Stream Temperatures & Climate Change:
Observed Patterns & Key Uncertainties

Dan Isaak, Bruce Rieman, Charlie Luce, Erin Peterson[1], Jay Ver Hoef[2], Jason Dunham[3], Brett Roper, Erik Archer, Dona Horan, Gwynne Chandler, Dave Nagel, Sharon Parkes

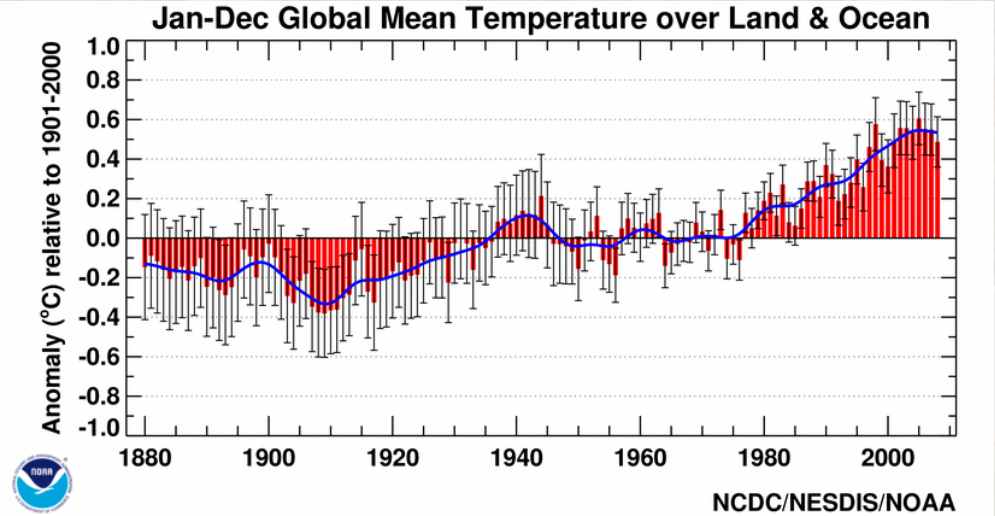
U.S. Forest Service

[1]CSIRO

[2]NOAA

[3]U.S. Geological Survey

Air, Water & Aquatics Program



CSIRO

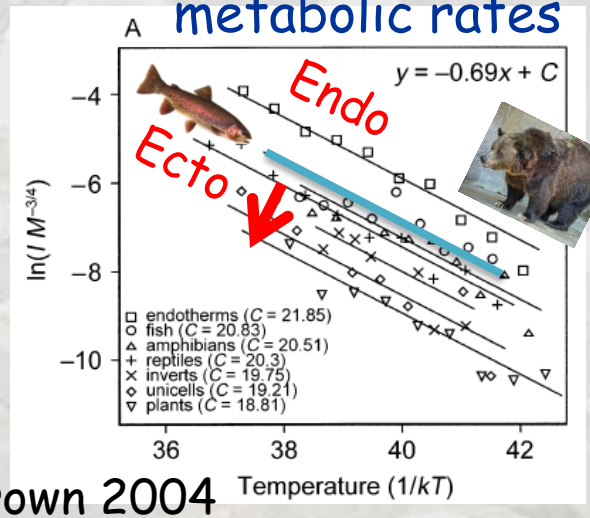
PIBO Fish & Aquatic Ecology Unit

NOAA

USGS science for a changing world

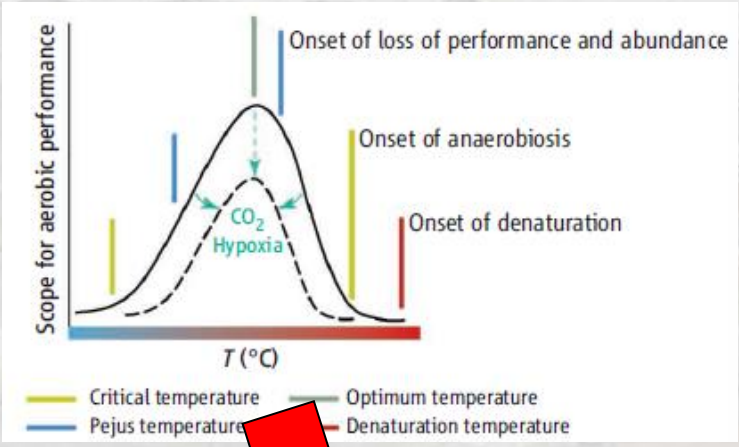
Metabolic Ecology and Thermal Niches

Temperature & metabolic rates

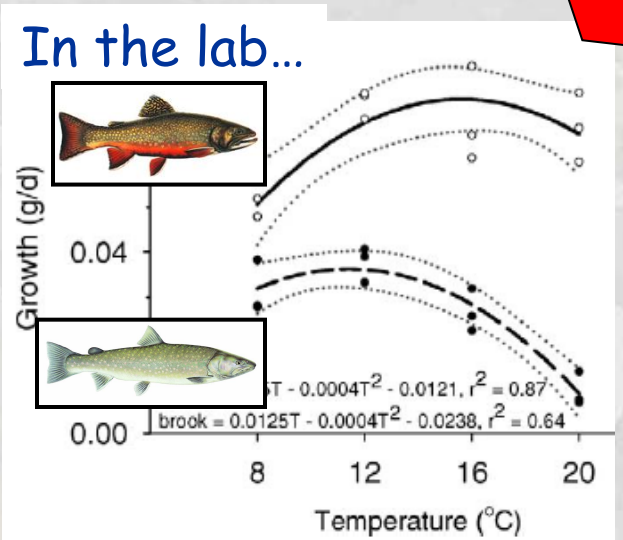


Brown 2004

Thermal Niche

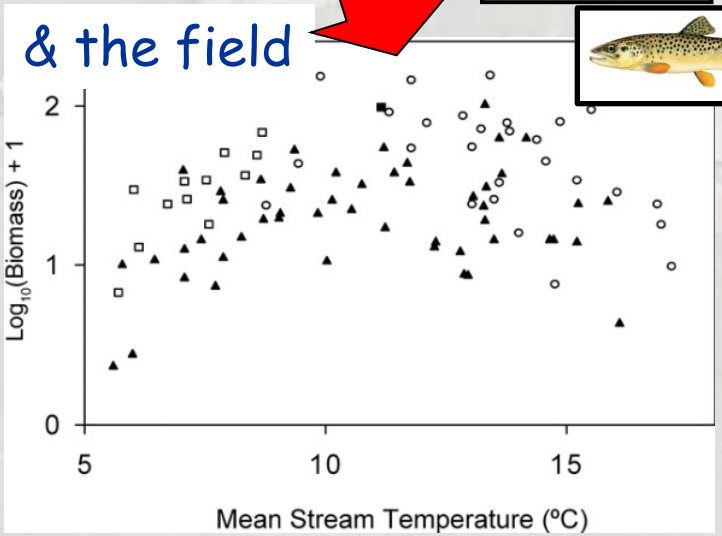


In the lab…



McMahon et al. 2007

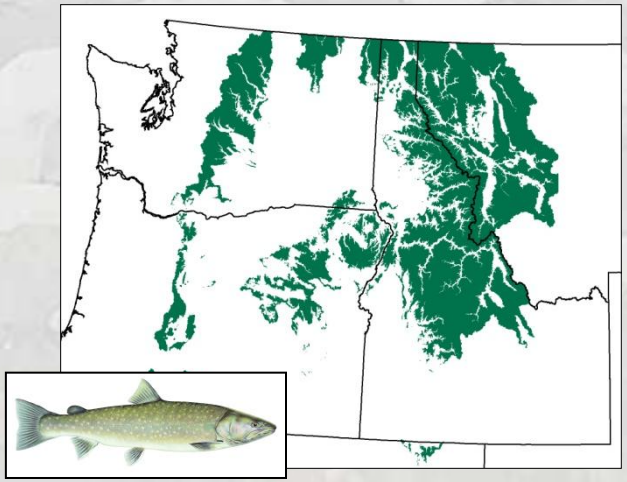
& the field



Isaak & Hubert 2004

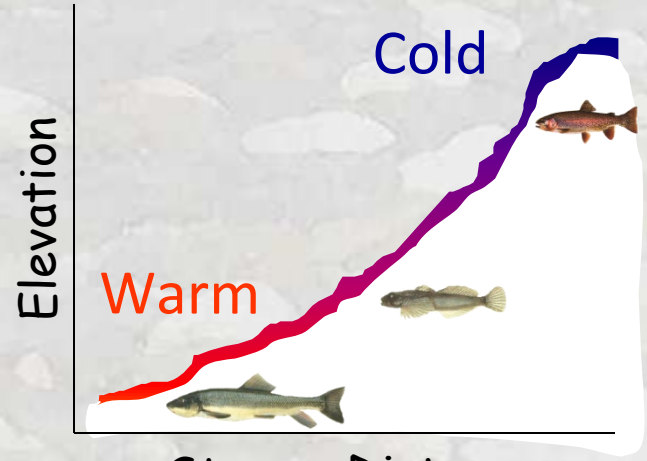
Temperature Regulation – Spatial Distributions

Regional Scale

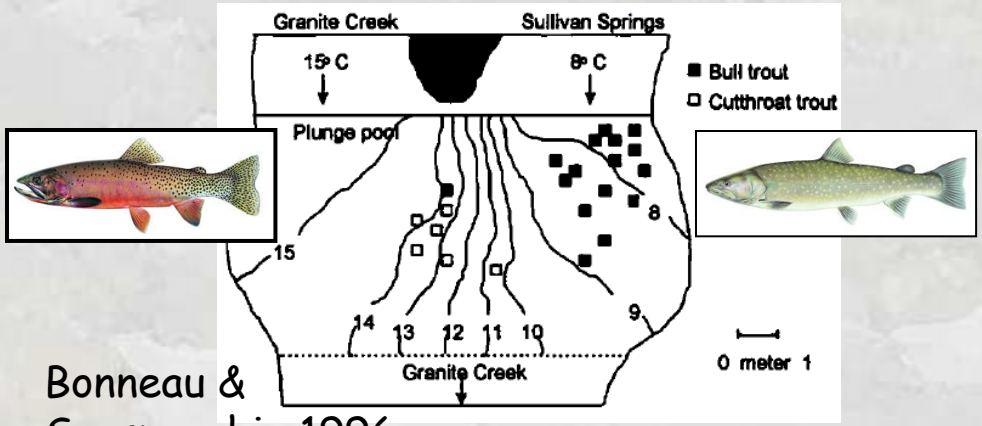


Rieman et al. 2007

Stream Scale



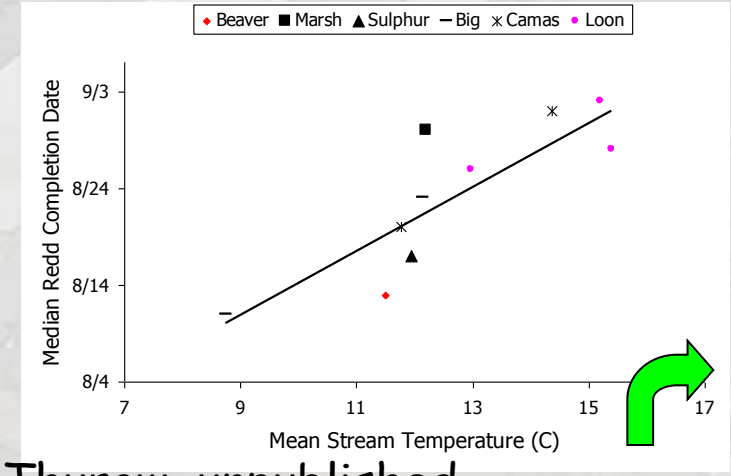
Channel Unit Scale



Bonneau & Scarnecchia 1996

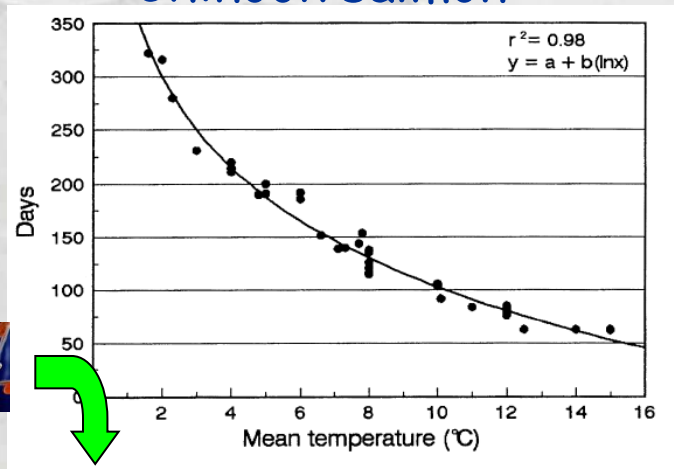
Temperature Regulation - Life Cycle

Spawn timing - Chinook salmon



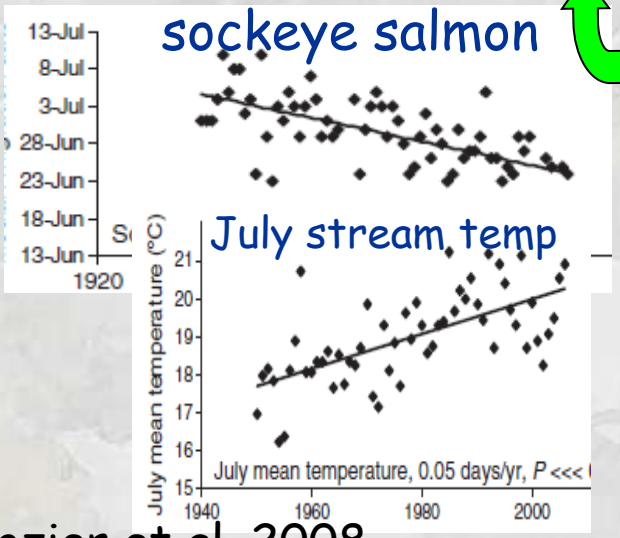
Thurow, unpublished

Incubation length - Chinook salmon



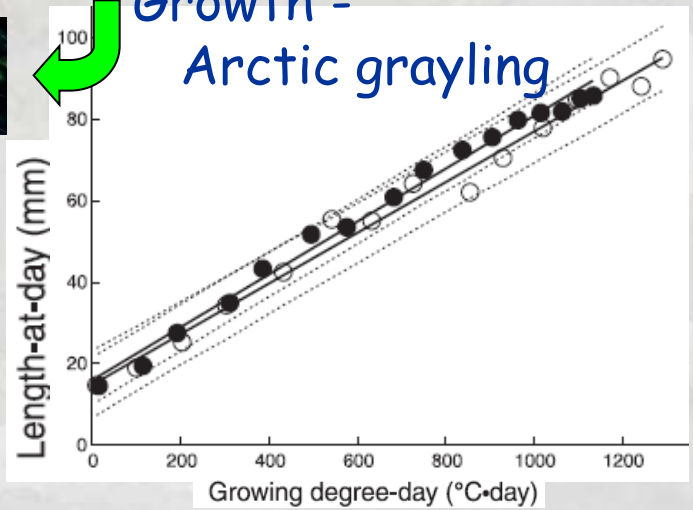
Brannon et al. 2004

Migration timing - sockeye salmon



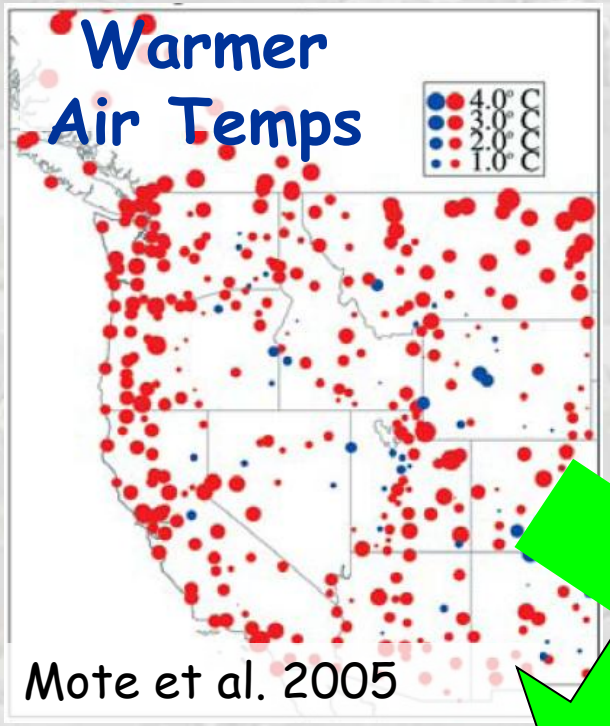
Crozier et al. 2008

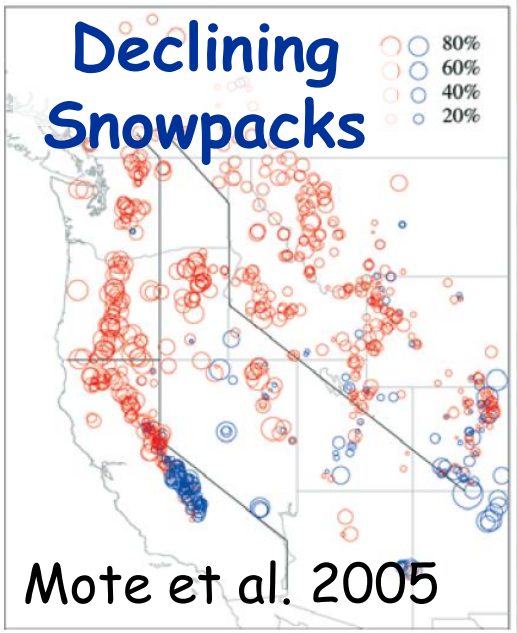
Growth - Arctic grayling

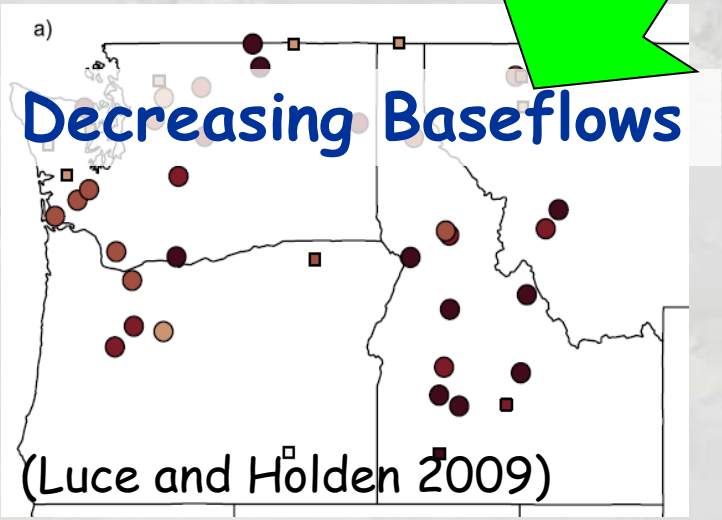


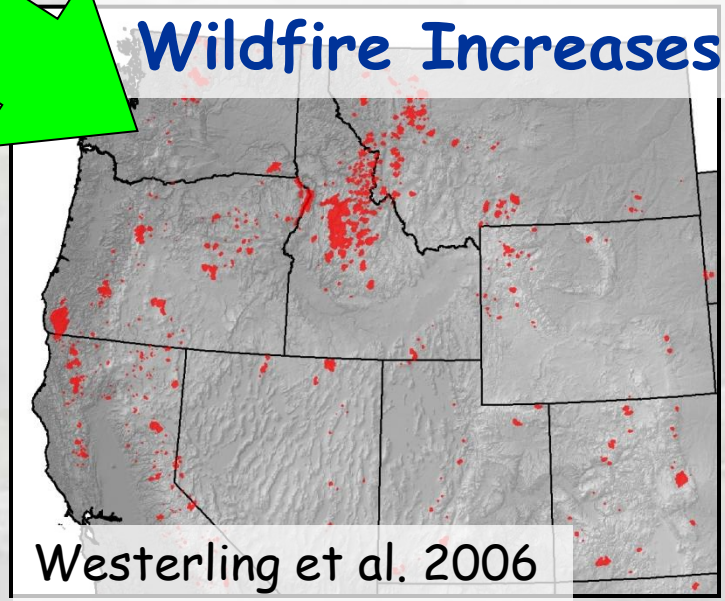
Dion and Hughes 1994

Western US – Observed Trends



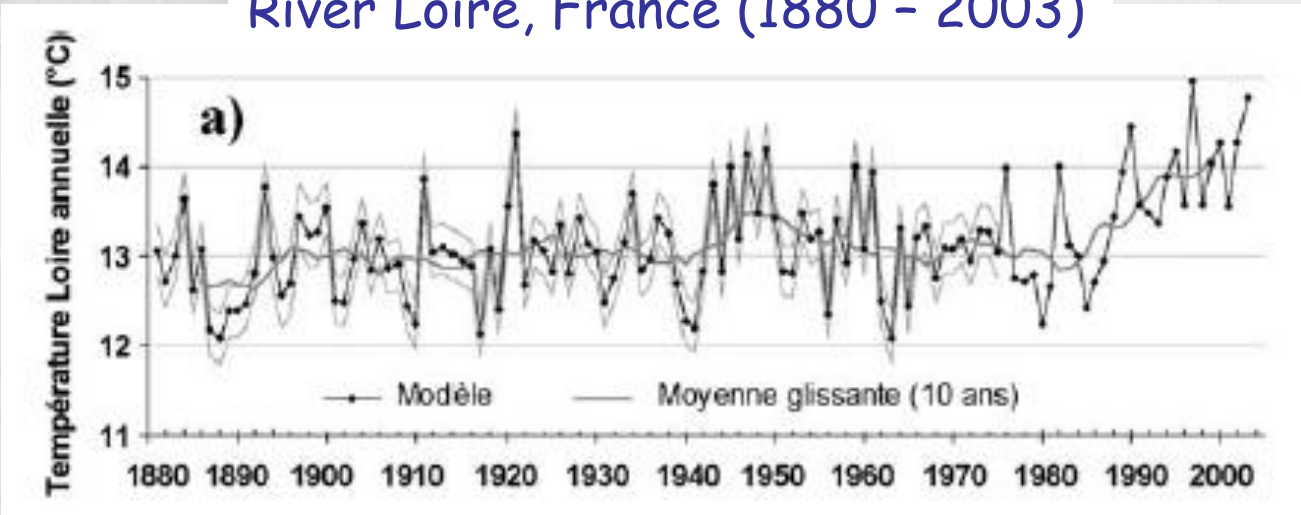






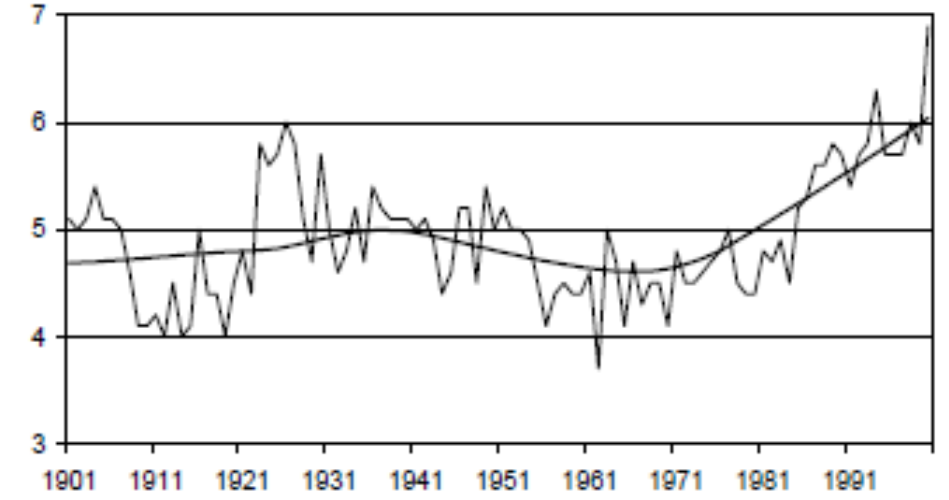
Global Trends in Stream Temperatures

River Loire, France (1880 – 2003)



Moatar and Gailhard 2006

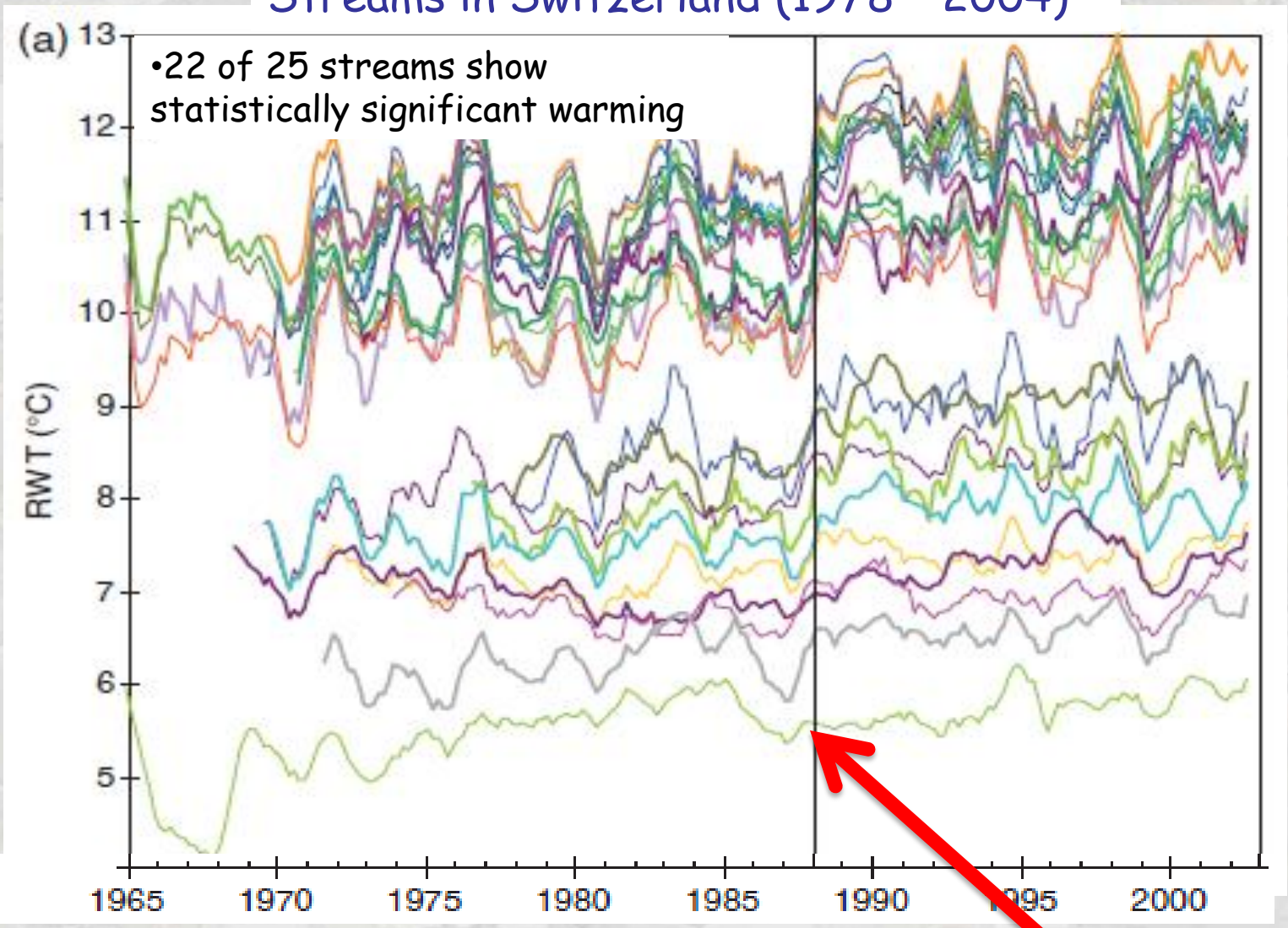
Danube River, Austria (1901 – 2000)



Webb and Nobilus 2007

Global Trends in Stream Temperatures

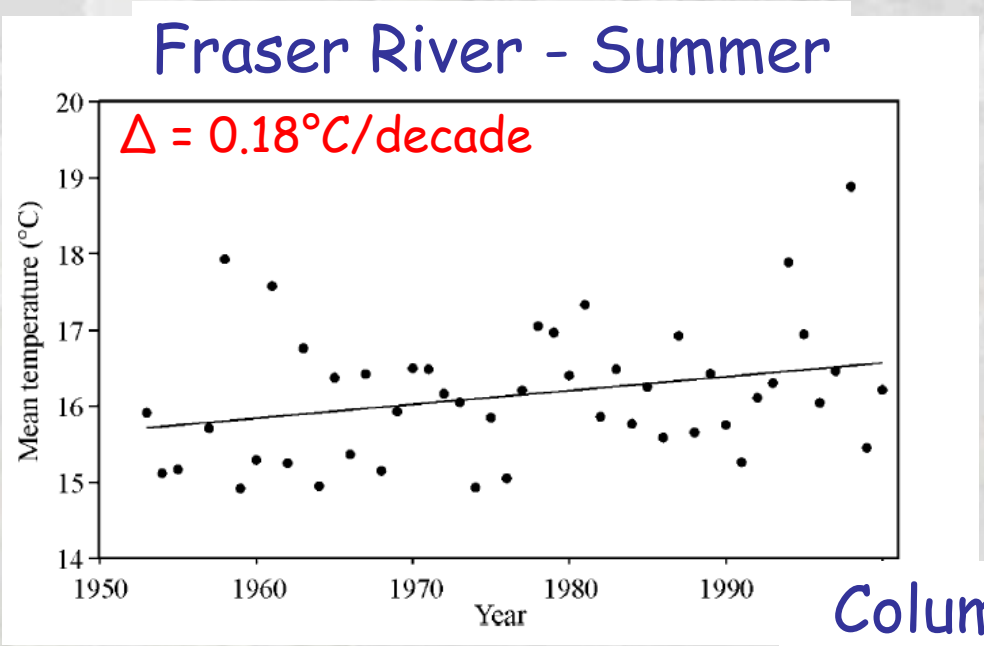
Streams in Switzerland (1978 – 2004)



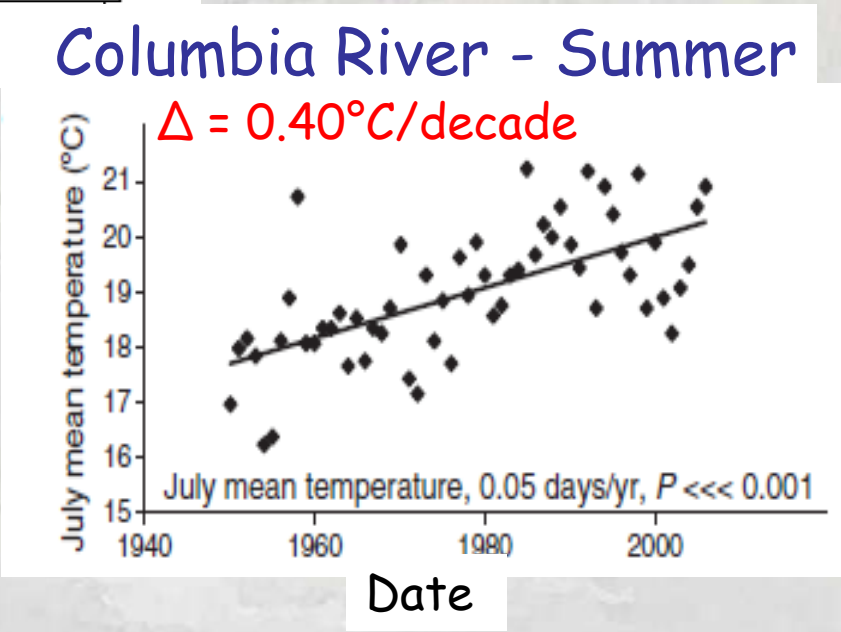
NAO shift

Hari et al. 2006

Regional Trends In Stream Temperatures



Morrison et al. 2002

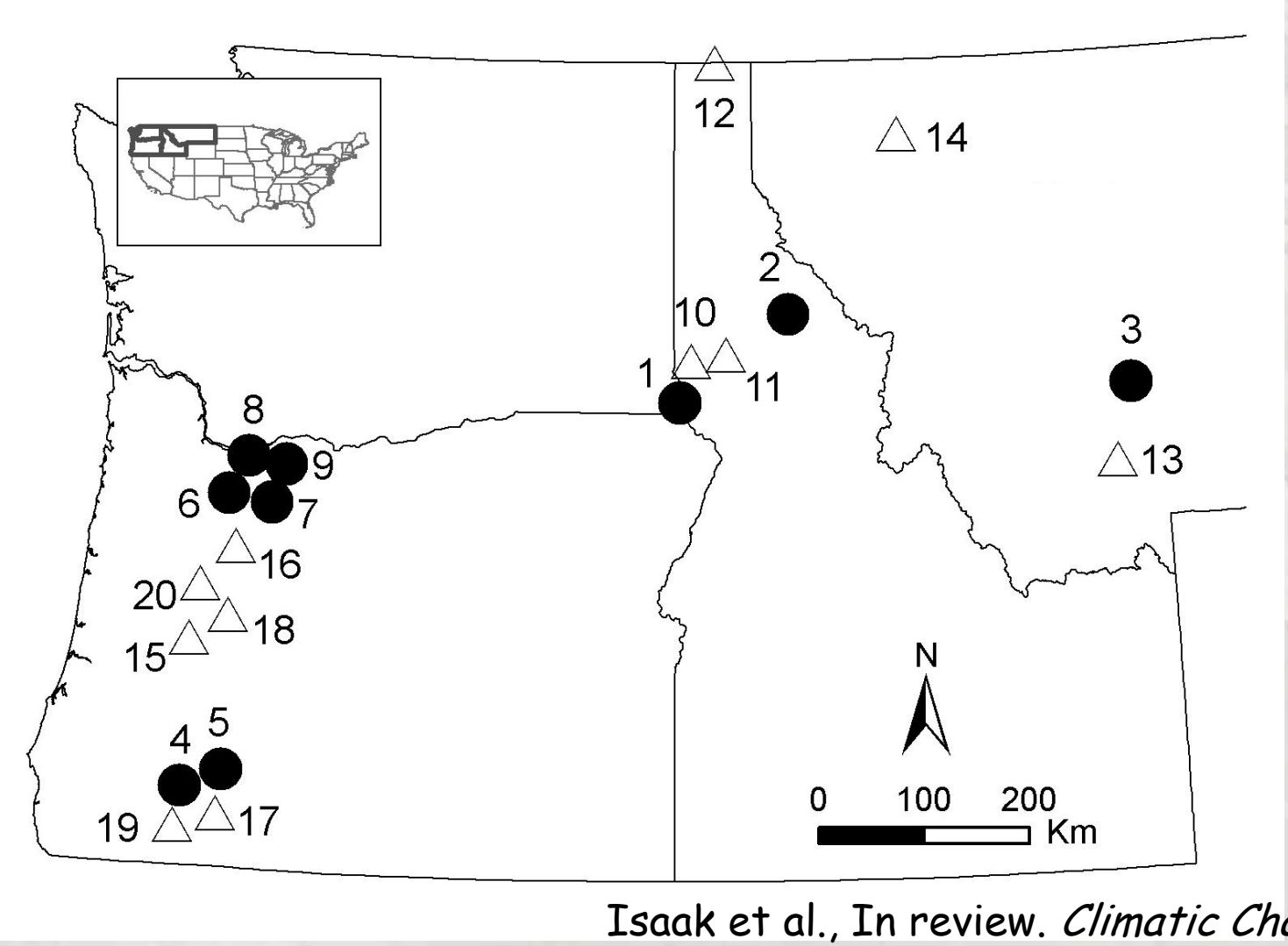


Petersen and Kitchell 2001; Crozier et al. 2008

Regional Trends In Stream Temperatures

USGS NWIS Monitoring Sites (1980 – 2009)

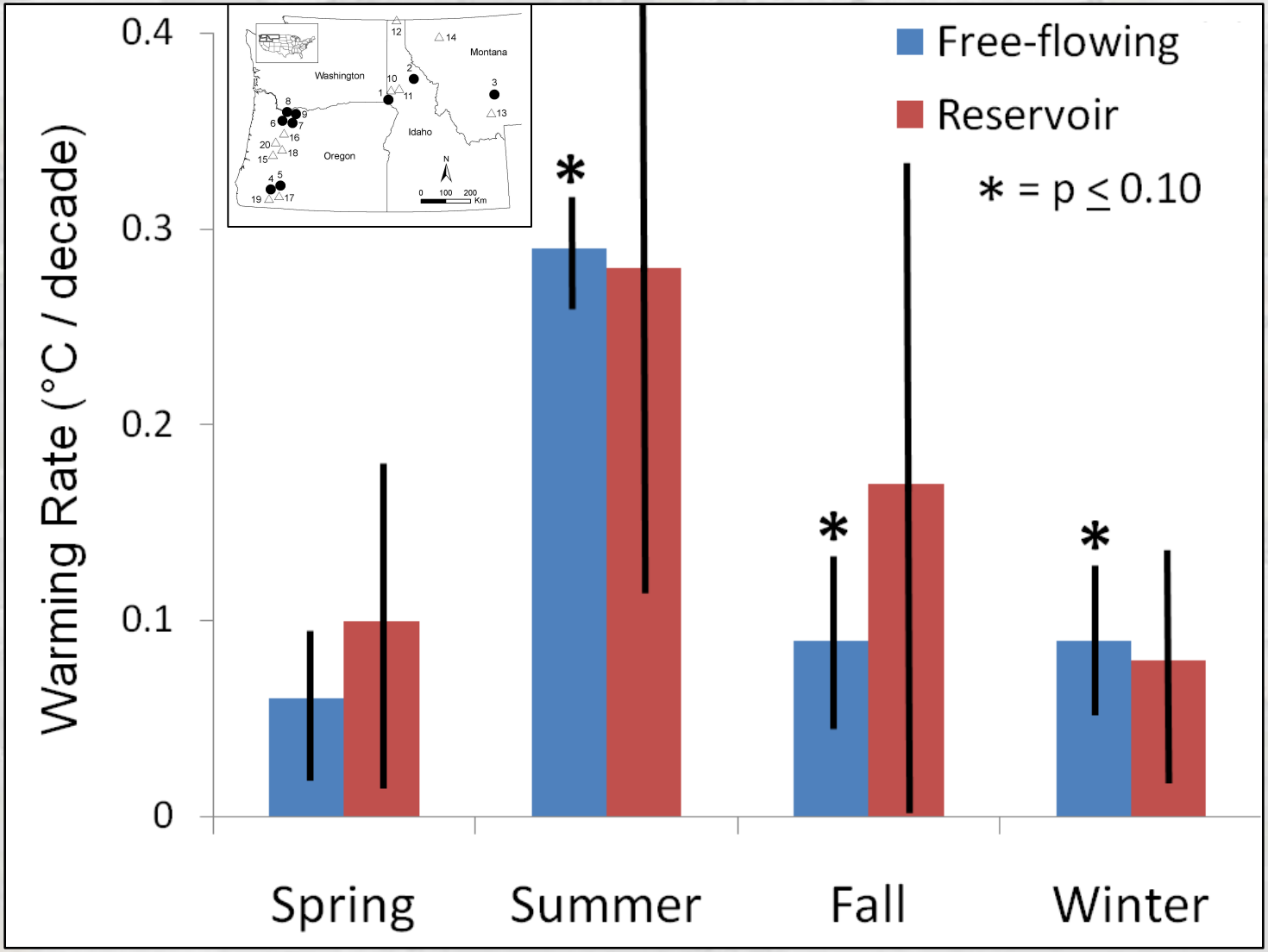
△ = reservoir affected (11) ● = free-flowing (9)



Isaak et al., In review. *Climatic Change*

Seasonal Trends In Stream Temperatures

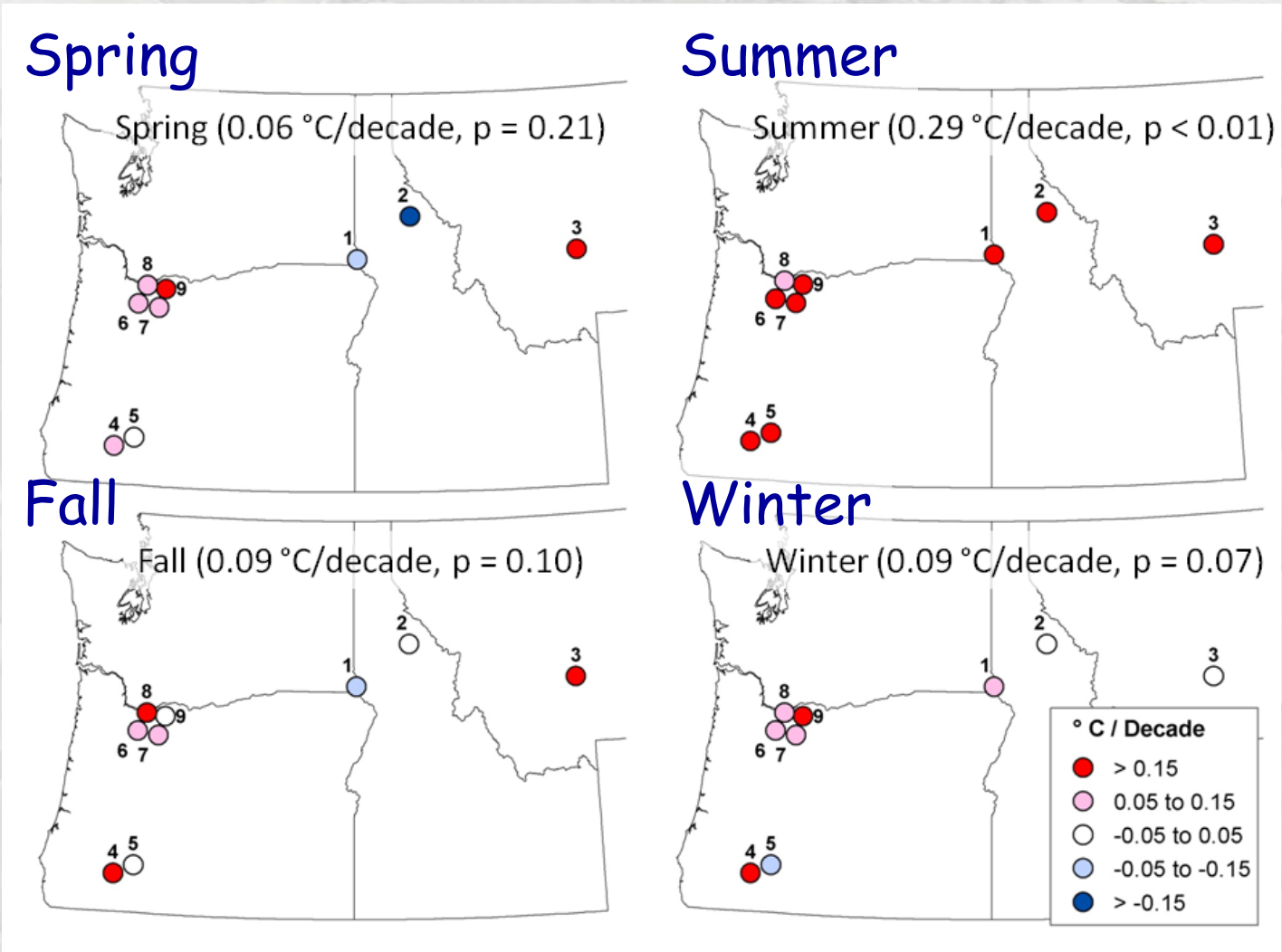
USGS NWIS Monitoring Sites (1980 – 2009)



Isaak et al., In review. *Climatic Change*

1980-2009 Warming Trends

Minimally Altered, Free-Flowing Sites



Isaak et al., In review. *Climatic Change*

Application of Spatial Statistical Models for Downscaling of Climate Effects on River Network Temperatures

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

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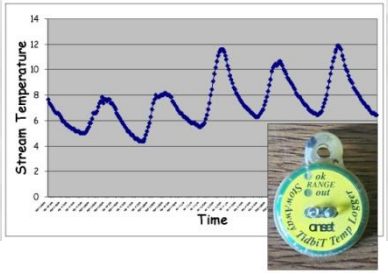
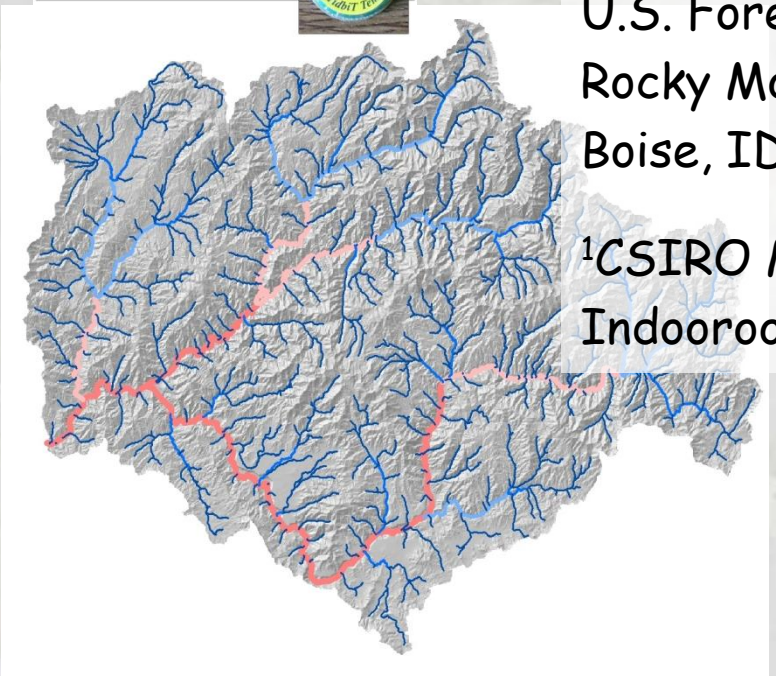
[1]CSIRO Mathematical and Information Sciences
Indooroopilly, Queensland, Australia



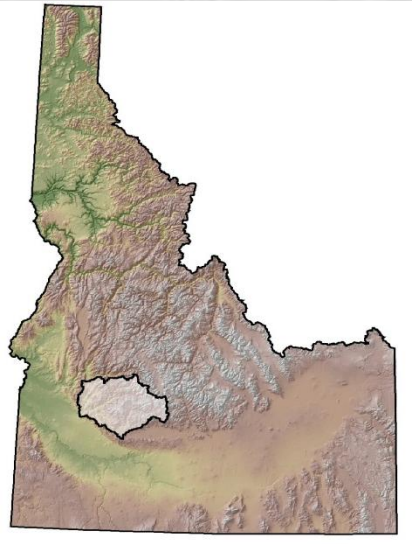


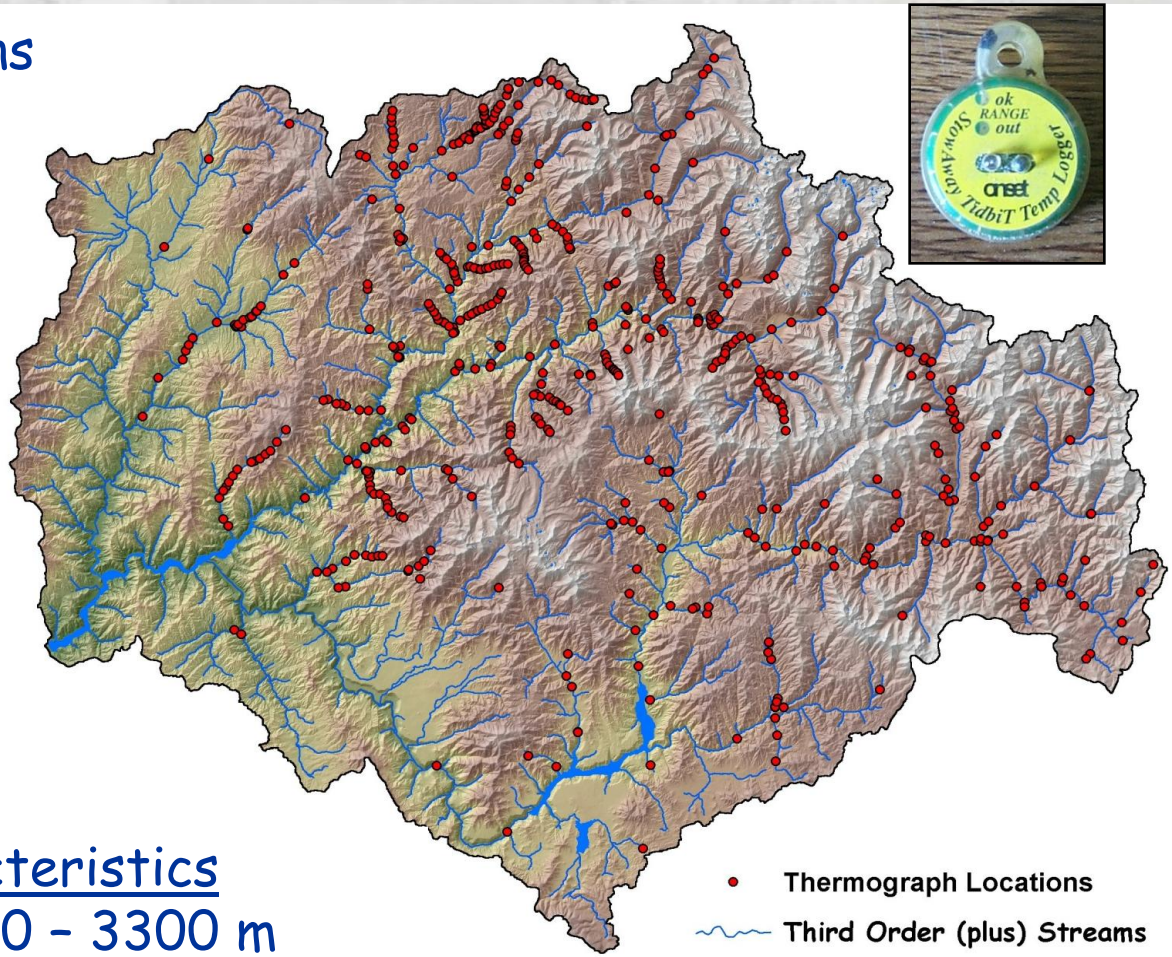
CSIRO

BOISE AQUATIC SCIENCES LAB
RMRS

Boise River Temperature Database

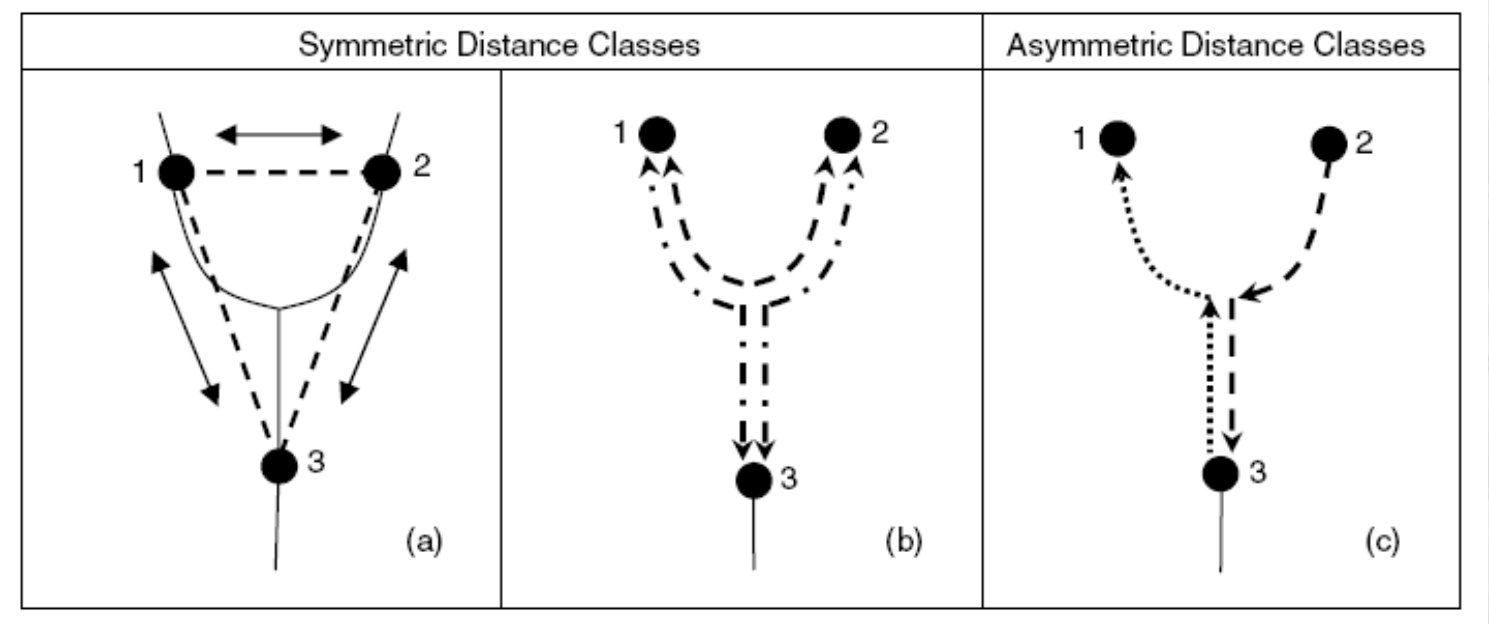
<u>Stream Temperature Database</u>
14 year period (1993 – 2006)
780 observations
518 unique locations





<u>Watershed Characteristics</u>
Elevation range 900 – 3300 m
Fish bearing streams ~2,500 km
Watershed area = 6,900 km^2

Spatial Statistical Models for Stream Networks



Advantages:

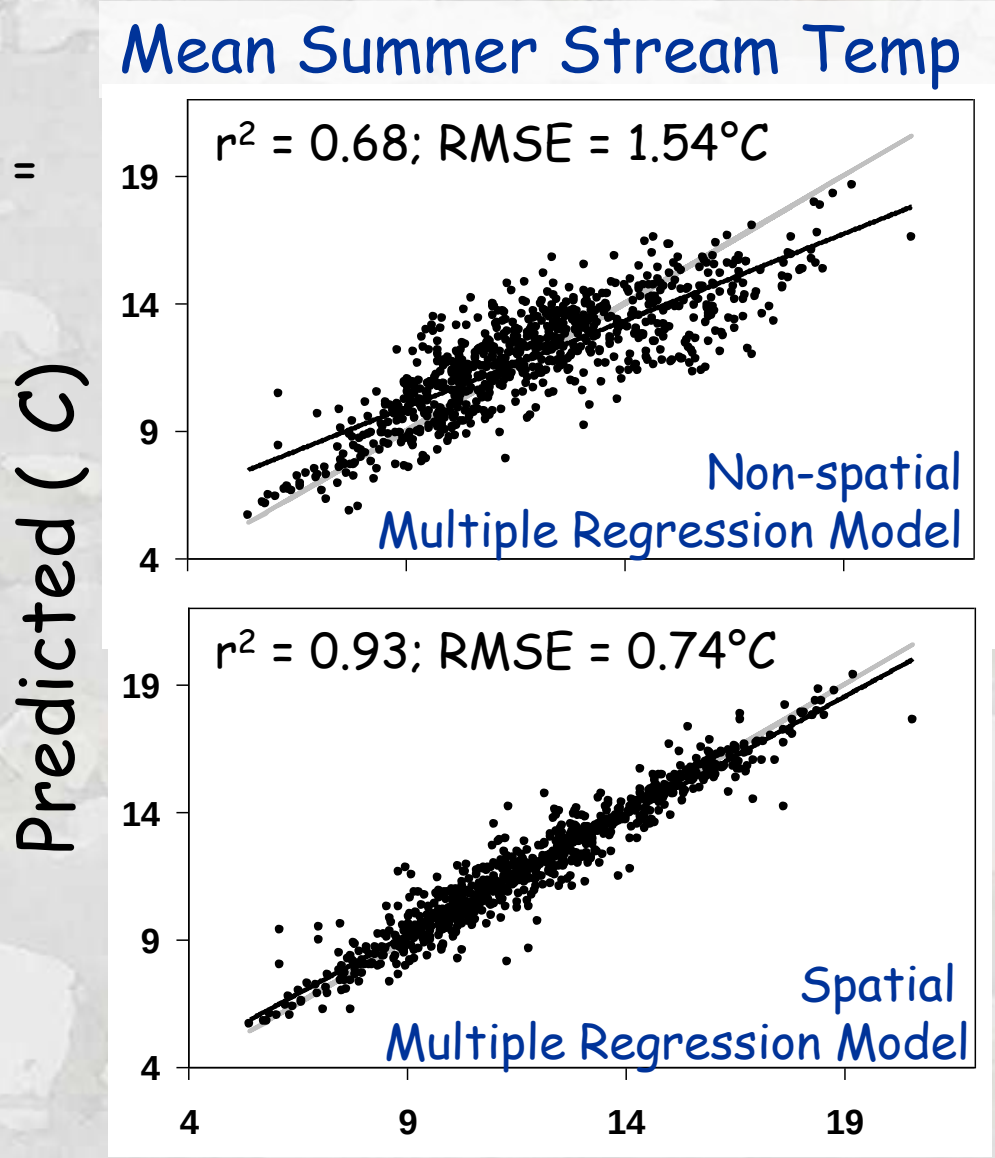
- -flexible & valid covariance structures by accommodating network topology
- -weighting by stream size
- -improved predictive ability & parameter estimates relative to non spatial models

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)

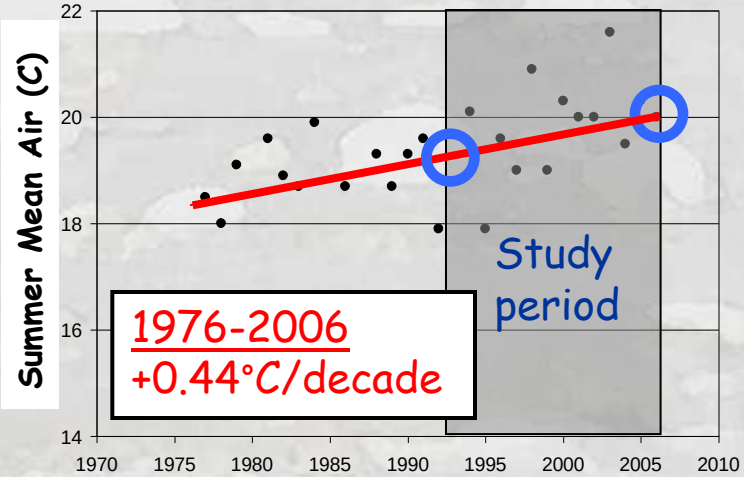
Spatial Stream Temp =
- 0.0045*Ele (m)
+ 0.0085*Rad
+ 0.48*AirTemp (C)
- 0.11*Flow (m^3/s)

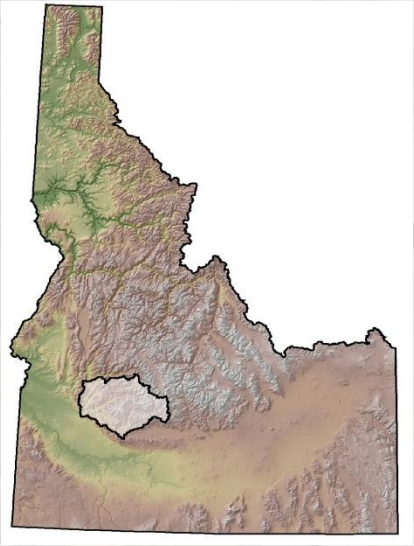


Isaak et al. 2010. *Eco. Apps.* 20:1350-1371

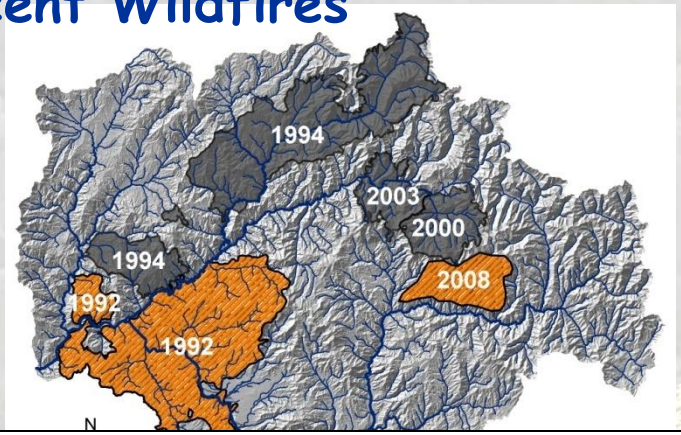
Environmental Trends in the Boise River Basin

Summer Air Temperature



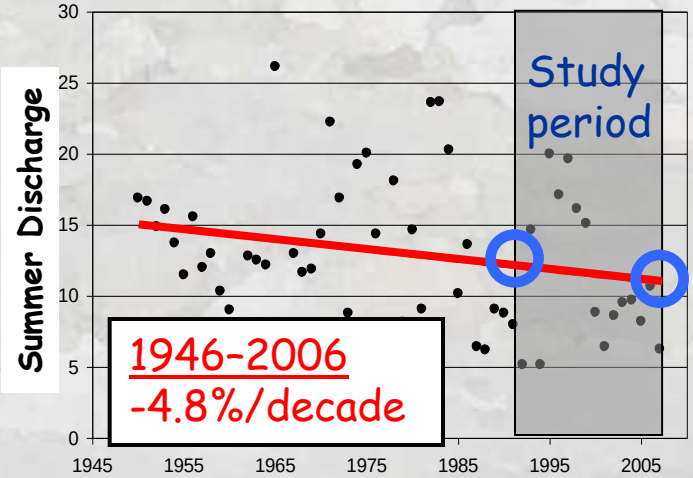


Recent Wildfires

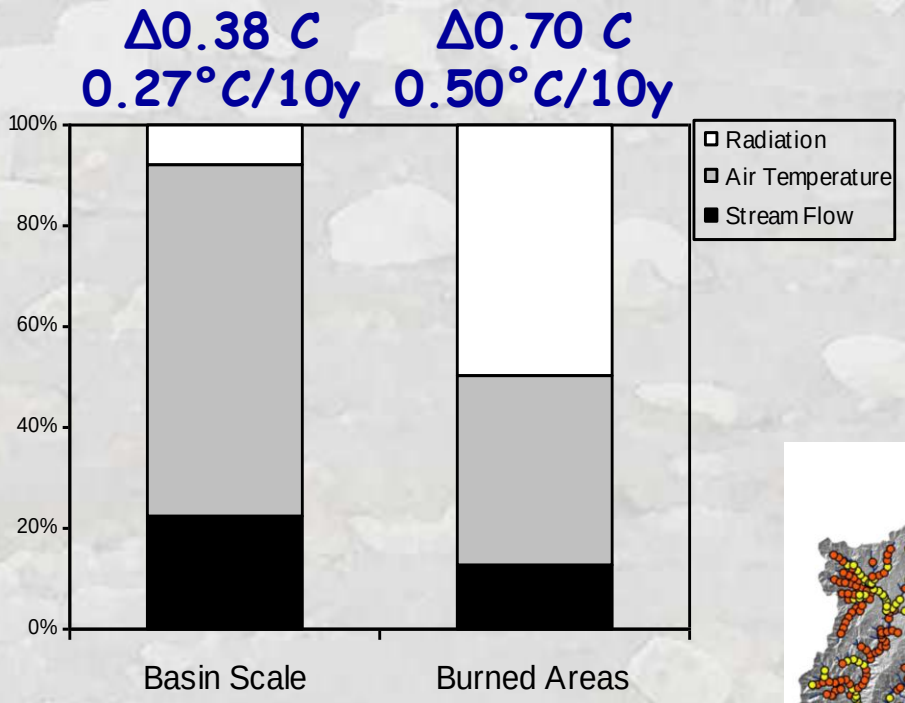


14% burned during 93-06 study period
30% burned from 92-08

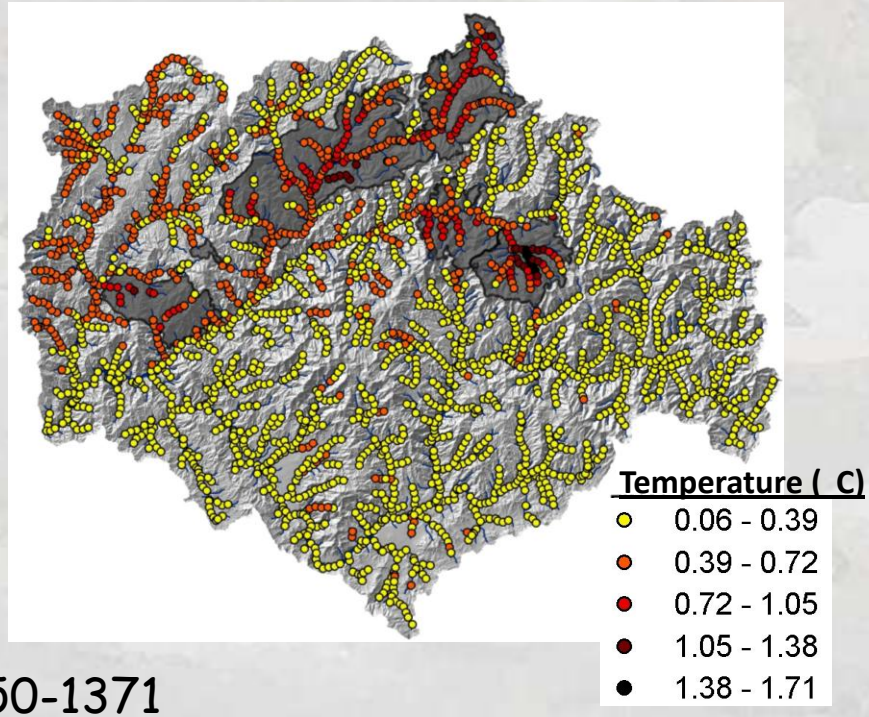
Summer Stream Flow



Changes in Summer Stream Temperatures (1993-2006)



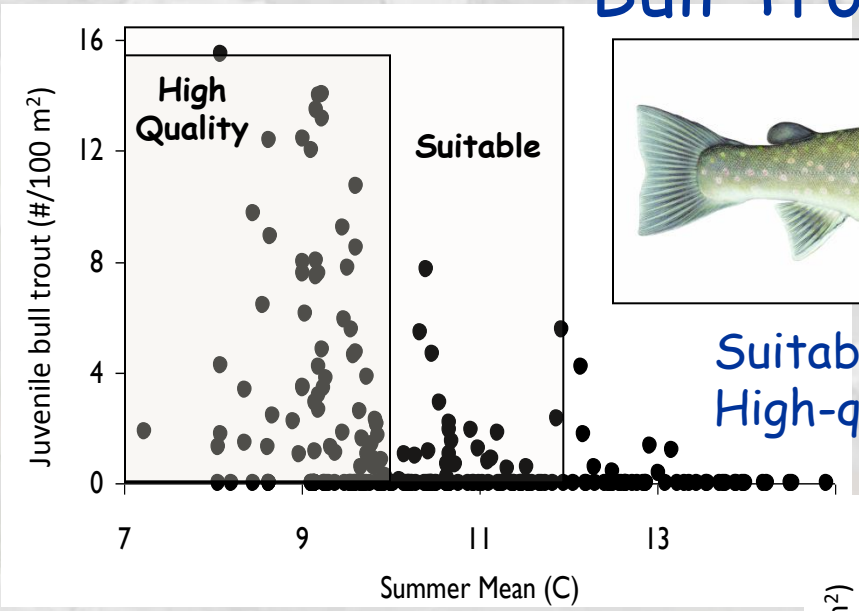
Thermal Gain Map

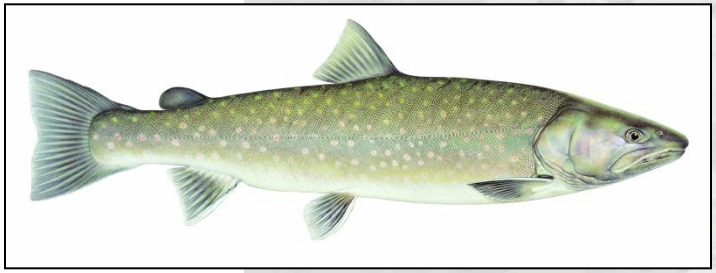


Isaak et al. 2010. *Eco. Apps.* 20:1350-1371

Effects on Thermal Habitat?

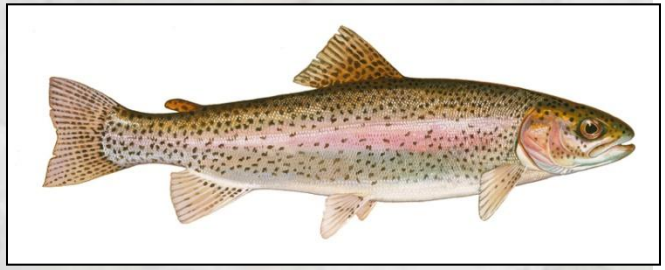
Bull Trout

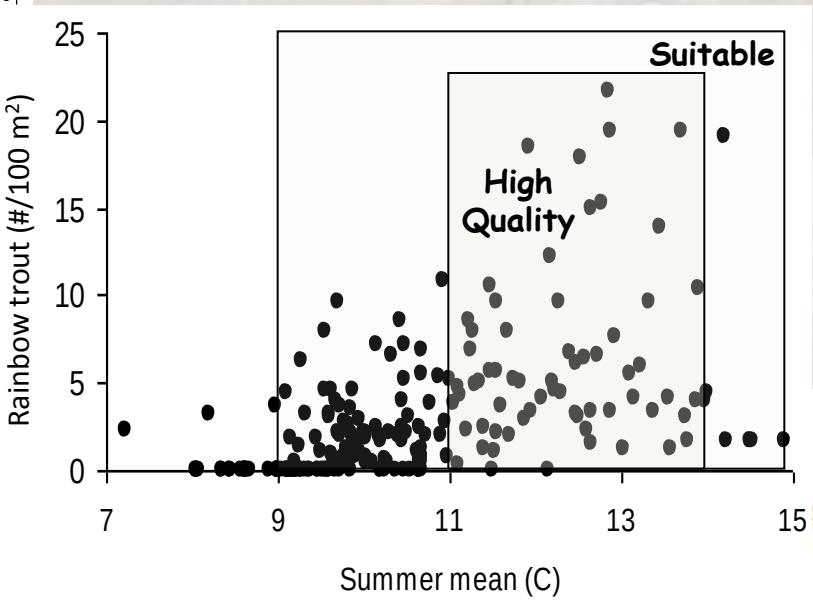




Suitable habitat < 12.0°C
High-quality habitat < 10.0°C

Rainbow Trout

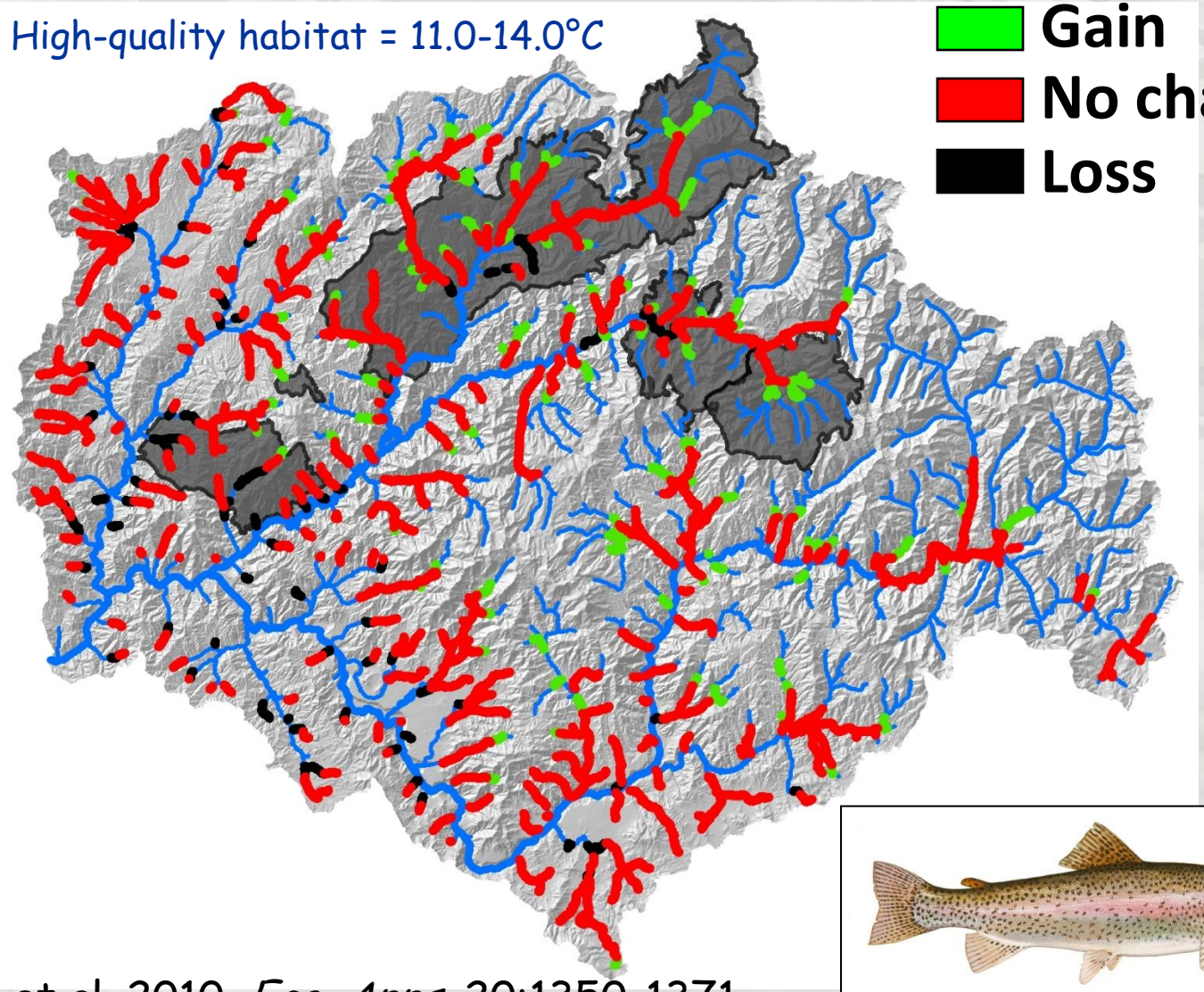


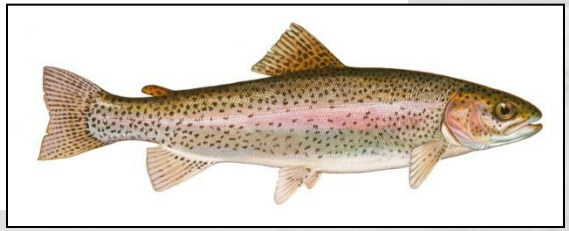


Suitable habitat = > 9.0°C
High-quality habitat = 11.0-14.0°C

93-06 Rainbow Trout Habitat Changes

Habitat is shifting, but no net gain or loss

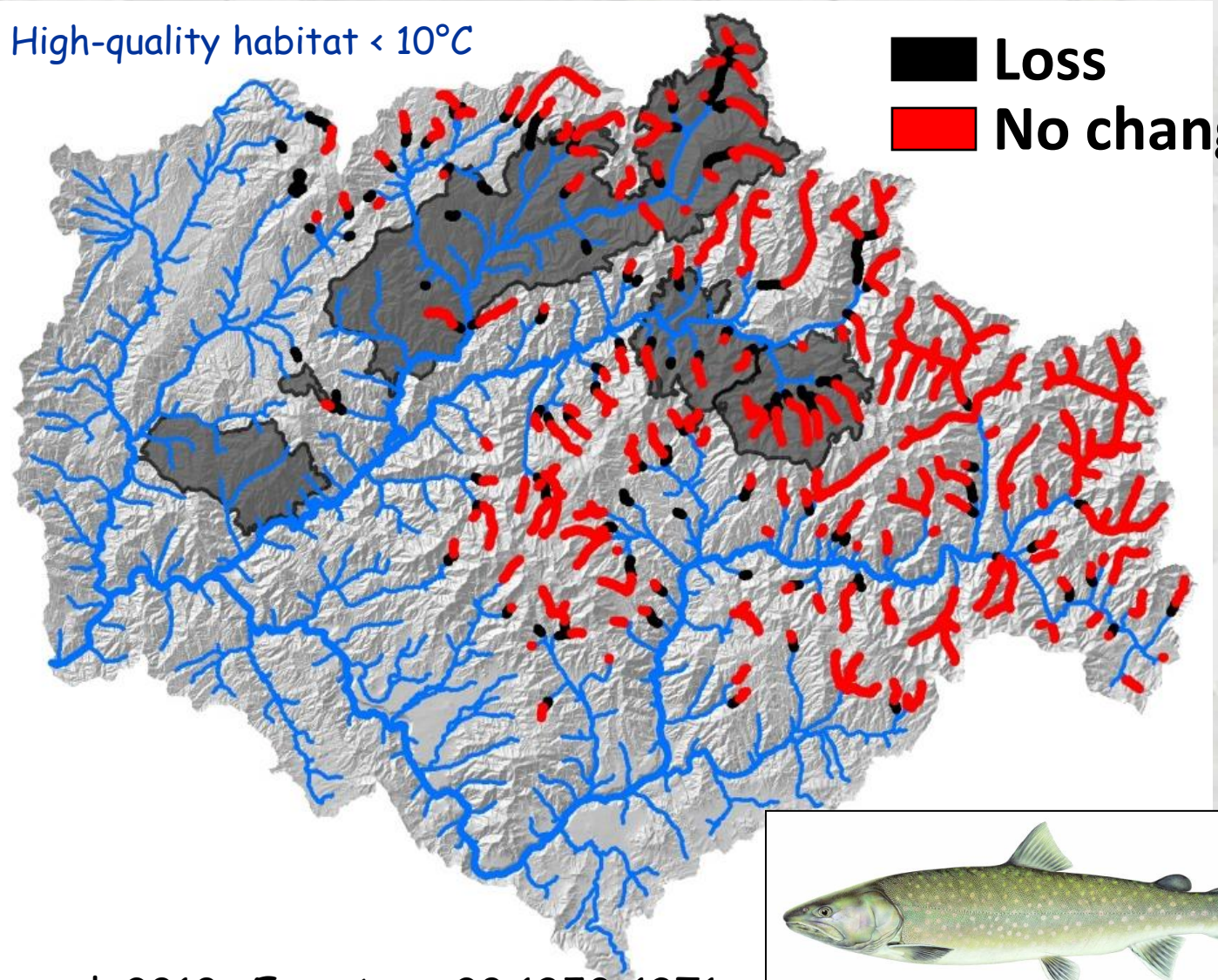


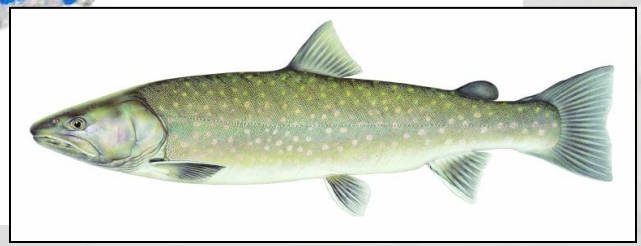


Isaak et al. 2010. *Eco. Apps.* 20:1350-1371

93-06 Bull Trout Natal Habitat Changes

Net loss of habitat occurring (8%-16%/decade)

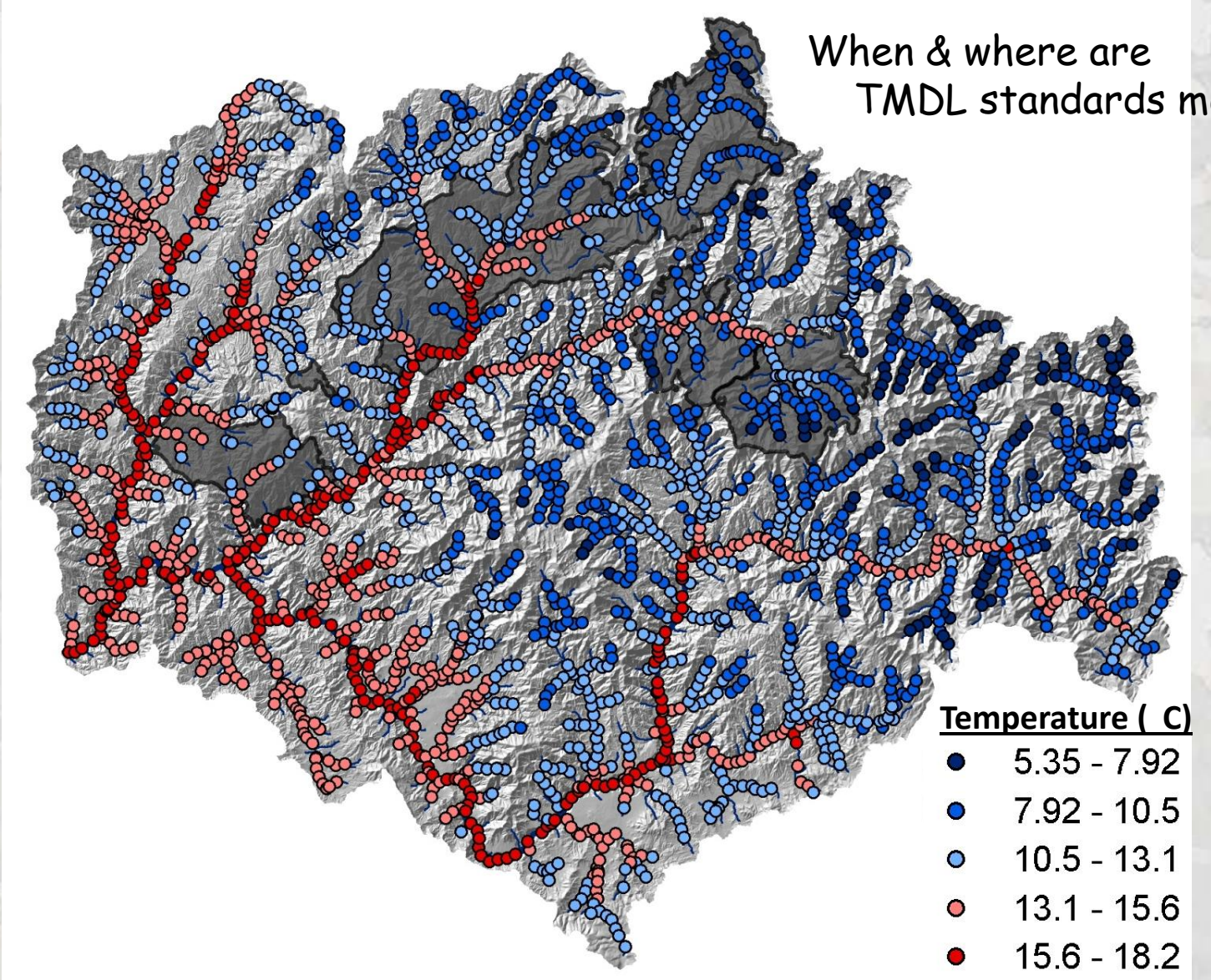




Isaak et al. 2010. *Eco. Apps.* 20:1350-1371

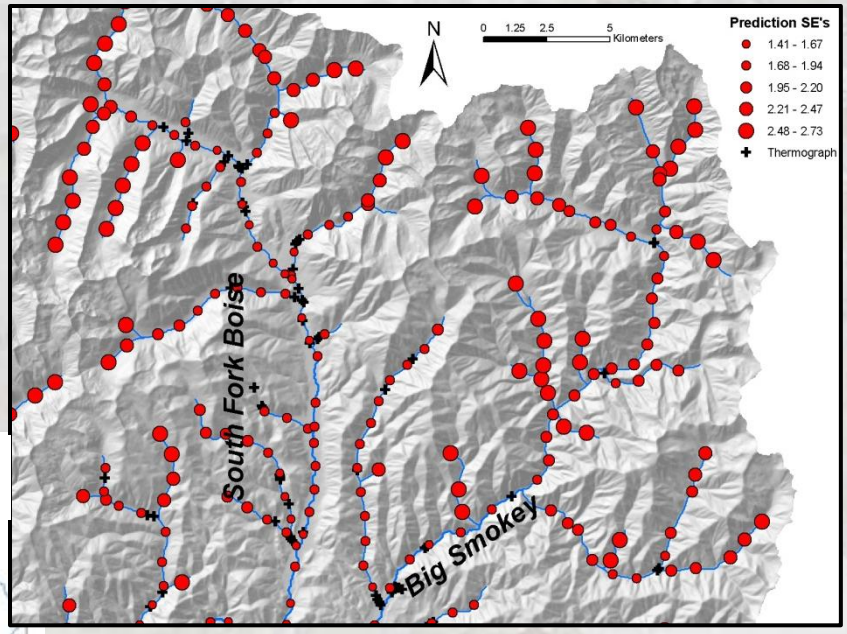
Additional Applications: River Network Thermal Maps

2006 Mean Summer Temperatures

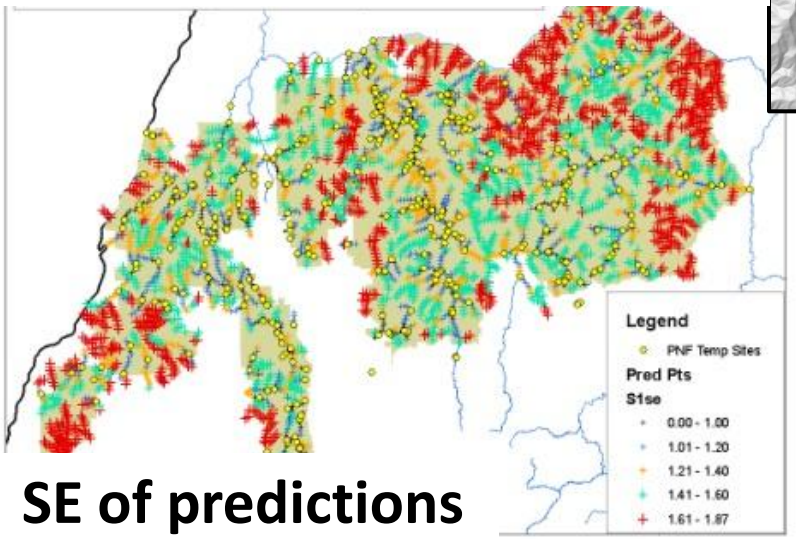


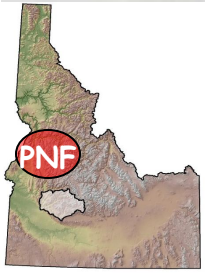
Additional Applications: Optimizing Sampling Efforts

Temperature Prediction Precision



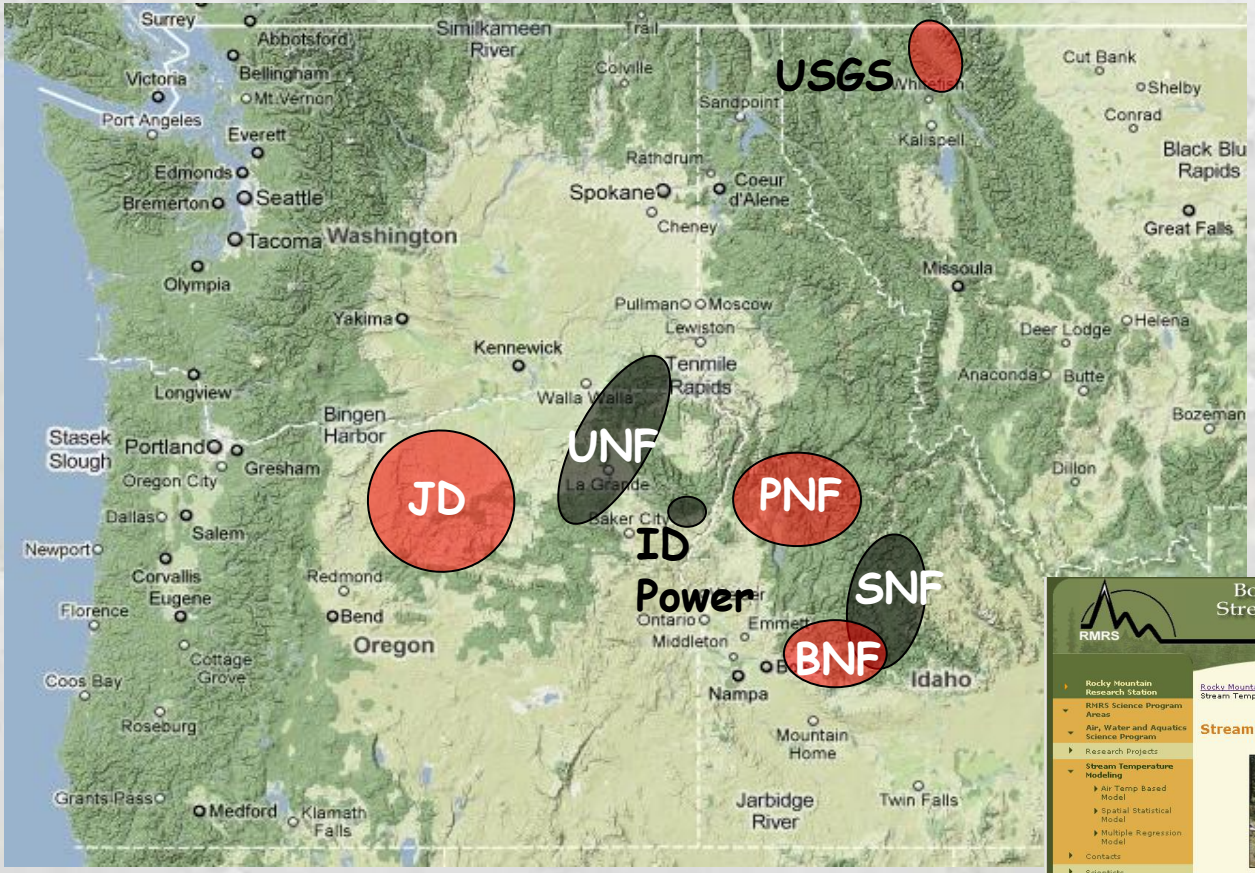
Maps of Spatial Uncertainty





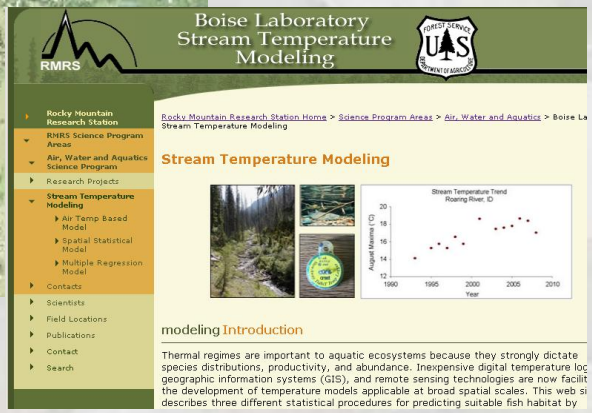
SE of predictions

River Network Temperature Models



= Spatial

= Non-spatial



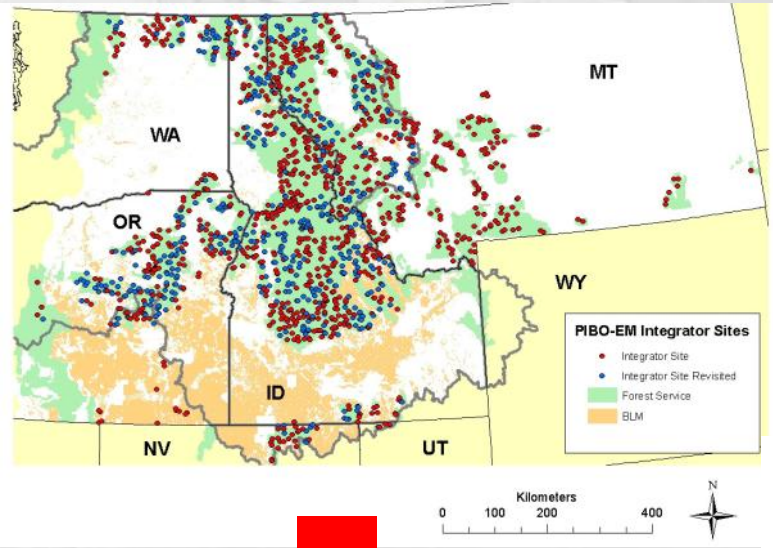
Methods online @:

www.fs.fed.us/rm/boise/AWAE/projects/stream_temperature.shtml

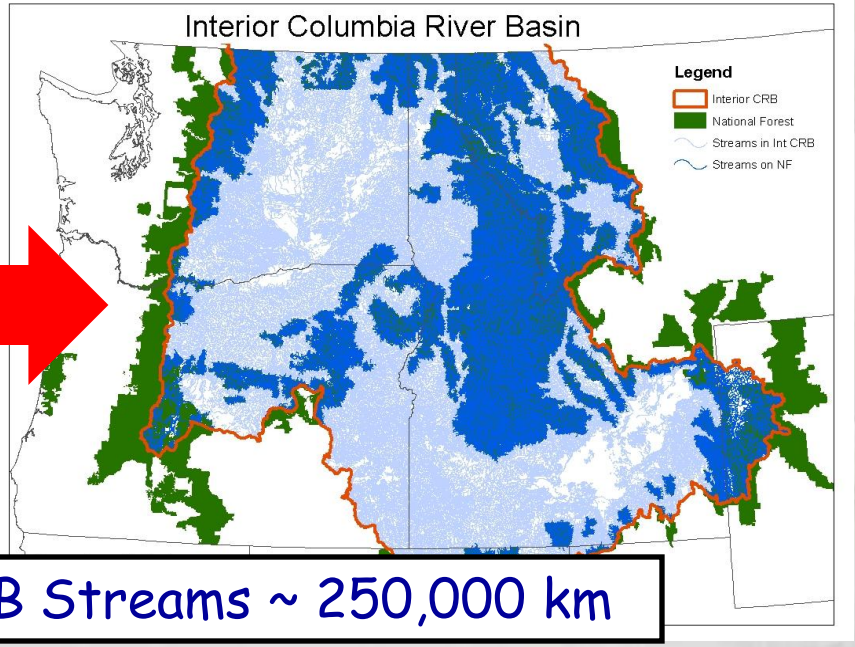
Google Search "Stream Temperature"

Regional Temperature Model Needed

Large regional temperature databases exist (n ~ 12,000 - 20,000 summers)

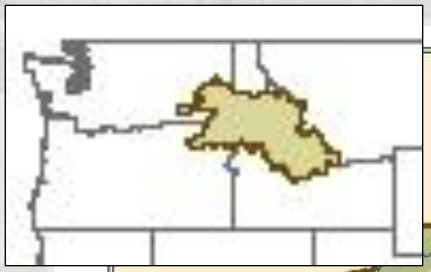


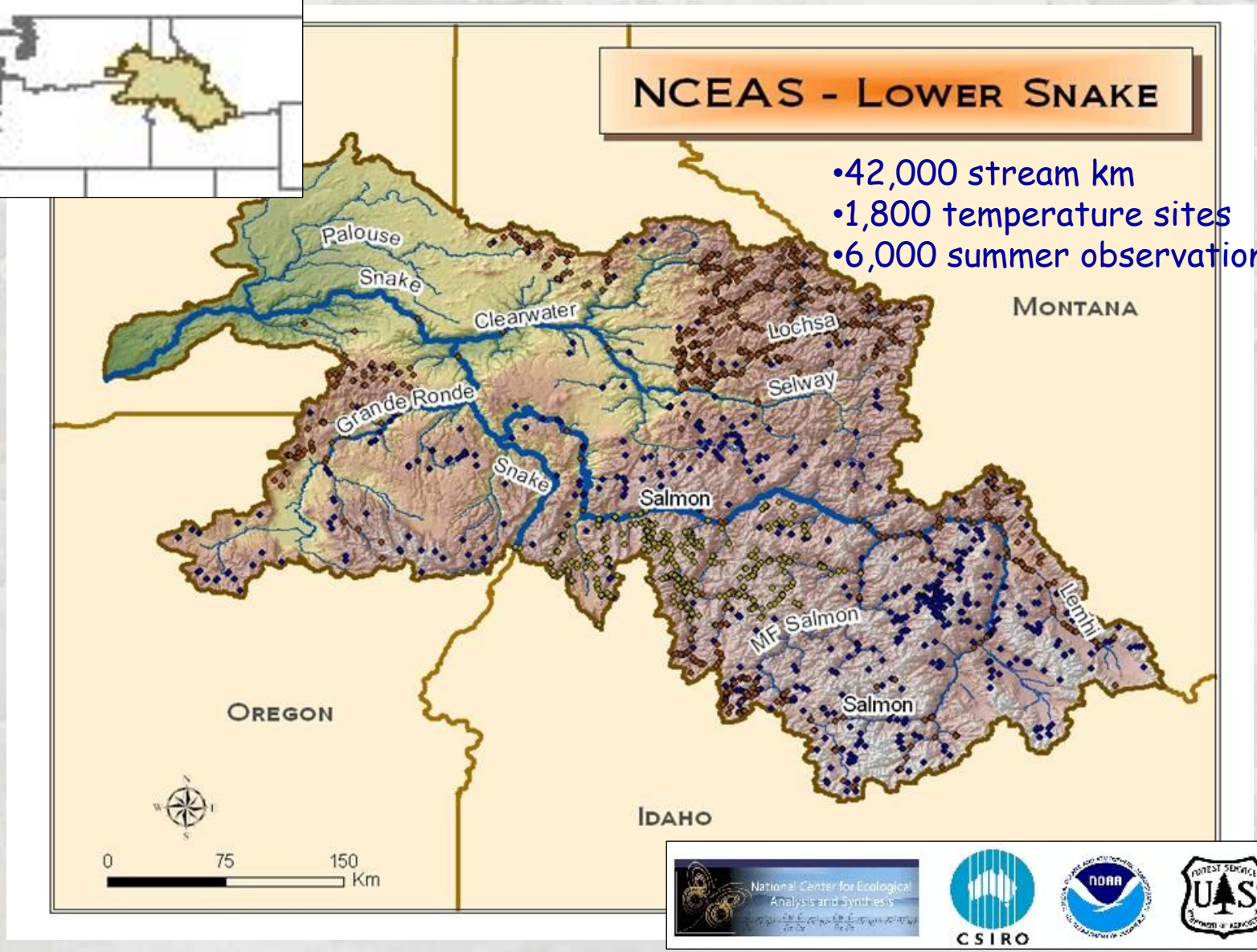
- Historical & future stream temps
- Species habitat summaries
- 1:100,000-Scale NHD+



ICB Streams ~ 250,000 km

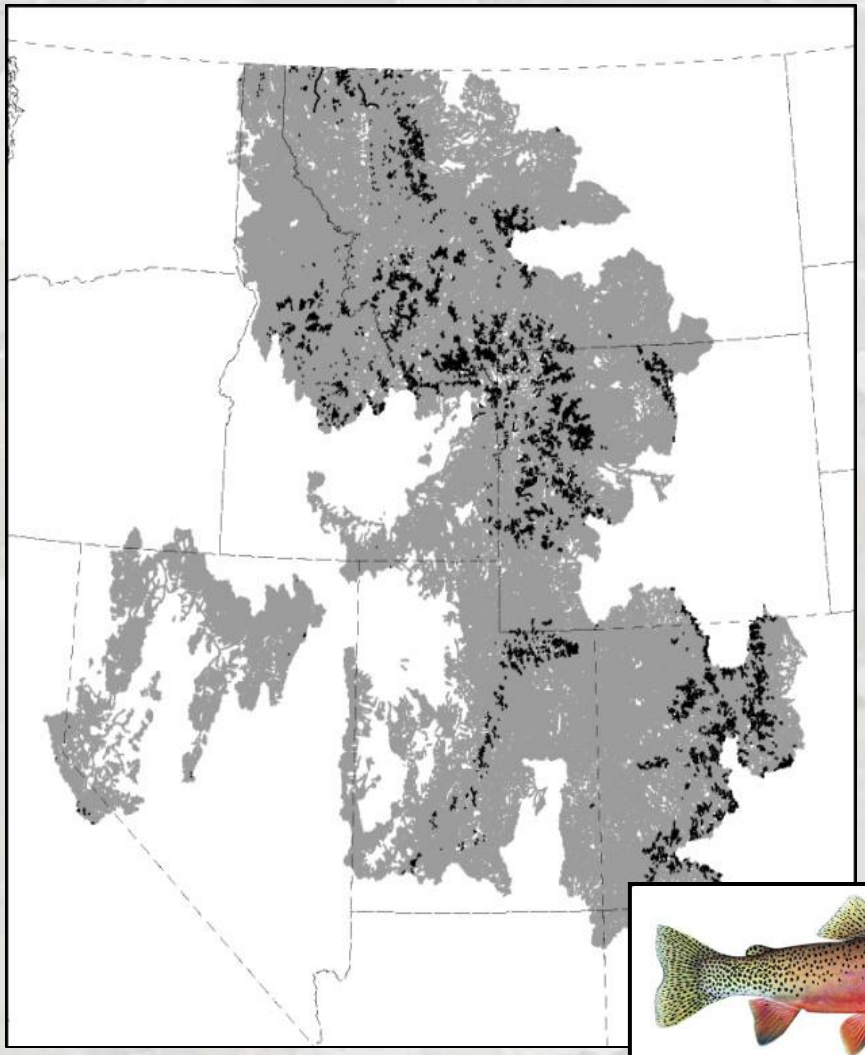
A Step Towards a Regional Temperature Model
NCEAS Lower Snake Study Domain

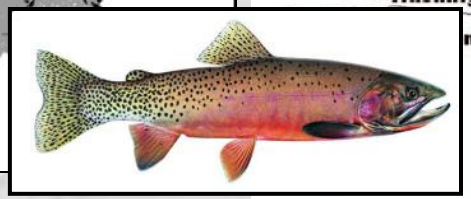




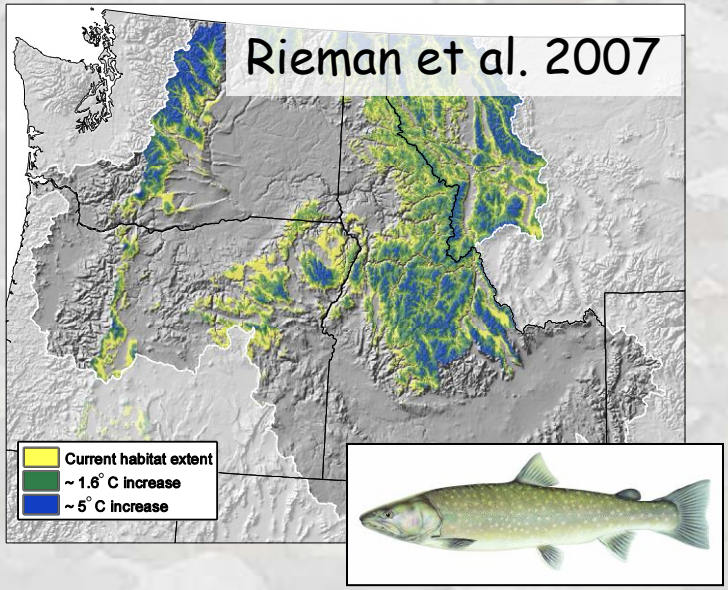
Regional Bioclimatic Assessments

No Stream Temperature Component

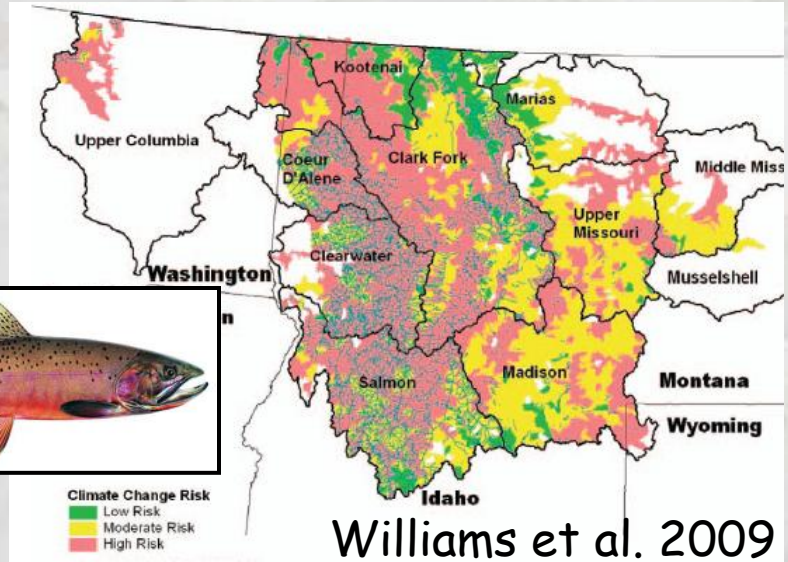




Wenger et al., Submitted.

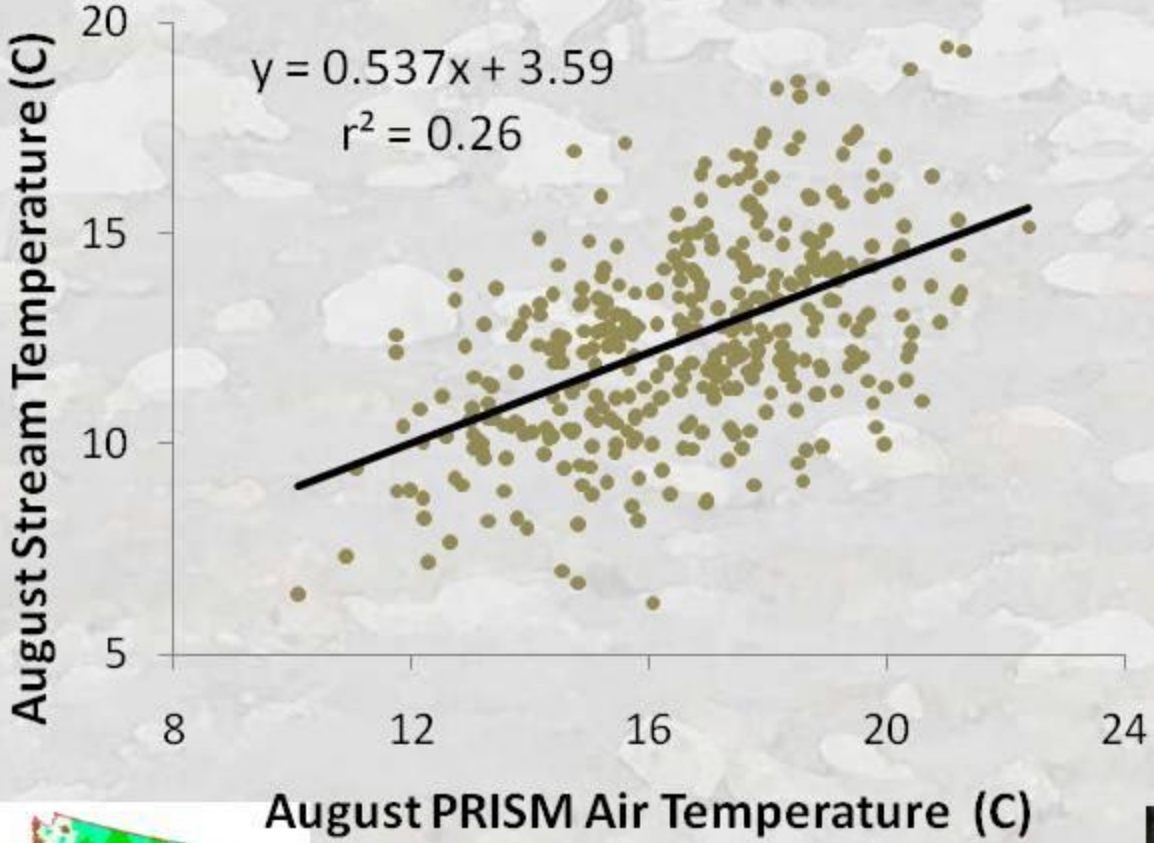


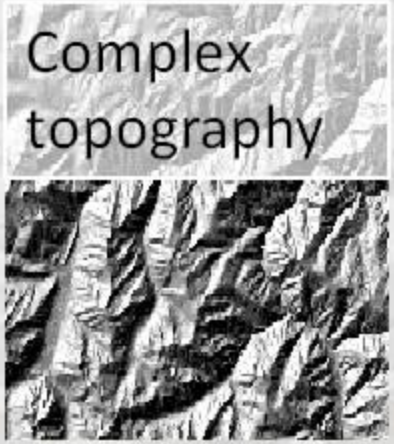
Rieman et al. 2007

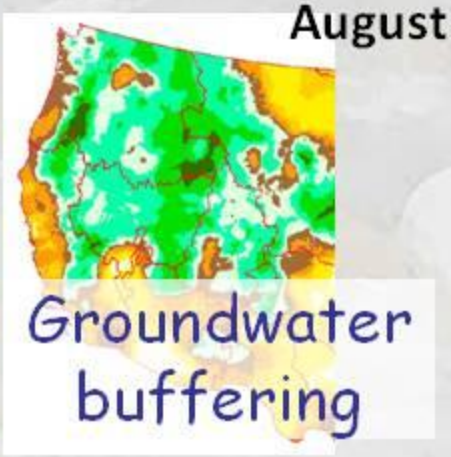


Williams et al. 2009

Air Temp ≠ Stream Temp

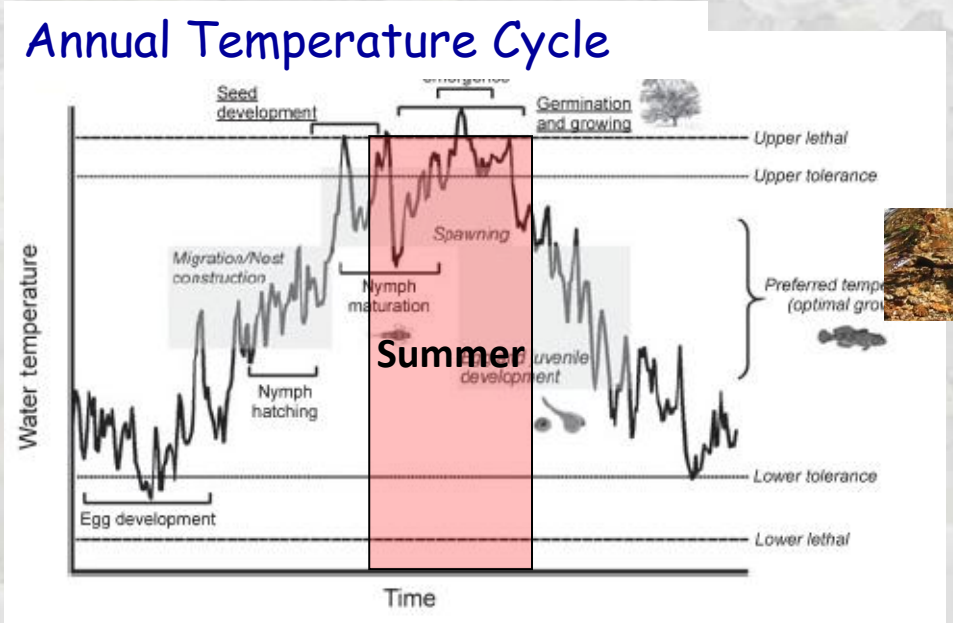




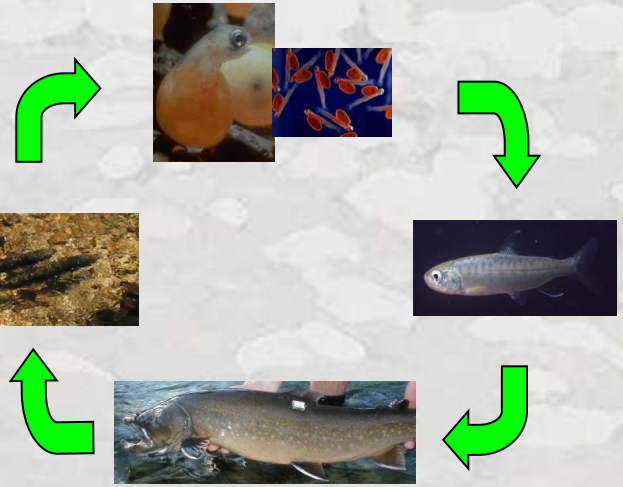


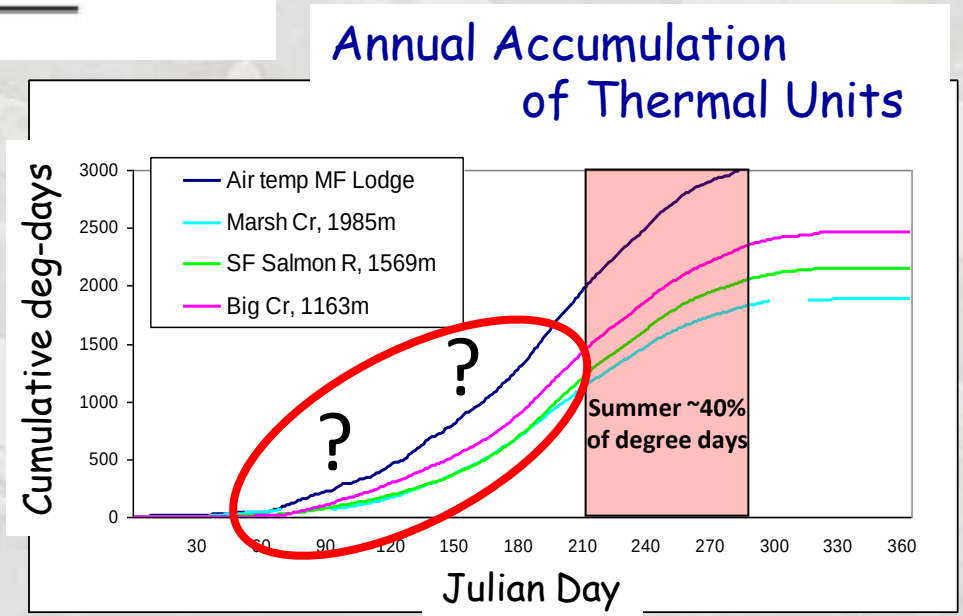
Summer is Not the Whole Story

Full-year Temp Data Needed



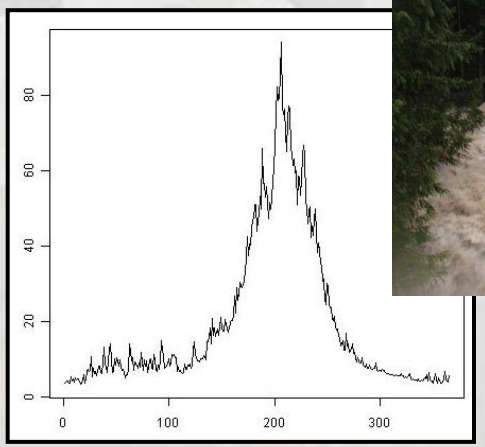
Olden and Naiman 2009





Acquiring Full-Year Temperature Data

Underwater Epoxy Protocol



Underwater epoxy

$100 = 5 years of data

Sensors glued to boulders

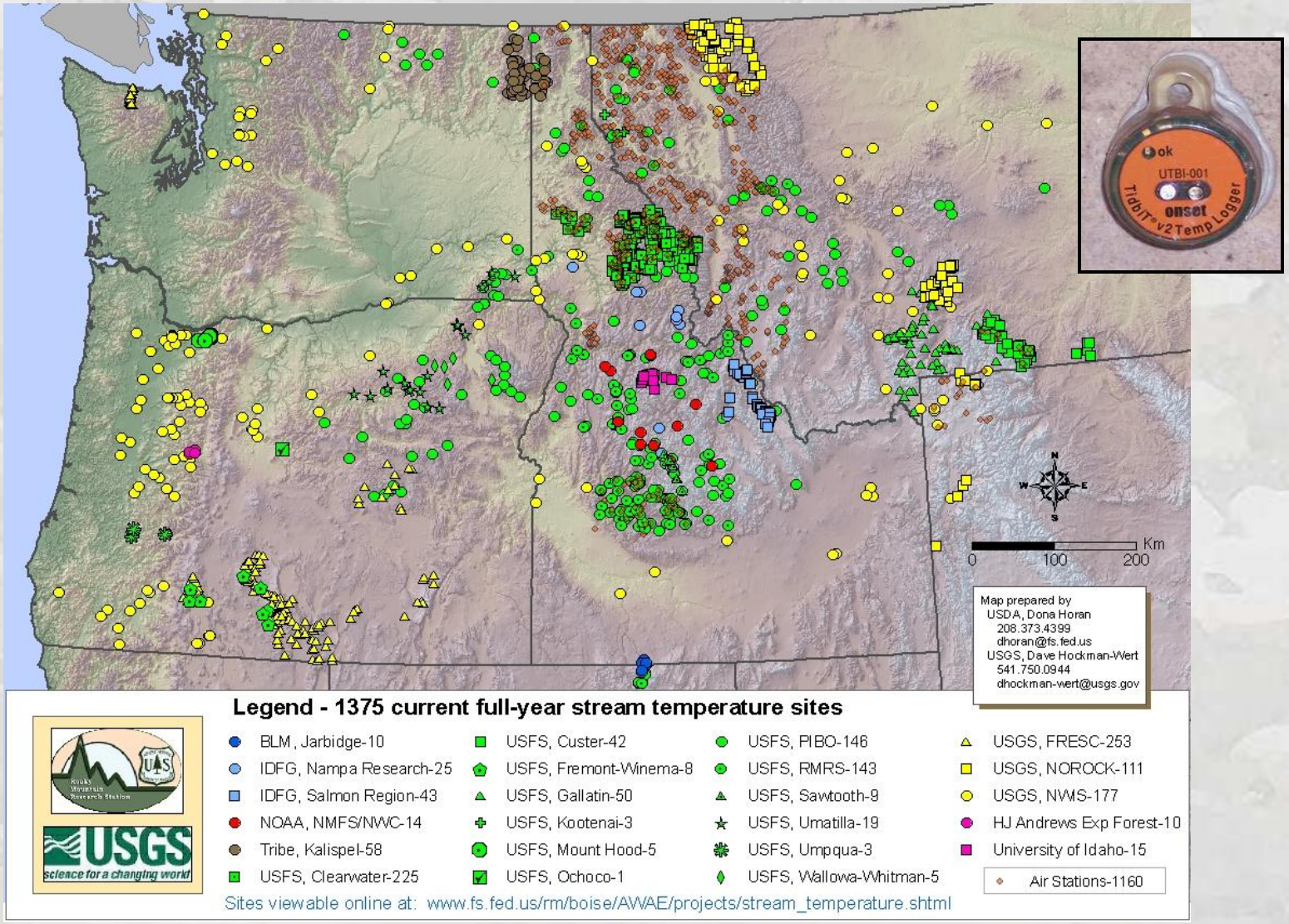
Retrieve data underwater

Isaak & Horan 2011. *NAJFM* 31:xxx-xxx

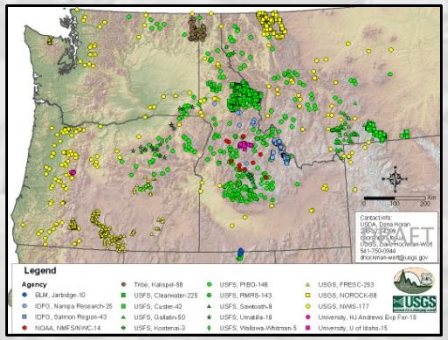
Regional Temperature Sensor Network

Current full-year stream temperature sites = 1375

Planned 2011 deployments ~1,000 (NOAA ~500, PIBO 150, USGS 100-200, R6/AREMP 200-300, misc. others ?)

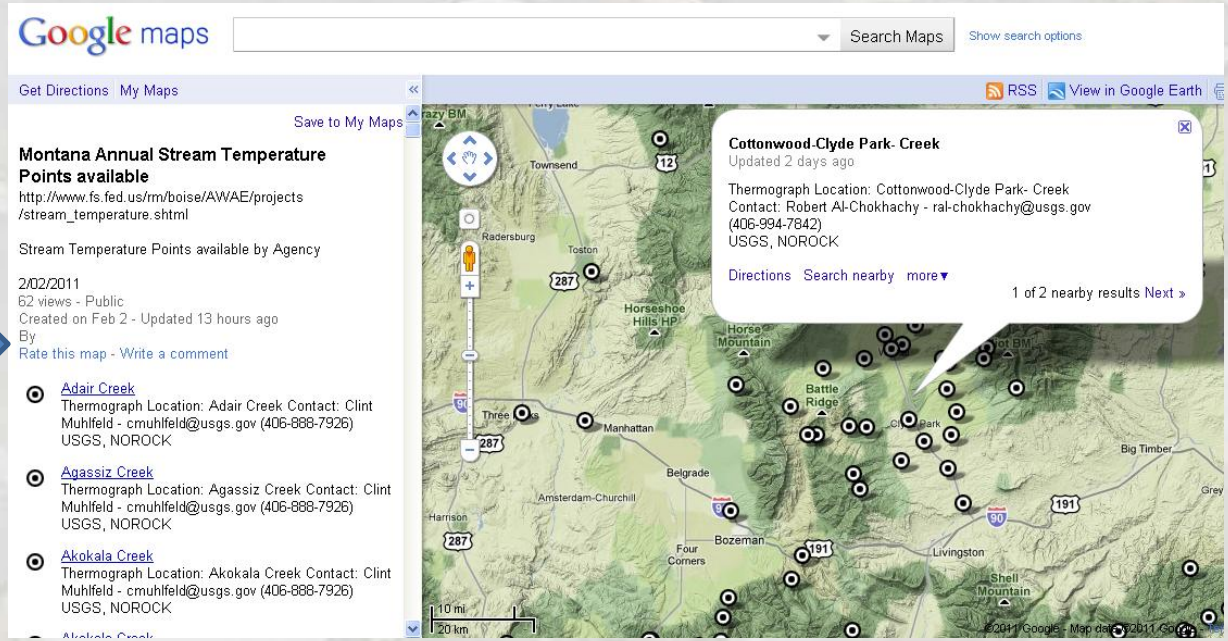


Dynamic GoogleMap Tool for Stream Temperature Monitoring Sites



Site Information

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

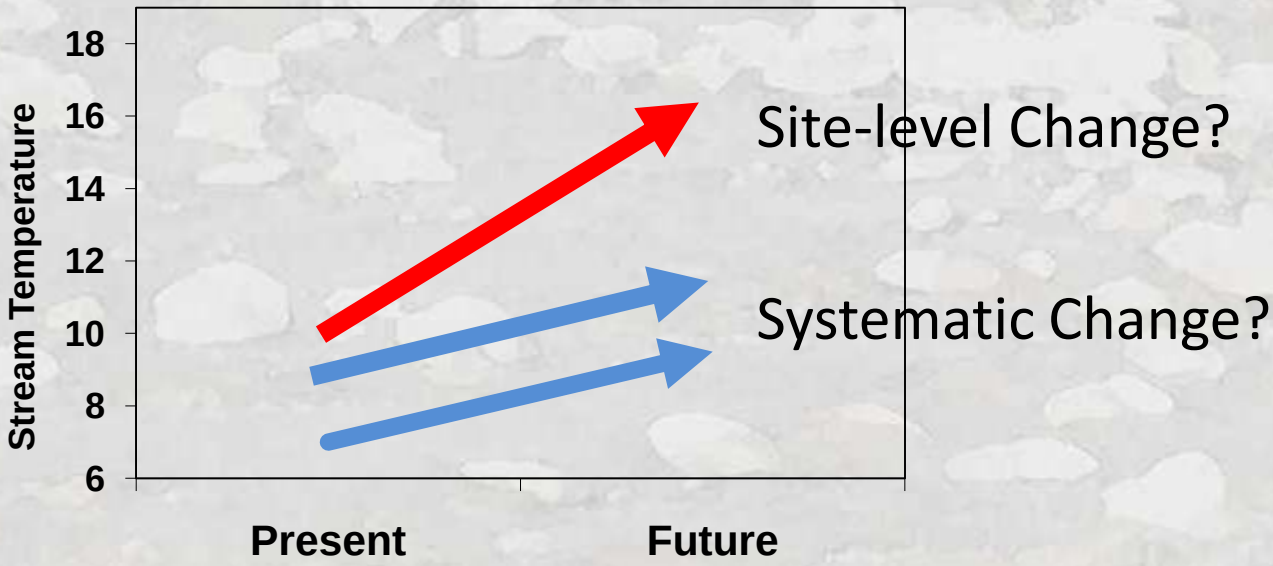


Webpage:

www.fs.fed.us/rm/boise/AWAE/projects/stream_temperature.shtml

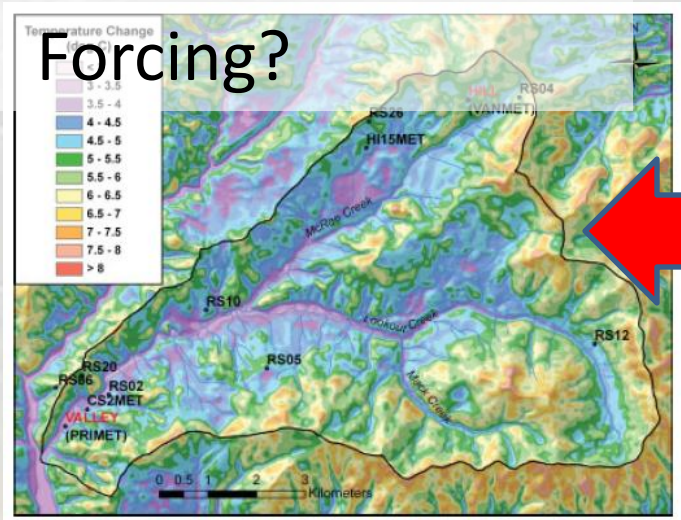
Google Search "Stream Temperature"

Spatial Variation in Temperature Changes



Different Climate Forcing?

Or Different Sensitivity?

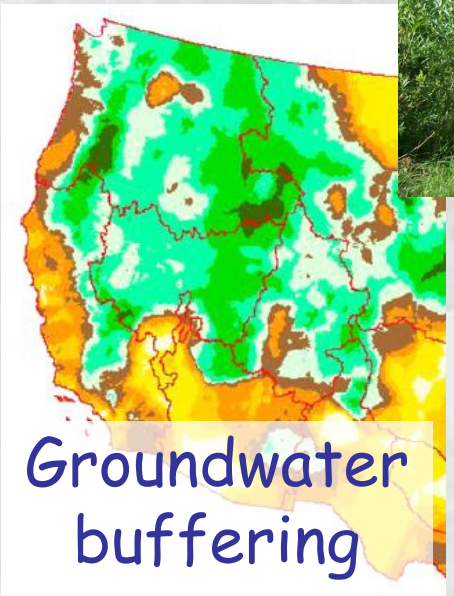


Past/present glaciation

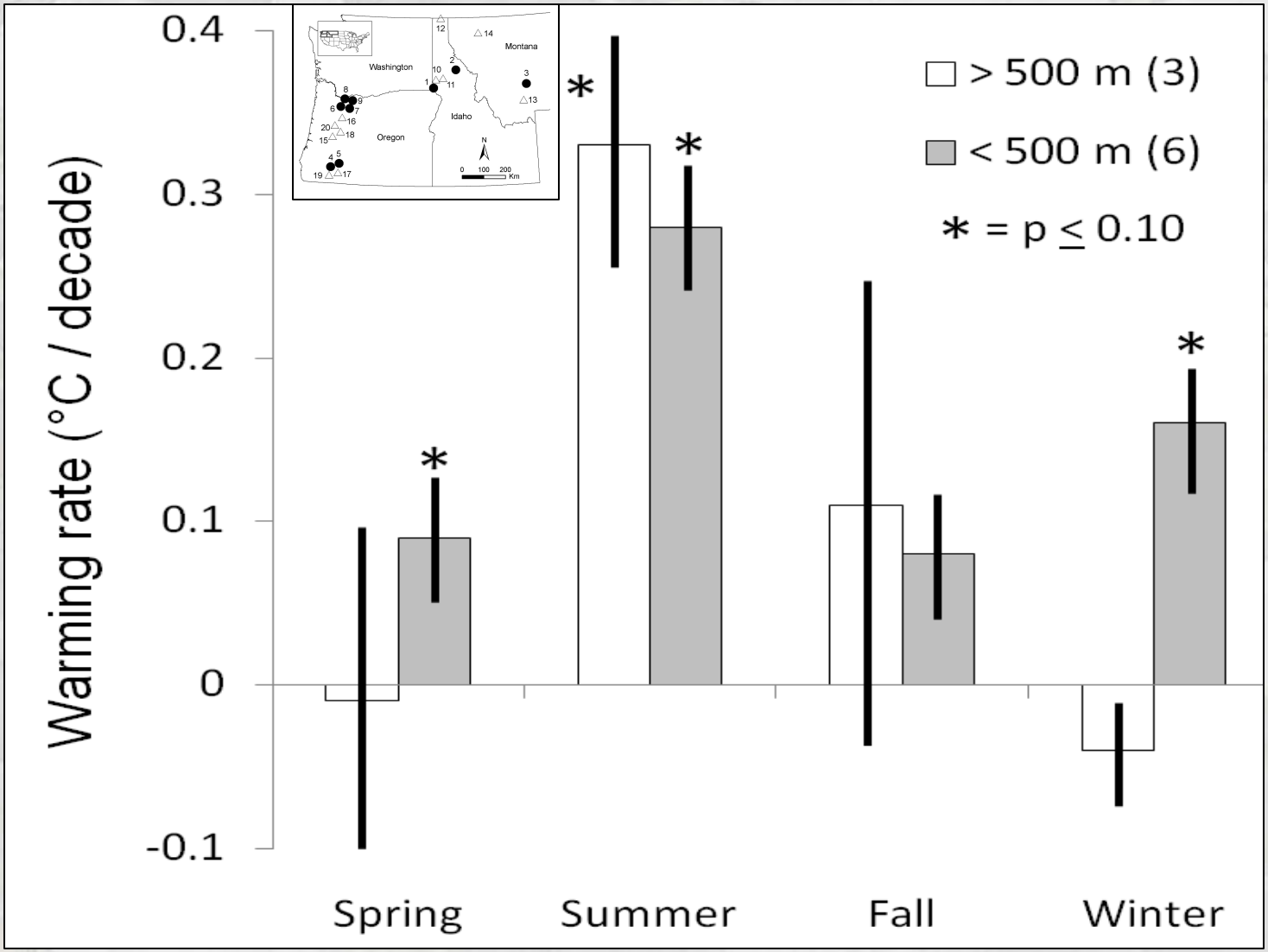
Daly et al. 2008

Hari et al. 2006

Which Factors Determine Sensitivity?



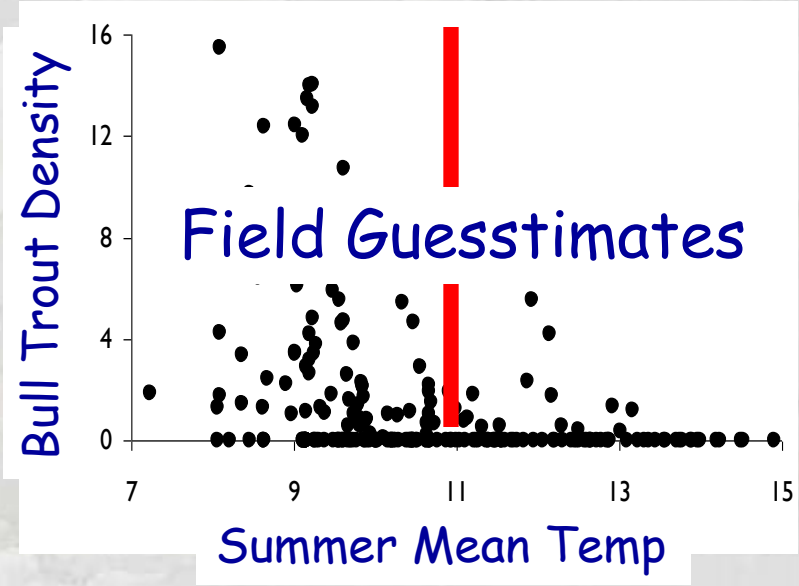
Elevational Trends in Warming of Northwest US Streams 1980-2009

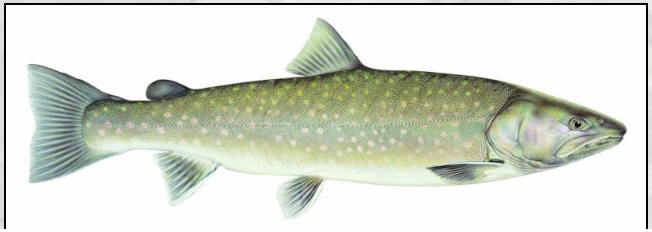


Isaak et al., In review. *Climatic Change*

Defining/Refining Thermal Habitat Criteria

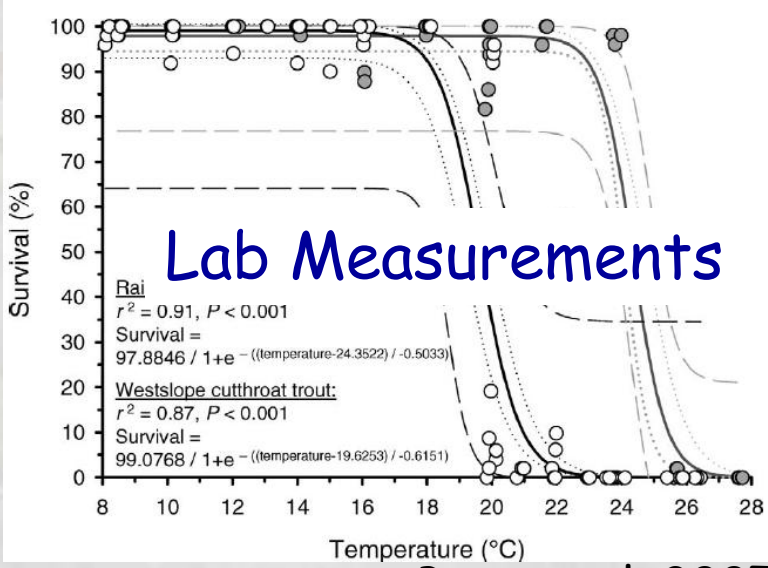
What is thermally suitable habitat?





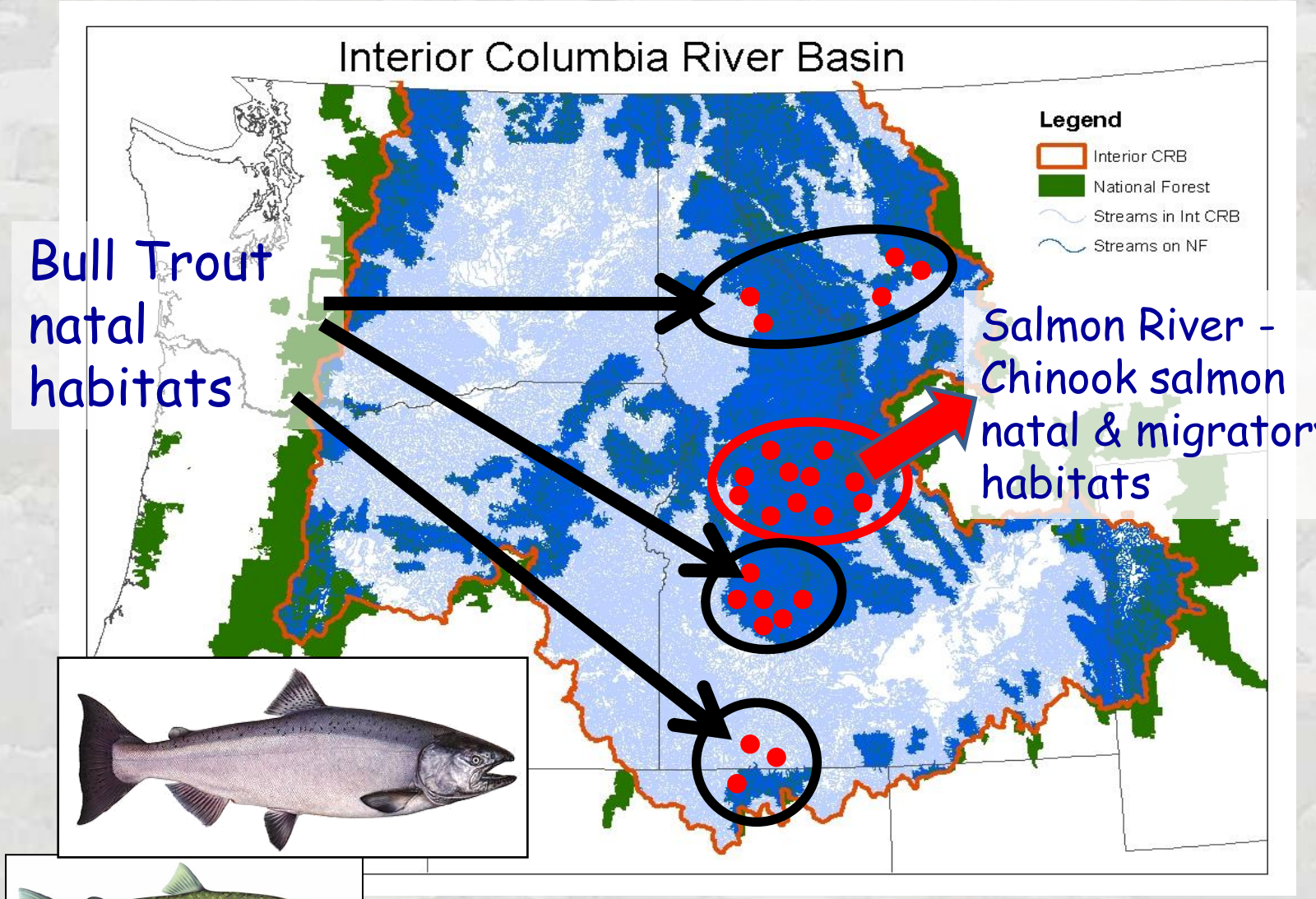
Bull trout thermal criteria

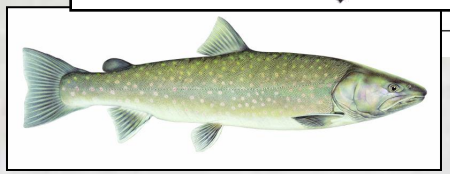
Suitable habitat < 12.0°C
High-quality habitat < 10.0°C



Bear et al. 2007

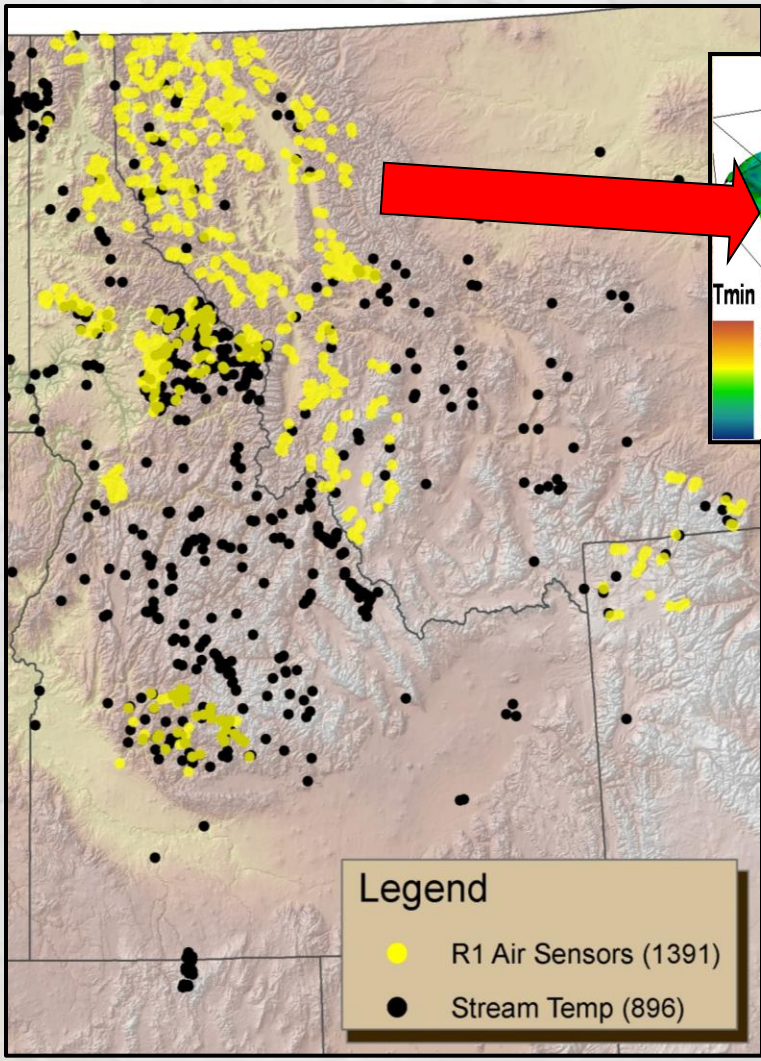
Ecological Temperature Sensor Networks

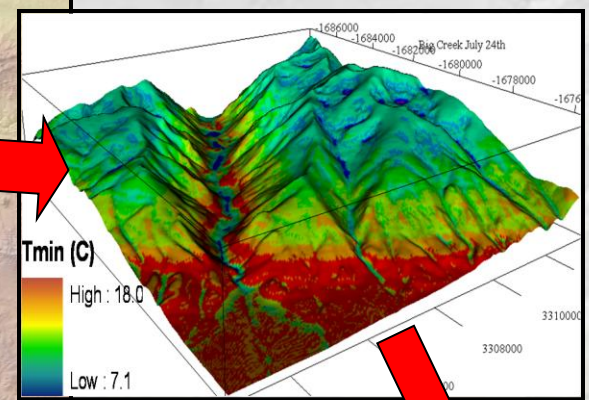




Massive Sensor Networks

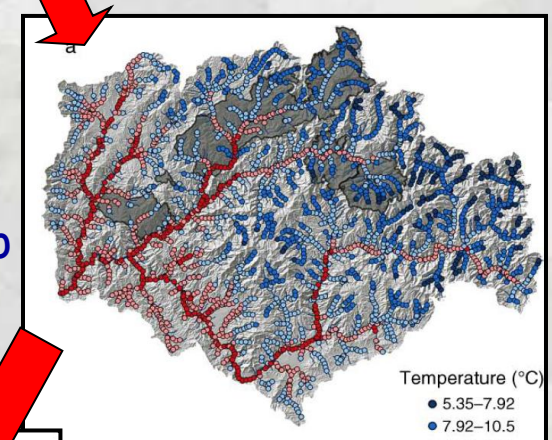
Ecologically Relevant Climate Downscaling

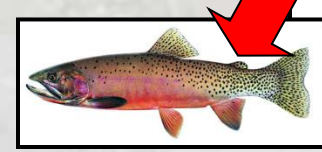




Continuous Space/Time Air Temp Surface

Continuous Space/Time Stream Temp Surface



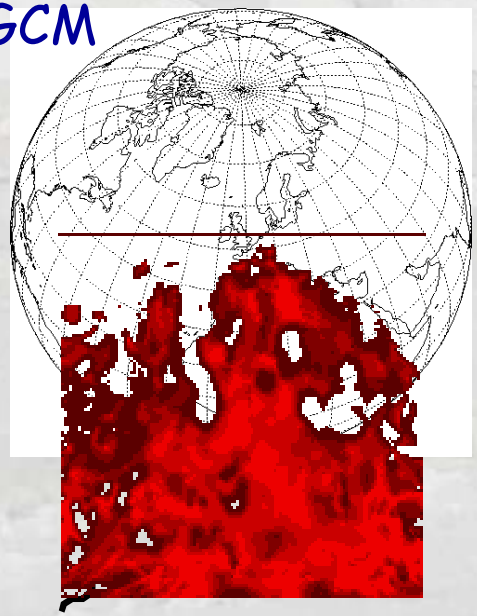


Wiens and Bachelet 2009

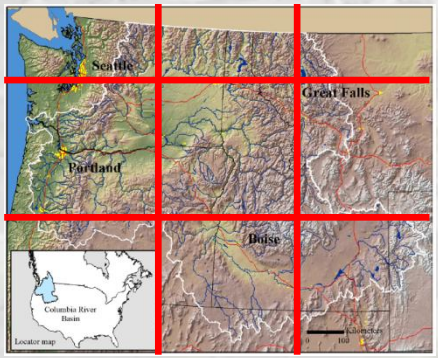
Better Downscaling

How will global trends affect my stream?

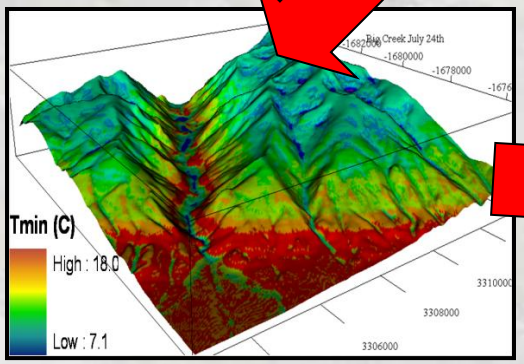
GCM

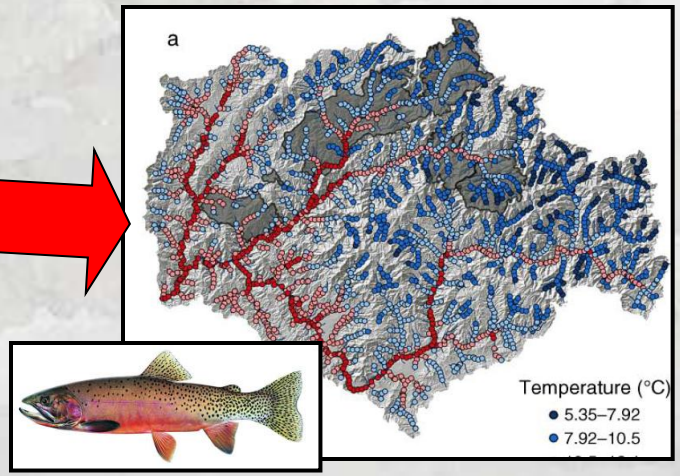


RCM



Integrated global-to-regional-to-landscape-to-stream systems





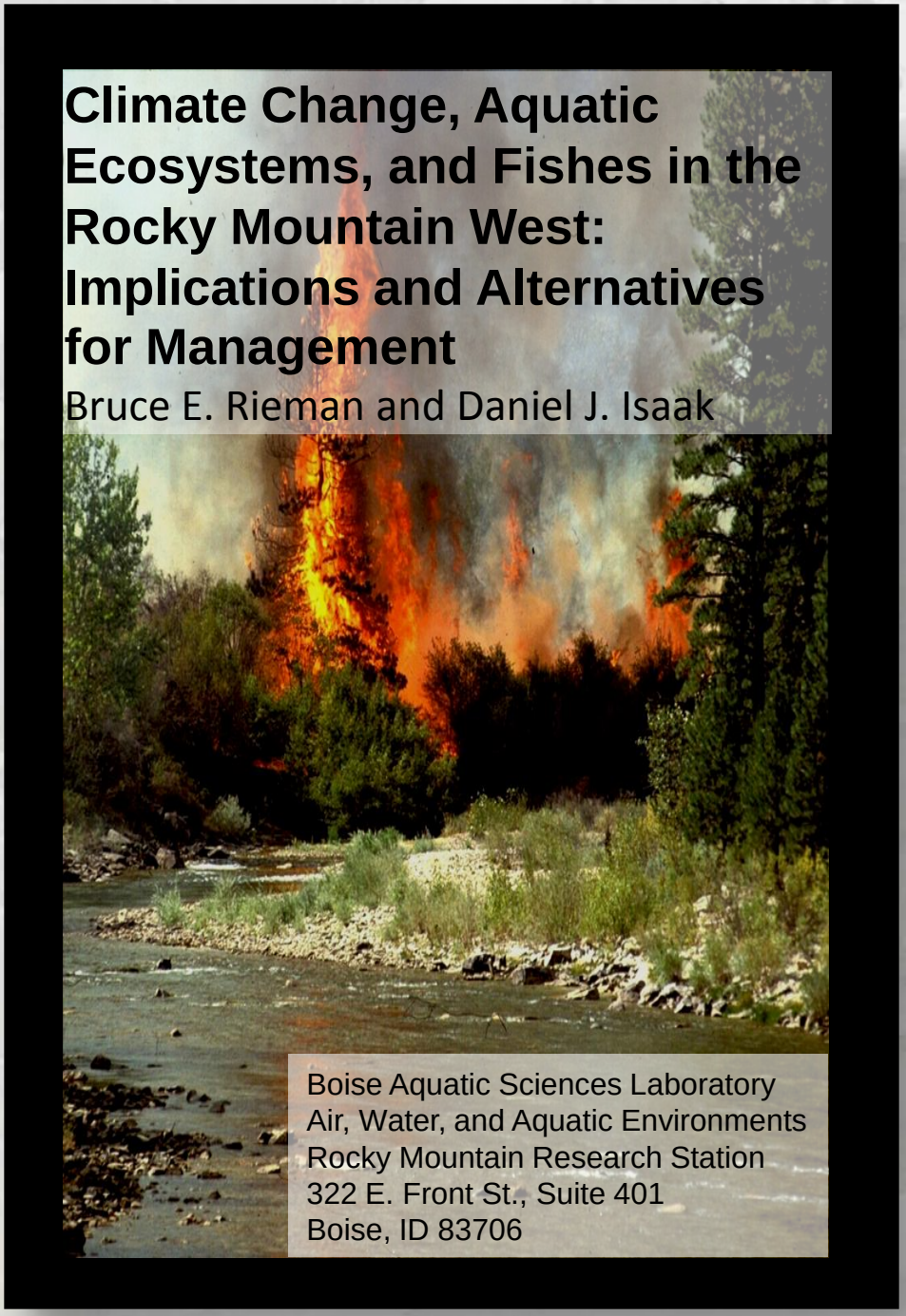
Key Points:

1) Stream temperature is a critical determinant of aquatic species growth, survival, distribution, and reproduction.

2) Empirical evidence suggests streams are warming in response to climate change. Warming rates are greatest during the summer but will be heterogeneous due to variation in climate forcing, geomorphic factors, and human/vegetative responses.

3) Regional models are needed for accurately predicting thermal responses of streams in a consistent manner. Development of regional models is possible using existing temperature databases in conjunction with new spatial analytical techniques.

4) More full-year, long-term stream temperature monitoring is needed. Full-year data have many applications for understanding climate effects & are inexpensive to collect using modern digital sensors.



Synthesis Document

Three Questions:

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?

Key References

Isaak, D.J., C. Luce, B.E. Rieman, D. Nagel, E. Peterson, D. Horan, S. Parkes, and G. Chandler. 2010. Effects of climate change and recent wildfires on stream temperature and thermal habitats for two salmonids in a mountain river network. Ecological Applications 20:1350-1371.

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Peterson, E.E., and J.M. Ver Hoef. 2010. A mixed-model moving-average approach to geostatistical modeling in stream networks. Ecology 91:644-651.

Rieman, B. E., D. Isaak, S. Adams, D. Horan, D., Nagel, and C. Luce. 2007. Anticipated climate warming effects on bull trout habitats and populations across the Interior Columbia River basin. Transactions of the American Fisheries Society 136:1552-1565.

Rieman, B. E., and D. J. Isaak. 2010. Climate change, aquatic ecosystems and fishes in the Rocky Mountain West: implications and alternatives for management. General Technical Report GTR-RMRS-250. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station

Ver Hoef, J.M., and E.E. Peterson. 2010. A moving average approach for spatial statistical models of stream networks. Journal of the American Statistical Association 105:6-18.

Wenger, S. J., D. J. Isaak, J. B. Dunham, K. D. Fausch, C. H. Luce, H. M. Neville, B. E. Rieman, M. K. Young, D. E. Nagel, D. L. Horan, and G. L. Chandler. In Press. Role of climate and invasive species in structuring trout distributions in the Interior Columbia Basin. Canadian Journal of Fisheries and Aquatic Sciences.

Wenger, S. J.; C.H. Luce, A.F. Hamlet, D.J. Isaak, H.M. Neville. 2010. Macroscale hydrologic modeling of ecologically relevant flow metrics. Water Resources Research. doi:10.1029/2009WR008839. Data for western US streams available @: http://www.fs.fed.us/rm/boise/AWAE/projects/modeled_stream_flow_metrics.shtml

Most publications available through: www.fs.fed.us/rm/boise/index.shtml or www.fs.fed.us/rm/boise/awae_home.shtml

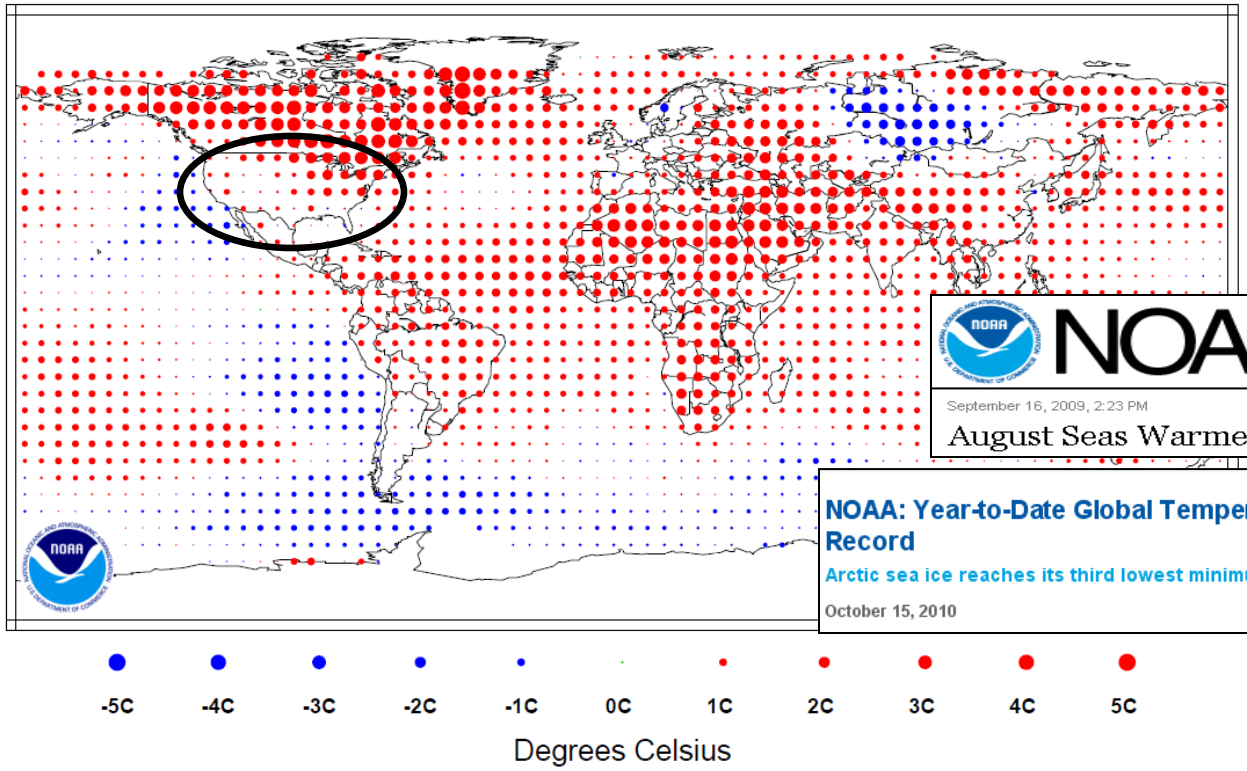
Don't Stop Believing

National Survey Finds Public Concern About Global Warming Drops Sharply January 29, 2010 , CBB

Temperature Anomalies Jan-Sep 2010

(with respect to a 1971-2000 base period)

National Climatic Data Center/NESDIS/NOAA



NOAA

September 16, 2009, 2:23 PM

August Seas Warmest in at Least 120 Years

NOAA: Year-to-Date Global Temperature Ties for Warmest on Record

Arctic sea ice reaches its third lowest minimum extent on record

October 15, 2010

US Forest Service
Rocky Mountain Research Station
Air, Water, and Aquatics Program
Boise Aquatic Sciences Lab

<u>websites:</u> www.fs.fed.us/rm/boise/index.shtml
www.fs.fed.us/rm/boise/awae_home.shtml