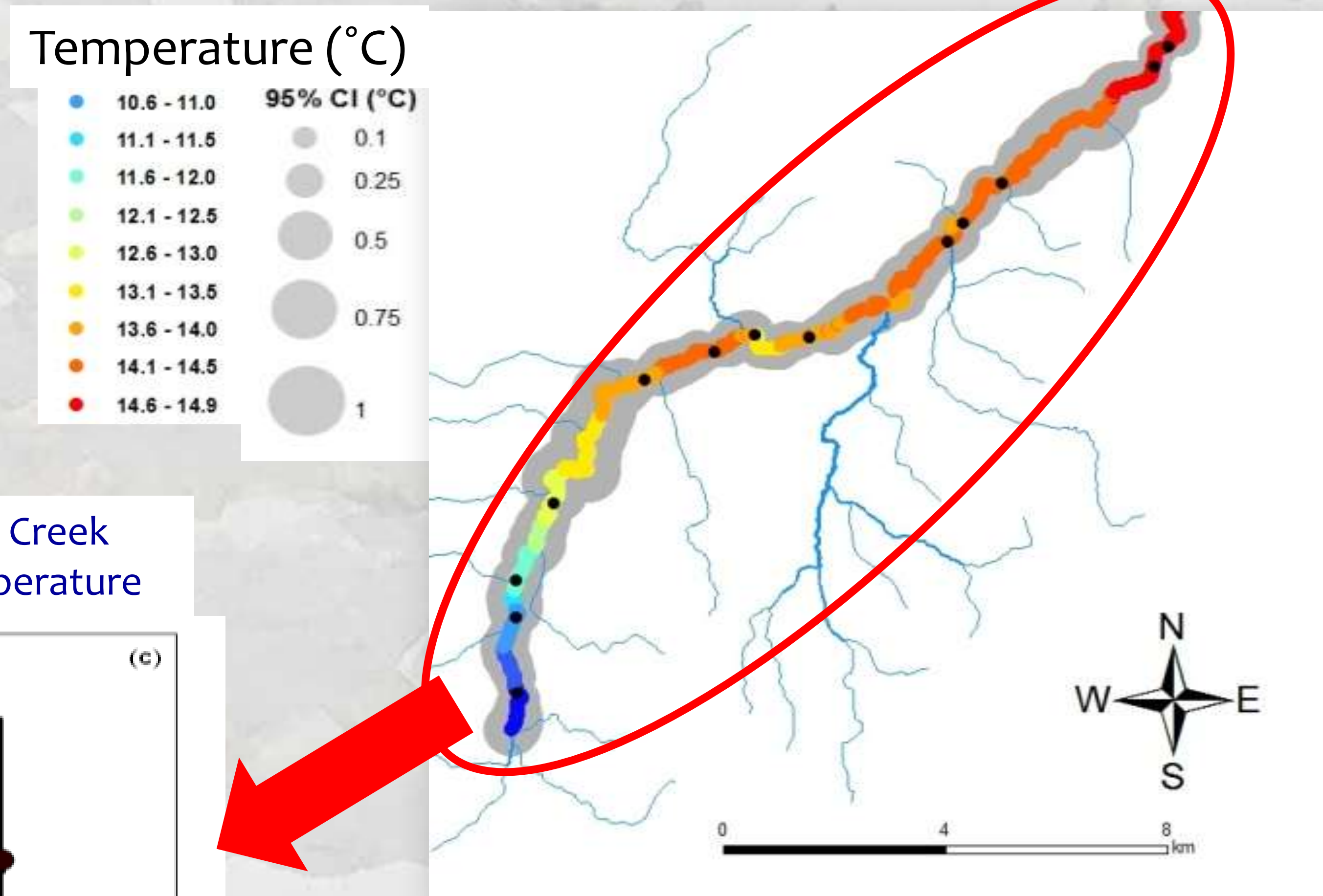
"How much cooler could we make this stream?"



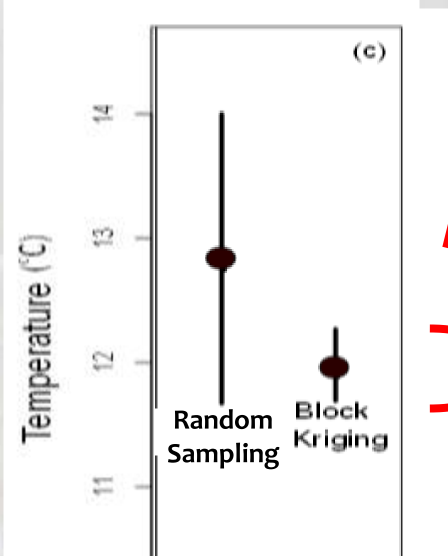
1) Pick "degraded" and "healthy" streams to compare

Application: Quantify Thermal Degradation

2) Block-krige estimates of temperature at desired scale



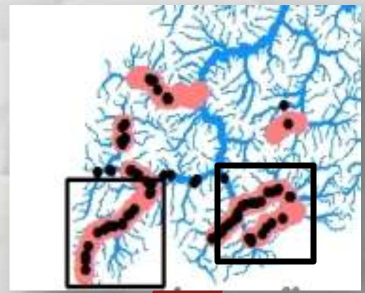
Bear Valley Creek
Mean Temperature

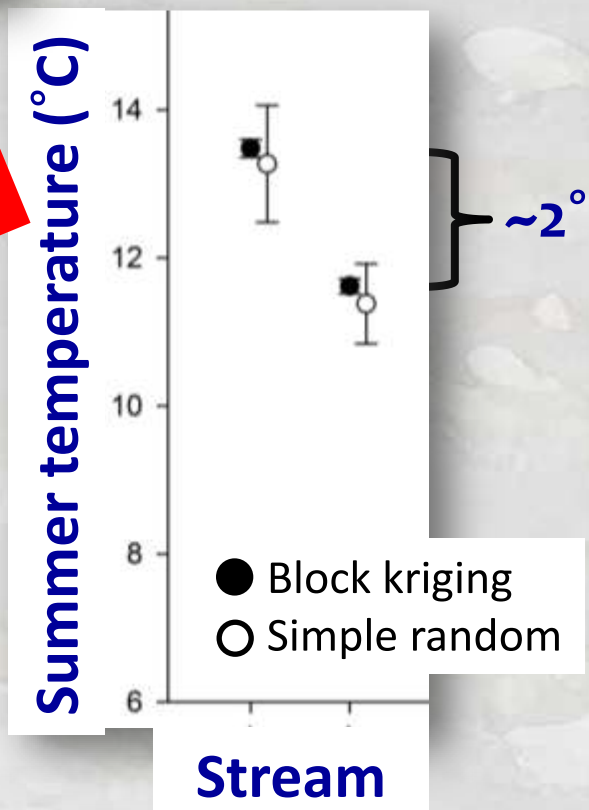


Precise & unbiased estimates

Application: Quantify Thermal Degradation

3) Compare estimates among streams



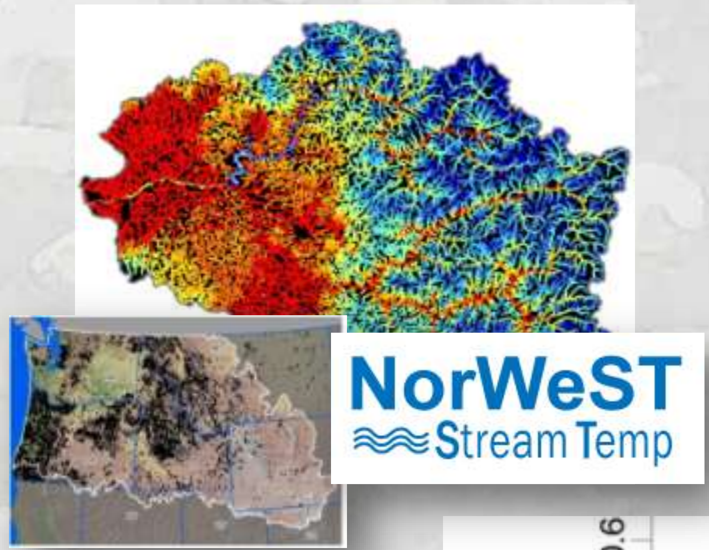


~2°C cooling is possible

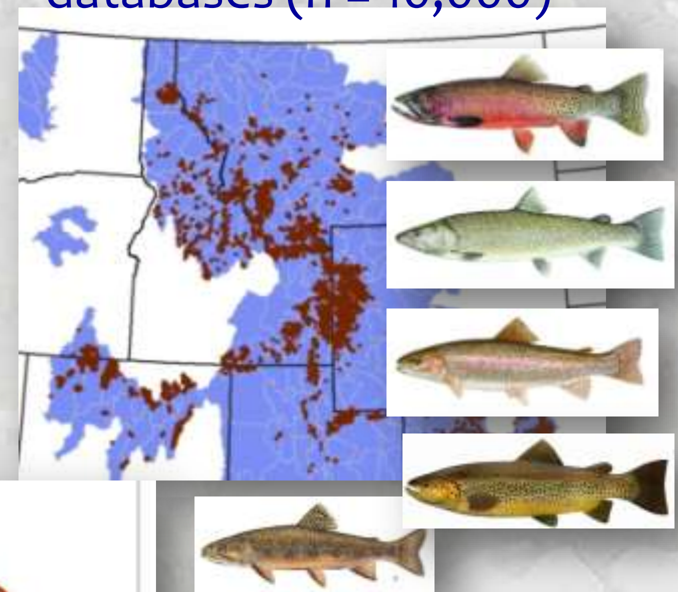
Translate Thermal Maps to Thermal Habitats

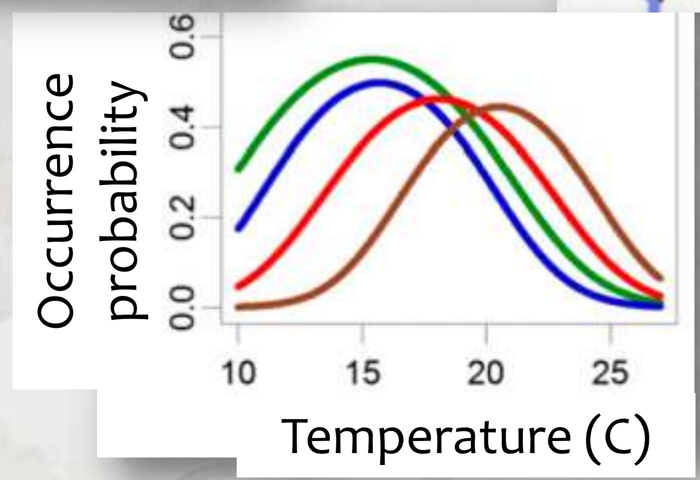
Apply Regionally Consistent Thermal Criteria

Stream temperature maps



Regional fish survey databases (n = 10,000)





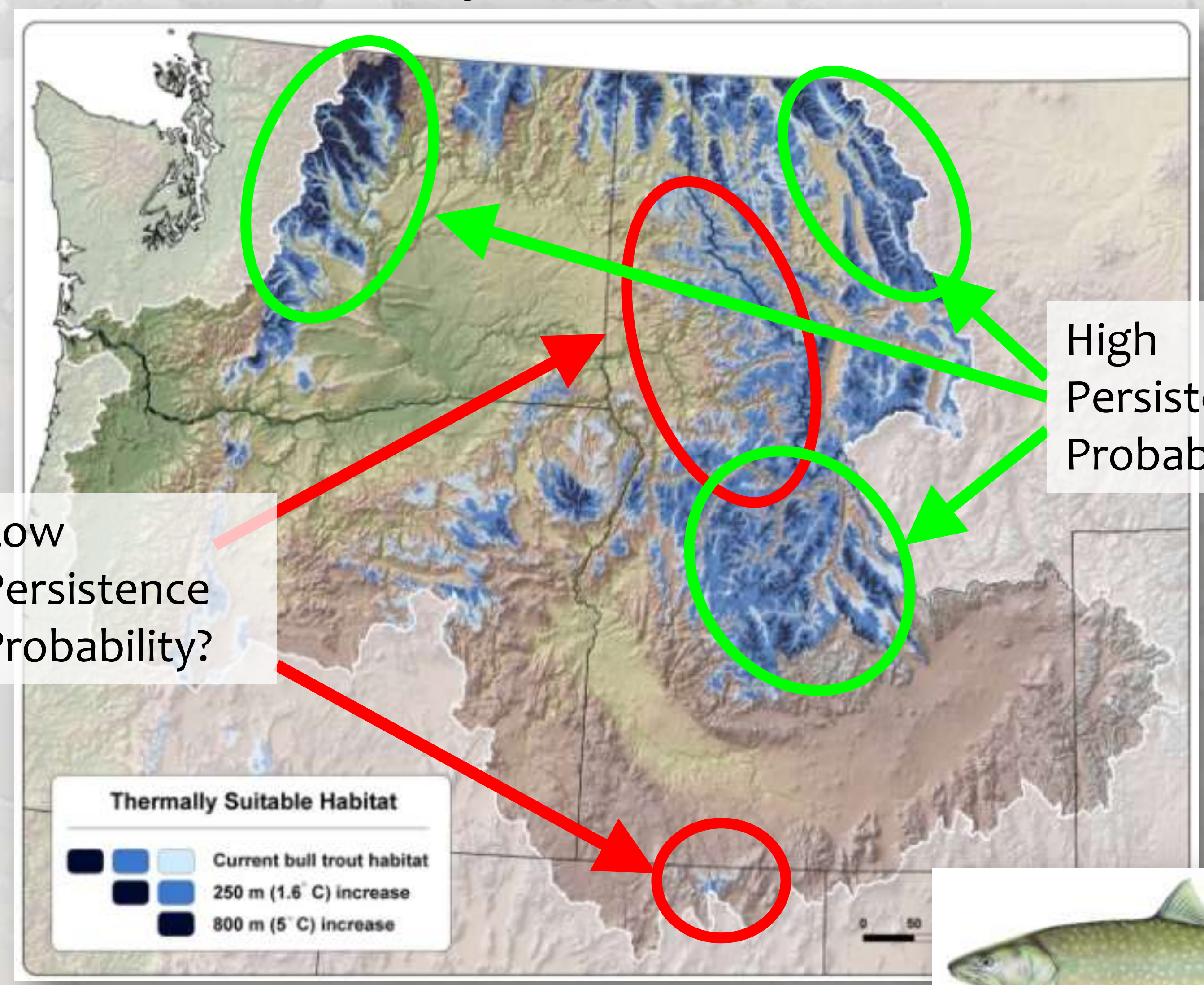
Wenger et al. 2011a. *PNAS* **108**:14175-14180

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

Thermal Niches For All Stream Critters

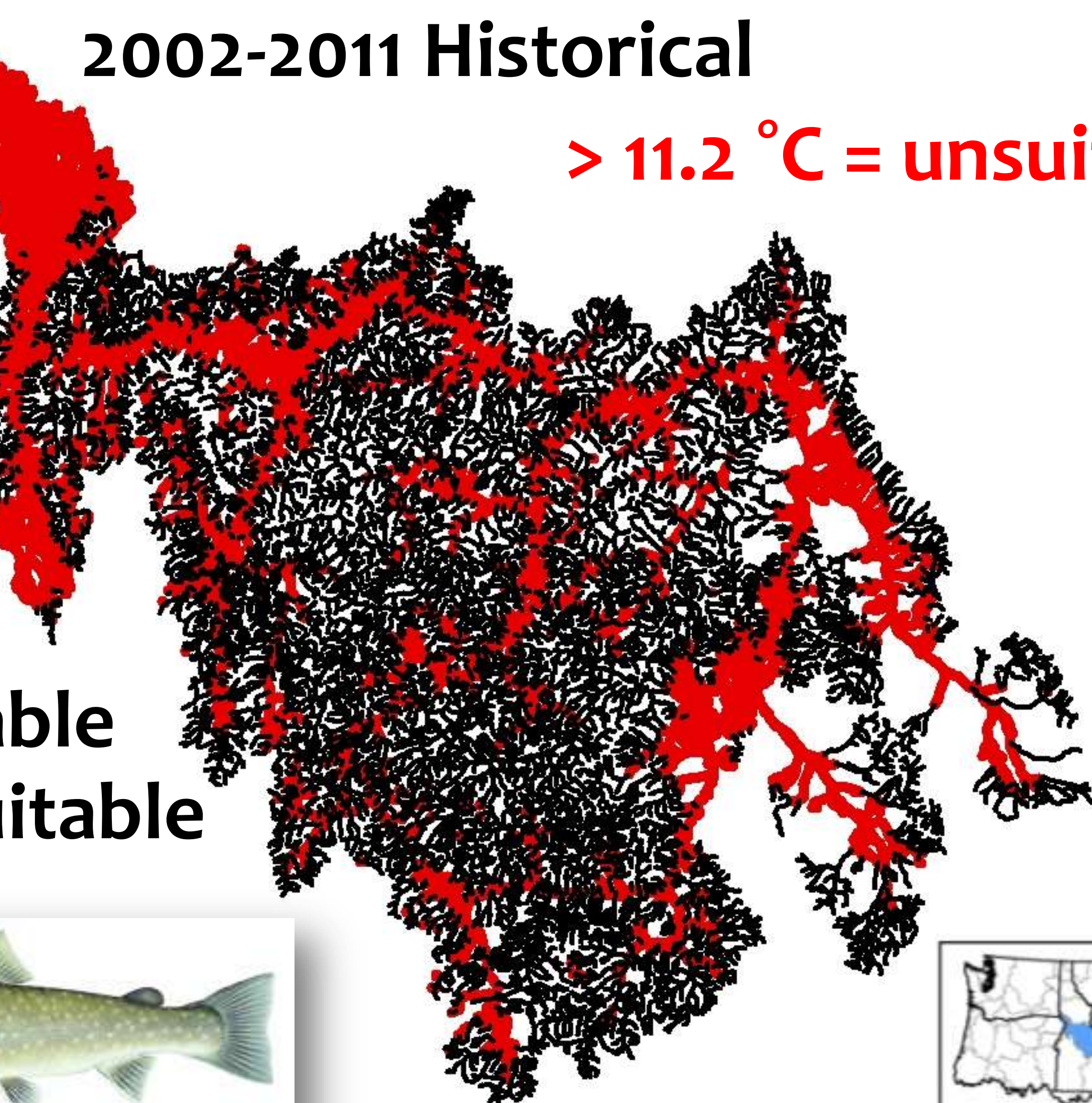
Just need georeferenced biological survey data

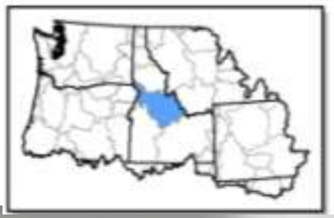
Improve Resolution of Climate Vulnerability Assessments



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

Salmon River Bull Trout Habitats

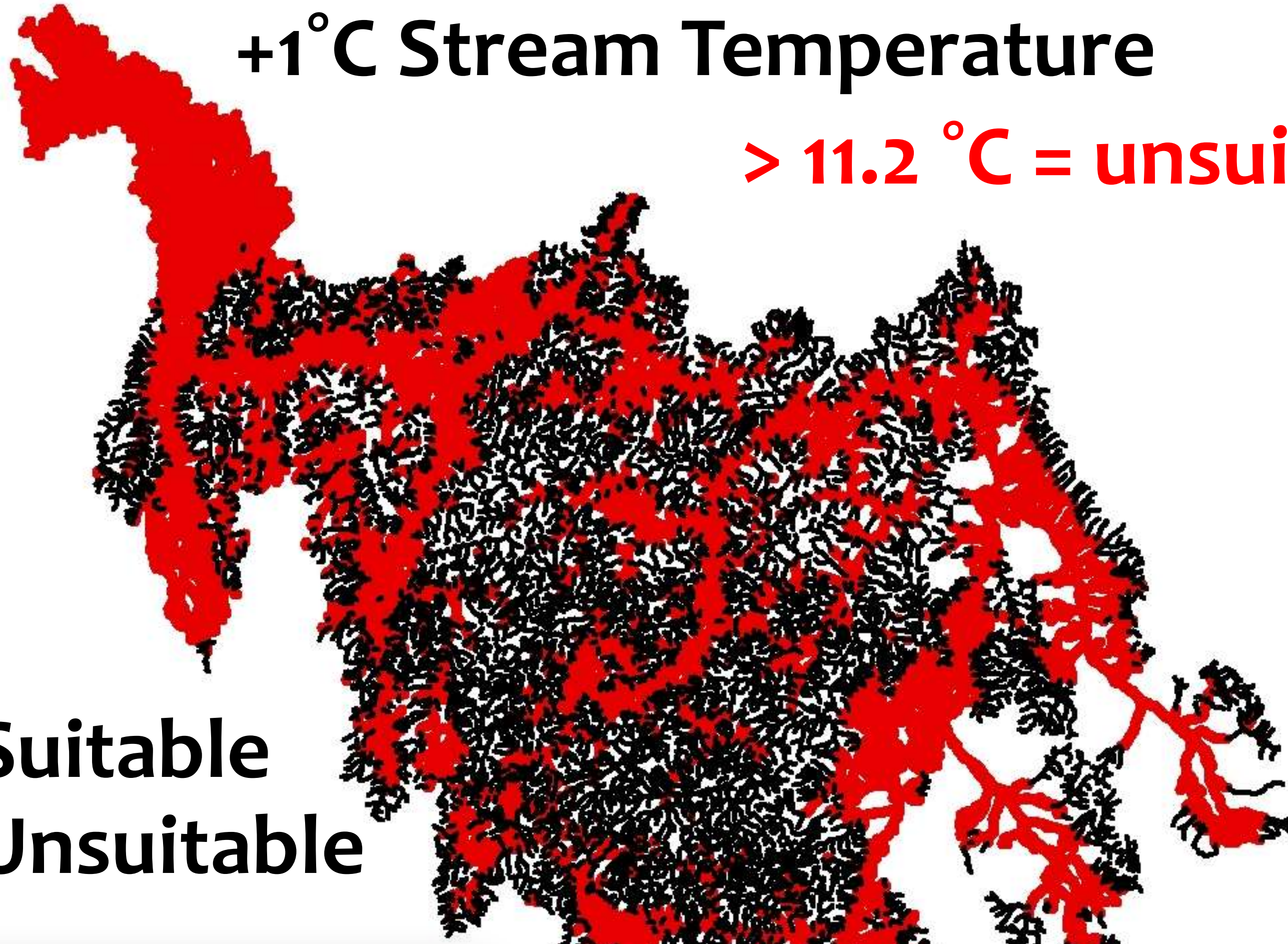




Salmon River Bull Trout Habitats

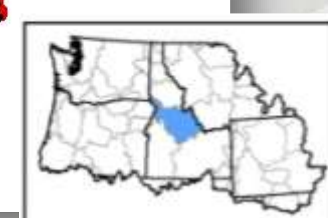
+1°C Stream Temperature

> 11.2 °C = unsuitable

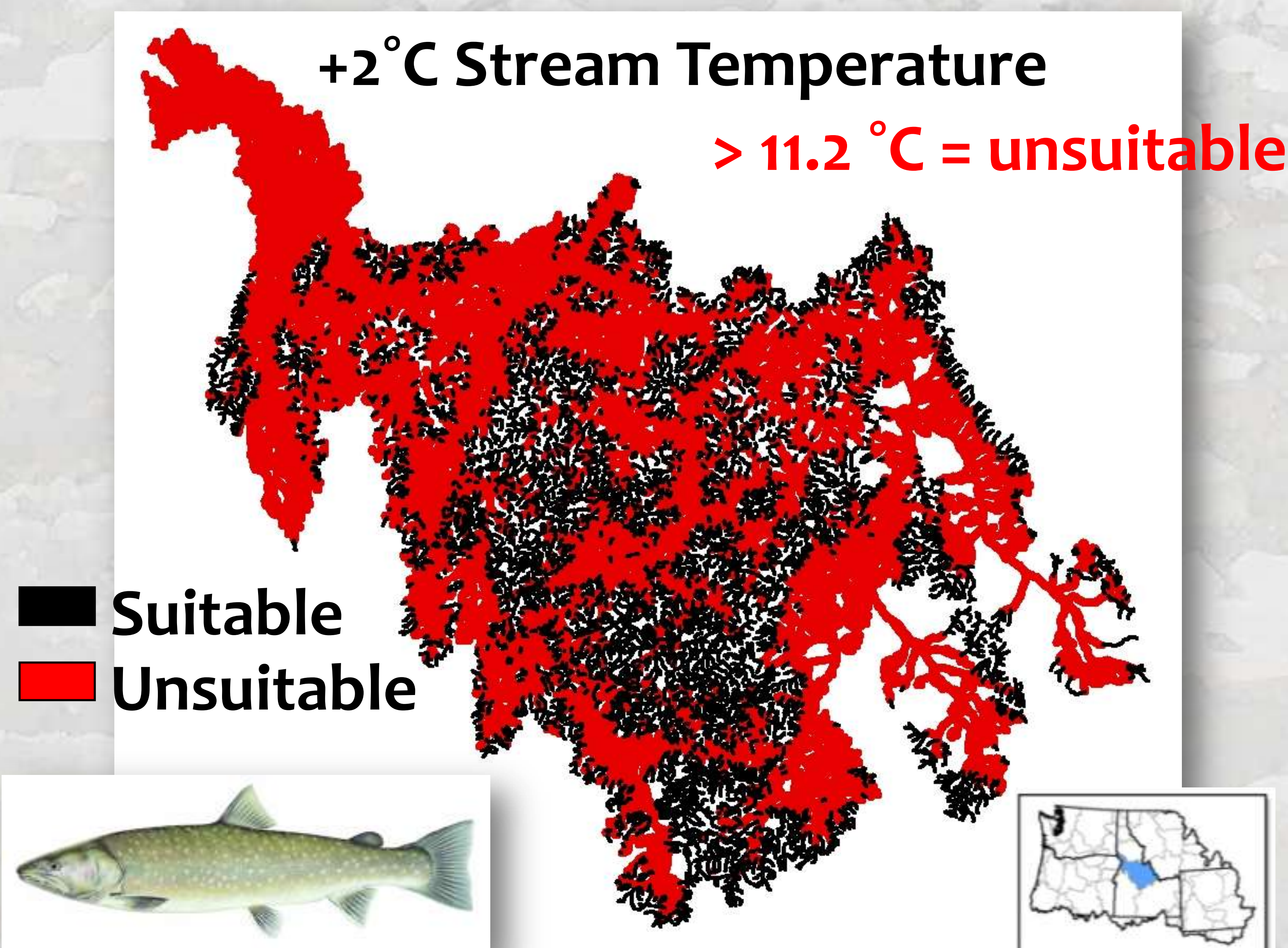


■ Suitable

■ Unsuitable

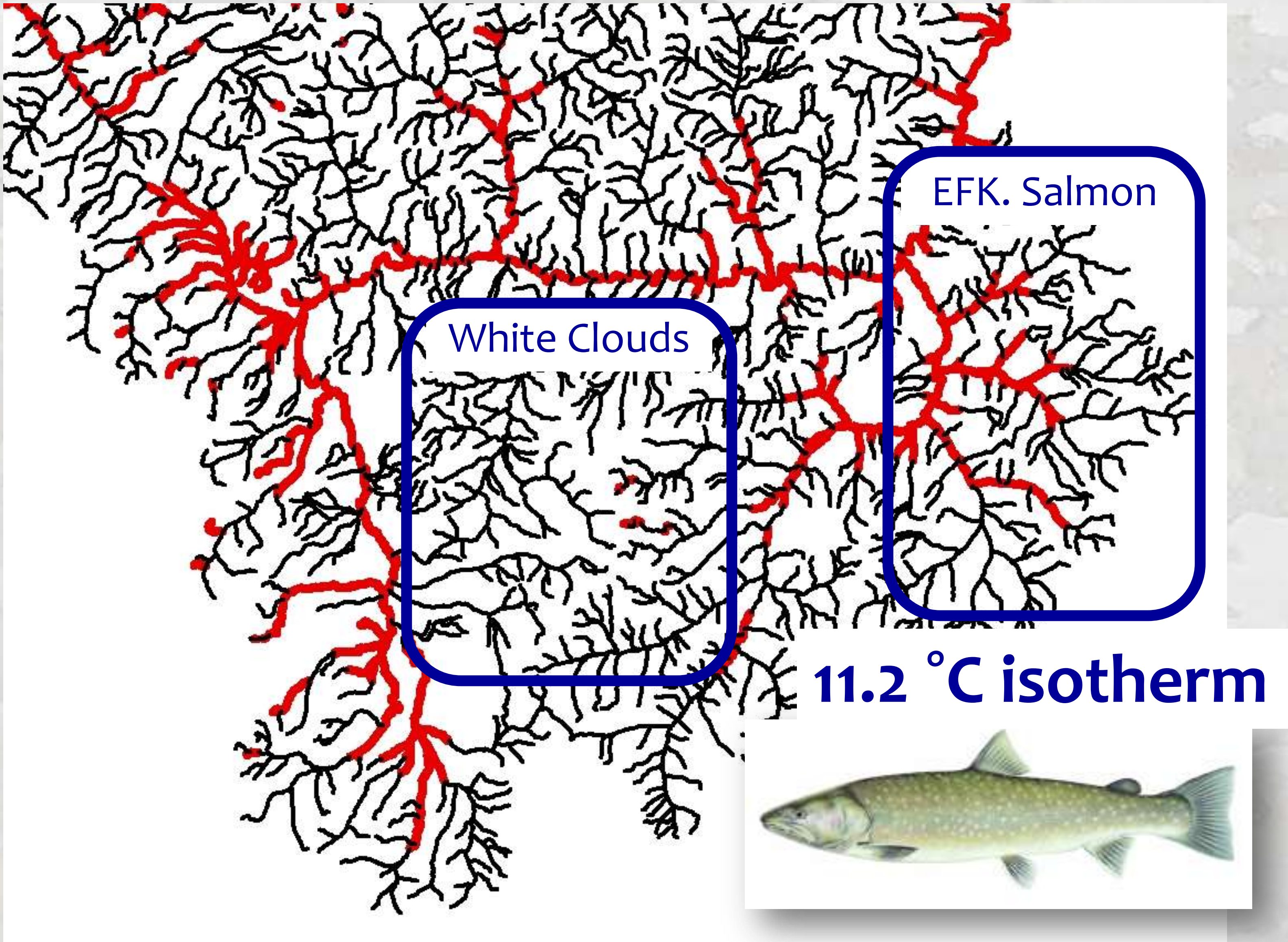


Salmon River Bull Trout Habitats



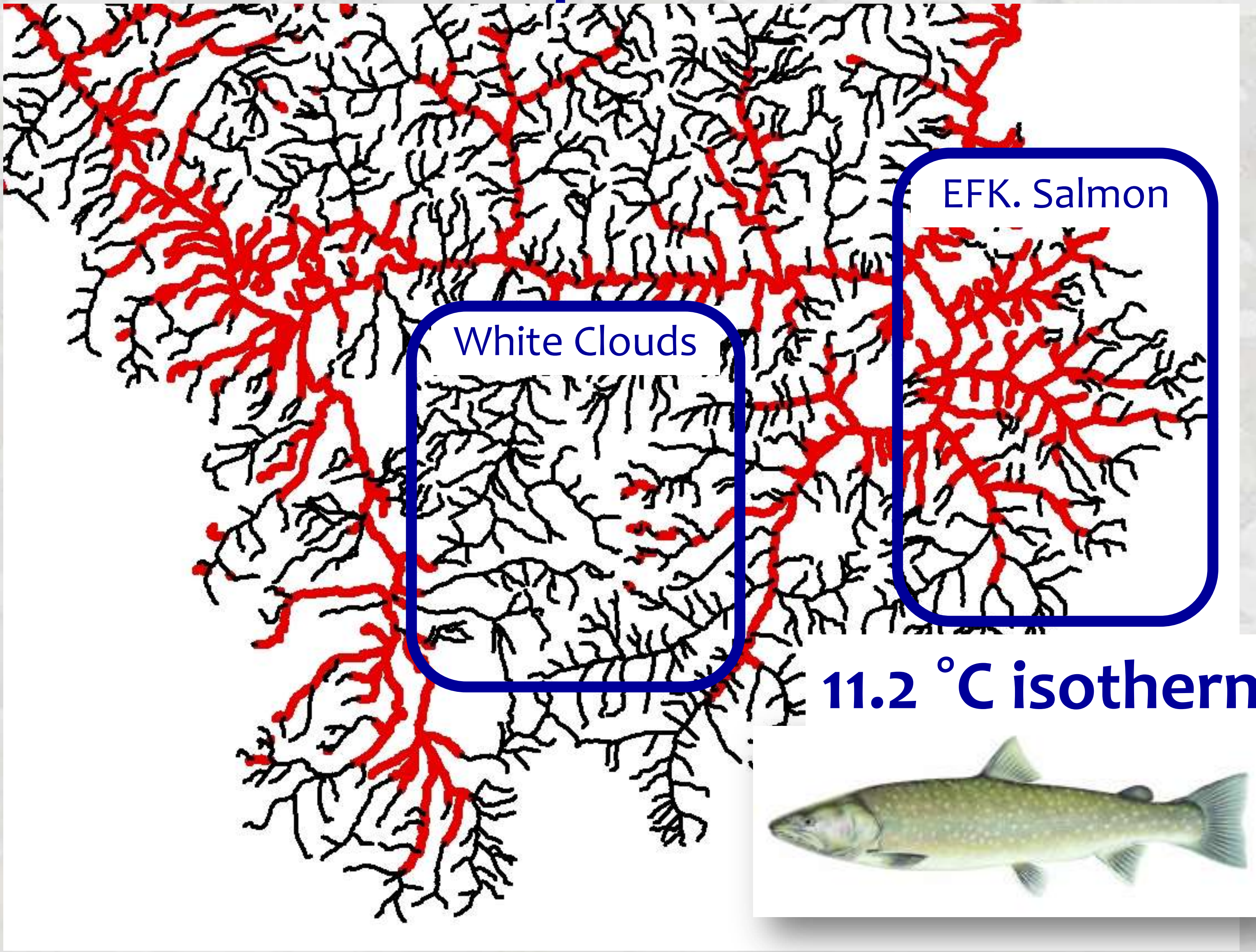
Spatial Variation in Habitat Loss

2002-2011 historical scenario



Spatial Variation in Habitat Loss

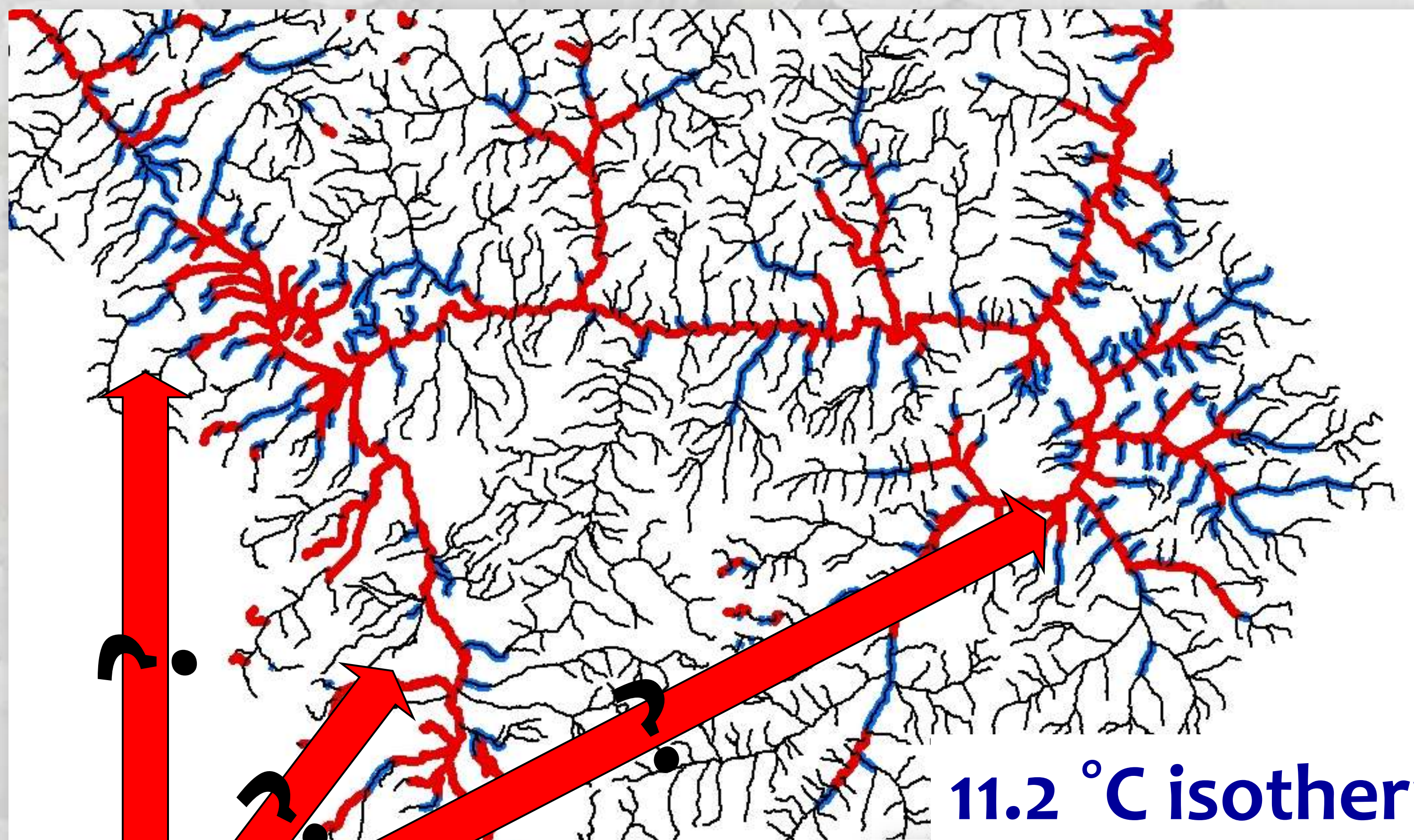
+1°C stream temperature scenario



11.2 °C isotherm

Difference Map Shows Vulnerable Habitats

+1°C stream temperature scenario



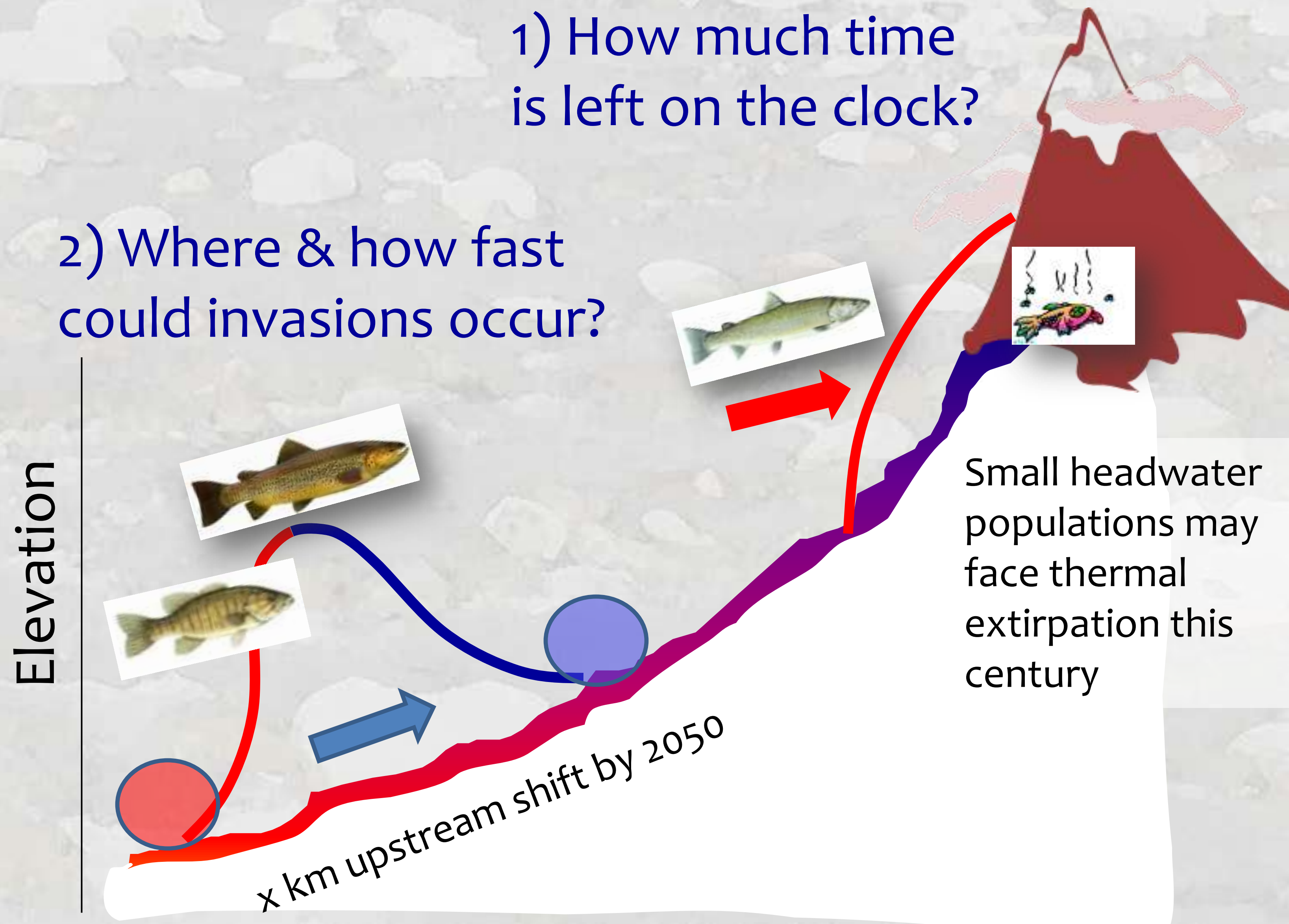
11.2 °C isotherm

Where to invest?

Precise Information Regarding Potential Species Invasions & Population Extirpations

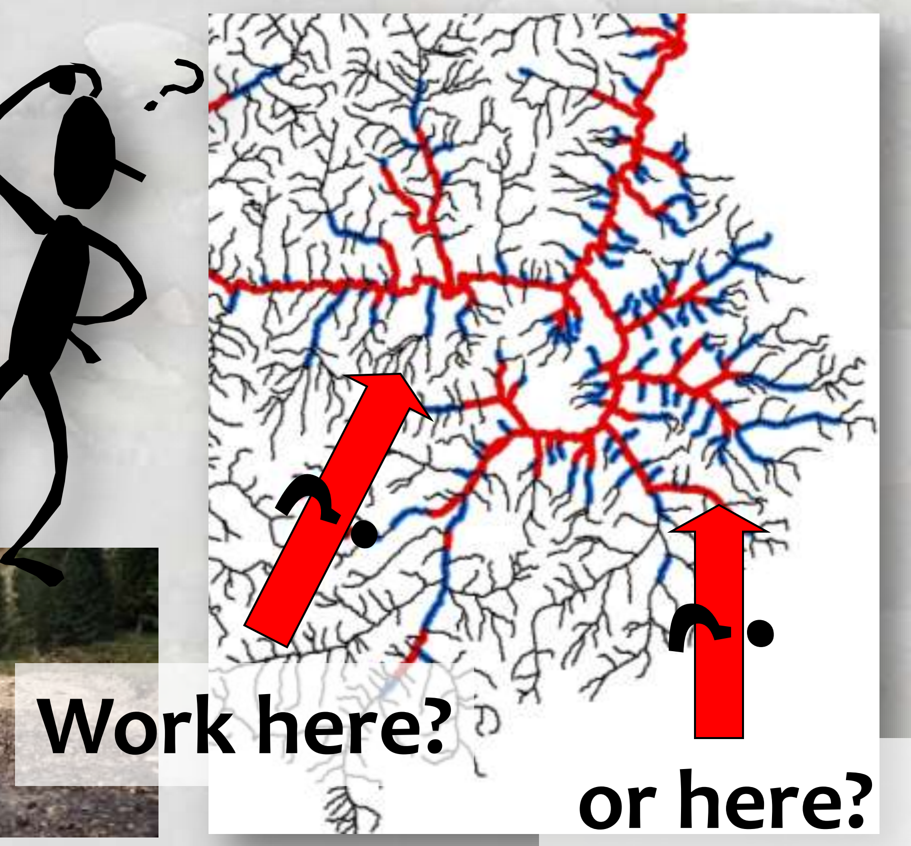
1) How much time is left on the clock?

2) Where & how fast could invasions occur?



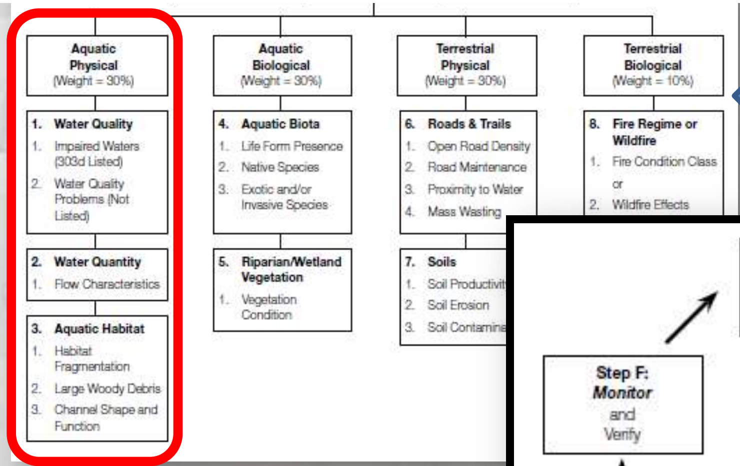
Strategic Prioritization of Restoration Actions is Possible

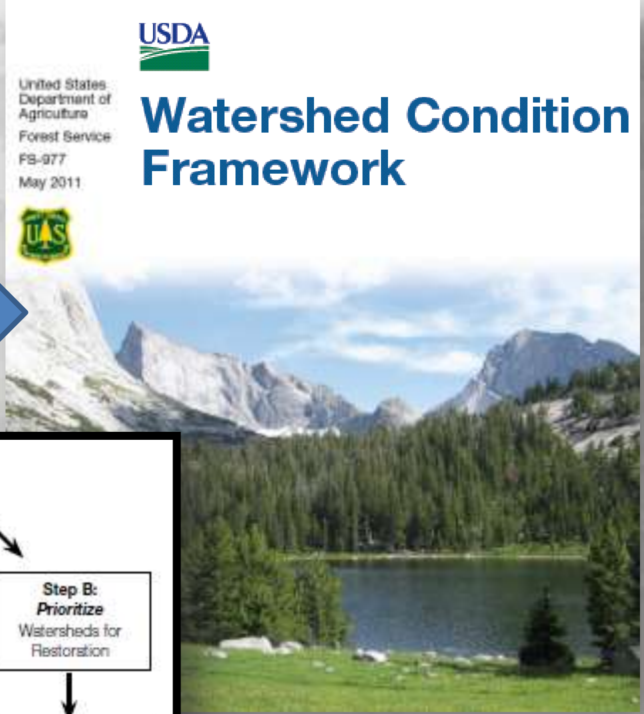
- Maintaining/restoring flow…
- Maintaining/restoring riparian…
- Restoring channel form/function…
- Prescribed burns limit wildfire risks…
- Non-native species control…
- Improve/impede fish passage…

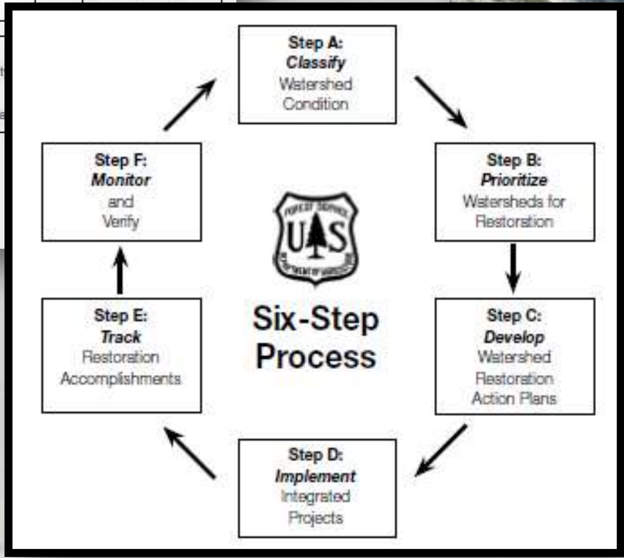


Integrate with…

Watershed Condition Indicators







Forest Plan Revisions

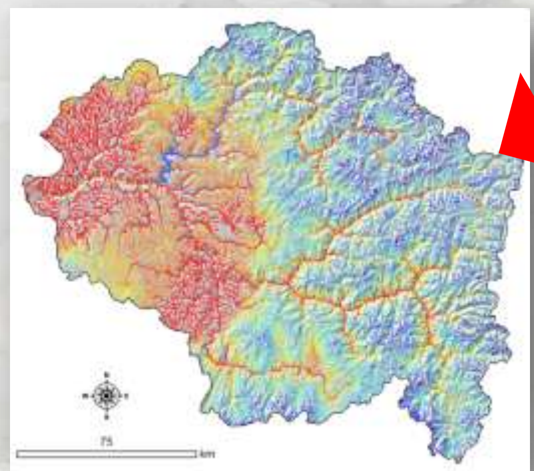
USDA
United States Department of Agriculture
Forest Service
Northern Region
March 2007

Proposed
Land Management Plan
Clearwater National Forest

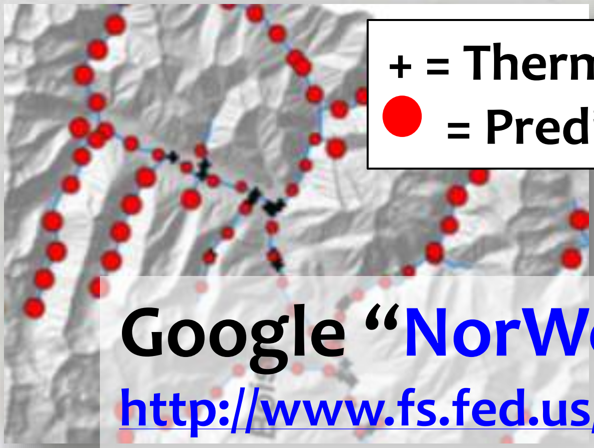
NorWeST is a “Crowd-Sourced” Model Developed from Everyone’s Data

NorWeST Website Distributes Scenarios & Other Temperature Products as GIS Layers

1) GIS shapefiles of stream temperature scenarios



2) GIS shapefiles of stream temperature model prediction precision

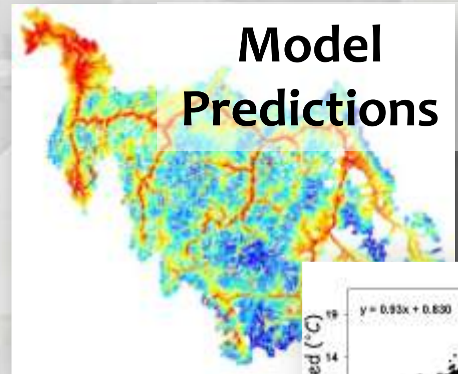


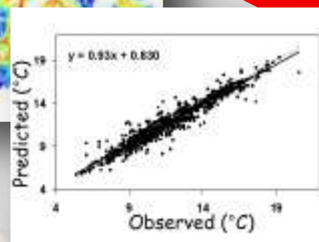
3) Temperature data summaries

Google "NorWeST" or go here…

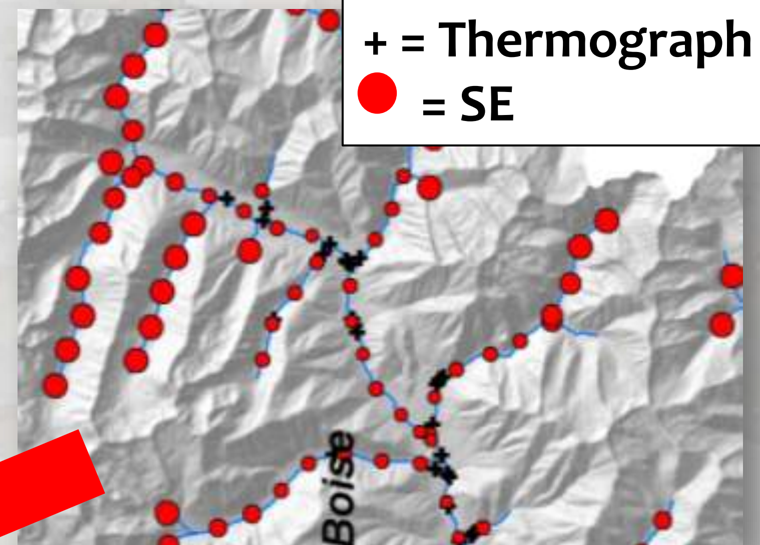
http://www.fs.fed.us/rm/boise/AWAE/projects/NorWeST.shtml

S34_PredSE = Spatially Explicit Maps of Prediction Uncertainty

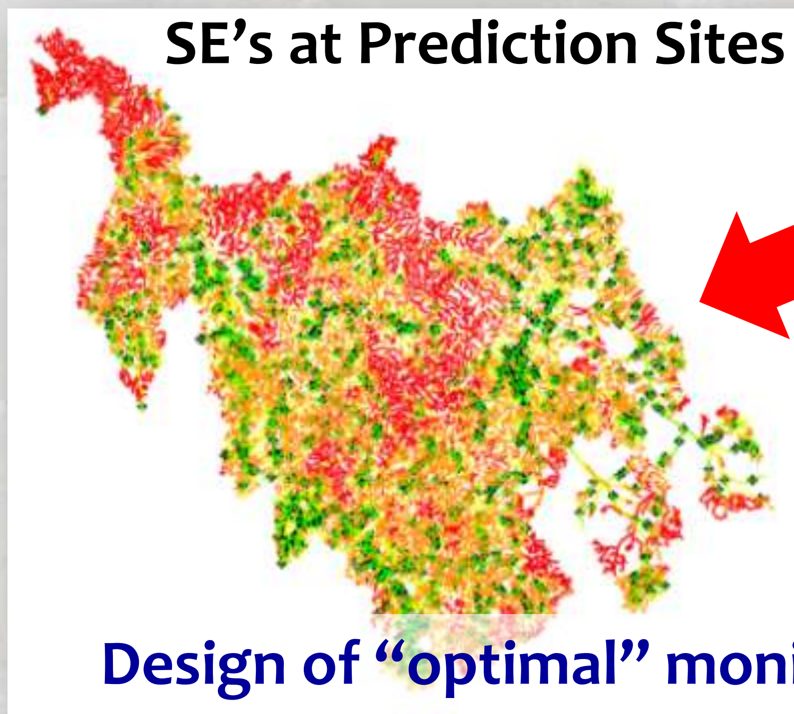




Temperature Prediction SE's

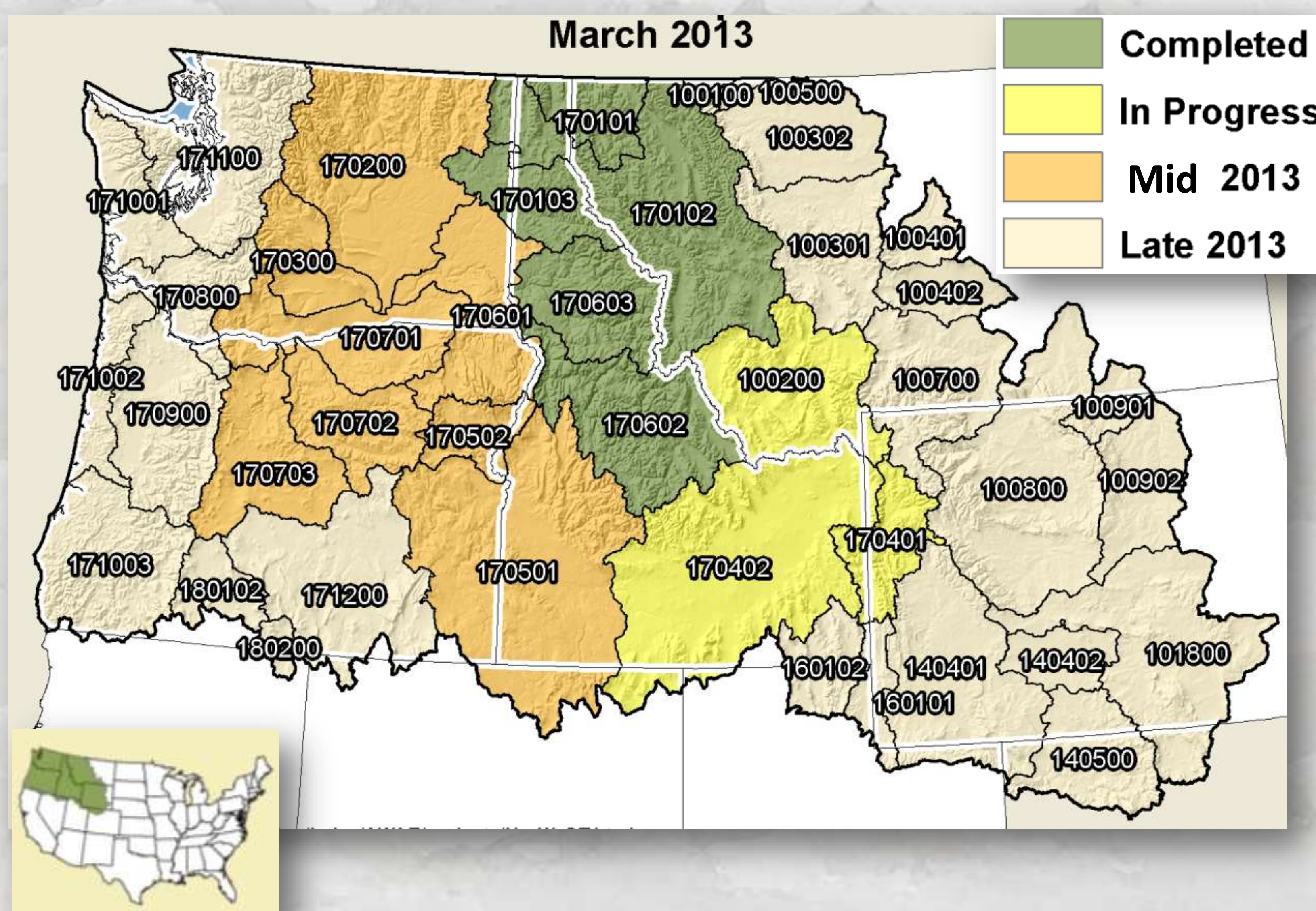


SE's are small near sites with temperature measurements



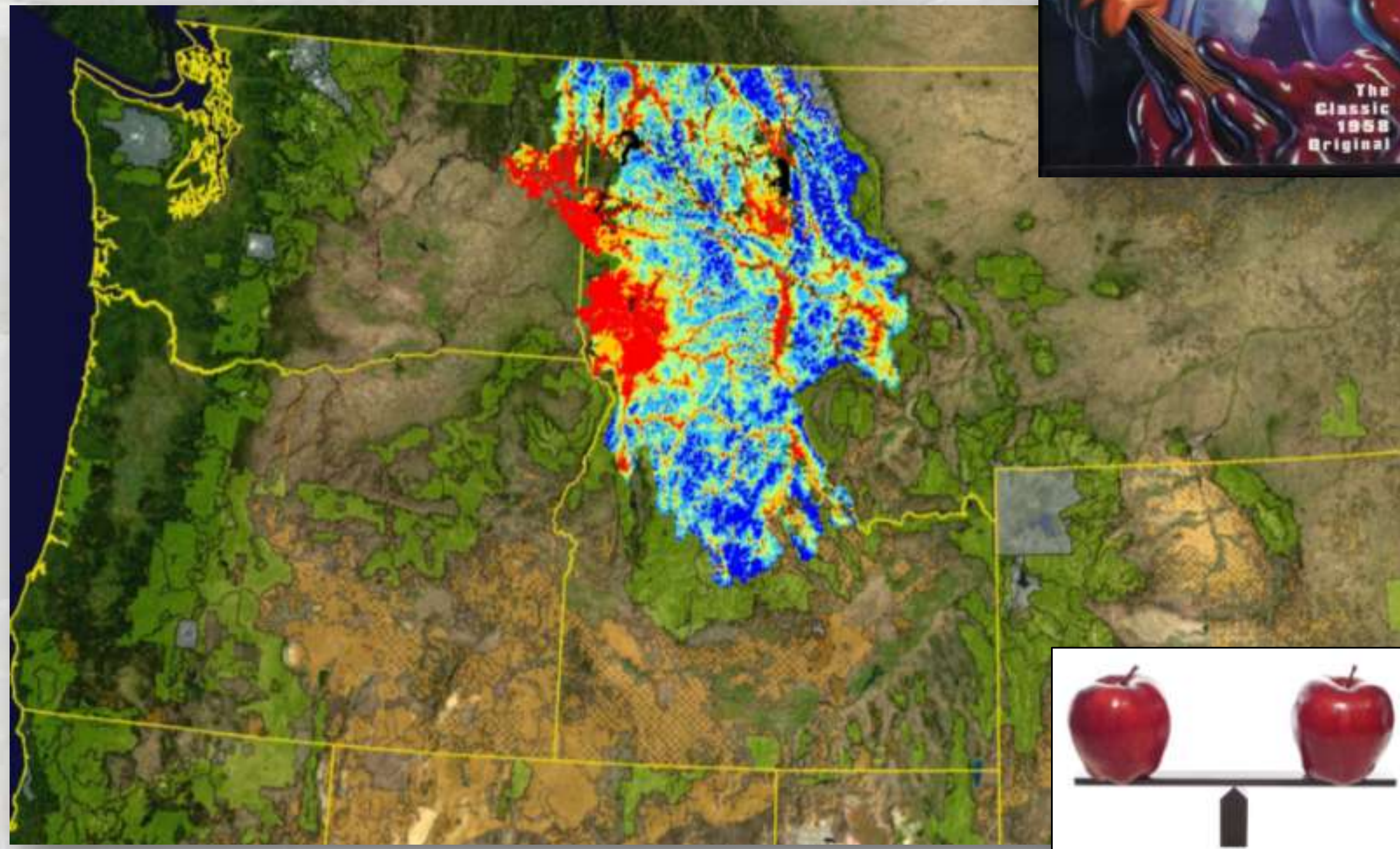
Design of "optimal" monitoring networks now possible

NorWeST Schedule



NorWeST Blob Growing…

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

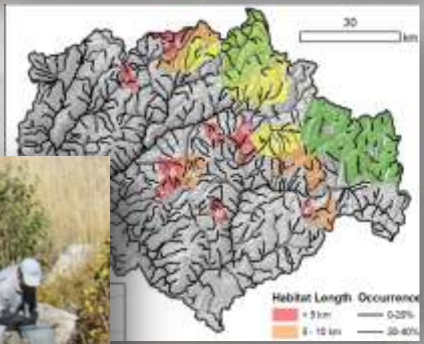


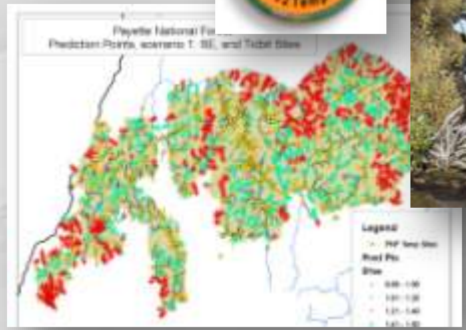
A Special Thanks to The 60+ Data Contributors and Partner Agencies…

Great Northern
LANDSCAPE CONSERVATION COOPERATIVE

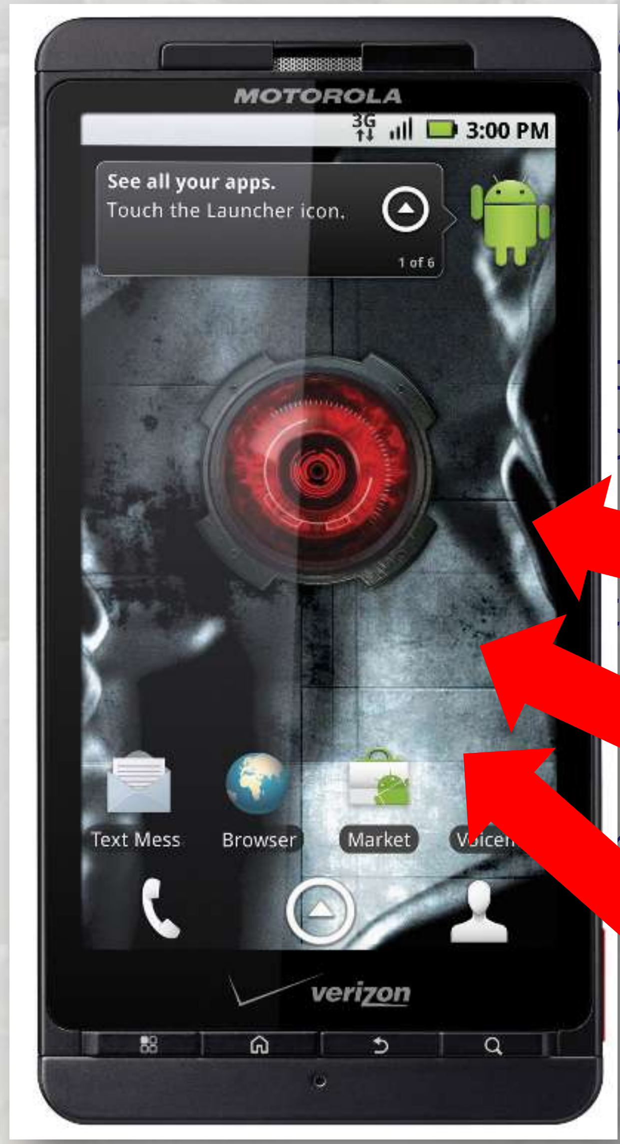
NorWeST Facilitating Related Projects

- 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

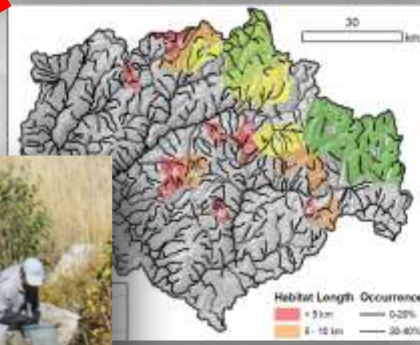




NorWeST Facilitating Related Projects



“Apps” Run on a Consistent Data Network



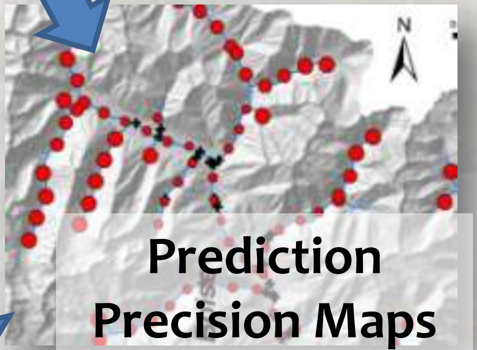
Real-time Access to Stream Spatial Data Anytime, Anywhere

Smartphones as field computers

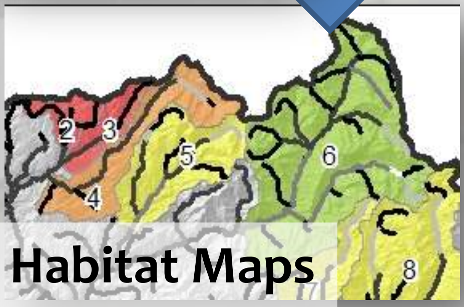
ArcGIS app

ESRI

Temperature Maps



Prediction Precision Maps



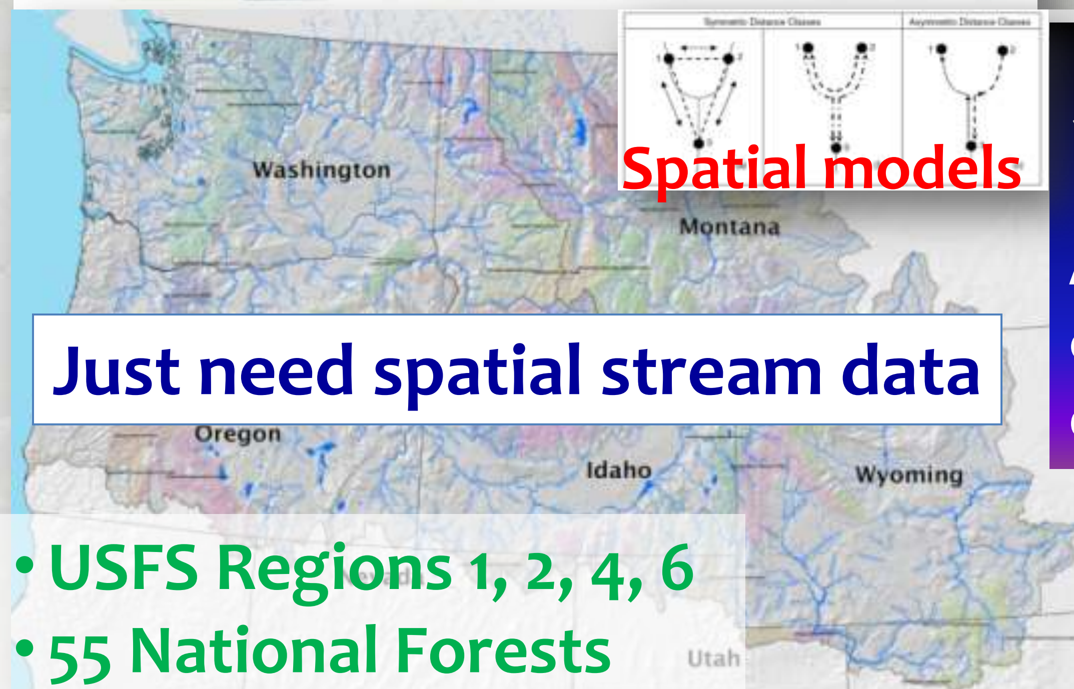
Habitat Maps

GoogleMaps

An InterNet for Stream Data

Technical & GIS infrastructure now exist

Great Northern
LANDSCAPE CONSERVATION COOPERATIVE



Spatial models

Just need spatial stream data

- USFS Regions 1, 2, 4, 6
- 55 National Forests

1G LCC

Accurate & consistent scaling of information

Boise Spatial Streams Group

Internet Needs "Packets" of Consistent Data

Standardized data collection protocols are key

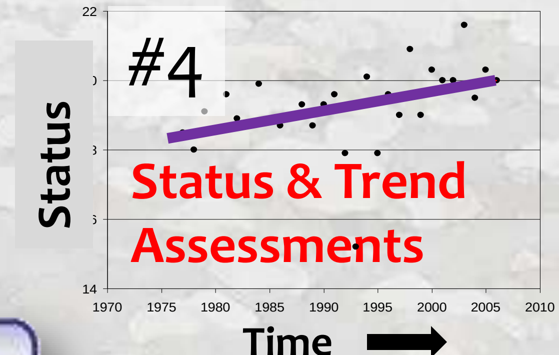
Data Needs to be Accessible

Data In → Information Out

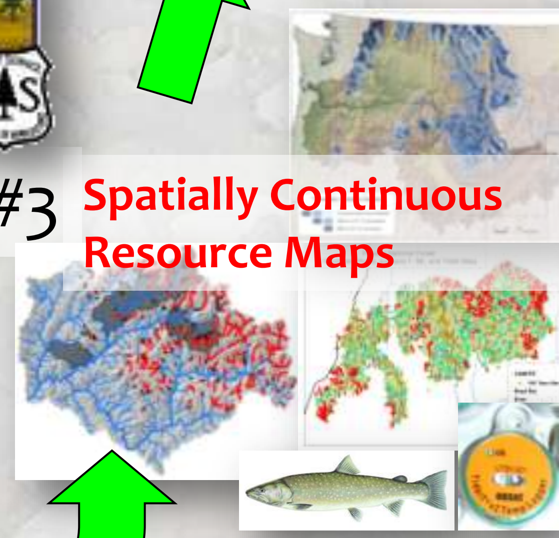
#1

Spatially referenced, corporate database

Aquatic Surveys Module

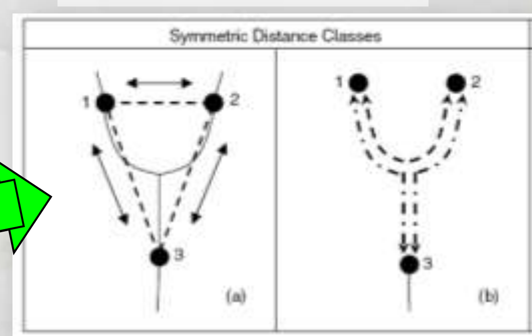


Status & Trend Assessments



#3 Spatially Continuous Resource Maps

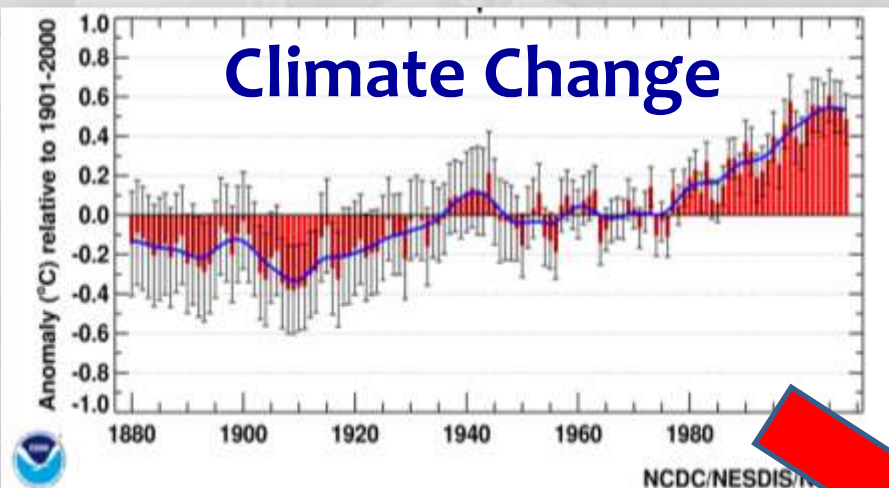
#2 Analysis



#2a

More data, monitoring design

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



Urbanization & Population Growth

Shrinking Budgets

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 Organisation (CSIRO), Division of Mathematical and Information Sciences, Indooroopilly, Queensland, Australia

A Moving Average Approach for Spatial Statistical Models of Stream Networks

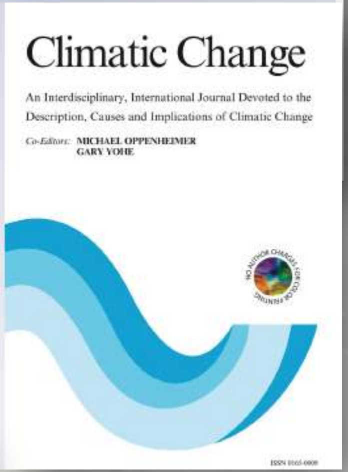
Jay M. Ver Hoef and Erin E. Peterson

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

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


The End