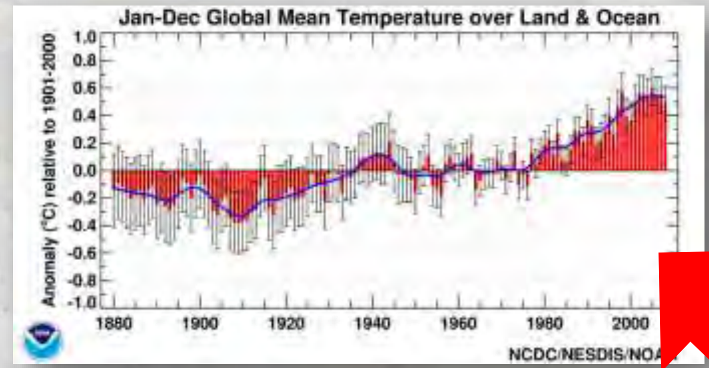
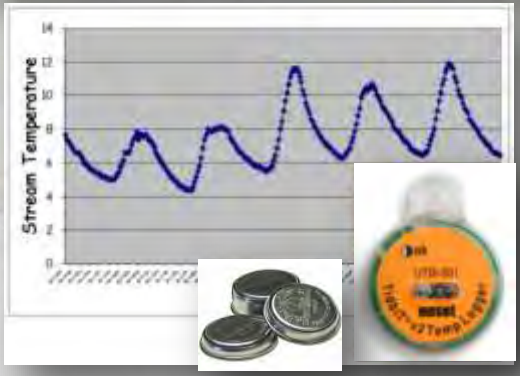
Monitoring & Modeling Stream Temperatures: Lessons Learned in the Northwest with Utility for the Northeast?

Dan Isaak, US Forest Service



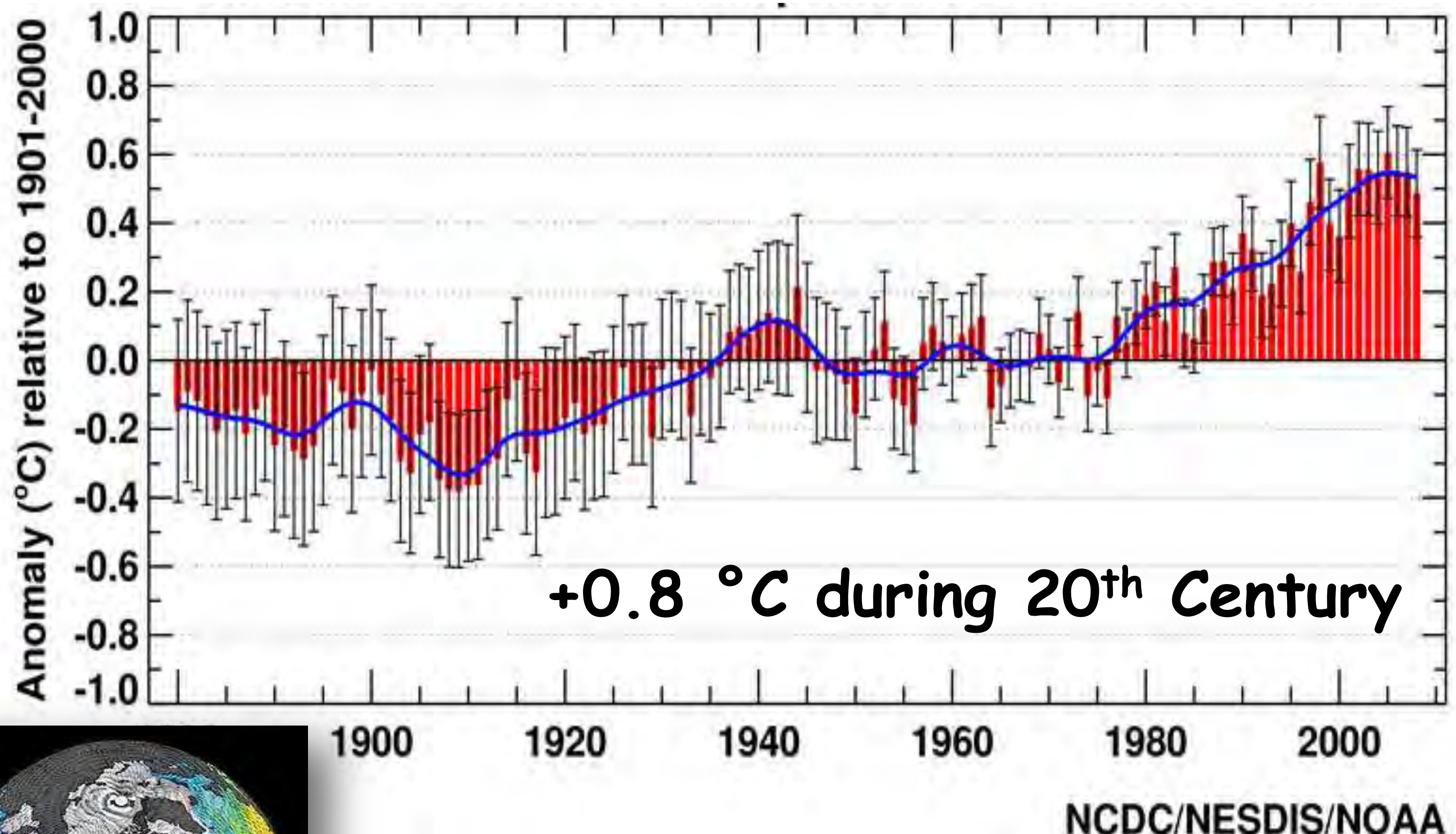


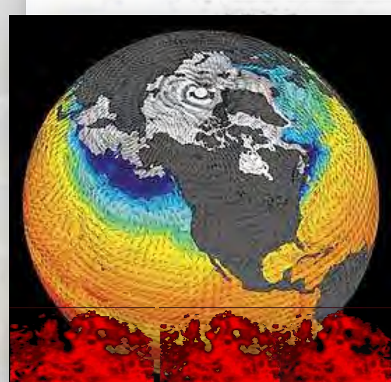
General outline:

1) Stream temperature importance & context
2) Stream temperature trends
3) An easy & inexpensive monitoring protocol
4) Leveraging information from aggregated, non-random databases
5) Temperature, a Stream Intranet, & "Killer apps"
6) Resources for monitoring & modeling

The New Reality - A Warming Climate

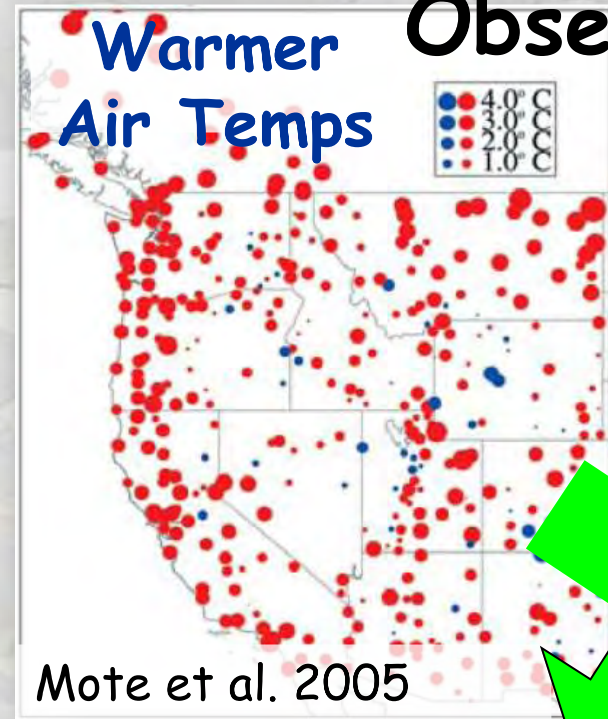
1880 - 2008 Global Air Temperature Trend





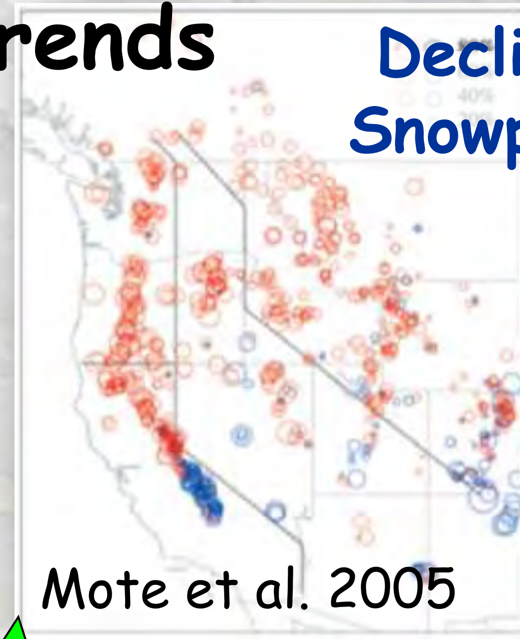
Western US – 20th Century Observed Trends

Warmer Air Temps



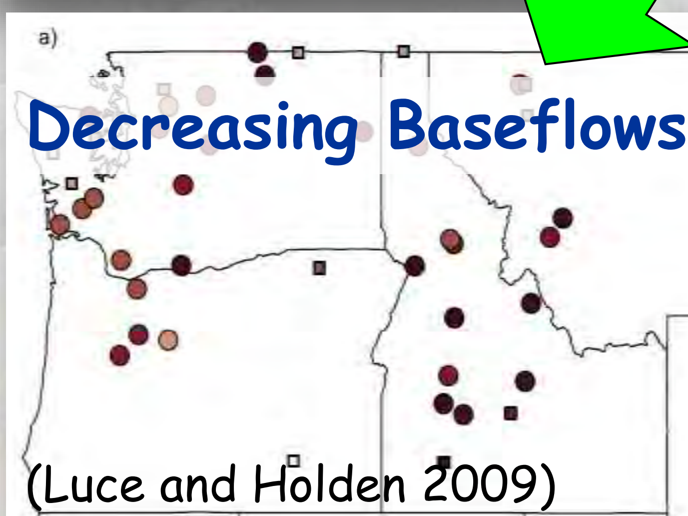
Mote et al. 2005

Declining Snowpacks



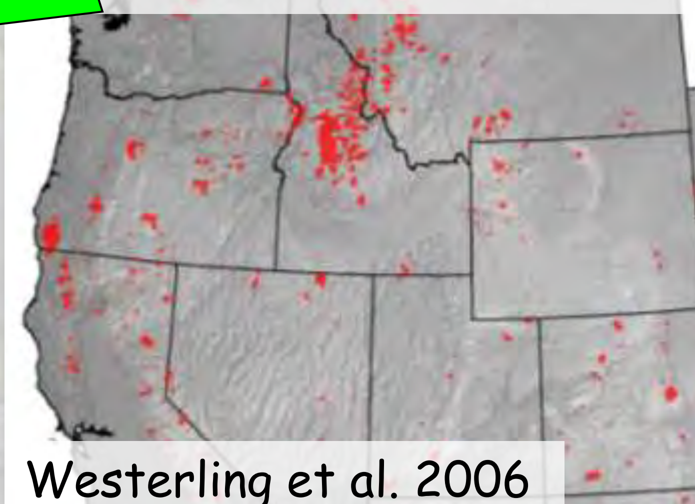
Mote et al. 2005

Decreasing Baseflows



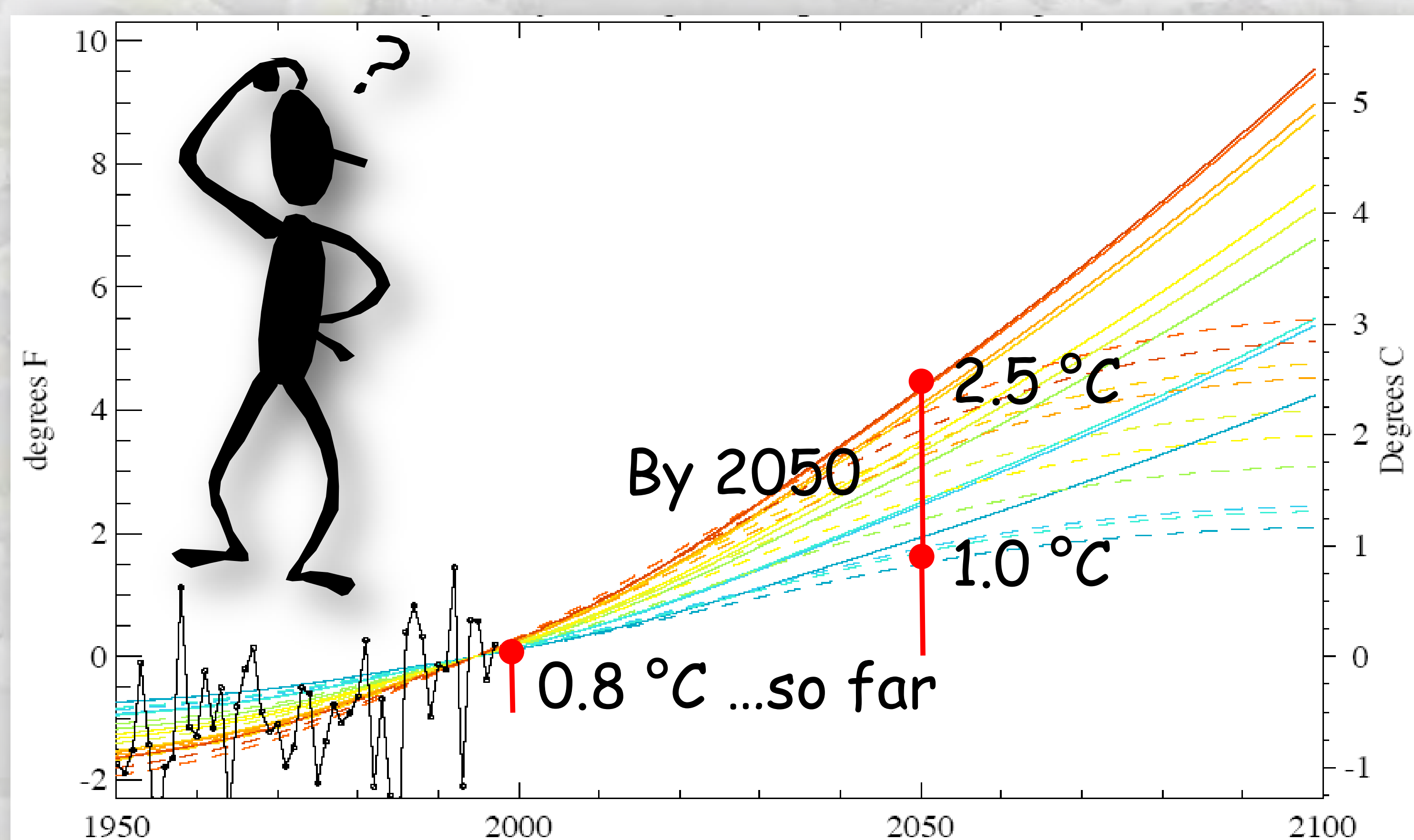
(Luce and Holden 2009)

Wildfire Increases



Westerling et al. 2006

Warming Trends Will Continue (& Accelerate?)

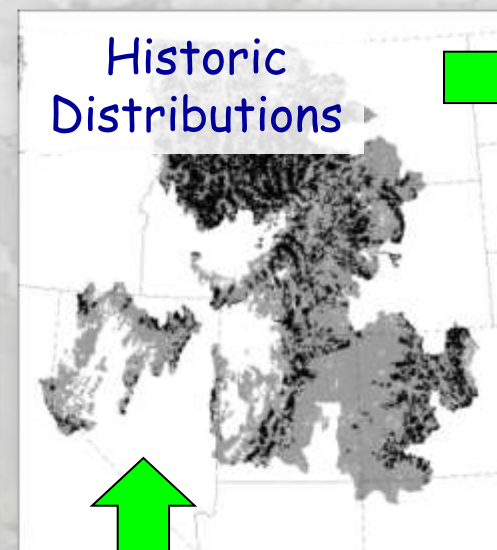


Mote et al. 2005; 2008

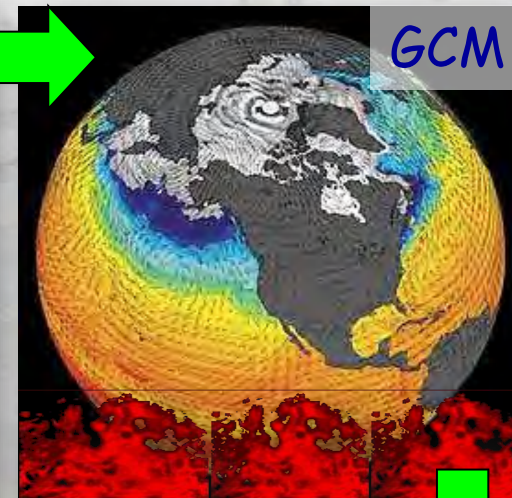
Western Trout Climate Assessment

Fish survey database
~10,000 sites

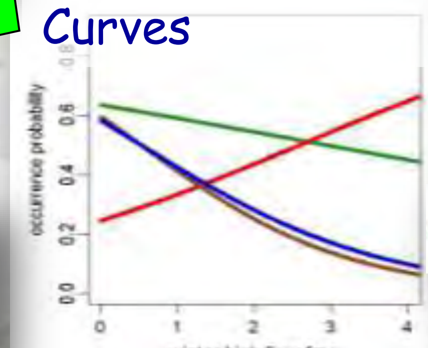
Historic
Distributions

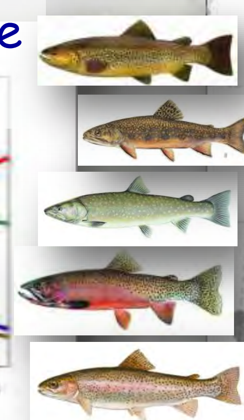


GCM

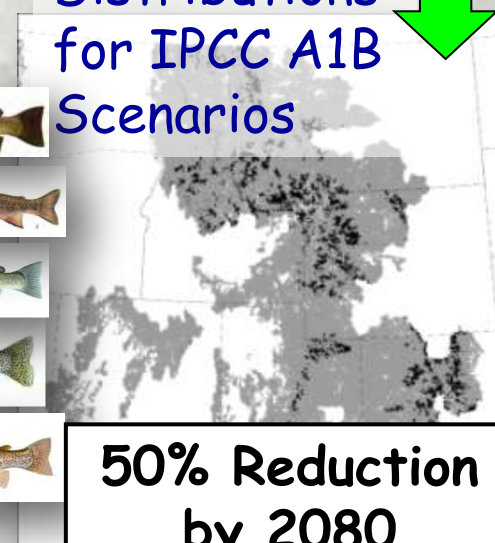


Species-Specific
Habitat Response
Curves





Distributions
for IPCC A1B
Scenarios

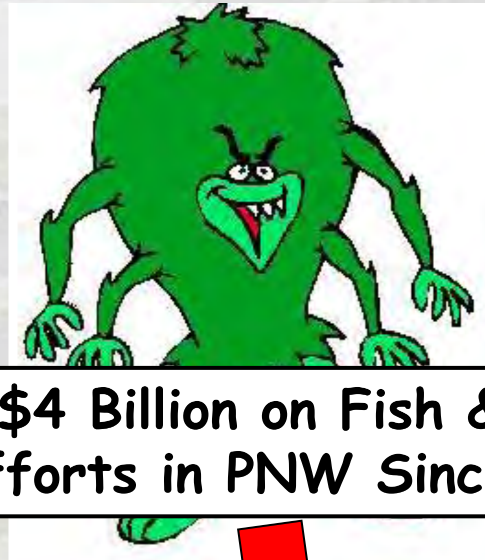


50% Reduction by 2080

Wenger et al. 2011. *Proc. Nat. Acad. Sciences*

There's A Lot on the Line

Climate Boogeyman



Recreational Fisheries

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

Wednesday, September 29, 2004
Fishing

High Water Temperature In Grande Ronde Kills 239 Adult Spring Chinook

Bulletin,
9 (PST)

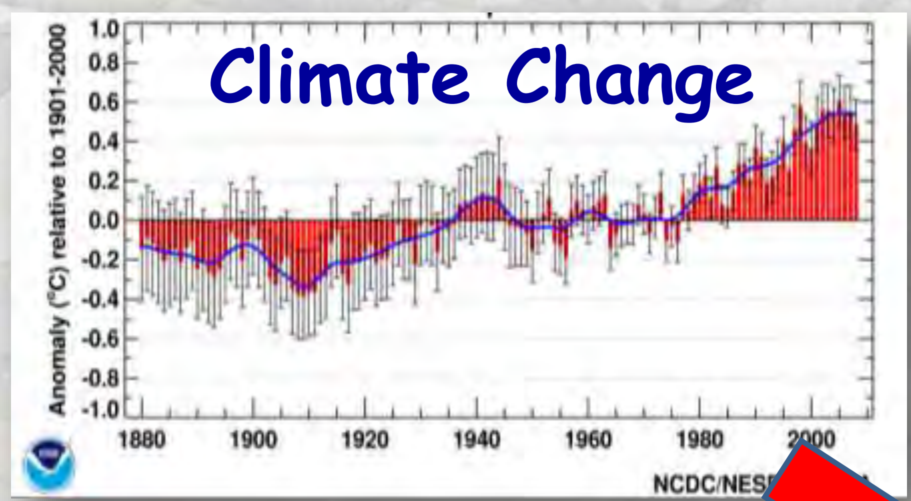
$4 Billion on Fish & Wildlife Recovery Efforts in PNW Since 1980 (ISAB/ISRP 2007)

ESA Listed Species

Land Use & Water Development

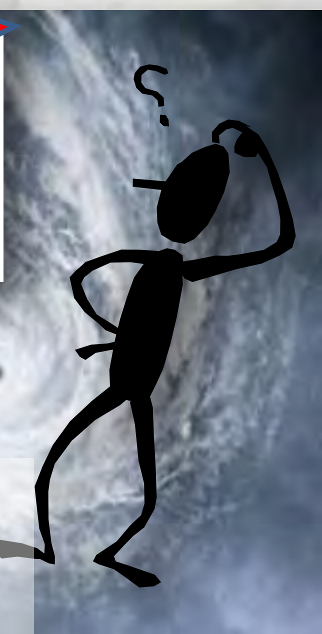
More Pressure, Fewer Resources

Climate Change



Urbanization & Population Growth

Shrinking Budgets



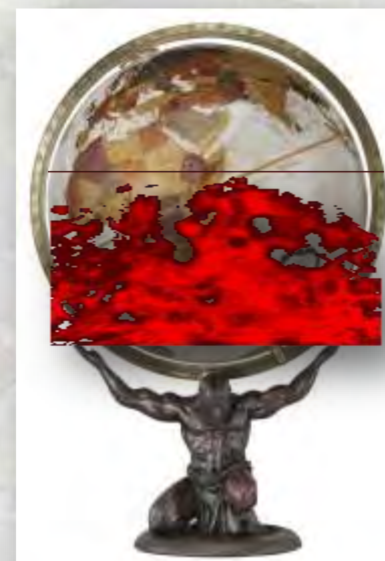
Need to do more with less

Climate Boogeyman

Analytical Capacity

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

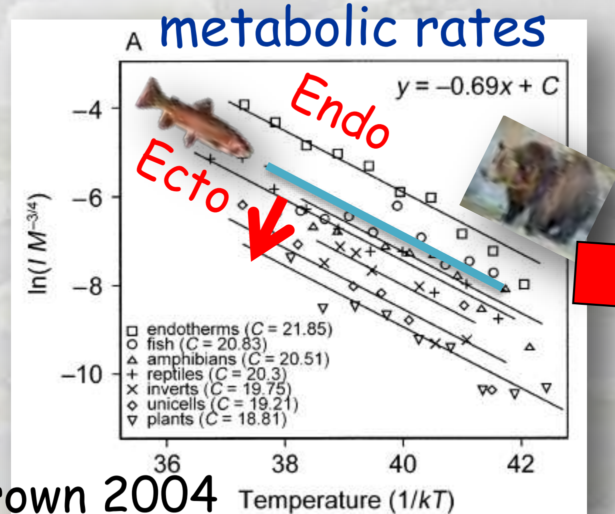
Interagency Collaboration



Geospatial Tools for Accurate Regional-to-Local Scale Models

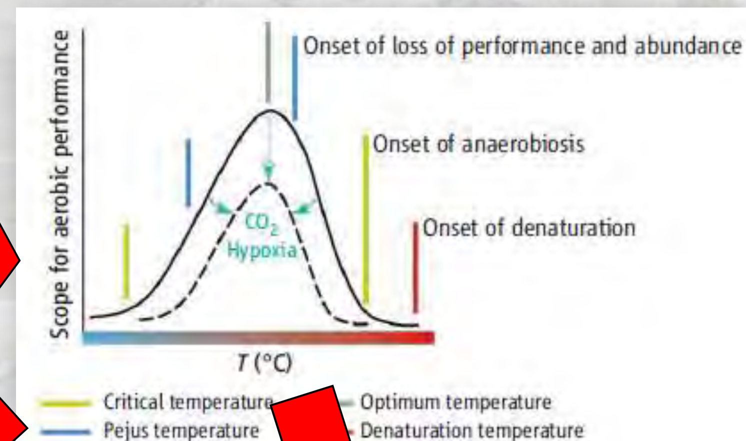
Temperature is Primary Control for Ectotherms Like Fish

Temperature & metabolic rates

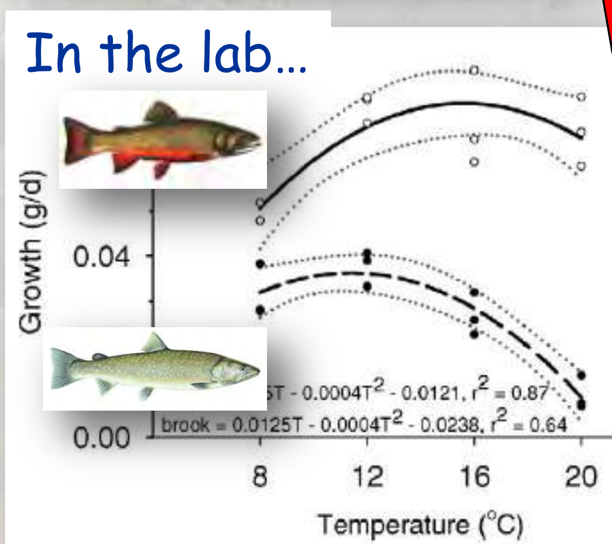


Brown 2004

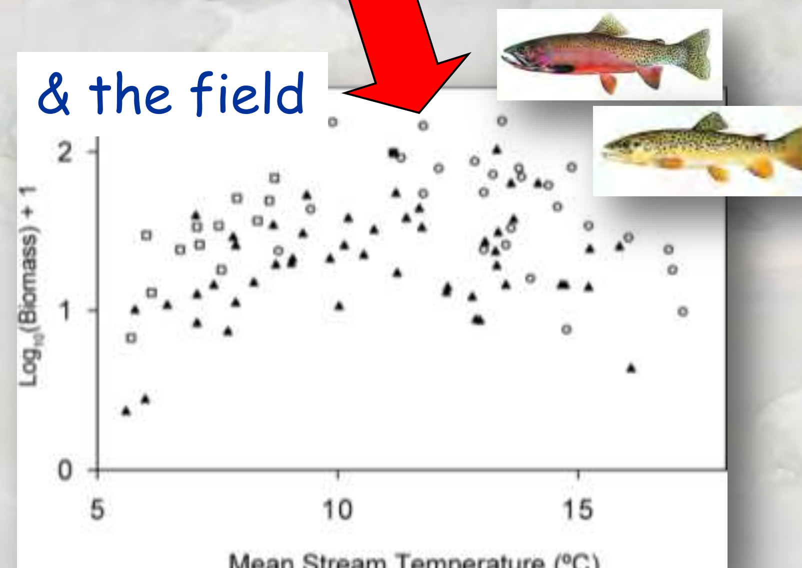
Thermal Niche



In the lab…



& the field

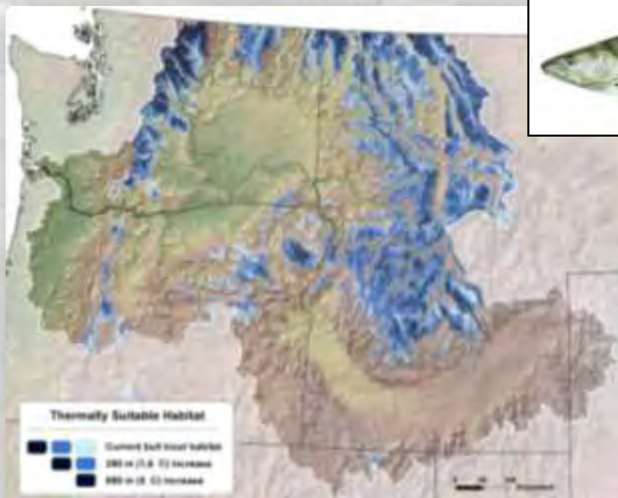


McMahon et al. 2007

Isaak & Hubert 2004

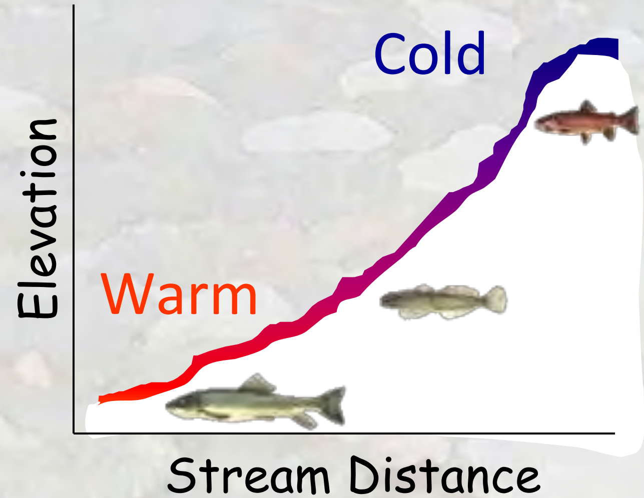
Temperature Regulation – Spatial Distributions

Regional Scale

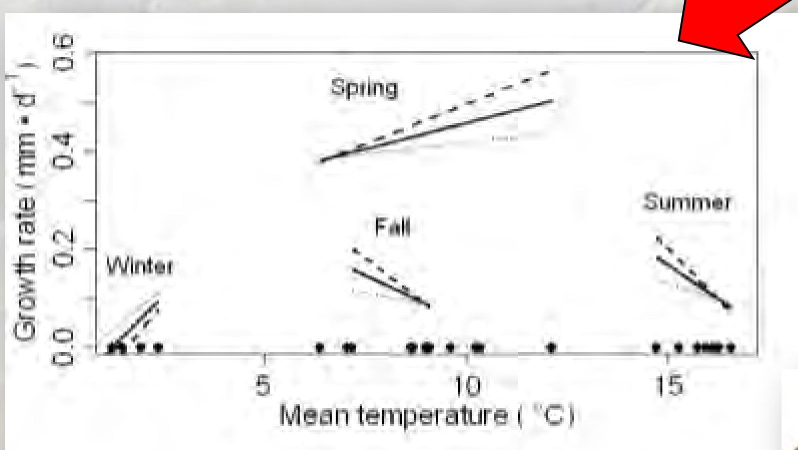


Rieman et al. 2007

Stream Scale



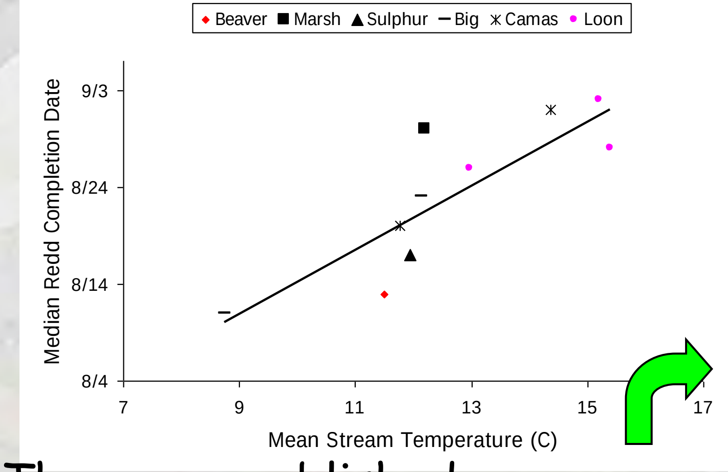
Channel Unit Scale



Xu, Letcher, and Nislow. 2010.

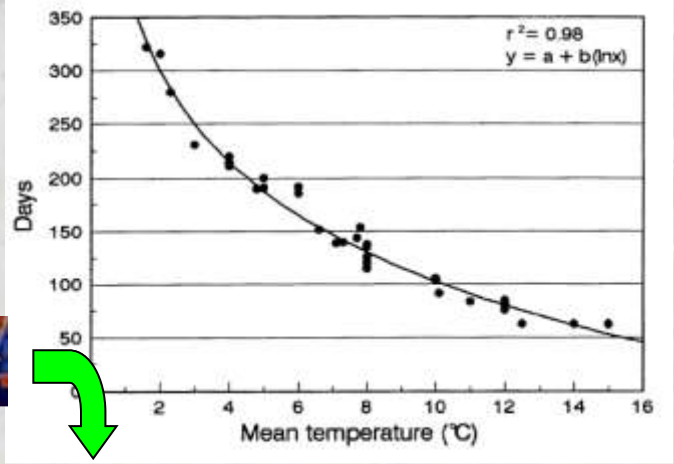
Temperature Regulation - Life Cycle

Spawn timing - Chinook salmon

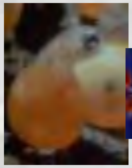


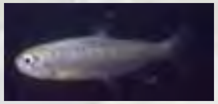
Thurow, unpublished

Incubation length - Chinook salmon

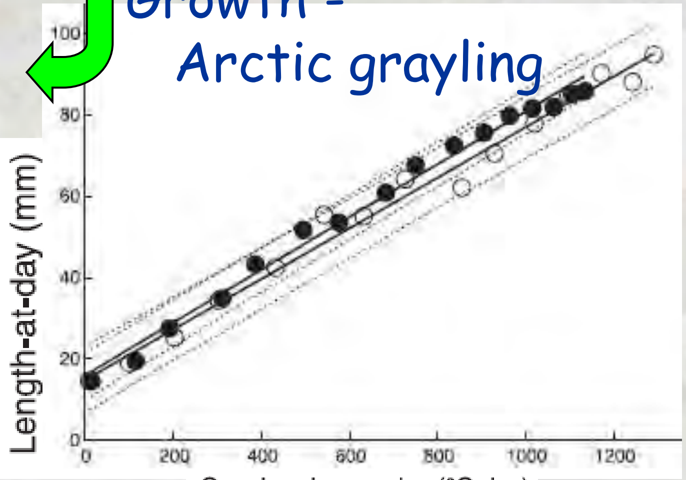


Brannon et al. 2004



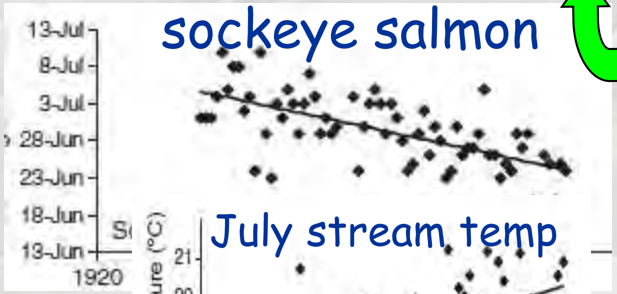


Growth - Arctic grayling

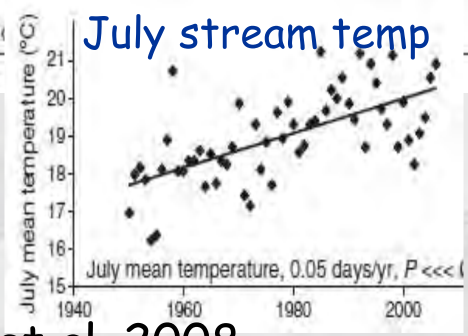


Dion and Hughes 1994

Migration timing - sockeye salmon

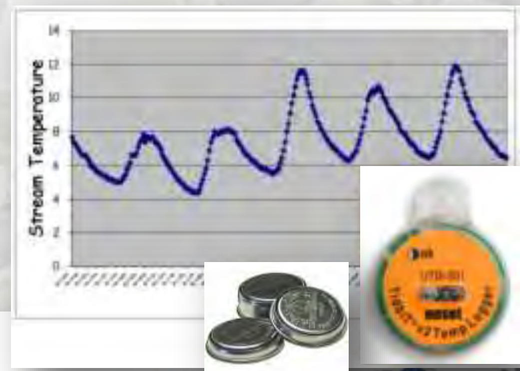


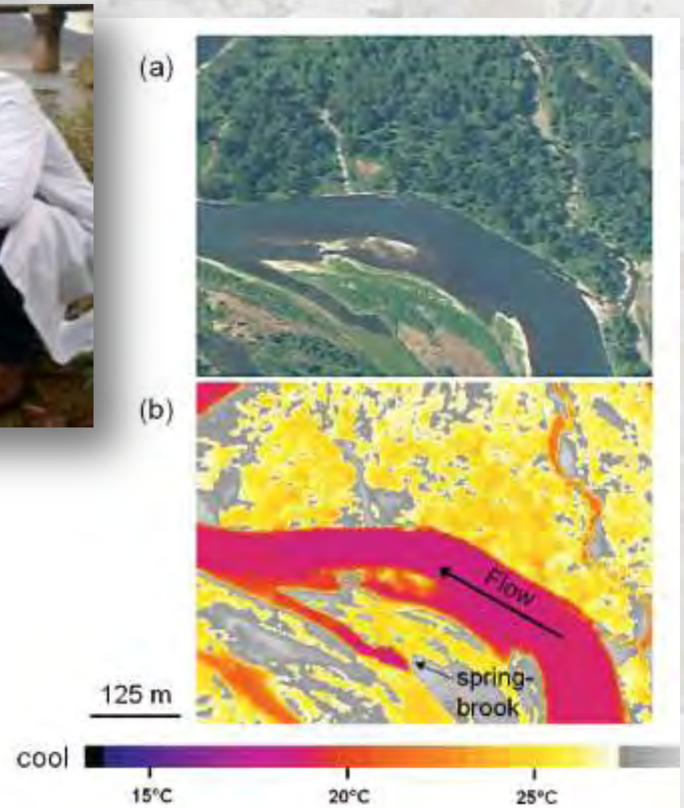
July stream temp

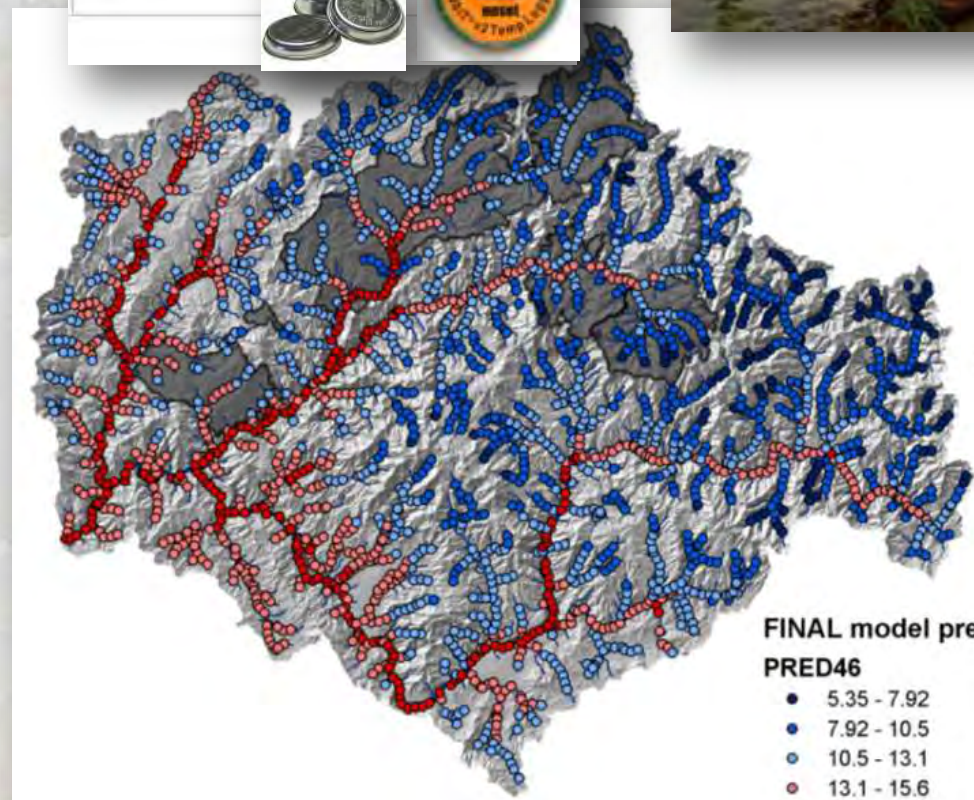


Crozier et al. 2008

Temperature & Water Quality/TMDL Standards

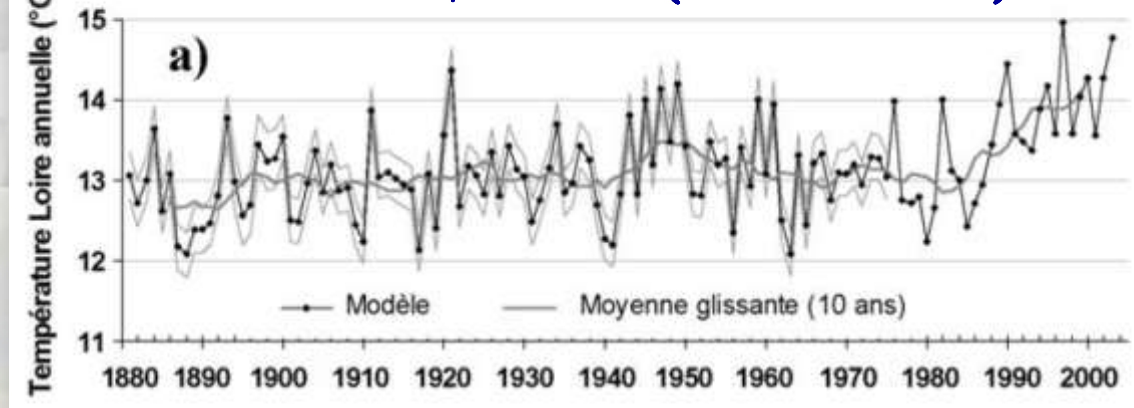




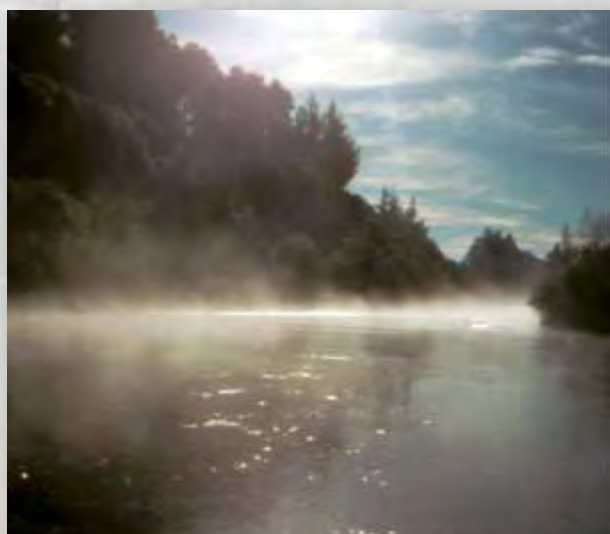


Global Trends in River Temperatures

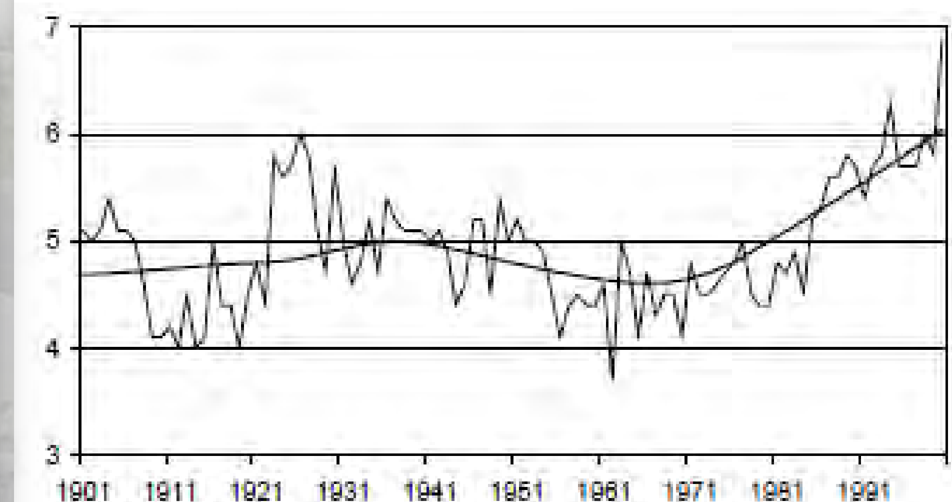
River Loire, France (1880 – 2003)



Moatar and Gailhard 2006



Danube River, Austria (1901 – 2000)



Webb and Nobilus 2007

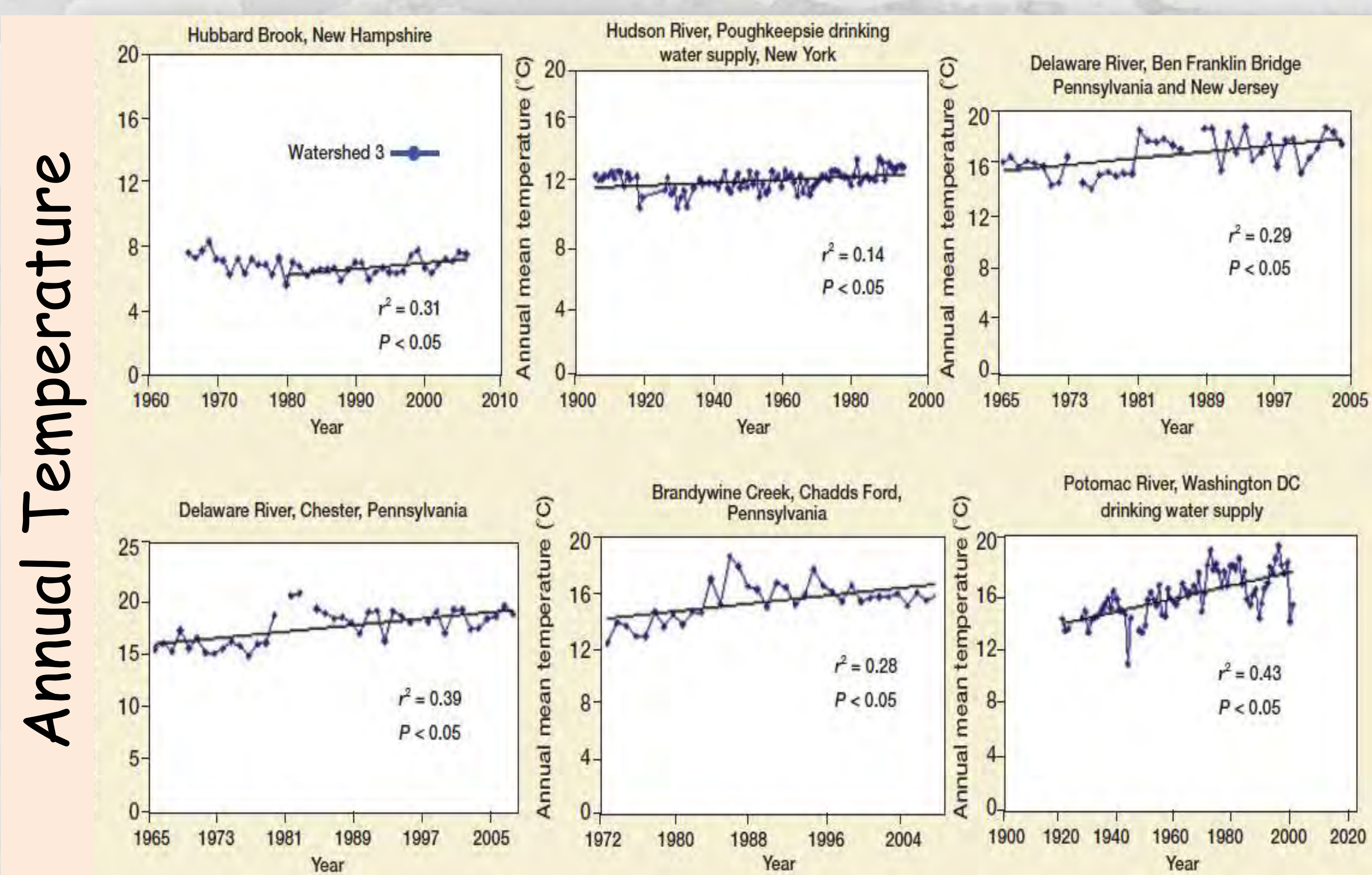
Urbanization & Landuse Conversion Contribute to Stream Warming

Rising stream and river temperatures in the United States

Sujay S Kaushal[1*], Gene E Likens[2], Norbert A Jaworski[3], Michael L Pace[2†], Ashley M Sides[1], David Seekell[4], Kenneth T Belt[5], David H Secor[1], and Rebecca L Wingate[1]

Kaushal et al. 2010. *Frontiers in Ecology & the Environment*

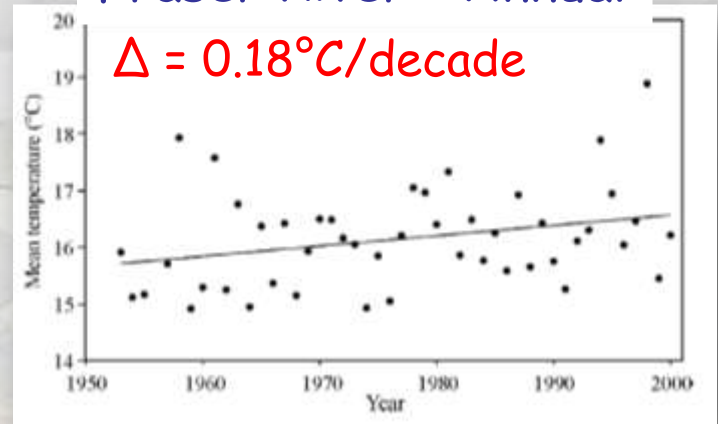
Urbanization & Landuse Conversion Contribute to Stream Warming



Kaushal et al. 2010. *Frontiers in Ecology & the Environment*

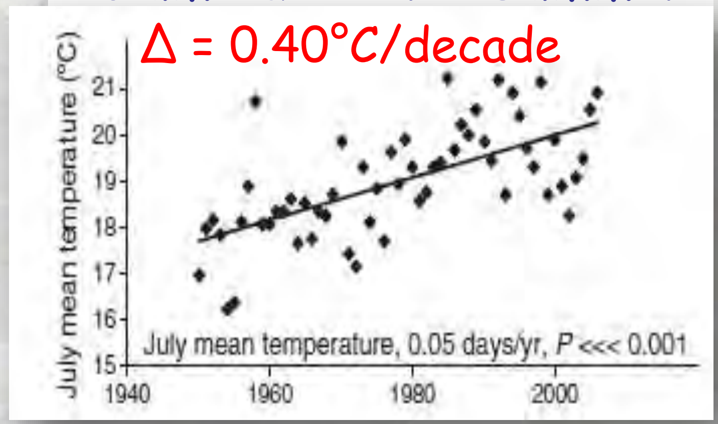
Regional Trends In Northwest Rivers

Fraser River - Annual



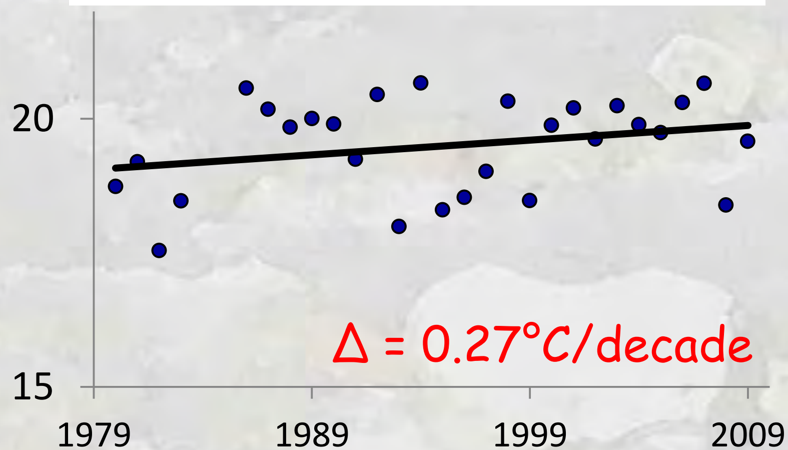
Morrison et al. 2002

Columbia River - Summer

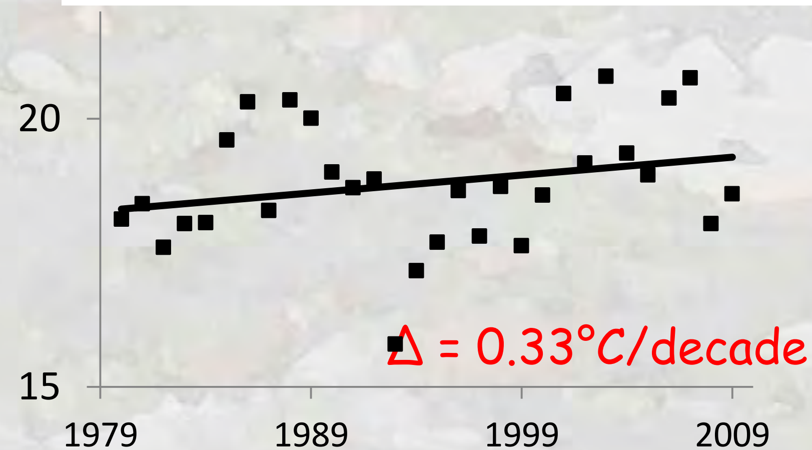


Crozier et al. 2008

Snake River, ID - Summer



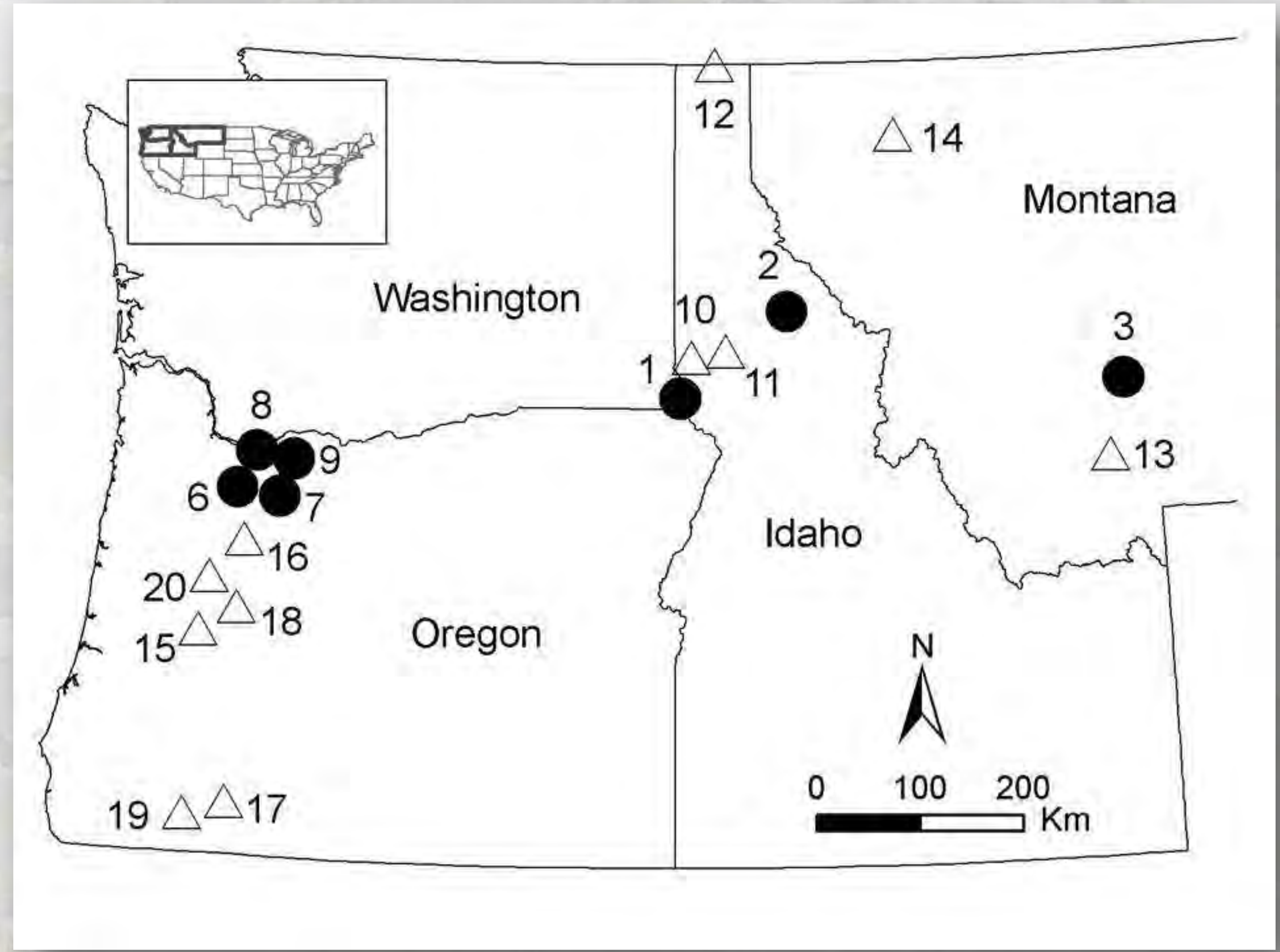
Missouri River, MT - Summer



Isaak et al. 2011. *Climatic Change*

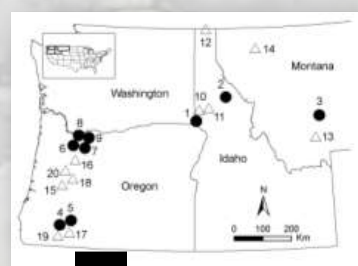
30 Year Monitoring Sites in NW U.S.

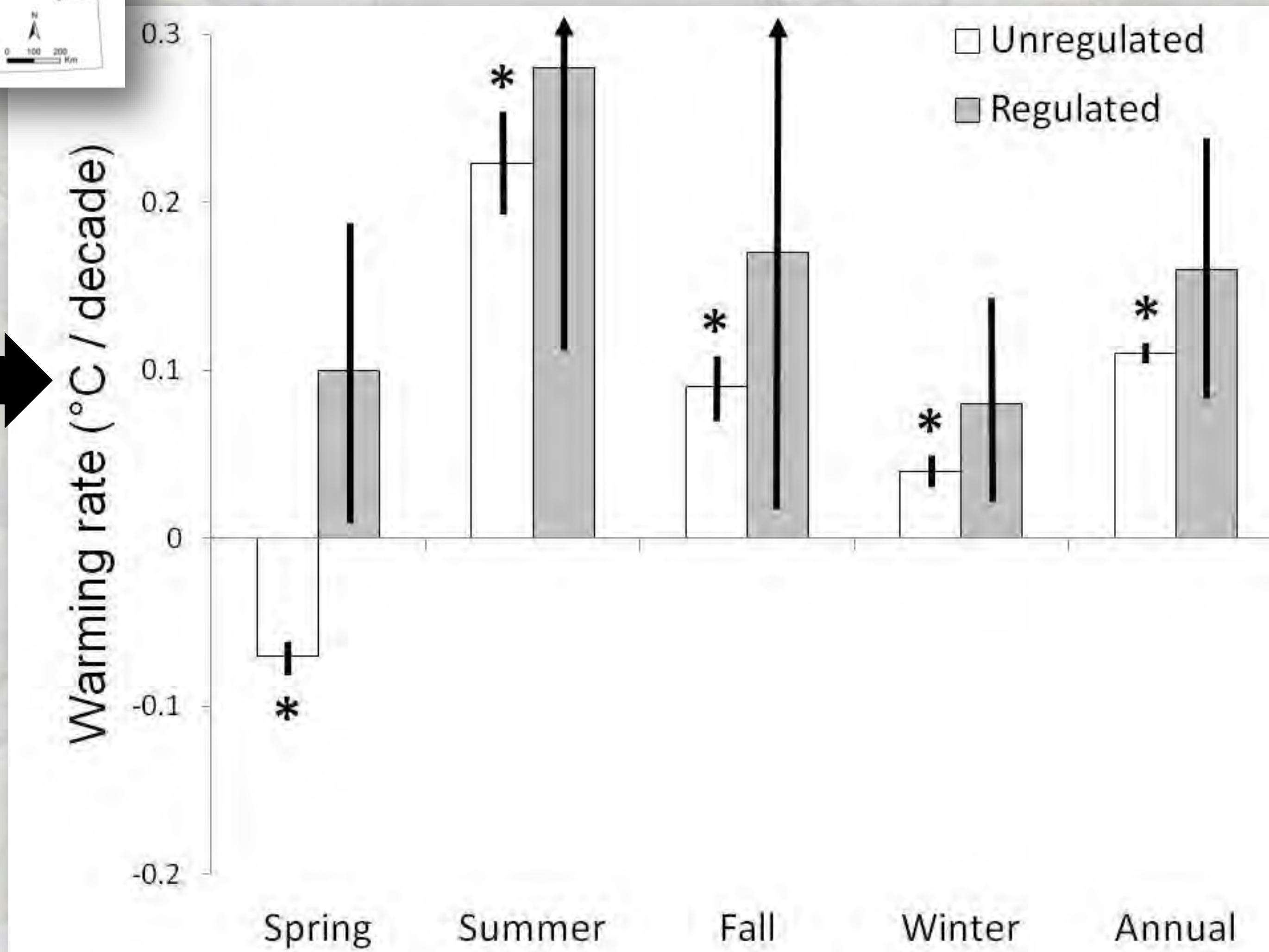
△ = regulated (11) ● = unregulated (7)



USGS NWIS Database (http://waterdata.usgs.gov/nwis)

Seasonal Climate Trends In Stream Temperatures (1980-2009)

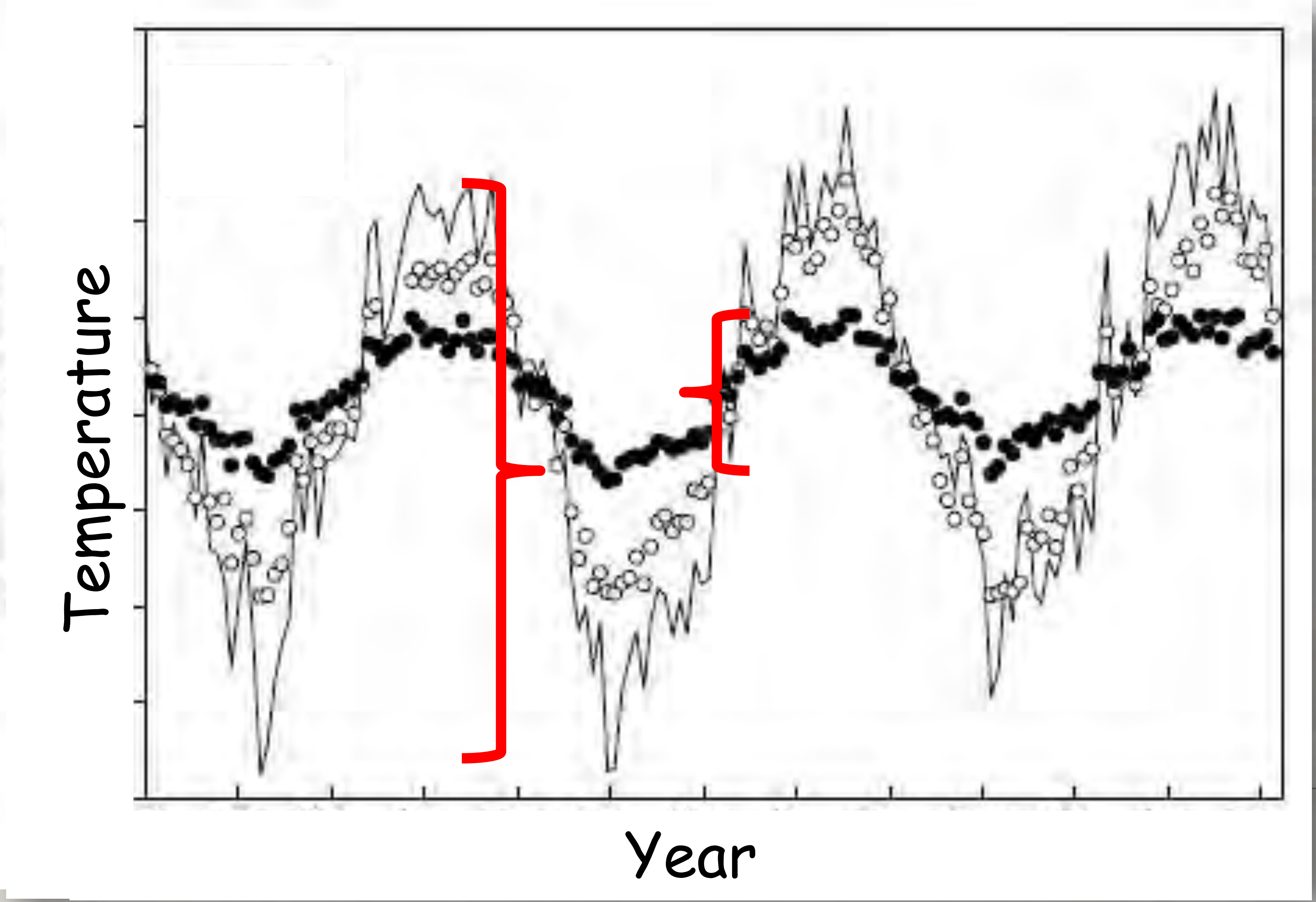




Isaak et al. 2011. *Climatic Change*

Attribution of Stream Warming Trends

Inter-annual variation ~ environmental noise



Attribution of Stream Warming Trends

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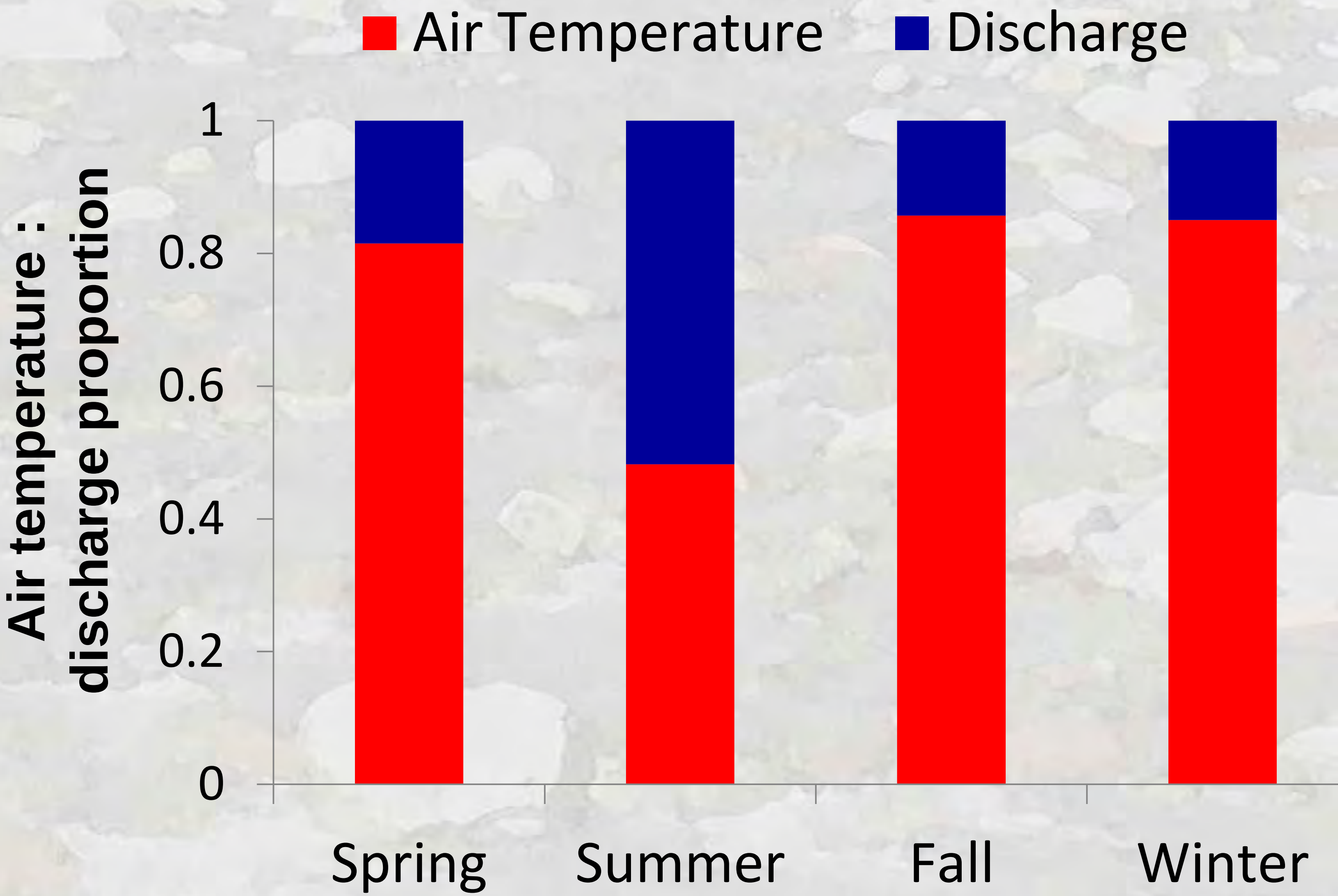
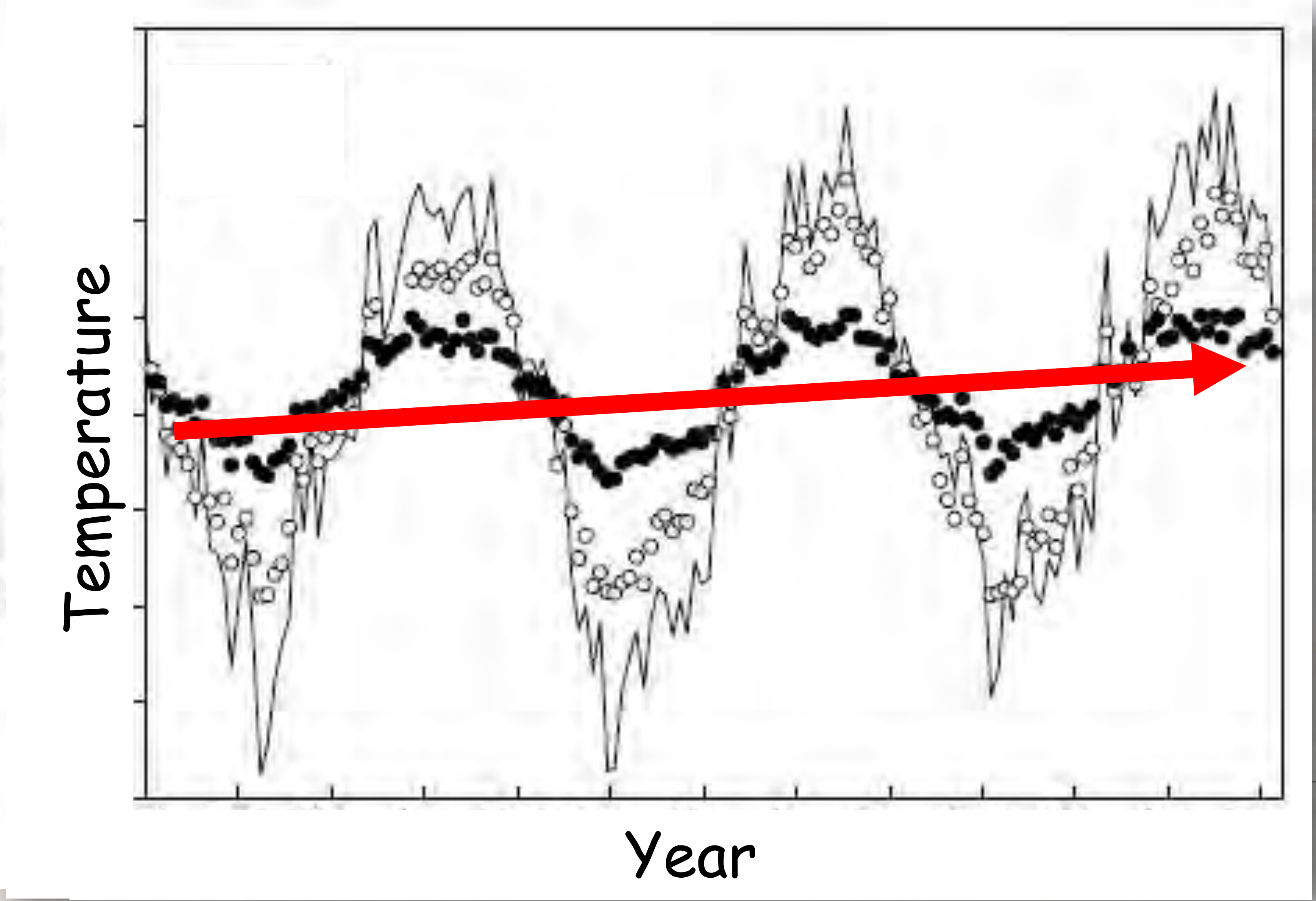


Attribution of Stream Warming Trends

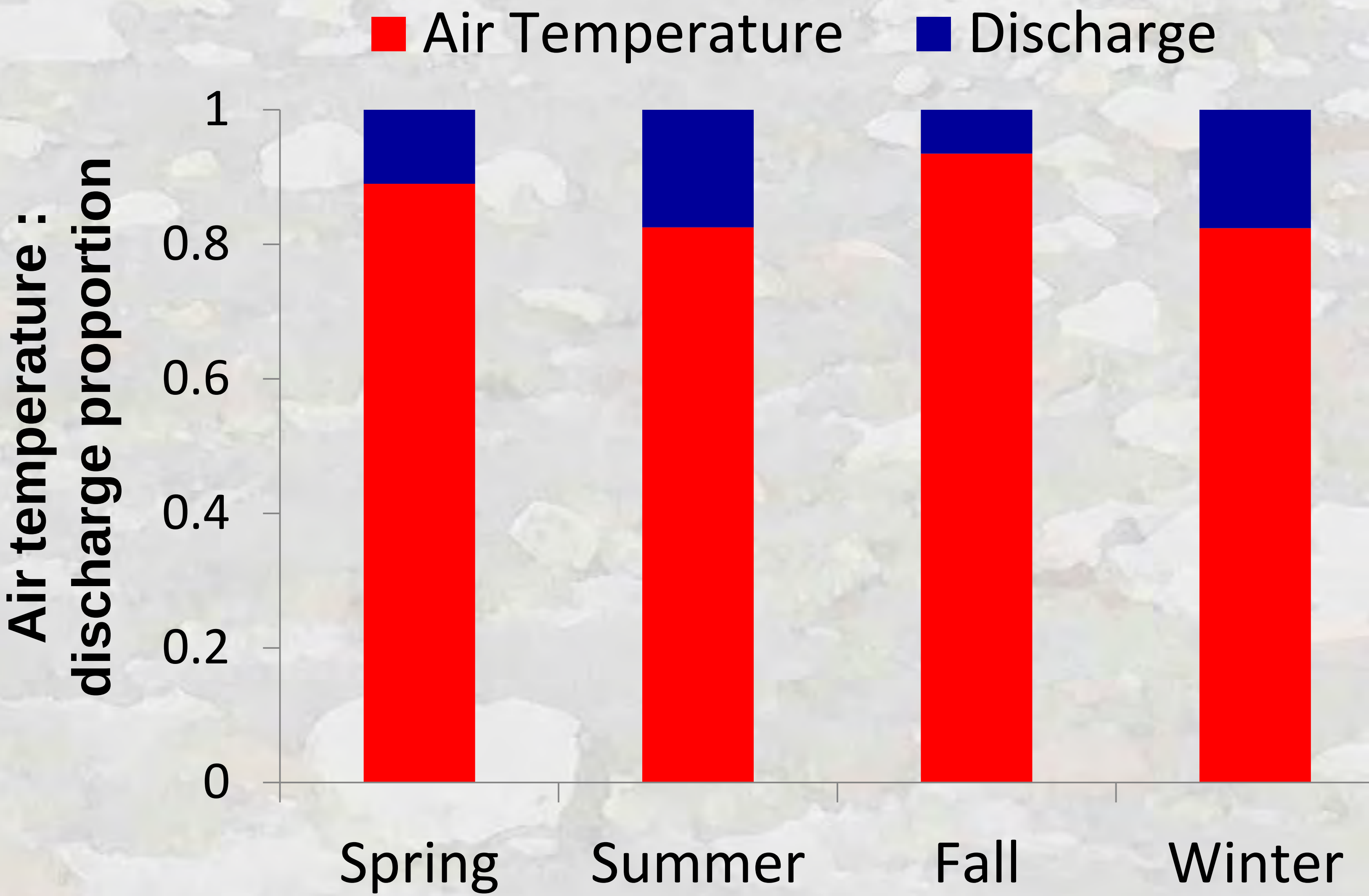
Long-term trend ~ environmental signal



Isaak et al. 2011. *Climatic Change*

Attribution of Stream Warming Trends

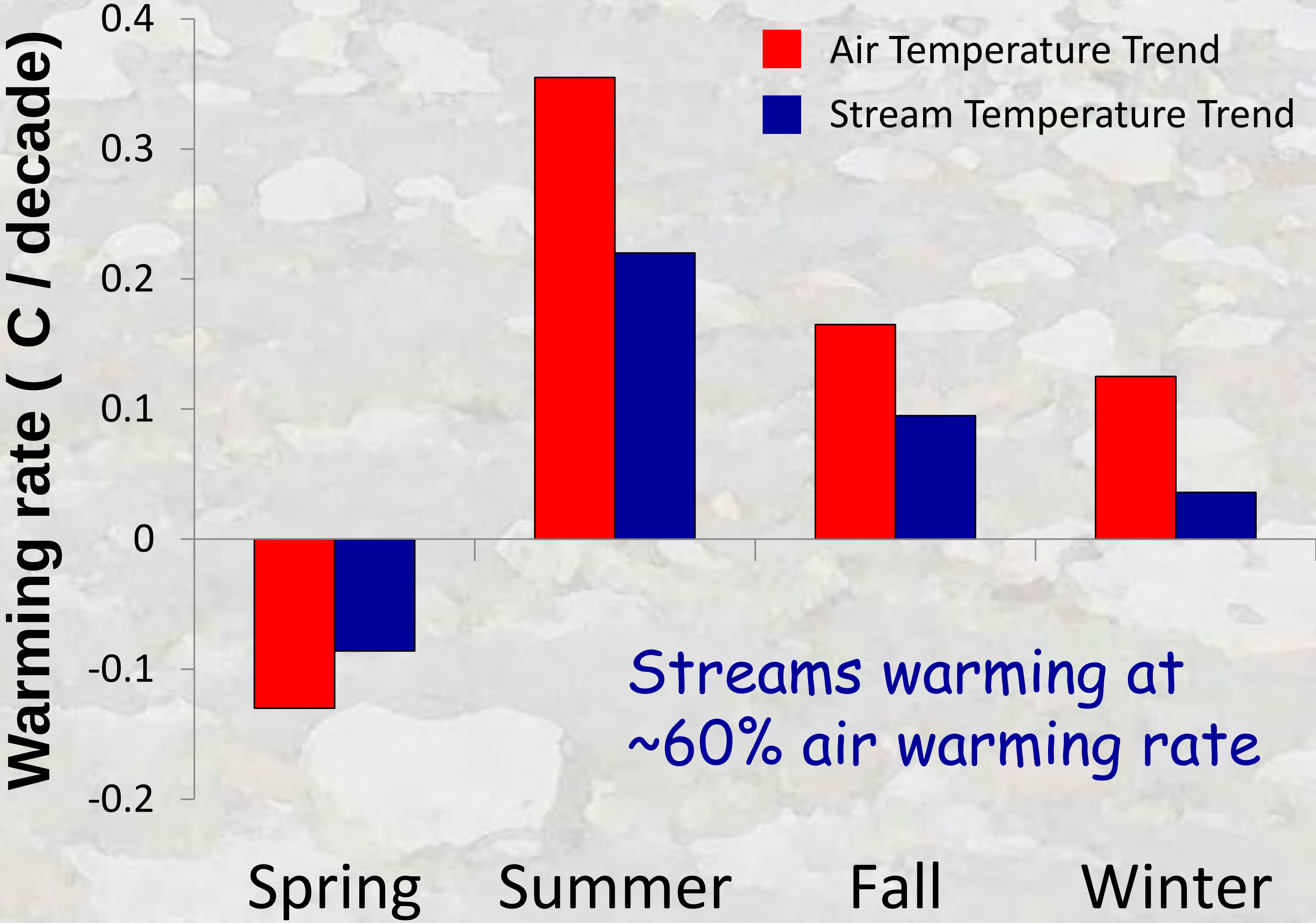
Long-term trend ~ environmental signal



Isaak et al. 2011. *Climatic Change*

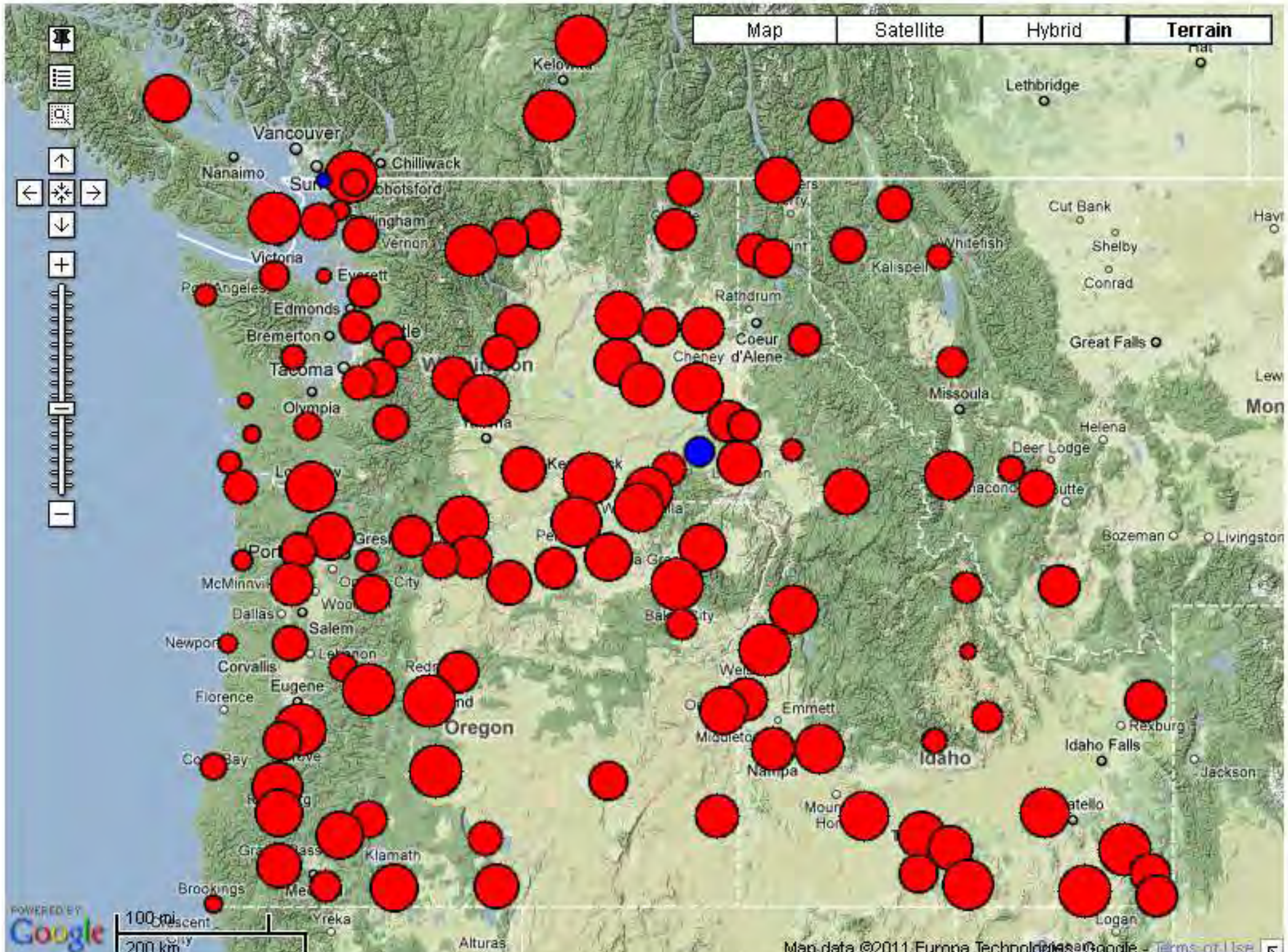
Attribution of Stream Warming Trends

Comparison to Air Temp Trends at Local Climate Stations



Similar Trends in Most Regional Streams?

Mean Summer Air Temp Trends (1980 – 2009)



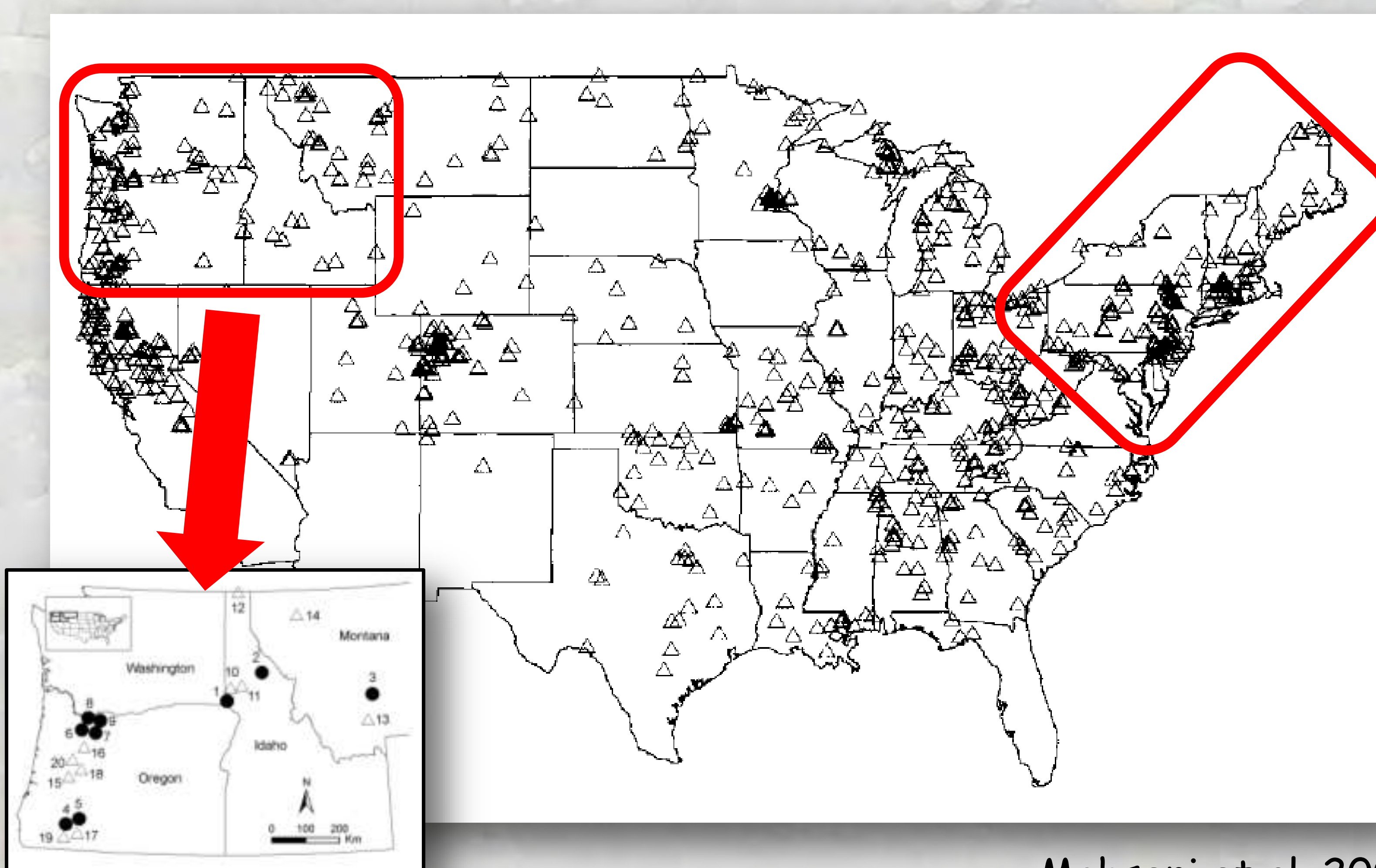
OWSC Climate Tool map

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

Long-term Monitoring Data?

764 gage sites have some temperature data

USGS NWIS Database (http://waterdata.usgs.gov/nwis)

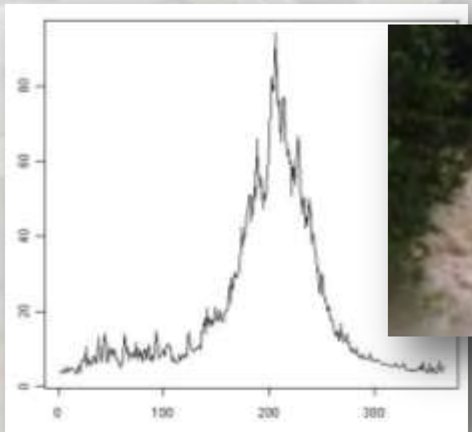


Mohseni et al. 2003

Easy Method for Full Year Monitoring

Underwater Epoxy Protocol

Annual Flooding Concerns



Underwater epoxy cement

$130 = 5 years of data

Data retrieved
from underwater

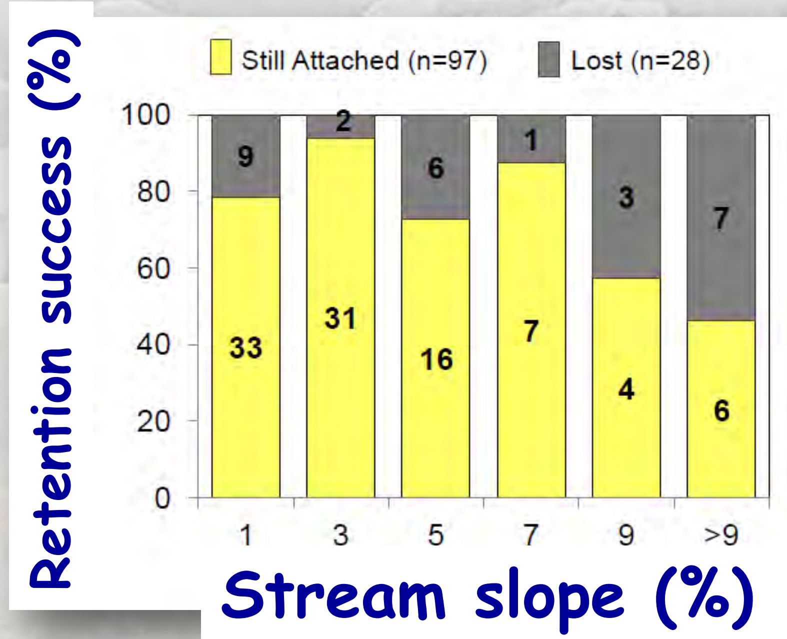
Sensors or PVC housings glued to large boulders

Isaak & Horan 2011. *NAJFM* 31:134-137

Big Boulders & Small Sensors

Bridge pilings also…

Epoxy Sensor Retention Rates

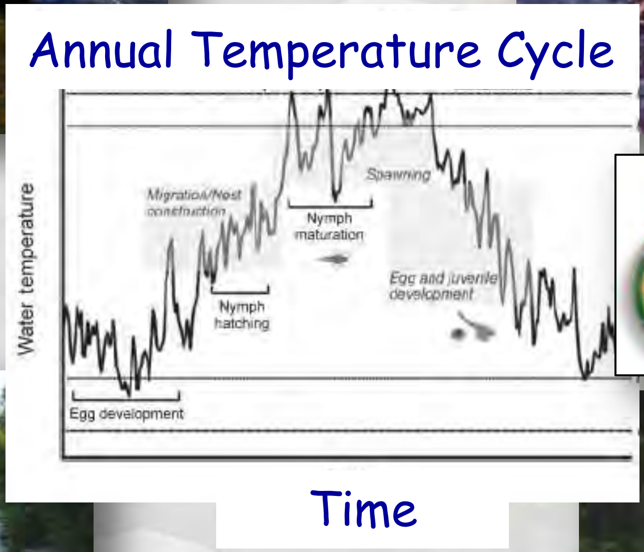


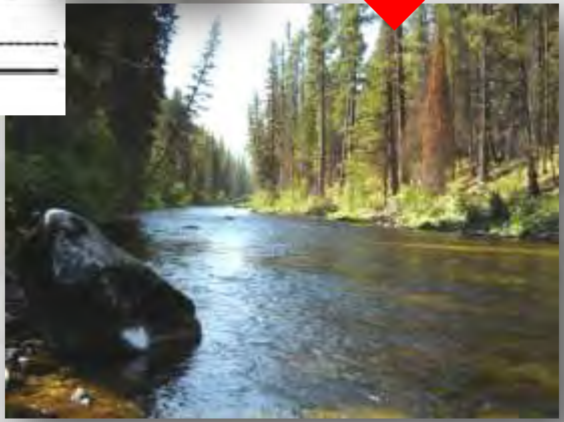
Sensors installed in 2010 & checked one year later

85% (64/75) retained in stream slopes $\leq$3%

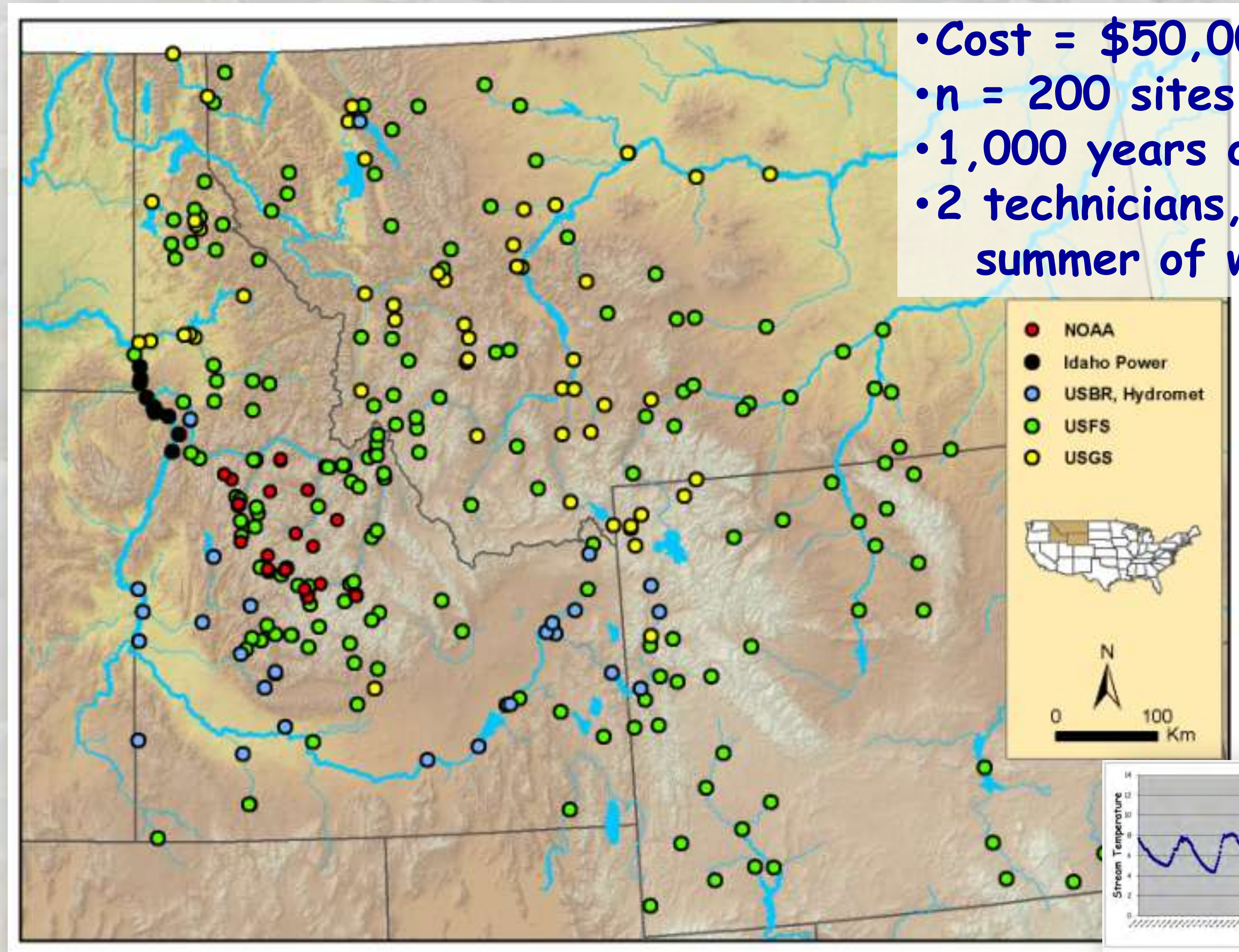
"How-to" installation video…
Google "Underwater Epoxy"

Monitoring GAP = Full-year data from large, unregulated rivers





NoRRTN: Northern Rockies River Temperature Network

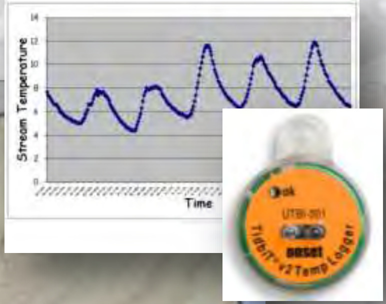


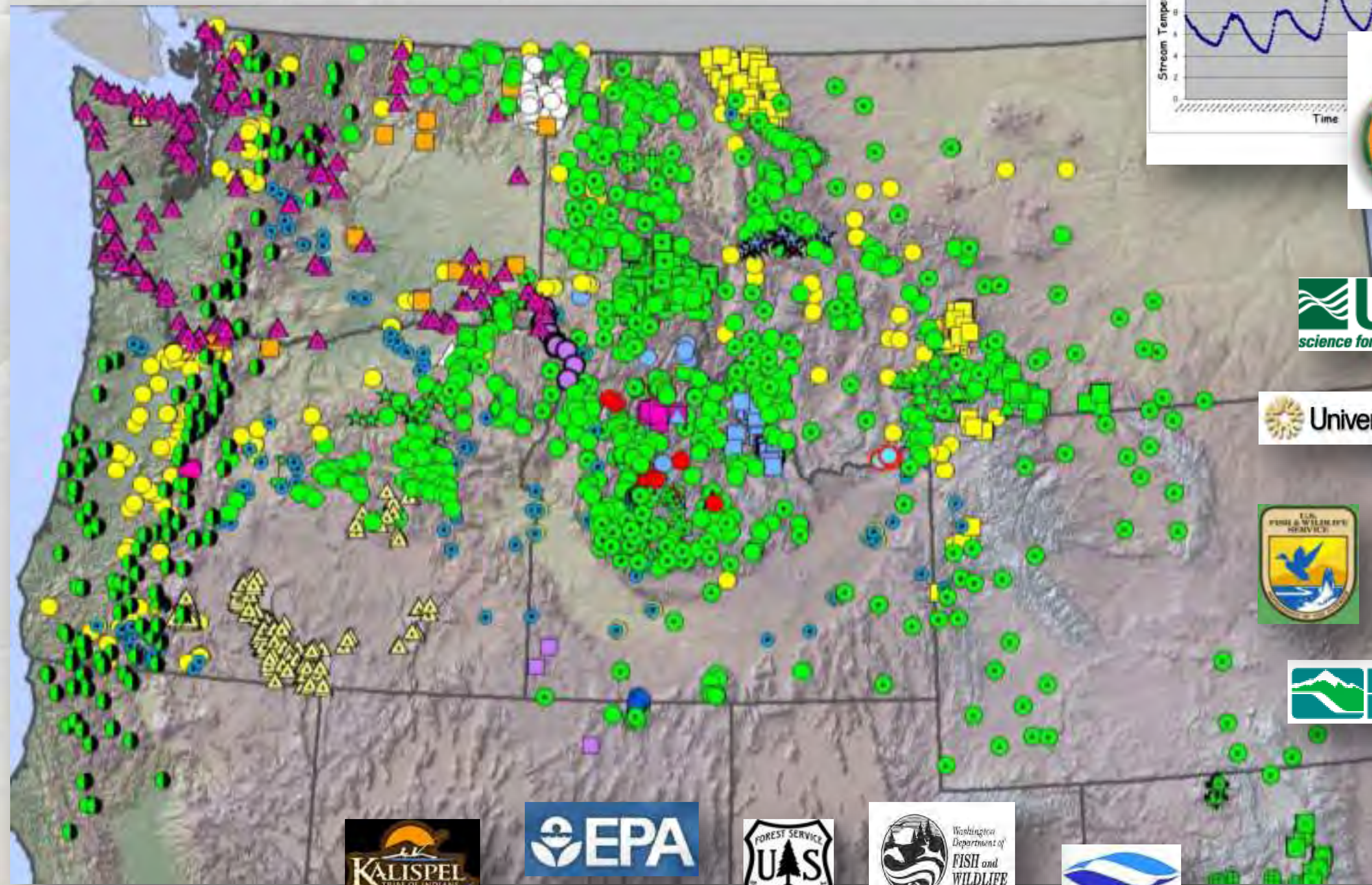
- Cost = $50,000
- n = 200 sites;
- 1,000 years of data
- 2 technicians, 1 summer of work

Regional Interagency Stream Temperature Monitoring Network

2,761 Current full-year monitoring sites

~1,000 New deployments last year





USGS science for a changing world

University of Idaho

U.S. Fish & Wildlife Service

Idaho Fish & Game

Idaho Power.

Kalispel Tribe of Indians

EPA

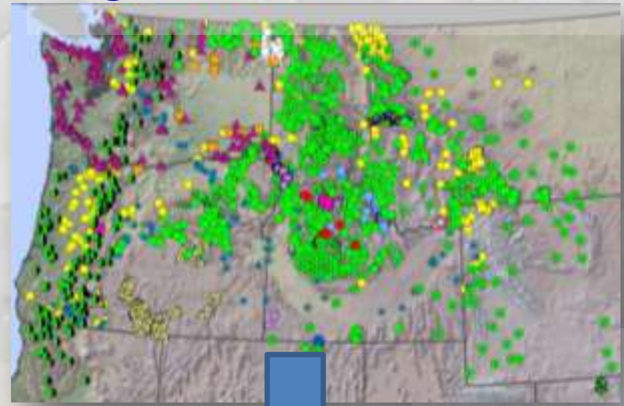
Forest Service U.S. Department of Agriculture

Washington Department of Fish and Wildlife

NOAA Fisheries

A GoogleMap Tool for Dynamic Queries of Temperature Monitoring Sites

Regional Sensor Network



Site Information

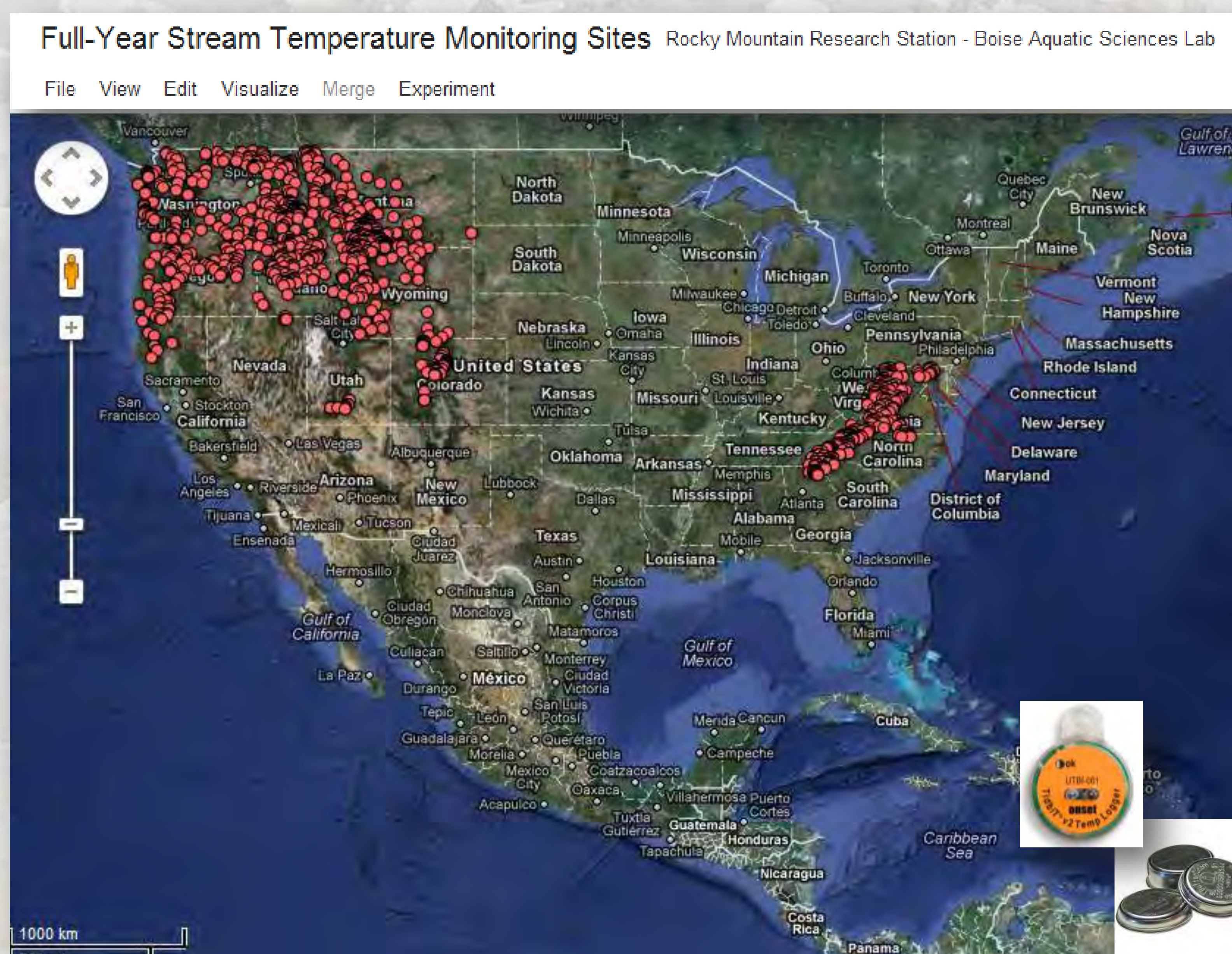
- Stream name
- Data steward contact information
- Agency
- Site Initiation Date

Query Individual Sites

Webpage:

Google Search "USFS Stream Temperature"

GoogleMap Tool – Sites (4/28/12)



Uses for Full Year Monitoring Data:

1) Characterize thermal "regimes" instead of summer maximas

2) Short-term sensitivity analysis to assess relative differences among sites to climate forcing

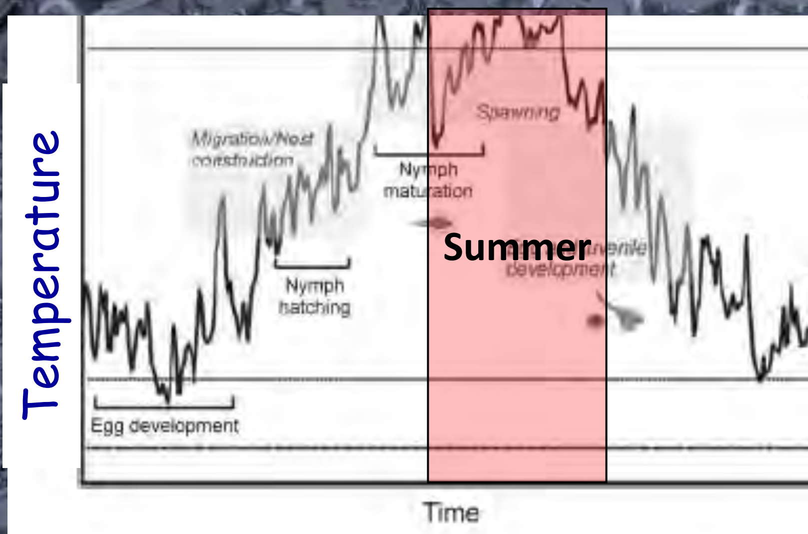
3) Better define thermal criteria & realized niches for aquatic organisms

4) Stream temperature reconstructions by linking to long-term climate station records (e.g., air temperature, discharge)

5) Parameterize statistical/mechanistic temperature models for spatial predictions/simulations

100x More Summer Temperature Data

Stealth Sensor Network



A Regional Stream Temperature Model for Mapping Thermal Habitats & Predicting Climate Vulnerability Across the Northwest

Dan Isaak[1], Erin Peterson[2], Jeff Kershner[3], Charlie Luce[1], Jason Dunham[3], Jay Verhoef[4], Seth Wenger[5], Brett Roper[1], Steve Hostetler[3], Dave Nagel[1], Dona Horan[1], Gwynne Chandler[1], Sherry Wollrab[1], Sharon Parkes[1], Dave Hockman[3]

1 FOREST SERVICE U.S. DEPARTMENT OF AGRICULTURE

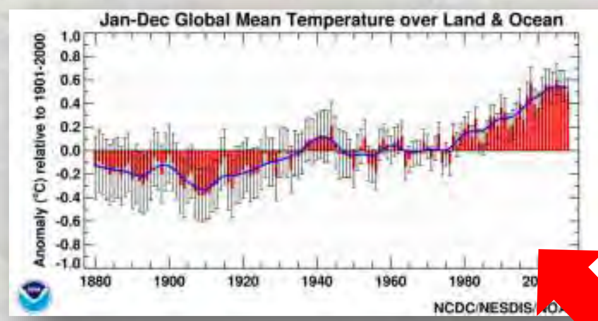
2 CSIRO

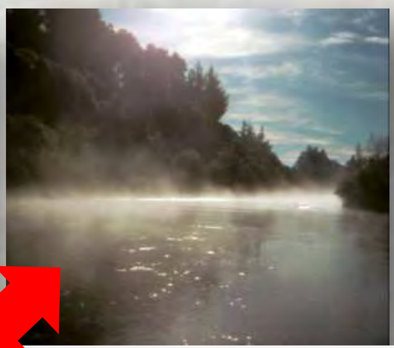
4 NOAA

5 TROUT UNLIMITED

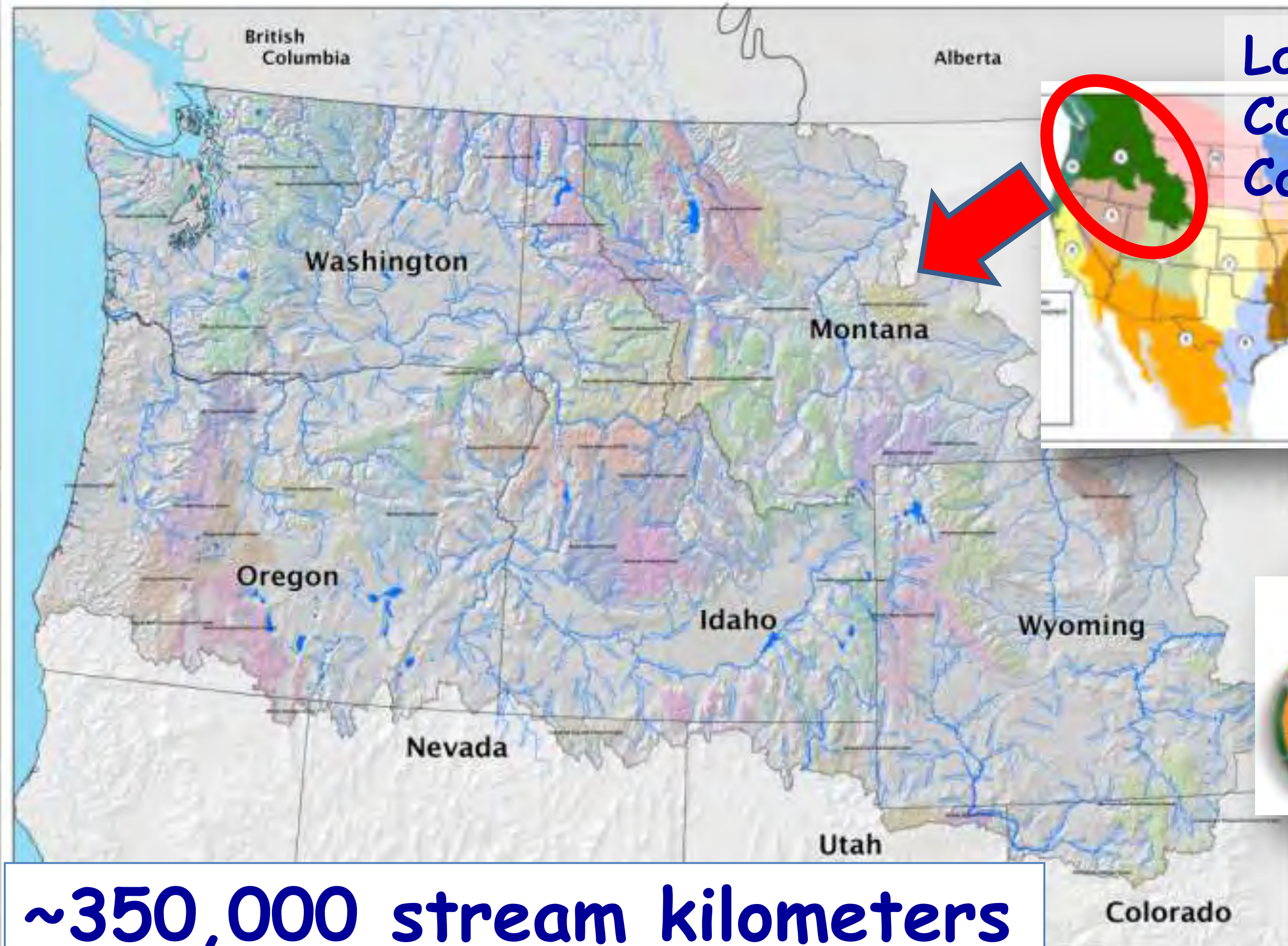
Boise Spatial Streams Group

3 USGS science for a changing world





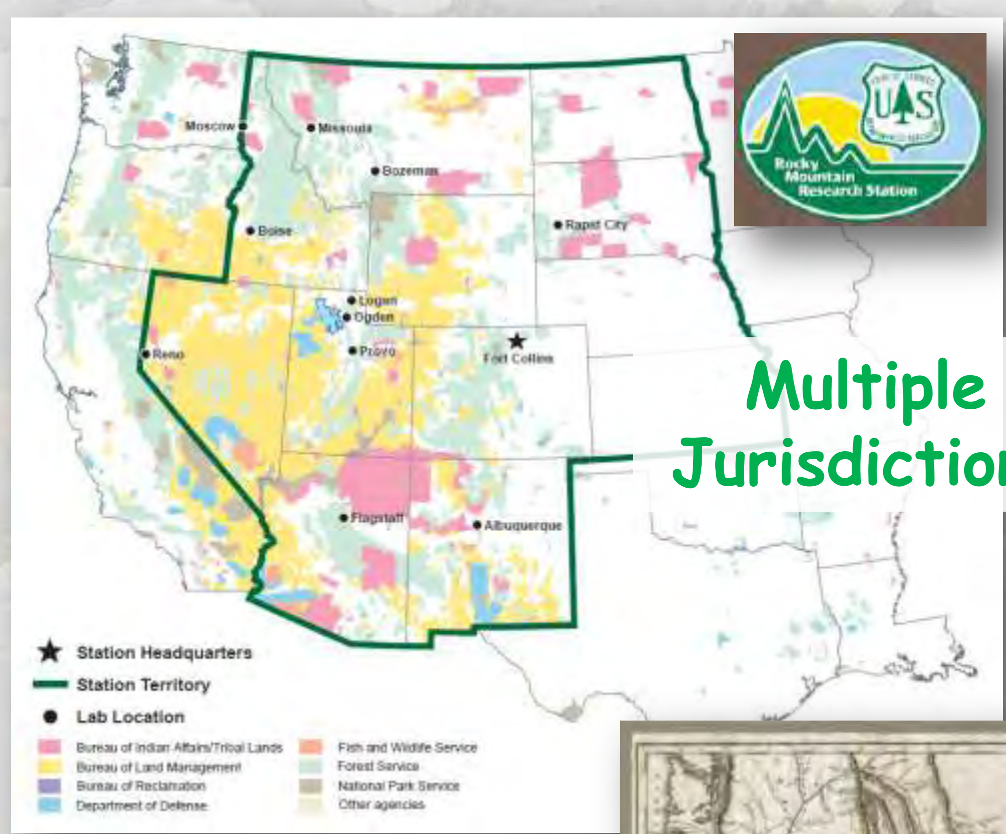
Great Northern
LANDSCAPE CONSERVATION COOPERATIVE



Landscape Conservation Cooperatives

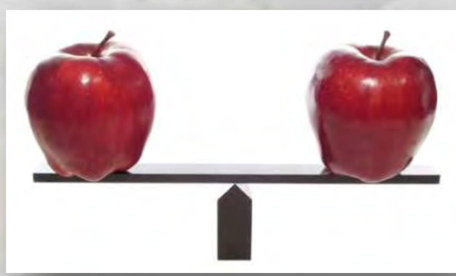
~350,000 stream kilometers

Making Accurate Regional "Maps" of Stream Temperatures



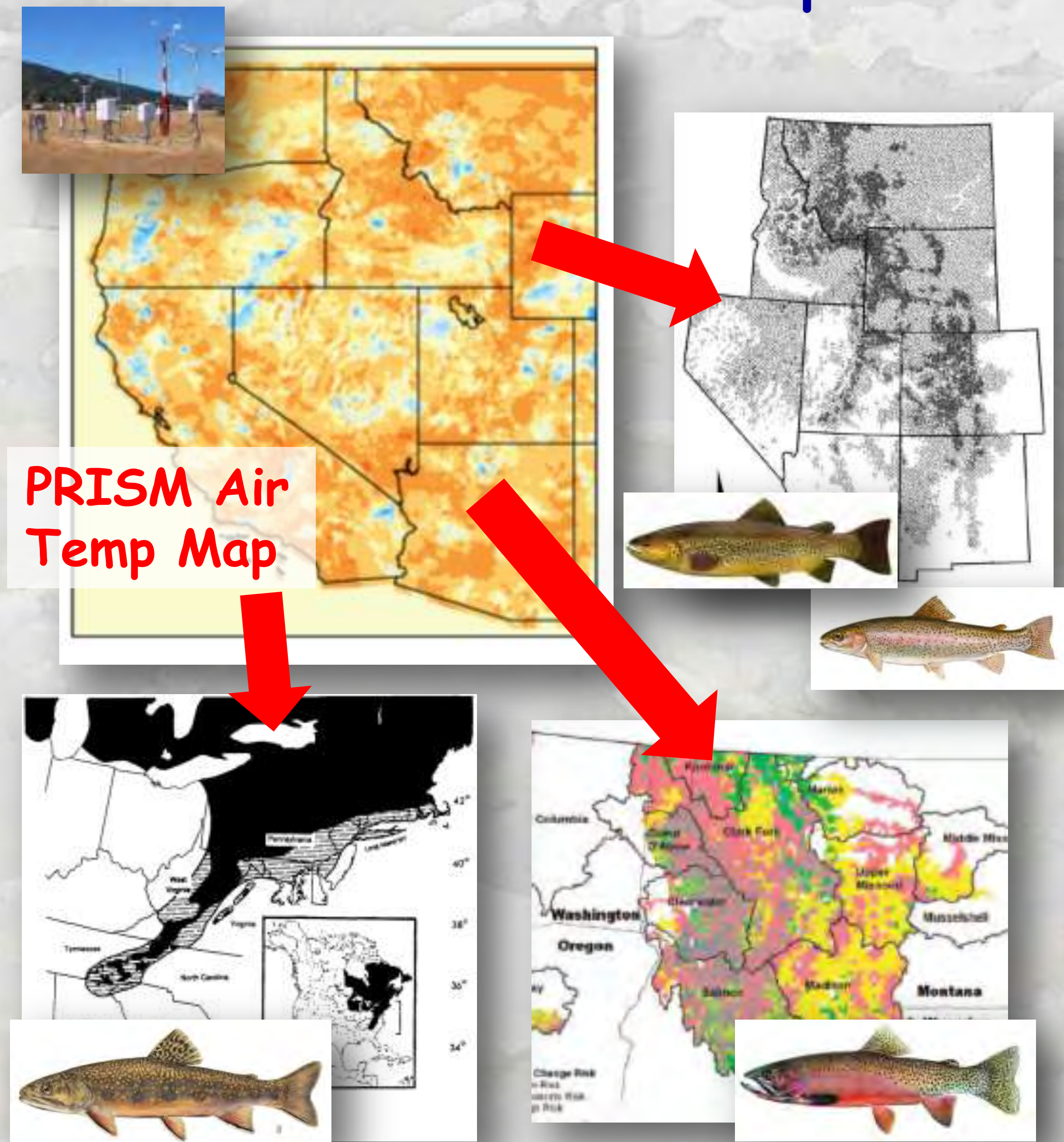
Multiple Jurisdictions

Maps are Powerful Tools



Regional BioClimatic Assessments

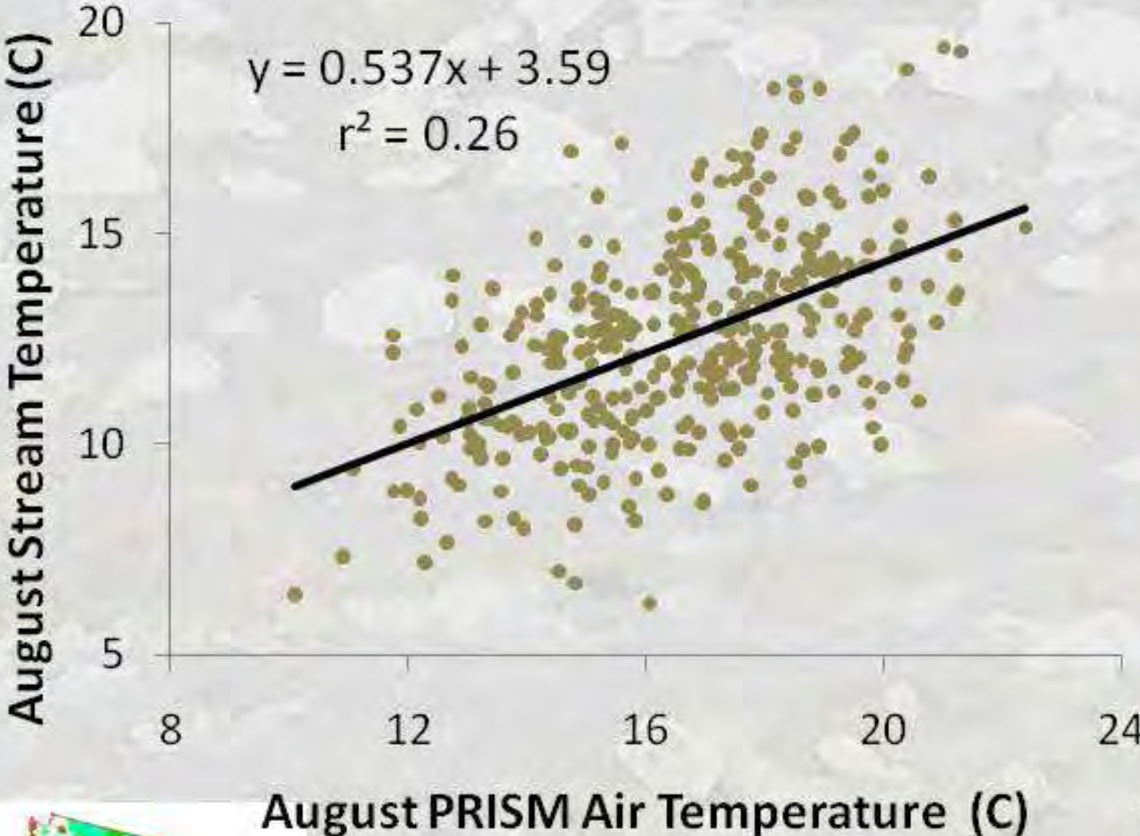
No Stream Temperature Component

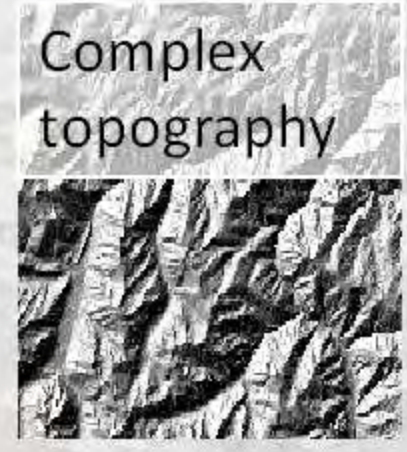


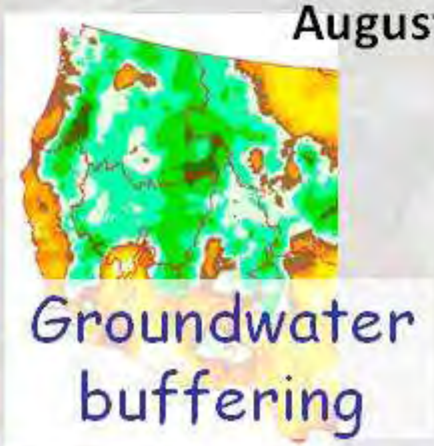
Air Temperatures…

- 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



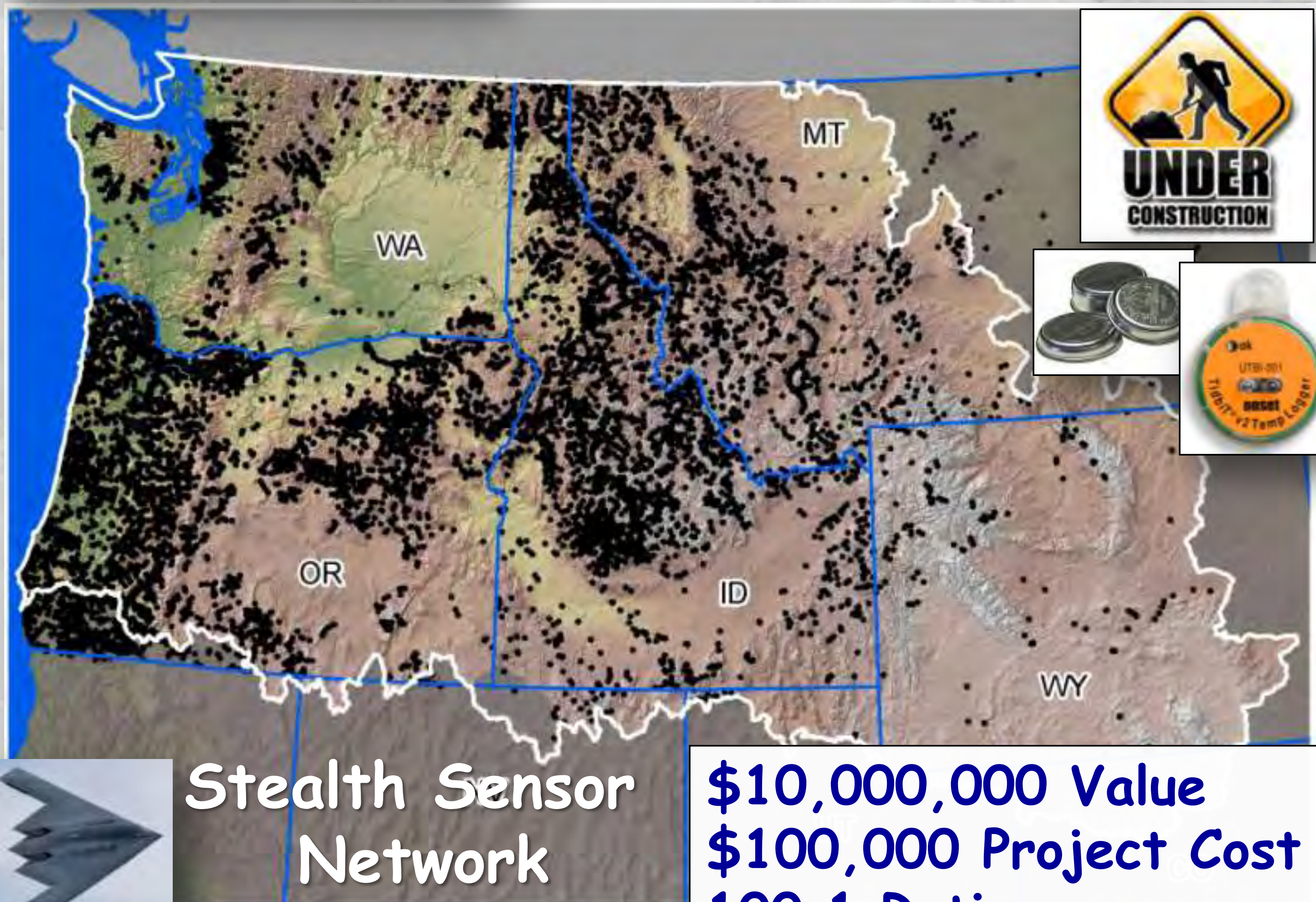




NorWeST Stream Temp

Database Status (4/2/12)

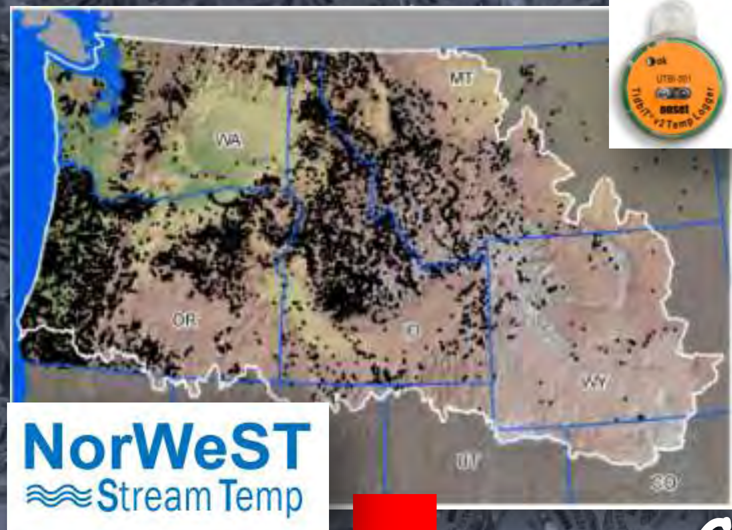
15,000+ unique stream sites
45,000+ summers measured



Stealth Sensor Network

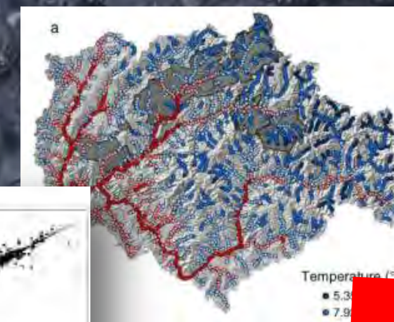
$10,000,000 Value
$100,000 Project Cost
100:1 Ratio

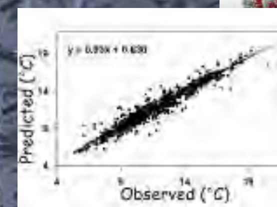
Regional Temperature Model



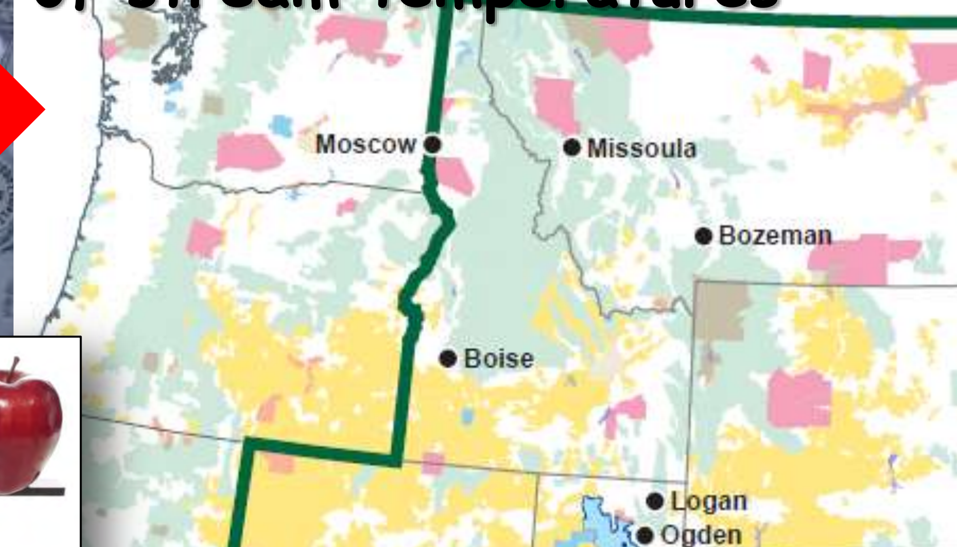
+

VHP models

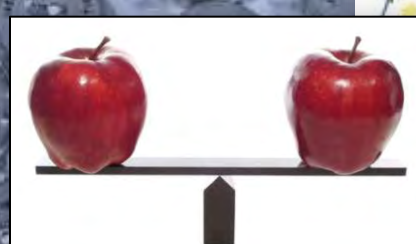




Cross-jurisdictional "maps" of stream temperatures

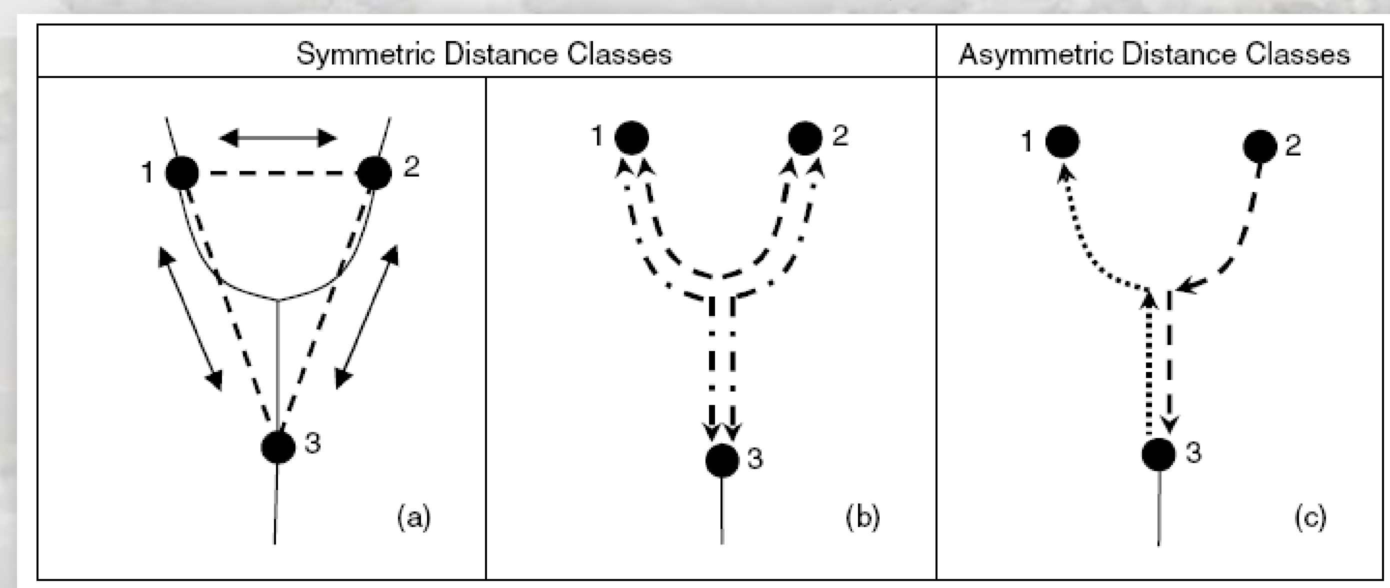


Consistent datum for strategic assessments



Spatial Statistical Models for Stream Networks

Valid Means of Interpolating Between Samples…Finally!



Advantages:

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

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

Training on left 2007 validation on right Data from 200

Boise River Network Temperature

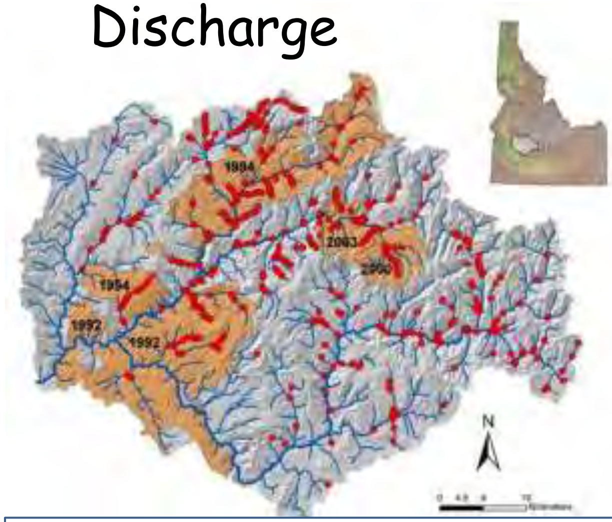
Summer Mean

Predicted (C°)

19
14
9
4

y = 0.93x + 0.830

Stream Temp =
Elevation +
Radiation +
AirMean +
Discharge

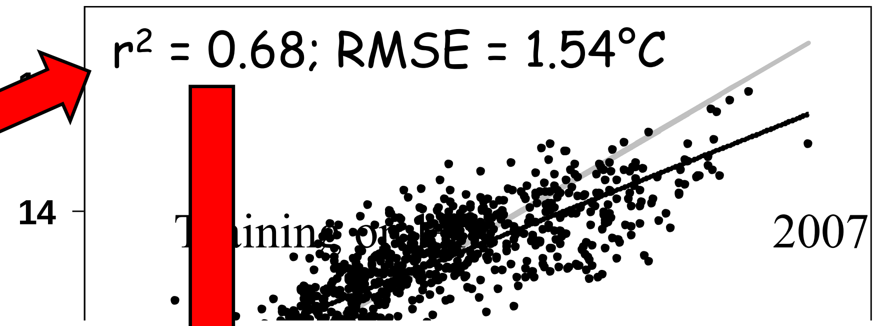


4
30
y
25
20
15
10
5
5 10 15 20 25 30

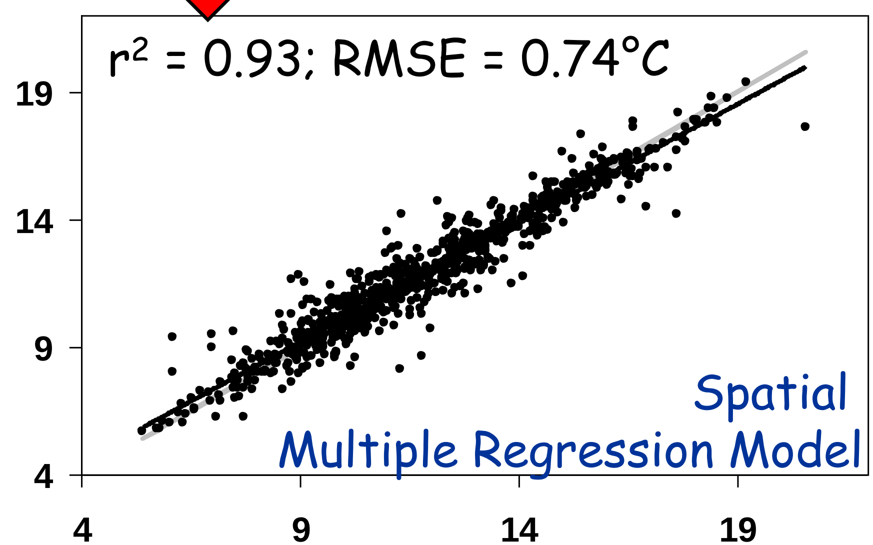
n = 780 temperature measurements

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

Mean Summer Stream Temp



Non-spatial
Multiple Regression Model



Spatial
Multiple Regression Model

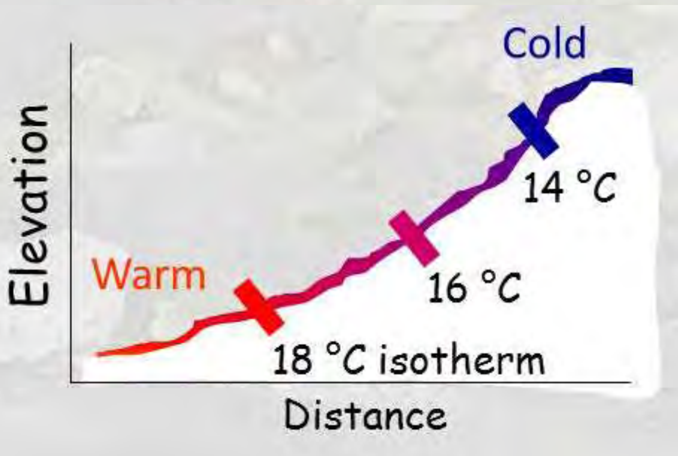
Predicted (C°) Predicted (C)

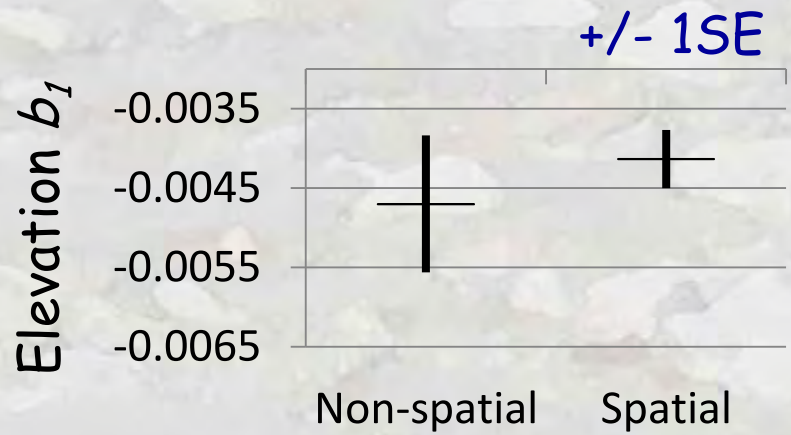
MWMT
Observed (C)

Elevation Parameter Estimated from 3 River Network Models

Temp Model	Non-spatial	Spatial
Boise basin	-0.0064	-0.0045
Payette NF	-0.0036	-0.0034
NCEAS	-0.0041	-0.0045

Elevation Parameter Estimates (°C / m)



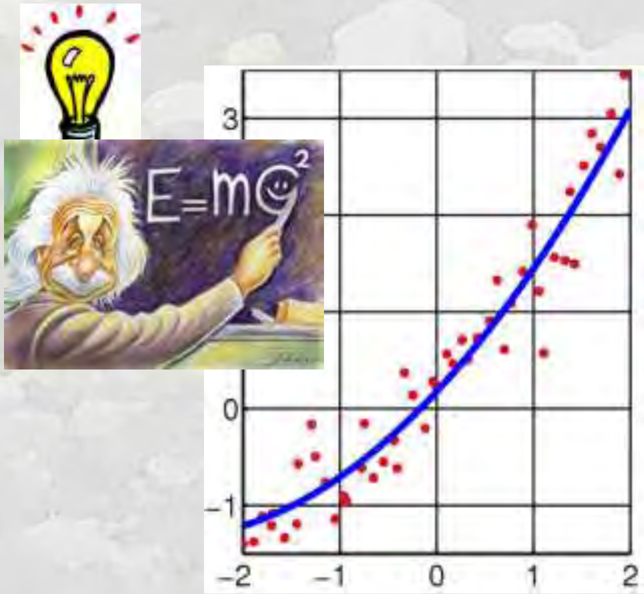


Beyond description: the active and effective way to infer processes from spatial patterns

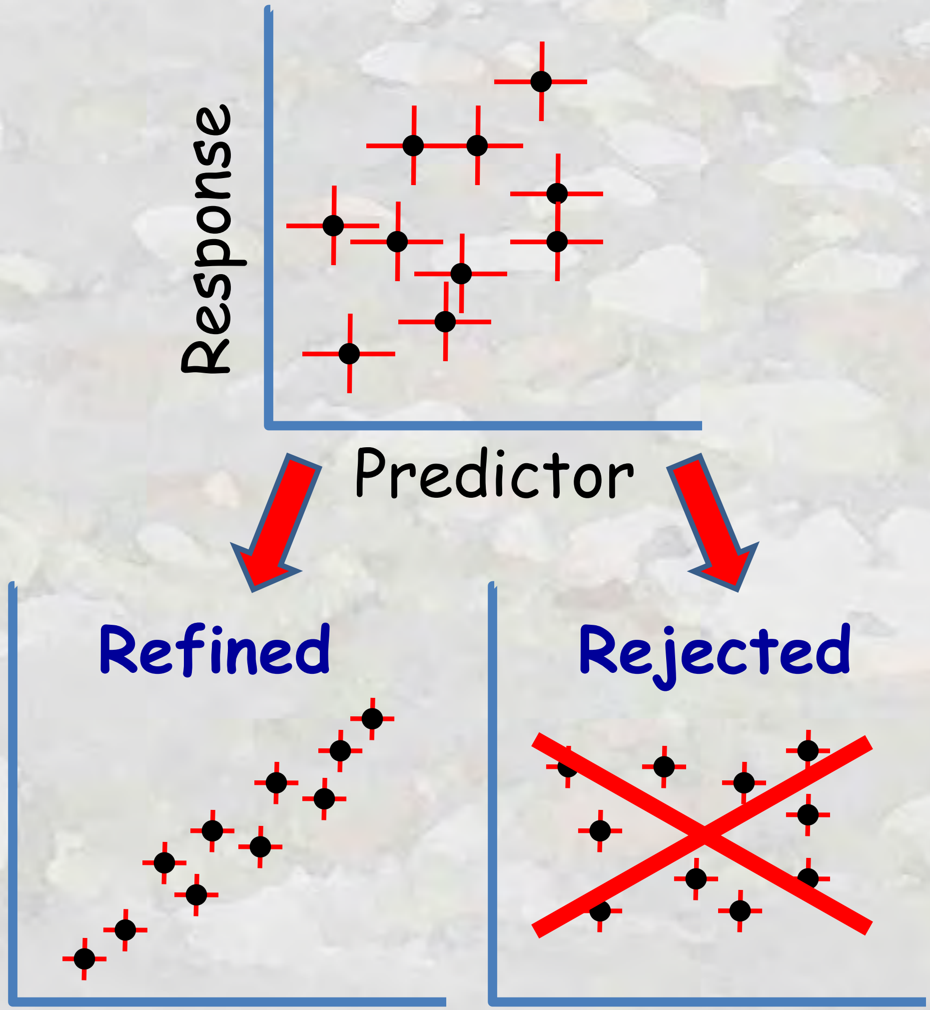
Eliot J. B. McIntire[1,4] and Alex Fajardo[2,3]

New Information & More Accurate Information ~ Better Understanding

New relationships described



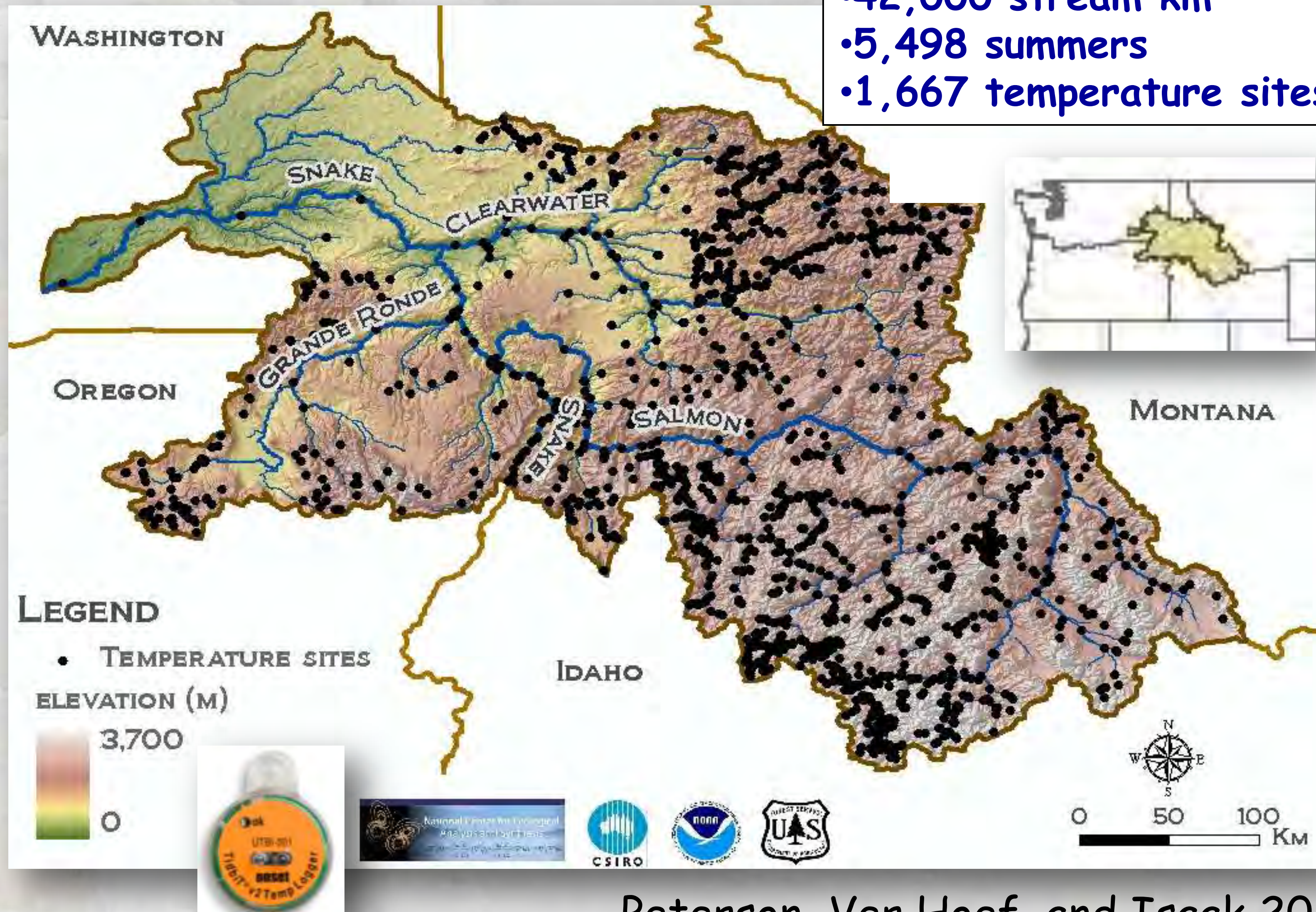
Old relationships tested



Big Databases & Computation Challenges

NCEAS - Lower Snake Hydrologic Region

- •42,000 stream km
- •5,498 summers
- •1,667 temperature sites

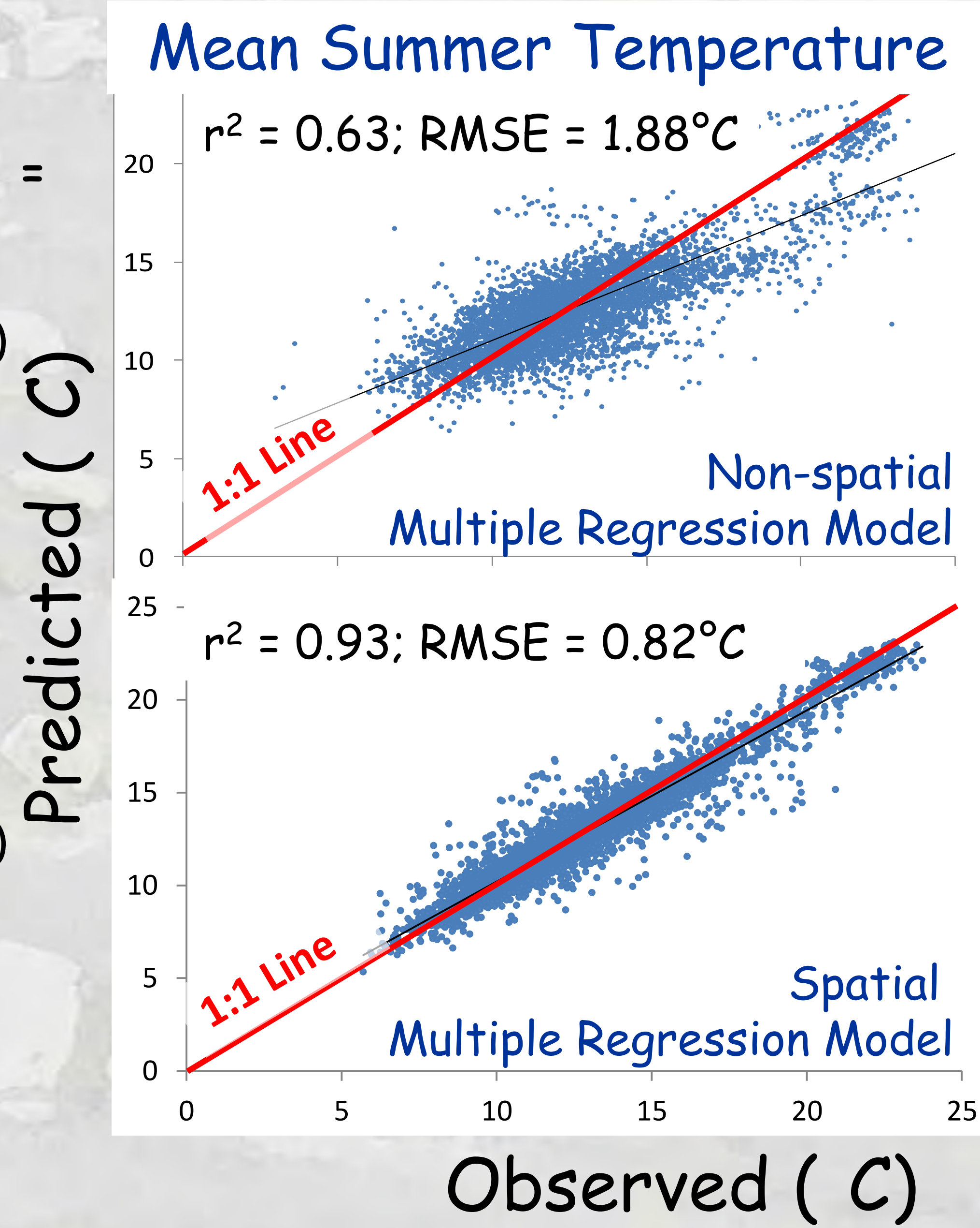


Peterson, Ver Hoef, and Isaak 2010

Lower Snake Temperature Model

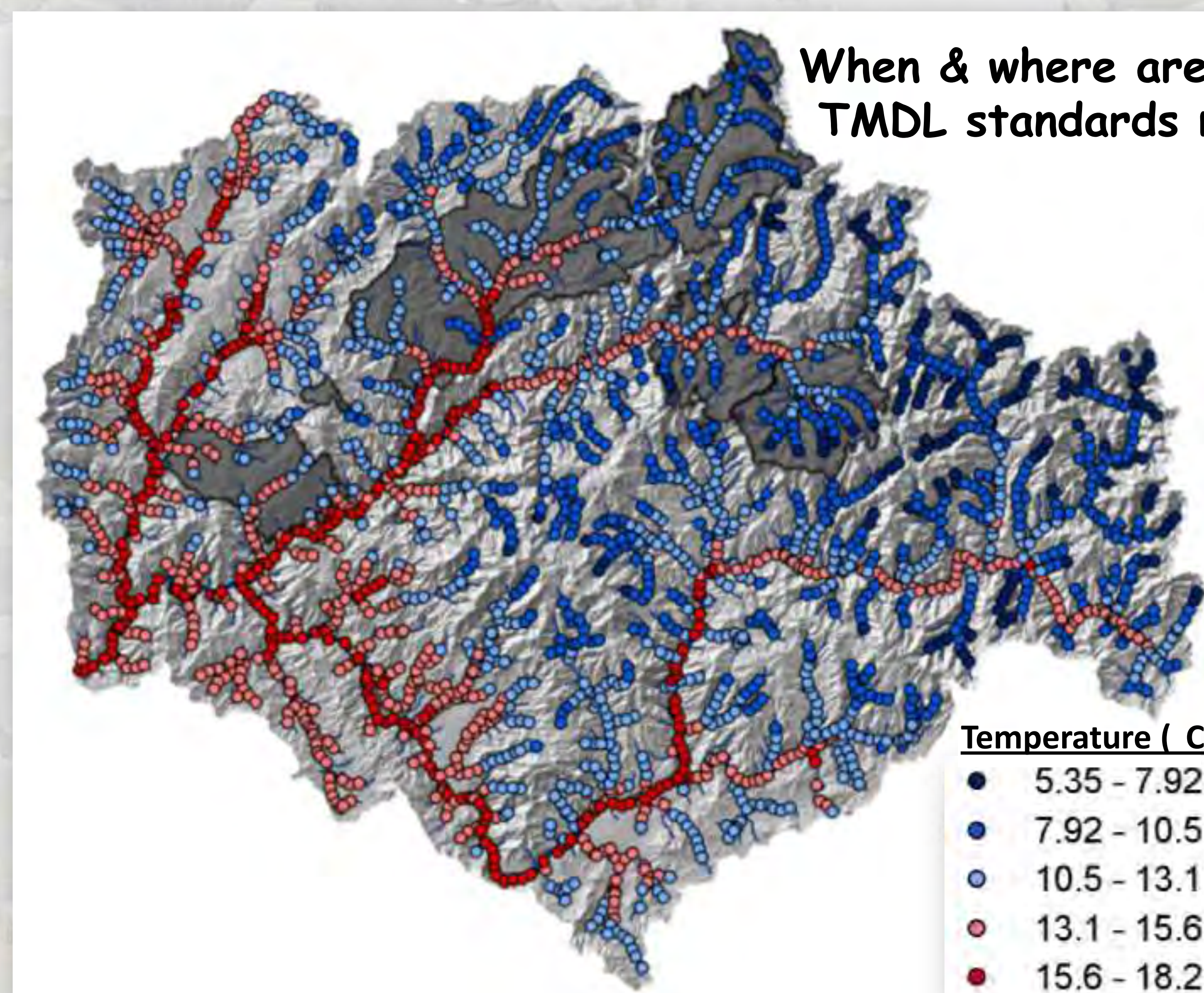
Non-spatial Stream Temp =
- 0.0041*Ele (m)
- 13.9*Slope (%)
+ 0.016*Wat_size (100km^2)
-0.0022*Ave_Precip
- 0.041*Flow (m^3/s)
+ 0.42*AirMean (C)

Spatial Stream Temp =
- 0.0045*Ele (m)
- 9.8*Slope (%)
+ 0.012*Wat_size (100km^2)
- 0.00061*Ave_Precip
- 0.037*Flow (m^3/s)
+ 0.46*AirMean (C)

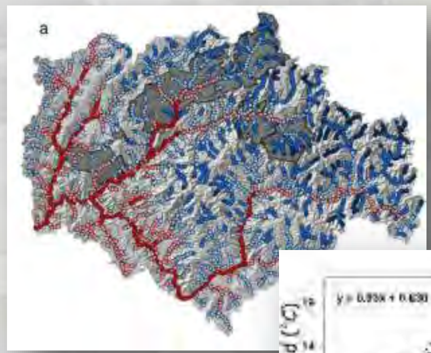


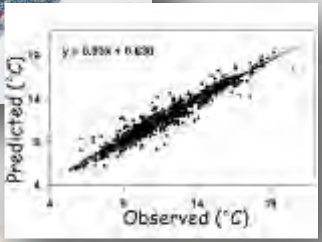
River Network Thermal Maps

2006 Mean Summer Temperatures

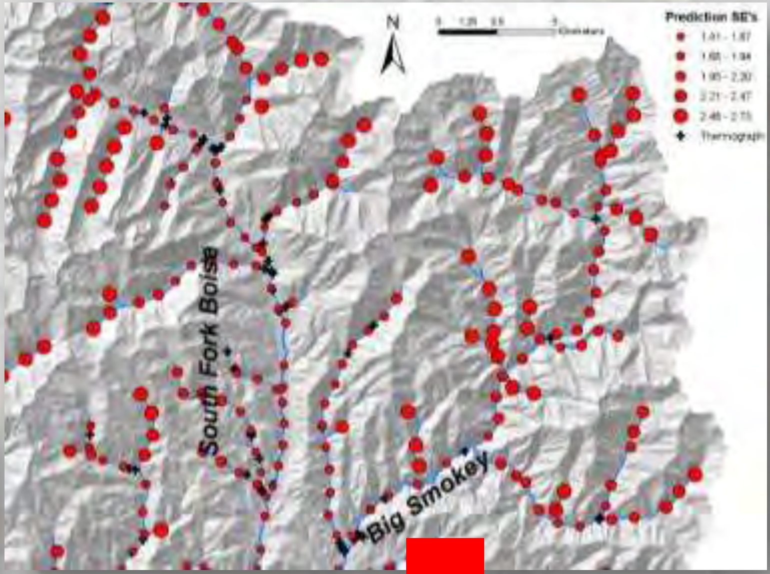


Spatially Explicit Maps of Prediction Uncertainty



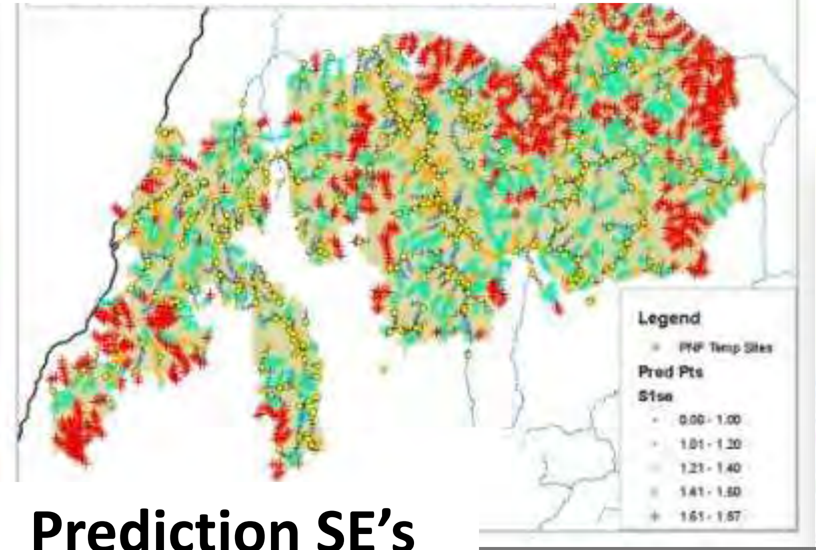


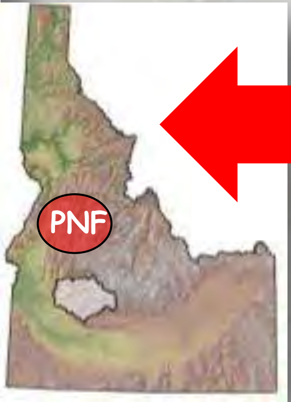
Temperature Prediction SE's



Payette National Forest

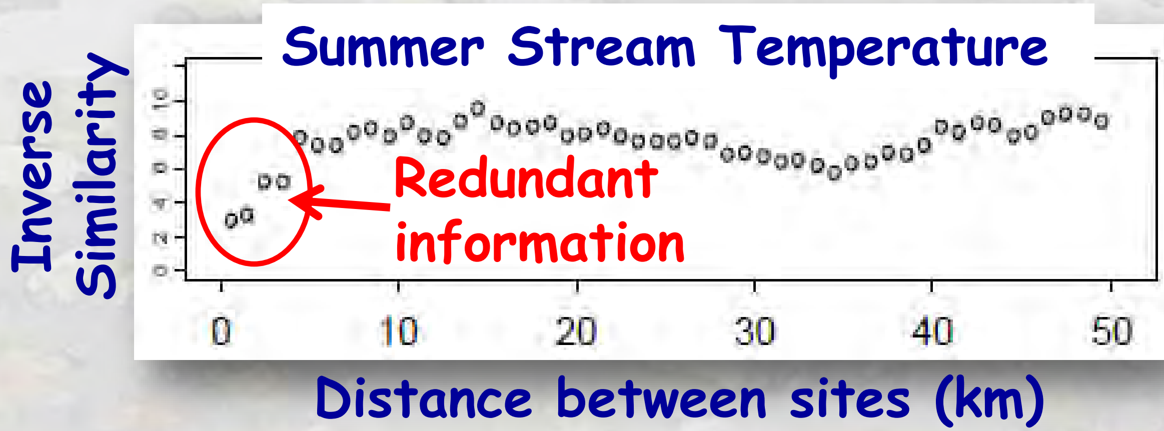
Spatial Uncertainty Map

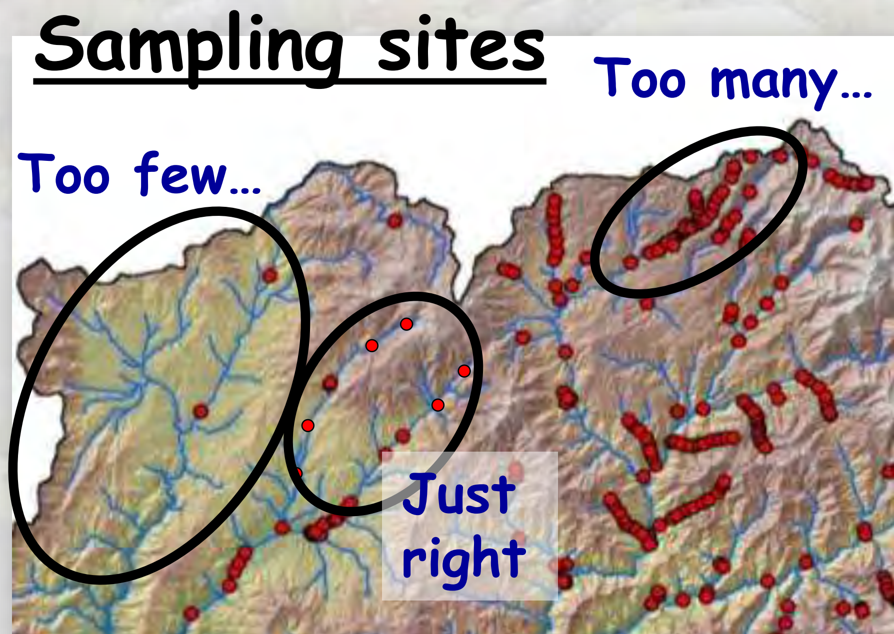




Prediction SE's

Designing Efficient Monitoring Strategies

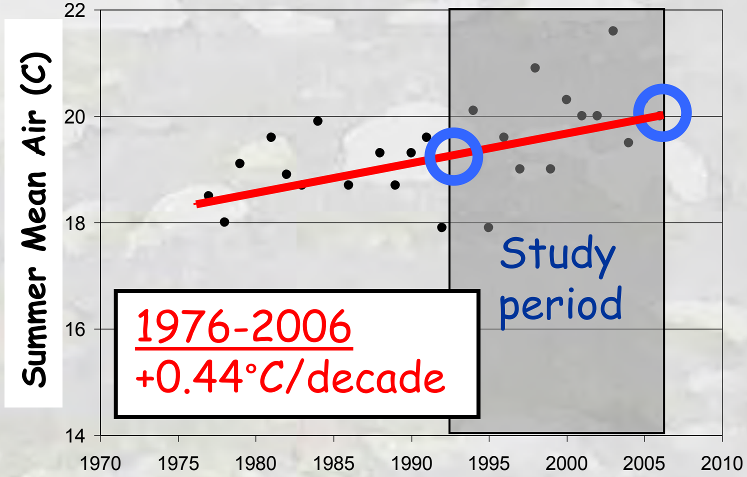




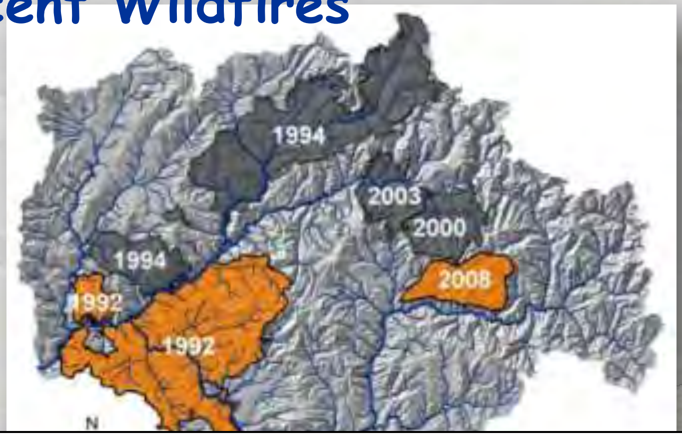
Measuring Climate Change Effects

Compare Temporal “Snapshots” of Averages

Summer Air Temperature

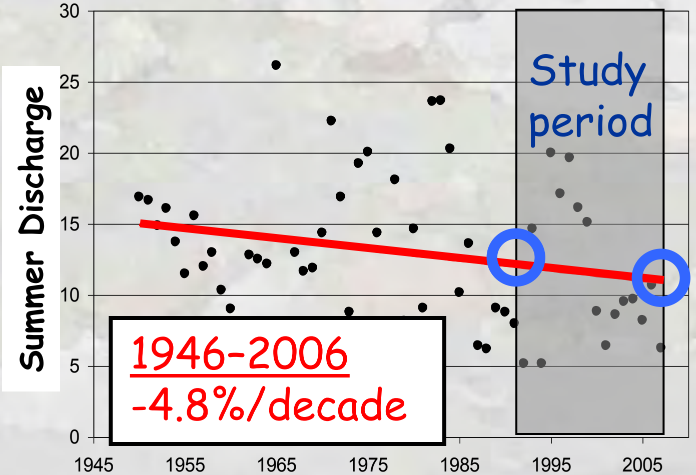


Recent Wildfires



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

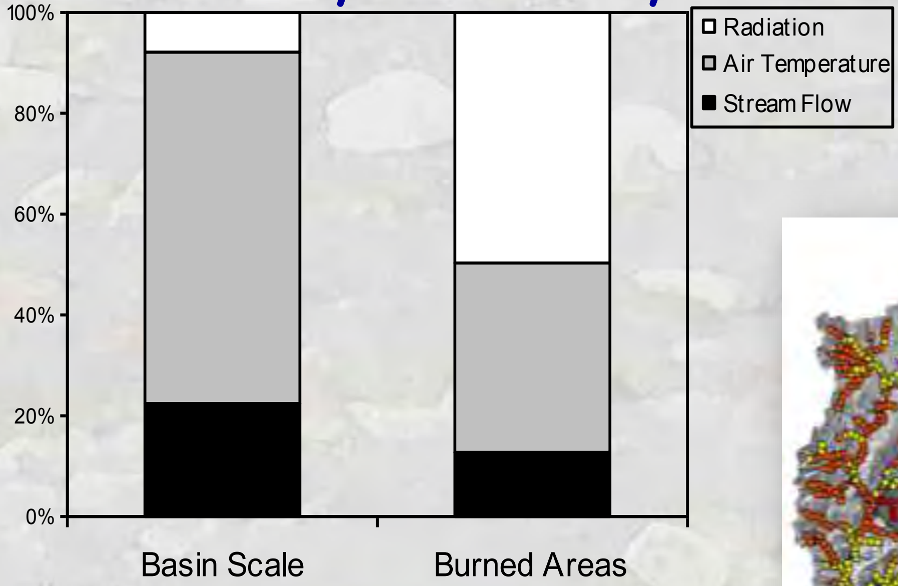
Summer Stream Flow



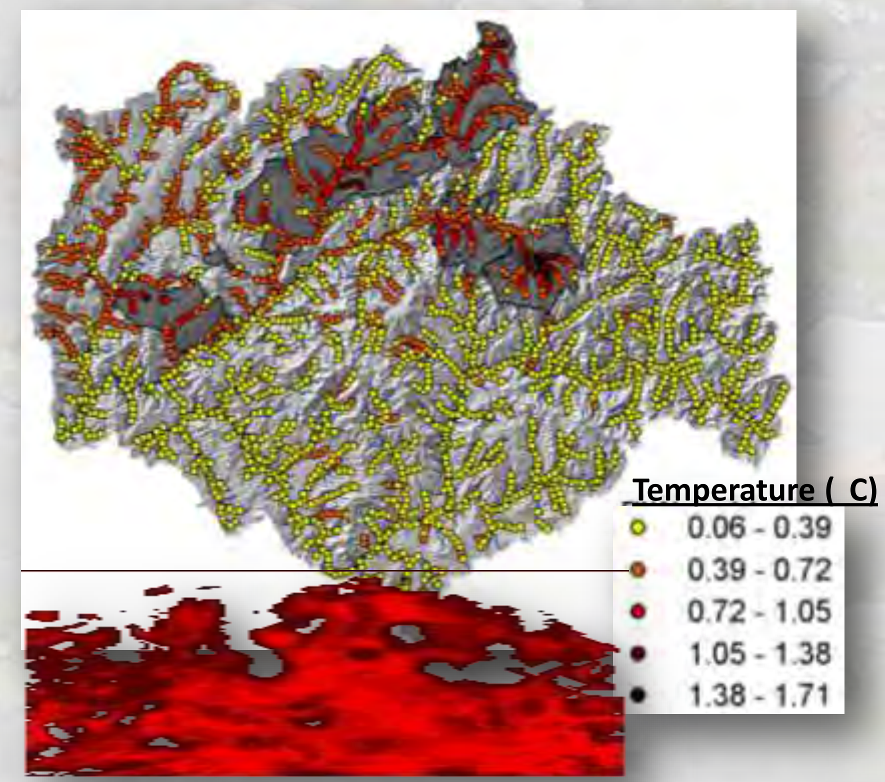
Changes in Average Summer Temperatures from 1993-2006

Δ0.38 C
0.27°C/10y

Δ0.70 C
0.50°C/10y

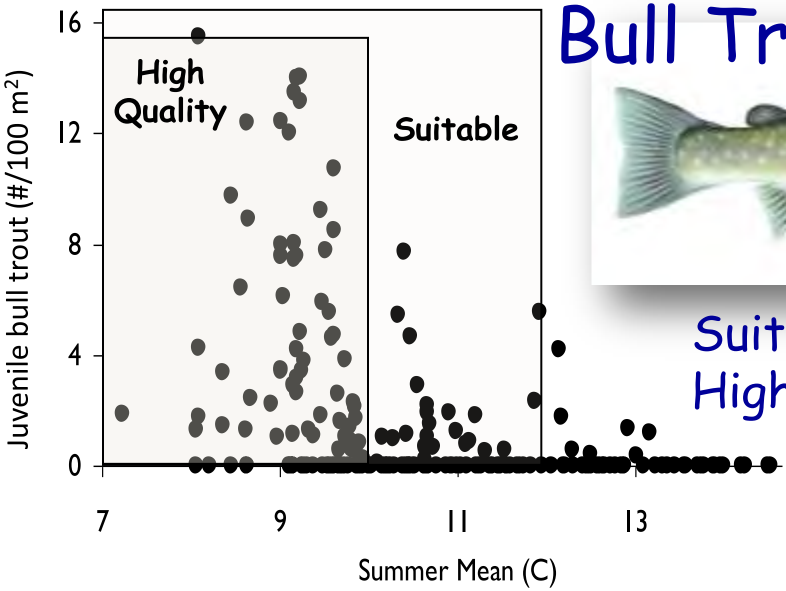


Thermal Gain Map



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

Translate Temperature to Thermally Suitable Habitat

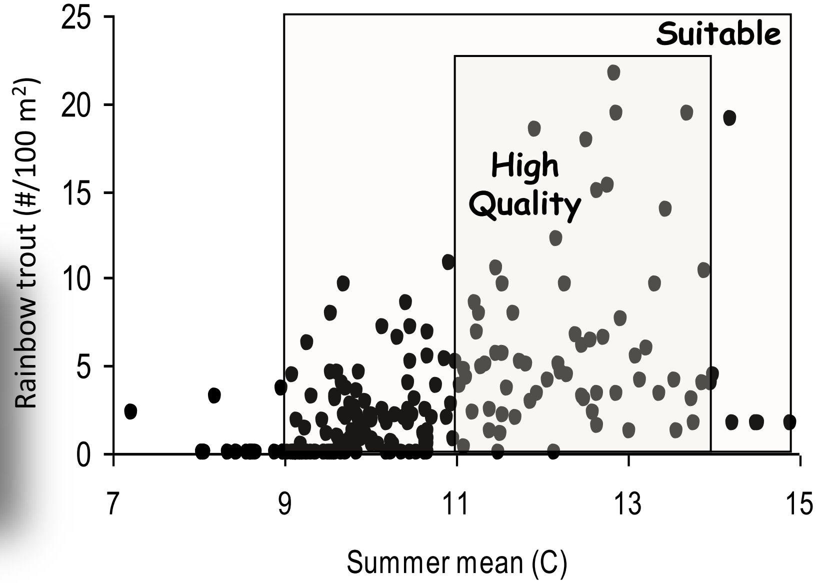


Bull Trout

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

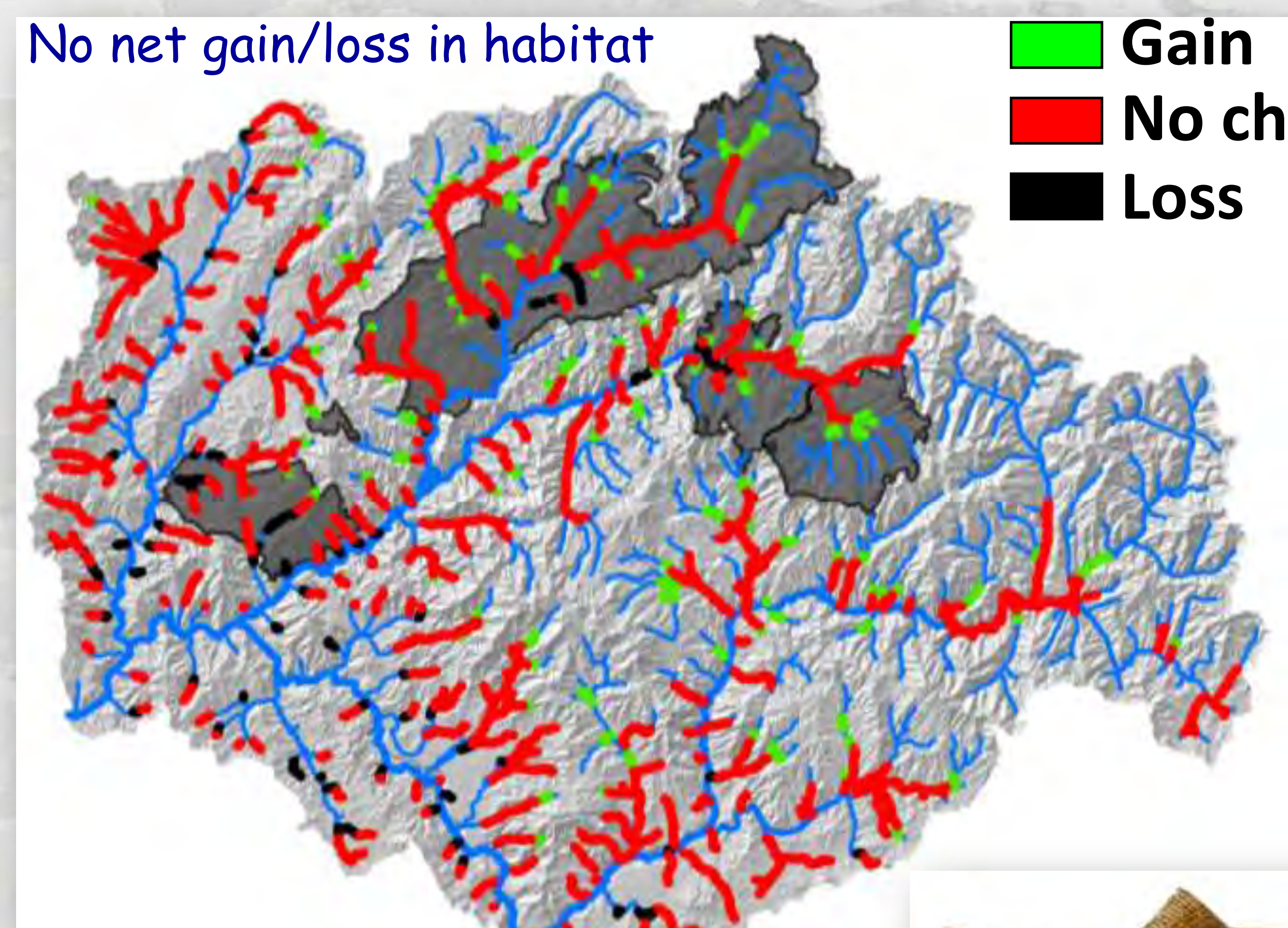
Rainbow Trout

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



Effects on Thermally Suitable Habitat

Rainbow Trout Habitats (1993-2006)

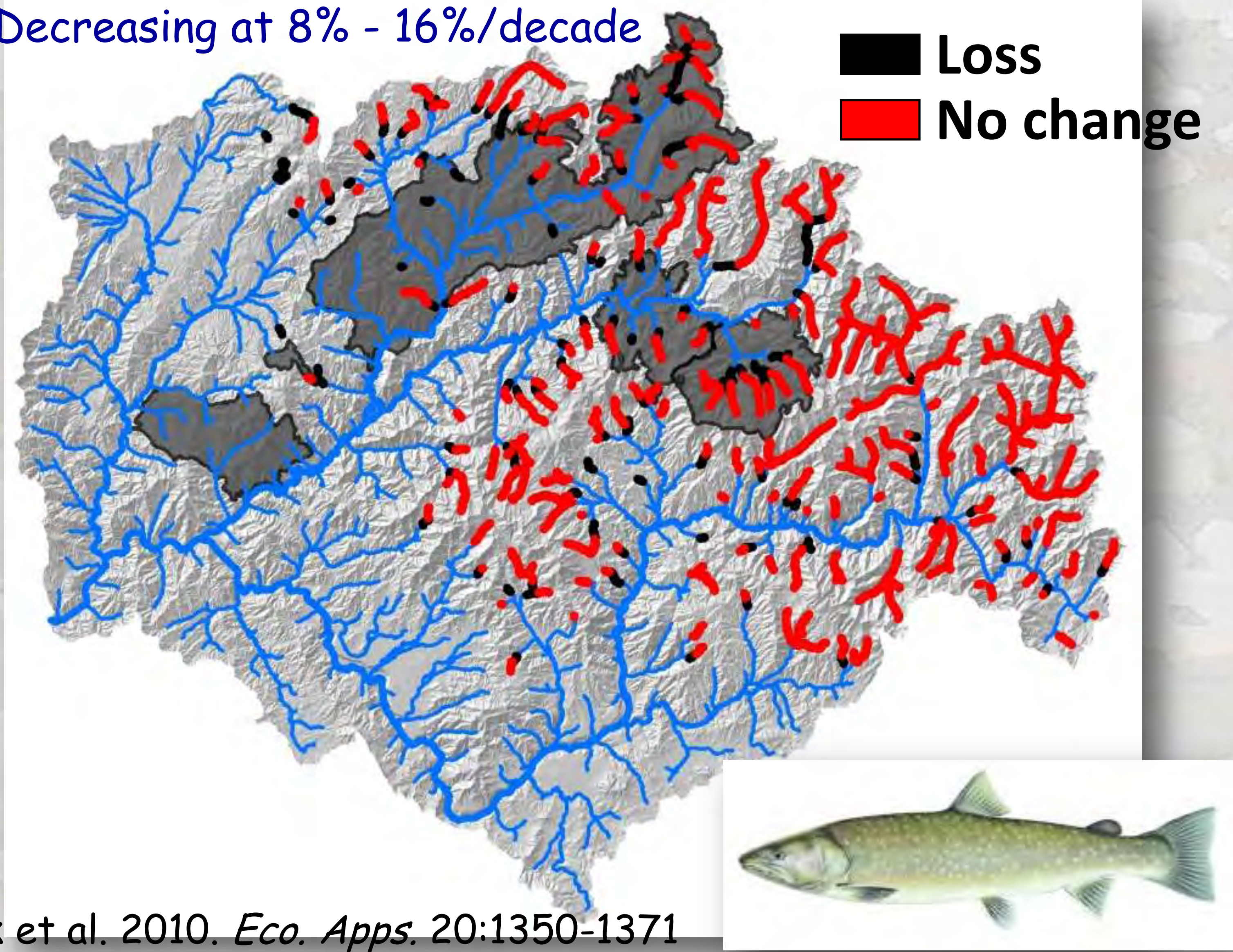


Isaak et al. 2010. *Eco. Apps.* 20:1350-1371

Effects on Thermally Suitable Habitat

Bull Trout Habitat Losses (1993-2006)

Decreasing at 8% - 16%/decade

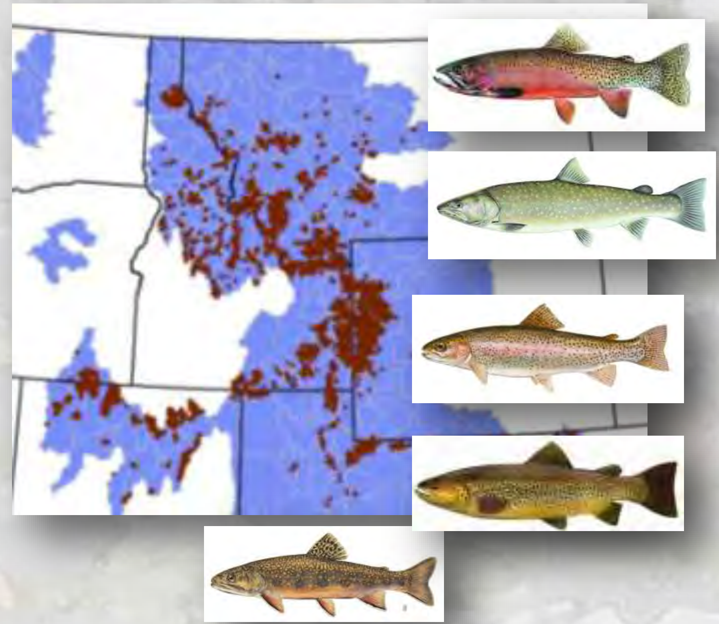


Isaak et al. 2010. *Eco. Apps.* 20:1350-1371

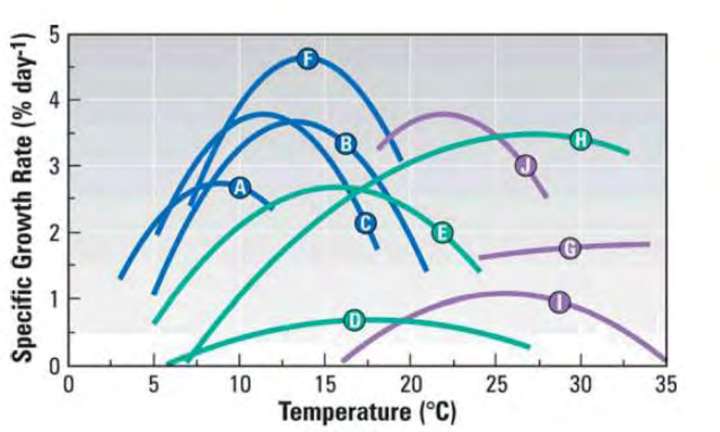
Accurate Definition of Thermal Niches

GNLCC stream temperature maps

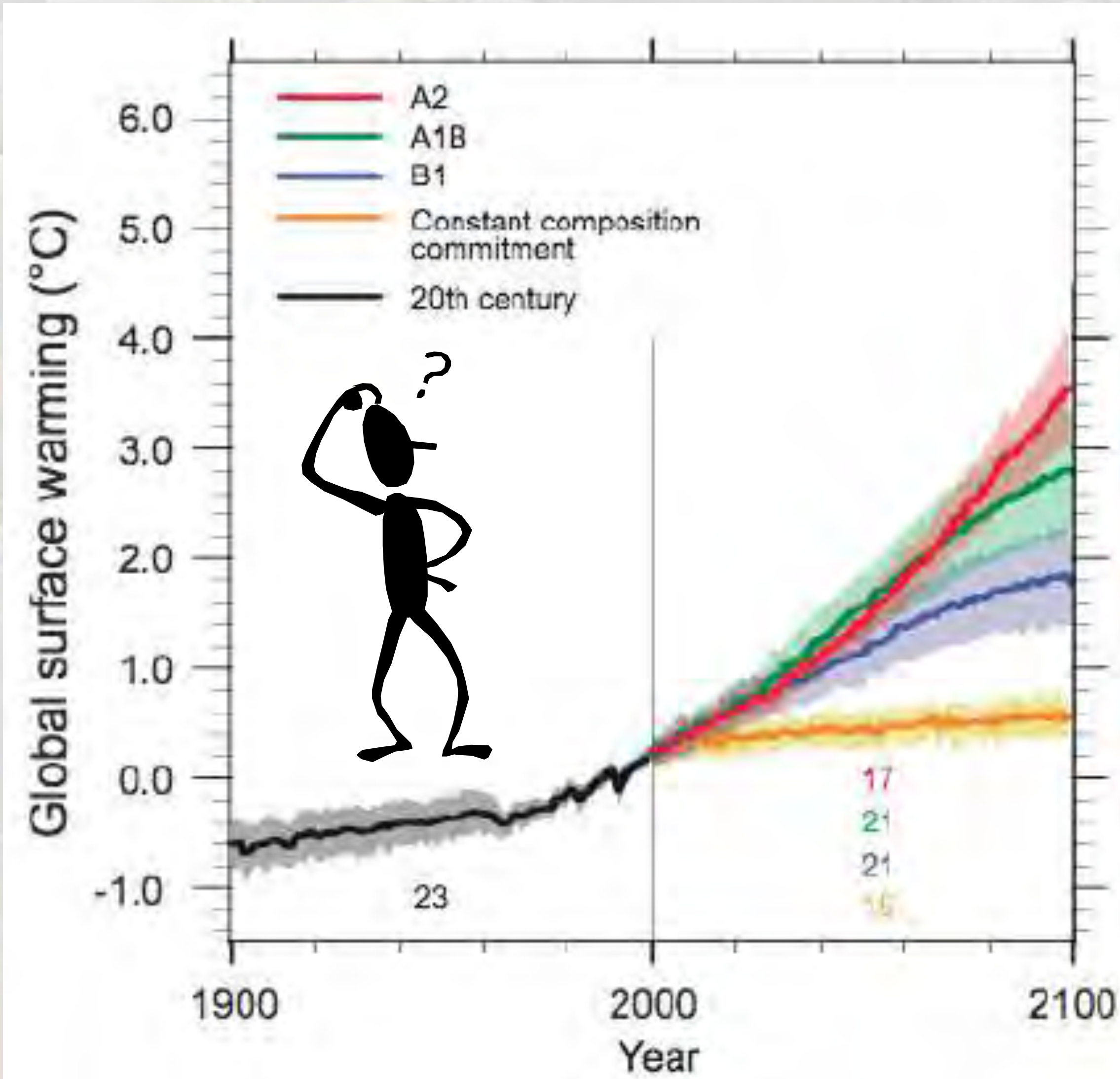
Regional fish survey databases



Realized Thermal Niches

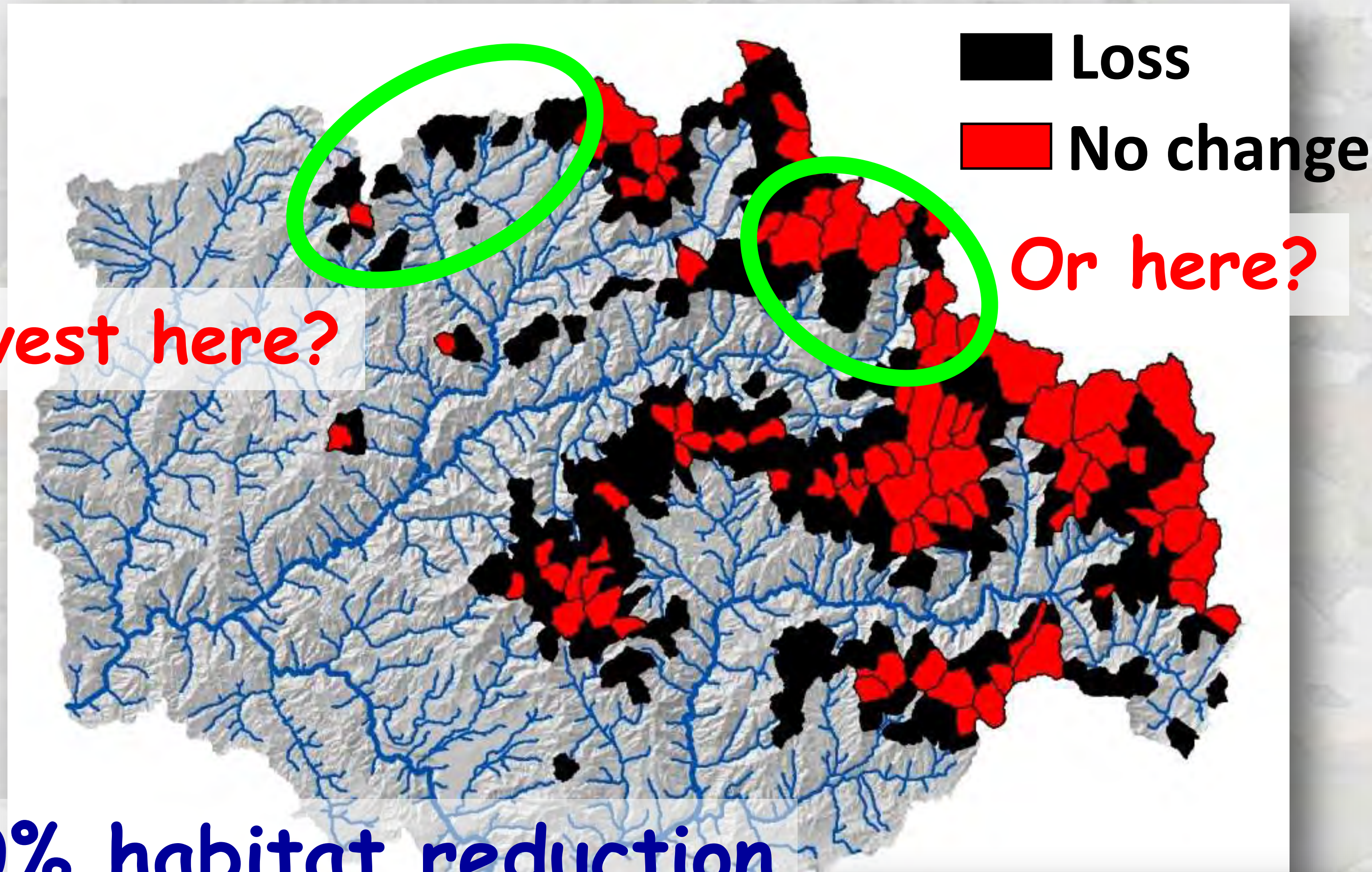


Forecasting Future Stream Temperature Scenarios



Bull Trout Habitats by 2046

Stream Temp Increase = +1.43 C



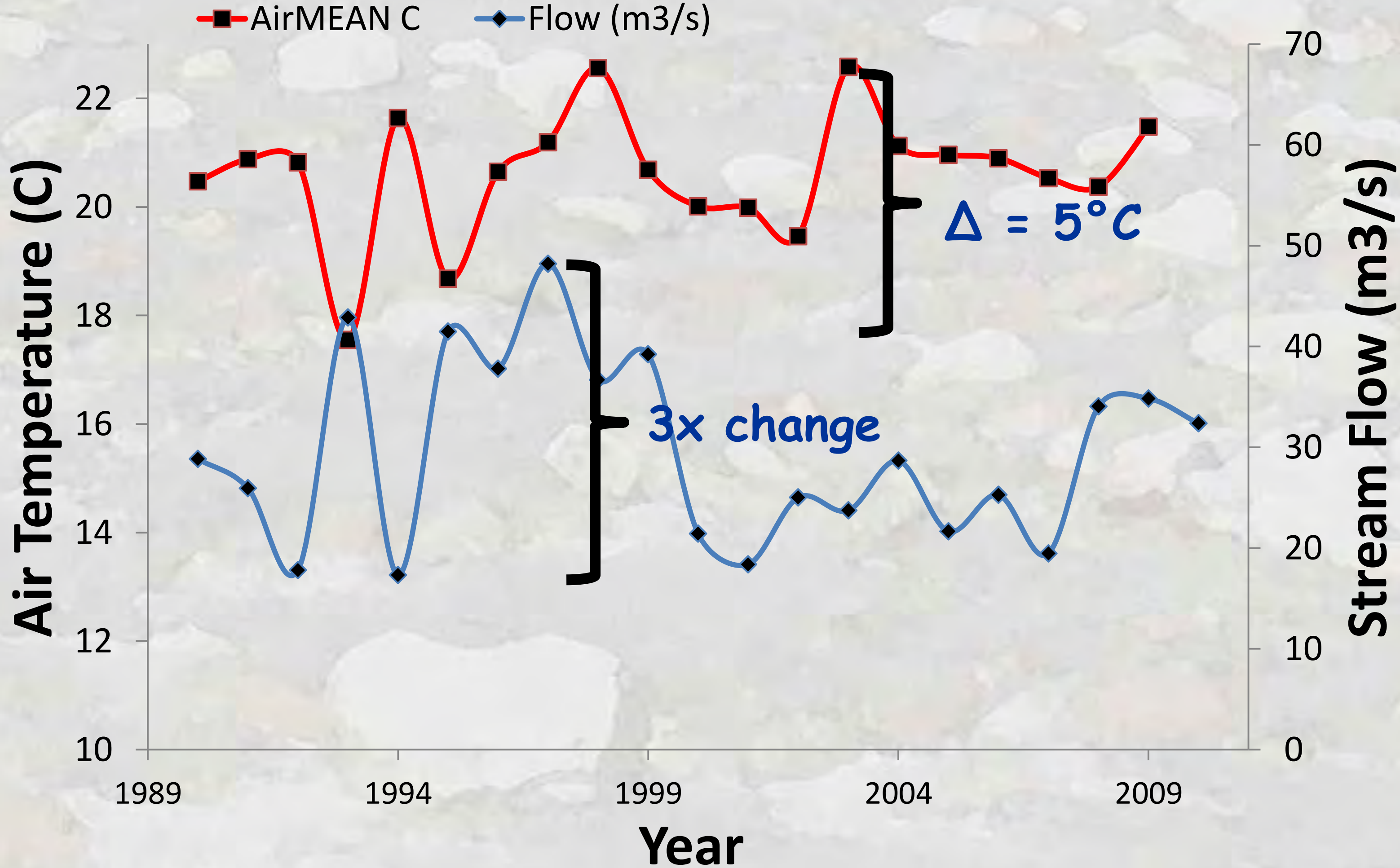
Invest here?

Or here?

~50% habitat reduction

Observed Climate Variability Encompasses Projected "Averages" for 21st-Century

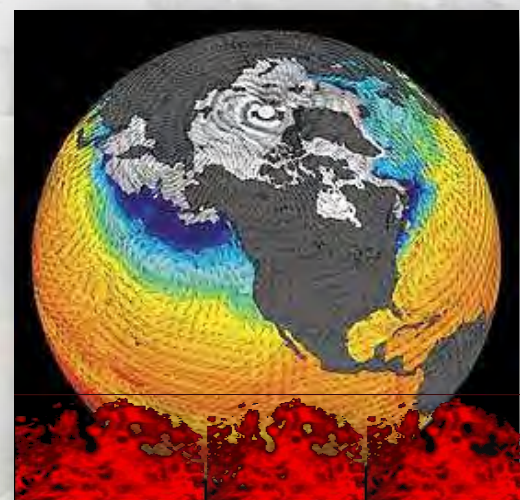
Lower Snake Temperature Database 1990–2010

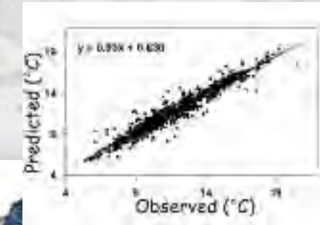


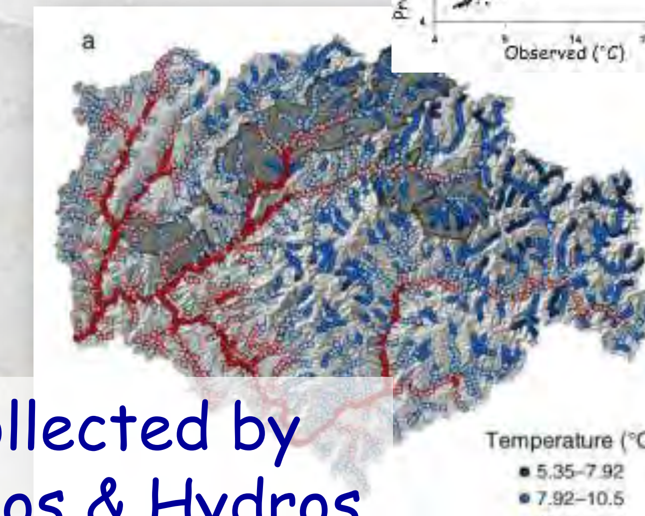
All With "Found" Data

& it's a home-grown approach

GCM







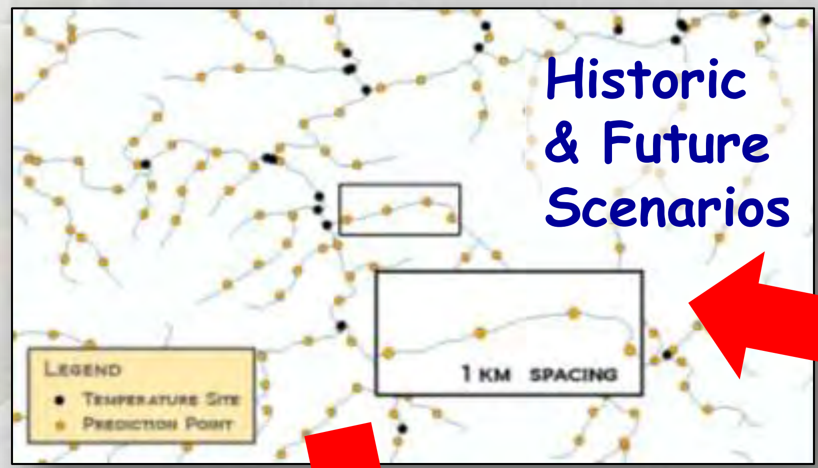
Data Collected by Local Bios & Hydros

?

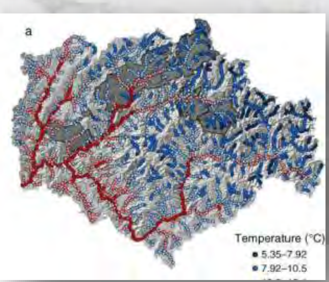
Management Decisions

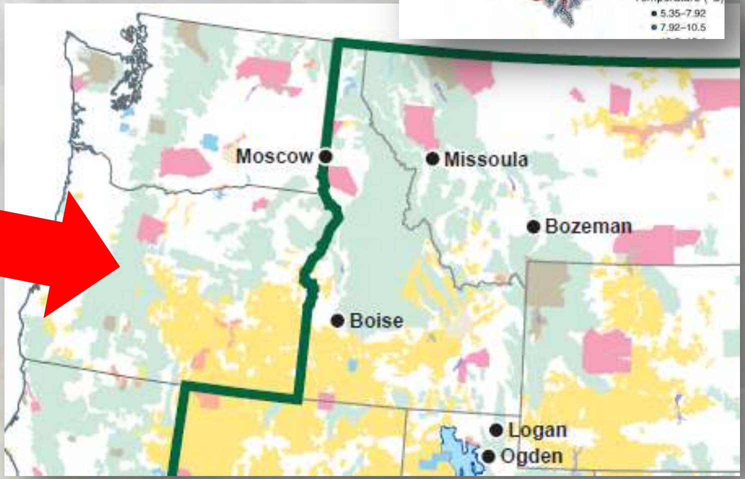
Website for Serving GIS Temperature Model "Map" Outputs

Temperature predictions at 1 km resolution on all streams…

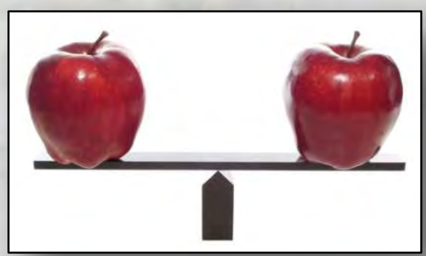


Historic & Future Scenarios

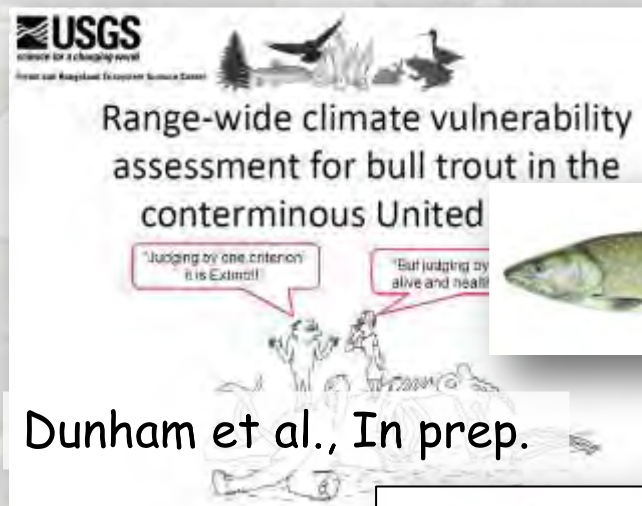




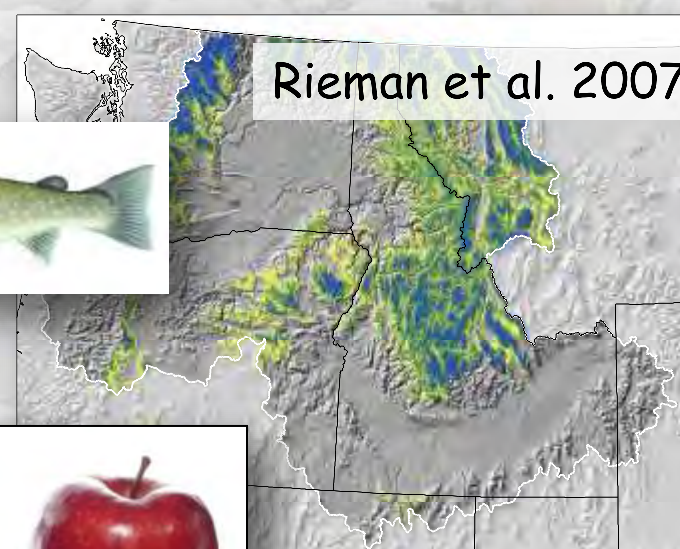
Websites for Distribution



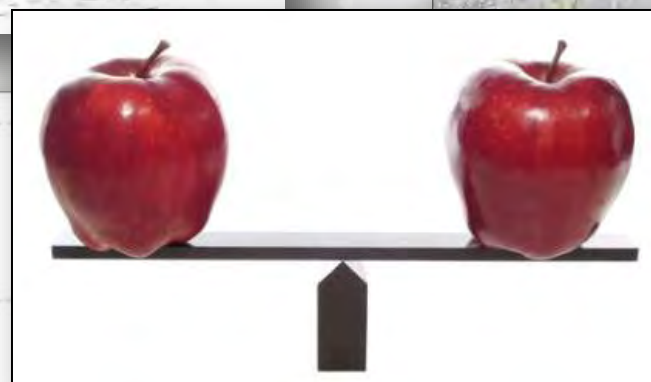
More Precise Bioclimatic Assessments

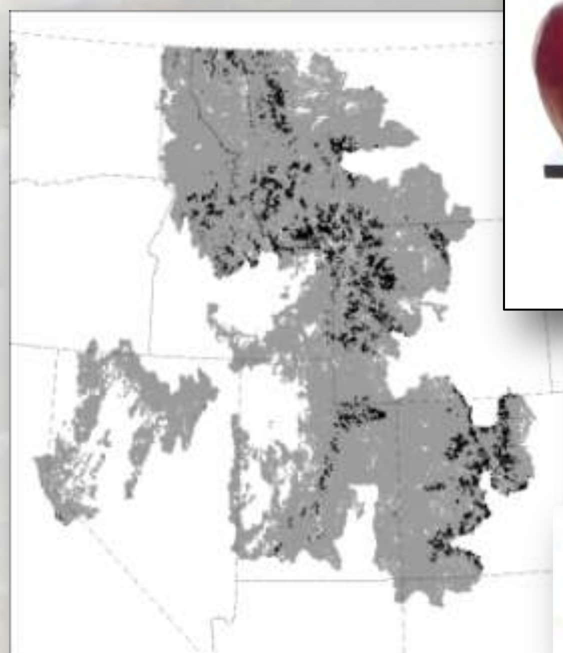


Dunham et al., In prep.

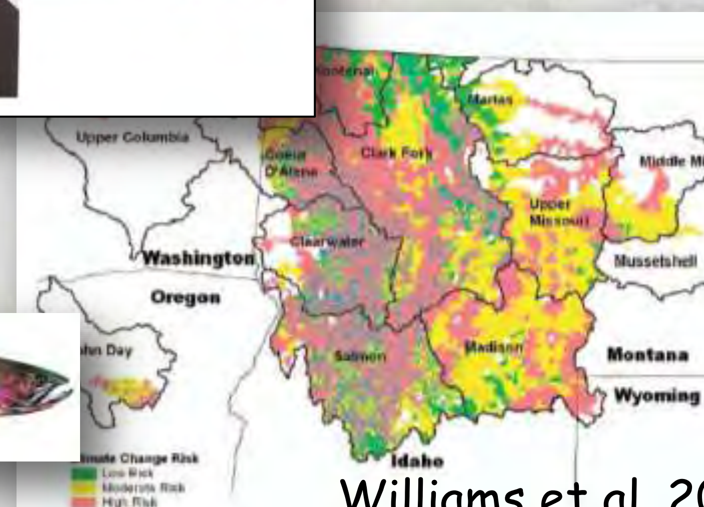


Rieman et al. 2007





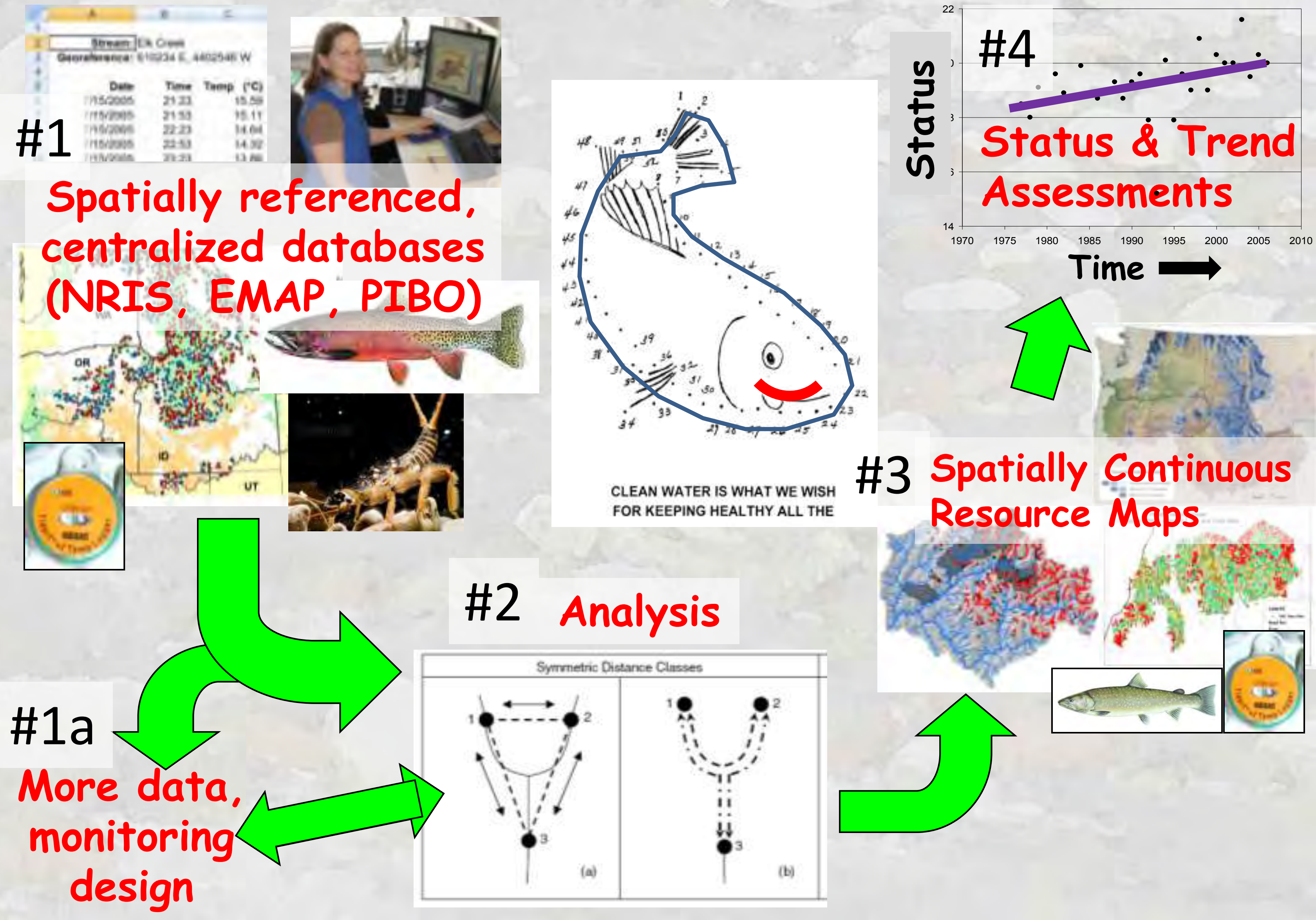
Wenger et al. 2011. *PNAS.*



Williams et al. 2009

The Basic Steps for Making it Work

Data In ➡ Information Out



EcoInformatics is a Team Effort

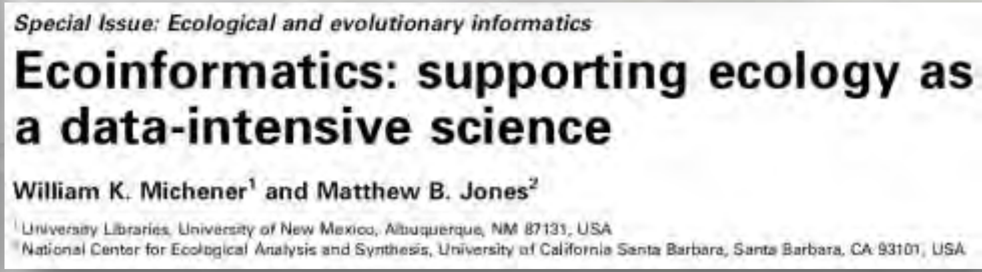
Regional Stream Team

Dan Isaak, Erin Peterson,
Jeff Kershner, Jason Dunham,
Jay Verhoef, Steve Hostetler,
Brett Roper, Charlie Luce,
Seth Wenger, Dave Nagel,
Dona Horan, Gwynne Chandler,
Sherry Wollrab, Sharon Parkes,
Dave Hockman

100's field biologists
10's of resource organizations

Skillsets

GIS analysts, stream ecologists, database technicians, climate modelers, stream statisticians, webpage designer, R programmers, postdocs



Special Issue: Ecological and evolutionary informatics

Ecoinformatics: supporting ecology as a data-intensive science

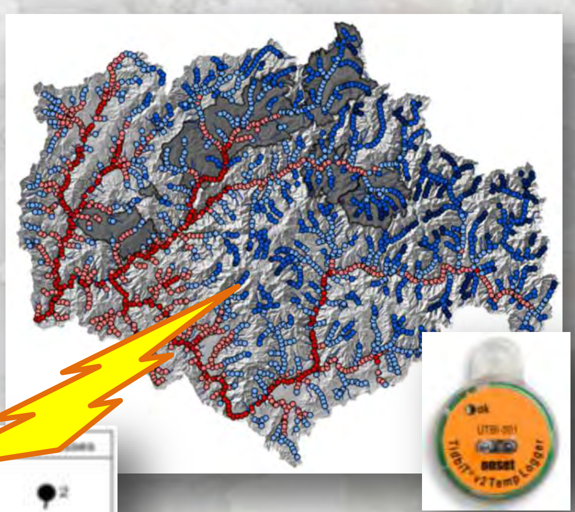
William K. Michener[1] and Matthew B. Jones[2]

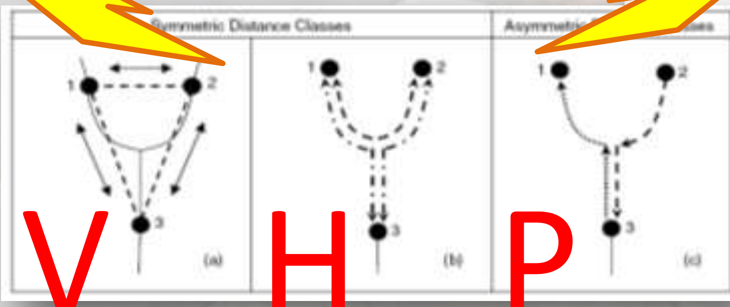
[1] University Libraries, University of New Mexico, Albuquerque, NM 87131, USA
[2] National Center for Ecological Analysis and Synthesis, University of California Santa Barbara, Santa Barbara, CA 93101, USA

Temperature Data, but also…

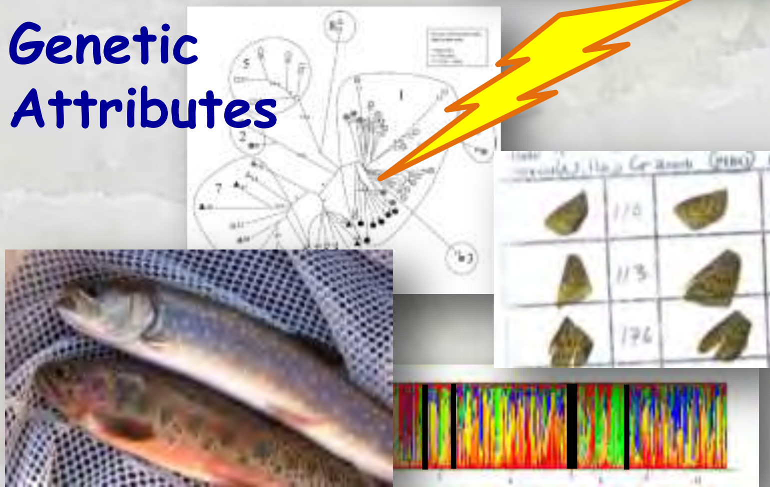
Distribution & abundance

Response Metrics
- Gaussian
- Poissan
- Binomial





Genetic Attributes

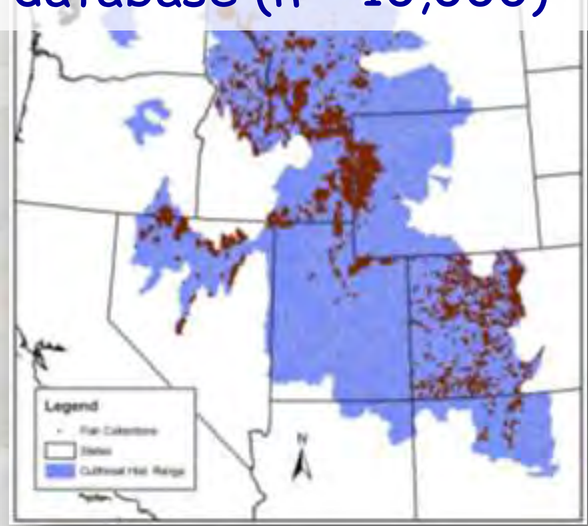


Water Quality Parameters

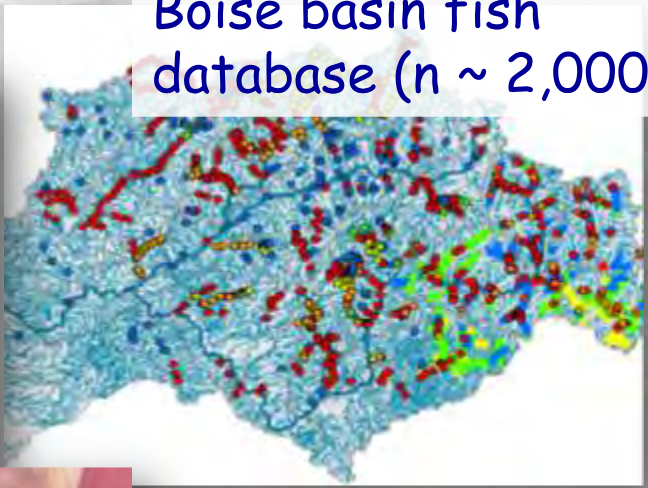
Harnessing Existing Databases

Aquatic organism distribution & abundance

Western US trout database (n = 10,000)

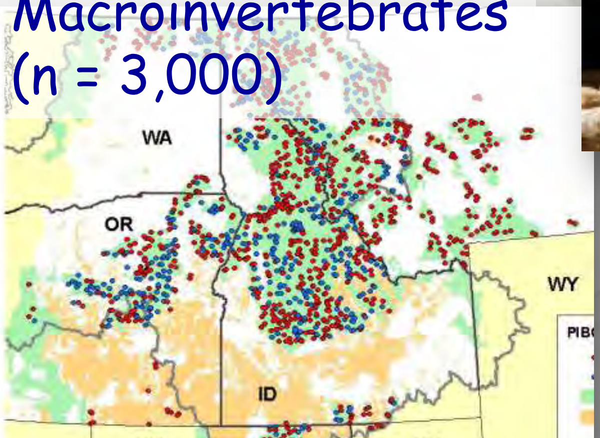


Boise basin fish database (n ~ 2,000)



Amphibians

USFS PIBO – Macroinvertebrates (n = 3,000)

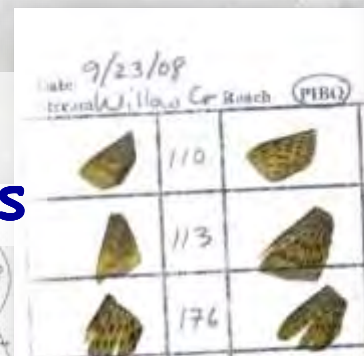


Harnessing Existing Databases

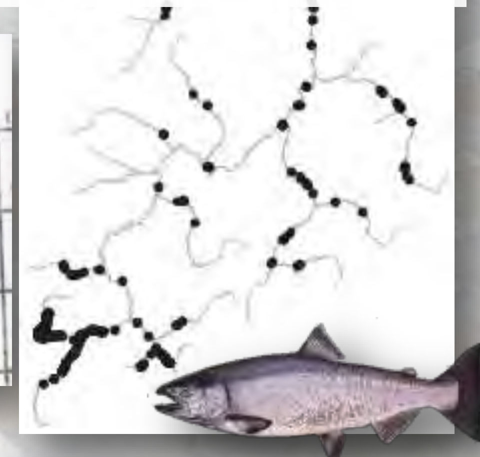
Aquatic organism genetic diversity

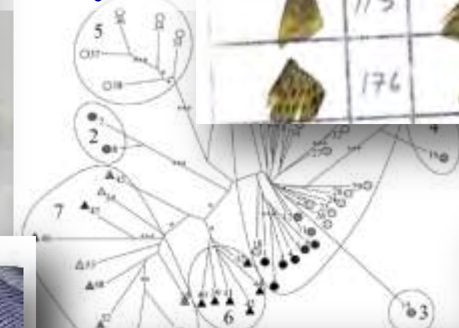
Young & McKelvey, unpublished
MT/ID tailed frogs

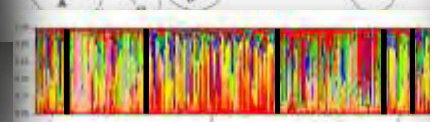
Tissue Samples



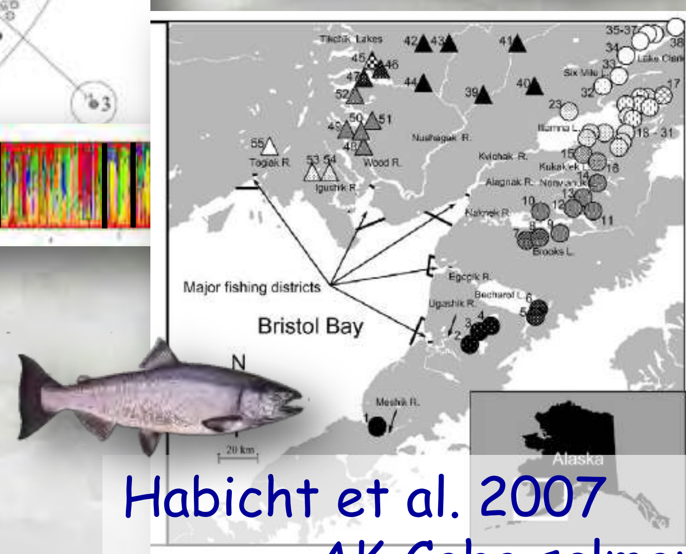
Neville et al. 2006; 2007
ID Chinook salmon







Young & McKelvey, unpublished
MT/ID Cutthroat trout

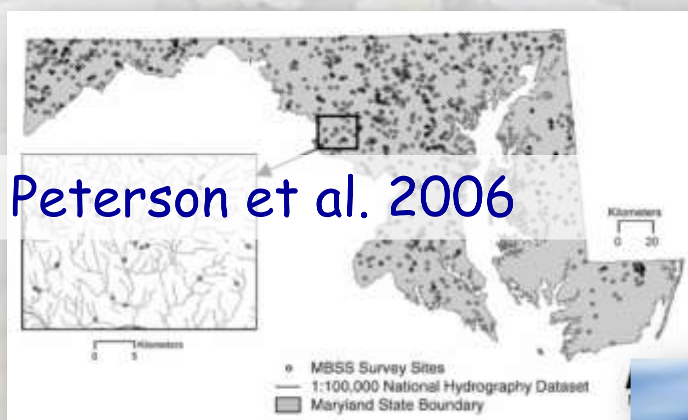


Habicht et al. 2007
AK Coho salmon

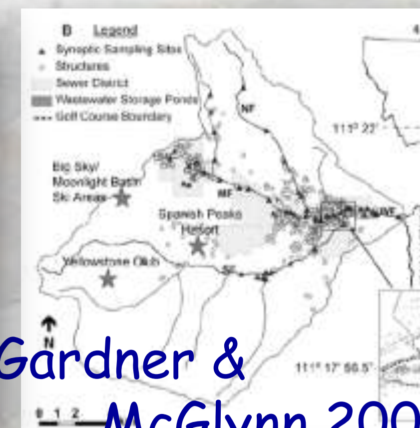
Harnessing Existing Databases

Water Quality/Chemistry Information

(Nitrates, alkalinity, ph, DOC, conductivity, etc.)

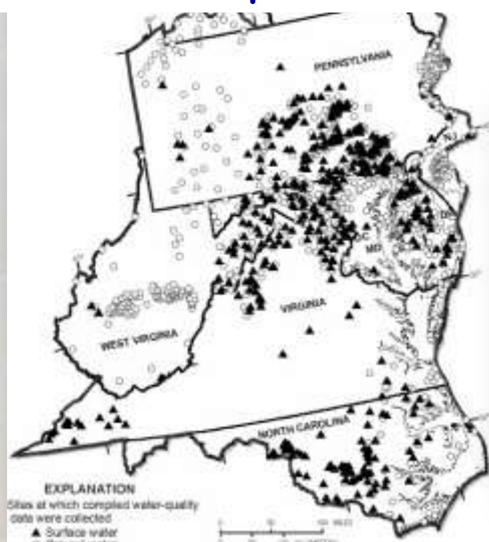


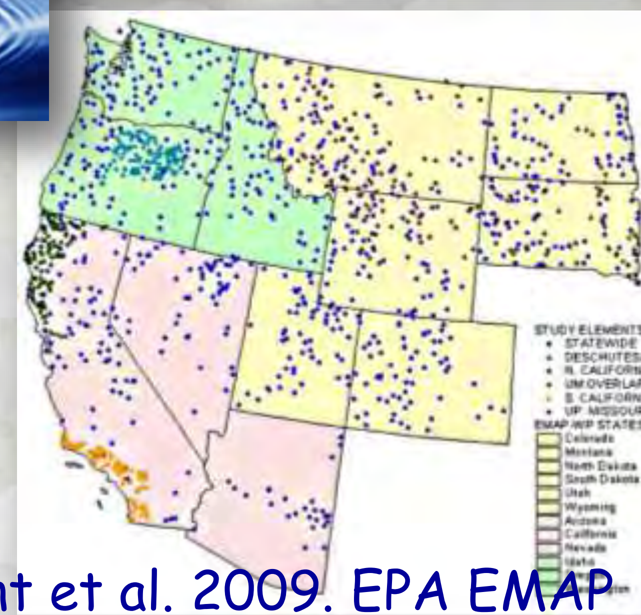
Peterson et al. 2006



Gardner & McGlynn 2009

USGS, unpublished

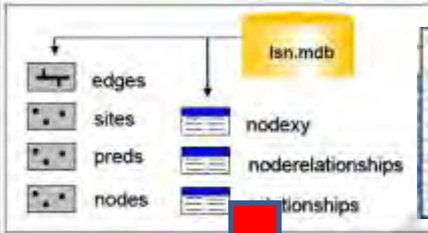


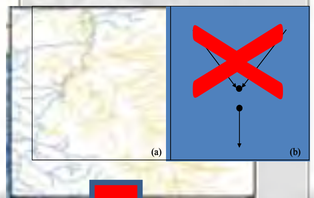


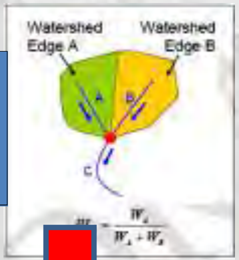
Pont et al. 2009. EPA EMAP

An InterNet for Stream Data

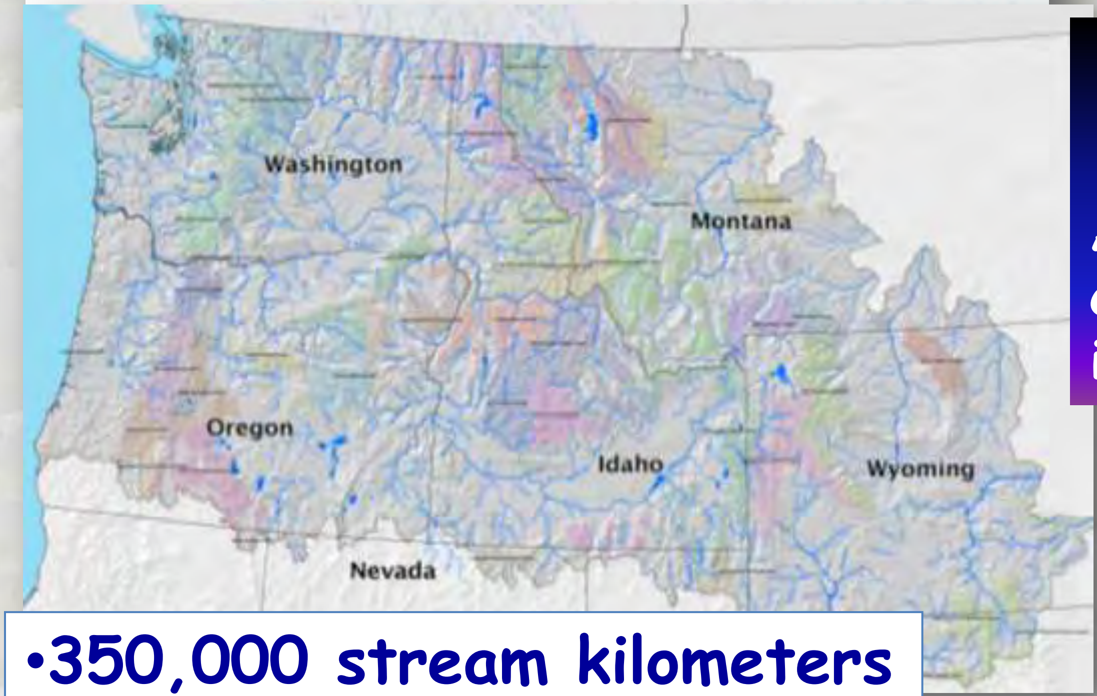
GIS infrastructure now exists…







Great Northern
LANDSCAPE CONSERVATION COOPERATIVE



•350,000 stream kilometers

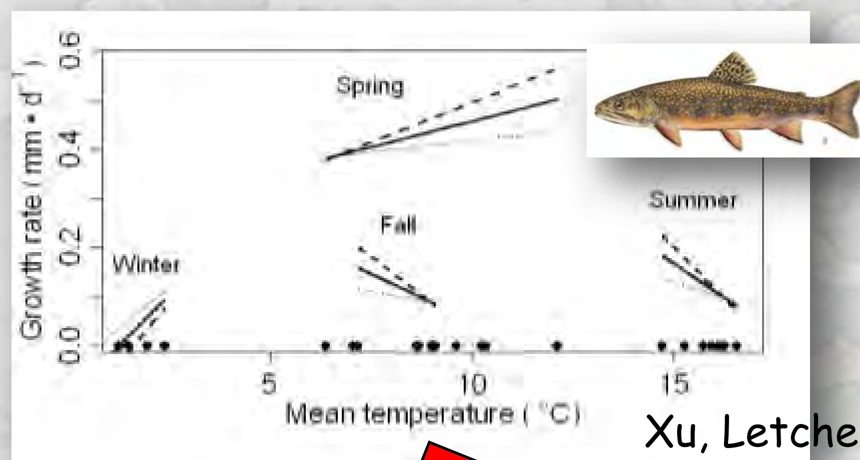
1G LCC

Accurate & consistent scaling of information

1G LCC

Accurate & consistent scaling of information

Channel Unit Scale

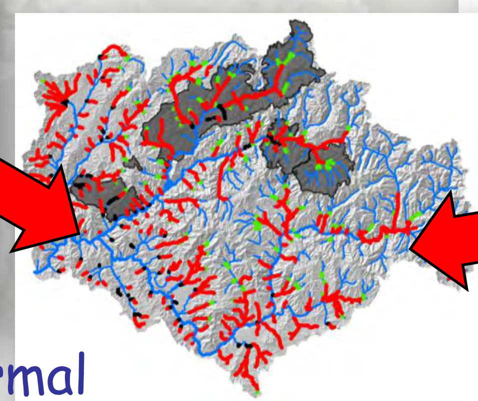


Xu, Letcher & Nislow 2010

Regional Network/Species Distribution Scale

River Network Scale

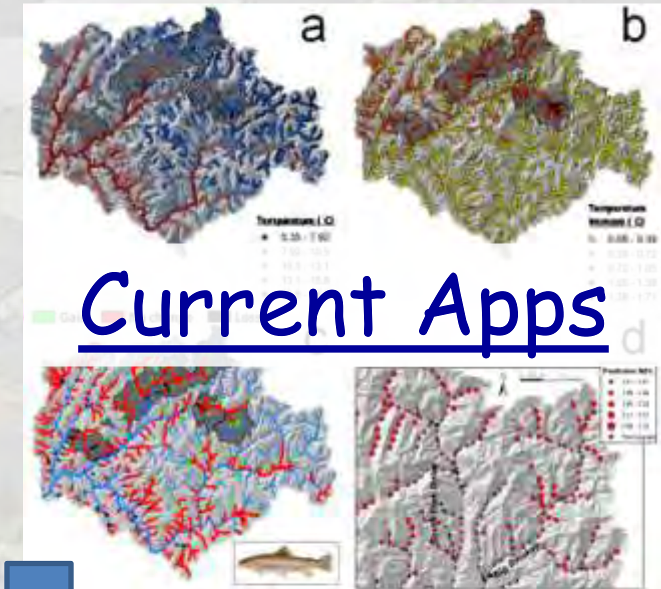
Temperature



Thermal Habitat

Temperature is a "Killer App"

But more are coming…



Current Apps

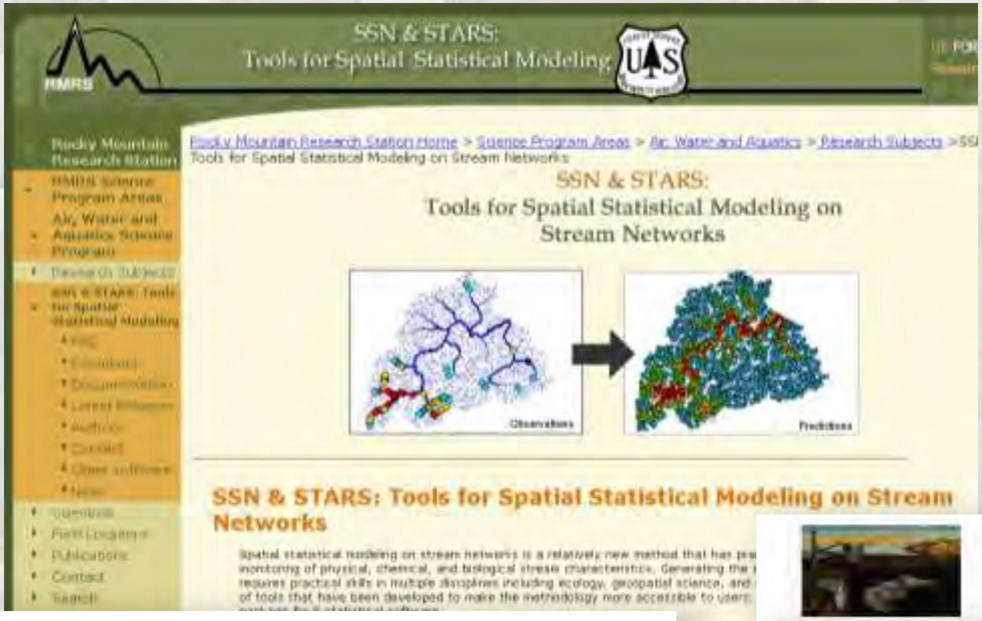
Tip of the Iceberg

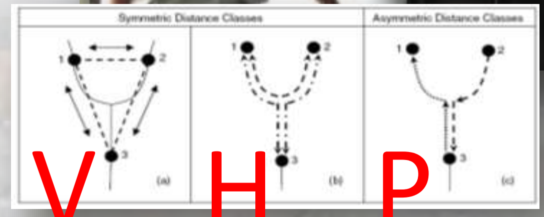
In the Pipeline…

- Bull trout climate decision support tool
- Optimal monitoring designs for biological & water quality parameters
- Block-krige estimates of mean/variance
- Accurate species distribution maps & models
- Precise thermal niche definitions & climate vulnerability assessments for aquatic organisms

Analytical Ecosystem for Stream Data

SSN & STARS Website Launch Impending…





Journal of Statistical Software

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

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

ORIGINAL ARTICLE

Spatial statistical models that use flow distance

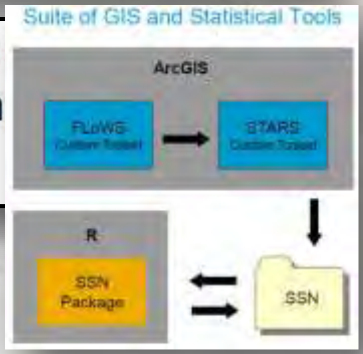
Jay M. Ver Hoef · Erin Peterson · David Theobald

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

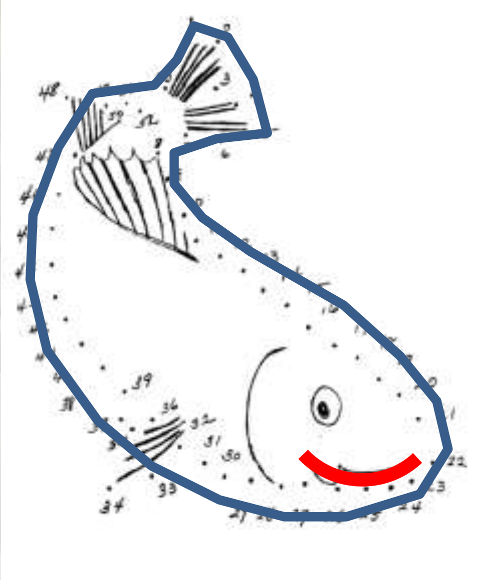
A Moving Average Approach for Spatial Models of Stream

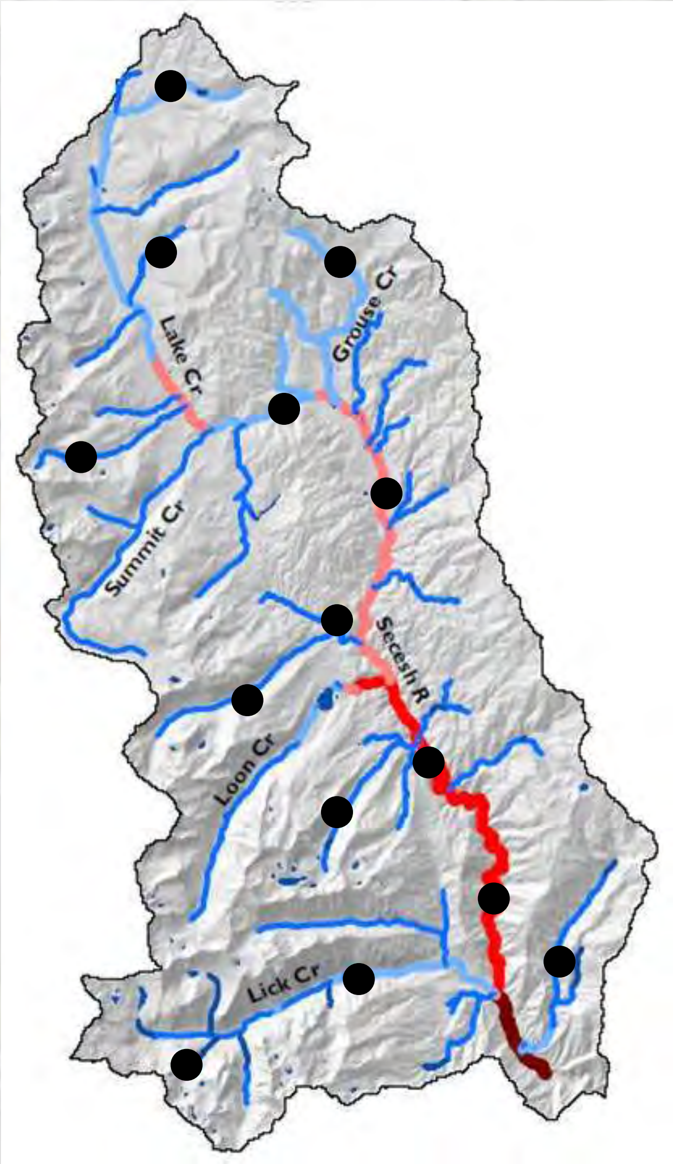
Jay M. Ver Hoef and Erin E. Peterson

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

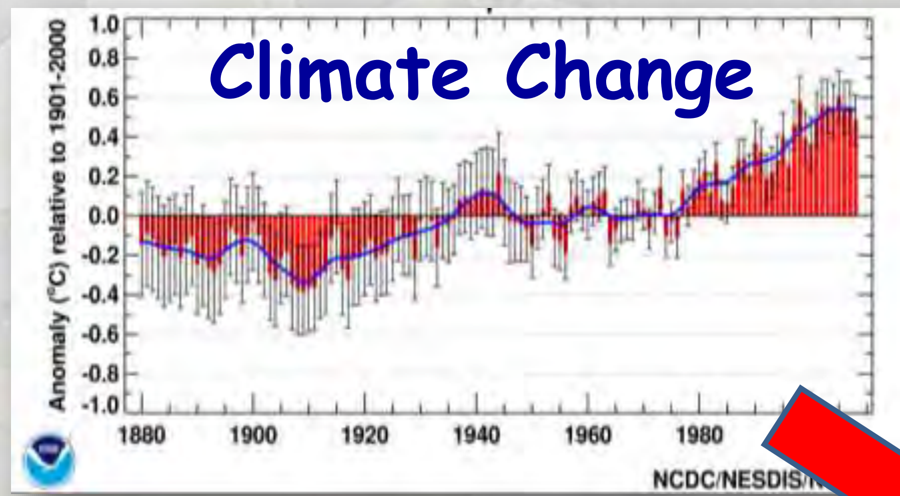


We Need to Connect the Dots



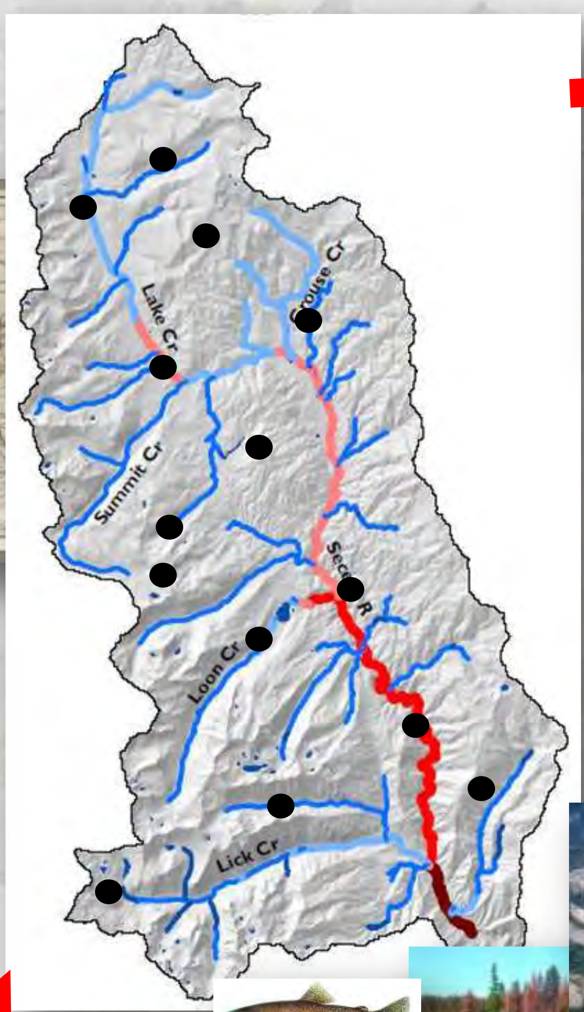


More With Less, but perhaps…Much More?

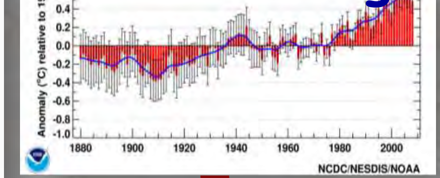


Shrinking Budgets

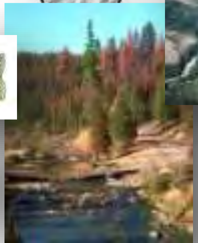
Connect the Dots ^ to Map the Future
& the People & the Agencies

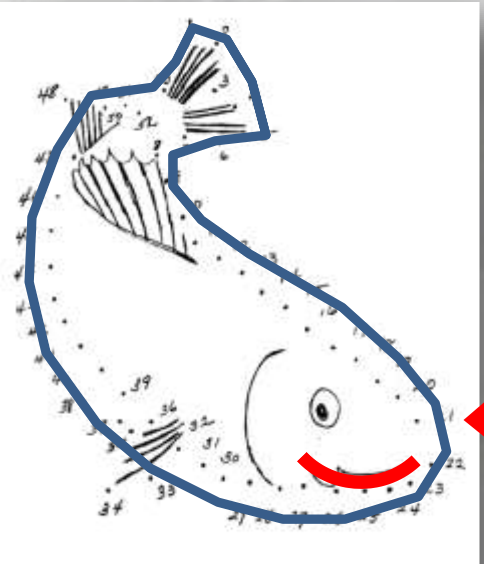


Climate Change



Urbanization & Population Growth





Land & Species Management

Resources – Stream Temperature

Google "USFS TreeSearch" & then author search

Isaak DJ, Wollrab S, Horan D, Chandler G (2011) Climate change effects on stream and river temperatures across the northwest U.S. from 1980 – 2009 and implications for salmonid fishes. *Climatic Change* doi: 10.1007/s10584-011-0326-z.

Isaak DJ, Horan DL (2011) An evaluation of underwater epoxies to permanently install temperature sensors in mountain streams. *North American Journal of Fisheries Management* 31:134-137.

Isaak DJ, Horan D, Wollrab S (2011) A visual guide to using underwater epoxy to permanently install temperature sensors in mountain streams. U.S. Forest Service Report.

Dunham JB, Chandler G, Rieman BE, Martin D (2005) Measuring stream temperature with digital dataloggers: a user's guide. RMRS GTR-150; U.S. Forest Service, Rocky Mountain Research Station, Fort Collins, Colorado.

Isaak DJ, Luce CH, Rieman BE, Nagel DE, Peterson EE, Horan DL, Parkes S, Chandler GL (2010) Effects of climate change and recent wildfires on stream temperature and thermal habitat for two salmonids in a mountain river network. *Ecological Applications* 20:1350-1371.

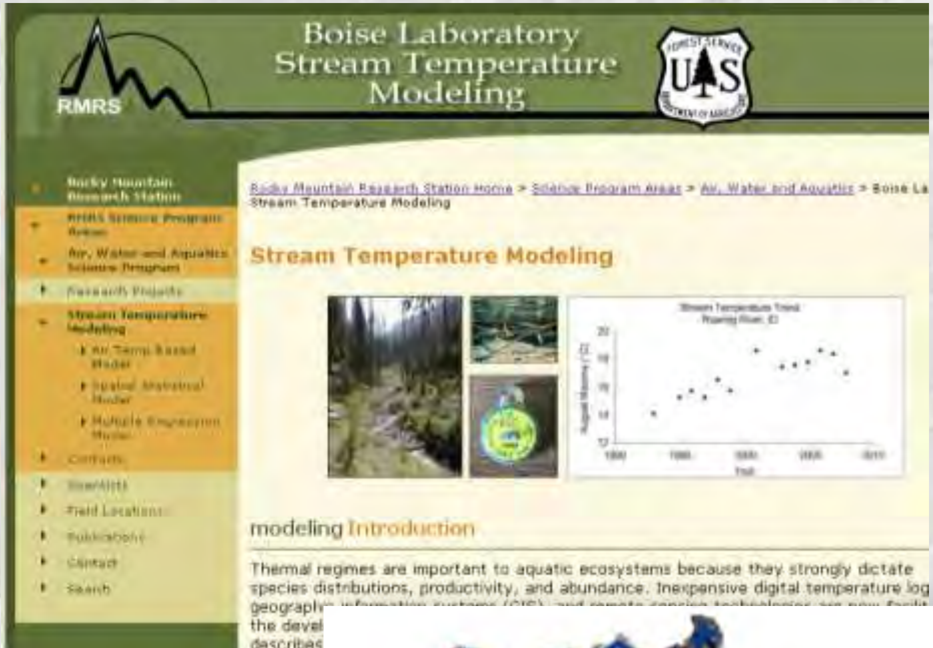
Related Websites - Google search…

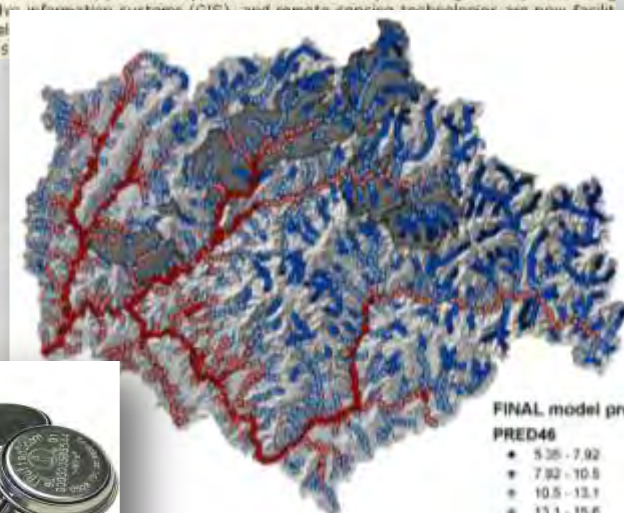
"USFS Climate-Aquatics BLOG"

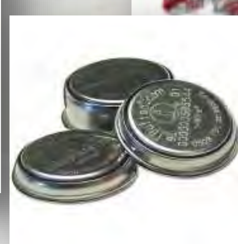
"USFS Climate-Aquatics Workshop"

"USFS Boise Stream Temperature"

Resources – Stream Temperature Website
Google " Forest Service Stream Temperature"







- Stream temperature publications & project descriptions & recent talks
- Protocols for temperature data collection & demonstration videos
- Processing macro for temperature data
- Dynamic GoogleMap showing current temperature monitoring sites

Resources – Stream Network Models

Peterson, E.E., J.M. Ver Hoef. 2012. STARS: An ArcGIS toolset used to calculate the spatial data needed to fit spatial statistical models to stream network data. *Journal of Statistical Software* x:xxx-xxx.

Peterson, E.E., D.M. Theobald, and J.M. Ver Hoef. 2007. Geostatistical modeling on stream networks: developing valid covariance matrices based on hydrologic distance and stream flow. *Freshwater Biology* 52:267–279.

Peterson, E.E., A.A. Merton, D.M. Theobald, and N.S. Urquhart. 2006. Patterns of spatial autocorrelation in stream water chemistry. *Environmental Monitoring and Assessment* 121:569–594.

Peterson, E.E., and N.S. Urquhart. 2006. Predicting water quality impaired stream segments using landscape-scale data and a regional geostatistical model: a case study in Maryland. *Environmental Monitoring and Assessment* 121:615–638.

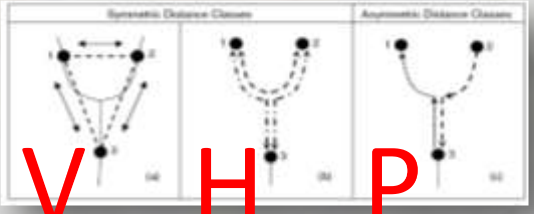
Ver Hoef, J.M., E.E. Peterson, D. Clifford, and R. Shah. 2012. SSN: An R package for spatial statistical modeling on stream networks. *Journal of Statistical Software* x:xxx-xxx.

Ver Hoef, J.M., and E.E. Peterson. 2010. A moving average approach for spatial statistical models of stream networks. *J American Stat Ass* 105:6-18.

Ver Hoef, J.M., E.E. Peterson, and D.M. Theobald. 2006. Spatial statistical models that use flow and stream distance. *Environmental and Ecological Statistics* 13:449–464.

Related Websites…

- Coming Soon…"SSN and STARS"




The End