Climate Change Effects on Coldwater Stream Ecosystems:

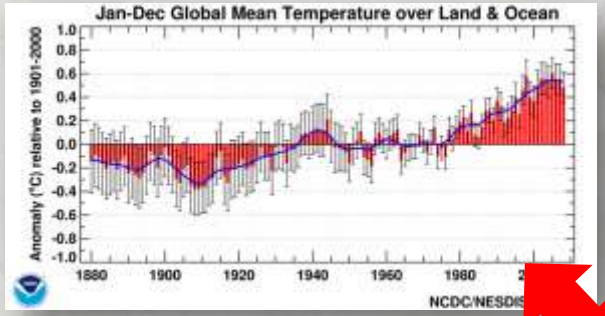
How Climate Concerns are Driving Development of Better Decision Support Tools & Improving Resource Management

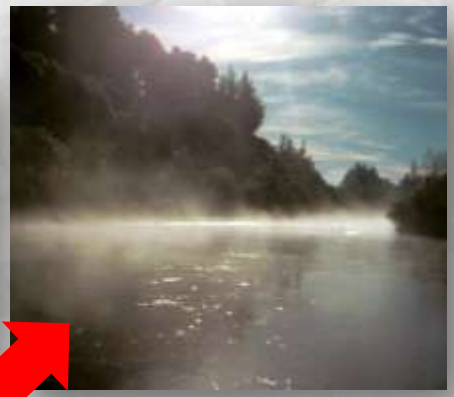
Dan Isaak, Seth Wenger[1], Bruce Rieman, Charlie Luce, Erin Peterson[2], Brett Roper

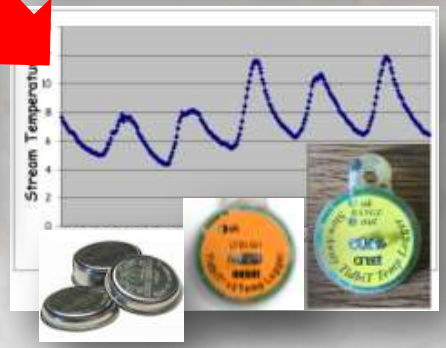
U.S. Forest Service

[1]Trout Unlimited

[2]CSIRO







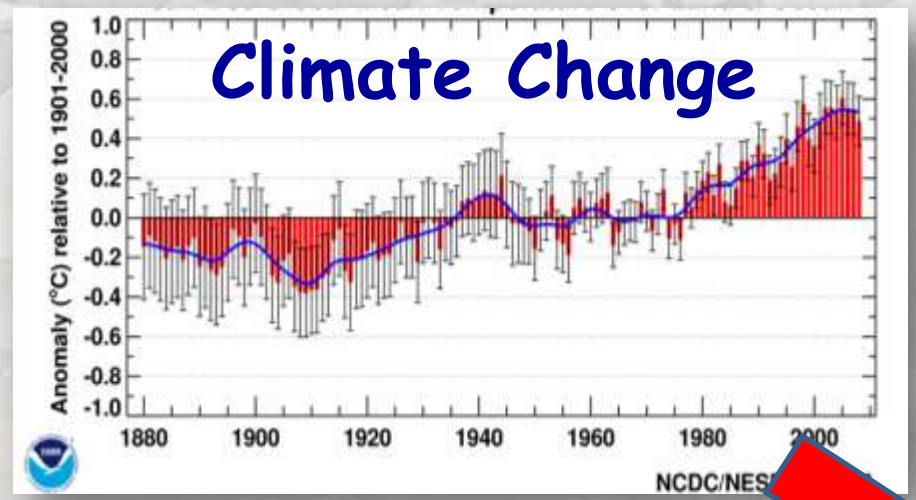
General outline:

1) Using interagency databases & geospatial technologies to develop relevant climate information for streams

2) Better spatial data = better resource management decisions

3) Better spatial data = better monitoring (for model validation & refinement) & mechanistic research (for understanding)

More Pressure, Fewer Resources

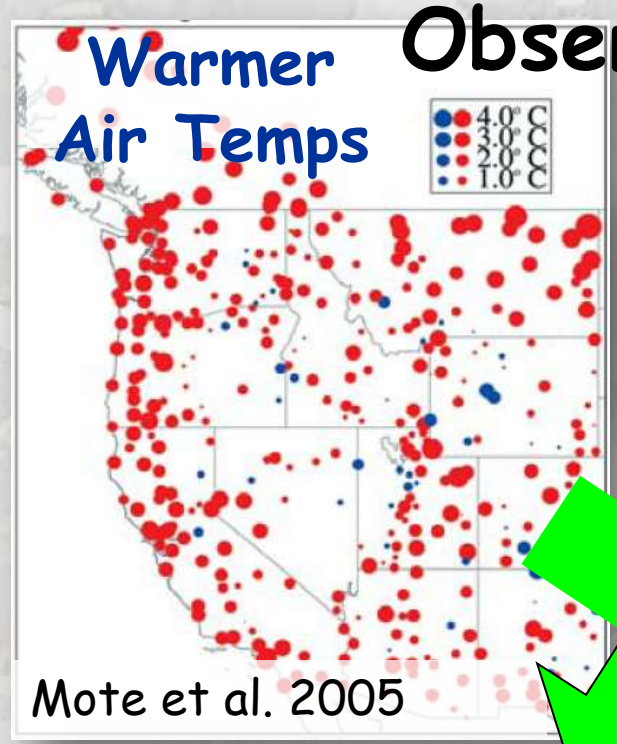


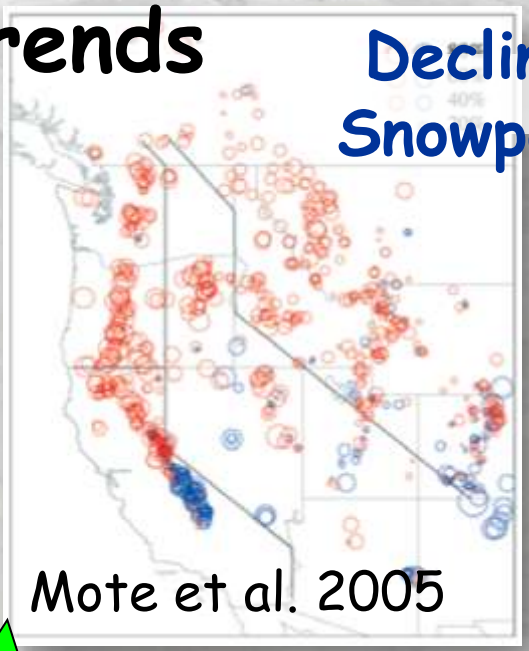
Urbanization & Population Growth

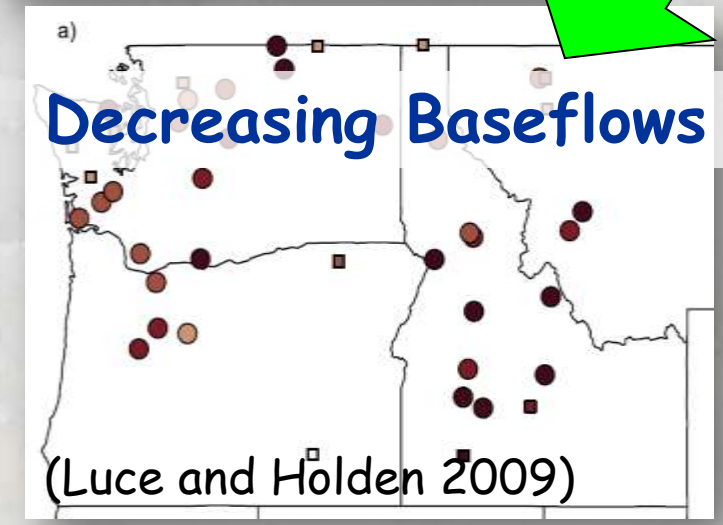
Shrinking Budgets

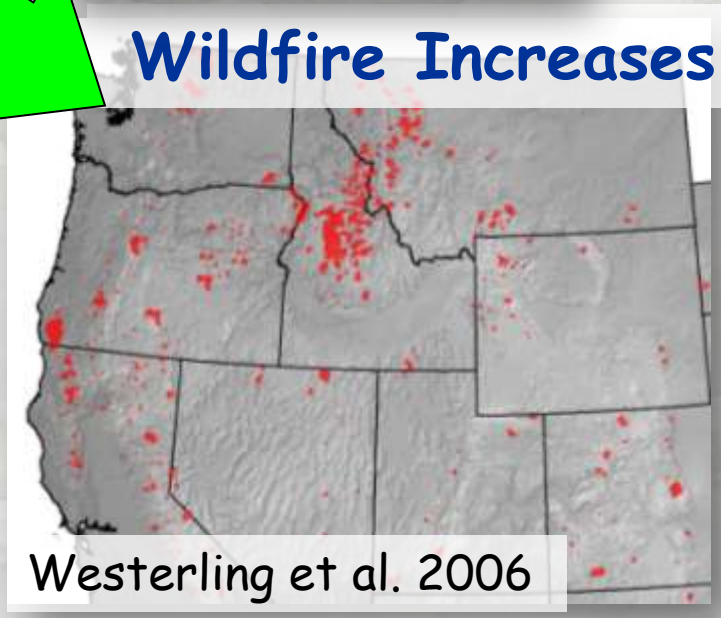
Need to do more with less

Western US – 20th Century Observed Trends









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
Columbia Basin Bulletin, August 14, 2009 (PST)

Land Use & Water Development

ESA Listed Species

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

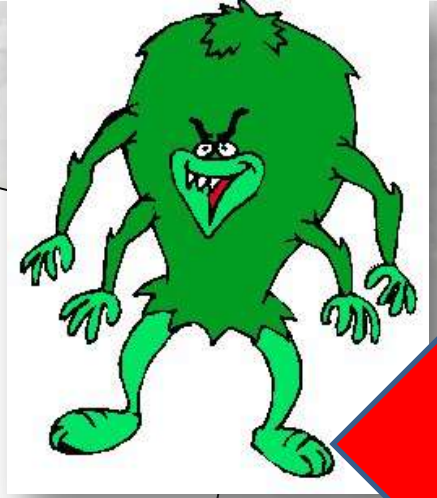
High Water Temperature In Grande

$4 Billion on Fish & Wildlife Recovery Efforts in PNW Since 1980

(ISAB/ISRP 2007)

ESA Listed Species

Climate Boogeyman



Analytical Capacity

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

NOAA Fisheries

IDAHO FISH & GAME

USGS science for a changing world

Washington Department of FISH and WILDLIFE

BONNEVILLE POWER ADMINISTRATION

FOREST SERVICE U.S. DEPARTMENT OF AGRICULTURE

Interagency Collaboration

CLIMATE IMPACTS GROUP

CENTER FOR ECOHYDRAULICS RESEARCH University of Idaho

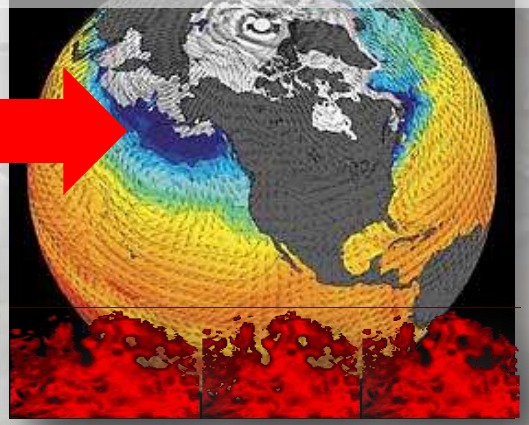
TROUT UNLIMITED

Geospatial Tools for Accurate Regional Scale Stream Models

Remote Sensing

GIS / Computing Capacity

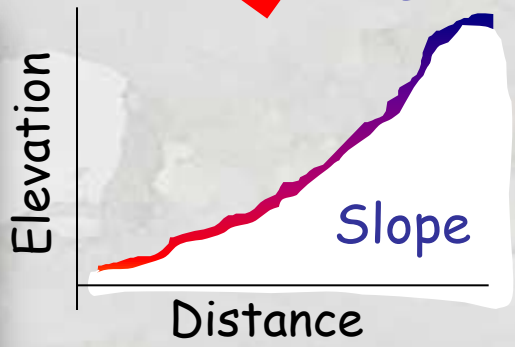
Climate, weather, GCM data availability



Visualization Tools

Nationally Consistent Hydrocoverages like USGS NHD+

Elevation



Drainage Area

Consistent, Accurate Information Needed Across Broad Areas

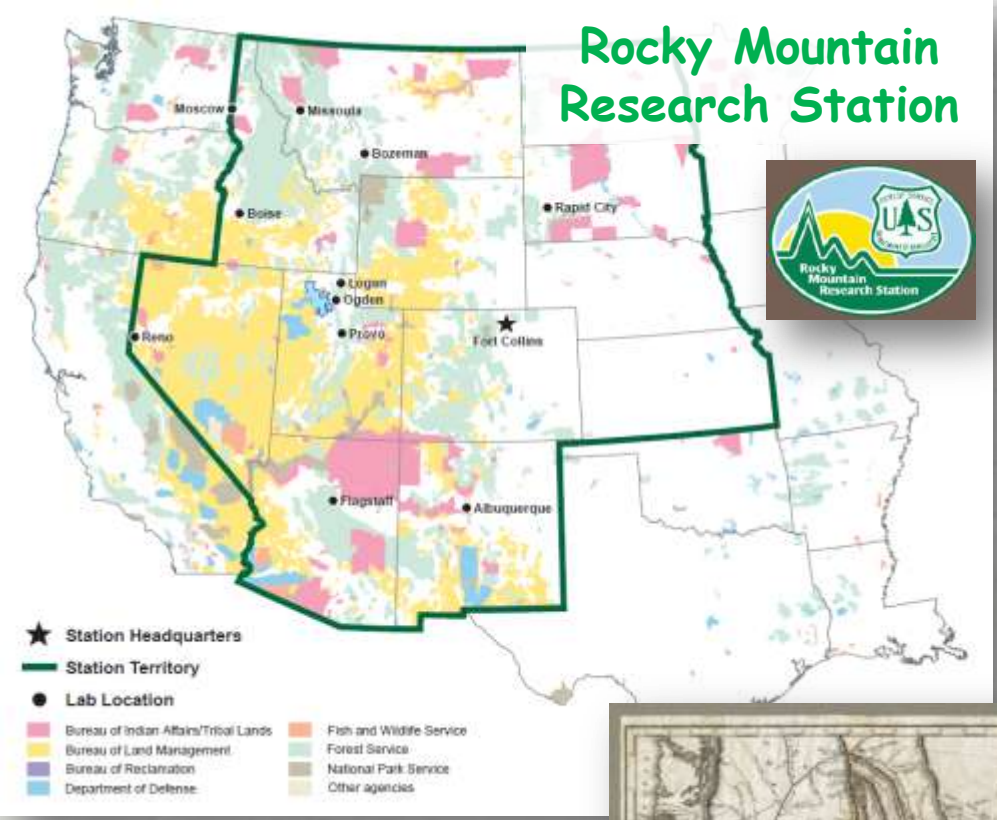
Lands Administered by USFS

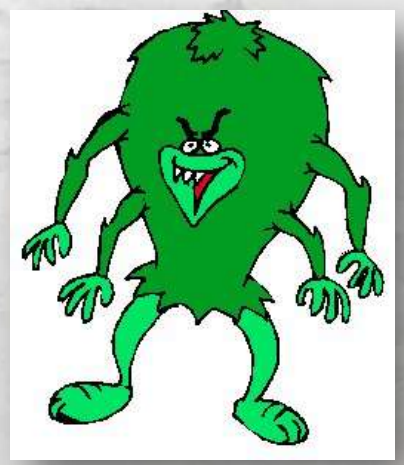
- 193 Million Acres (10% of US)
- 155 National Forests
- ~500,000 stream kilometers

Diverse streams

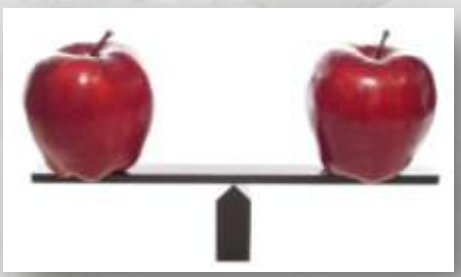
Remote landscapes

Consistent, Accurate Information Needed Across Jurisdictions





Maps are Powerful Tools

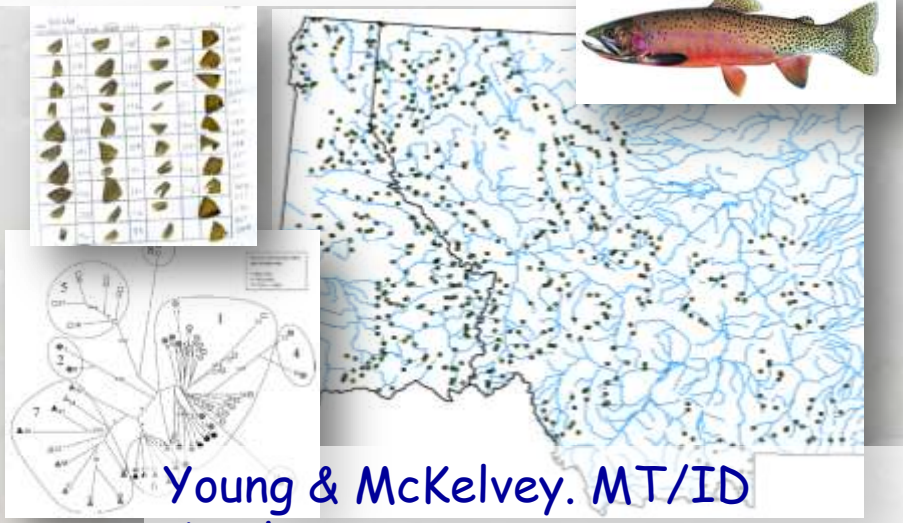


Existing Databases for Streams

1) Organism Distribution & Abundance

Massive information extraction is possible

2) Genetic Attributes



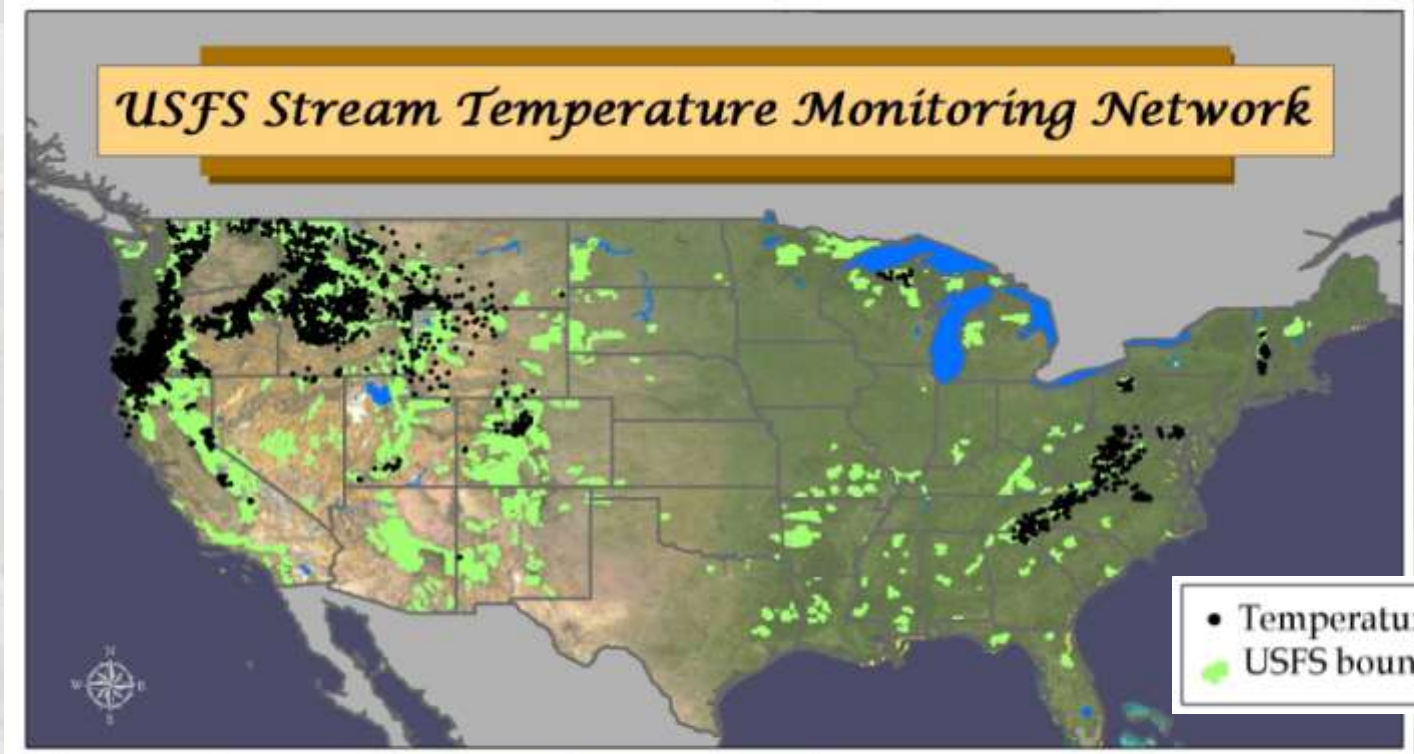
Young & McKelvey. MT/ID Cutthroat trout genetic surveys

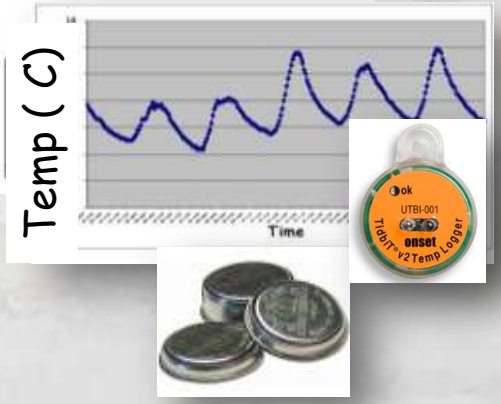
3) Water Quality Data & TMDL Standards

Pont et al. 2009. Water Quality Data from EMAP

Existing Databases for Streams

Nation's Largest Network (2,000-3,000 sites?)?





Work In Progress…

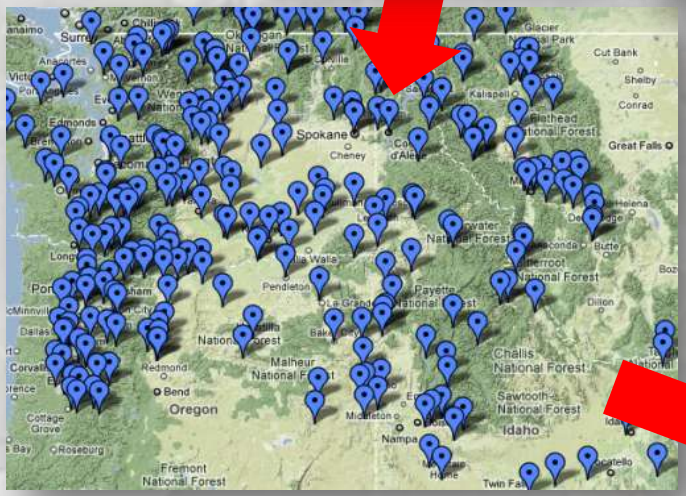
Mapping Hydrologic Responses to Climate Change Across River Networks

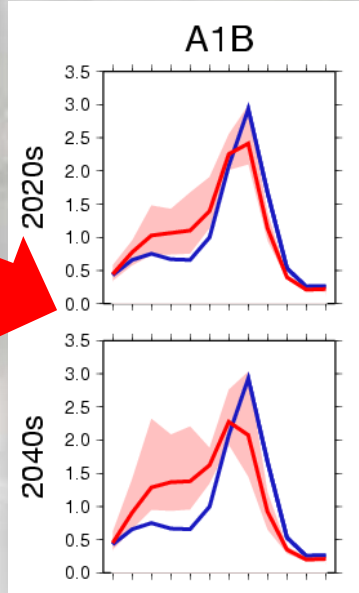
Seth Wenger[1], Charlie Luce, Alan Hamlet[2], Helen Neville[1], Dan Isaak

[1]Trout Unlimited
1020 W. Main St., #440
Boise, ID 83702

U.S. Forest Service
RMRS
Boise, ID 83702

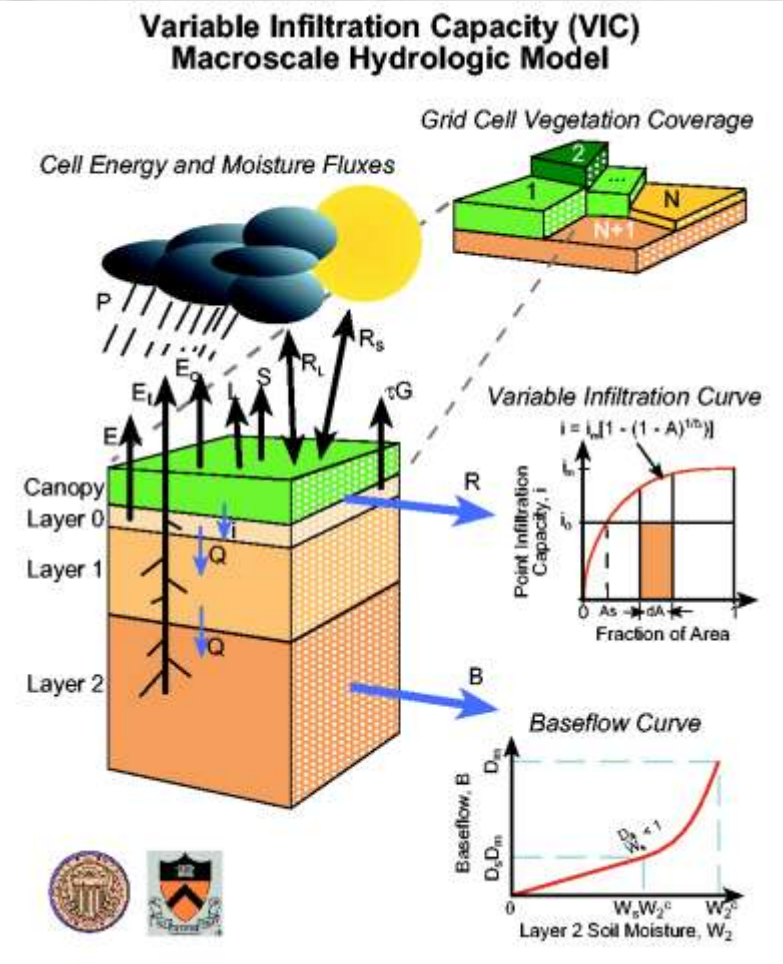
[2]Climate Impacts Group
University of Washington
Seattle, WA 98195-2700





Variable Infiltration Capacity (VIC) Hydrologic Model

1/8th degree grid resolution (~144 km^2) – western US
1/16th degree grid resolution (~36 km^2) – Columbia Basin



VIC Outputs

- Snowpack
- Soil water moisture
- Evaporation
- Flood timing, freq, & size
- Daily streamflows

References

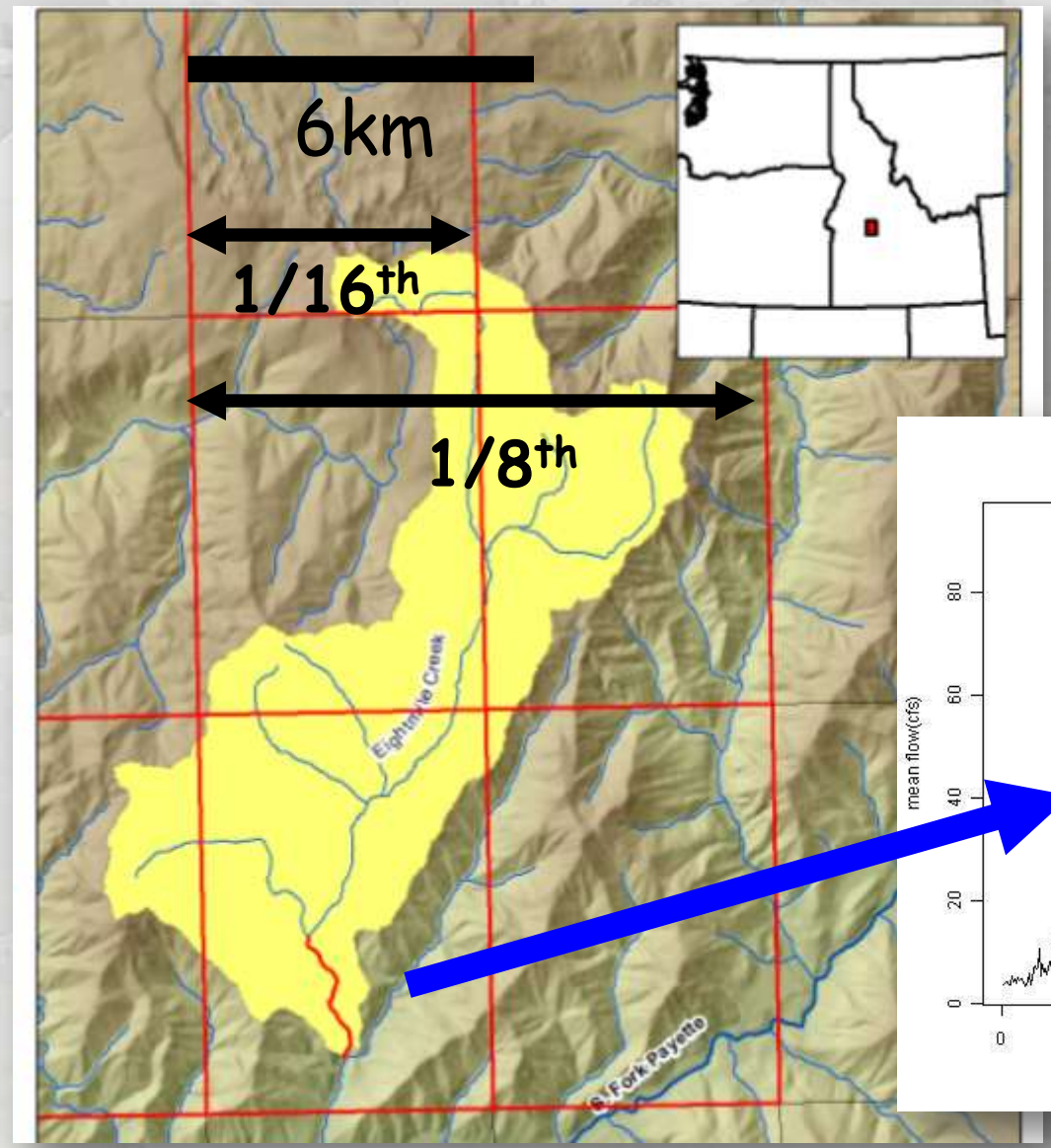
Liang et al. 1994. *J. Geophys. Res.* 99:14,415–14,428.

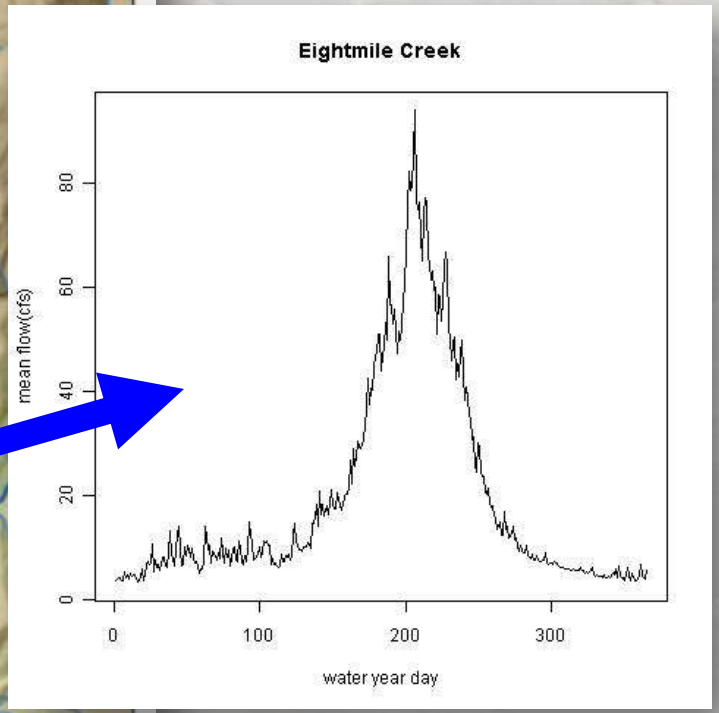
Christensen et al. 2004. *Climatic Change* 62: 337–363.

Hamlet & Lettenmaier. 2007. *Water Resour. Res.*, 43, W06427, doi:10.1029/2006WR005099.

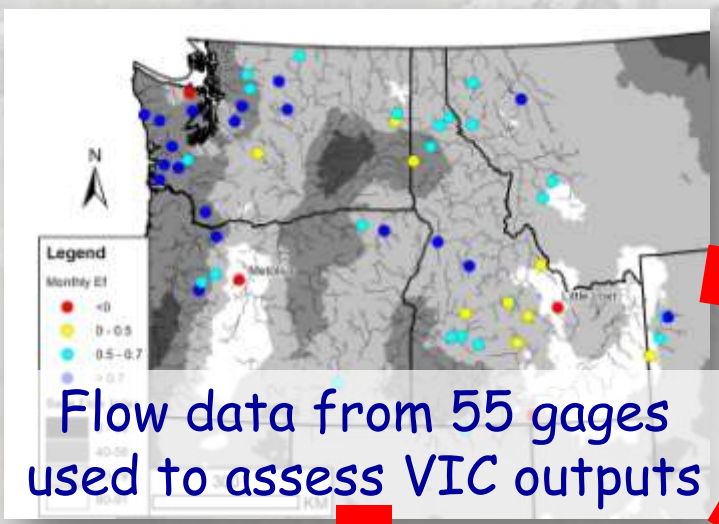
Hidalgo et al. 2009. *J. Climate* 22:3838–3855.

Adapting VIC for Smaller Rivers & Streams



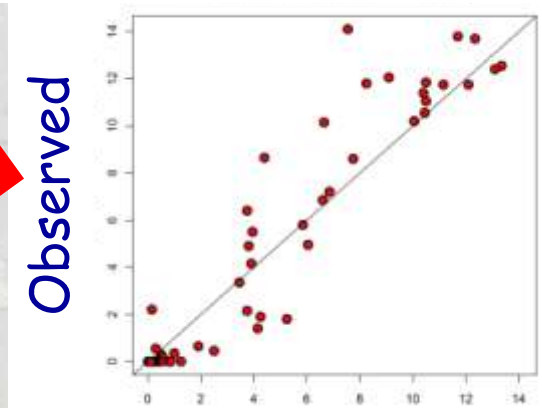


Validation of Stream Flow Metrics Predicted by VIC

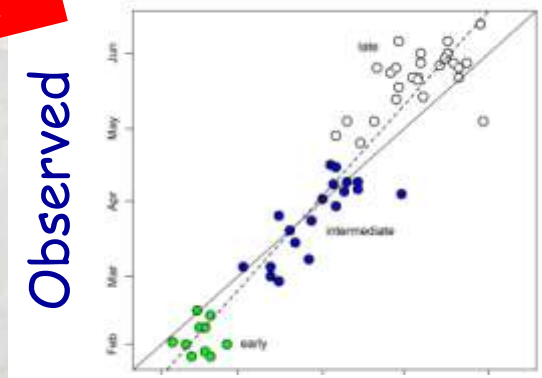


Flow data from 55 gages used to assess VIC outputs

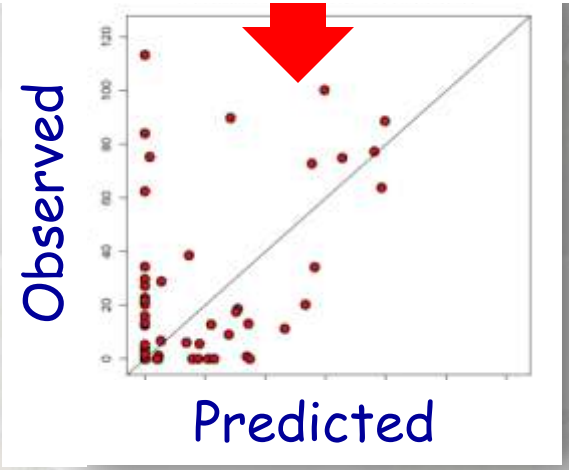
Frequency of winter high flows



Run-off timing



Frequency of low summer flows

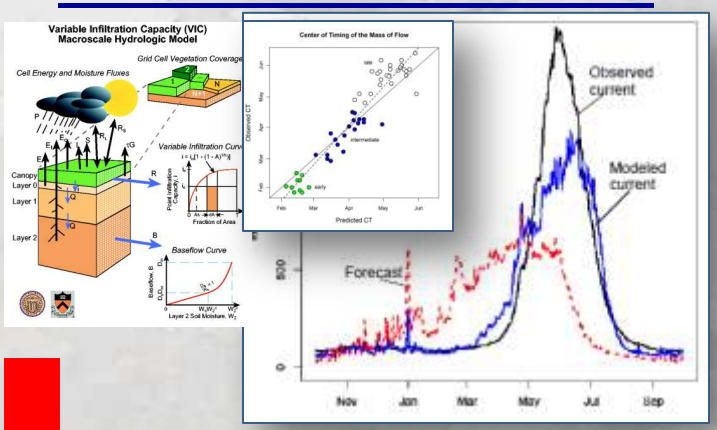


Wenger et al. 2010. *Water Resources Research* 46, W09513

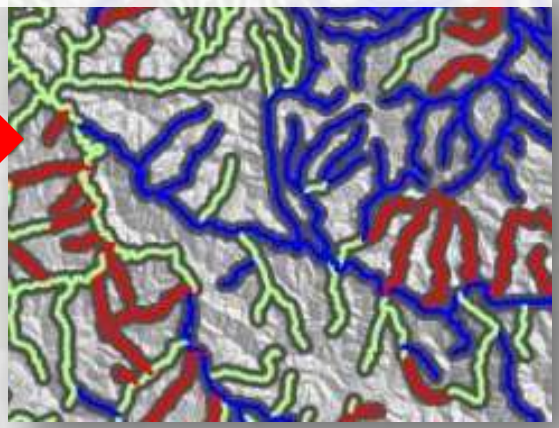
Western U.S. Flow Metrics Webpage

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

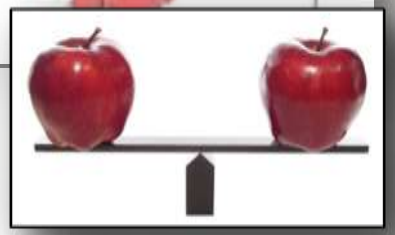
VIC Modeled Flow Metrics



…are available for all NHD+ stream segments & historic or future climate scenarios



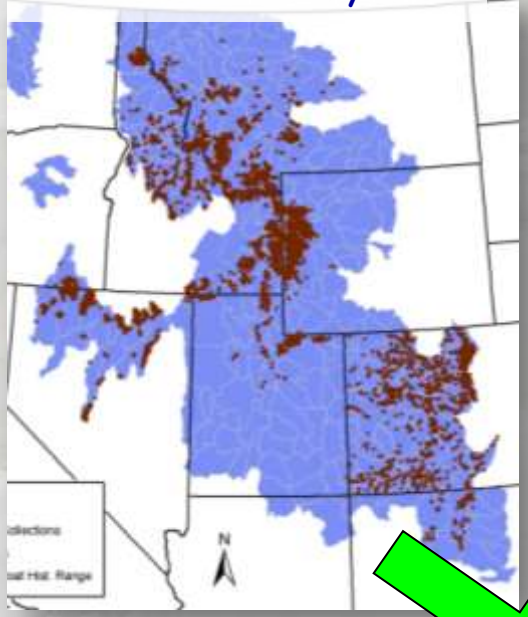
…across the western U.S.



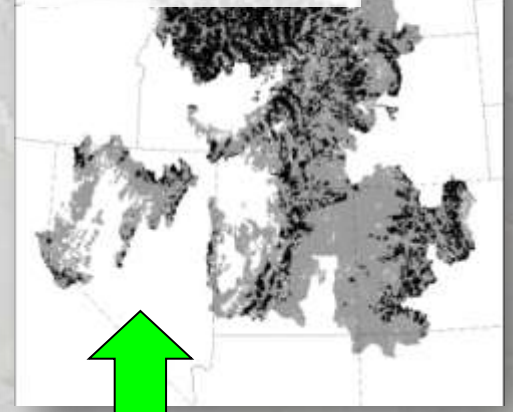
to make apples-to-apples comparisons and climate assessments possible.

Regional Bioclimatic Assessment for Western Trouts

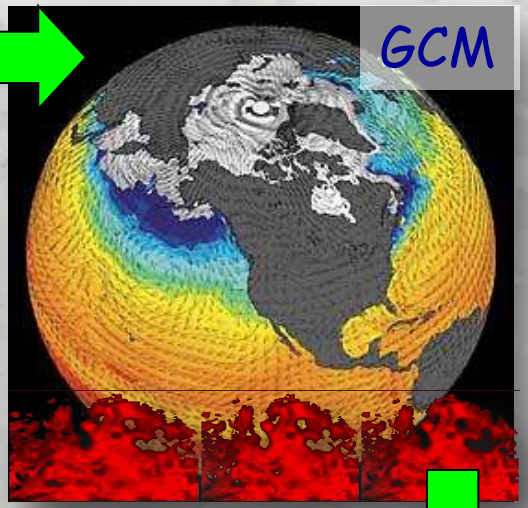
Fish survey database ~10,000



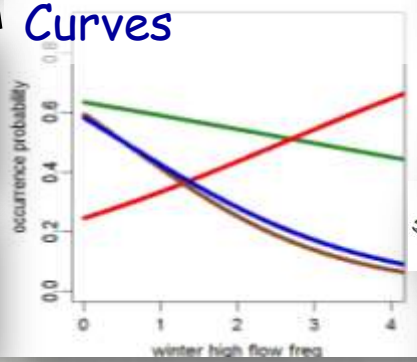
Historic Distributions



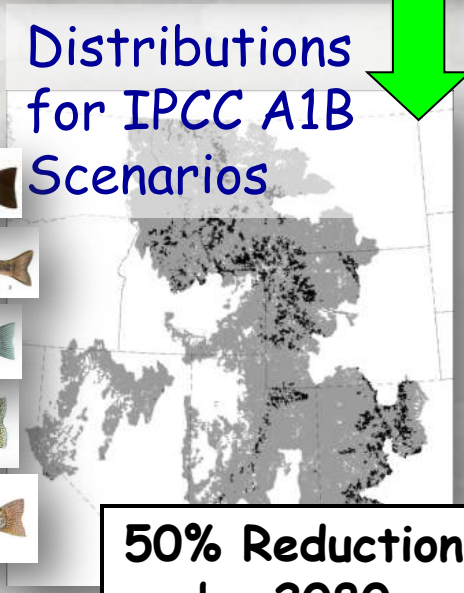
GCM



Species-Specific Habitat Response Curves



Distributions for IPCC A1B Scenarios

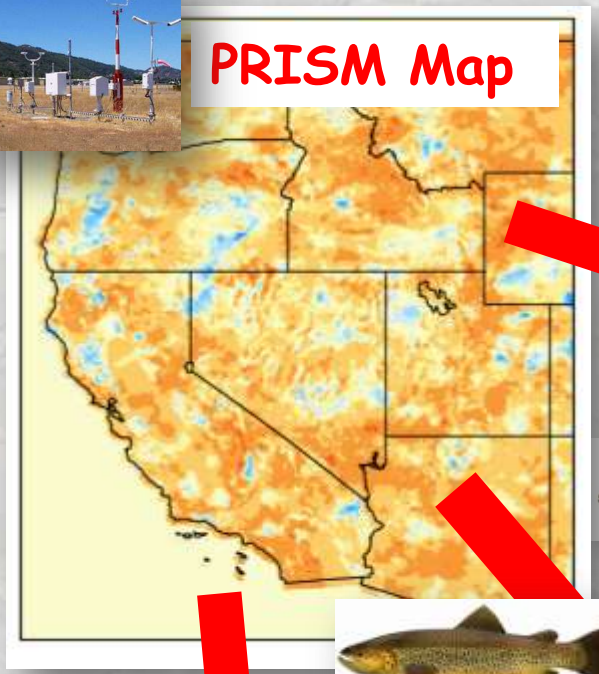


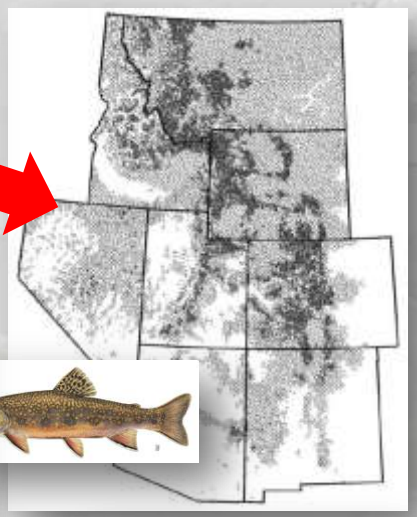
50% Reduction by 2080

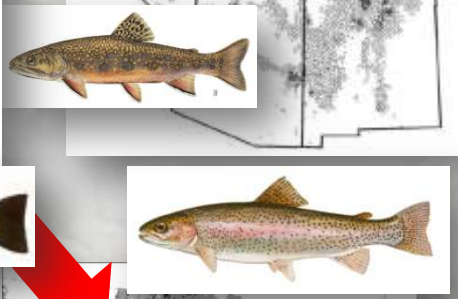
Wenger et al. 2011. *Proc. Nat. Acad. Sciences*

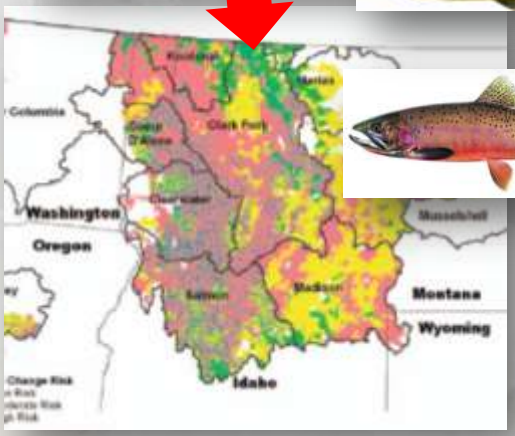
Something's Missing…

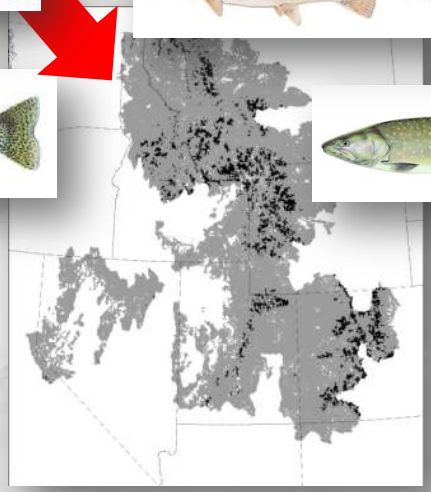
No Stream Temperature Component

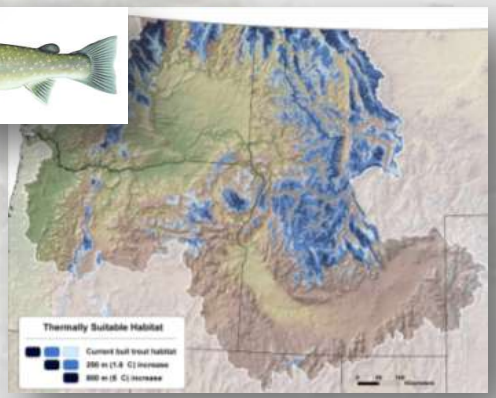








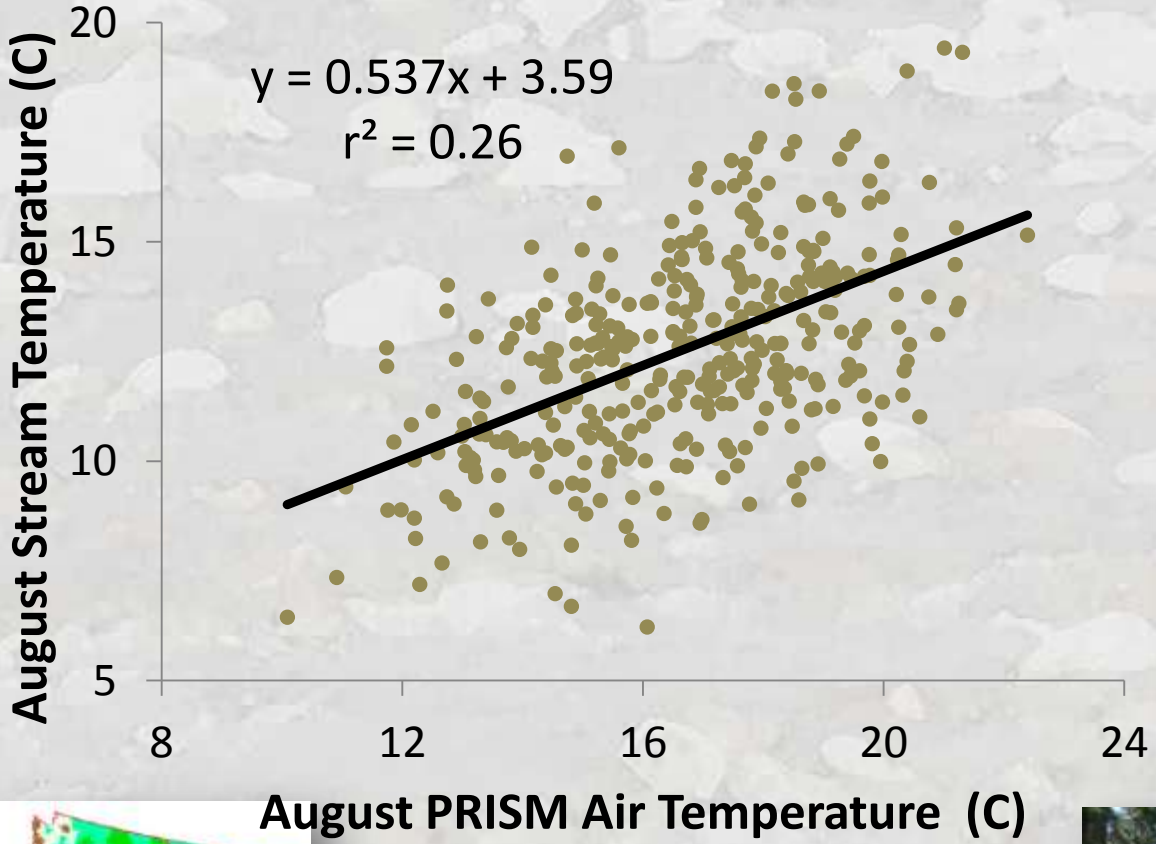


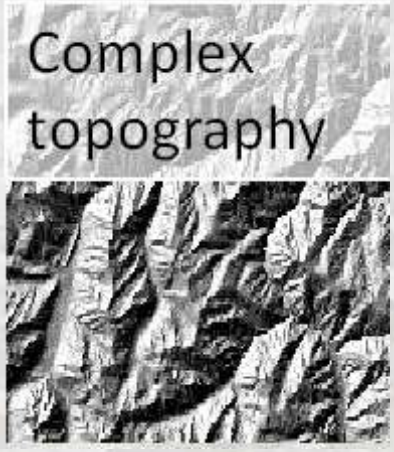


Air Temperatures Also In…

- 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
- Etc.

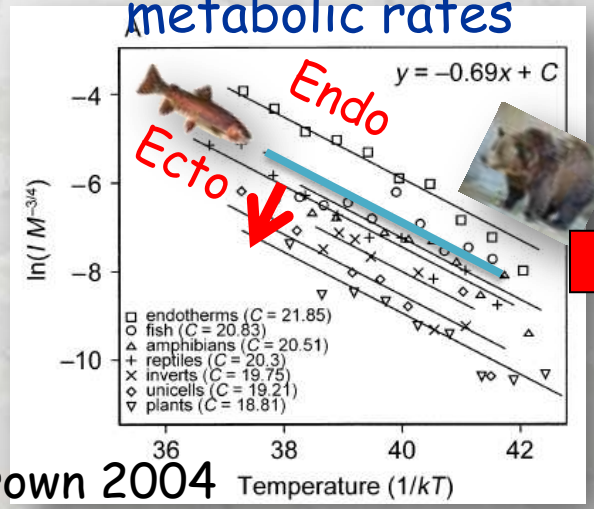
Air Temp ≠ Stream Temp





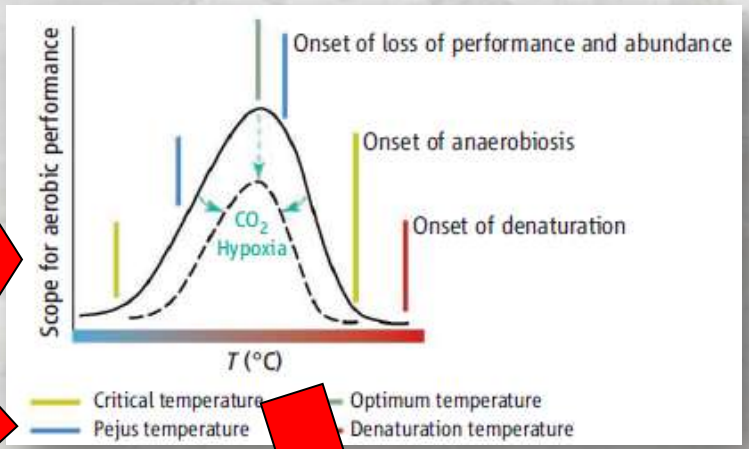
Temperature is Primary Control for Aquatic Organisms Like Fish

Temperature & metabolic rates

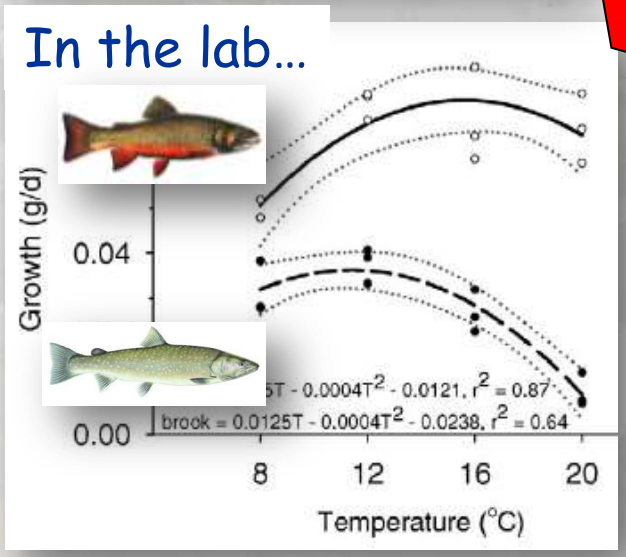


Brown 2004

Thermal Niche

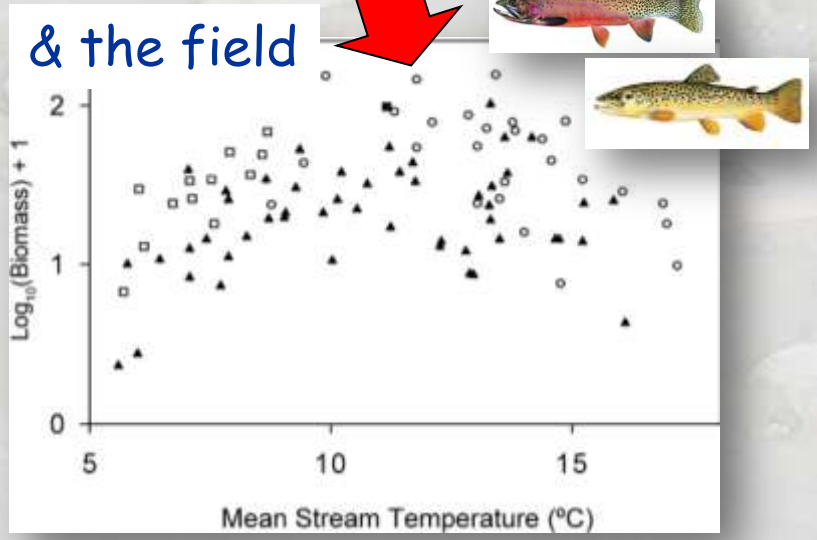


In the lab…



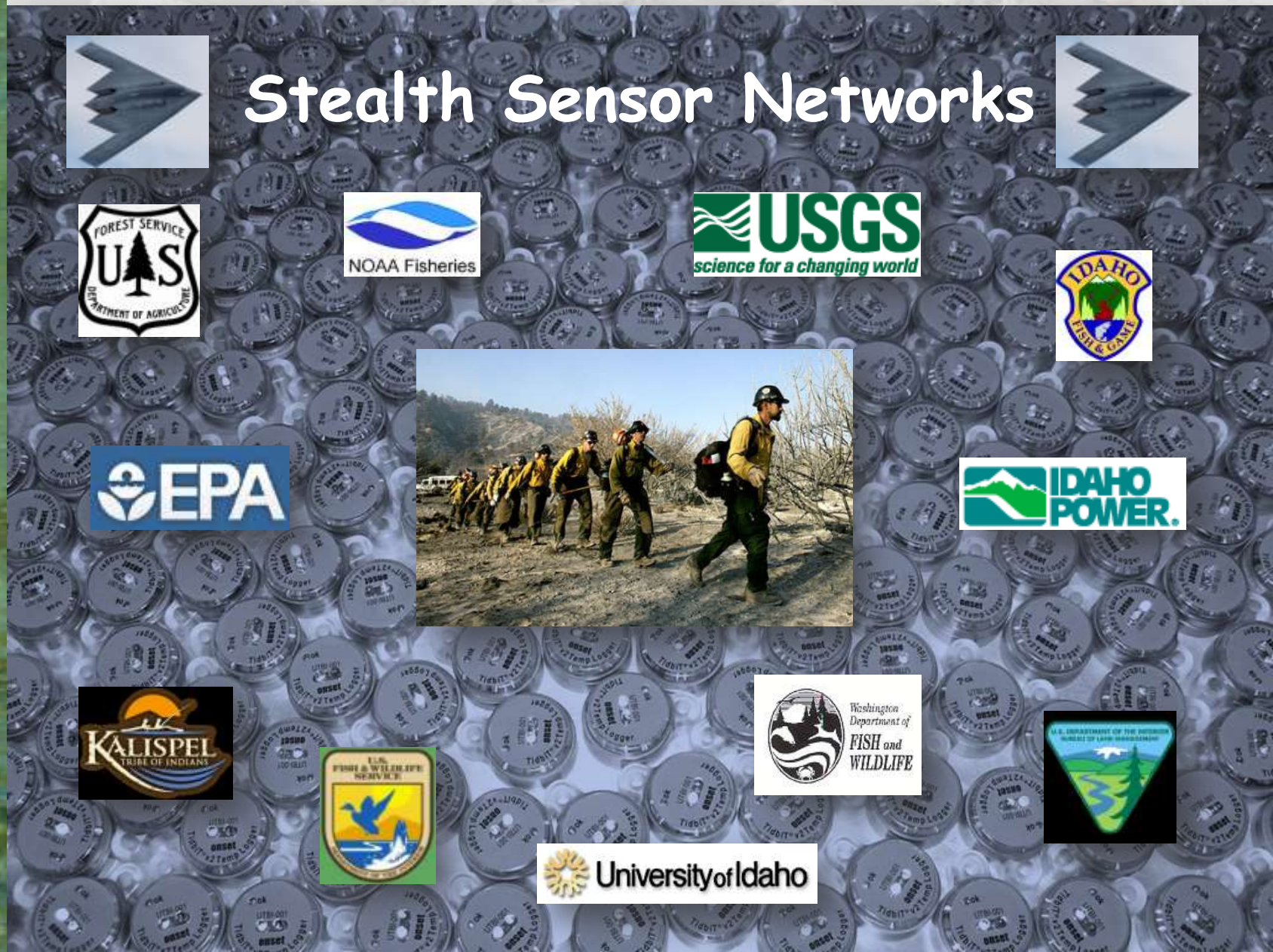
McMahon et al. 2007

& the field

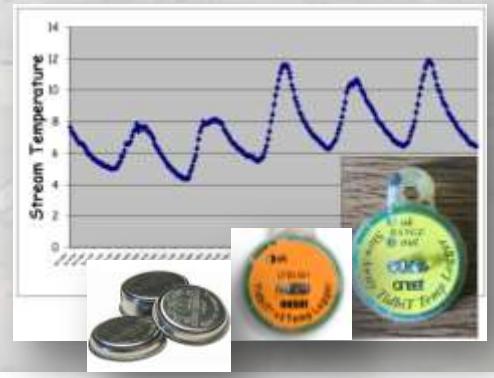


Isaak & Hubert 2004

Lots of Summer Stream Temp Data



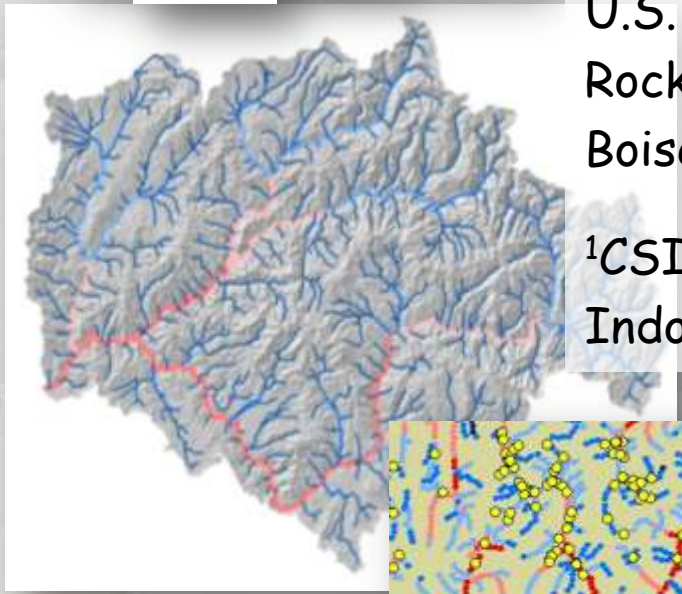
Mapping Temperature Responses to Climate Change Across River Networks

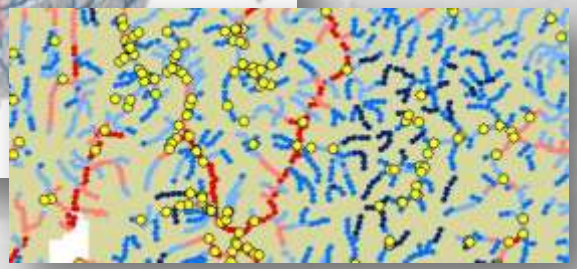


Dan Isaak, Charlie Luce, Bruce Rieman, Dave Nagel, Erin Peterson[1], Dona Horan, Sharon Parkes, and Gwynne Chandler

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

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

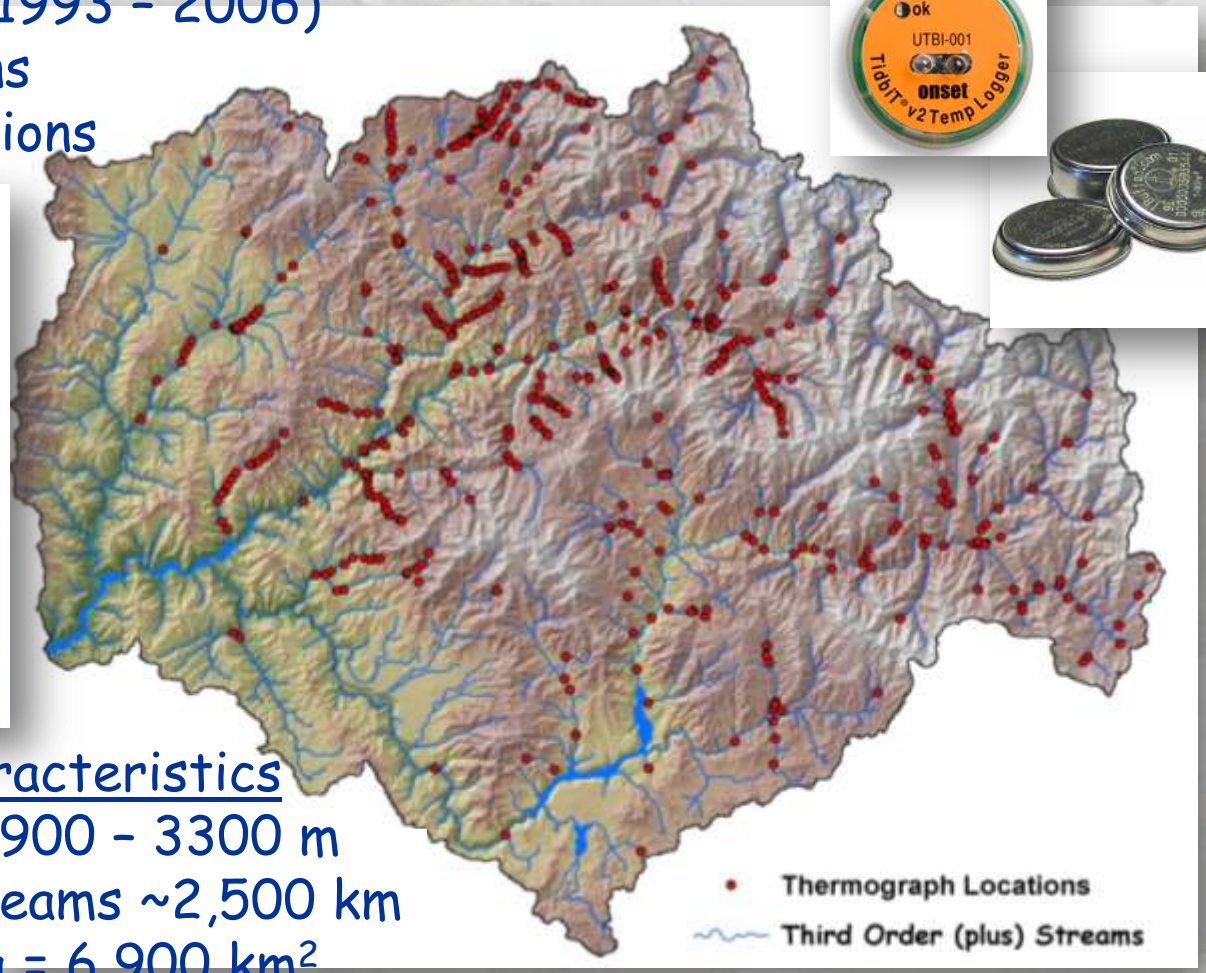




Boise River Temperature Database

Stream Temperature Database

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



Watershed Characteristics

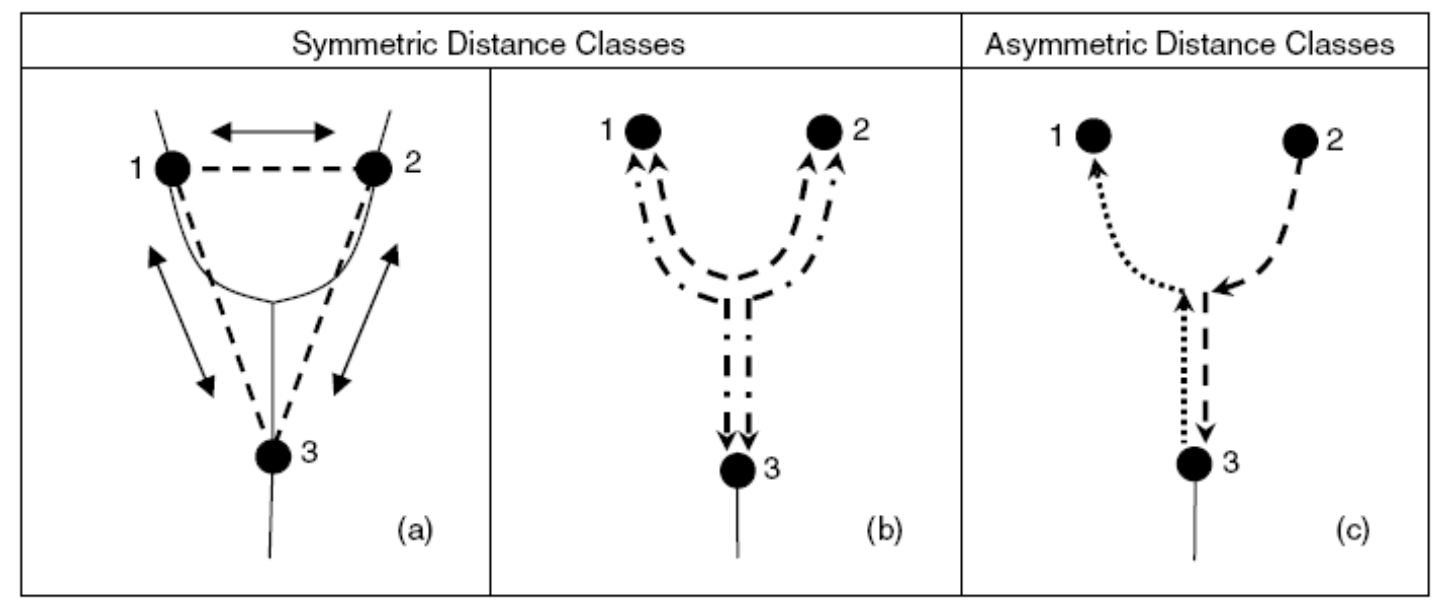
Elevation range 900 – 3300 m
Fish bearing streams ~2,500 km
Watershed area = 6,900 km^2

Data Providers:

Idaho DEQ | City of Boise | EPA | USGS science for a changing world | Forest Service U.S. Department of Agriculture | Idaho Fish & Game | BOR

Spatial Statistical Models for Stream Networks

Valid Means of Interpolation Between Samples…Finally!



Advantages:

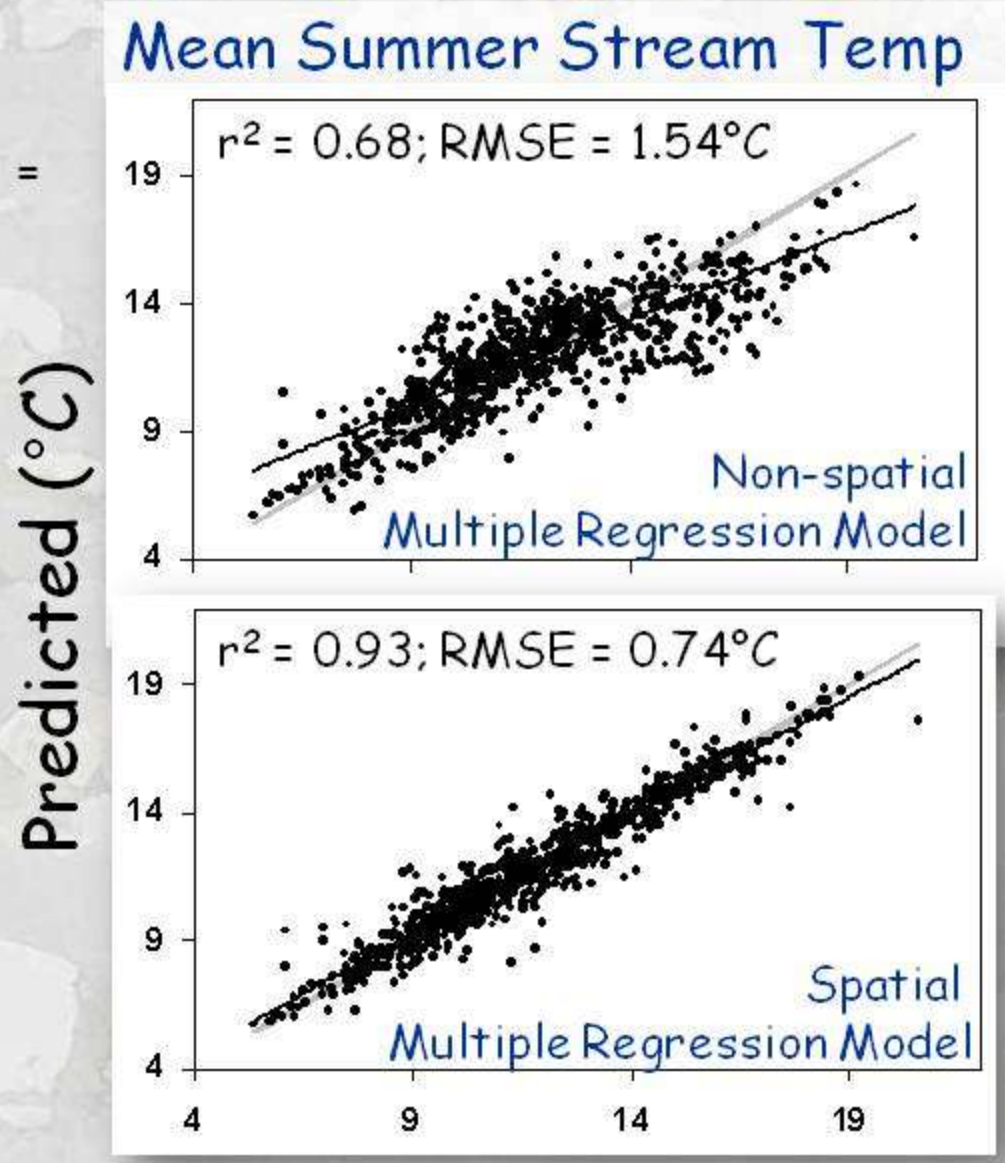
- -flexible & valid covariance structures by accommodating network topology
- -weighting by stream size
- -improved predictive ability & parameter estimates relative to non spatial models

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

Boise River Temperature Models

Non-spatial Stream Temp =
- 0.0064*Ele (m)
+ 0.0104*Rad
+ 0.39*AirTemp (C)
- 0.17*Flow (m^3/s)

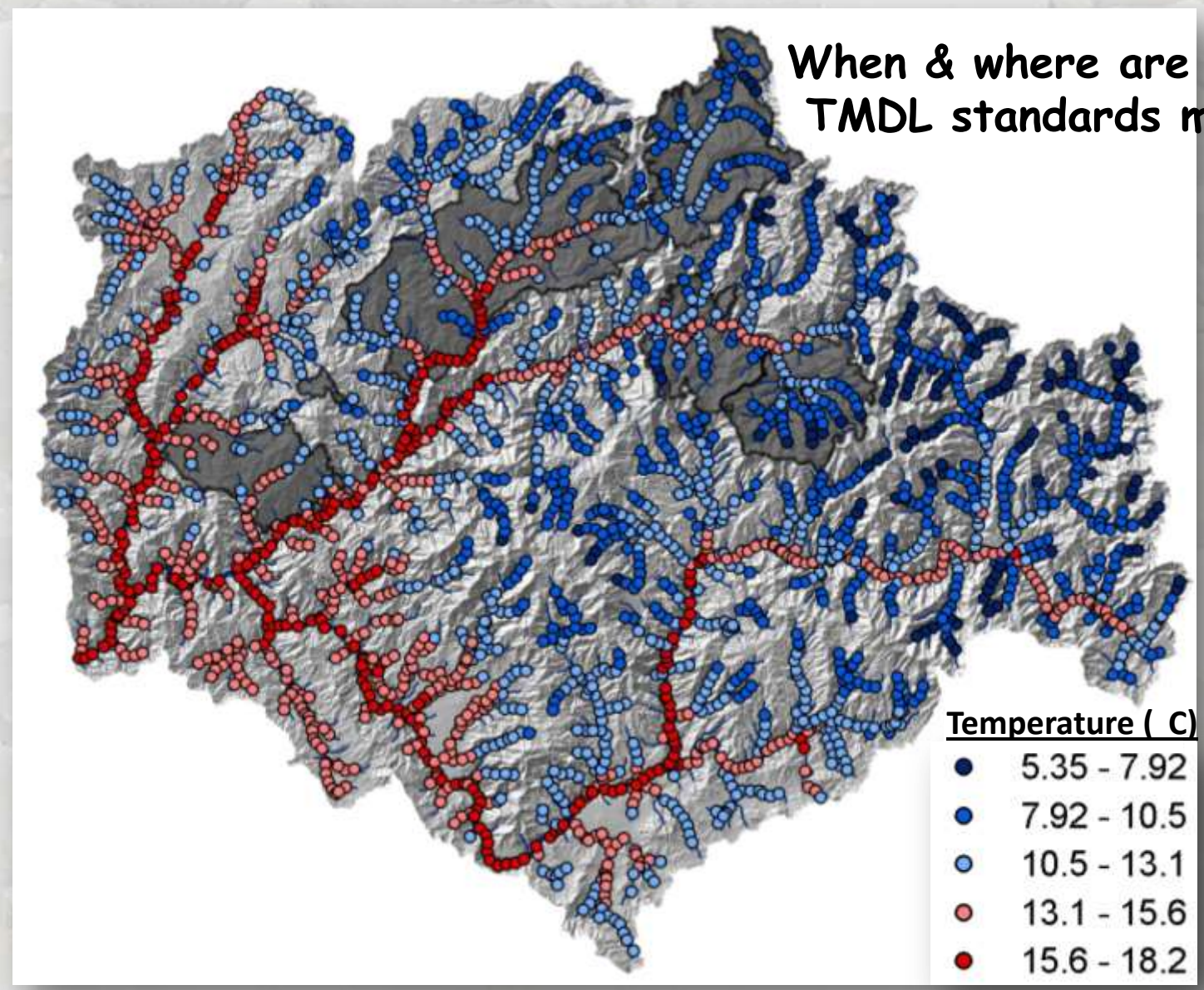
Spatial Stream Temp =
- 0.0045*Ele (m)
+ 0.0085*Rad
+ 0.48*AirTemp (C)
- 0.11*Flow (m^3/s)



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

River Network Thermal Maps

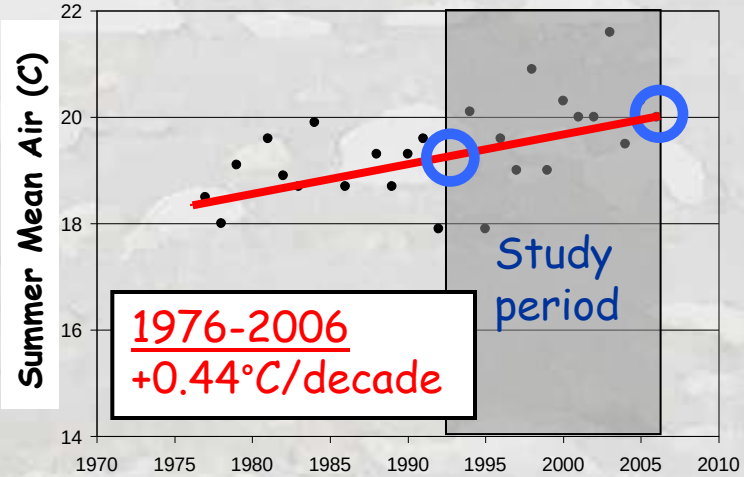
2006 Mean Summer Temperatures



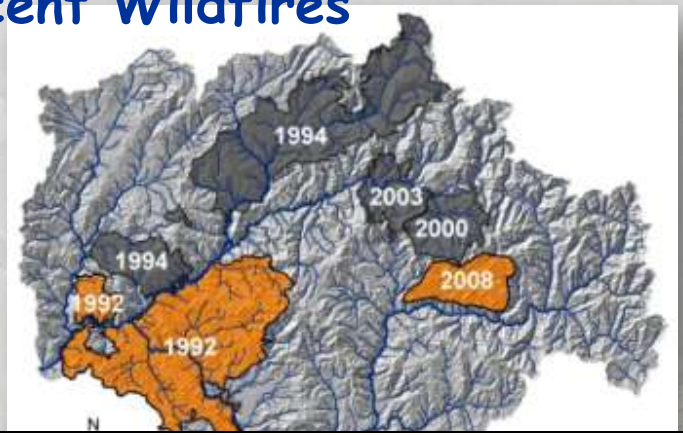
Measuring Climate Change Effects

Climate Trends Observed in the Boise River Basin

Summer Air Temperature

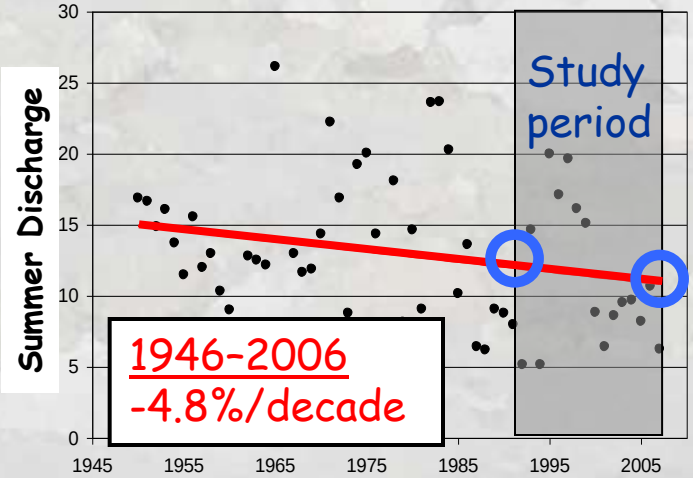


Recent Wildfires



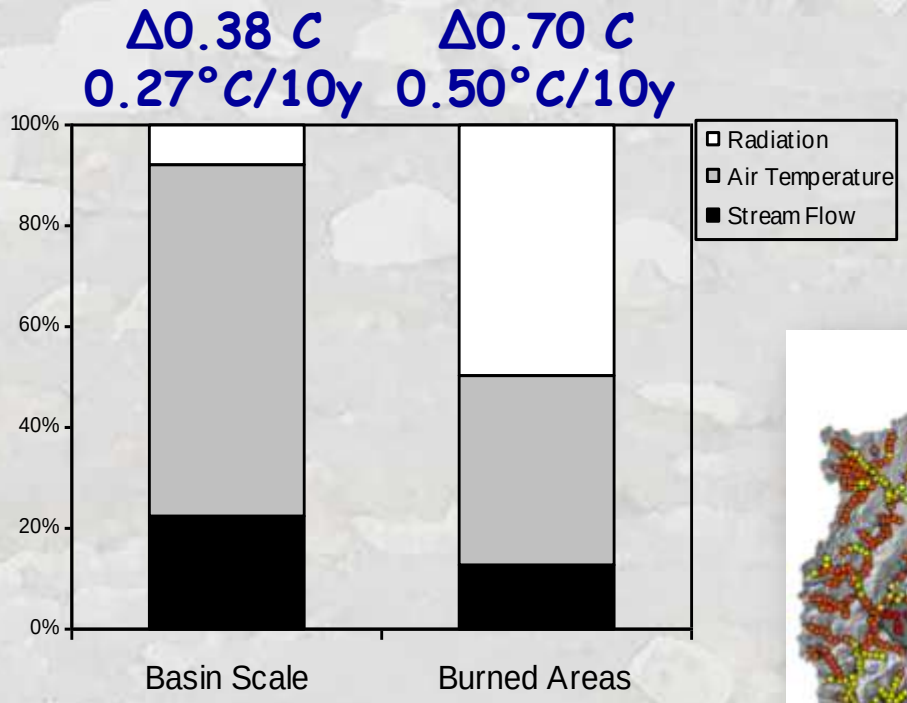
14% burned during 93-06 study period
30% burned from 92-08

Summer Stream Flow

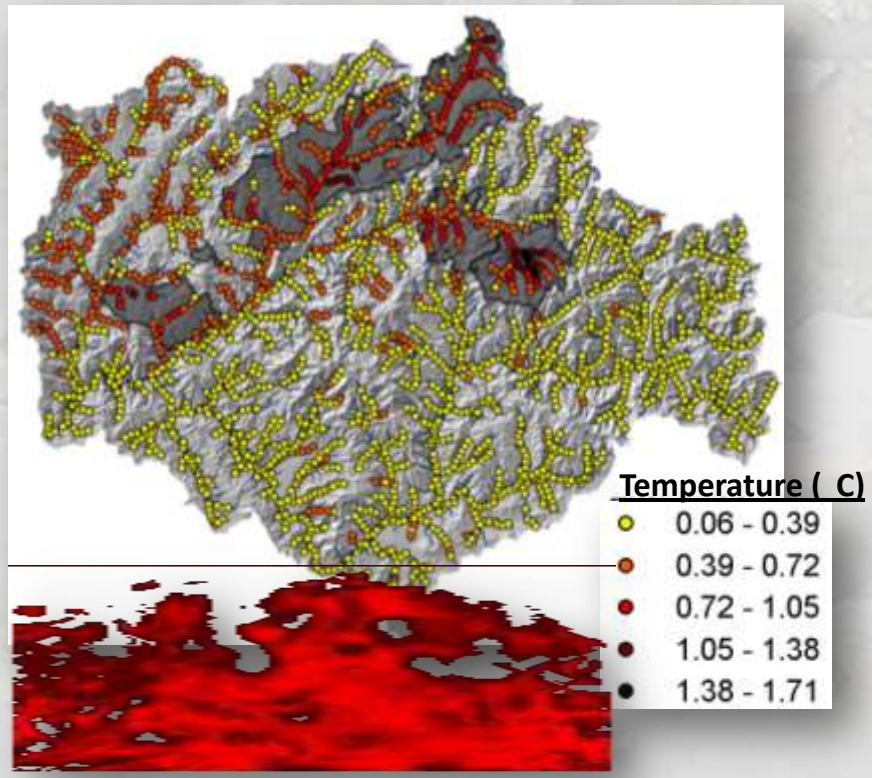


Measuring Climate Change Effects

Changes in Summer Temps (1993-2006)



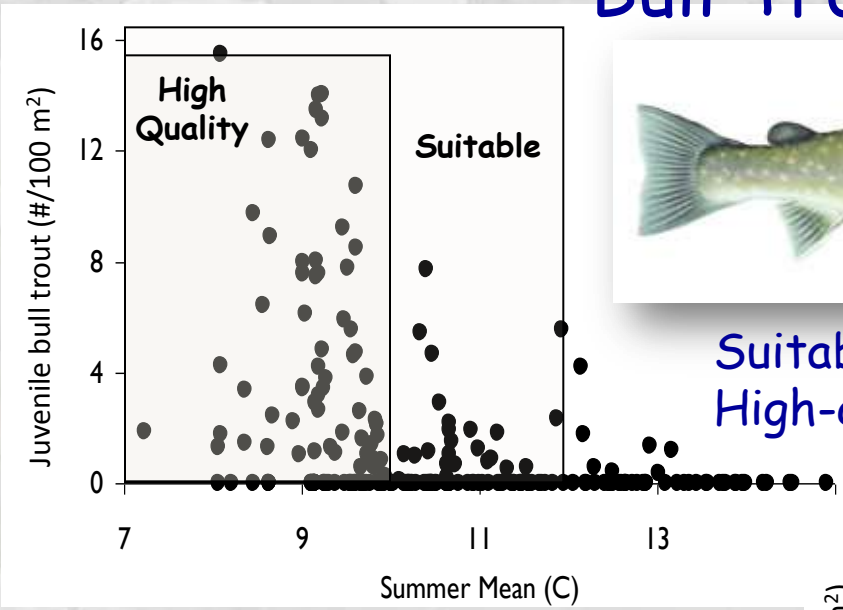
Thermal Gain Map



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

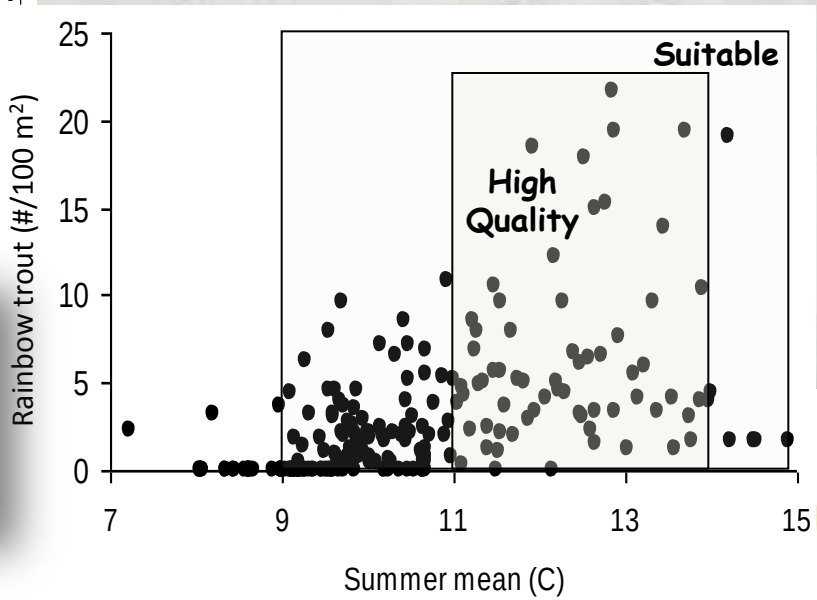
Derivation of Thermal Niche Criteria

Bull Trout



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

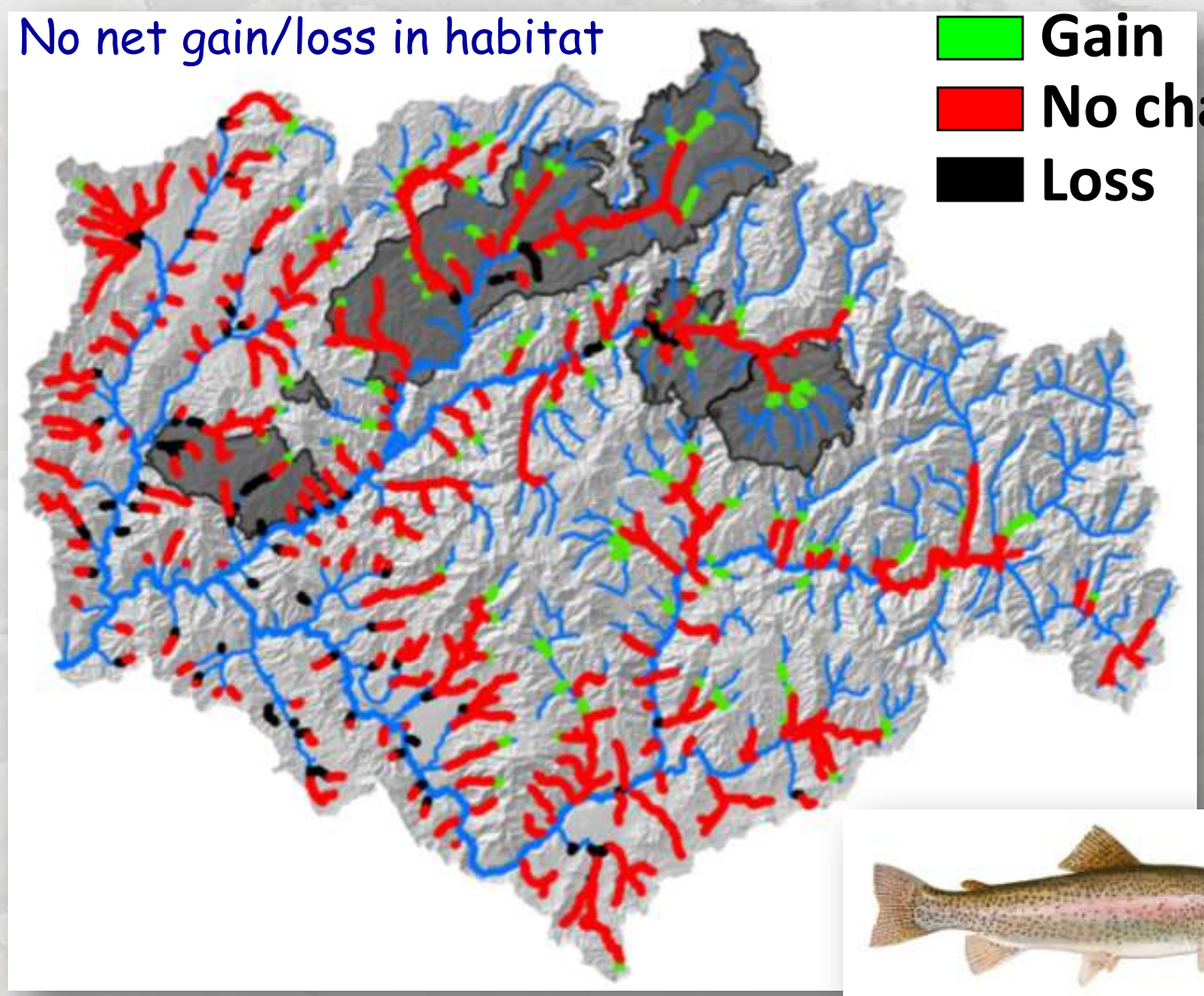
Rainbow Trout



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

Mapping Thermal Habitat Effects

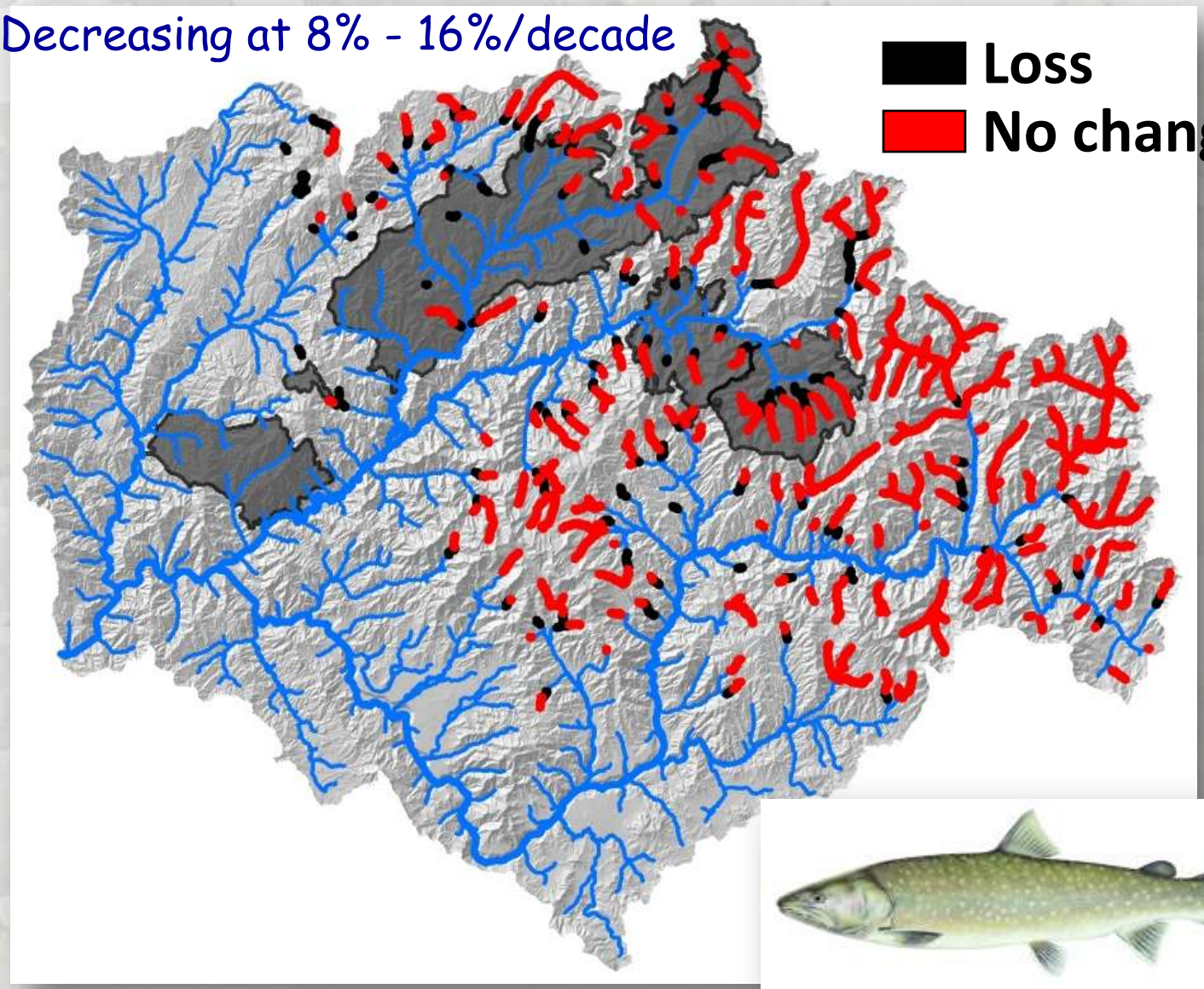
Rainbow Trout Habitat Losses (1993-2006)



Mapping Thermal Habitat Effects

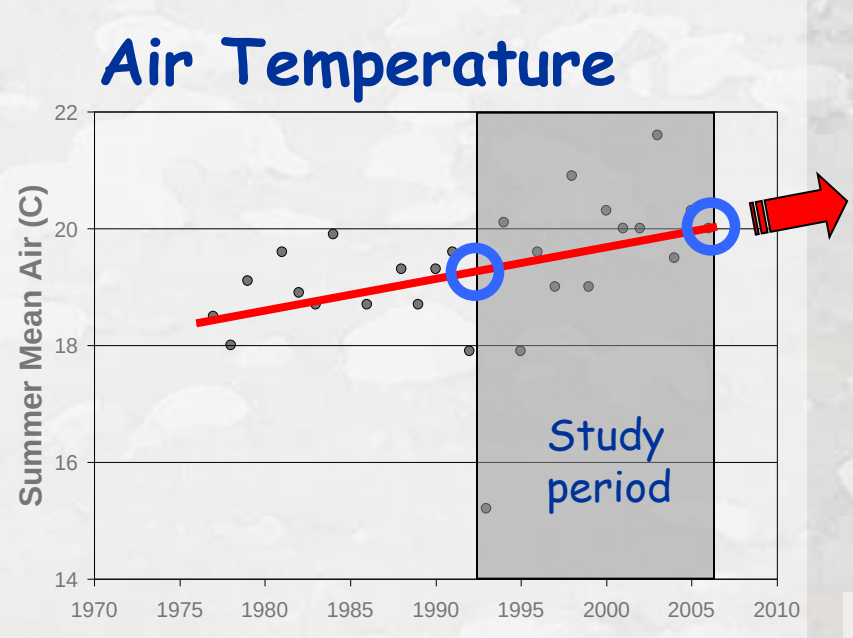
Bull Trout Habitat Losses (1993-2006)

Decreasing at 8% - 16%/decade

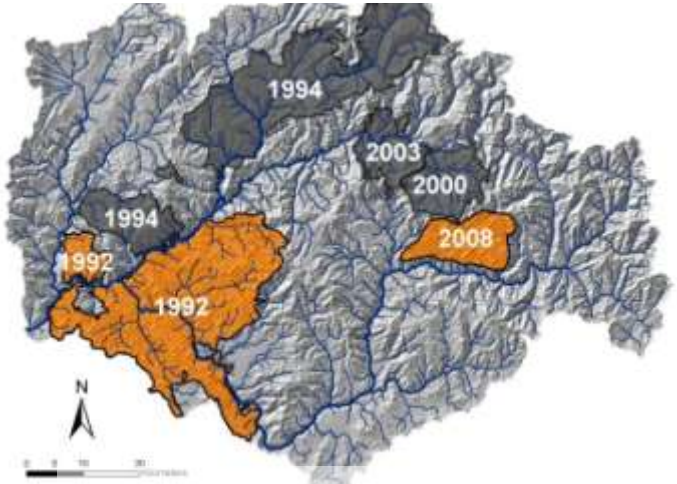


Predicting Future Climate Effects

Air Temperature

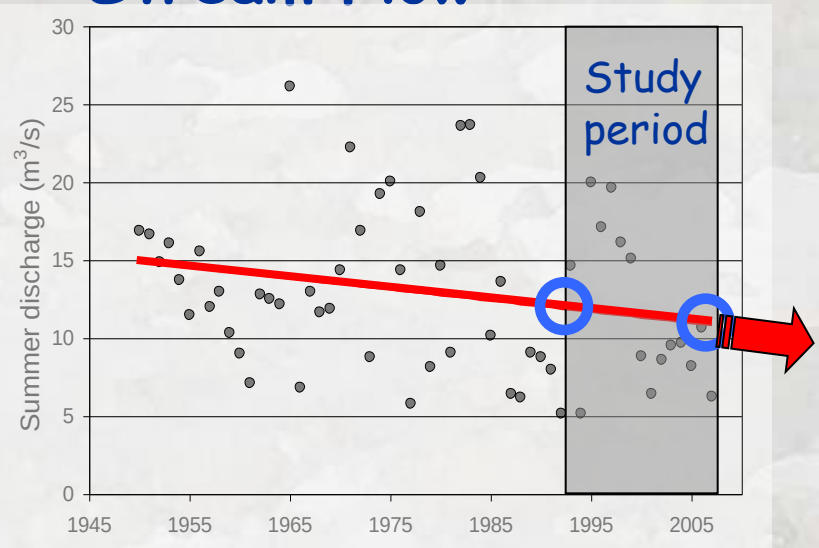


Wildfires



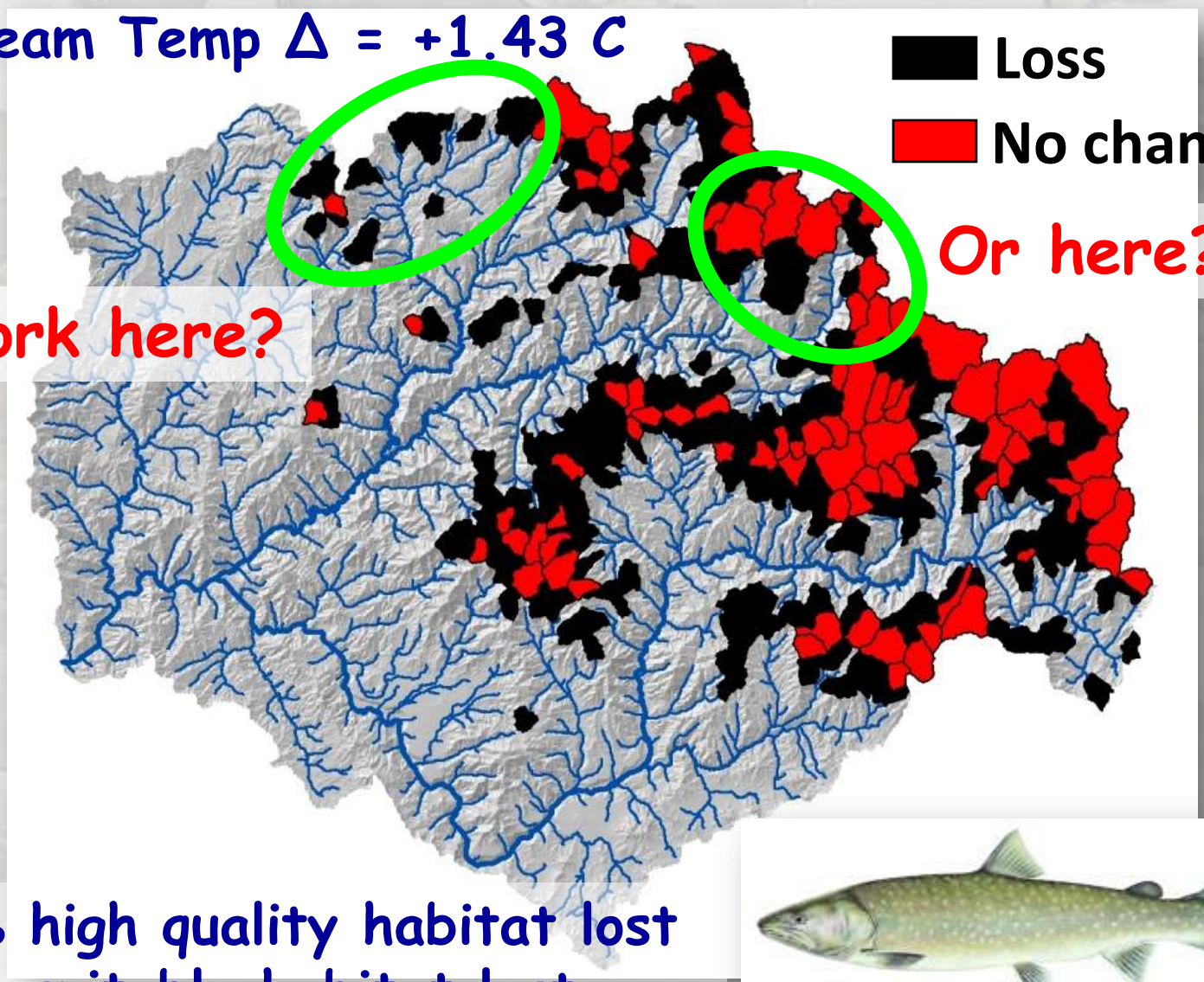
Assumption: None

Stream Flow



Bull Trout Habitats by 2046

Stream Temp Δ = +1.43 C

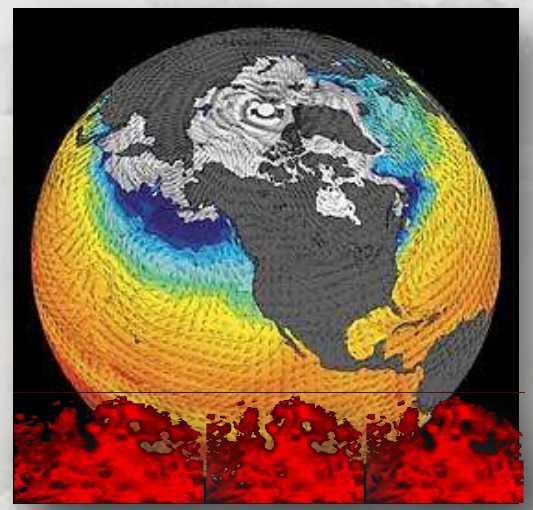


- 63% high quality habitat lost
- 39% suitable habitat lost

Getting Local "Buy-In"

It's a home-grown approach

GCM



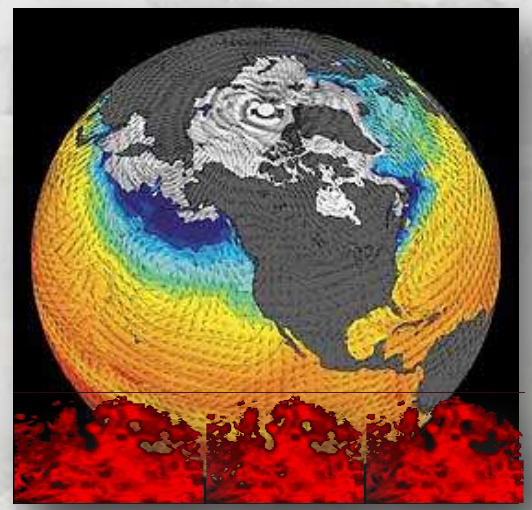
TRUST?

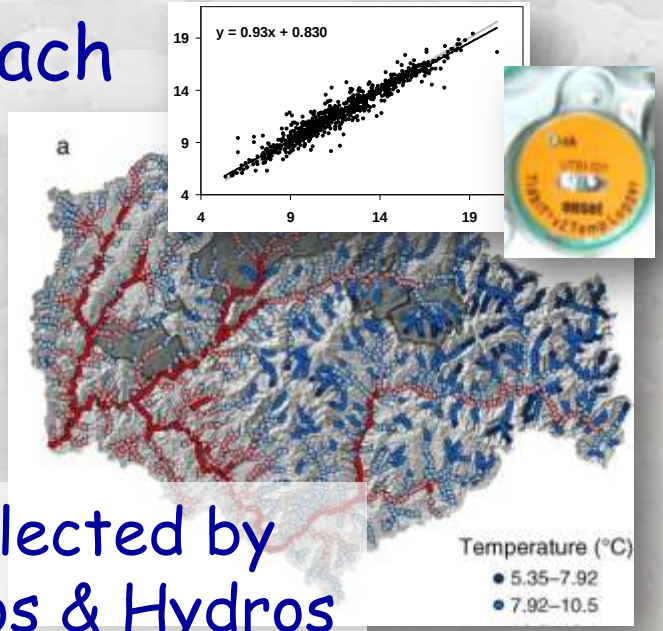
Management Decisions

Getting Local "Buy-In"

It's a home-grown approach

GCM



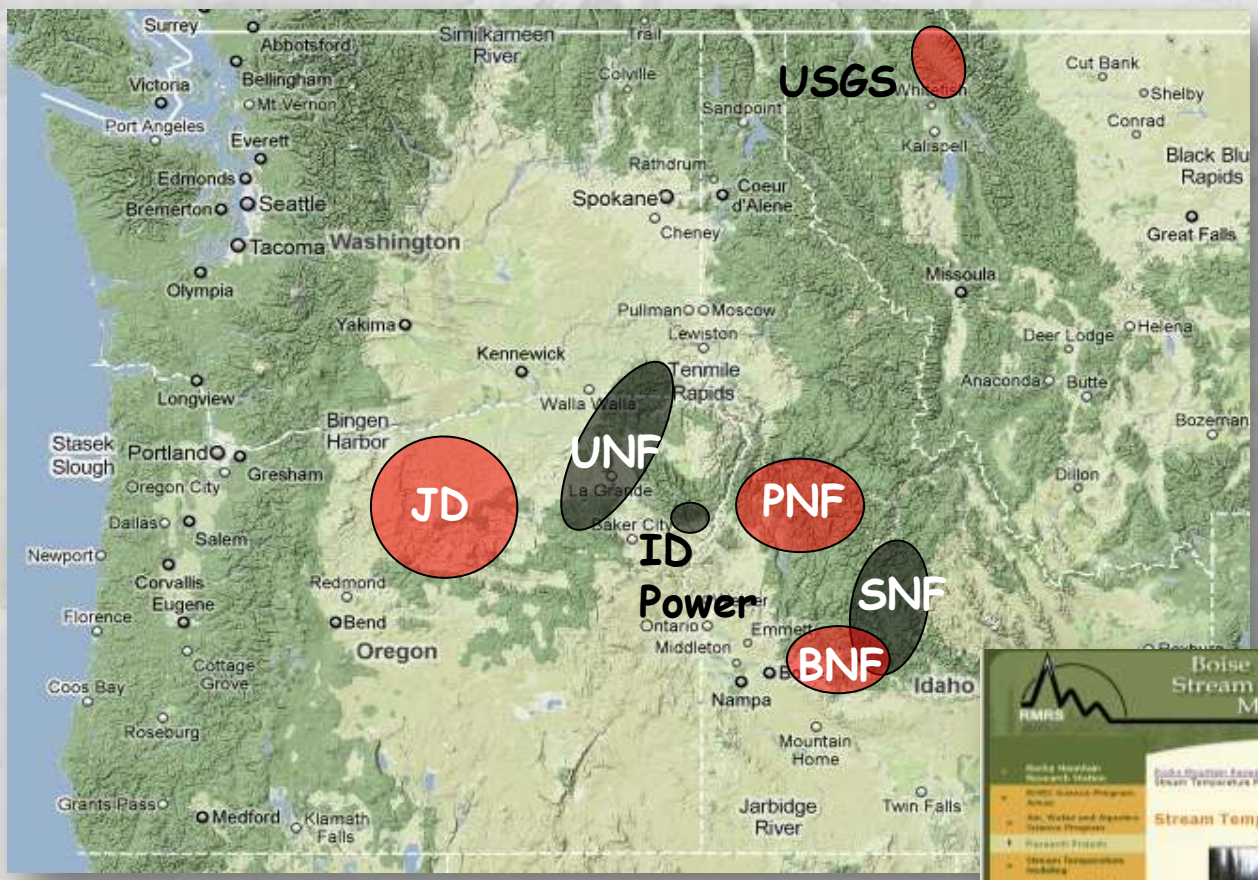


Data Collected by
Local Bios & Hydros

TRUST?

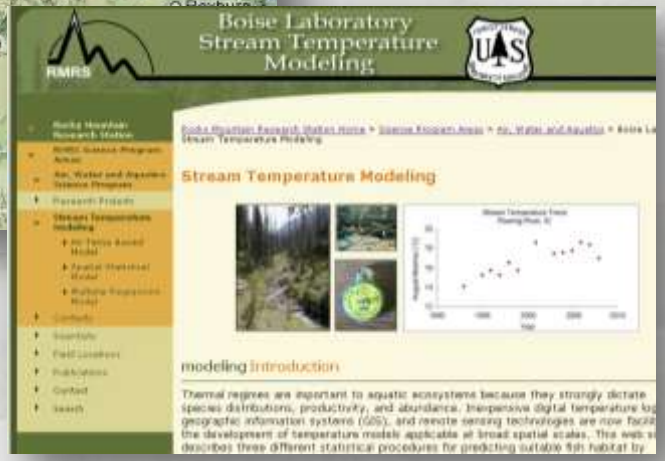
Management
Decisions

River Network Temperature Models



= Spatial

= Non-spatial

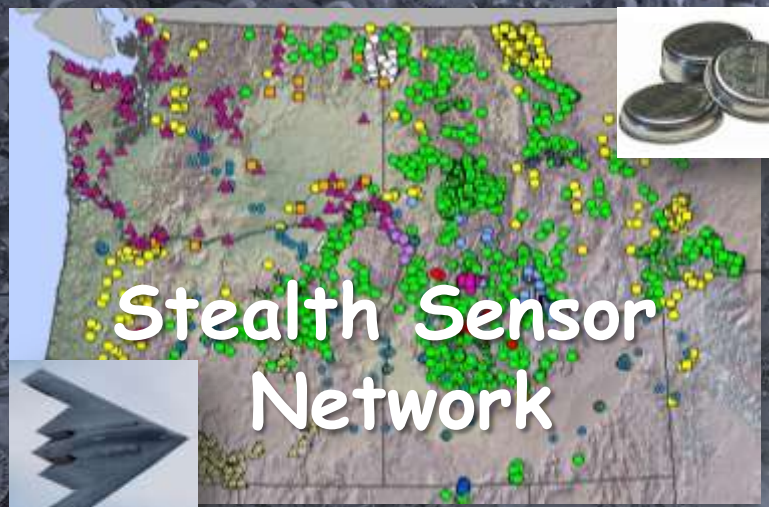


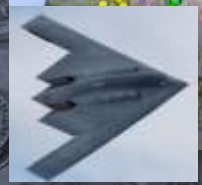
Methods online @:

Google Search "USFS Stream Temperature Website"

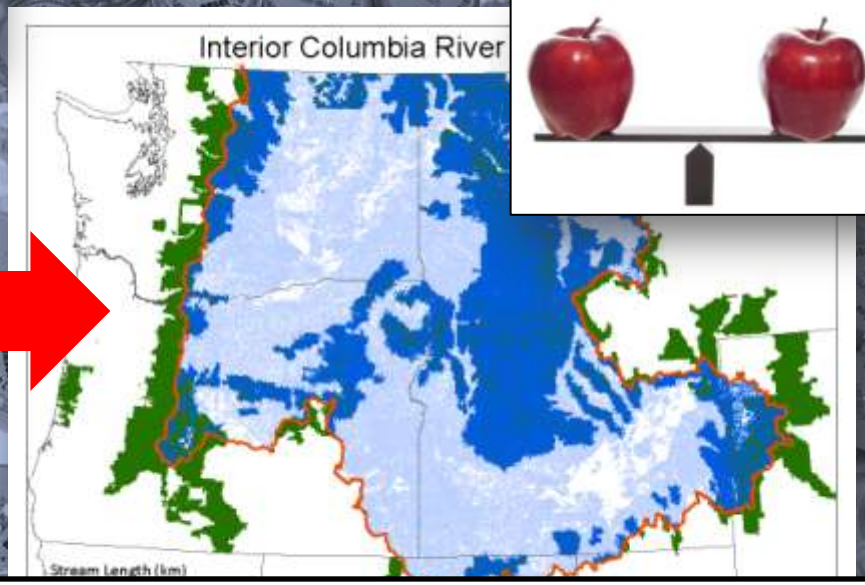
Regional Temperature Model Needed

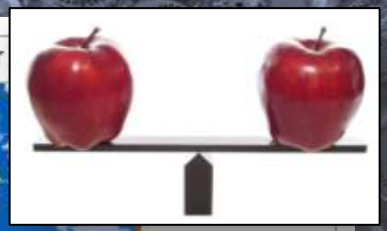
Large amounts of temperature data exist (n ~ 20,000 – 30,000 summers?)





- Historical & future stream temps
- Species habitat summaries
- 1:100,000-Scale NHD+

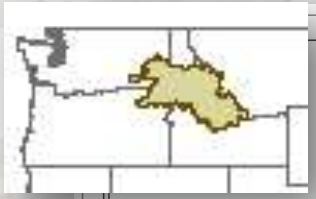




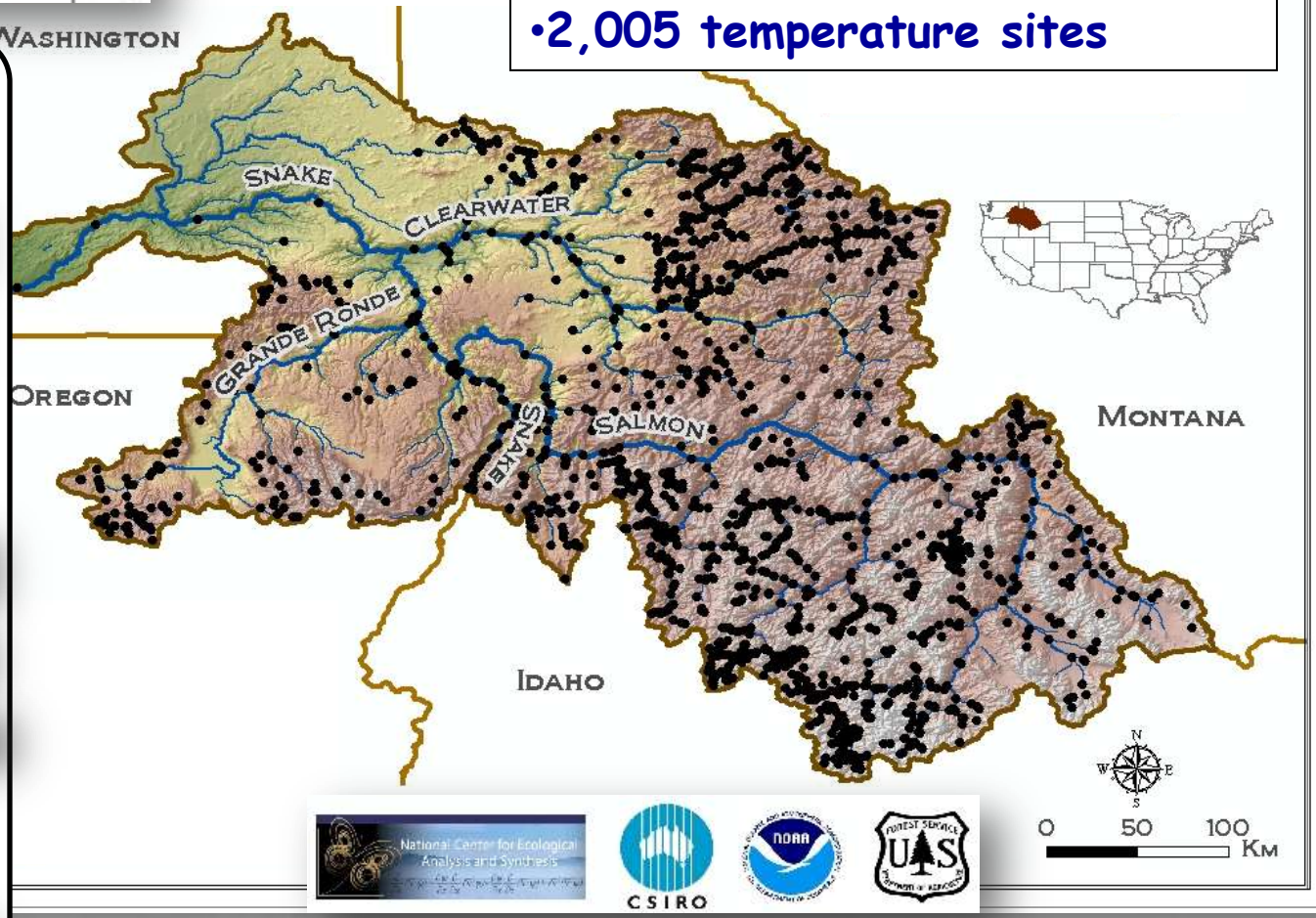
ICB Fish Bearing Streams ~ 250,000 km

A Step Towards a Regional Model

Lower Snake Study Domain – NCEAS Workshop



- 42,000 stream km (15x Boise)
- 6,734 summer observations
- 2,005 temperature sites



Data Providers:

EPA
NOAA Fisheries
Idaho Fish & Game
Idaho State University
Idaho Power
University of Idaho
Forest Service
USGS science for a changing world

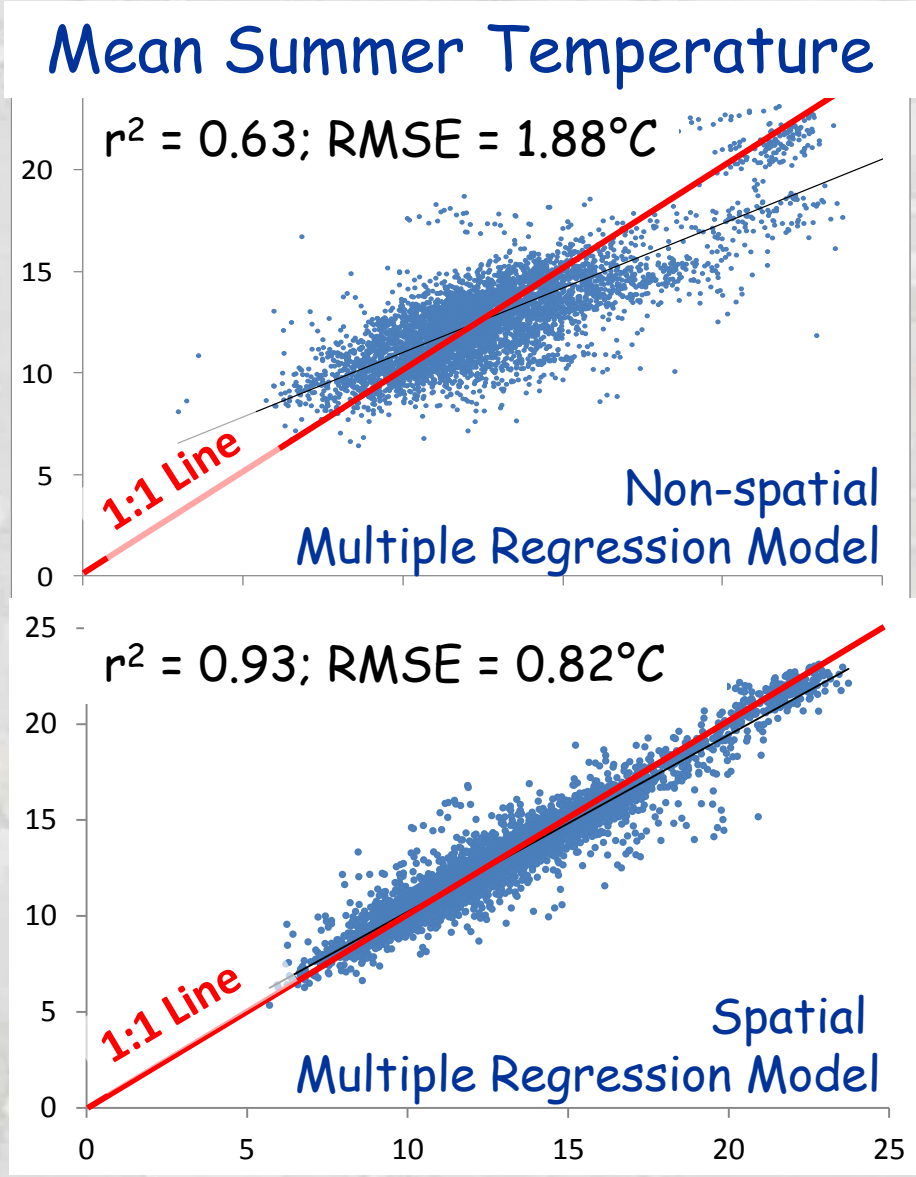
National Center for Ecological Analysis and Synthesis
CSIRO
NOAA
Forest Service

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)

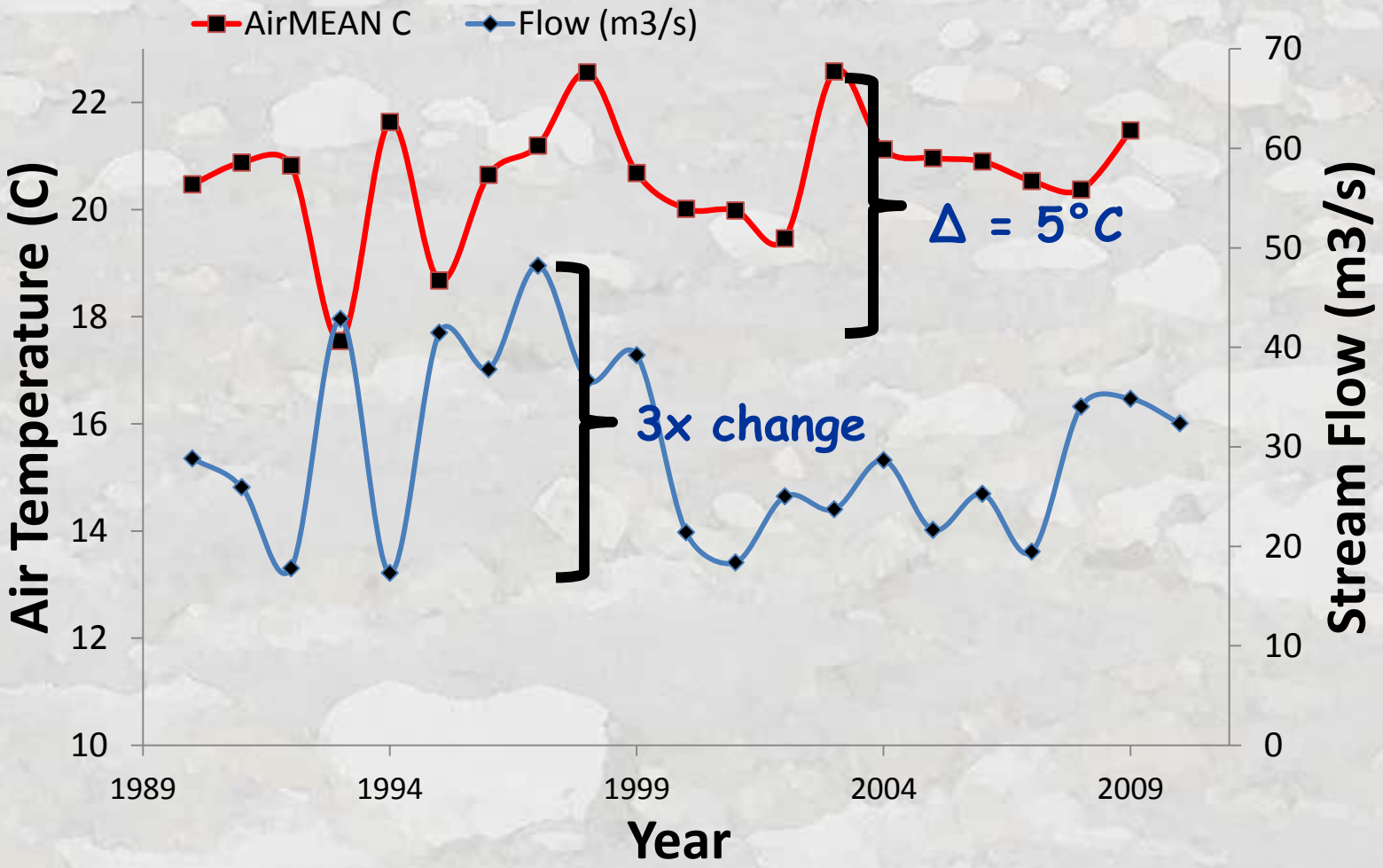
Spatial Stream Temp =
- 0.0045*Ele (m)
- 9.8*Slope (%)
+ 0.012*Wat_size (100km^2)
- 0.00061*Ave_Precip
- 0.037*Flow (m^3/s)
+ 0.46*AirMean (C)



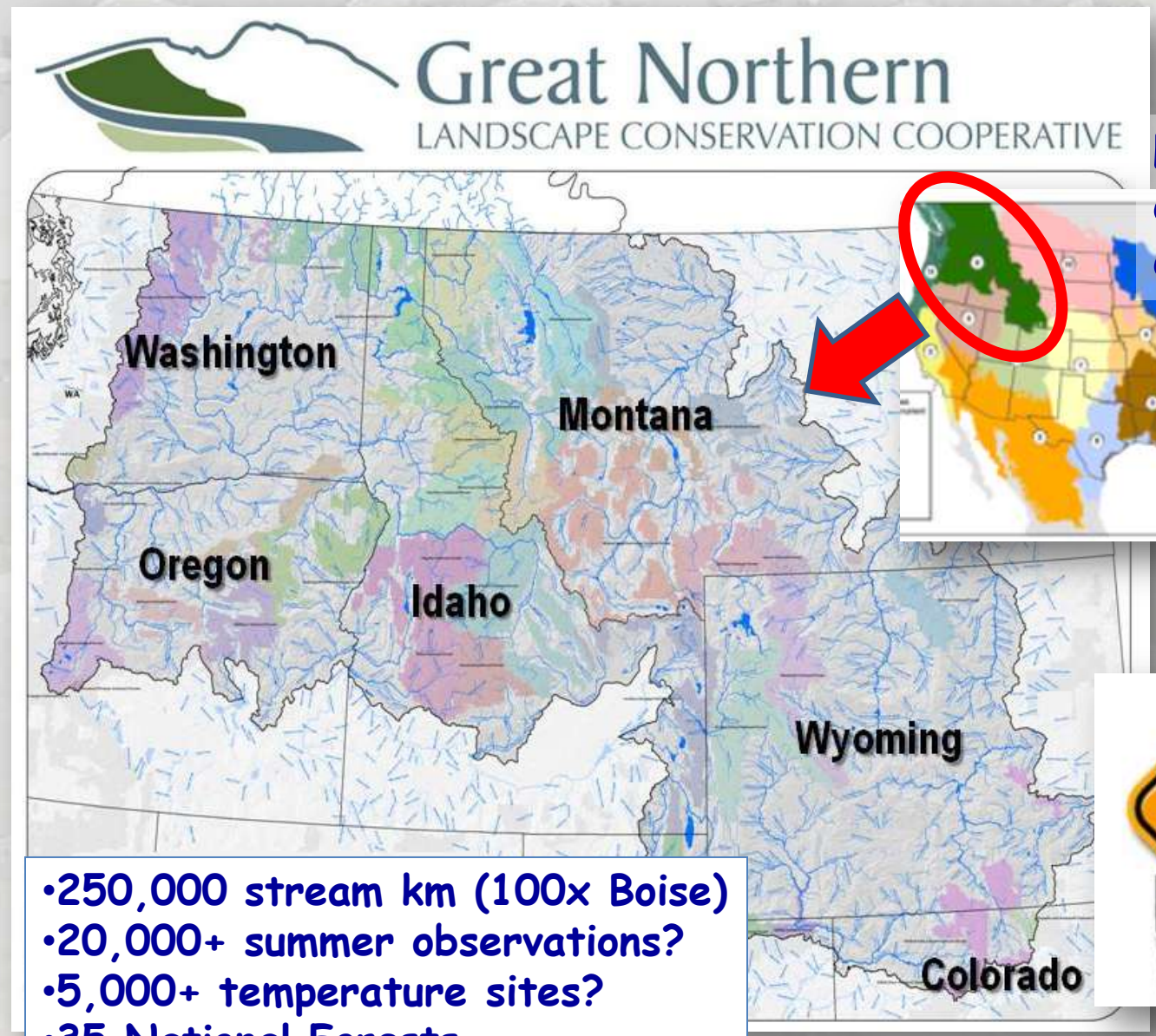
Climate Variation in Lower Snake Database

20 years from 1990–2010

Summer = July 16 – Aug 31



A Regional Stream Temp Database & Model



Landscape Conservation Cooperatives

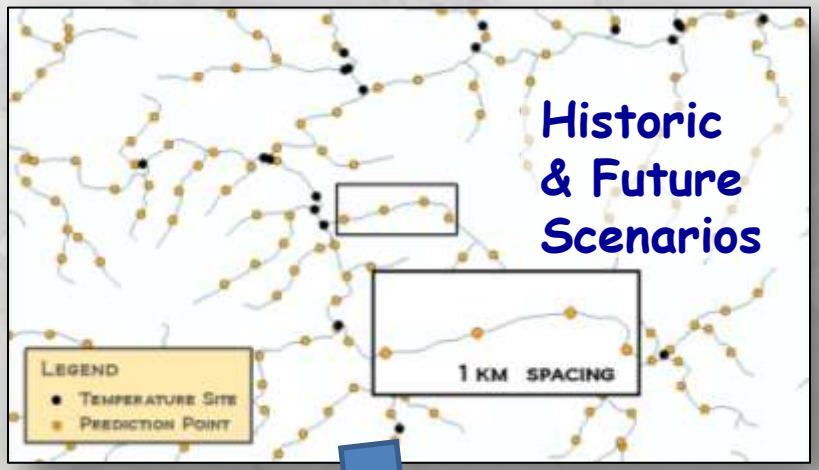
- 250,000 stream km (100x Boise)
- 20,000+ summer observations?
- 5,000+ temperature sites?
- 35 National Forests

UNDER CONSTRUCTION

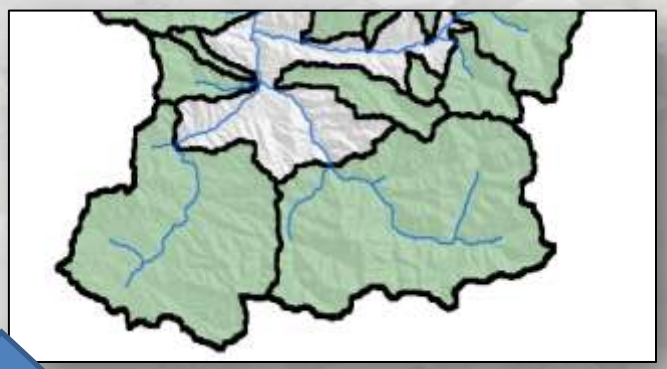
Isaak et al. 2011

Model Outputs & Distribution

GIS files for linkage to NHD+ hydrography layer…

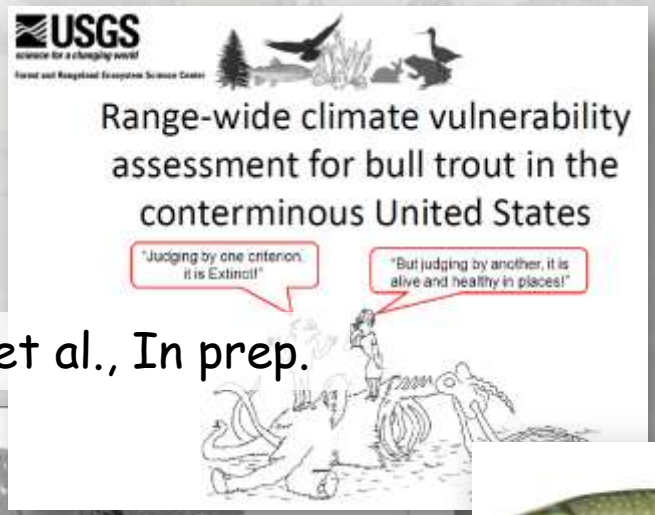


& thermally suitable habitat patch polygons based on species-specific criteria

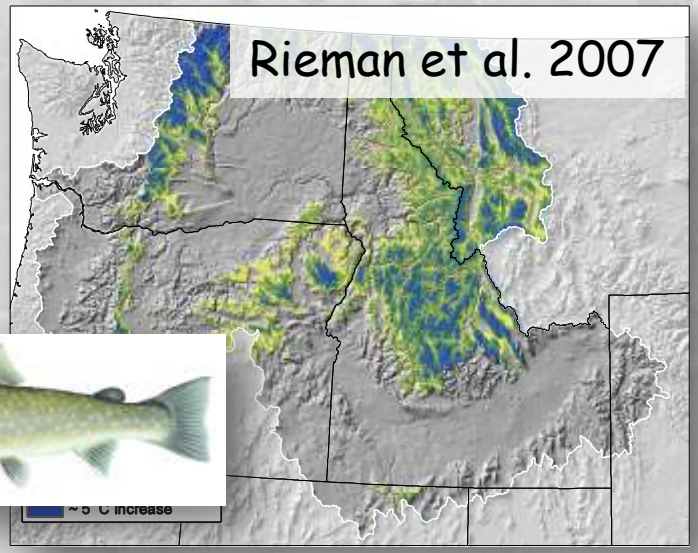


Websites for Distribution

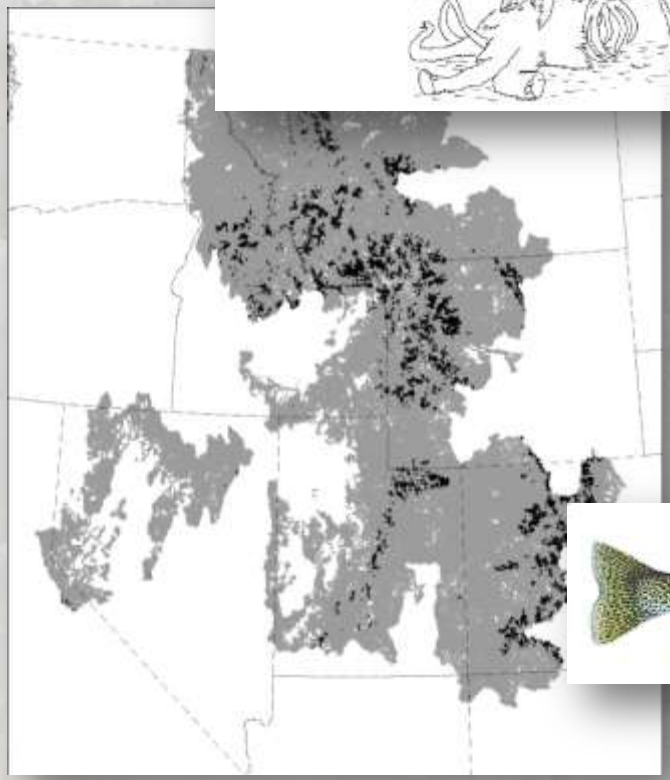
More Precise Bioclimatic Assessments



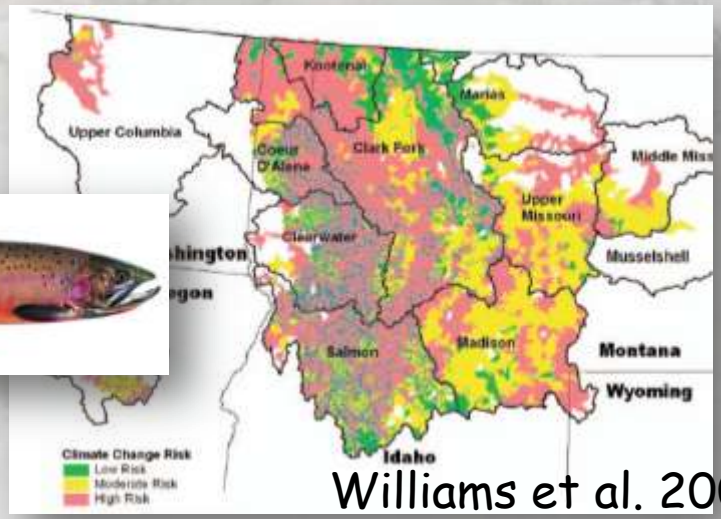
Dunham et al., In prep.



Rieman et al. 2007



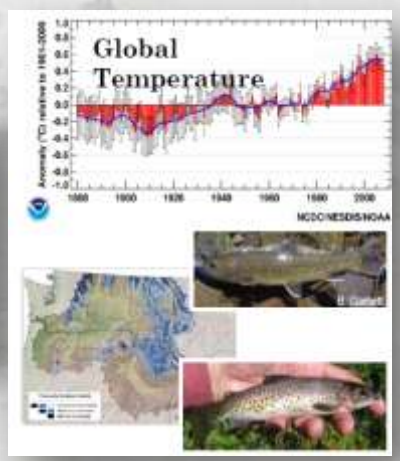
Wenger et al. 2011. *PNAS*.



Williams et al. 2009

2) Better Spatial Data = Better Resource Management

Climate-Aquatics Workshop in Boise



Understanding and Adapting To Climate Change in Aquatic Ecosystems at Landscape and River Basin Scales: A decision support workshop for integrating research and management

U.S. Forest Service

Science Application & Integration Program

Air, Water & Aquatics Program

Objectives: 1) climate-aquatics short-course, 2) share latest/greatest biophysical model outputs & downscaled climate scenarios, 3) receive manager feedback

Co-sponsors:

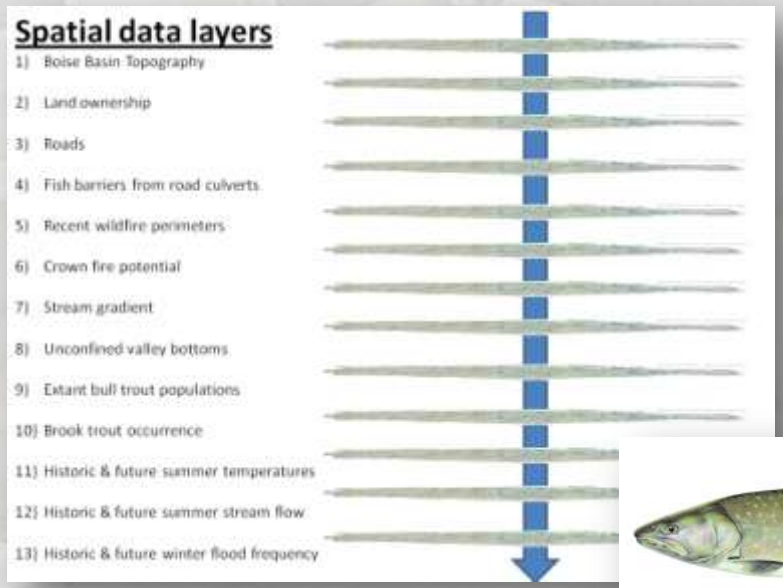
Great Northern LCC

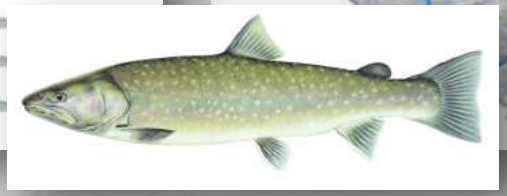
USGS science for a changing world

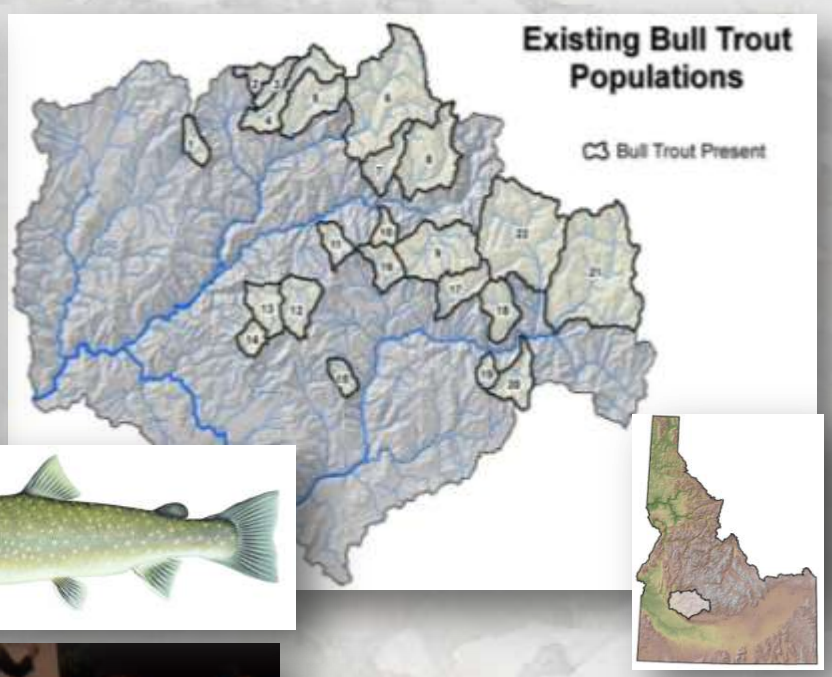
TROUT UNLIMITED

Attendees: In-house 60 attendees from 16 different state, federal, tribal, private resource organizations; Online > 400 webinar short-course participants

A Real World Example Using Spatial Data & Climate Scenarios

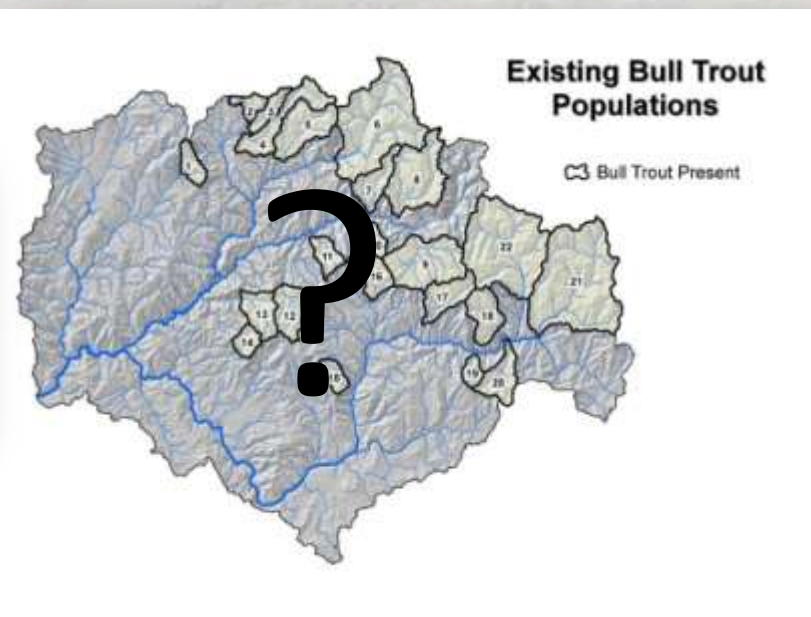






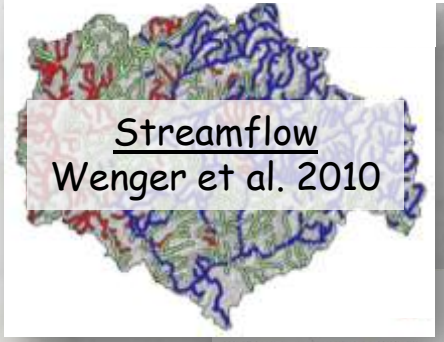
Interagency, Interdisciplinary Groups

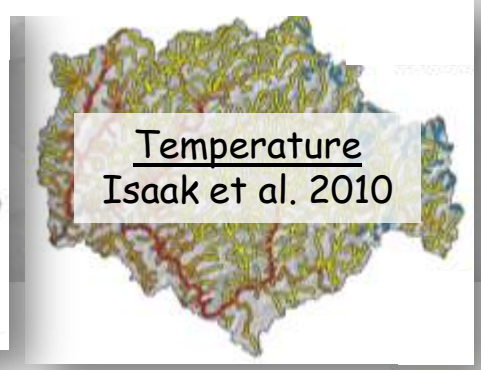
Day 1 task: Use the spatial data at your disposal to rank from 1 to 5 (1 = highest priority) the populations where your limited budget will be spent to maximize the long-term persistence of bull trout in the Boise basin.

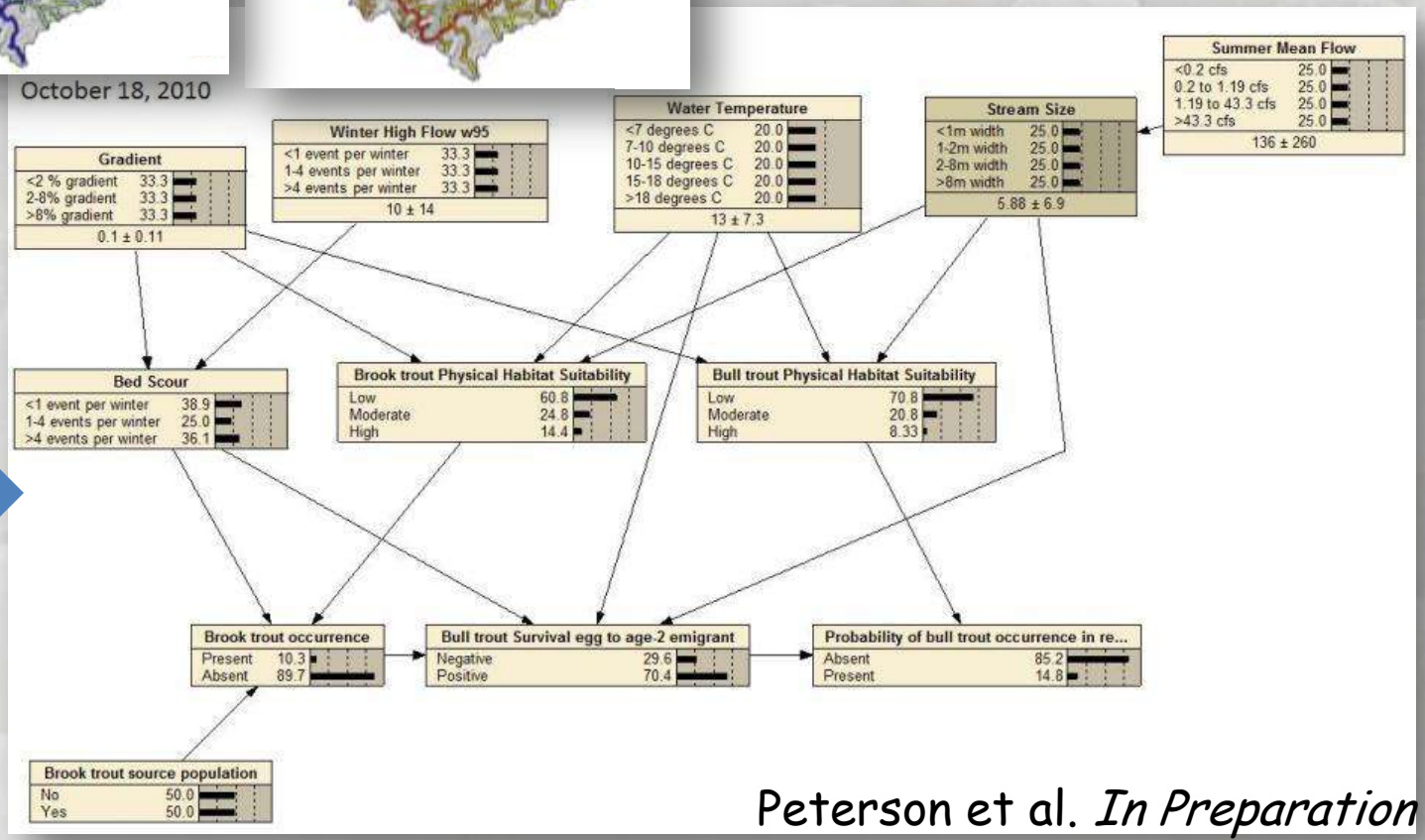


Bull Trout Climate Decision Support Tool

Downscaled Climate Scenarios

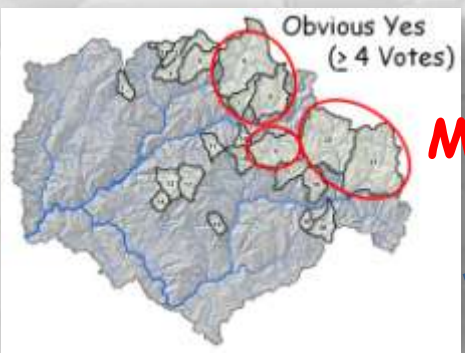




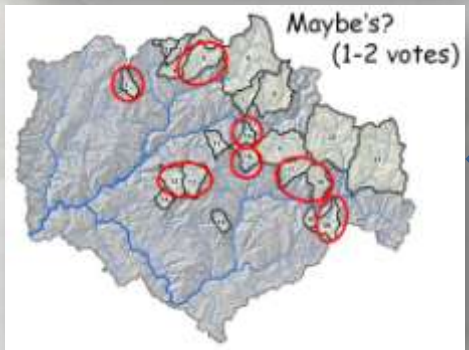


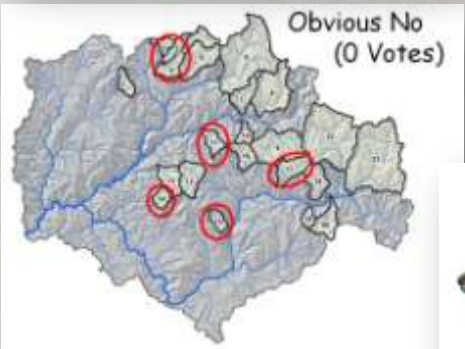
Peterson et al. *In Preparation*

Decision Support Tools for Spatial Data Integration



Management Priorities



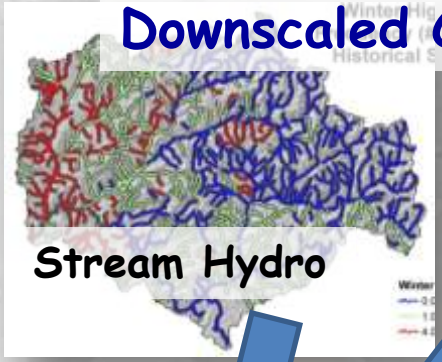


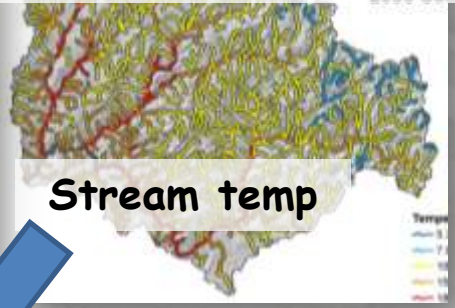
Yes

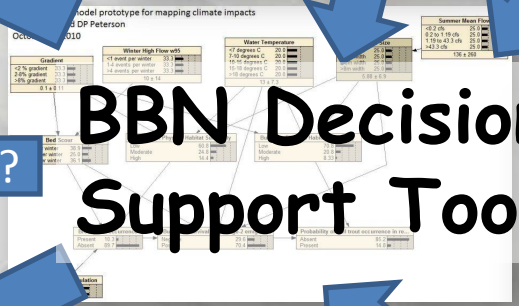
Maybe?

No

Downscaled Climate Scenarios

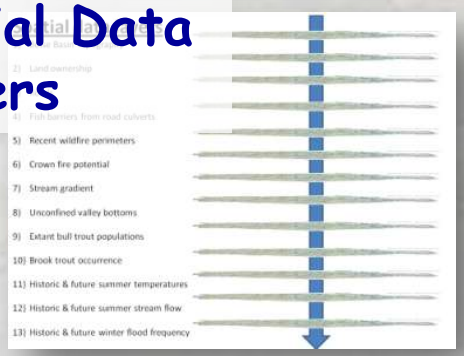






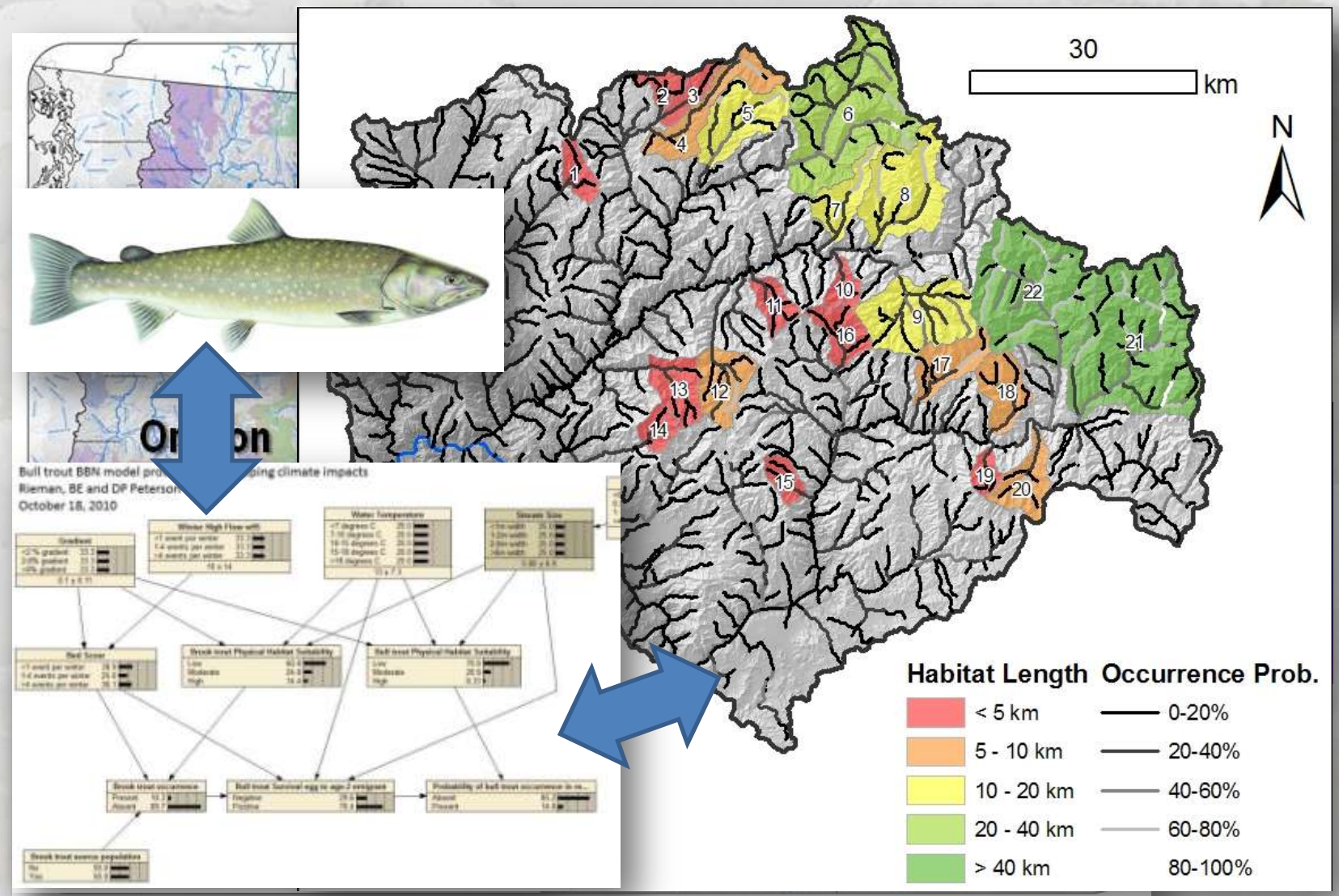
BBN Decision Support Tool

Spatial Data Layers



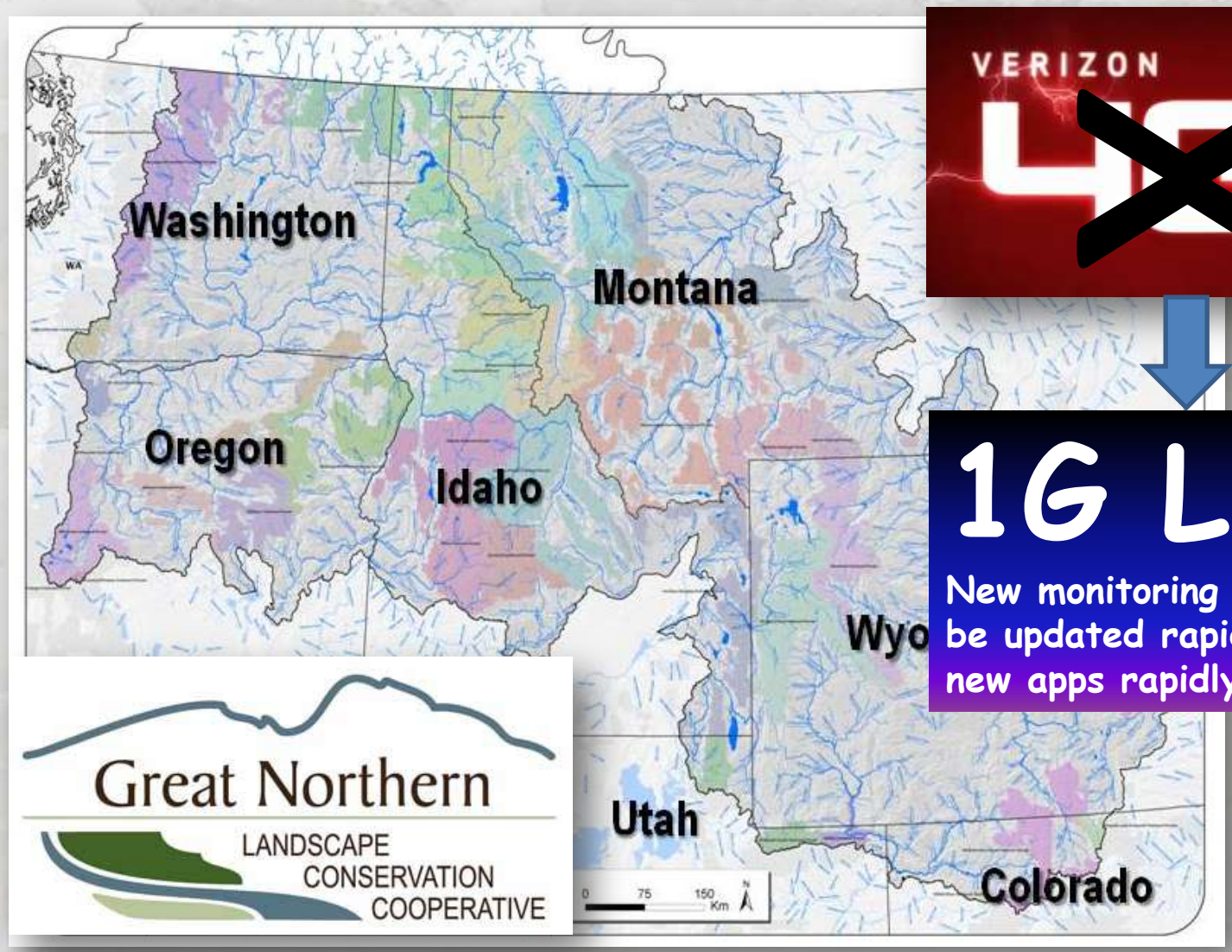
Decision Support Tool is an "App" that runs on the Network

Spatial data layers will soon exist rangewide



Decision Support Tool is an "App" that runs on the Network

Spatial data layers will soon exist rangewide



VERIZON 4G LTE

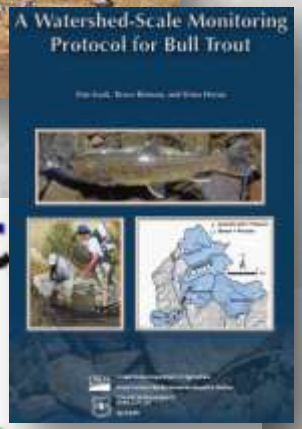
1G LCC

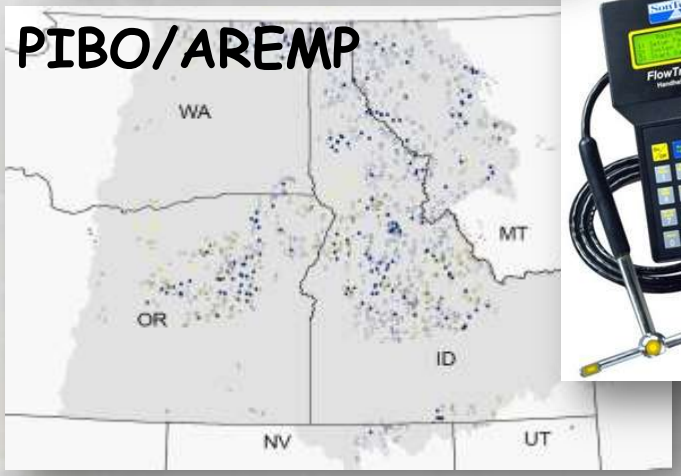
New monitoring sites can be updated rapidly & new apps rapidly scaled

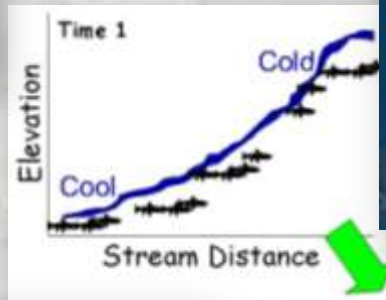
Great Northern LANDSCAPE CONSERVATION COOPERATIVE

3) Better Spatial Data = Better Resource Monitoring

- Temperature
  - Flow
- Species distributions

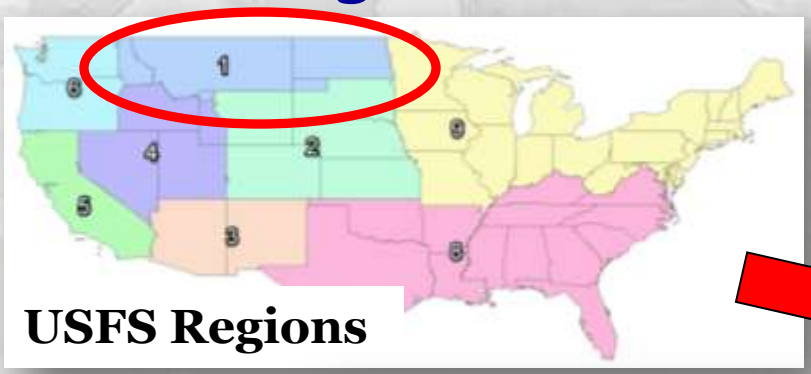






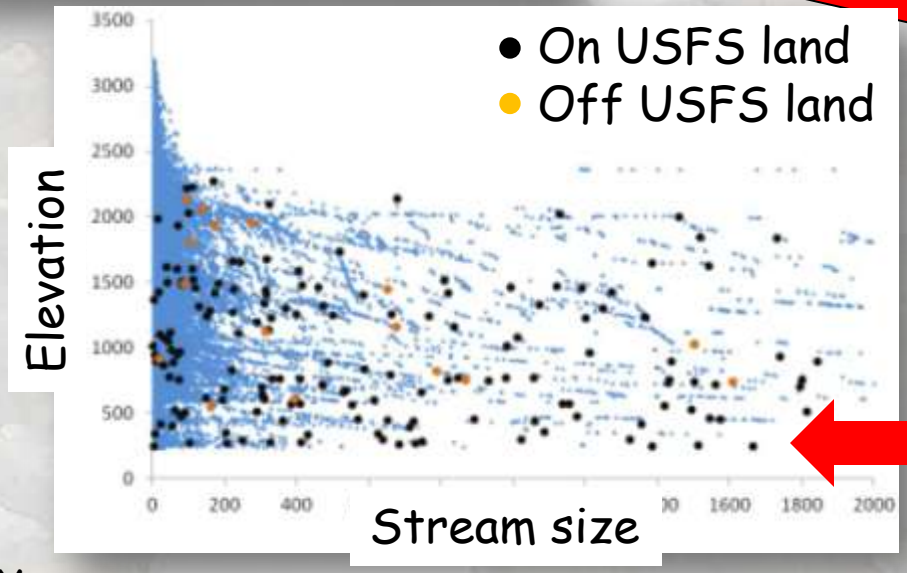
USFS Flow Gaging GAP Analysis

Region 1 Pilot Assessment



USFS Regions

NHD+ Hydrography
+
GIS



Prepared by
Dona Horan, Dan Isaak, and Charlie Luce, RMRS

Commissioned by
Chris Carlson and Katherine Smith, WO

Cheap & Reliable Sensor Technology

Stream discharge monitoring

Traditional techniques =
labor intensive & expensive

Portable
Doppler
Velocimeter

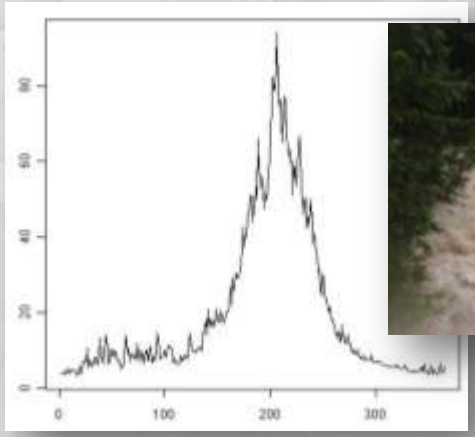
Pressure Transducers

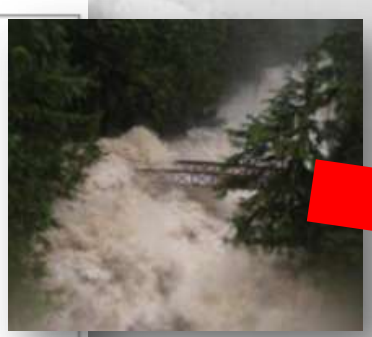
New sensors =
new possibilities

Cheap & Reliable Sensor Technology

Stream temperature monitoring

Annual Flooding Concerns





Underwater epoxy cement

$100 = 5 years of data

Data retrieved every few years

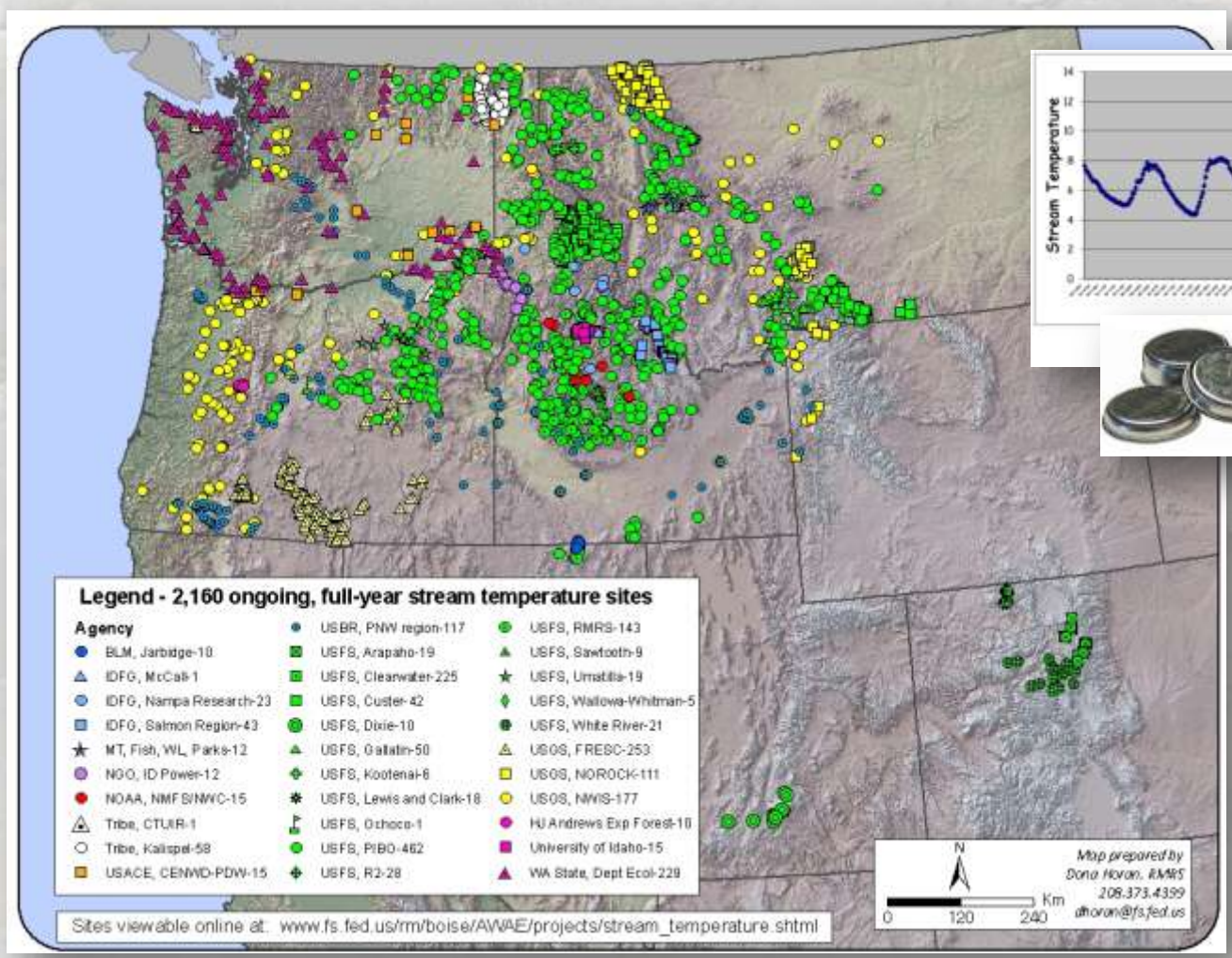
Sensors or protective housings glued to large boulders

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

Regional Interagency Stream Temperature Monitoring Network

2,160 Current full-year monitoring sites

~1,000 New deployments last year



A Google Map 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"

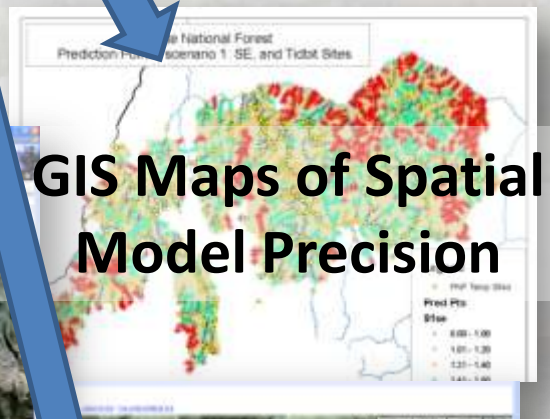
Real-time Access to Spatial Stream Data Anytime, Anywhere

Smartphones as Field Computers

ArcGIS app for Android

Monitoring Site Locations

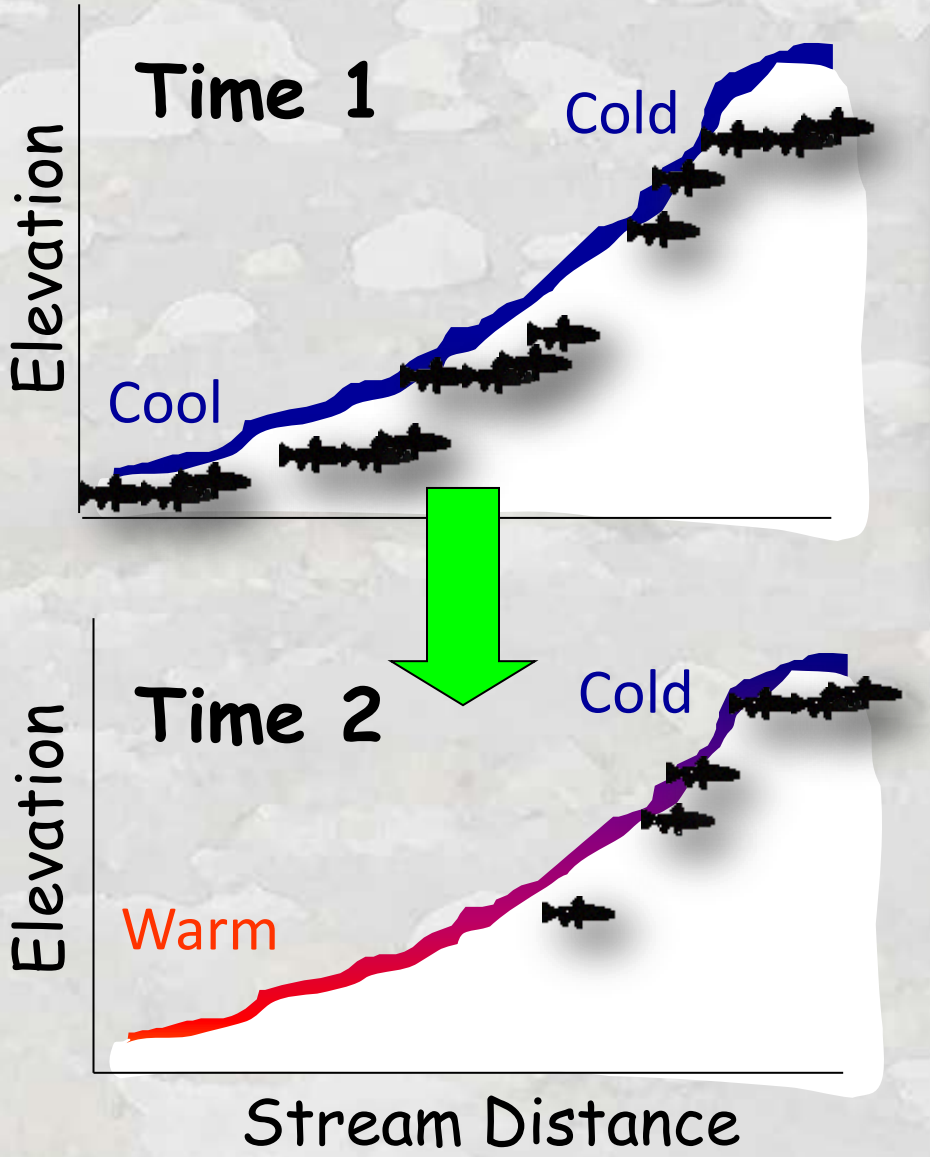
GIS Maps of Spatial Model Precision

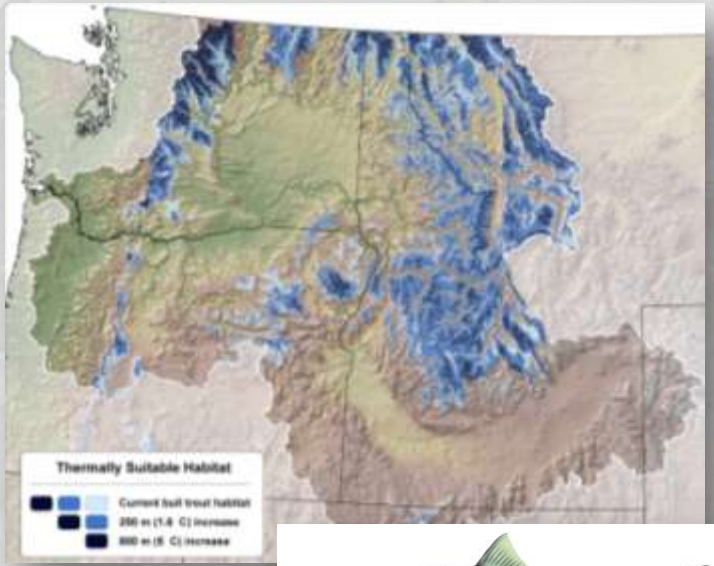


GoogleMaps

How Fast Are Distribution Shifting?

We Don't Know for Aquatic Organisms





Average distribution shift across taxa =

6.1 km/decade poleward

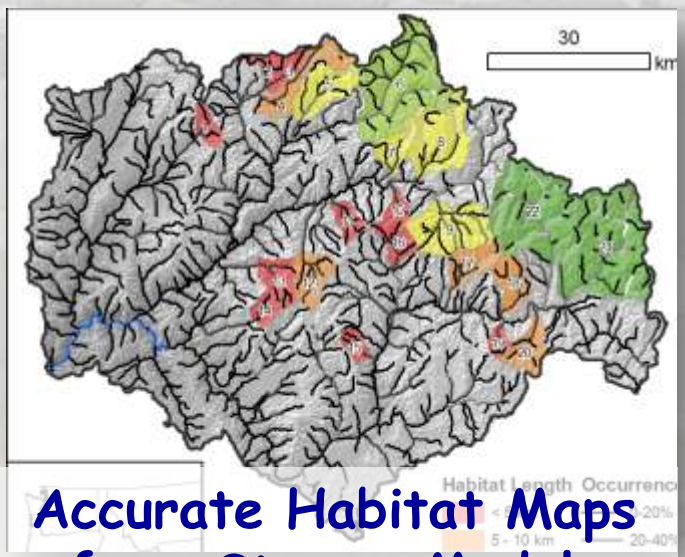
OR

6.1 m/decade higher

Parmesan and Yohe 2003

Efficient Biological Monitoring

Distributional Status & Trend

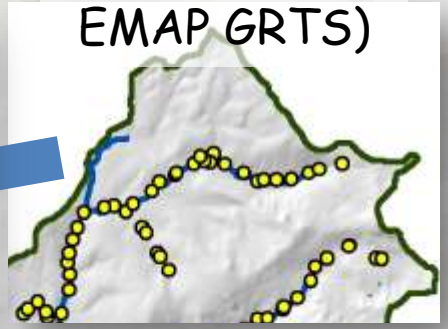


Accurate Habitat Maps from Stream Models

=

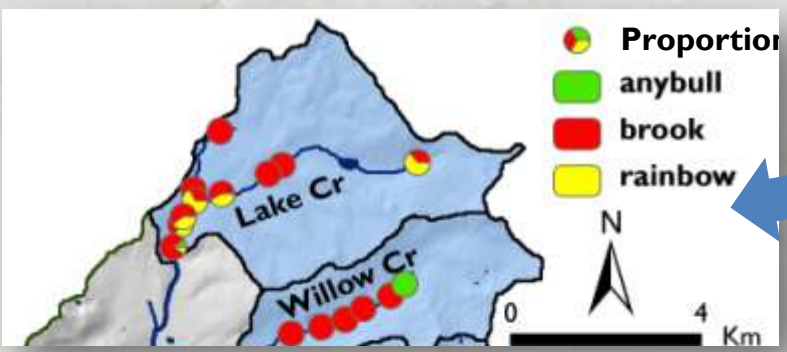
Map

Probabilistic Sample (i.e., EMAP GRTS)



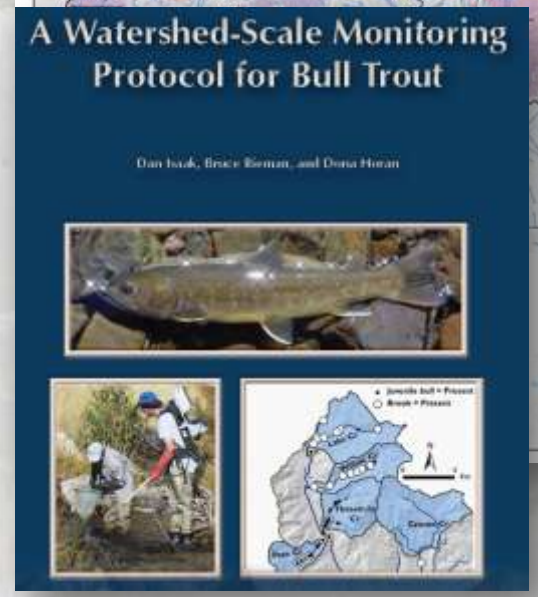
Biological Survey

Precise, Representative Sample



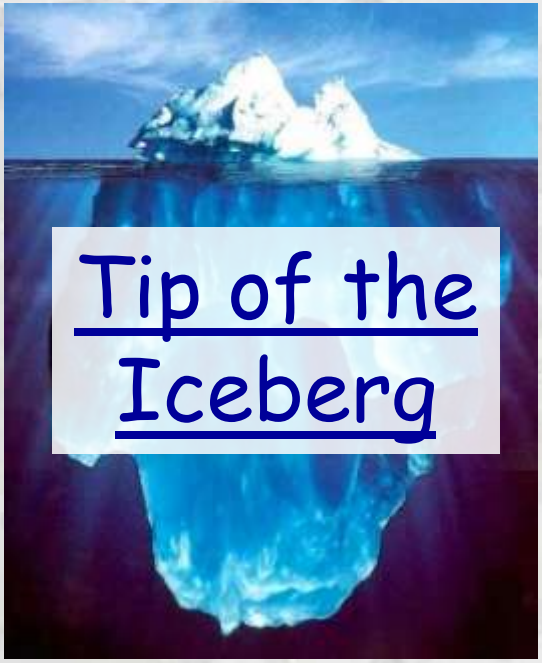
Regionally Consistent Framework

Status & Trend Monitoring



First "Killer Apps" but more coming soon…

1st Generation Apps



In the Pipeline…

- Bull trout climate decision support tool
- Improved monitoring designs for biological & water quality parameters
- Improved fish distribution maps & models
- Precise thermal niche definitions for trout
- Improved climate vulnerability assessments

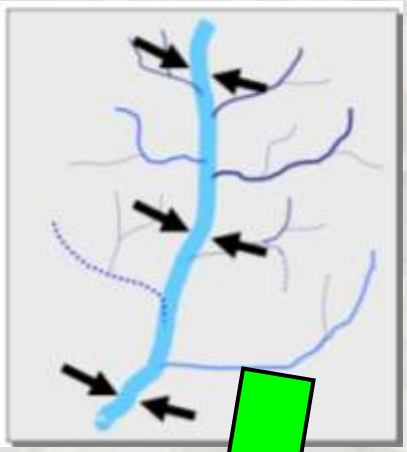
Significant Unknowns Remain

Defining Bioclimatic Thresholds

What is too warm, too small, or too variable?

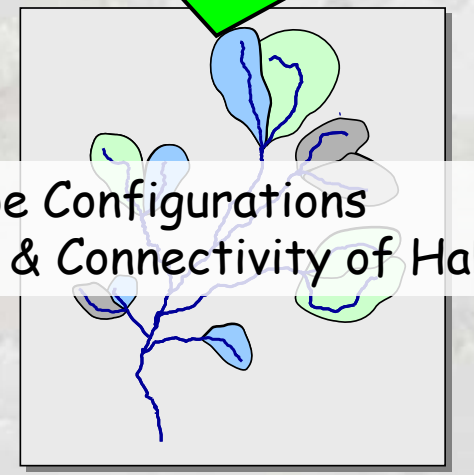
Upper/Lower
thermal tolerances

Minimum Flow Volumes



Disturbance Frequencies
Floods, Debris Flows, Fires

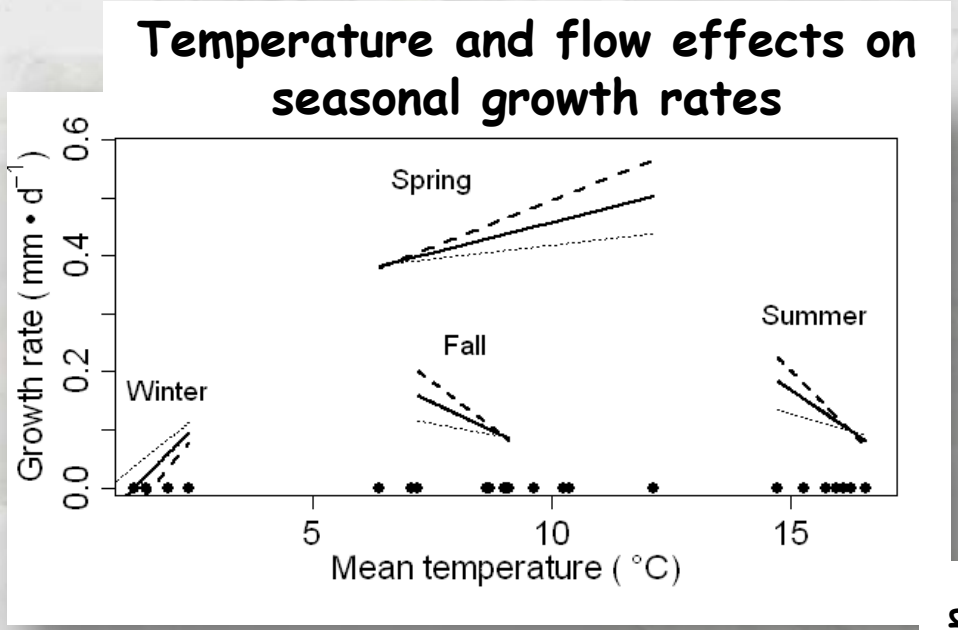
Landscape Configurations
Size & Connectivity of Habitats

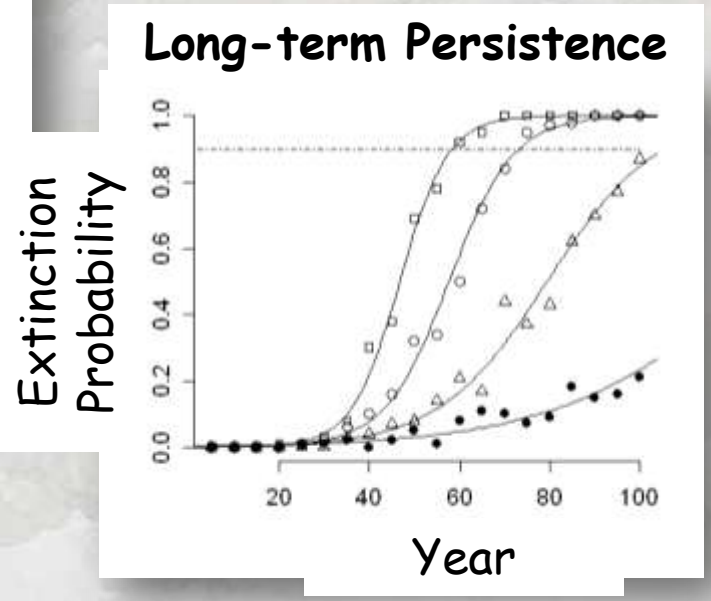


Significant Unknowns Remain

Understanding Biological Mechanisms

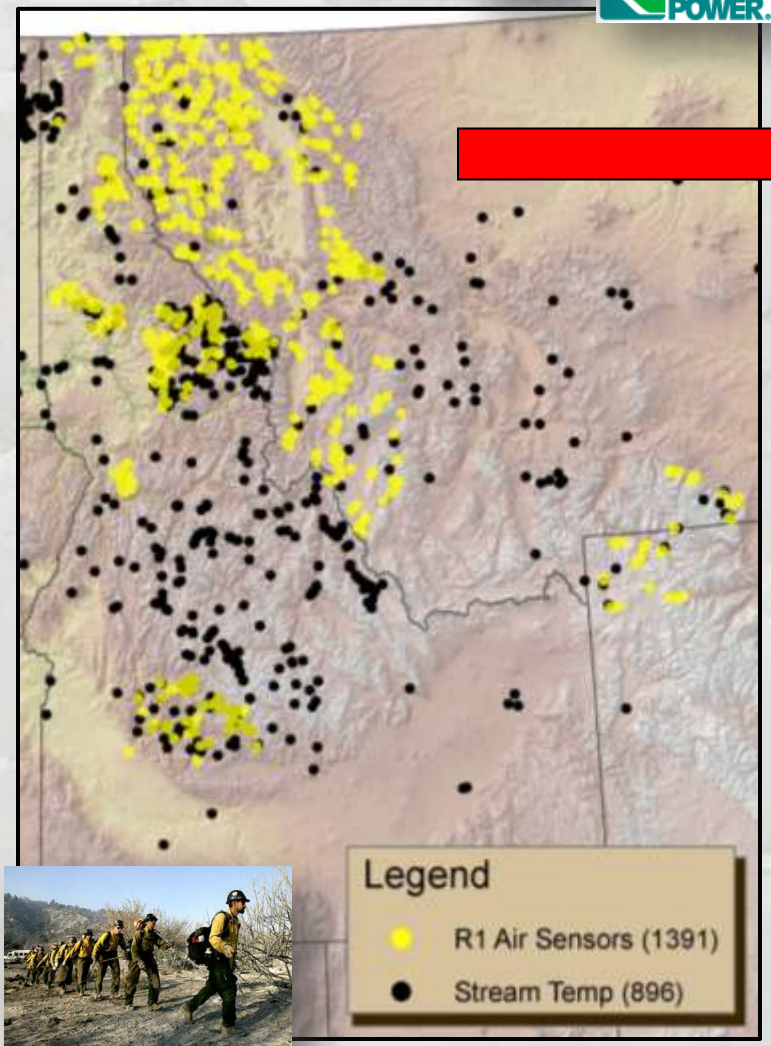
How do populations integrate to climate effects?

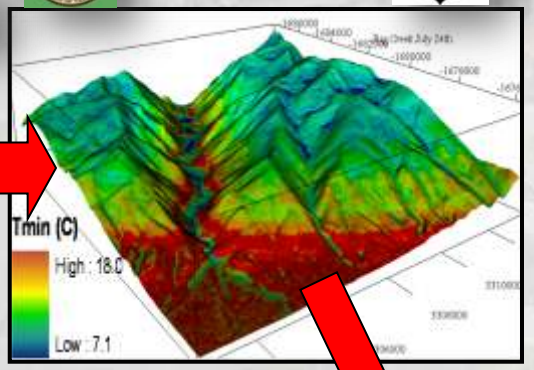




Xu, Letcher, and Nislow. 2010. *Freshwater Biology* 55:2253-2264.

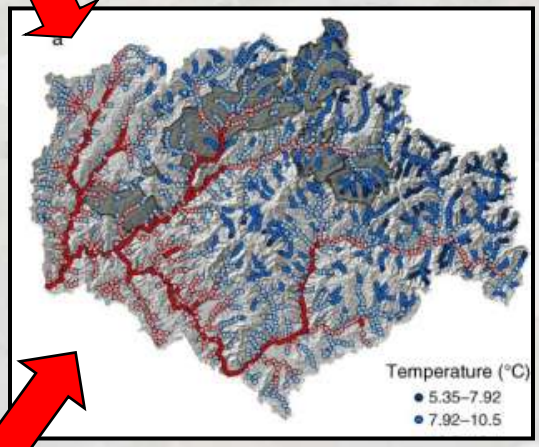
Linking BioClimatic Information Across Scales by Harnessing Interagency Databases

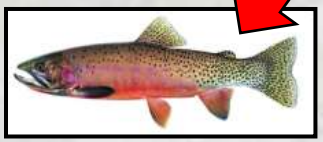




Continuous Space/Time Air Temp Surface

Continuous Space/Time Stream Temp Surface





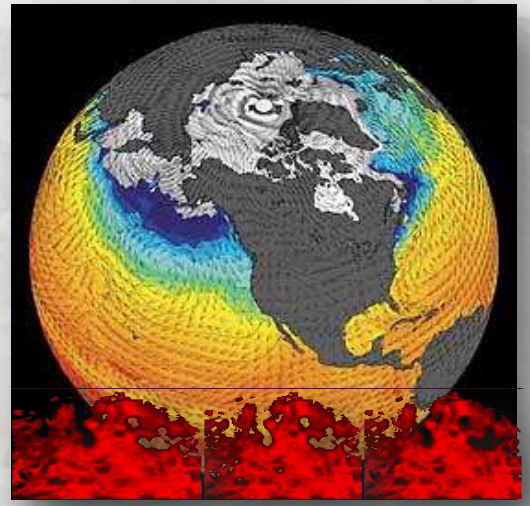
Biological Mechanisms

Wiens and Bachelet 2009

Better Downscaling

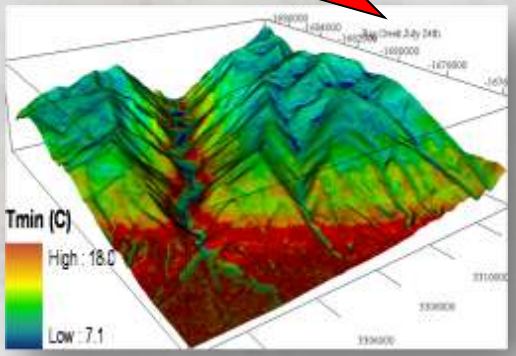
How will global trends affect my stream?

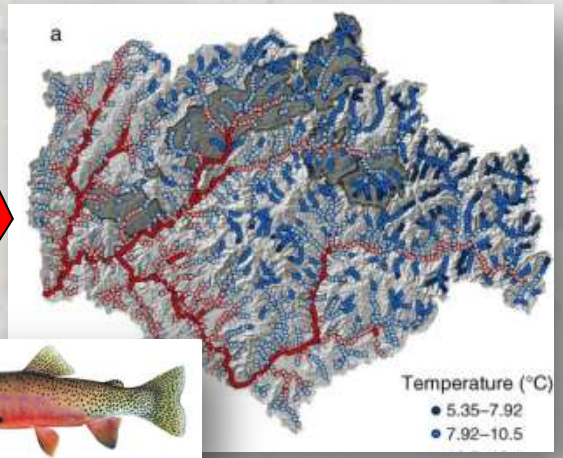
GCM



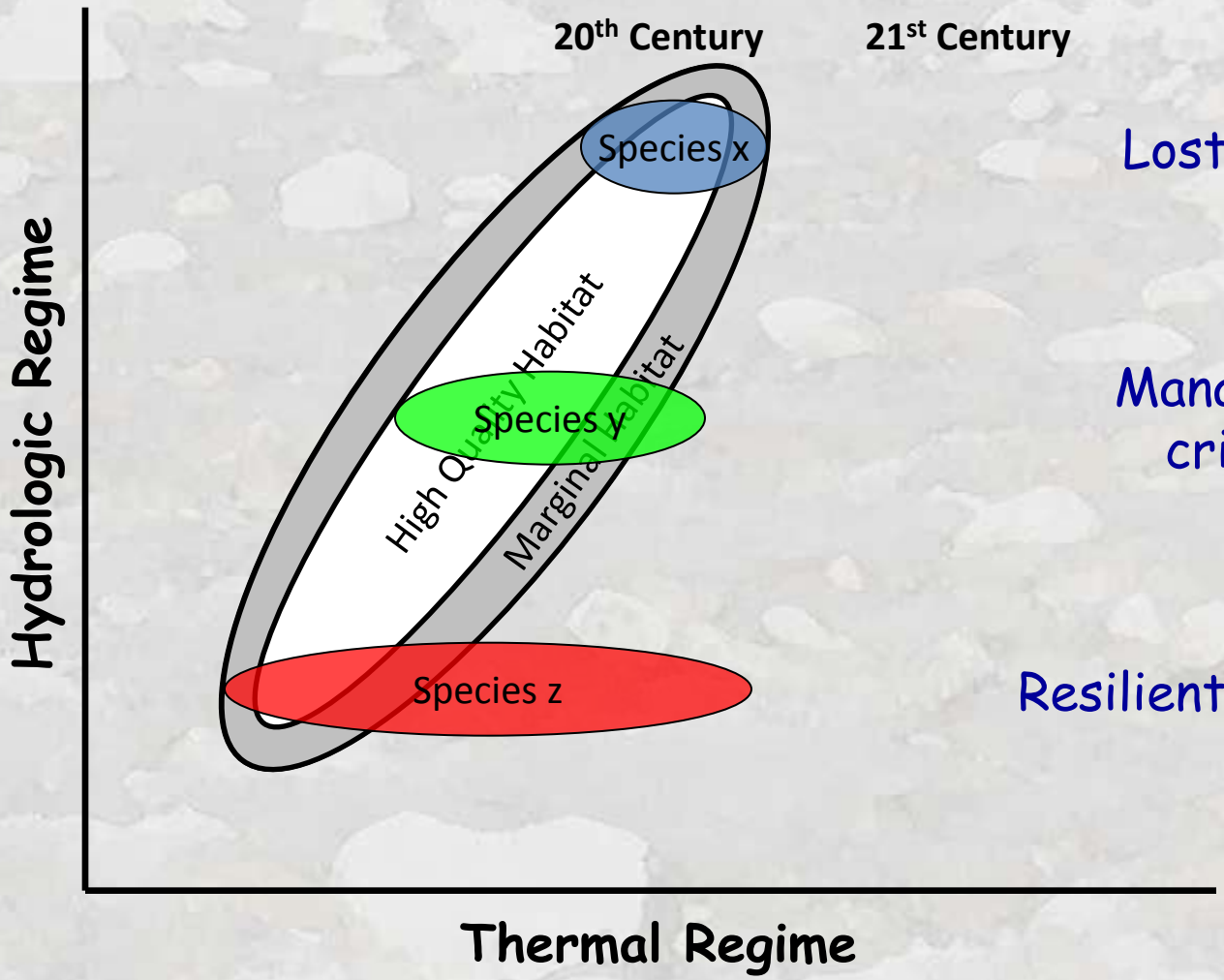
RCM

Integrated global-to-regional-to-landscape-to-stream system





Where Can Management Make a Difference?



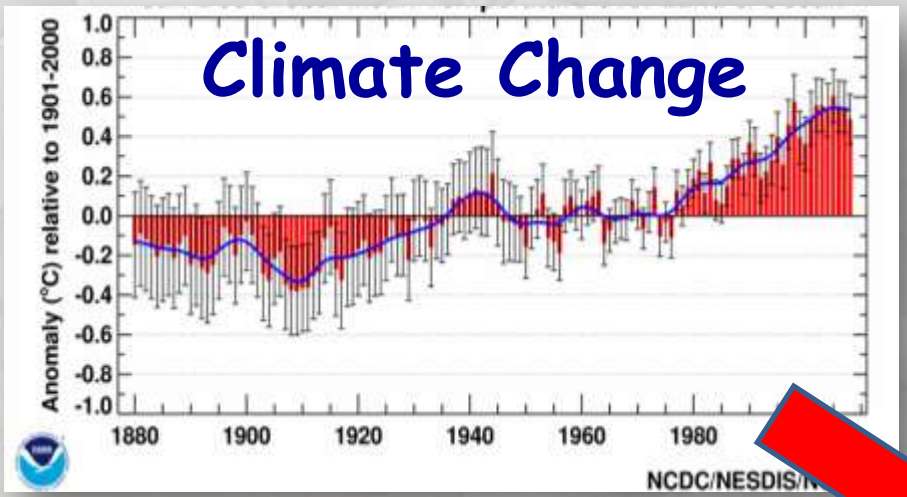
Lost Cause?

Management critical?

Resilient Population?

Modified from Williams et al. 2007

More With Less, but perhaps…Much More?

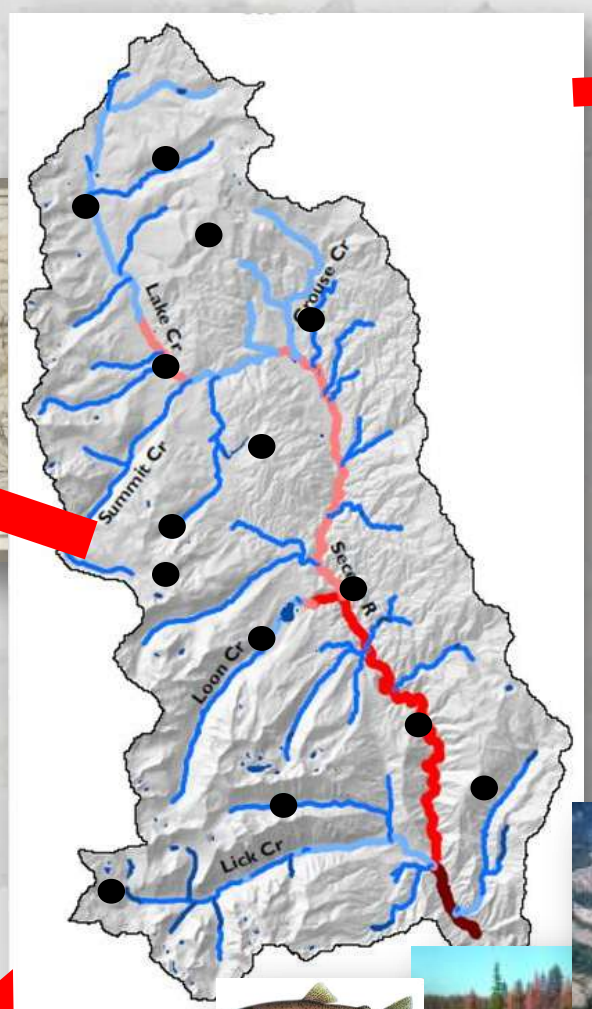


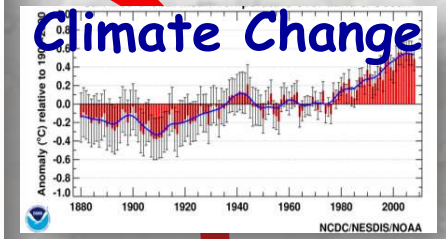
Urbanization & Population Growth

Shrinking Budgets

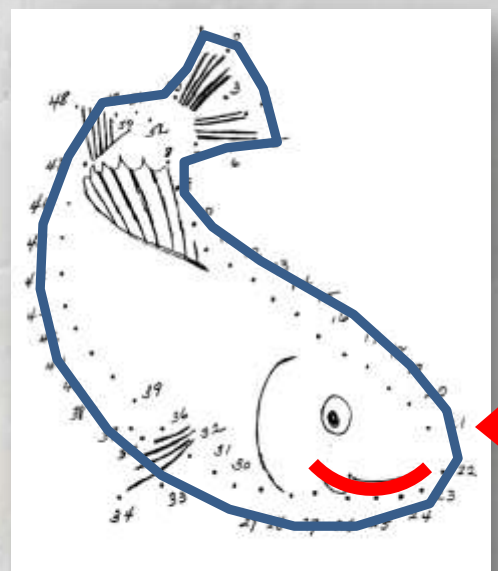
HERE I COME TO SAVE THE DAY!

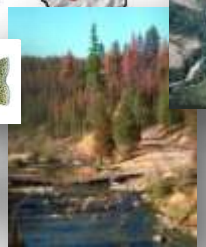
Connect the Dots & the Agencies & the People to Map the Future





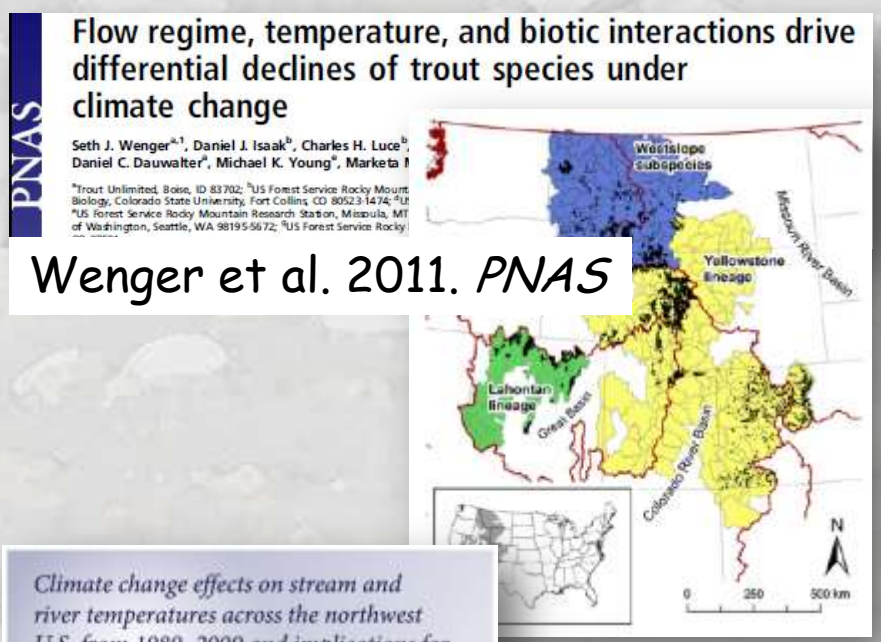
Urbanization & Population Growth



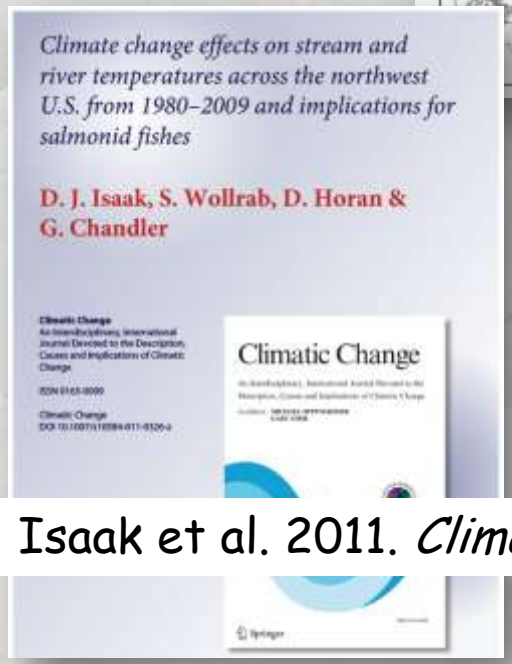


Land & Species Management

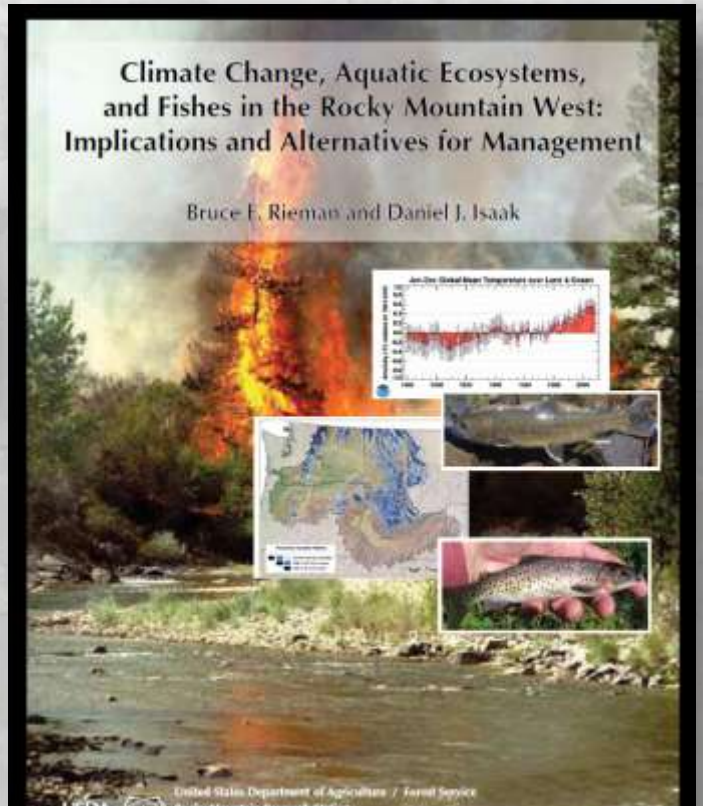
Key Publications…



Wenger et al. 2011. *PNAS*



Isaak et al. 2011. *Climatic Change*



Rieman & Isaak 2010. USFS Report.

1) ***What is changing*** in the climate and related physical processes that may influence aquatic species and their habitats?
2) ***What are the implications*** for fish populations, aquatic communities and related conservation values?
3) ***What can we do about it?***

Additional Research

Google "USFS TreeSearch" & then search author

Goode JR, Luce CH, Buffington JM (2011) Enhanced sediment delivery in a changing climate in semi-arid mountain basins: implications for water resource management and aquatic habitat in the northern Rocky Mountains. *Geomorphology* x:xxx

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

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. *Ecol Appl* 20:1350-1371.

Luce C, Holden Z (2009) Declining annual streamflow distributions in the Pacific Northwest United States, 1948-2006. *Geophysical Research Letters* 36, L16401.

Rieman BE, Isaak DJ, Adams S, Horan D, Nagel D, Luce C, Myers D (2007) Anticipated climate warming effects on bull trout habitats and populations across the Interior Columbia River Basin. *TAFS* 136:1552-1565.

Wenger SJ, Isaak DJ, Luce CH, Neville HM, Fausch KD, Dunham JD, Dauwalter DC, Young MK, Elsner MM, Rieman BE, Hamlet AF, and Williams JE (2011b) Flow regime, temperature, and biotic interactions drive differential declines of trout species under climate change. *PNAS* doi:10.1073/pnas.1103097108.

Wenger SJ, Luce CH, Hamlet AF, Isaak DJ, Neville HM (2010) Macroscale hydrologic modeling of ecologically relevant flow metrics. *Water Resour Res* 46, W09513, doi:10.1029/2009WR008839.

Related Websites - Google search…

"USFS Boise Stream Temperature"

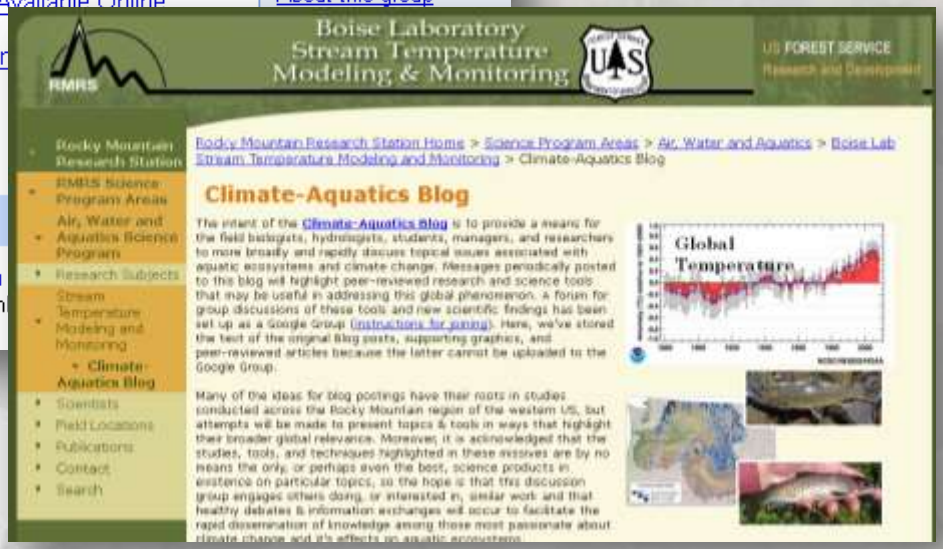
"Climate-Aquatics Decision Support Workshop"

"Western US Stream Flow Metrics"

"USFS Climate Change Resource Center"

Climate-Aquatics BLOG

Speed Information Transfer Regarding Latest Science
(3,326-person international mailing list & growing!)



Google search…

"Climate-Aquatics Blog"

The End