Monitoring & Modeling Stream Temperature Response to Climate Change:

Lessons Learned from the Northwest US

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

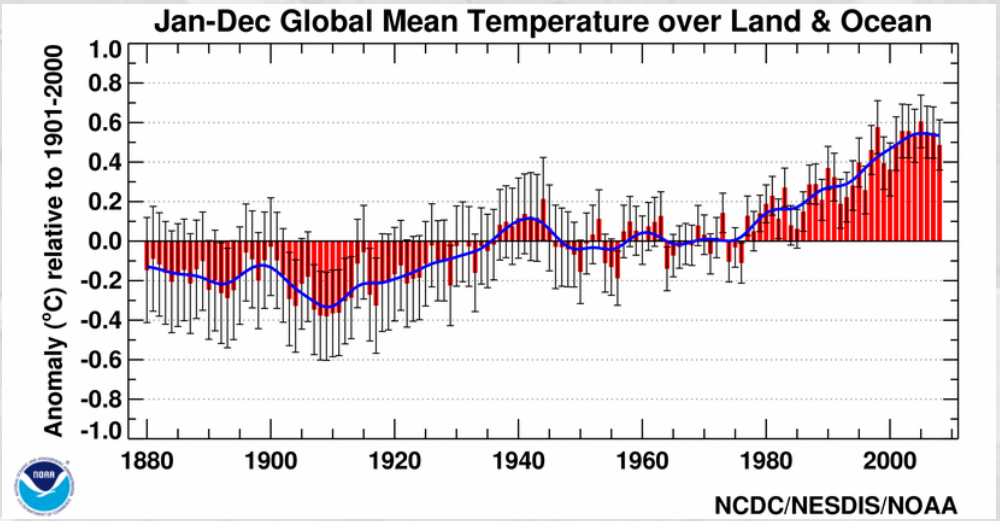
U.S. Forest Service

[1]CSIRO

[2]NOAA

[3]U.S. Geological Survey

Air, Water & Aquatics Program



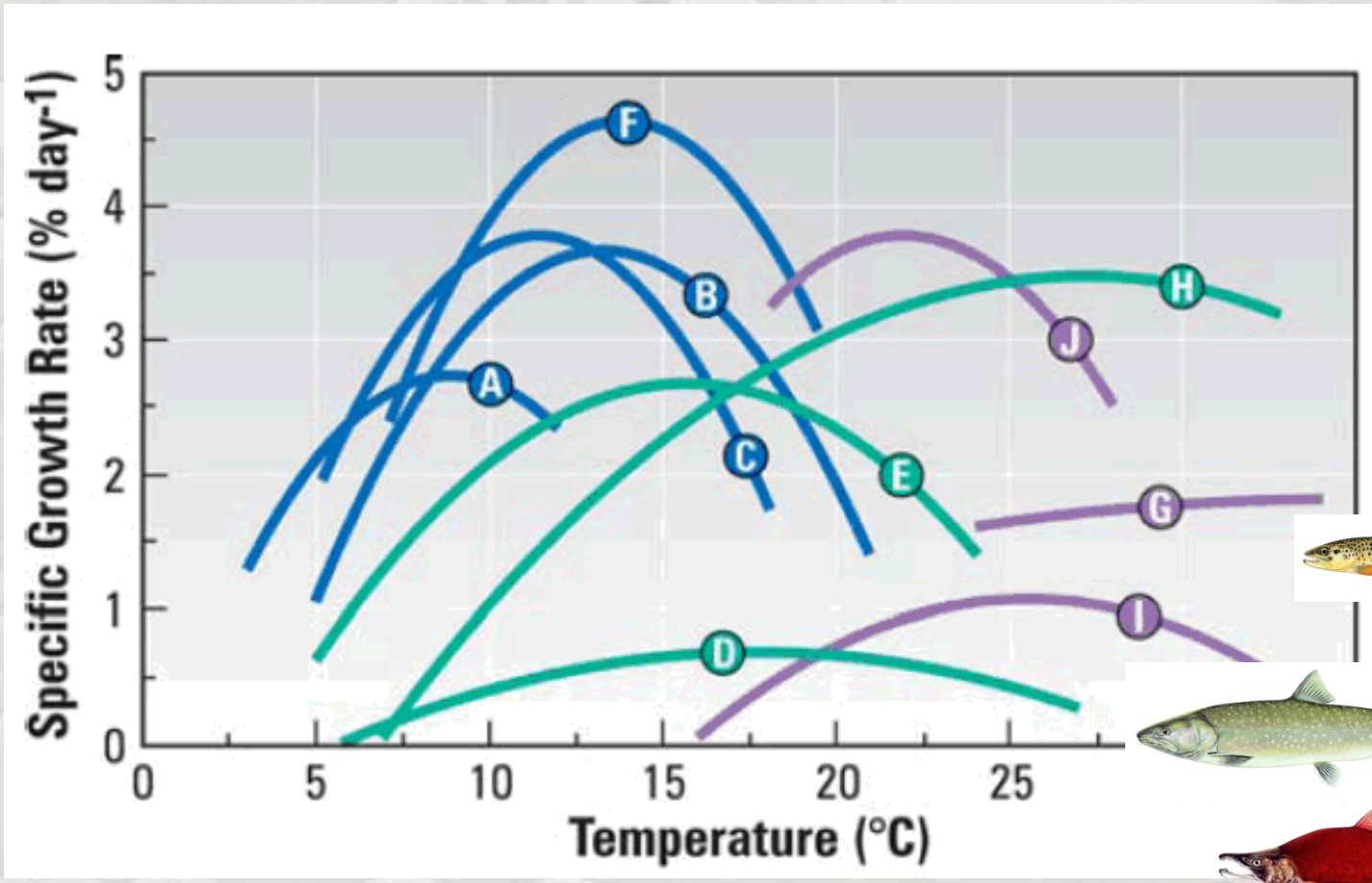
CSIRO

PIBO Fish & Aquatic Ecology Unit

NOAA

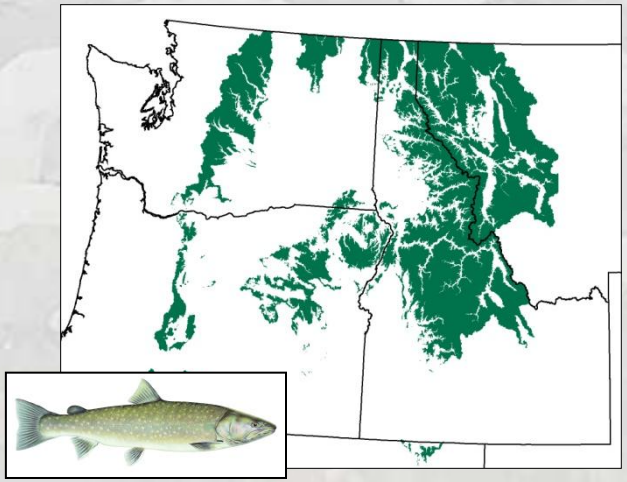
USGS science for a changing world

Species-Specific Thermal Niches



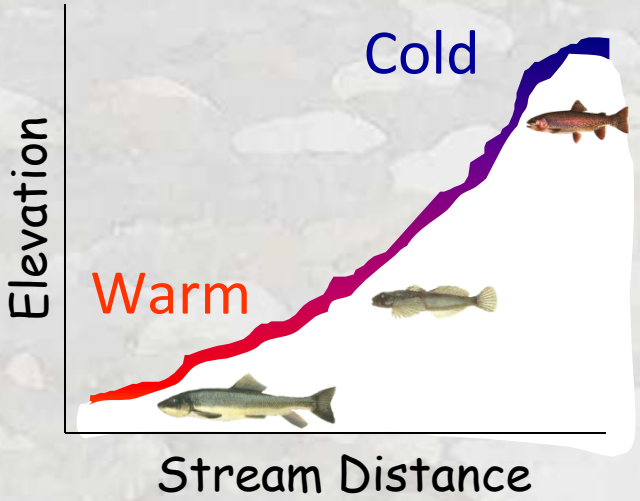
Temperature Regulation – Spatial Distributions

Regional Scale

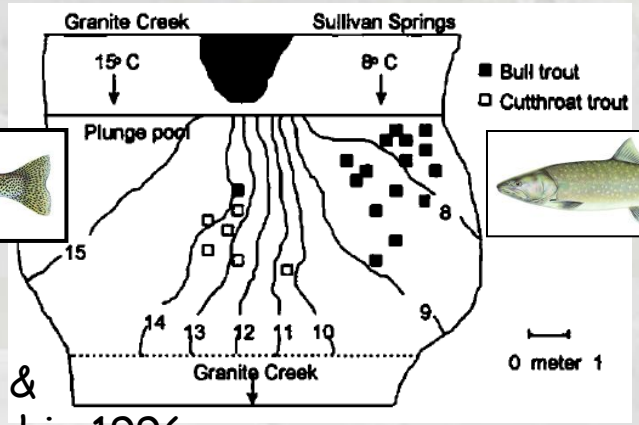


Rieman et al. 2007

Stream Scale



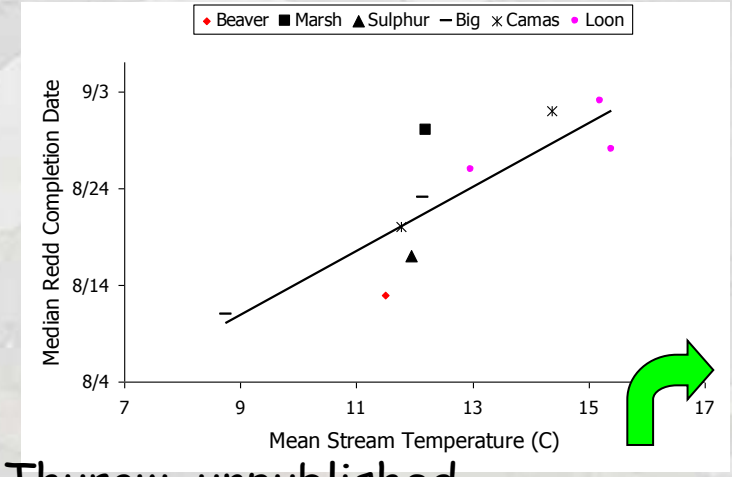
Channel Unit Scale



Bonneau & Scarnecchia 1996

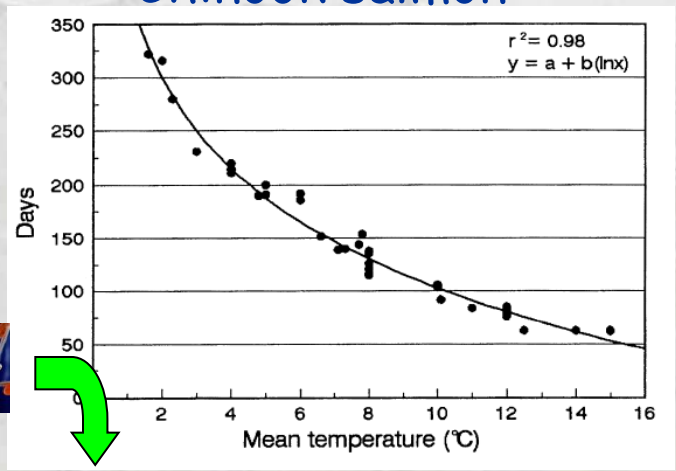
Temperature Regulation - Life Cycle

Spawn timing - Chinook salmon



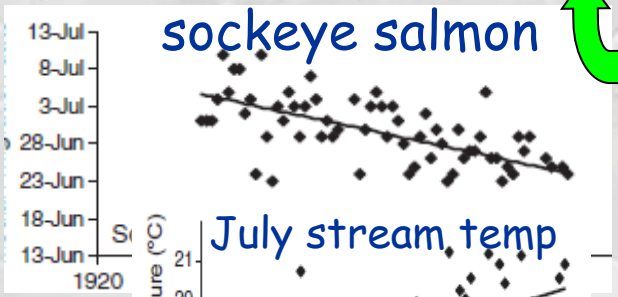
Thurow, unpublished

Incubation length - Chinook salmon

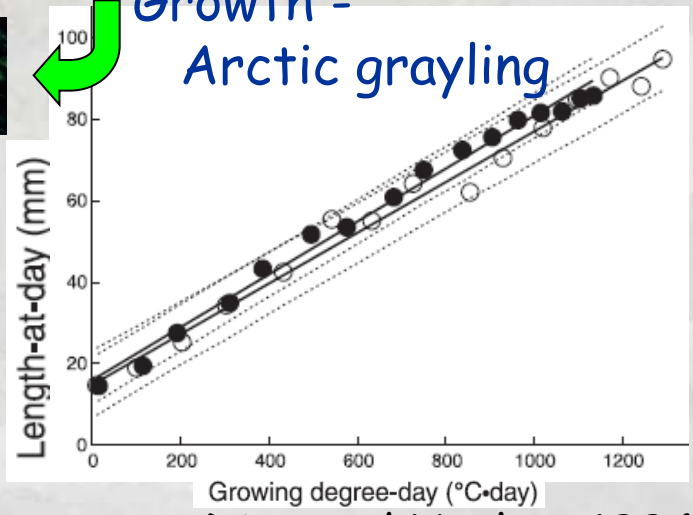


Brannon et al. 2004

Migration timing - sockeye salmon

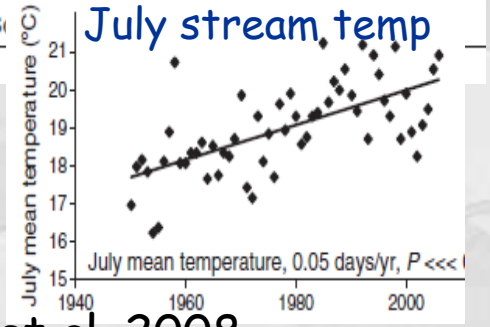


Growth - Arctic grayling



Dion and Hughes 1994

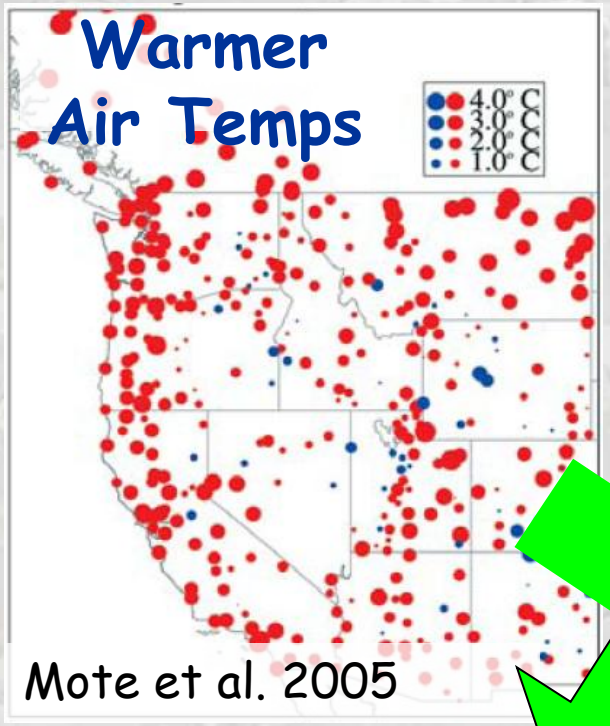
July stream temp



Crozier et al. 2008

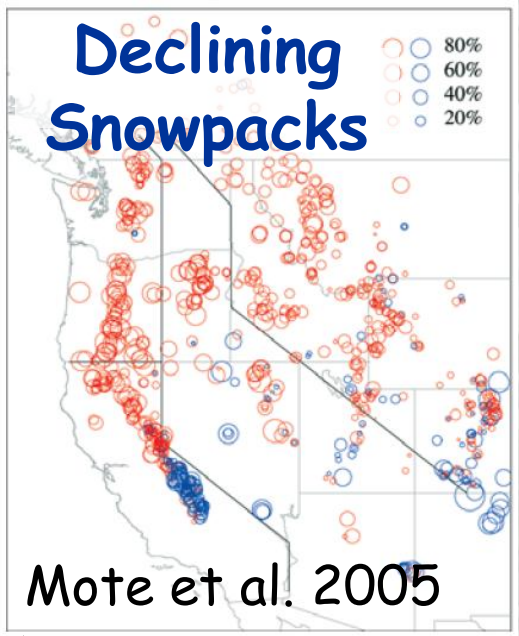
Western US – Observed Trends

Warmer Air Temps



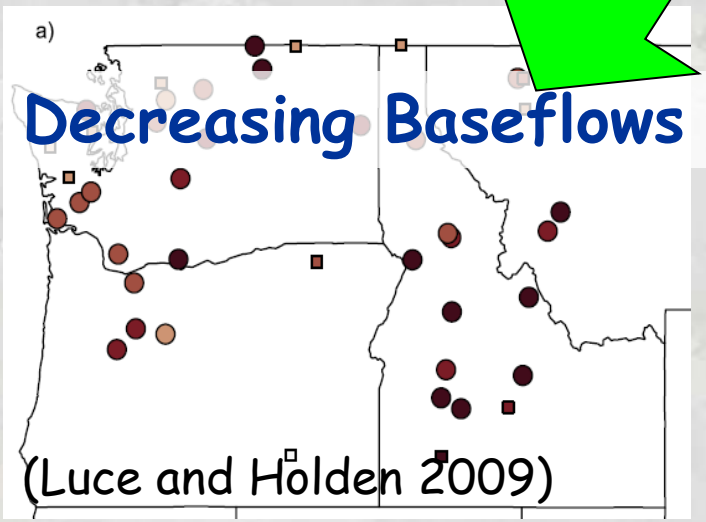
Mote et al. 2005

Declining Snowpacks



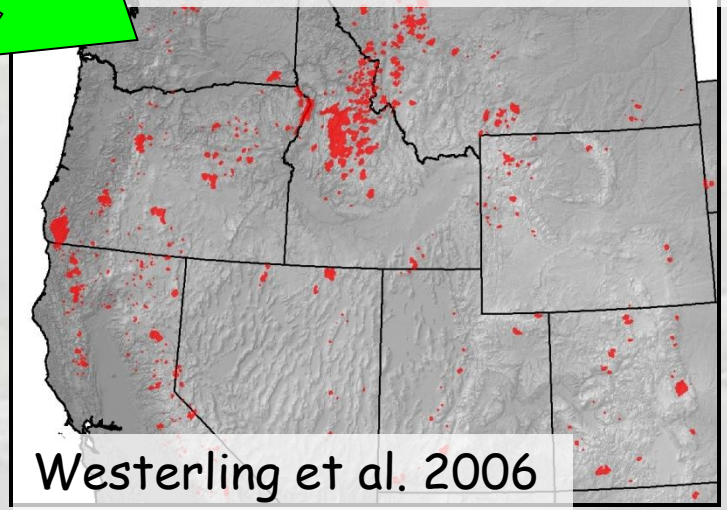
Mote et al. 2005

Decreasing Baseflows



(Luce and Holden 2009)

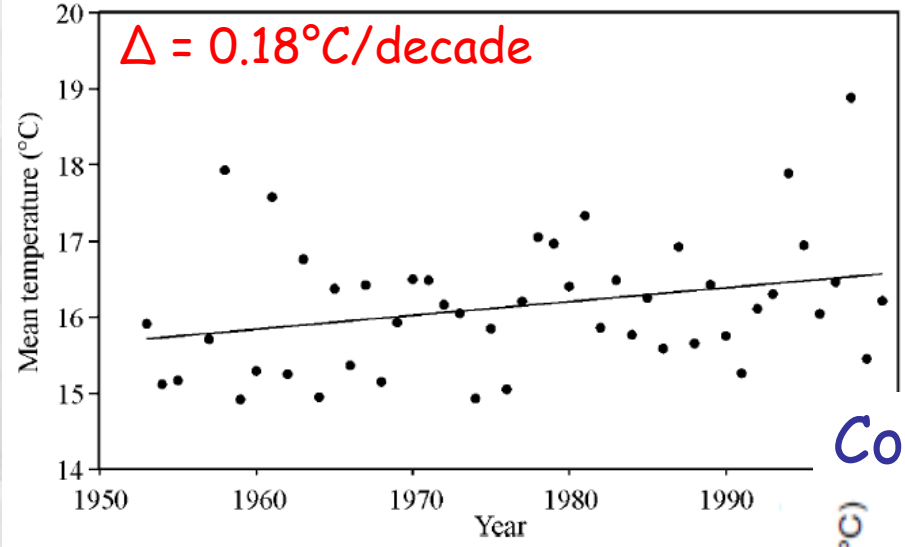
Wildfire Increases



Westerling et al. 2006

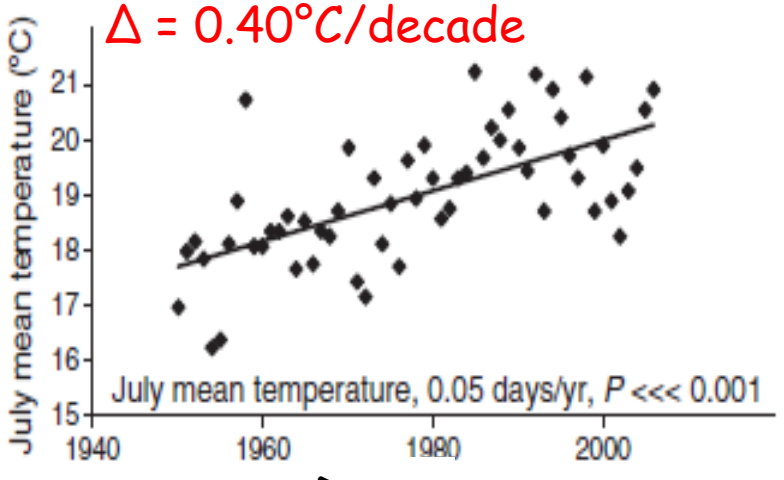
Observed Temperature Trends In Northwest US Rivers

Fraser River - Summer



Morrison et al. 2002

Columbia River - Summer

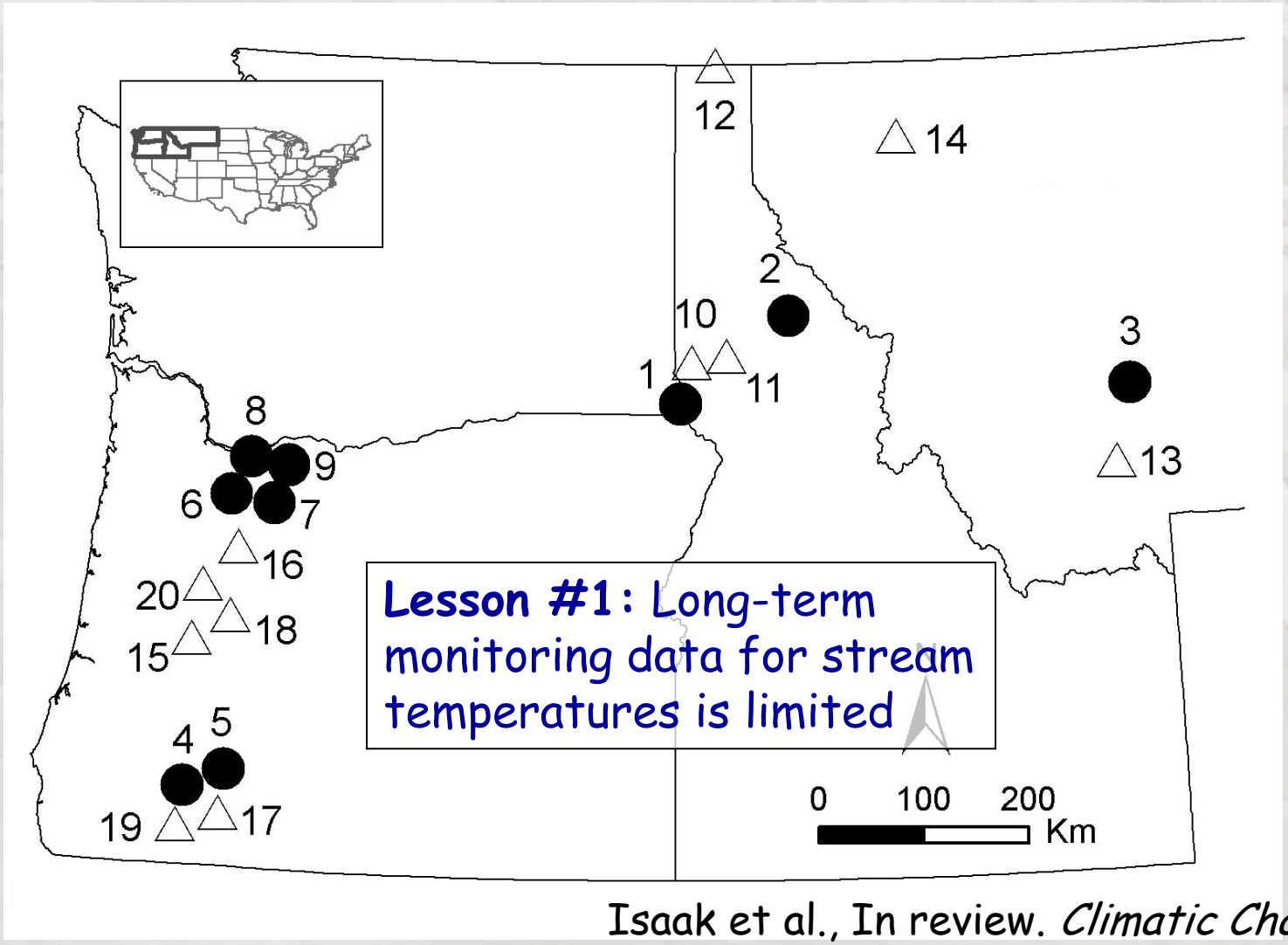


Petersen and Kitchell 2001; Crozier et al. 2008

Regional Trends In Stream Temperatures

USGS NWIS Monitoring Sites (1980 – 2009)

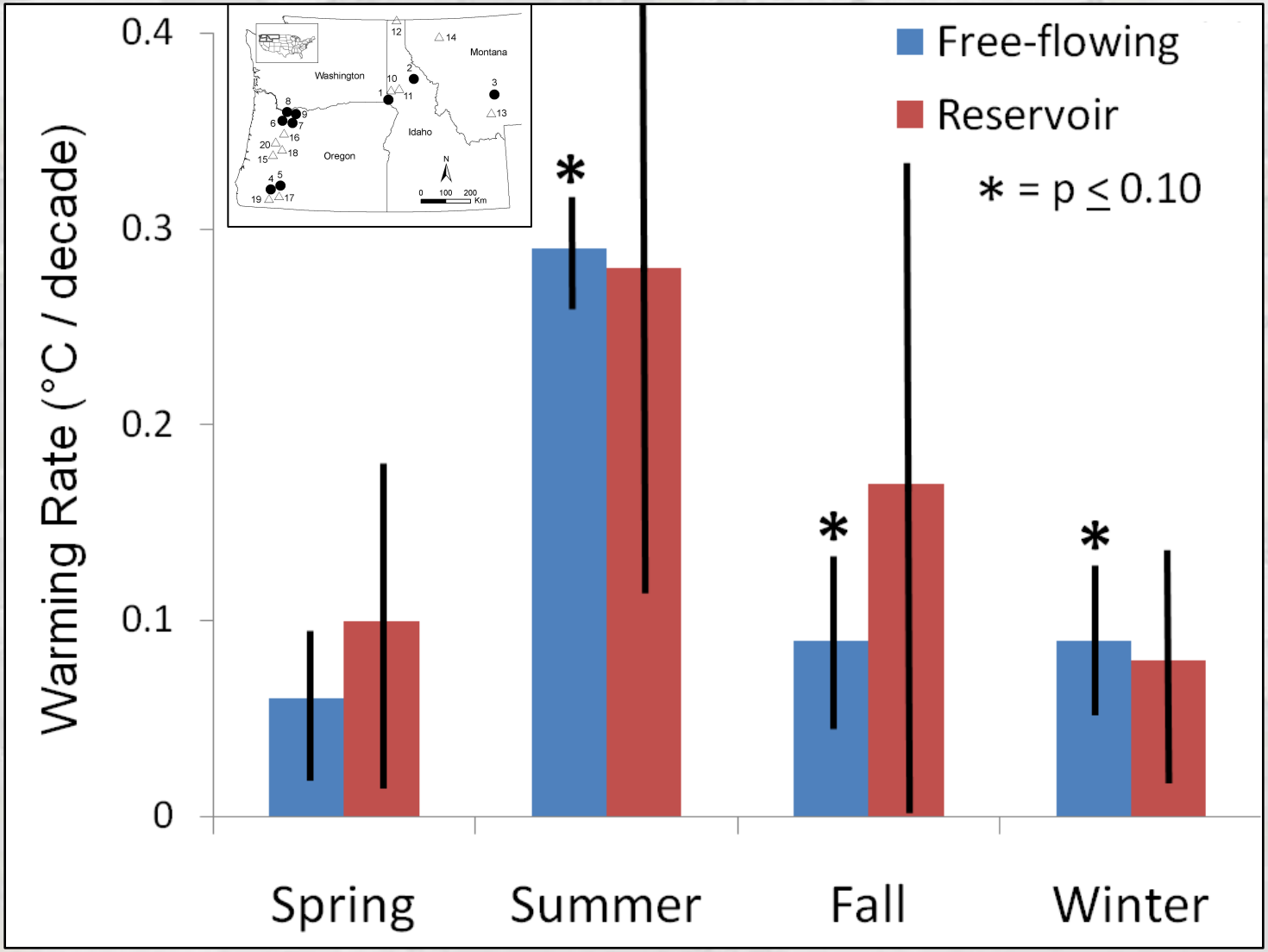
△ = reservoir affected (11) ● = free-flowing (9)



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*

Application of Spatial Statistical Stream Models to Develop River Network Temperature Models

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

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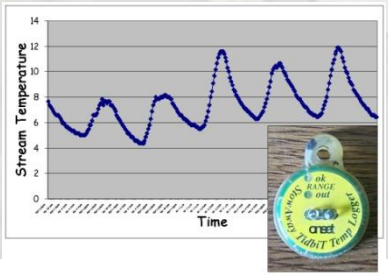
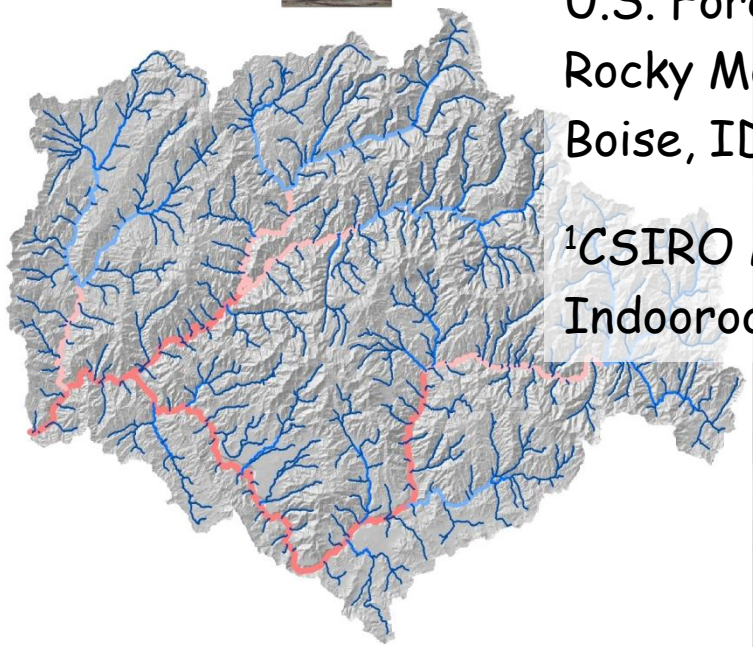
Indooroopilly, Queensland, Australia





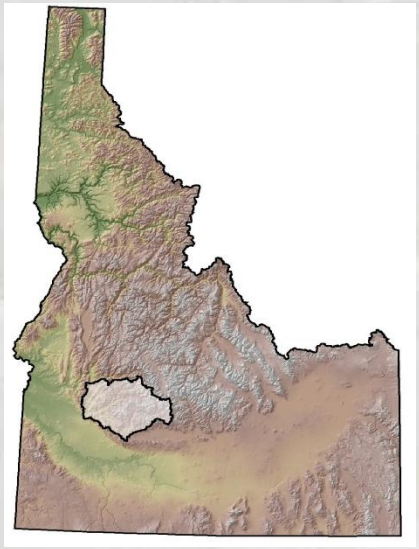
CSIRO

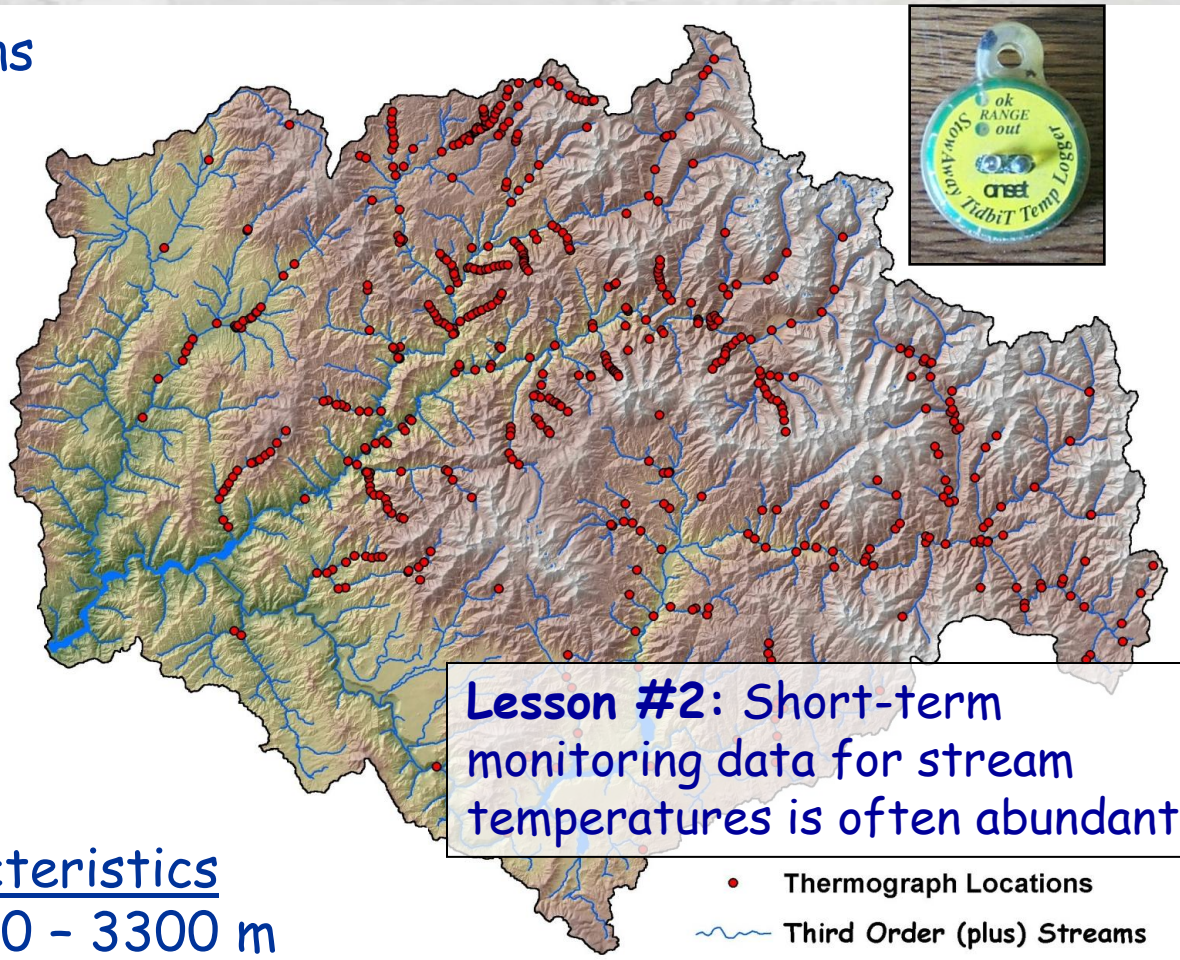
BOISE AQUATIC SCIENCES LAB
RMRS

Boise River Temperature Database

Stream Temperature Database

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



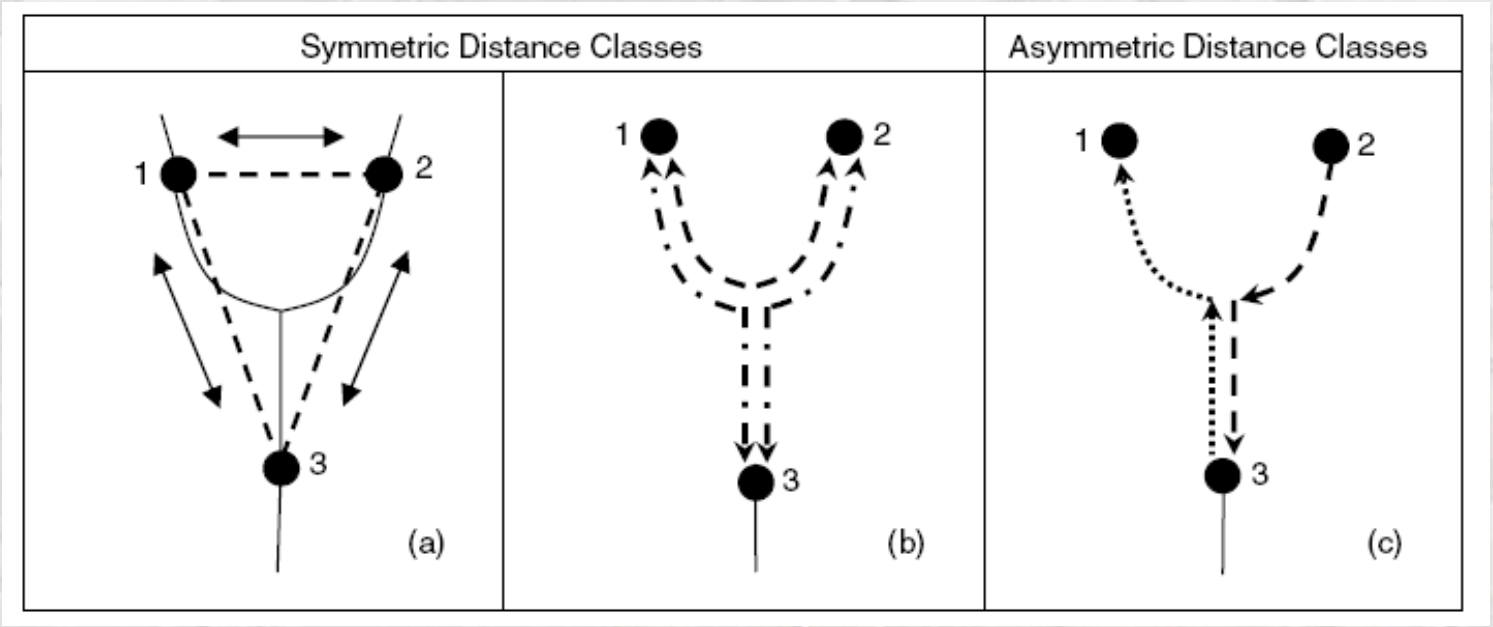


Lesson #2: Short-term monitoring data for stream temperatures is often abundant

Watershed Characteristics

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

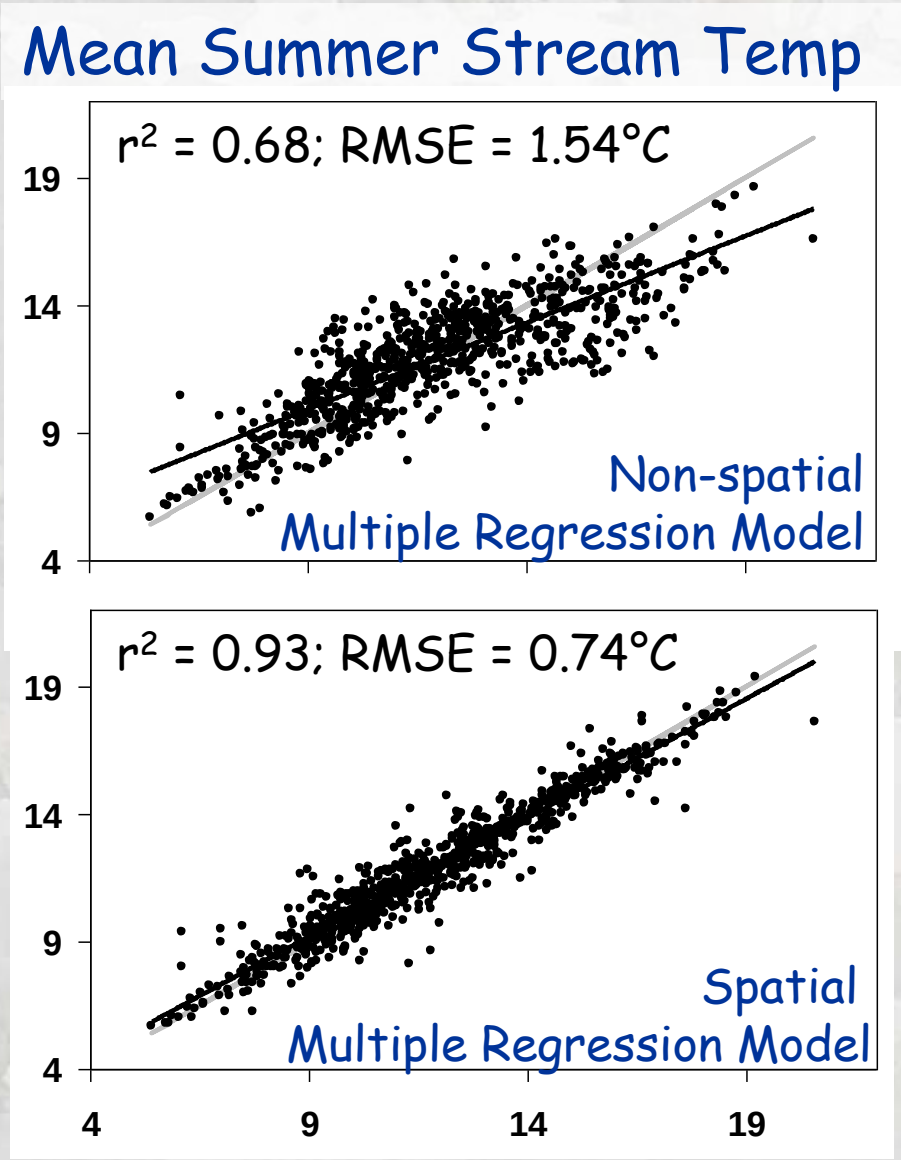
Peterson et al. 2006; Ver Hoef et al. 2006; Ver Hoef and Peterson 2010

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)

Lesson #3: Very accurate models can be built with short-term monitoring data to reconstruct historical (or predict future) temperatures across river networks

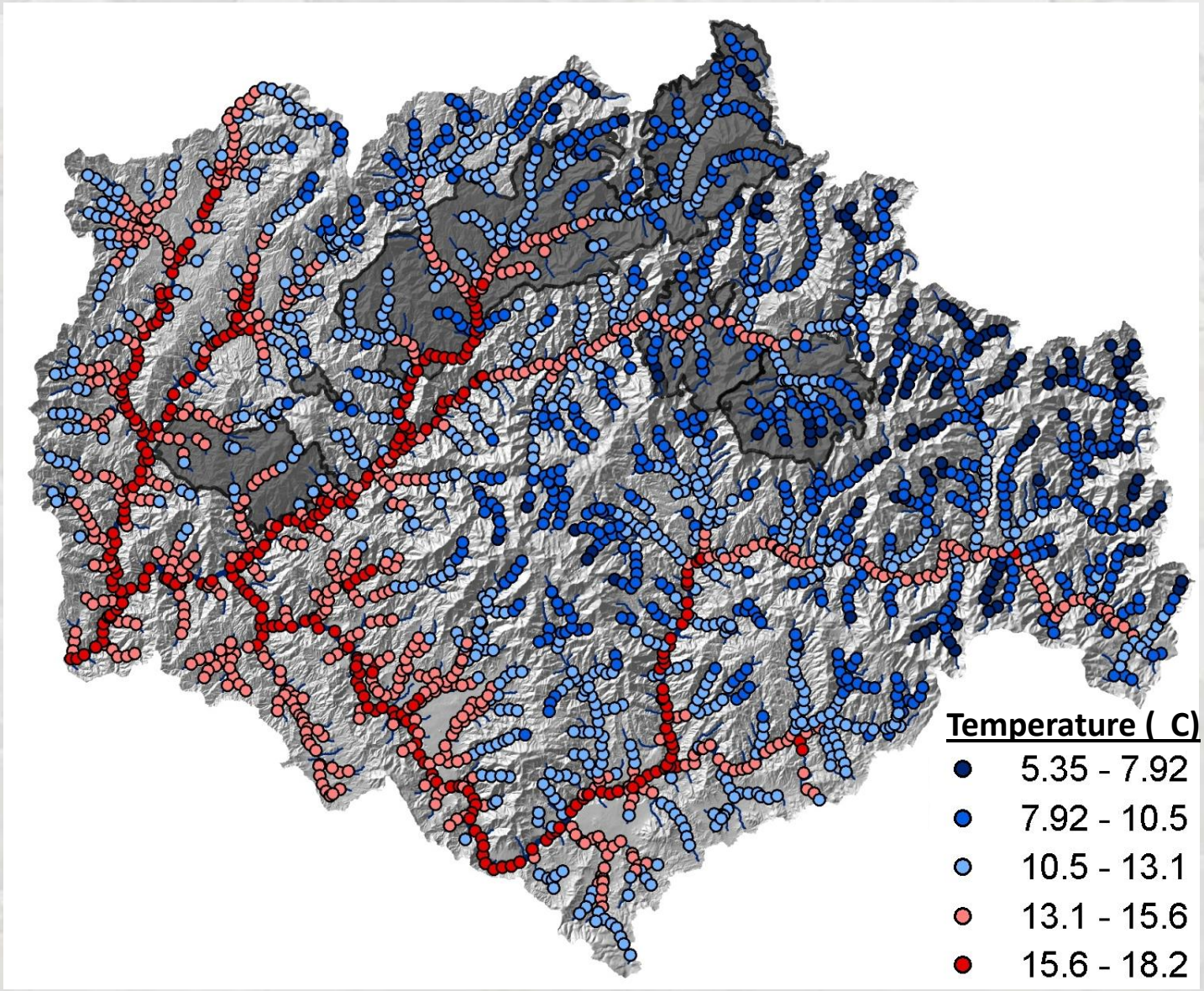
Spatial Stream Temp =
- 0.0045*Ele (m)
+ 0.0085*Rad
+ 0.48*AirTemp (C)
- 0.11*Flow (m^3/s)



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

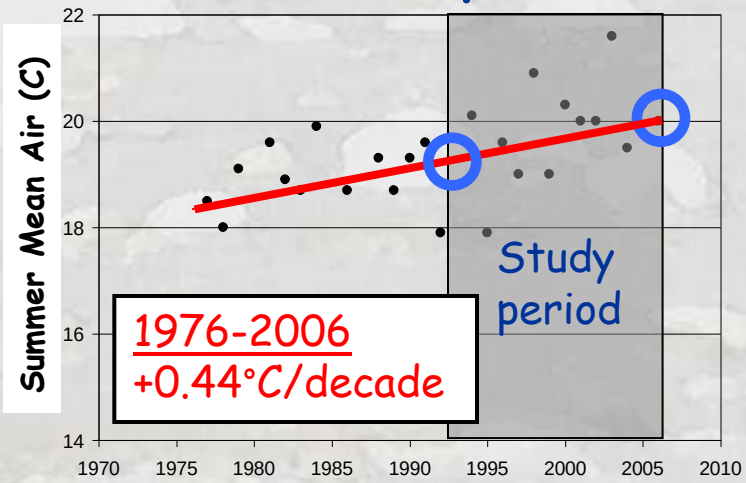
River Network Thermal Maps

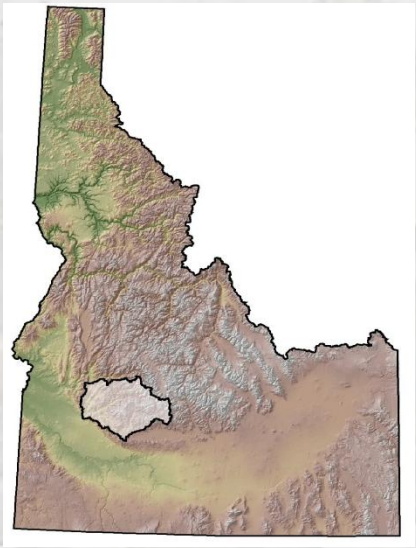
2006 Mean Summer Temperatures



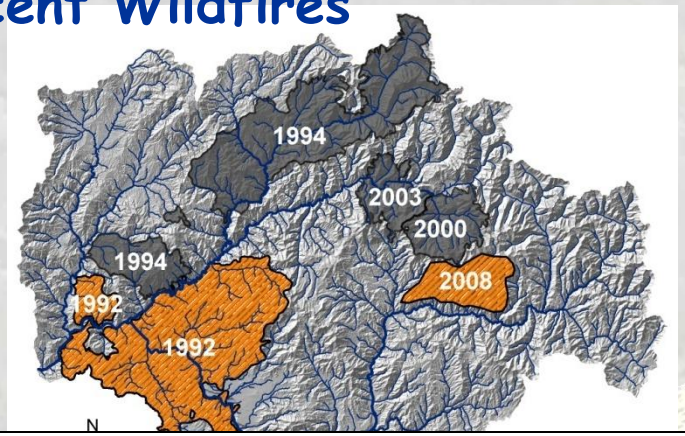
Environmental Trends in the Boise River Basin

Summer Air Temperature



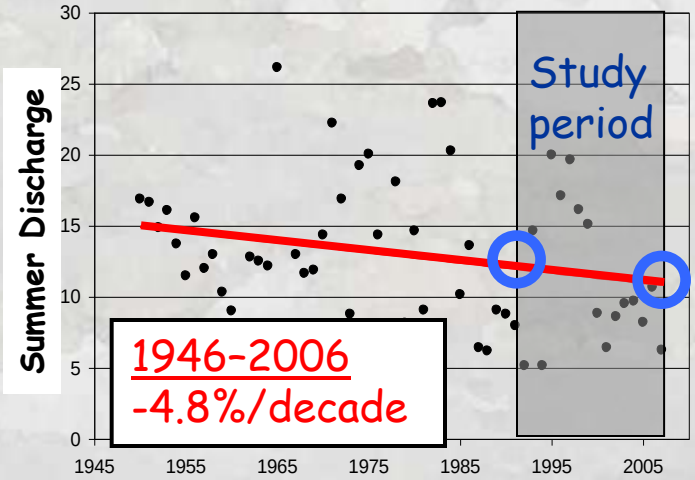


Recent Wildfires



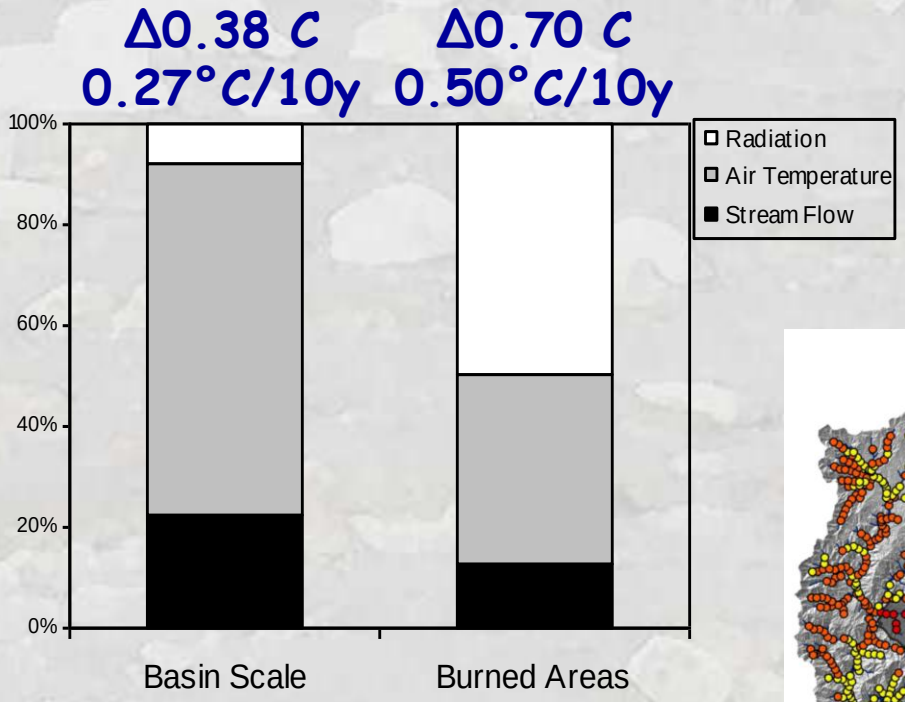
14% burned during 93-06 study period
30% burned from 92-08

Summer Stream Flow

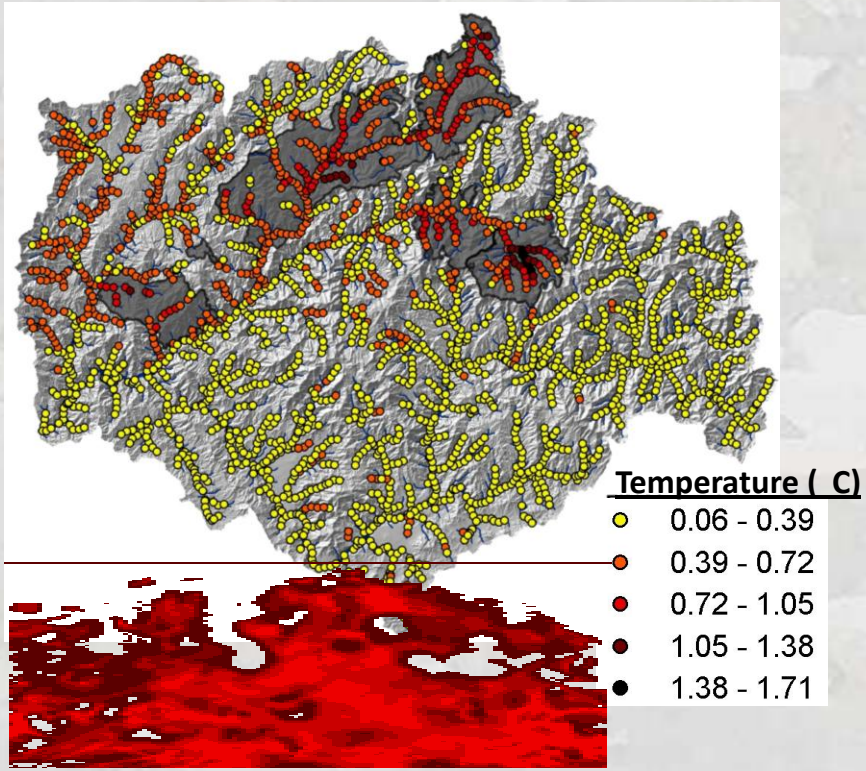


Reconstruction of Climate Change Effects

Changes in Summer Temps (1993-2006)



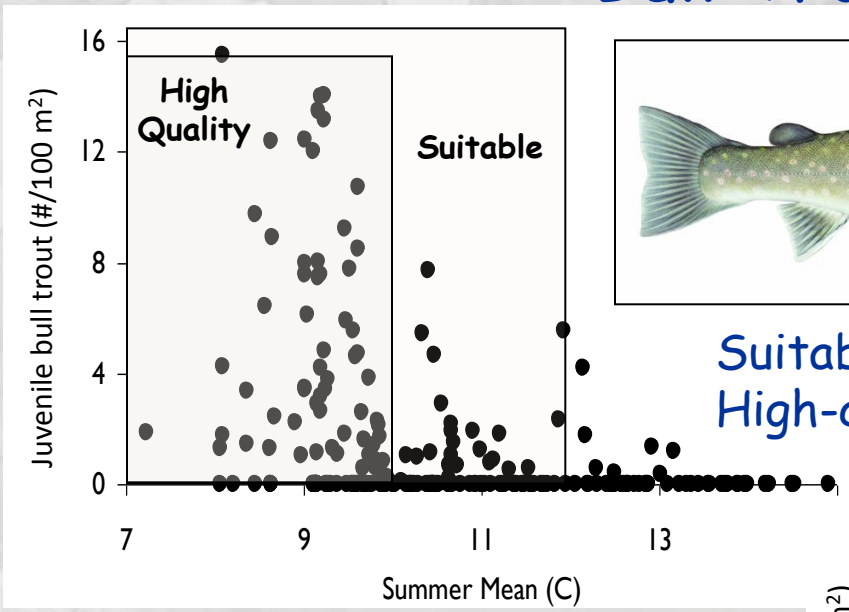
Thermal Gain Map

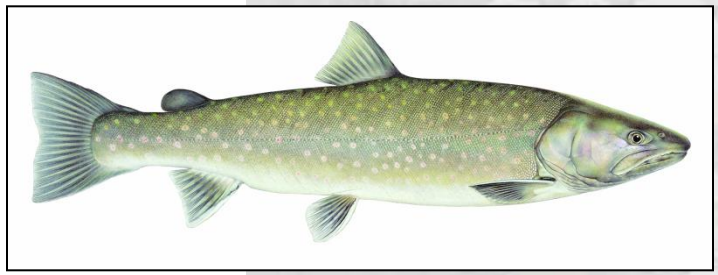


Isaak et al. 2010. *Eco. Apps.* 20:1350-1371

Climate Trend Effects on Thermal Habitat

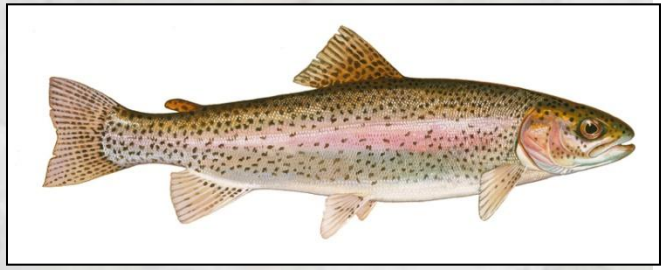
Bull Trout

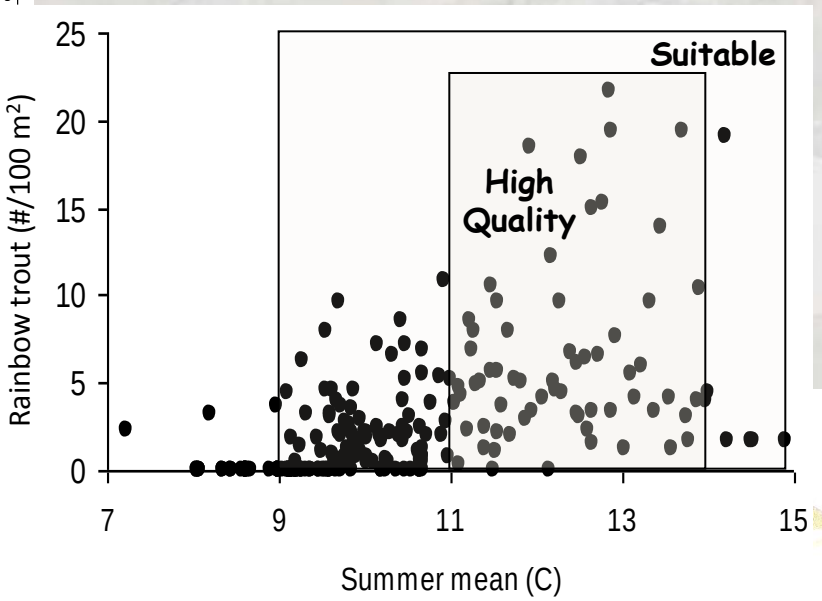




Suitable habitat < 12.0°C
High-quality habitat < 10.0°C

Rainbow Trout

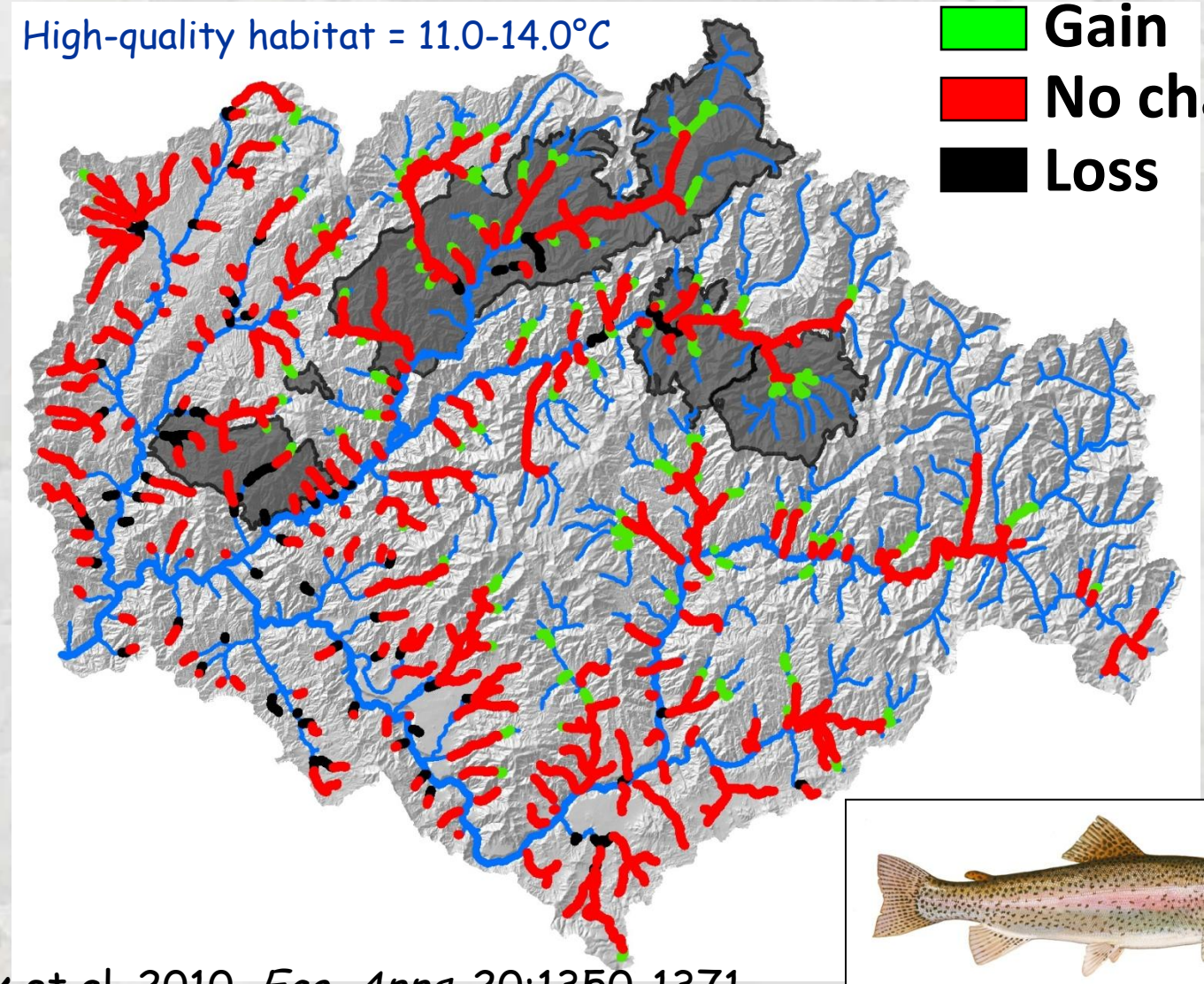




Suitable habitat = > 9.0°C
High-quality habitat = 11.0-14.0°C

Rainbow Trout Thermal Habitat Changes

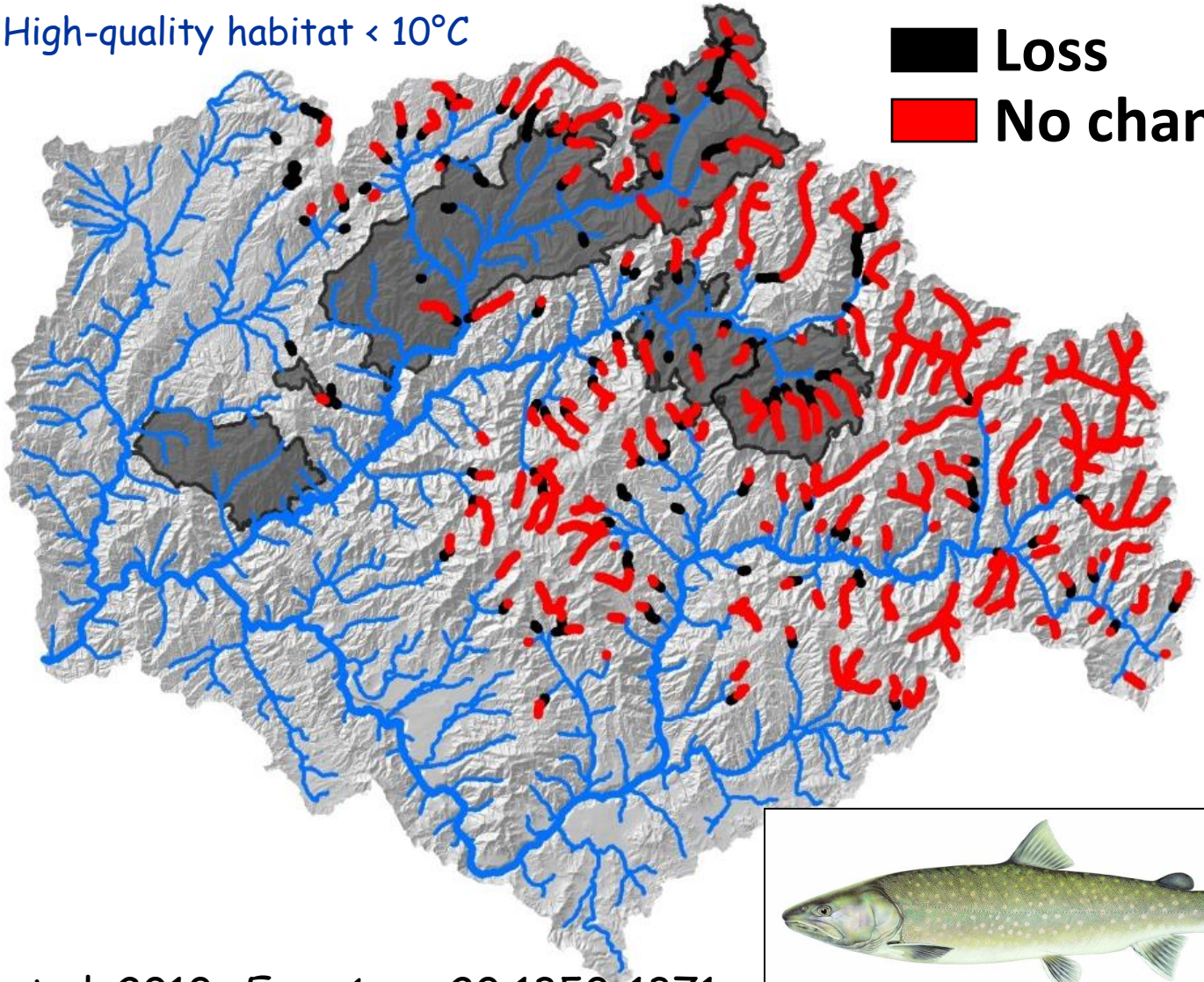
No net gain/loss (1993-2006)



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

Bull Trout Thermal Habitat Changes (1993-2006)

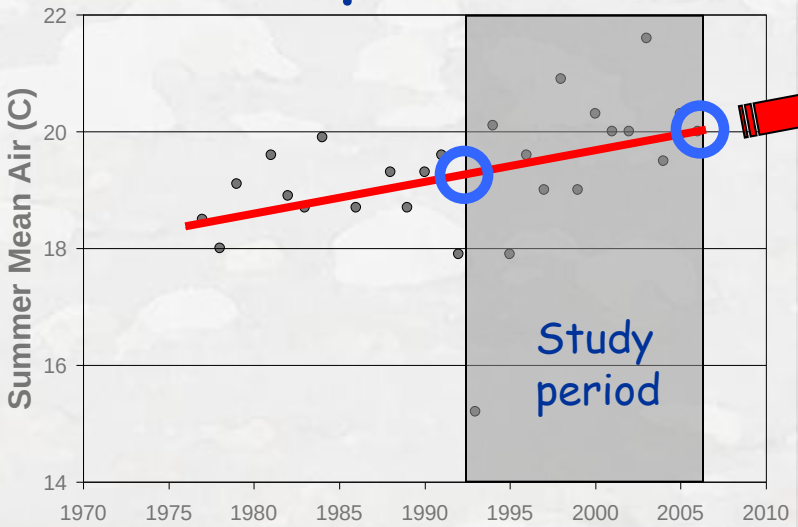
Losses occurring at 8%-16%/decade



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

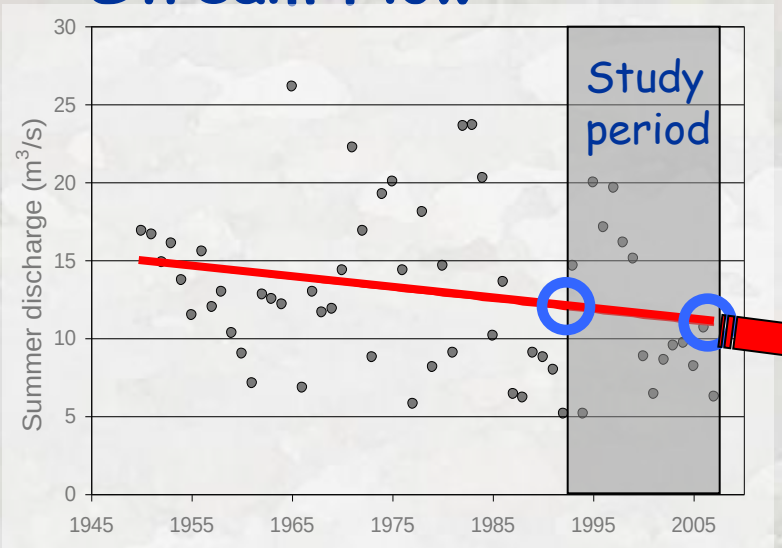
Predictions of Future Temperatures

Air Temperature



Radiation gains

Stream Flow



Future Changes in Stream Temp & Bull Trout Habitats

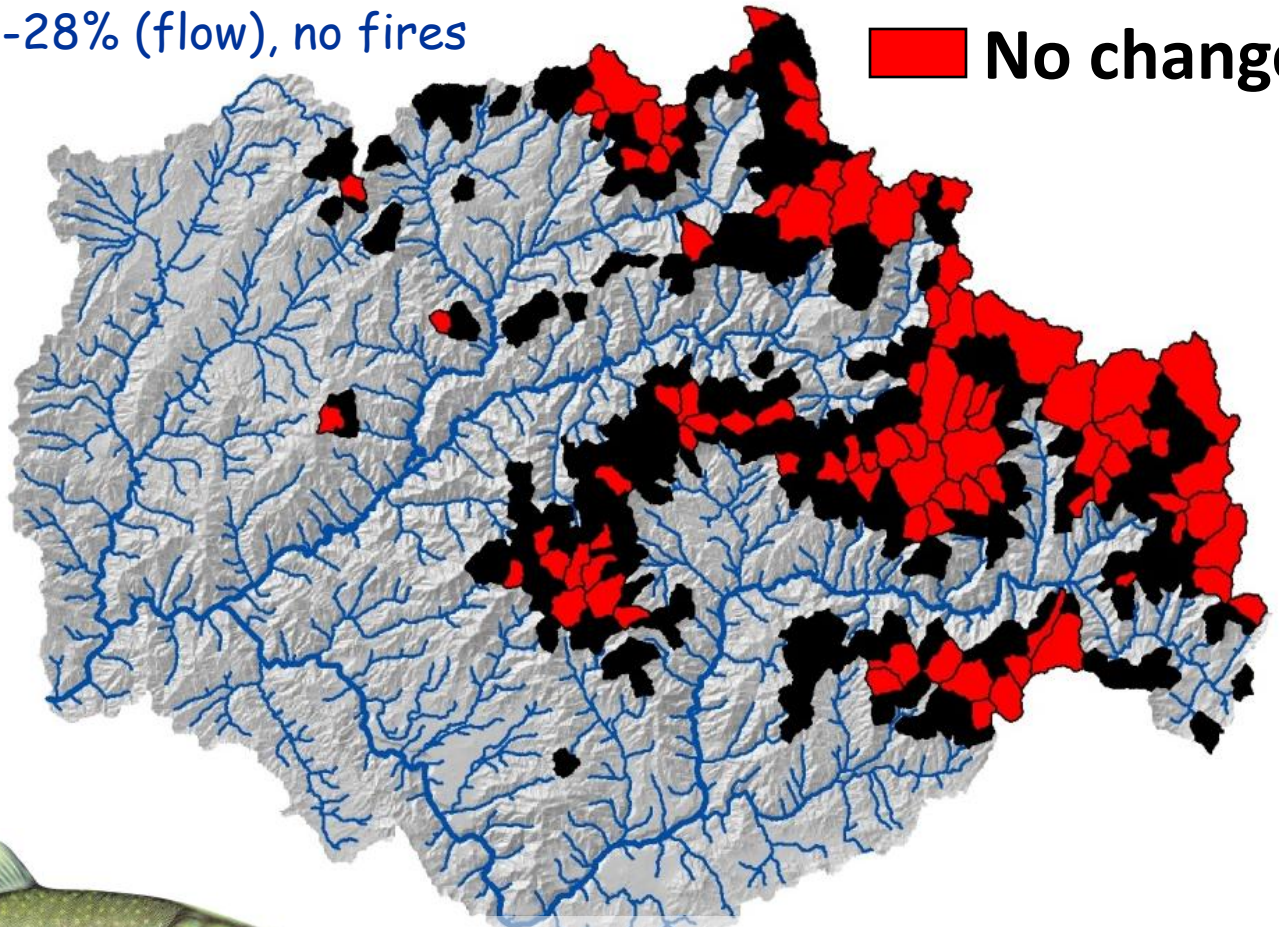
By 2046

Stream Δ = +1.43 C

+2.2 C (air), -28% (flow), no fires

Loss

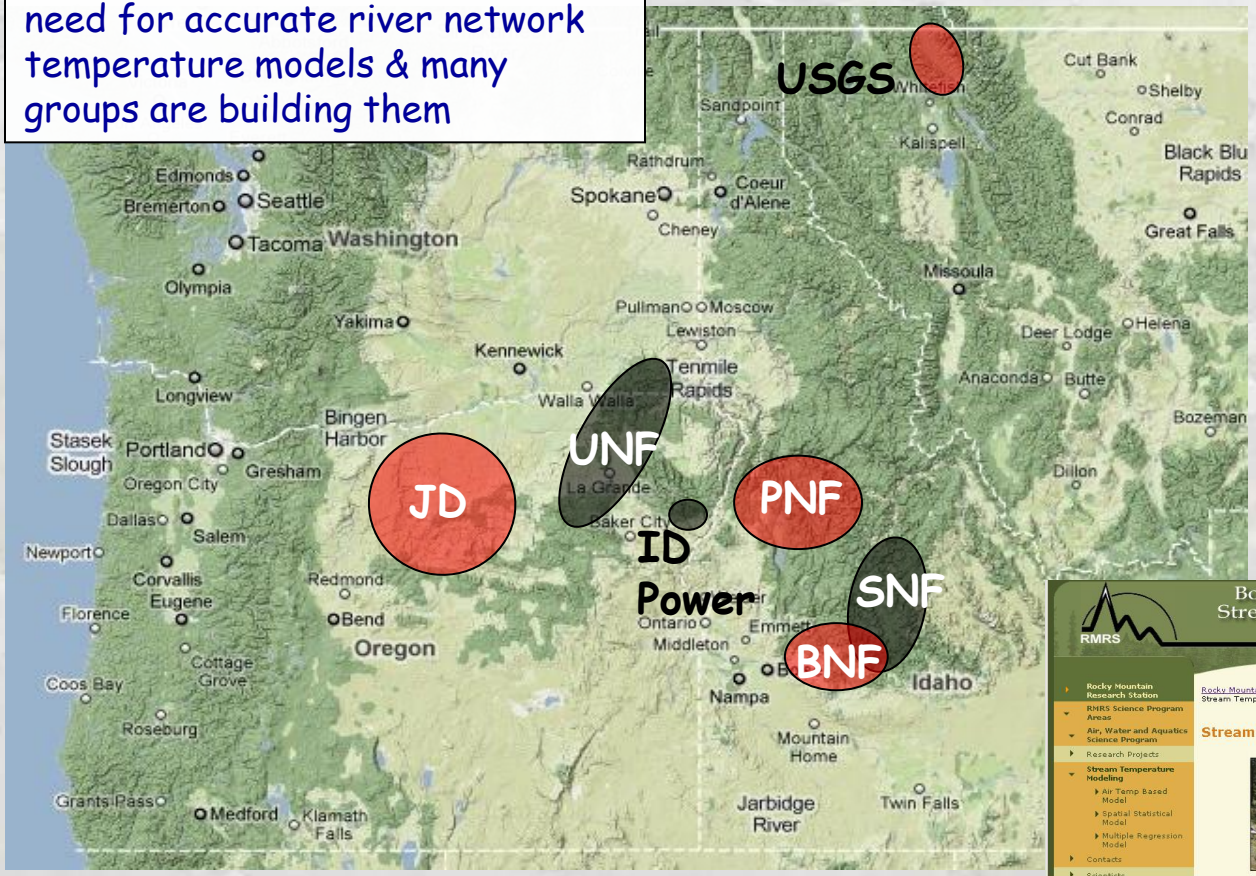
No change



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

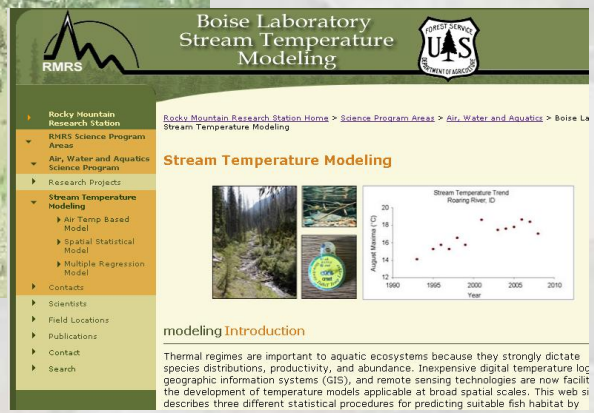
River Network Temperature Models

Lesson #4: There is a strong need for accurate river network temperature models & many groups are building them



= Spatial

= Non-spatial



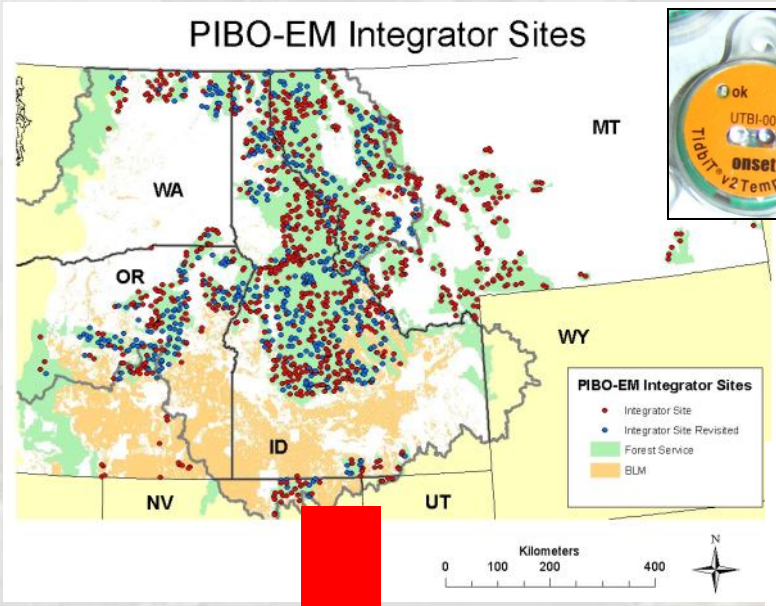
Methods online @:

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

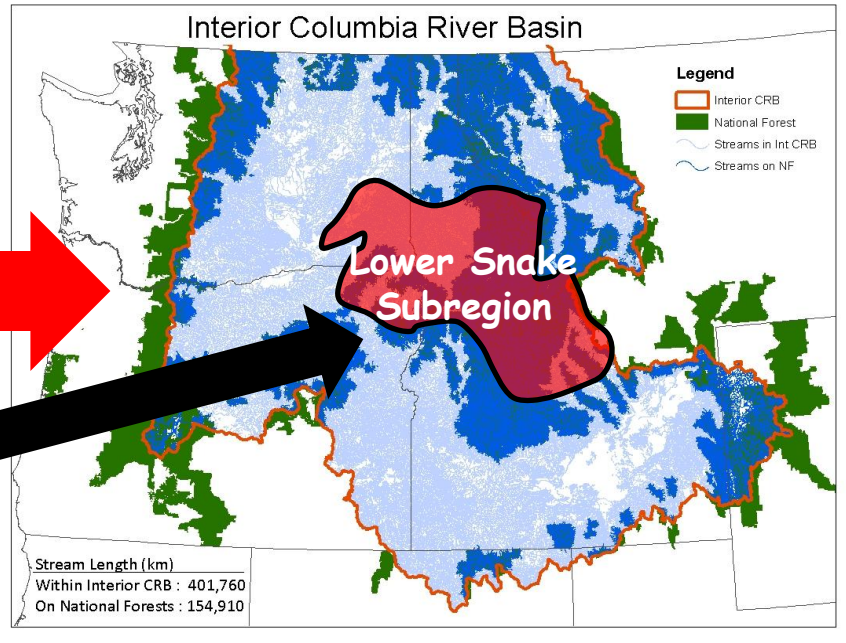
Google Search "Stream Temperature"

Regional Stream Temp Models Needed

Large regional temperature databases exist (10,000's observations)



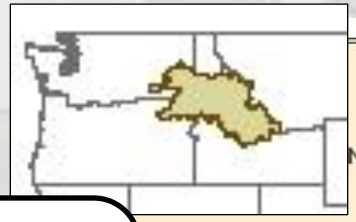
- Historical & future stream temps
- Species habitat summaries
- 1:100,000-Scale NHD+



2011 NCEAS workshop grant

A Step Towards a Regional Model

Lower Snake Hydrologic Region – NCEAS Workshop



- 42,000 stream km
- 2,000 temperature sites
- 6,700 summer observations

Palouse
Snake
Clearwater
Lochsa
Selway
Grande Ronde
Snake
Salmon
MF Salmon
Lemhi
MONTANA
OREGON
IDAHO
0 75 150 Km

Data Providers:

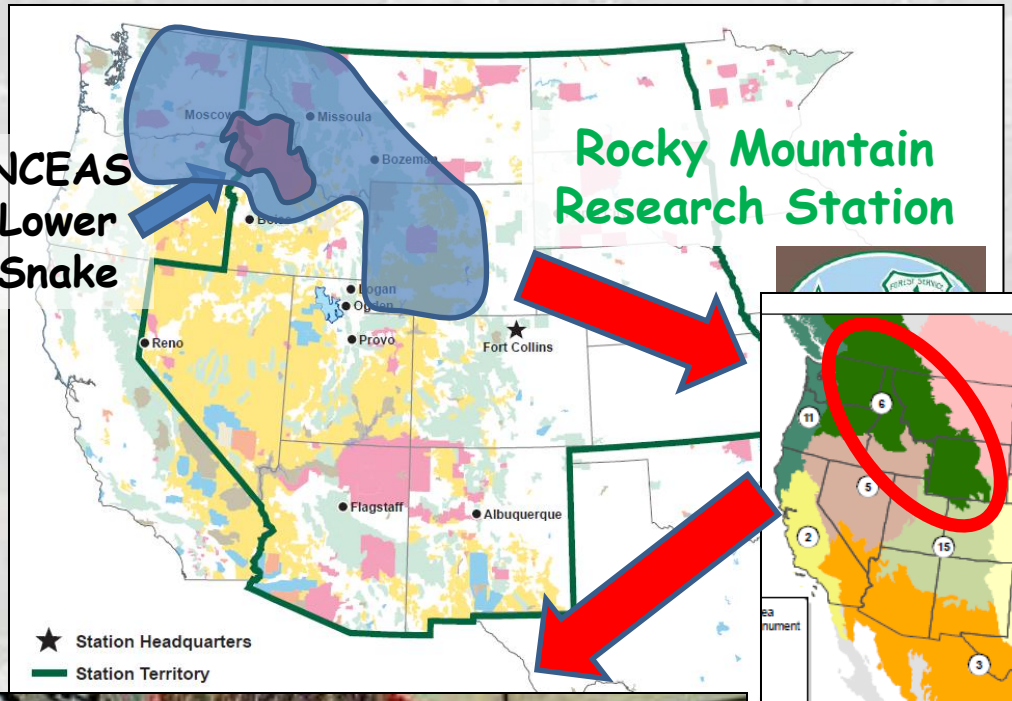
EPA
NOAA Fisheries
IDAHO FISH & GAME
Idaho State University
IDAHO POWER.
University of Idaho
USFS
USGS science for a changing world

- 87% USFS data!

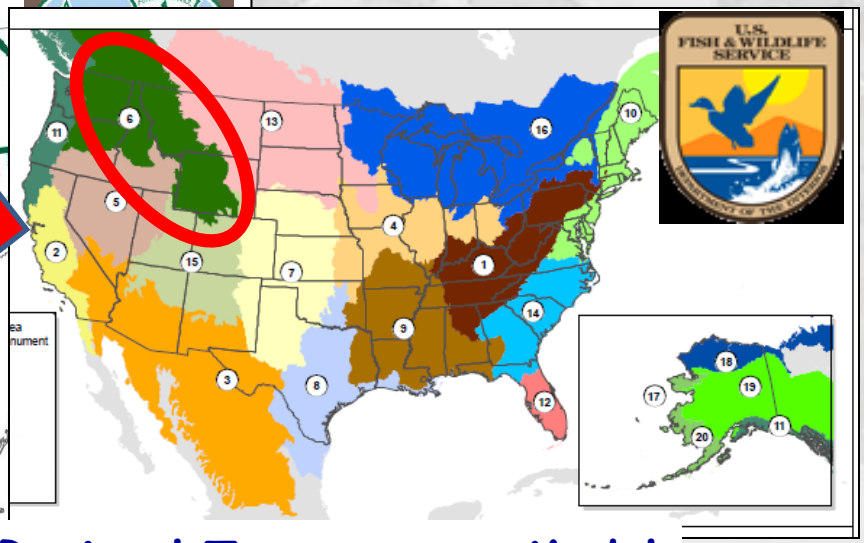
Lesson #5: USFS is the dominant temperature monitoring agency in some areas

National Center for Ecological Analysis and Synthesis
CSIRO
NOAA
USFS

Building a Regional Model for the GNLCC



USFWS Landscape Conservation Cooperatives



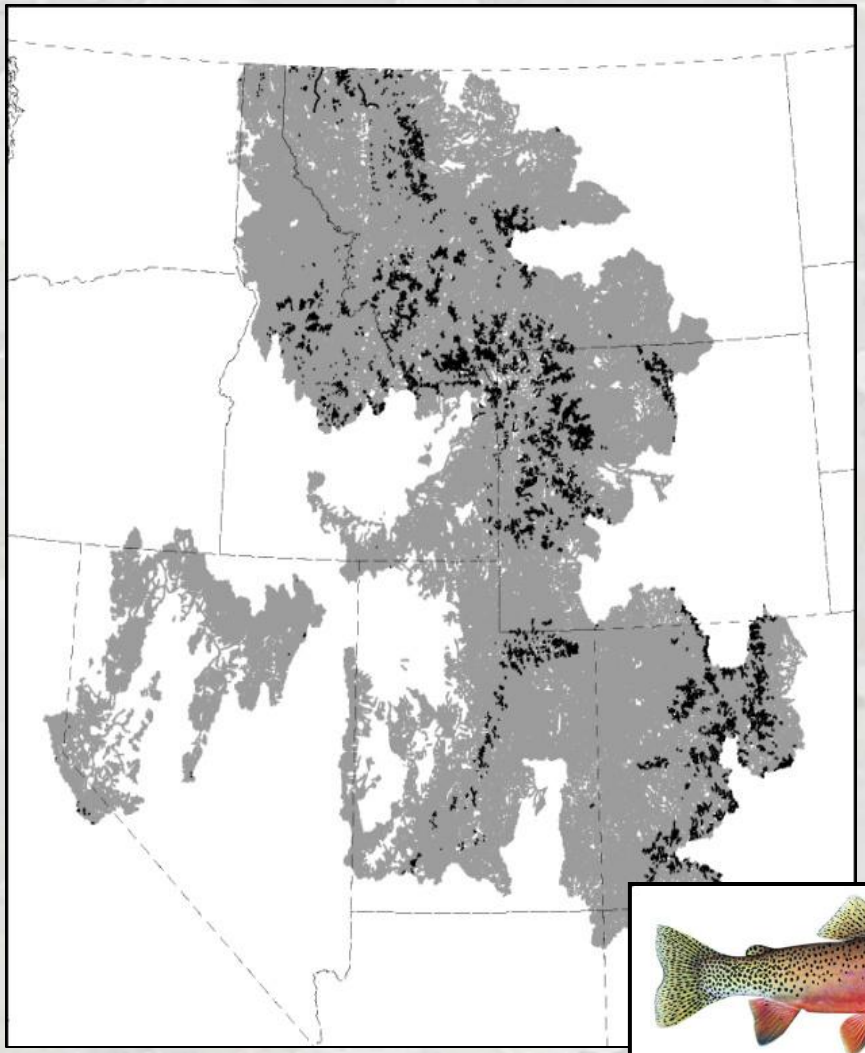
Regional Temperature Model

- 35 National Forests
- 250,000 km's fish-bearing streams
- 15,000-30,000 summer's of stream temperature data

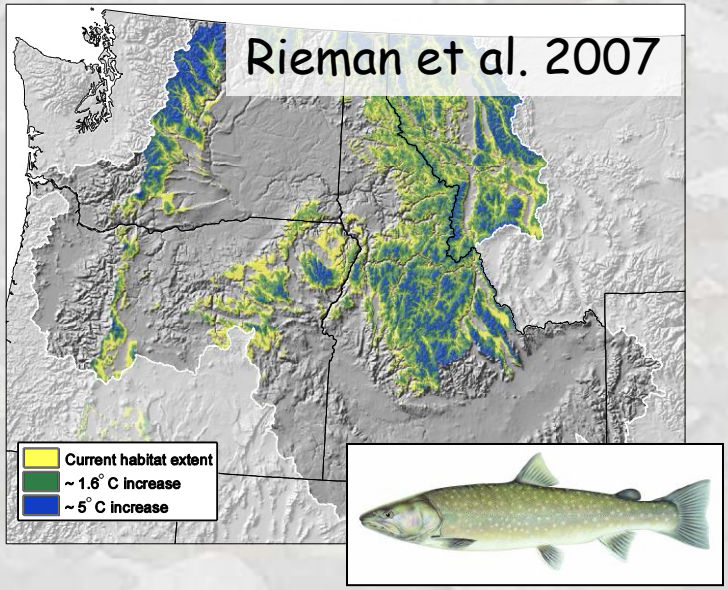
Great Northern LCC

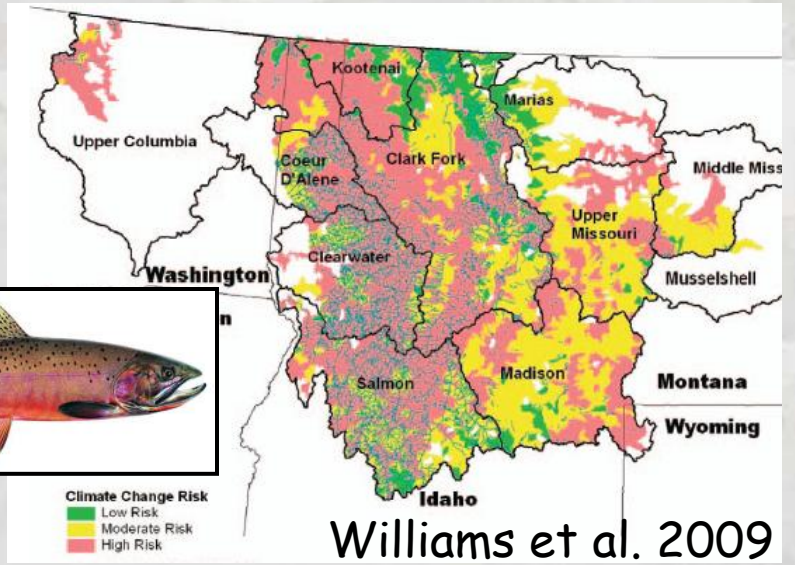
Regional Bioclimatic Assessments

No Stream Temperature Component



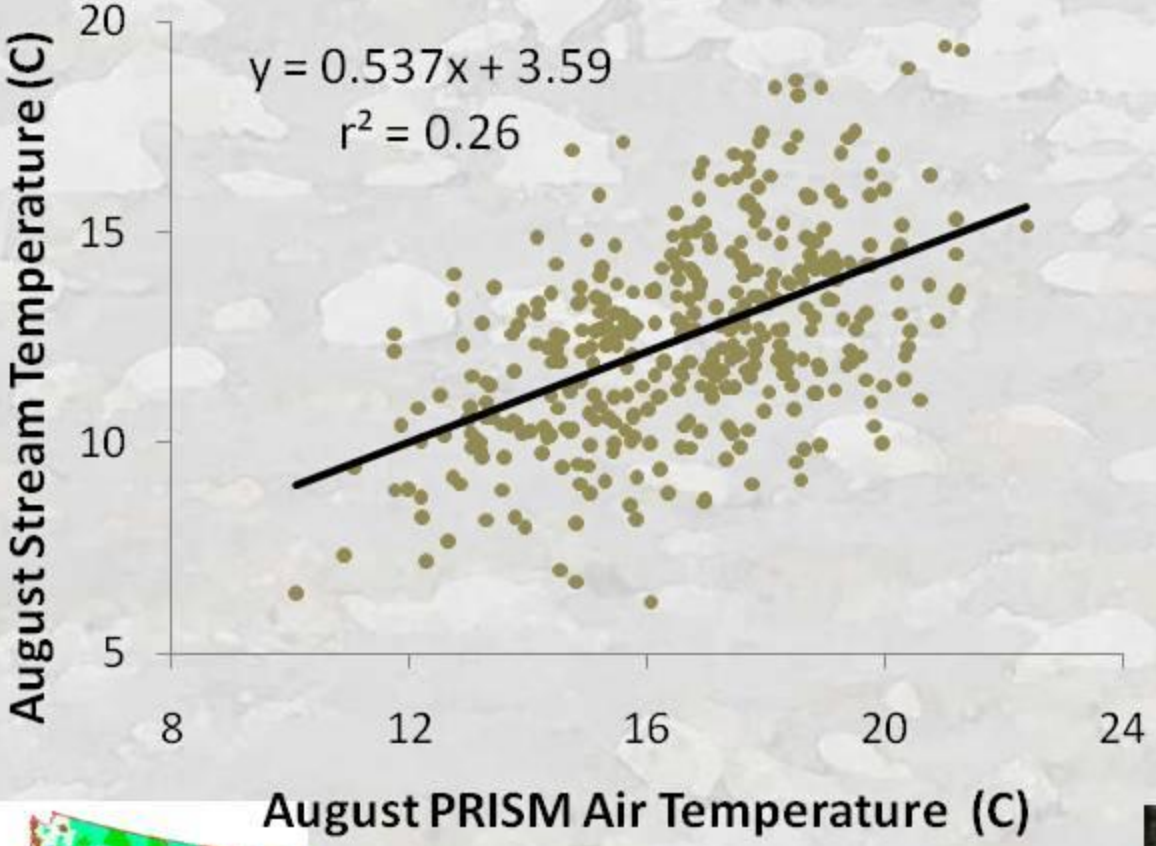
Wenger et al. 2011 *CJFAS*;
Wenger et al. Submitted *PNAS*.

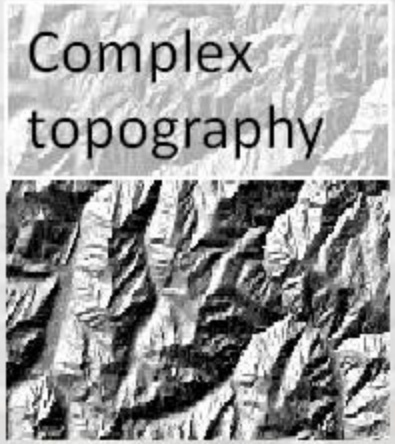


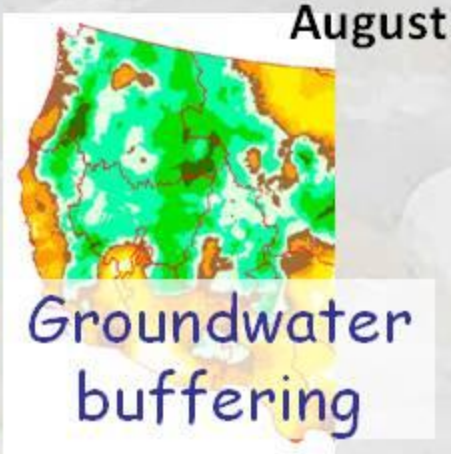


Williams et al. 2009

Air Temp ≠ Stream Temp



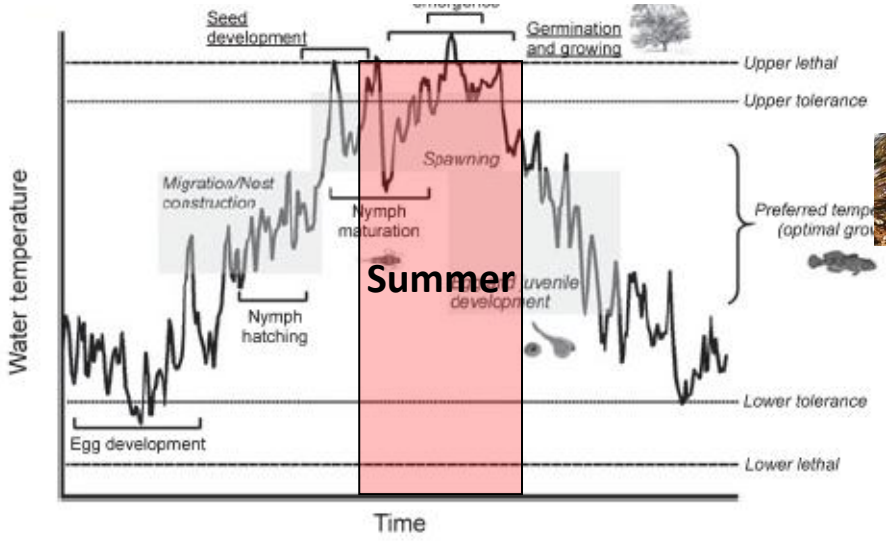


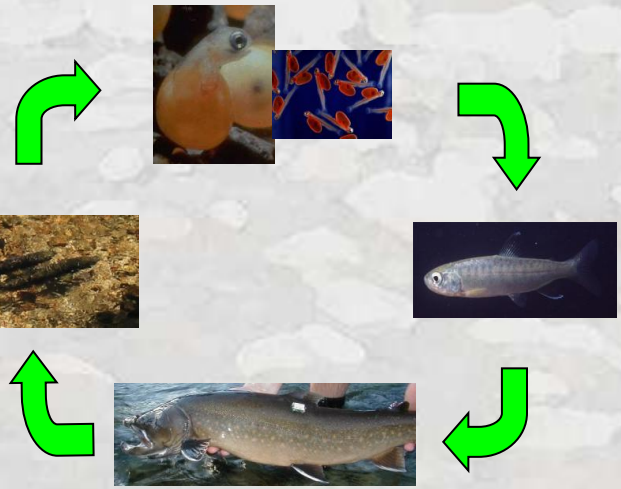


Summer is Not the Whole Story

Full Year Temperature Data Needed

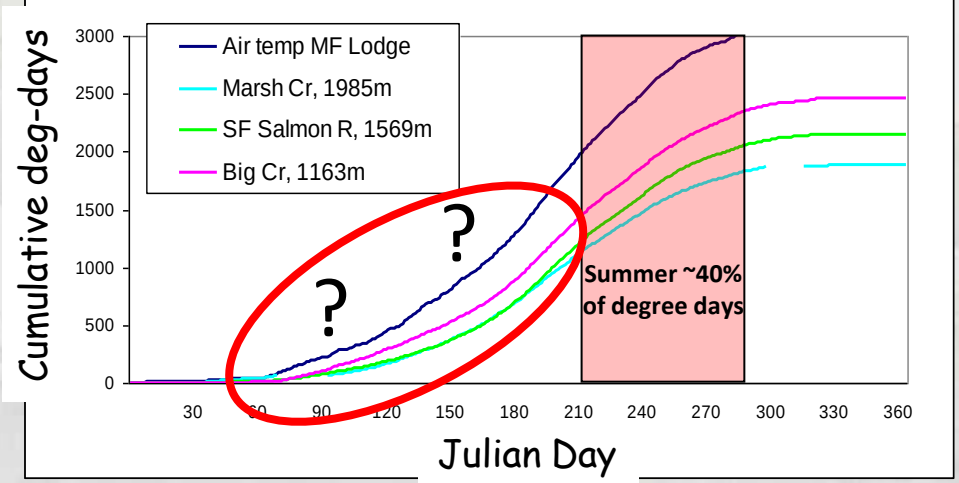
Annual Temperature Cycle





Olden and Naiman 2009

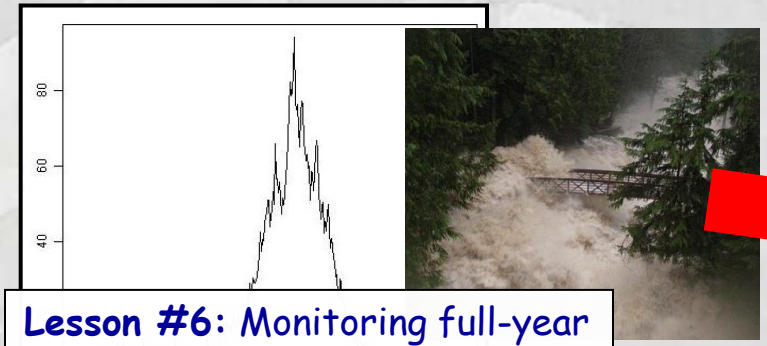
Annual Accumulation of Thermal Units



Acquiring Full Year Temperature Data

Underwater Epoxy Protocol

Annual Flooding Concerns



Lesson #6: Monitoring full-year stream temperature data is very inexpensive now

Underwater epoxy cement

$100 = 5 – 10 years of data

Data retrieved from underwater

Sensors or protective housings glued to large boulders

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

Google "Stream Temperature Boise"

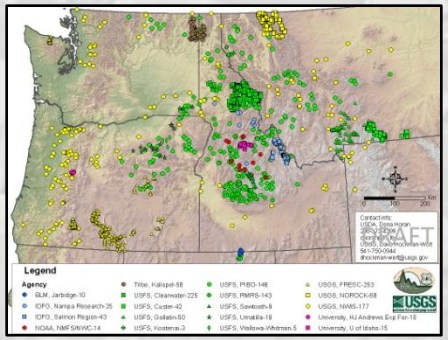
Regional Temperature Sensor Network

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 ?)

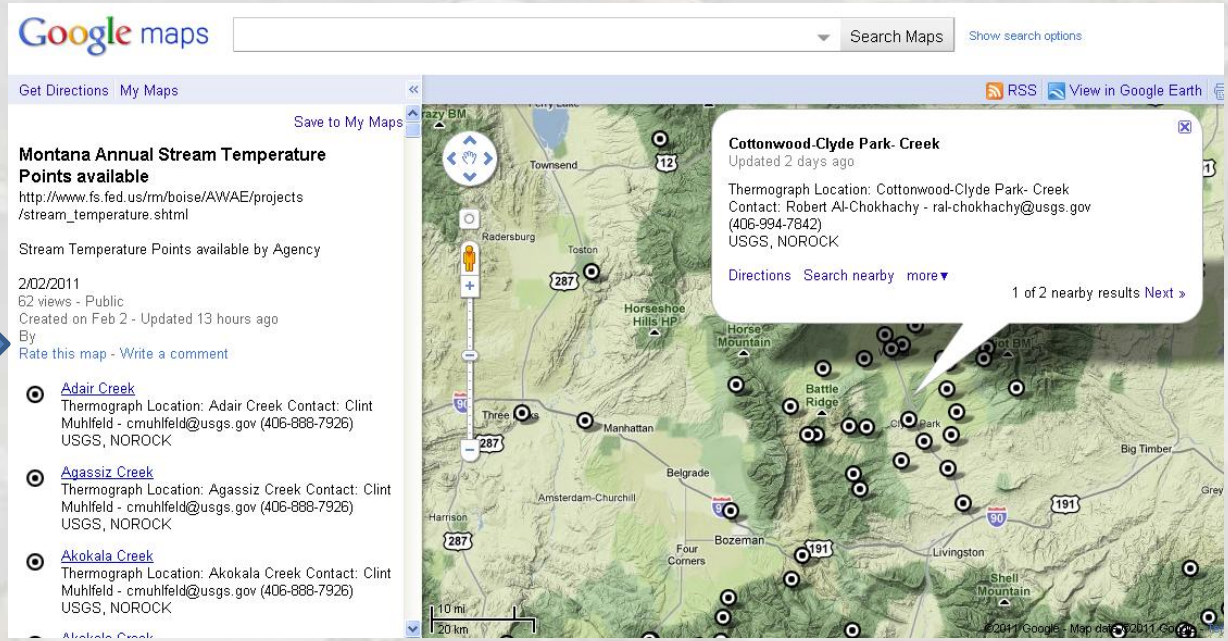
Lesson #7: Monitoring networks can be established rapidly & but require interagency coordination

Dynamic GoogleMap Tool for Coordinating Stream Temperature Monitoring Sites



Site Information

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



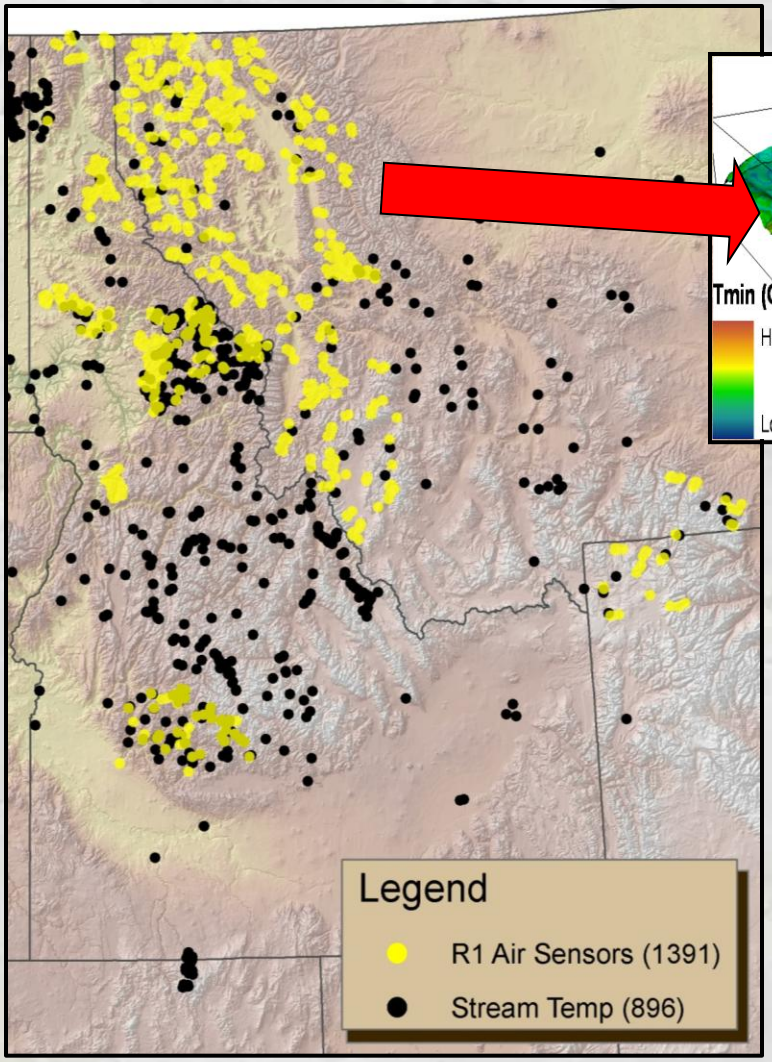
Webpage:

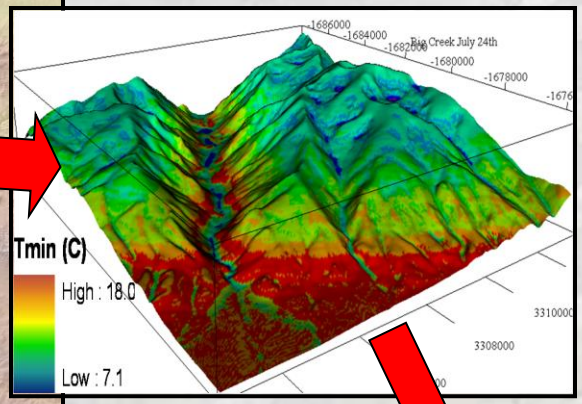
www.fs.fed.us/rm/boise/AWAE/projects/stream_temperature.shtml

Google Search "Stream Temperature Boise"

Massive Sensor Networks

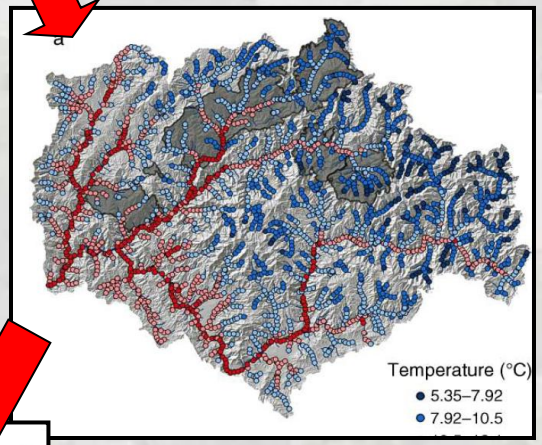
Ecologically Relevant Climate Downscaling





Continuous Space/Time Air Temp Surface

Continuous Space/Time Stream Temp Surface

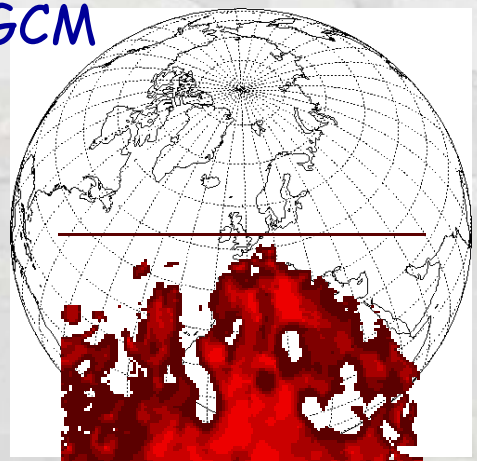


Wiens and Bachelet 2009

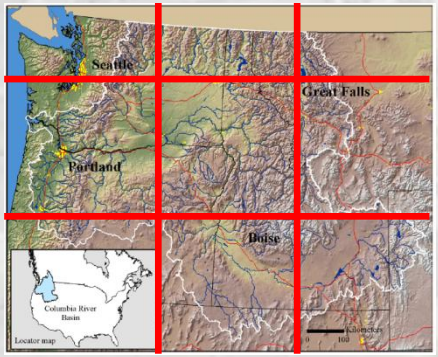
Better Downscaling

How will global trends affect my stream?

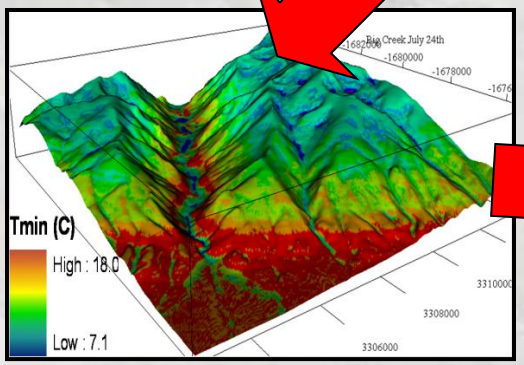
GCM

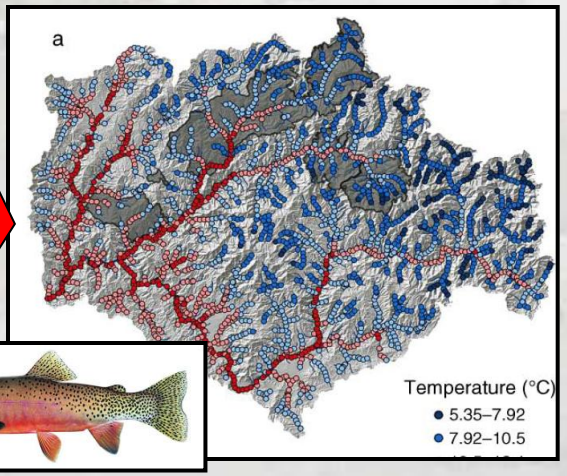


RCM

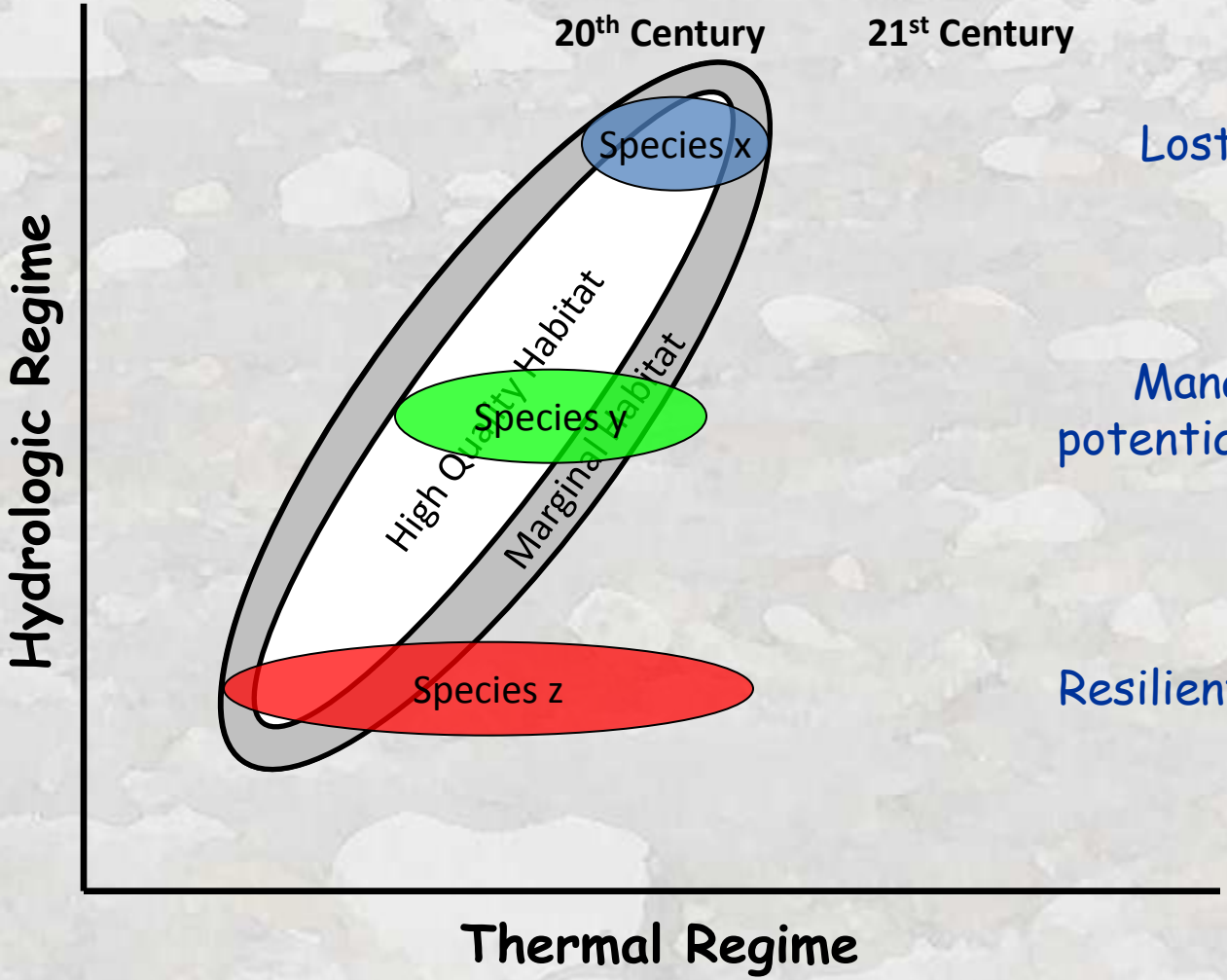


Integrated global-to-regional-to-landscape-to-stream systems





Where Can Management Make a Difference?



Lost Cause?

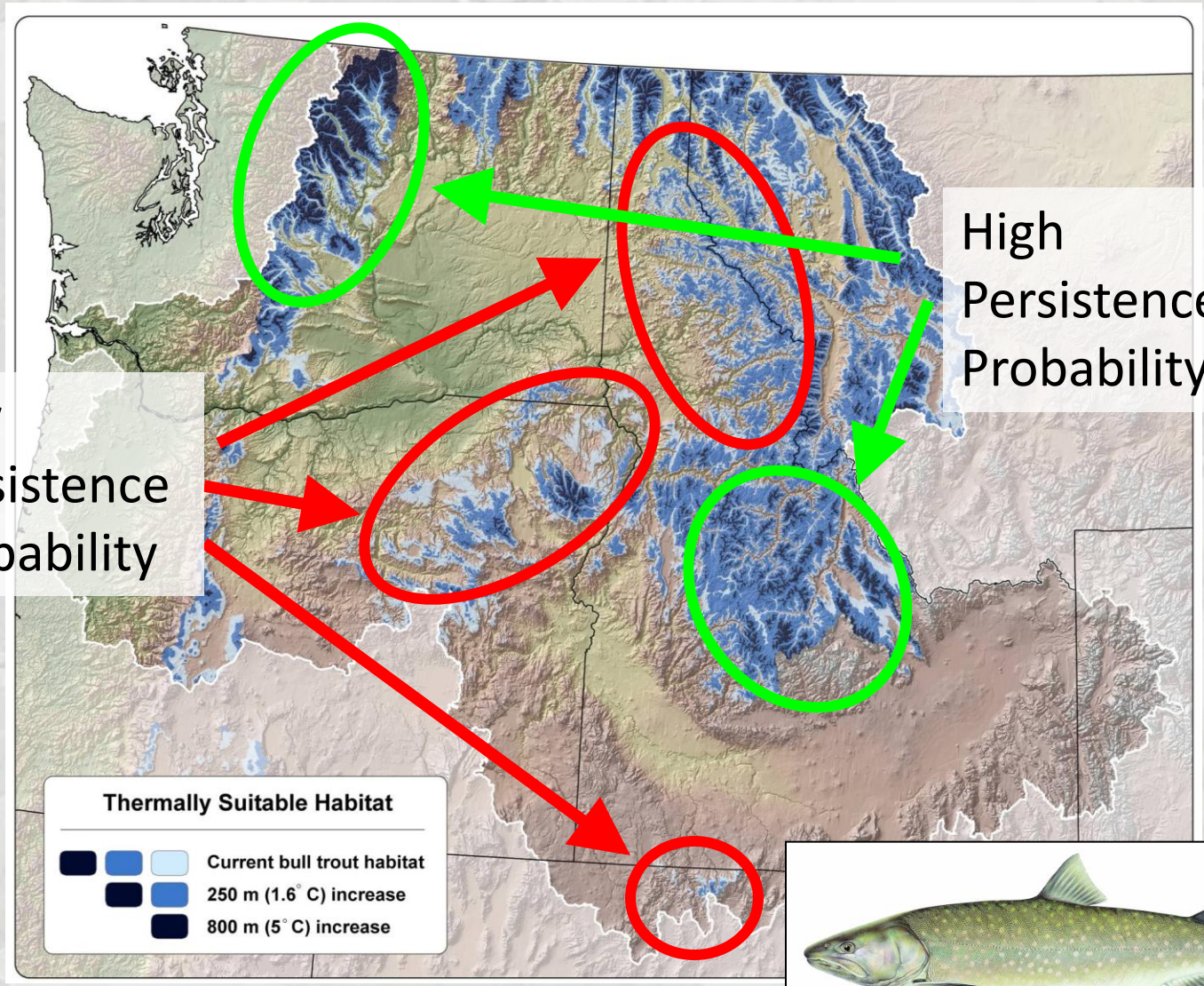
Management potentially critical?

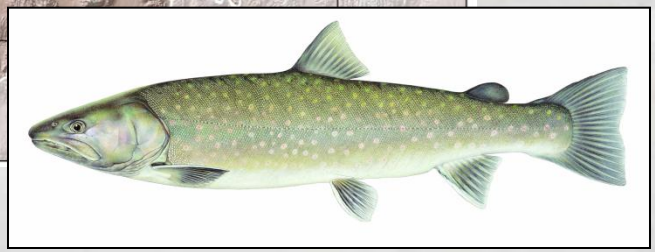
Resilient Population

Modified from Williams et al. 2007

Spatial Variation in Species Sensitivity

How & Where to Allocate Resources?





Rieman et al. 2007

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

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