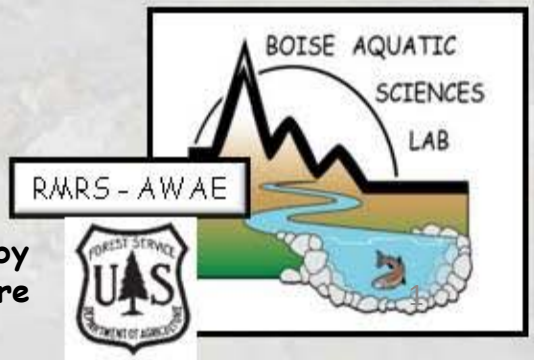
*Click on icon in upper left for speaker notes

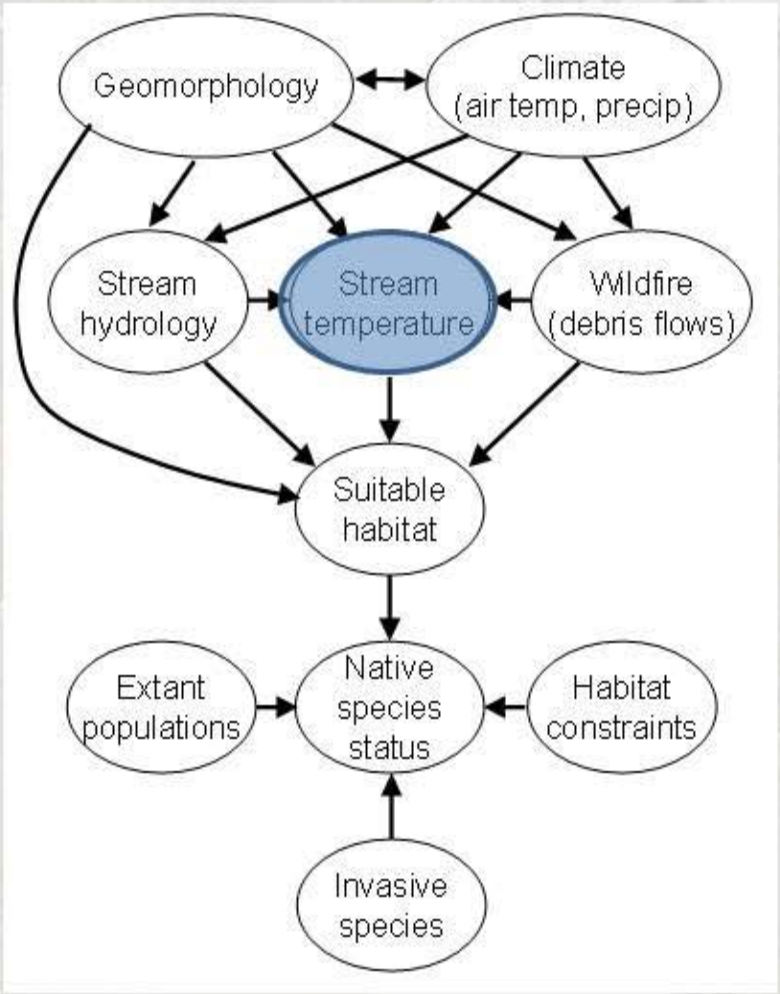
Stream Thermal Regimes & Aquatic Ecosystems in a Changing Climate

Dan Isaak, Bruce Rieman, Charlie Luce
U.S. Forest Service
Rocky Mountain Research Station
Boise, ID 83702



Originally prepared for the November 17-19, 2009 Boulder, CO workshop on "Western Watersheds and Climate Change" organized by Chuck Rhodes and Linda Joyce of RMRS. Videos of presentations are available at the CCRC website (http://www.fs.fed.us/ccrc/).

Climate Change & Aquatic Biotas



Part 1

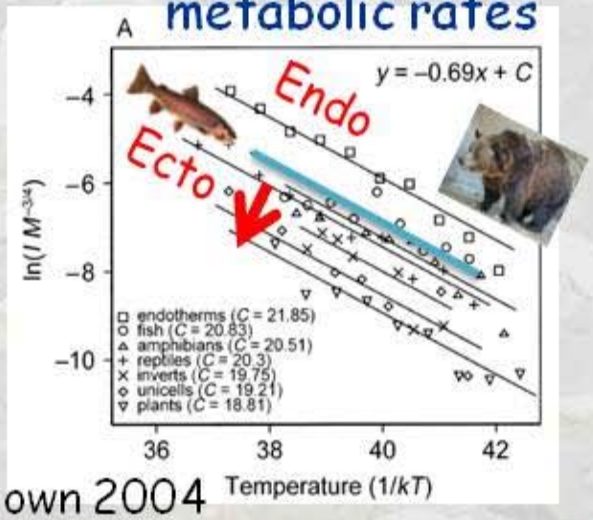
- The case for stream temperature
- Stream thermal regimes & climate
- Evidence of stream warming & biological responses
- Projected stream warming
- Contextualizing thermal effects

Part 2

- Previous modeling approaches
- Stream temperature databases
- Mechanistic & statistical models
- A central Idaho case history
- Research agenda/data gaps

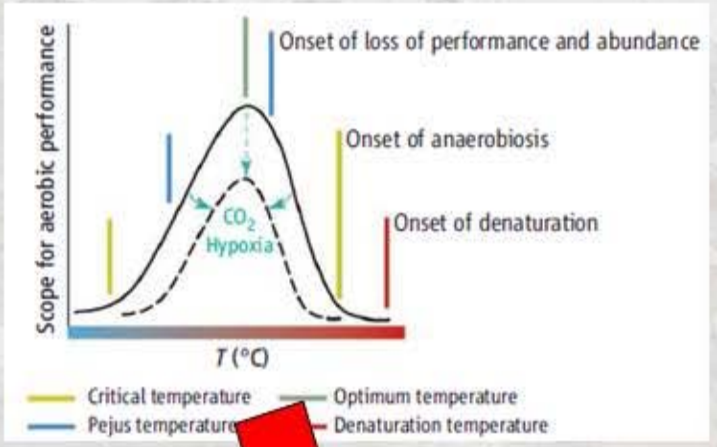
Metabolic Ecology and Thermal Niches

Temperature & metabolic rates

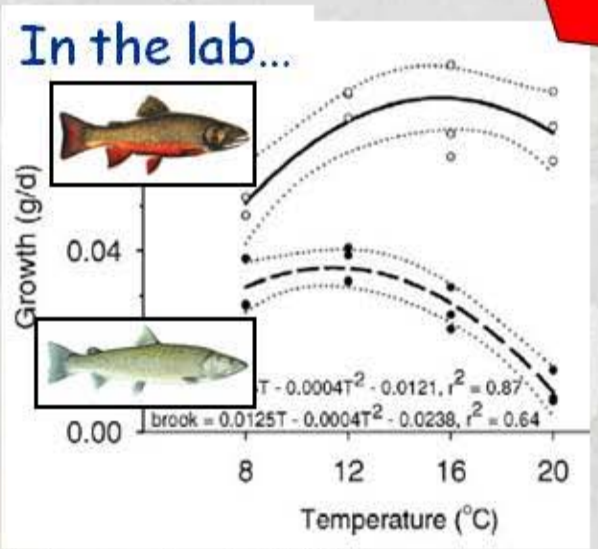


Brown 2004

Thermal Niche

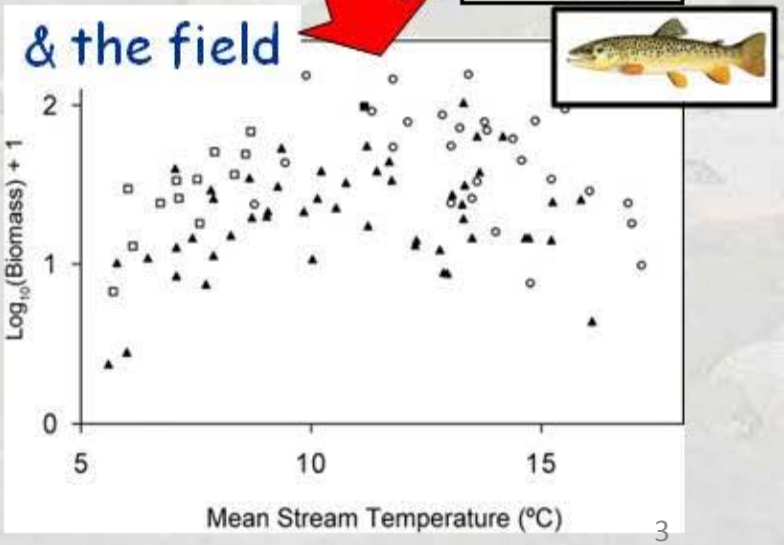


In the lab...



McMahon et al. 2007

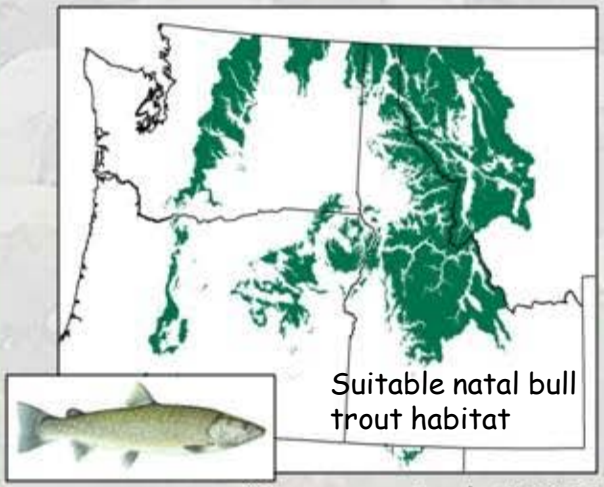
& the field



Isaak & Hubert 2004

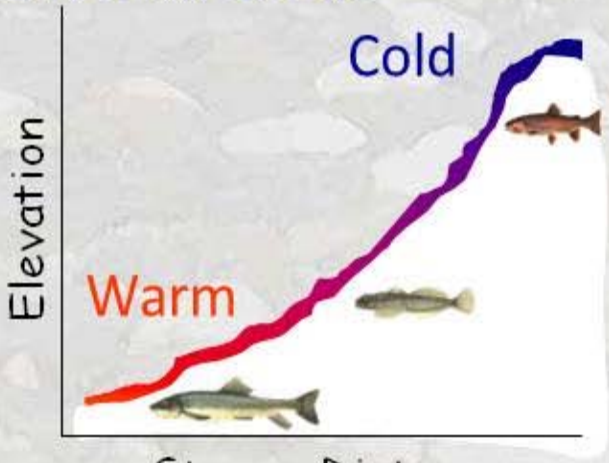
Temperature Regulation - Spatial Distributions

Regional Scale

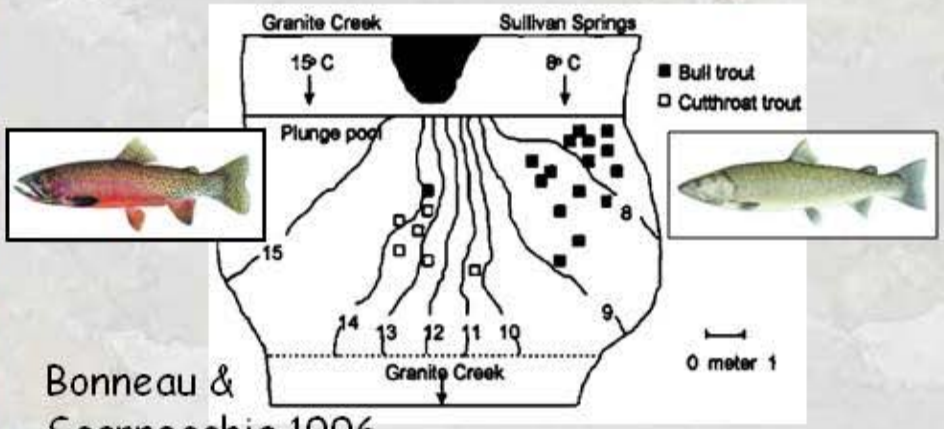


Rieman et al. 2007

Stream Scale



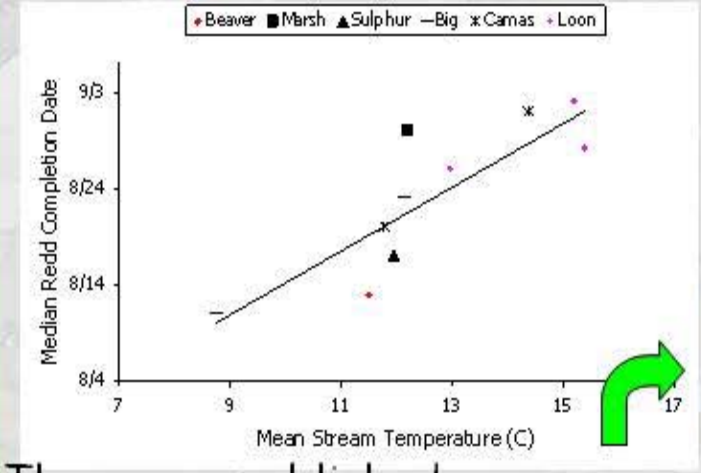
Channel Unit Scale



Bonneau & Scarnecchia 1996

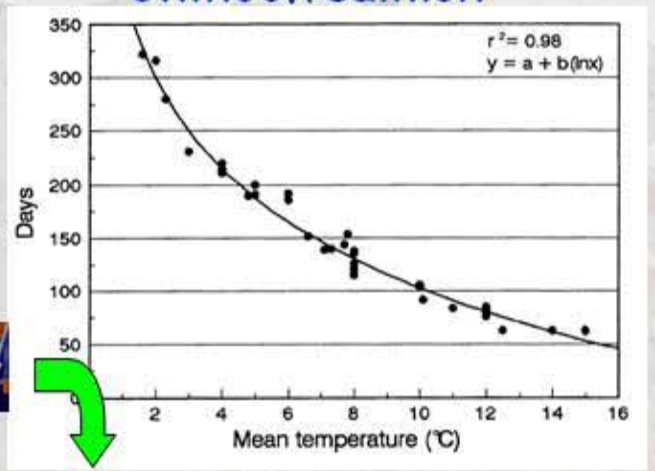
Temperature Regulation - Life Cycle

Spawn timing - Chinook salmon



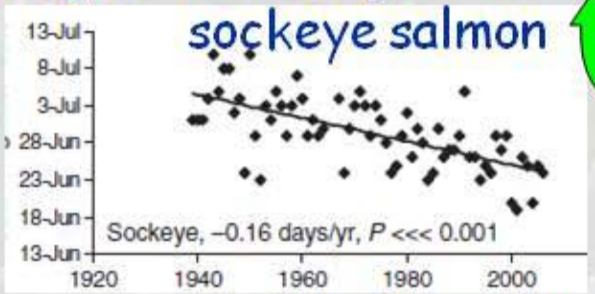
Thurow, unpublished

Incubation length - Chinook salmon

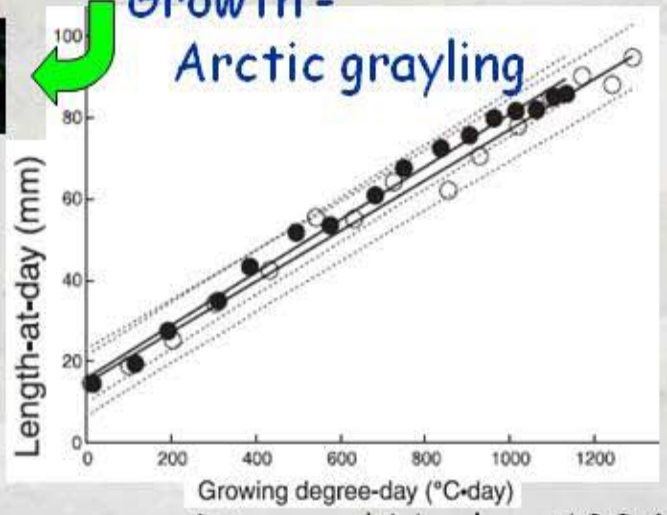


Brannon et al. 2004

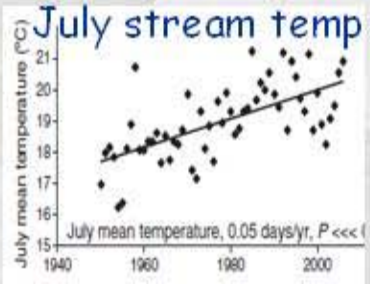
Migration timing - sockeye salmon



Growth - Arctic grayling

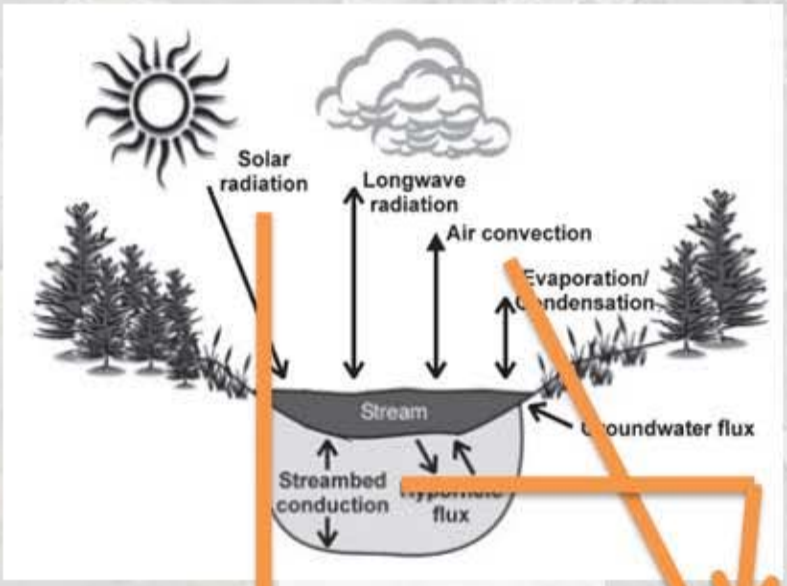


Dion and Hughes 1994



Crozier et al. 2008

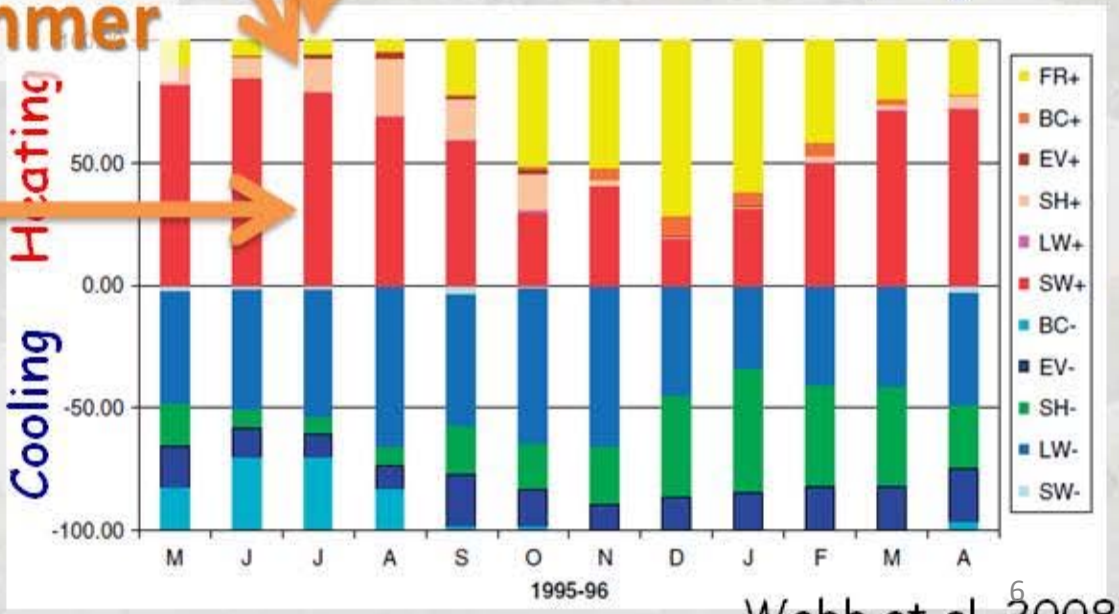
Stream Heat Budgets



Mediated by…

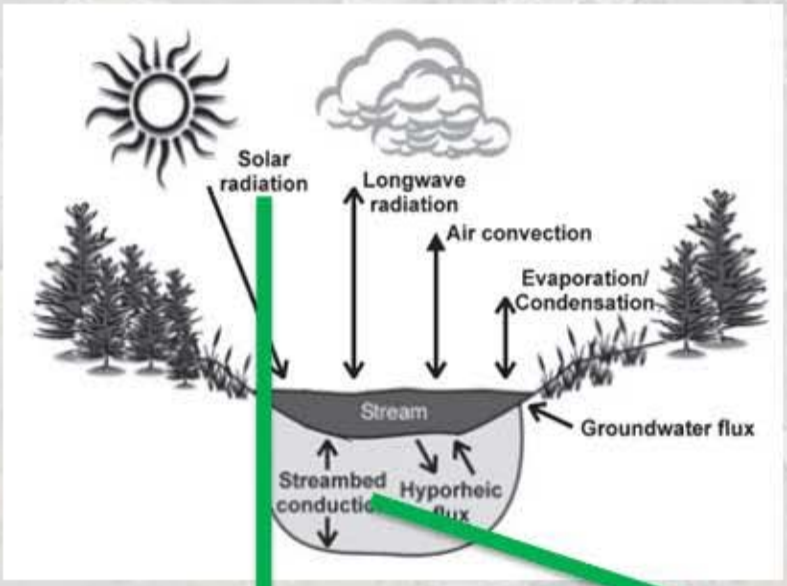
- Topography
- Riparian Vegetation
- Reach discharge

Monthly heat budget -
Black Ball Stream, England



Webb et al. 2008

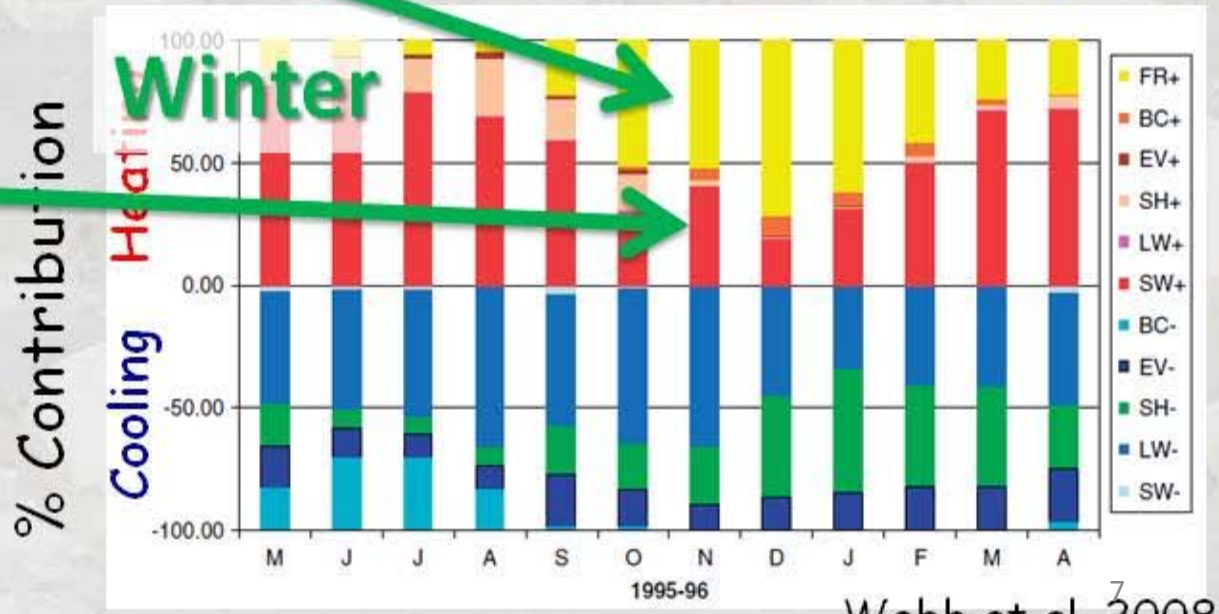
Stream Heat Budgets



Mediated by…

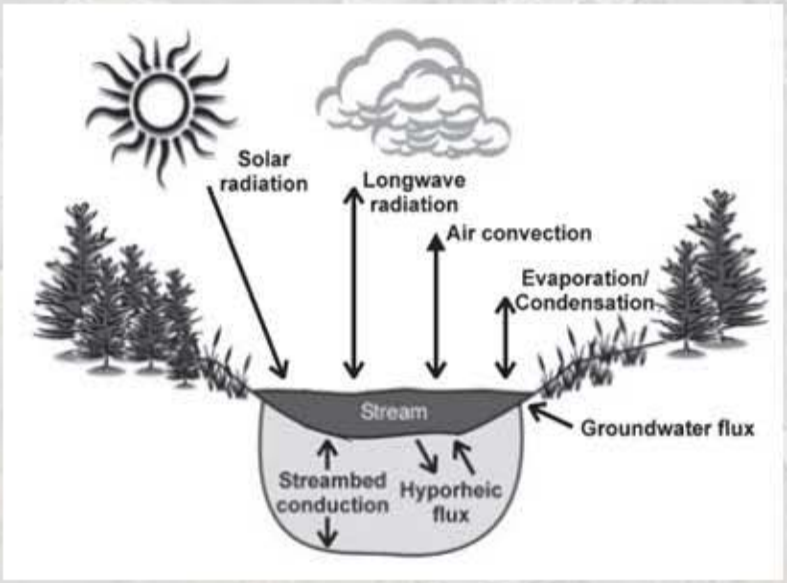
- Topography
- Riparian Vegetation
- Reach discharge

Monthly heat budget - Black Ball Stream, England



Webb et al. 2008

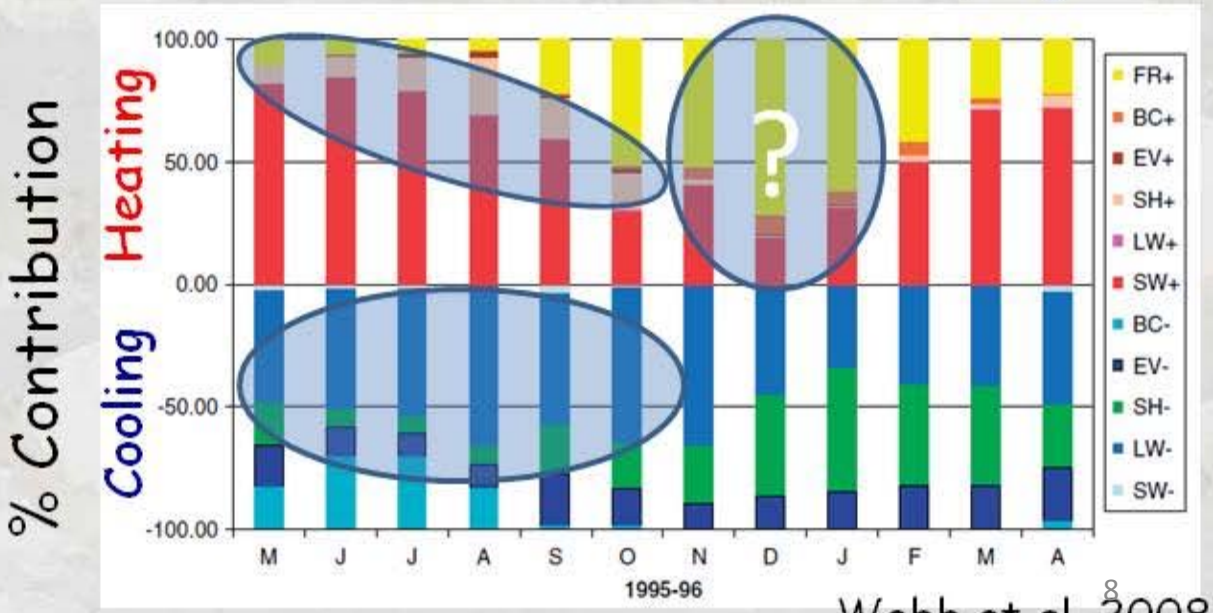
Stream Heat Budgets - Climate Effects



Mediated by…

- Topography
- Riparian Vegetation
- Reach discharge

Monthly heat budget - Black Ball Stream, England

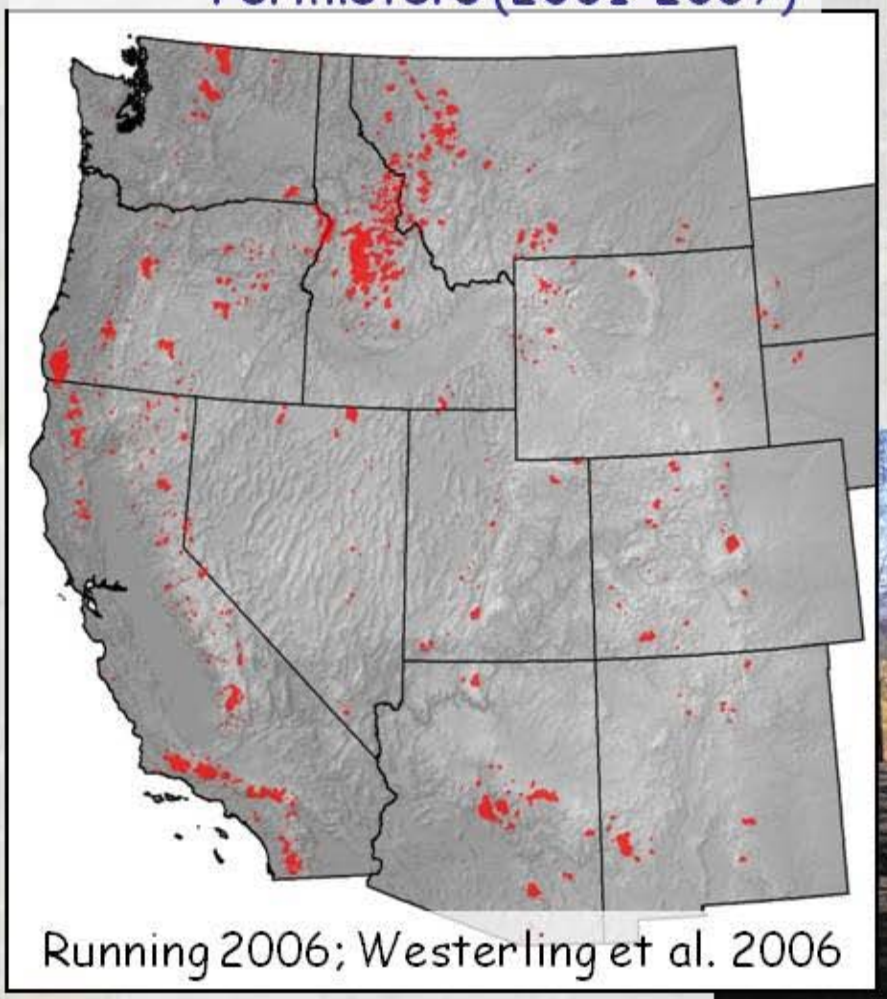


Webb et al. 2008

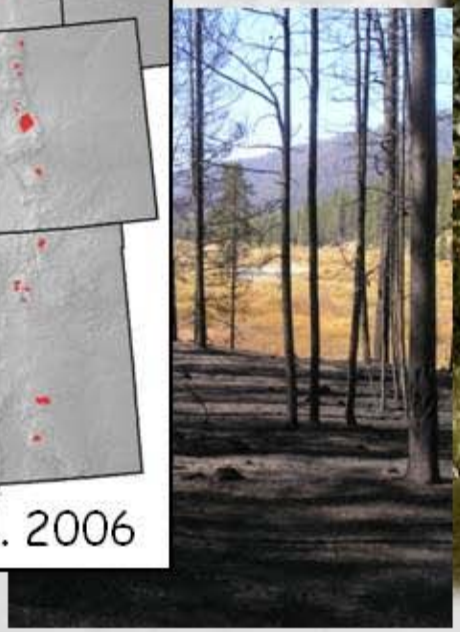
Factors That May Speed Warming

Wildfires & vegetation reductions

USFS Land - Burn Perimeters (2001-2007)

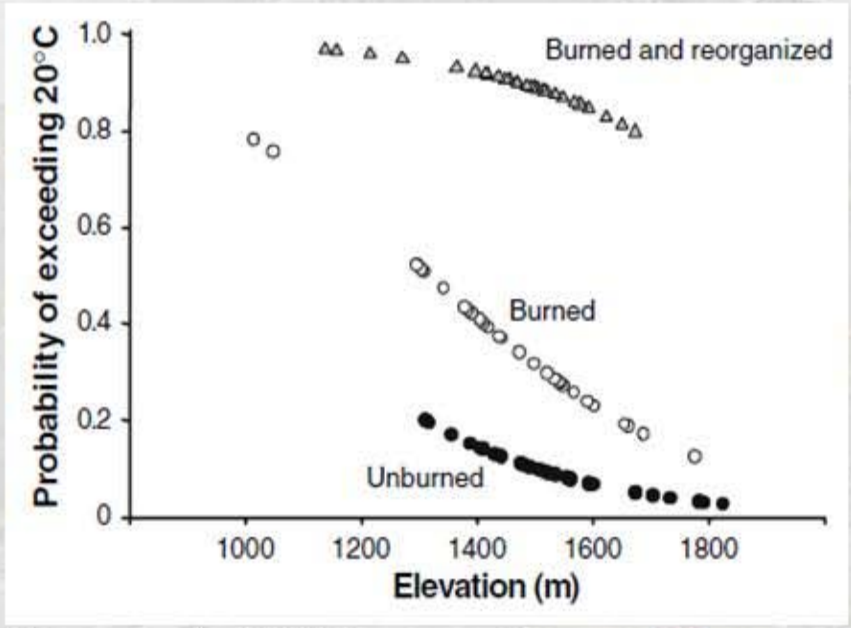


Running 2006; Westerling et al. 2006

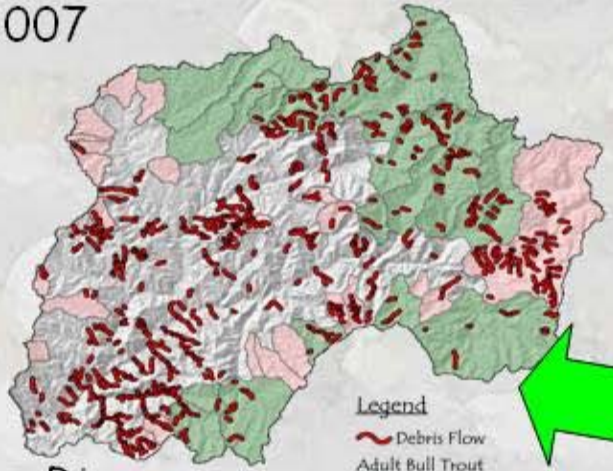


Factors That May Speed Warming

Wildfires & debris flows



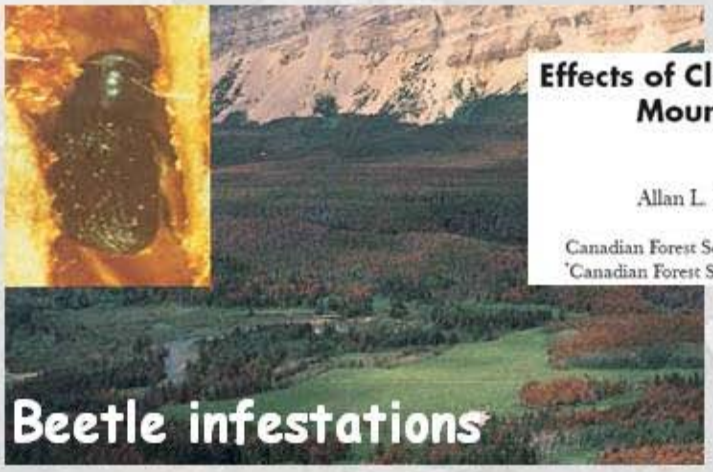
Dunham et al. 2007



Debris Flows -
MFK Boise River

Factors That May Speed Warming

Droughts, beetles, veg conversion



Effects of Climate Change on Range Expansion by the Mountain Pine Beetle in British Columbia

Allan L. Carroll, Steve W. Taylor, Jacques Régnière* and Les Safranyik

Canadian Forest Service, Pacific Forestry Centre, 506 W. Burnside Rd., Victoria, BC V8Z 1M5
*Canadian Forest Service, Laurentian Forestry Centre, PO Box 3800, Sainte Foy, QC G1V 4C7

2002 → 2004

Widespread Increase of Tree Mortality Rates in the Western United States

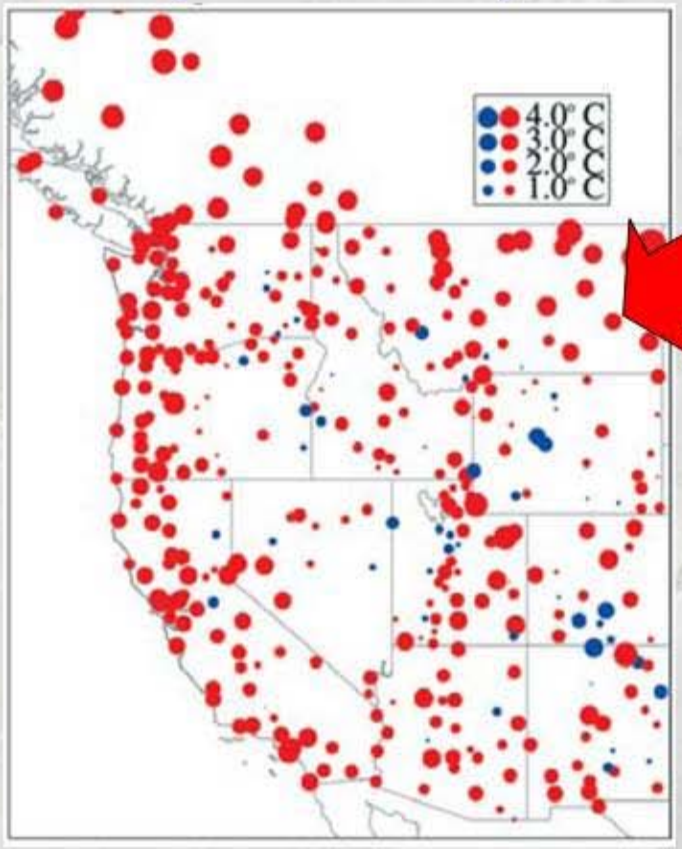
Phillip J. van Mantgem,[1*††‡] Nathan L. Stephenson,[1*†] John C. Byrne,[2] Lori D. Daniels,[3] Jerry F. Franklin,[4] Peter Z. Fulé,[5] Mark E. Harmon,[6] Andrew J. Larson,[4] Jeremy M. Smith,[7] Alan H. Taylor,[8] Thomas T. Veblen[7]

Regional vegetation die-off in response to global-change-type drought

David D. Breshears[a,b], Neil S. Cobb[c], Paul M. Rich[d], Kevin P. Price[e,f], Craig D. Allen[g], Randy Jude H. Kastens[f,j], M. Lisa Floyd[k], Jayne Belnap[l,m], Jesse J. Anderson[c], Orrin B. Myers[n], and

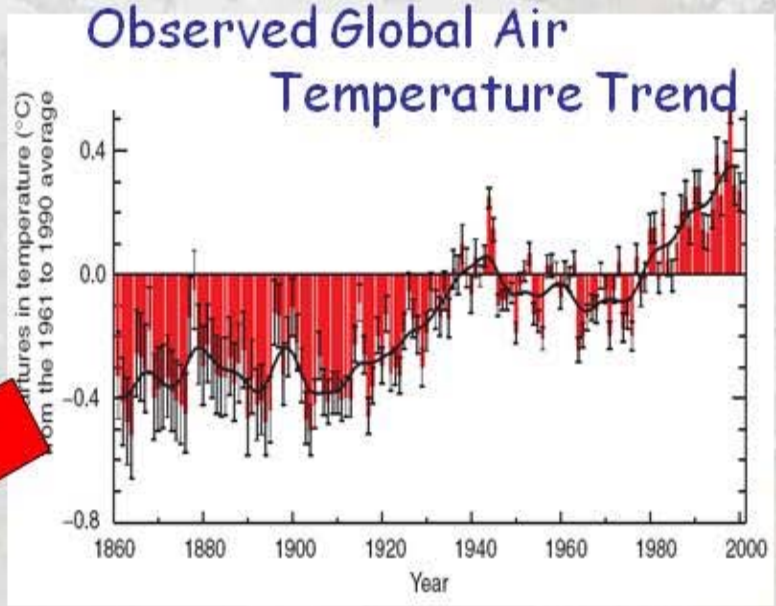
Systematic Effects - Air Temperatures

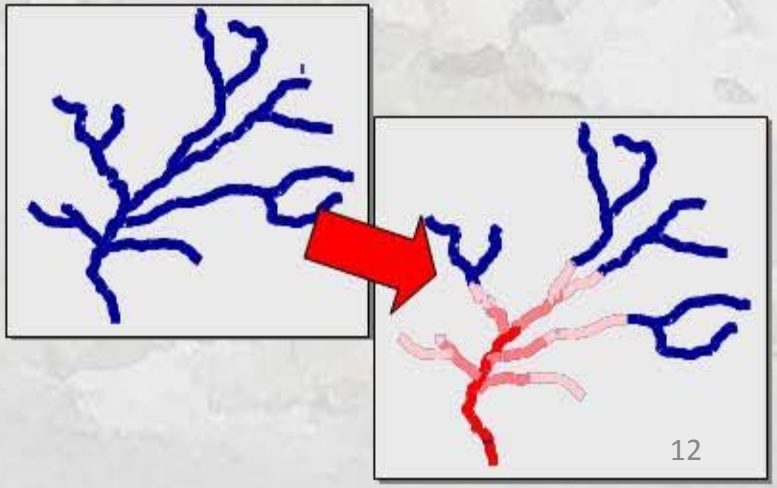
Warming Air Temps (1950-1997)



Mote et al. 2005

Observed Global Air Temperature Trend

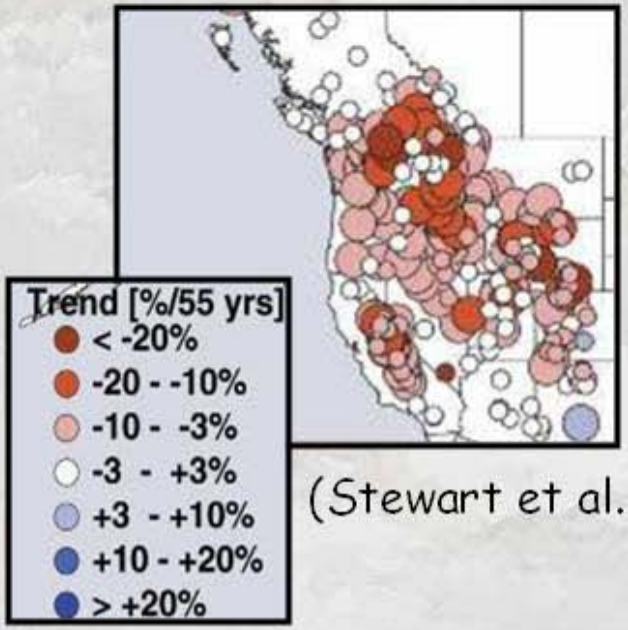




Systematic Effects - Hydrology

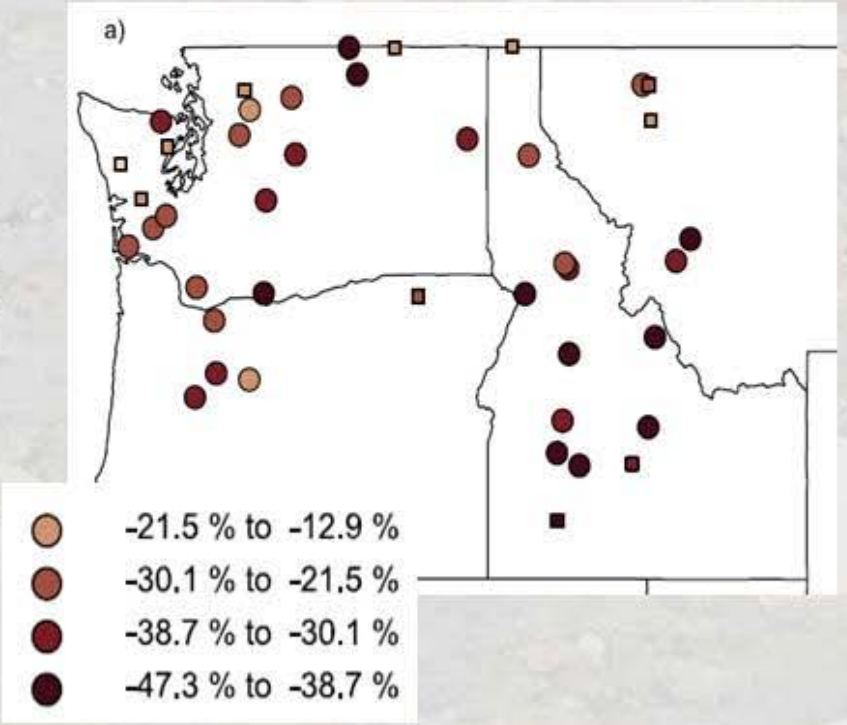
Summer baseflow decreases

June flow trends (1948-2002)



(Stewart et al. 2005)

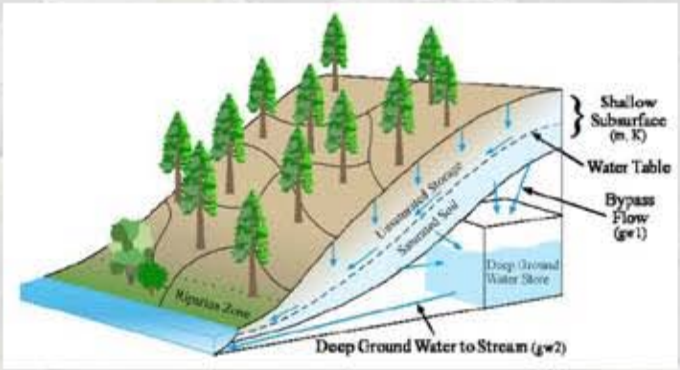
25th % summer flow trends (1948-2006)



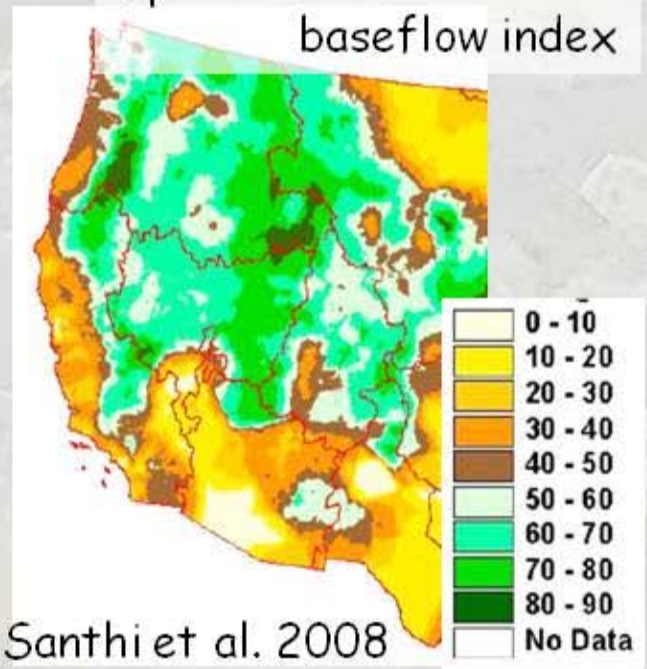
(Luce and Holden 2009)

Factors That May Slow Warming

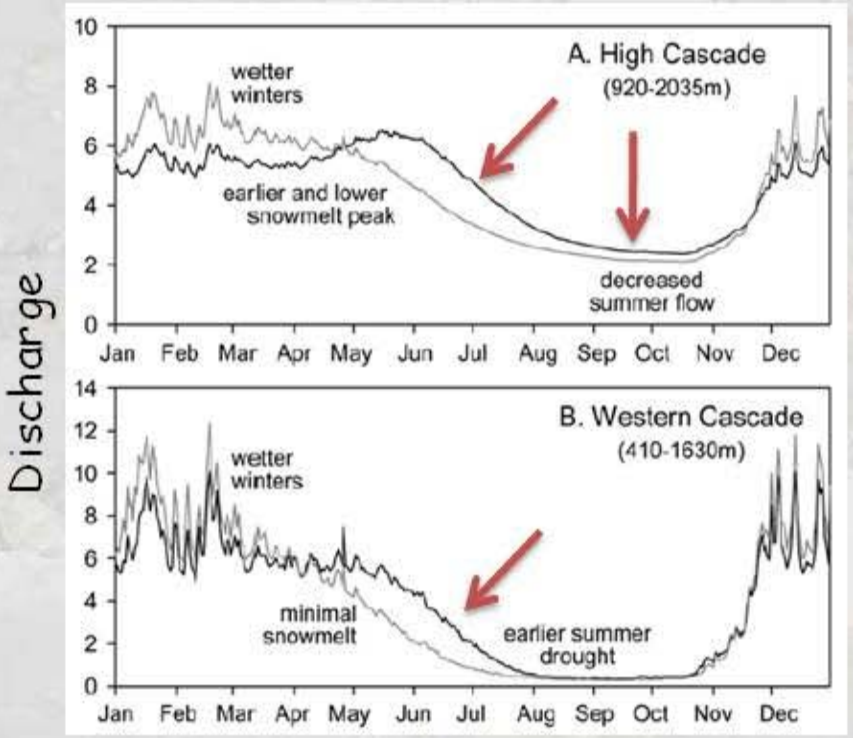
Groundwater Inflow Buffering



Spatial variation in baseflow index



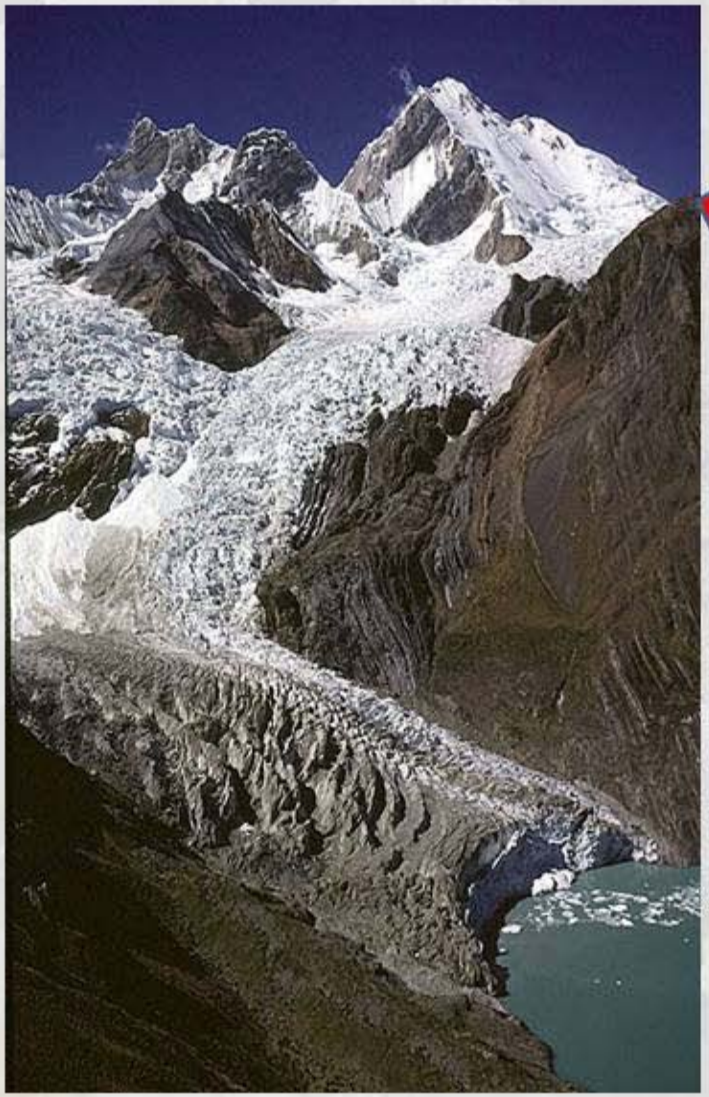
Santhi et al. 2008



Tague and Grant 2007, 2008

Factors That May Slow Warming

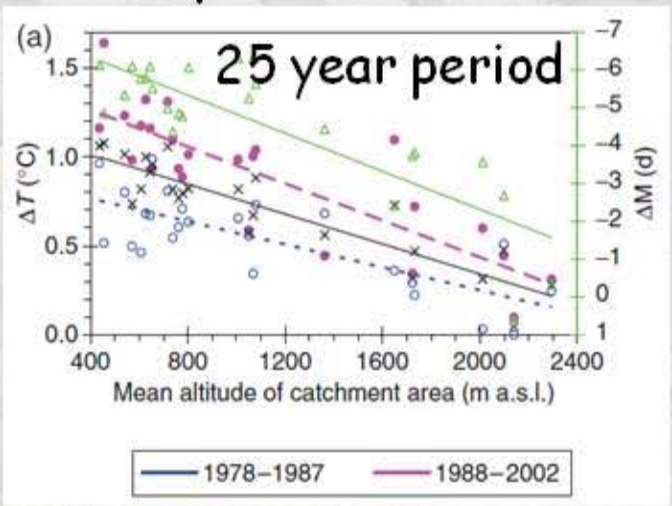
Past or present glacial activity



Factors That May Slow Warming

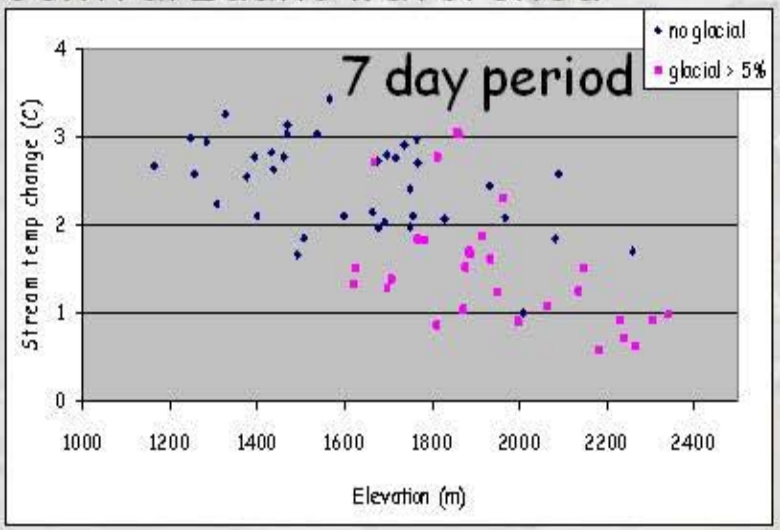
Past or present glacial activity

Swiss alpine streams

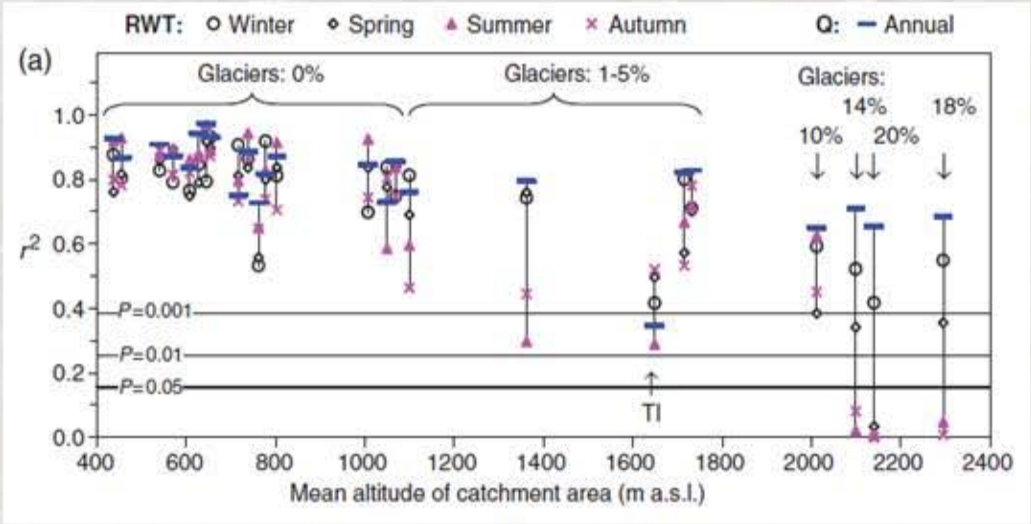


Hari et al. 2006

Central Idaho watershed

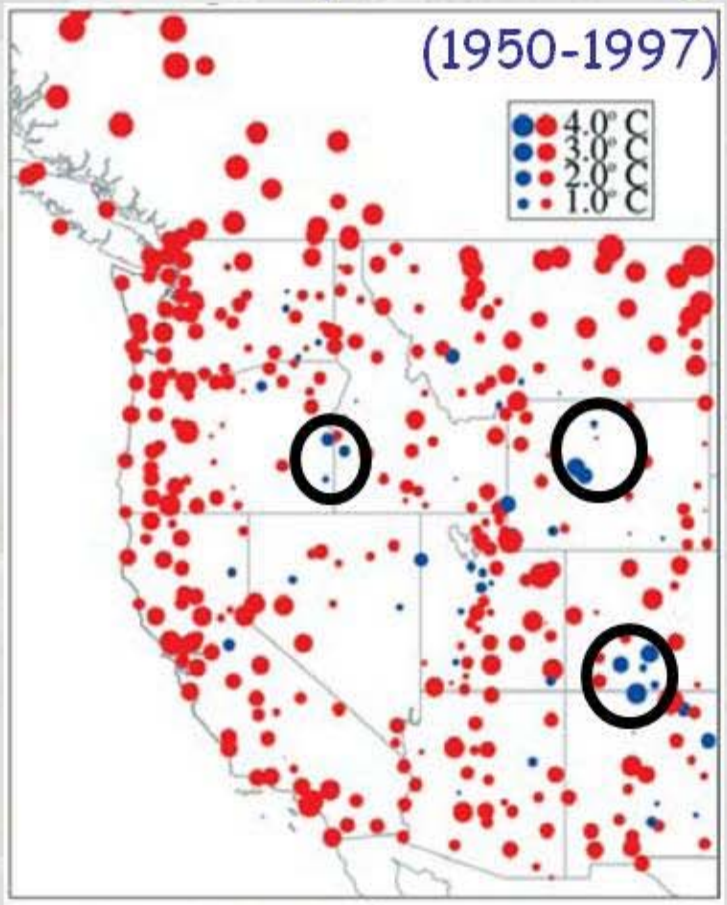


Isaak, unpublished.



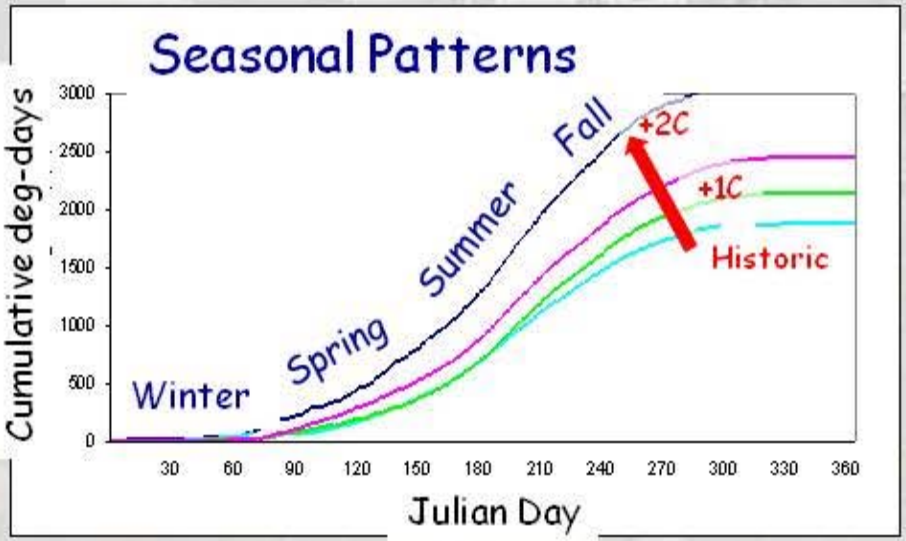
Factors That May Reverse Warming

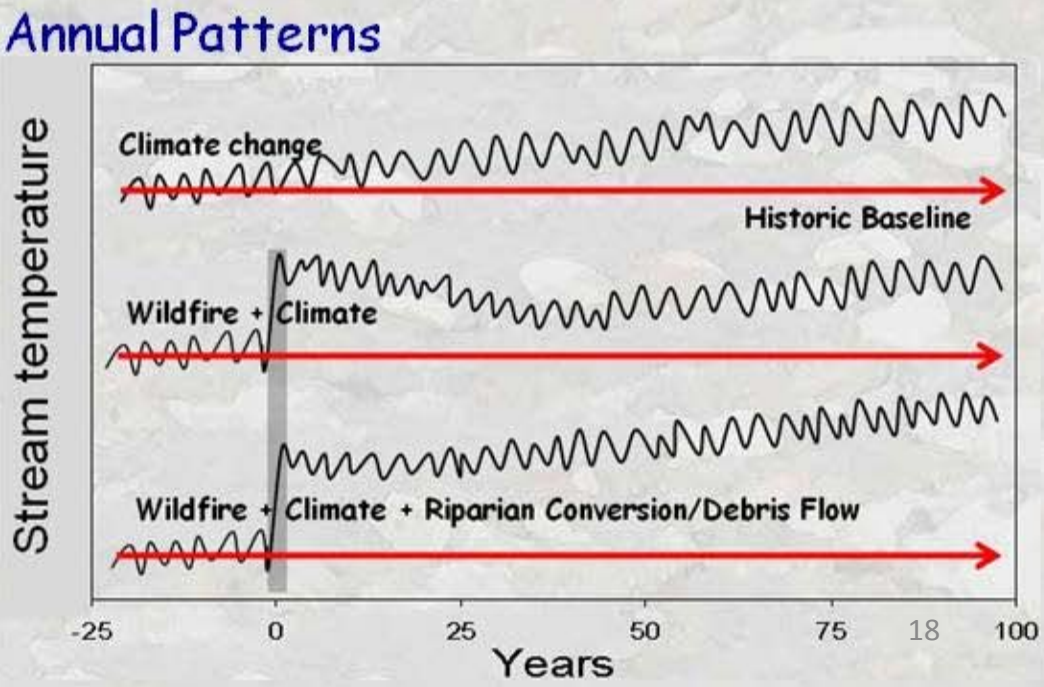
Local air temperature cooling?



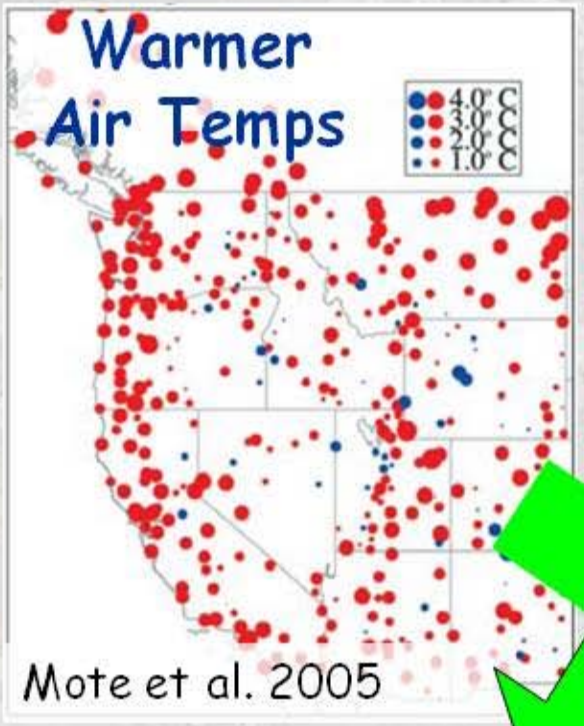
Dams/reservoirs
(variable depth releases)

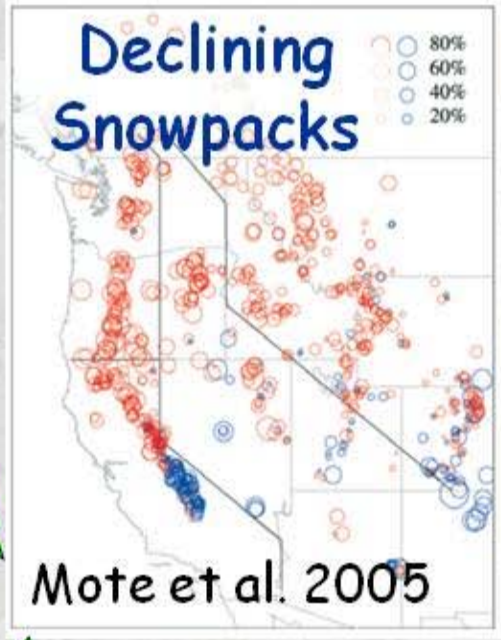
Future Stream Temperature Trends?

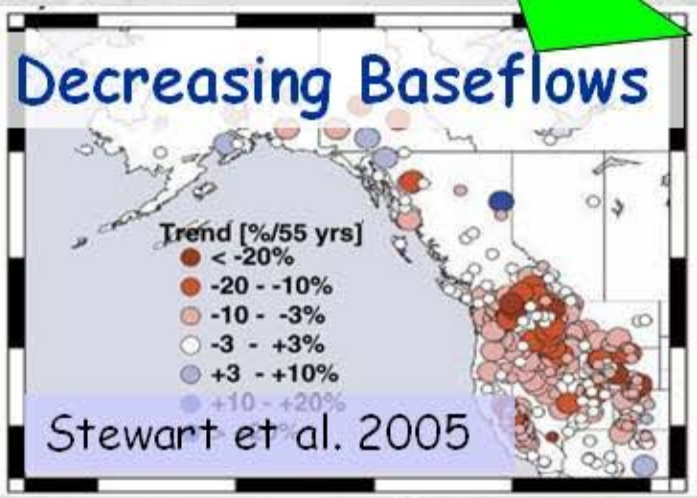


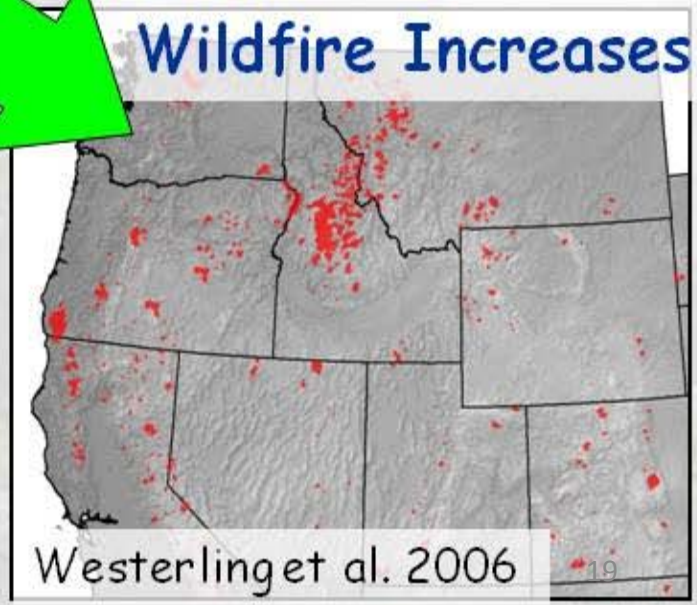


Western US - Observed Trends







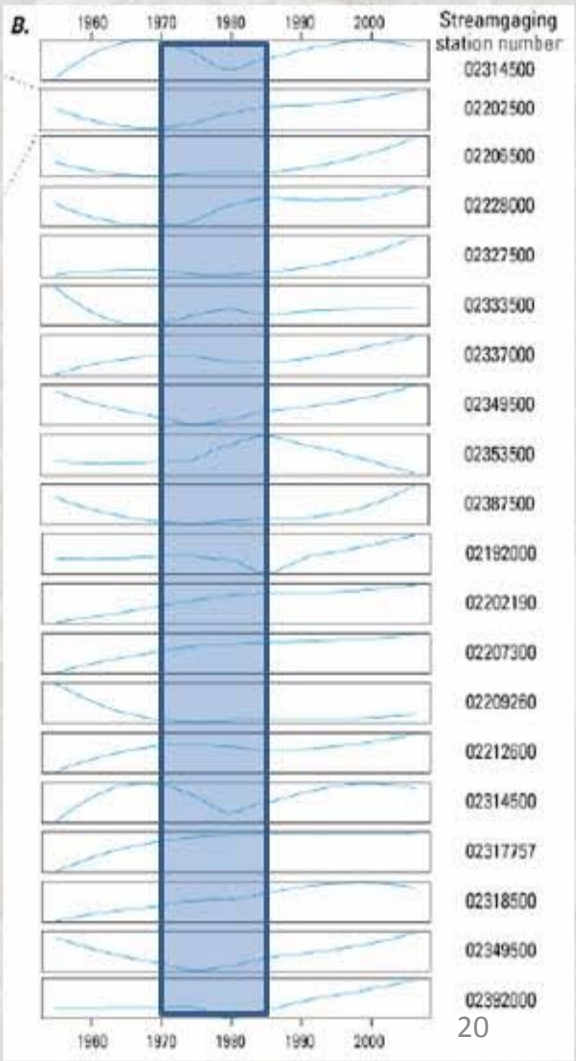


Observed Temperature Trends in…

Rivers/Streams of Georgia

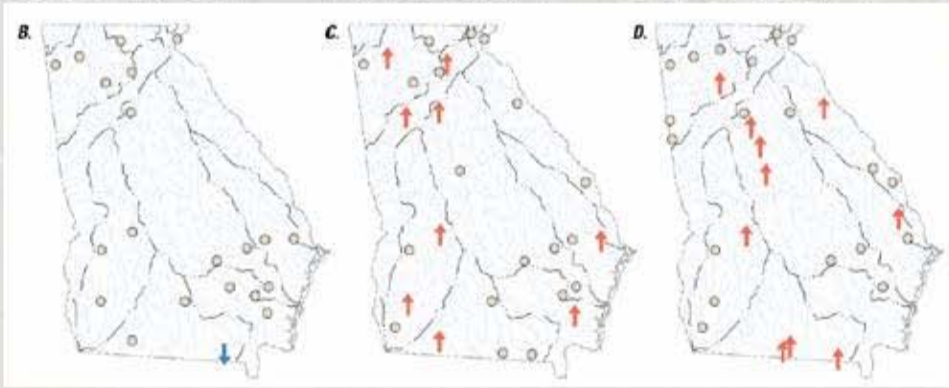
Temps measured @ stream flow gages

1955-2004



Statistically significant changes from…

1955-1984 1965-1994 1975-2004

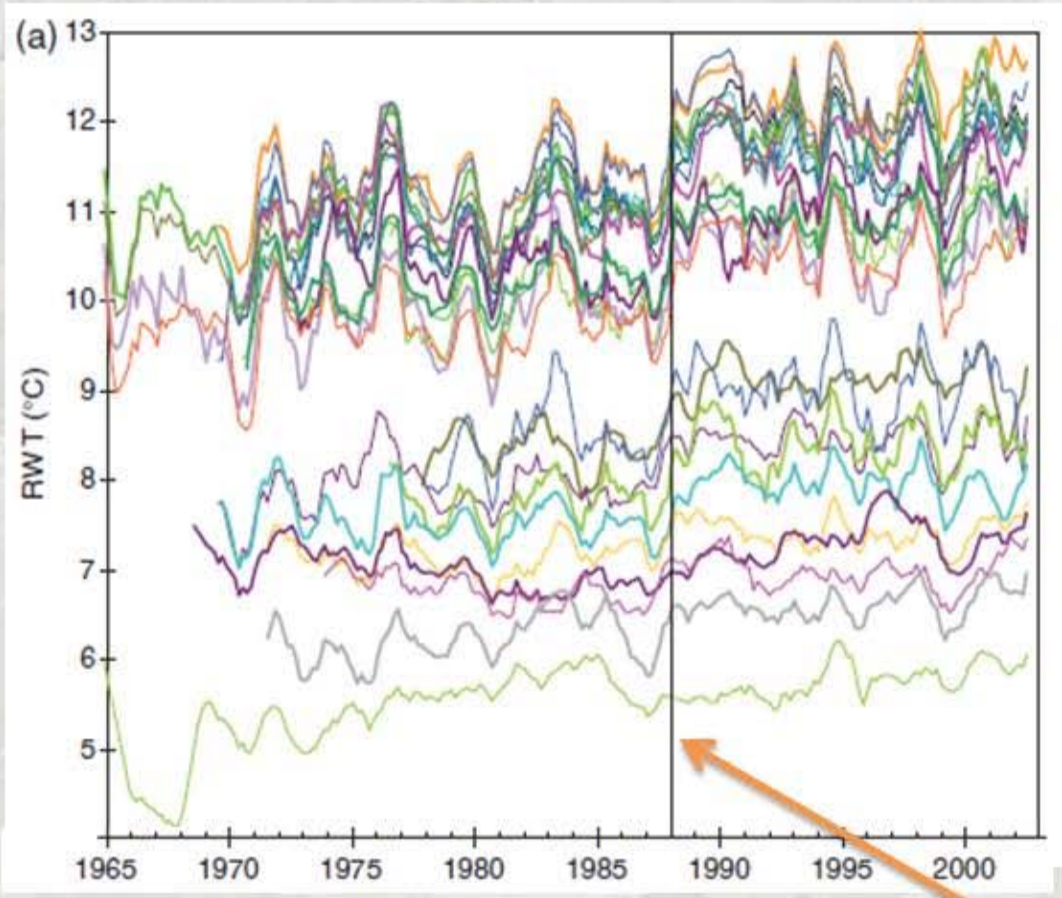


Musser and Leath 2007

Observed Temperature Trends in…

Rivers/Streams of Switzerland

1978-2004



- 22 of 25 streams show statistically significant warming

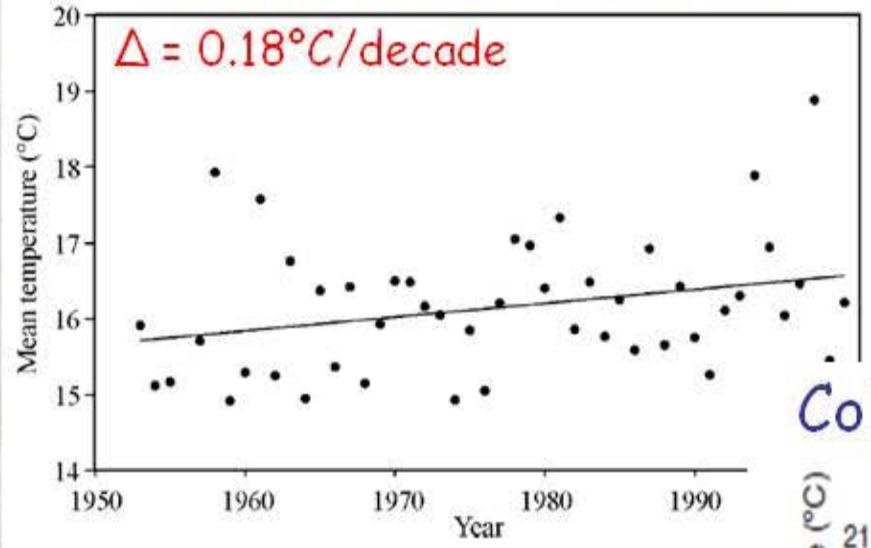
NAO shift

Hari et al. 2006

Observed Temperature Trends in…

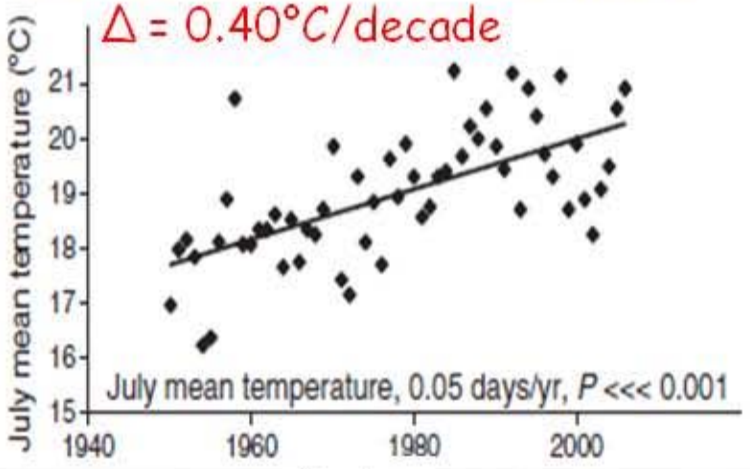
Mainstem Rivers in PNW

Fraser River - Summer



Morrison et al. 2002

Columbia River - Summer

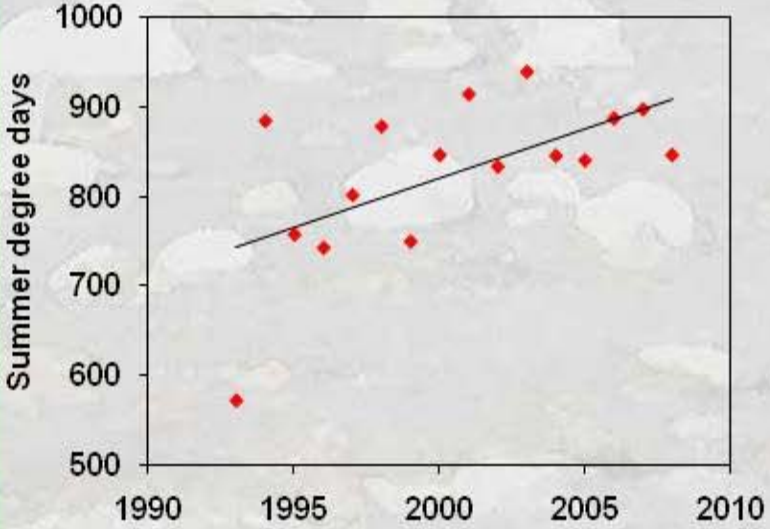


Petersen and Kitchell 2001; Crozier et al. 2008

Observed Temperature Trends in…

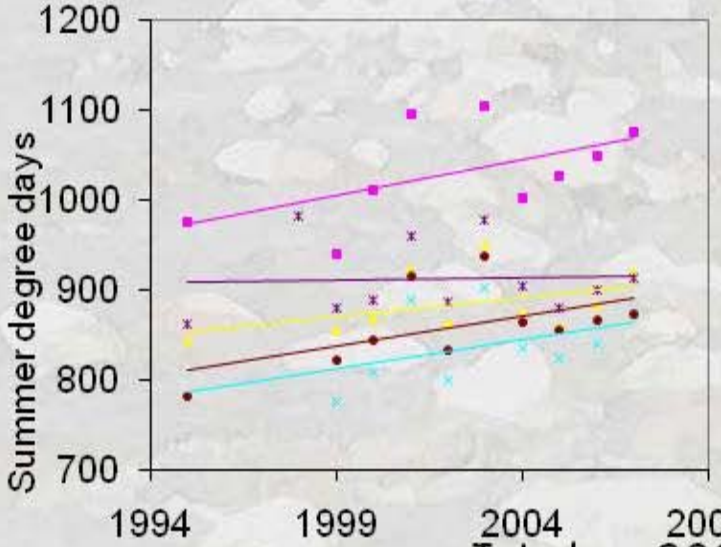
Small Western Streams

Northwest Montana



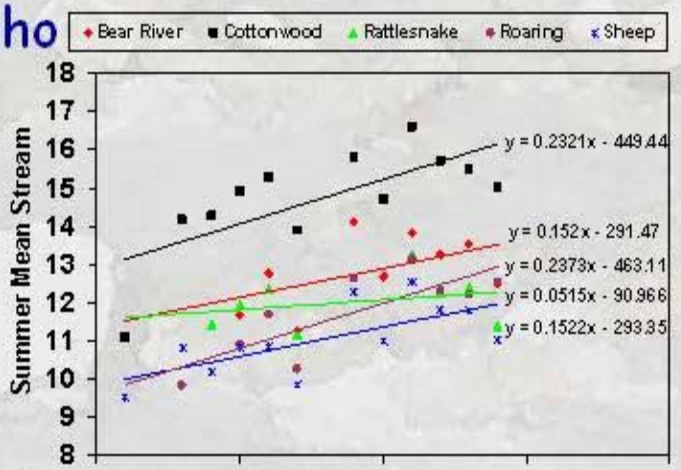
Clancy, unpublished.

Northern Idaho



Jakober 2009

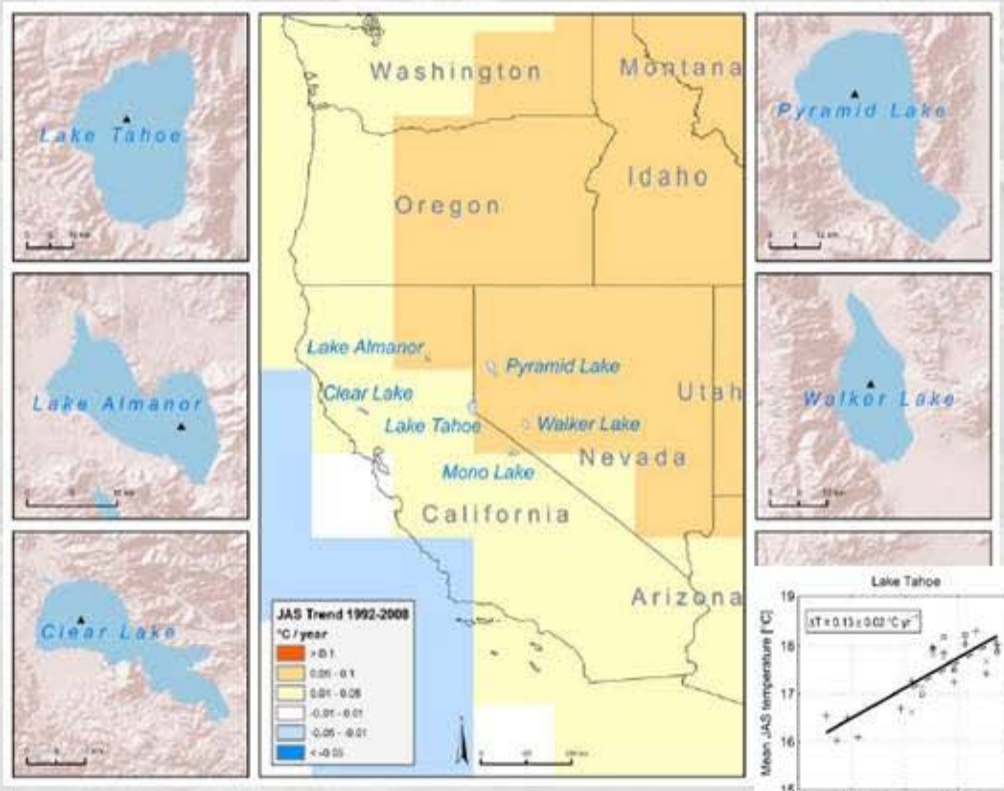
Southern Idaho

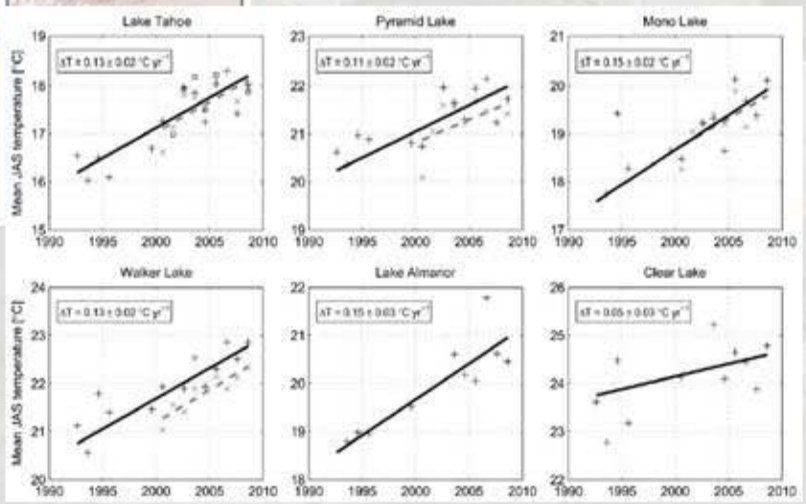


Rieman & Isaak, unpublished.

Observed Temperature Trends in…

Western Lakes from 1992-2008





Schneider et al. 2009

Boise River Temperature Database

Stream Temperature Database

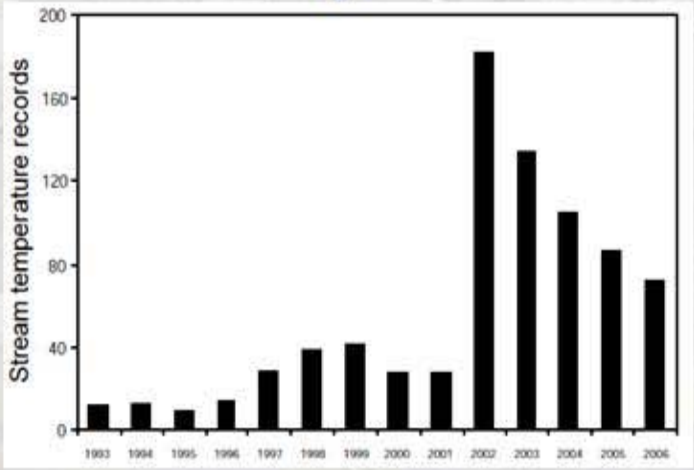
14 year period (1993 - 2006)
780 observations
518 unique locations

Watershed Characteristics

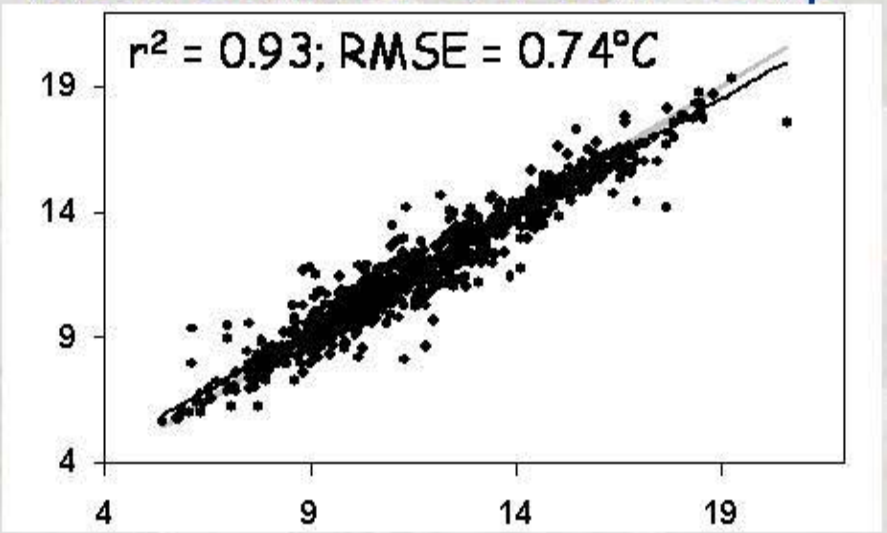
Elevation range 900 - 3300 m
Fish bearing streams ~2,500 km
Watershed area = 6,900 km^2

Boise River Temperature Models

Years With Temperature Data



Mean Summer Stream Temp



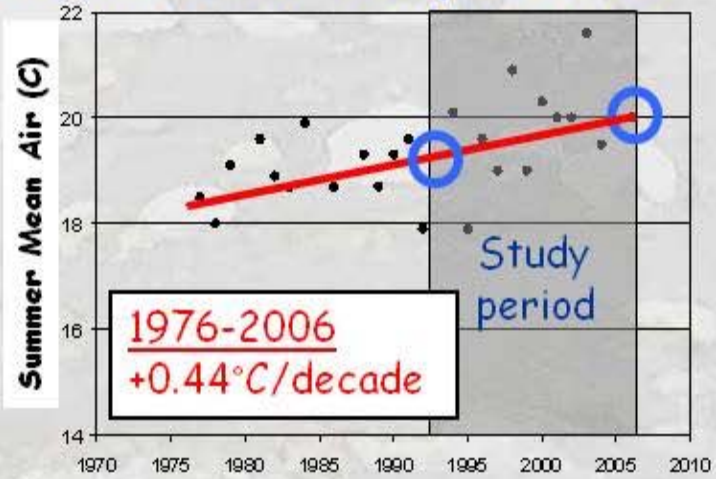
Predictor variables

- Elevation
- Summer Air Temp
- Summer Stream Flow
- Radiation

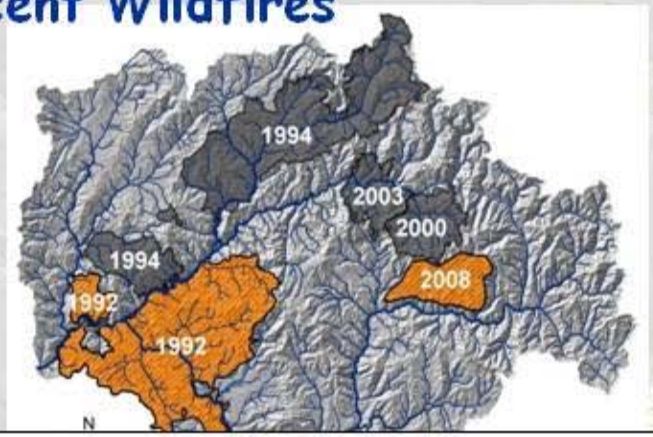
Isaak et al., In press

Environmental Trends in the Boise River Basin

Summer Air Temperature

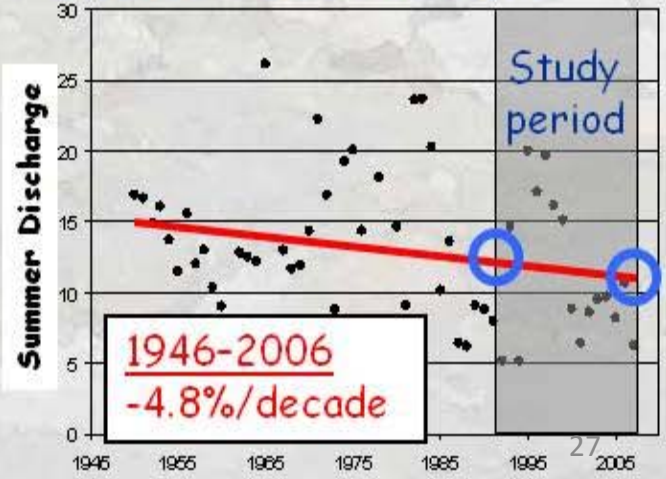


Recent Wildfires

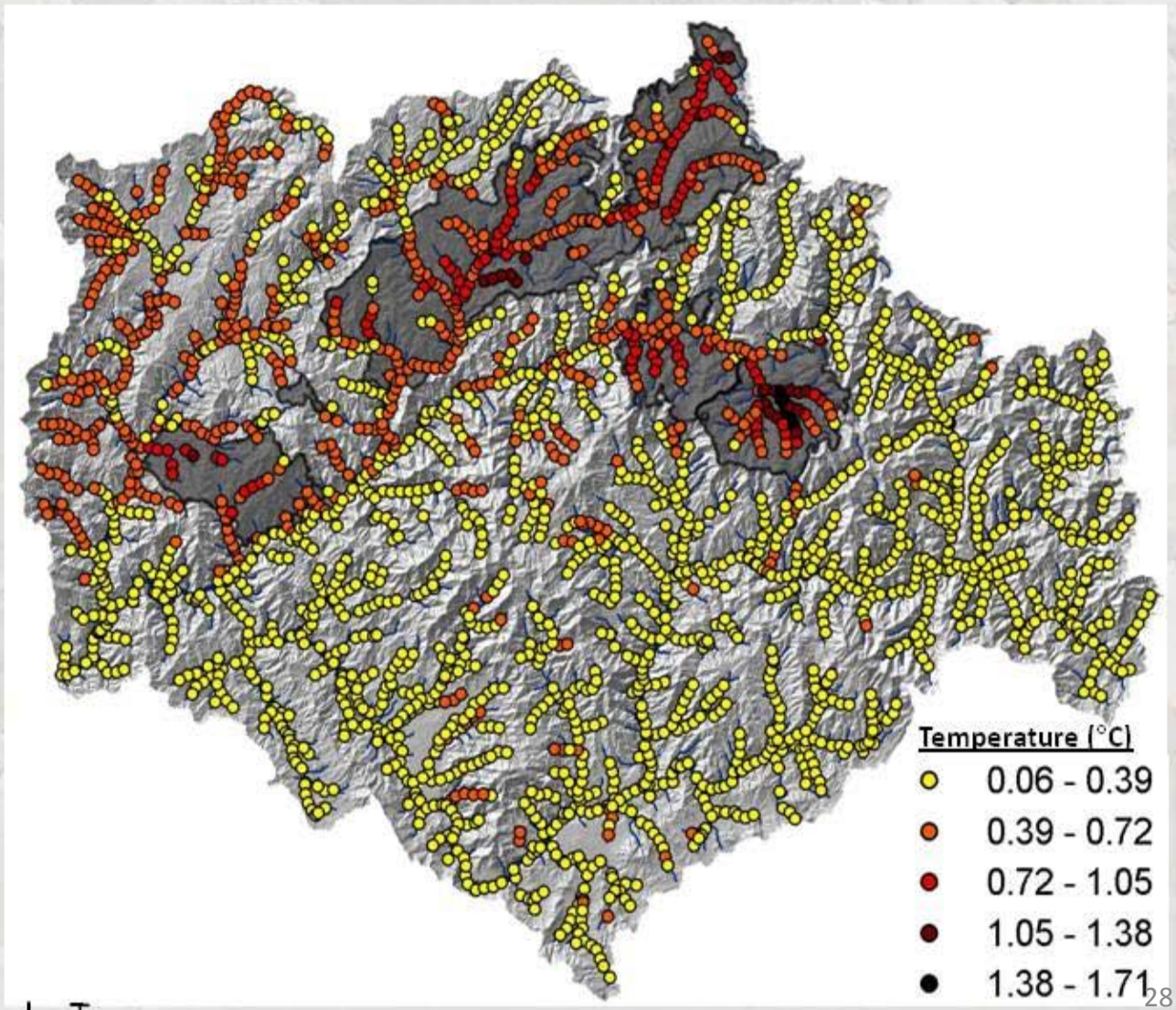


14% burned during 93-06 study period
30% burned from 92-08

Summer Stream Flow

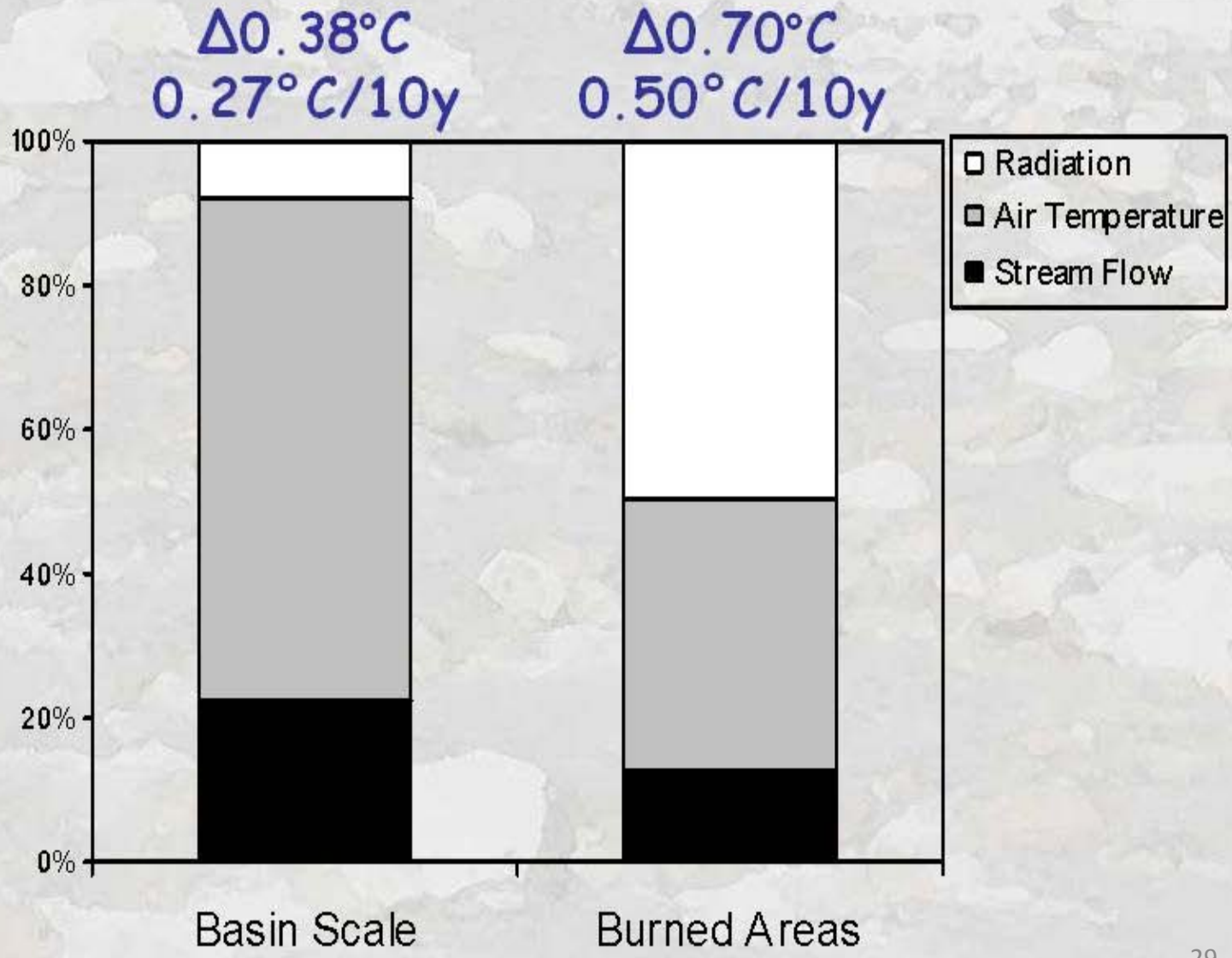


Changes in Mean Summer Stream Temperature (1993-2006)



Isaak et al., In press

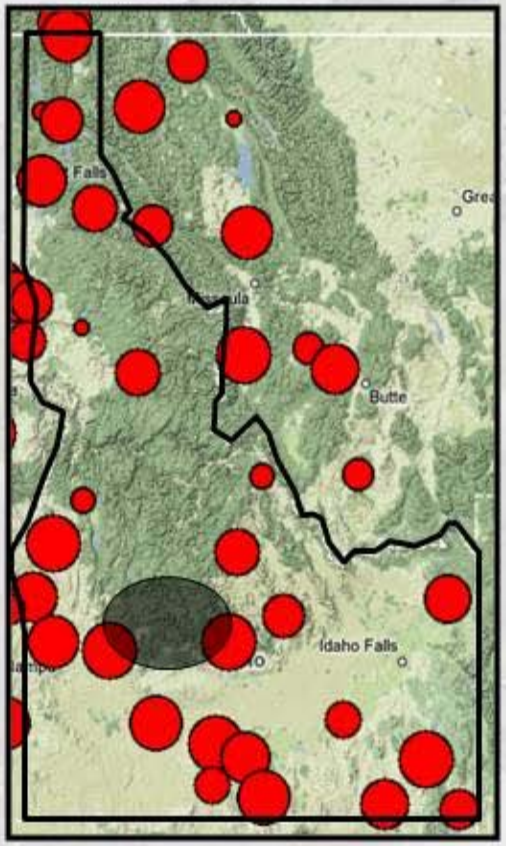
93-06 Stream Temperature Changes



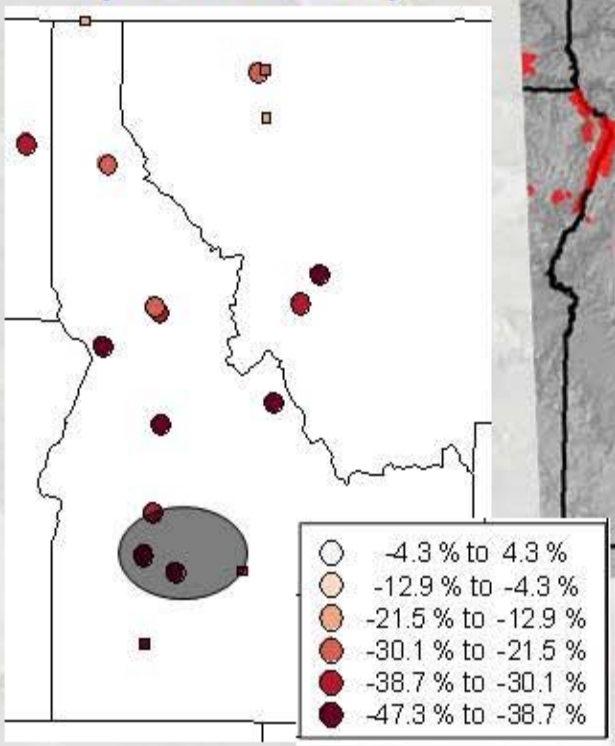
Isaak et al., In press

Similar Trends Elsewhere?

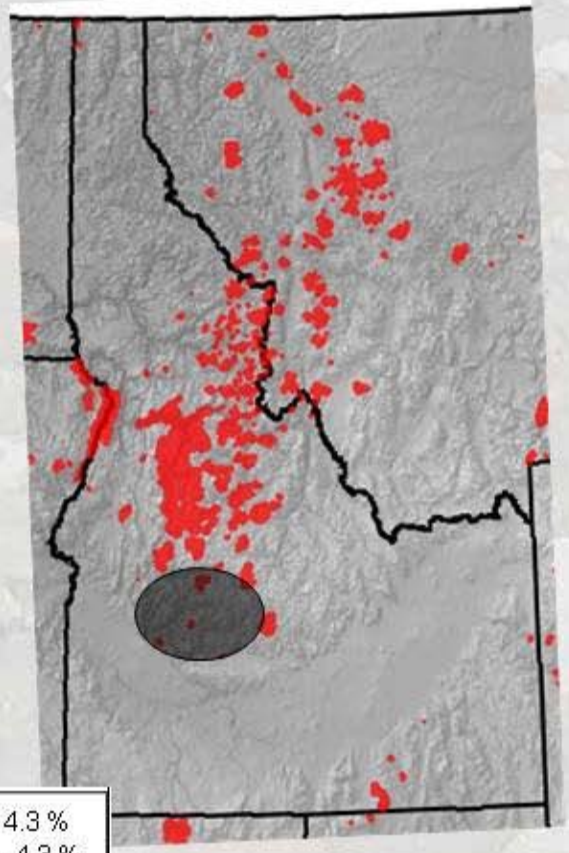
Summer air temp trends (1976-2006)



25% flow trends (1946-2006)

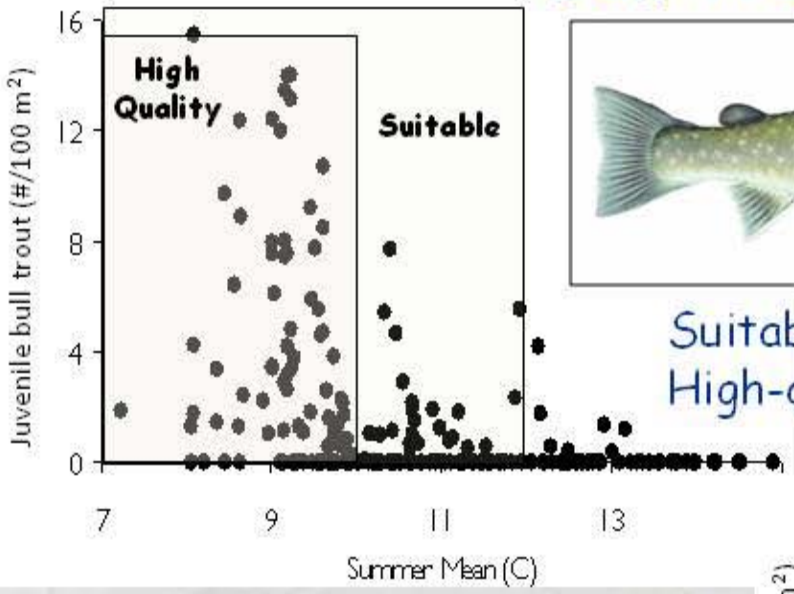


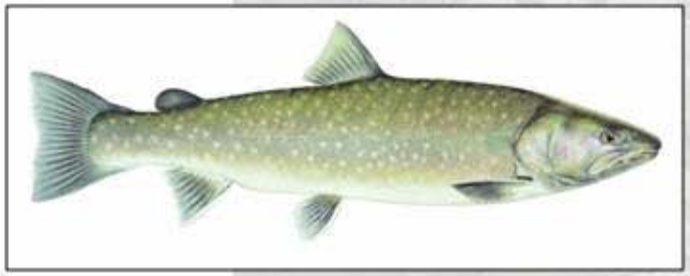
Wildfires on National Forests (2001-2007)



How Were Thermal Habitats Affected?

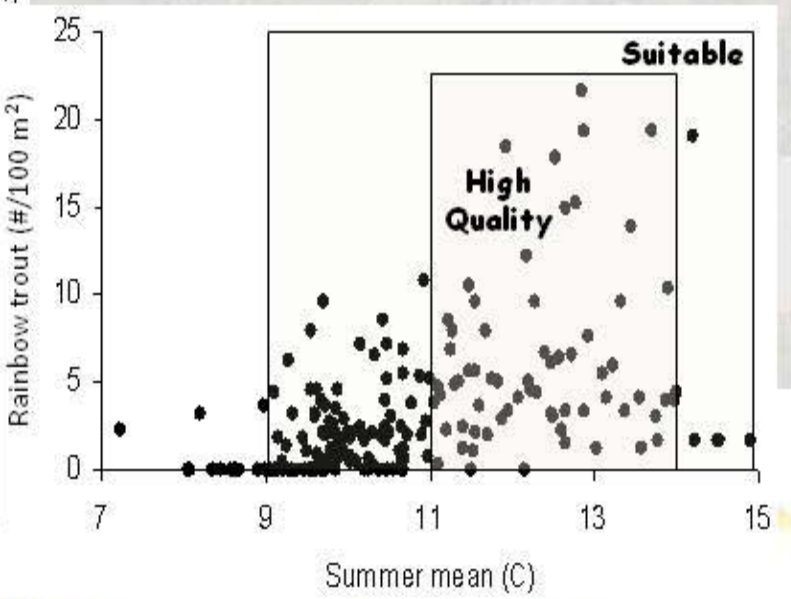
Bull Trout





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

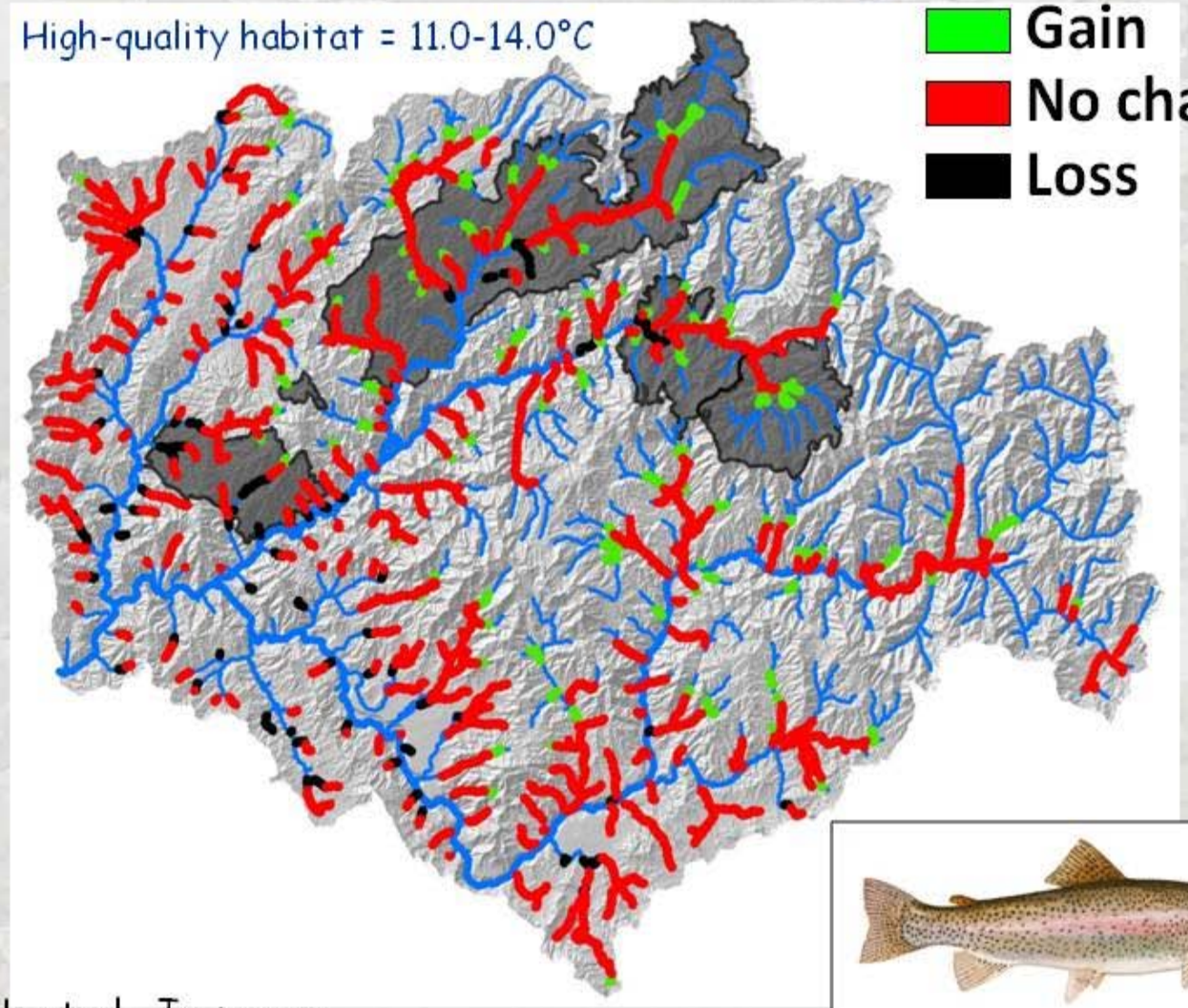
Rainbow Trout



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., In press

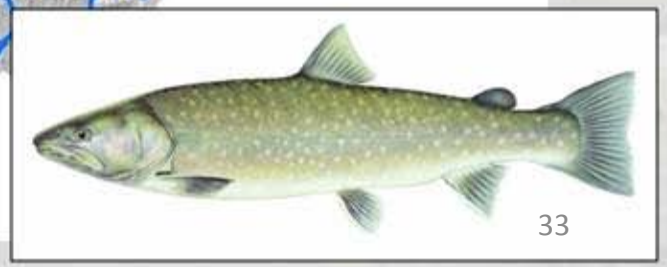
93'-06' Bull Trout Natal Habitat Changes

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

High-quality habitat < 10°C

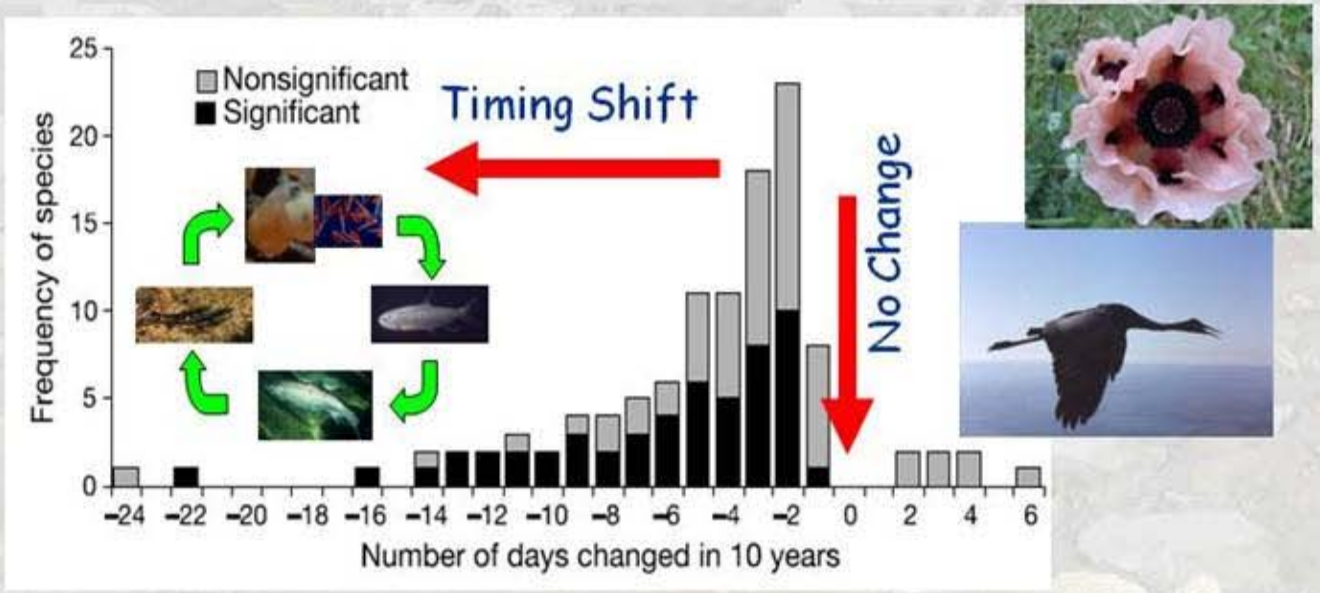
Loss

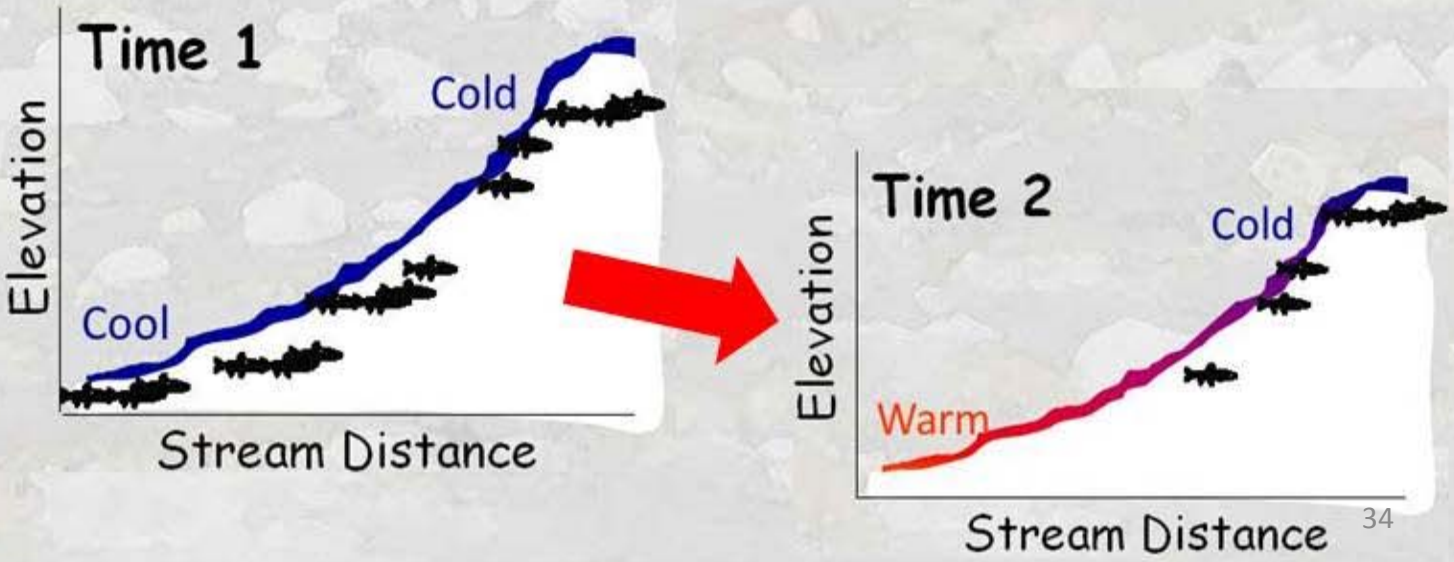
No change



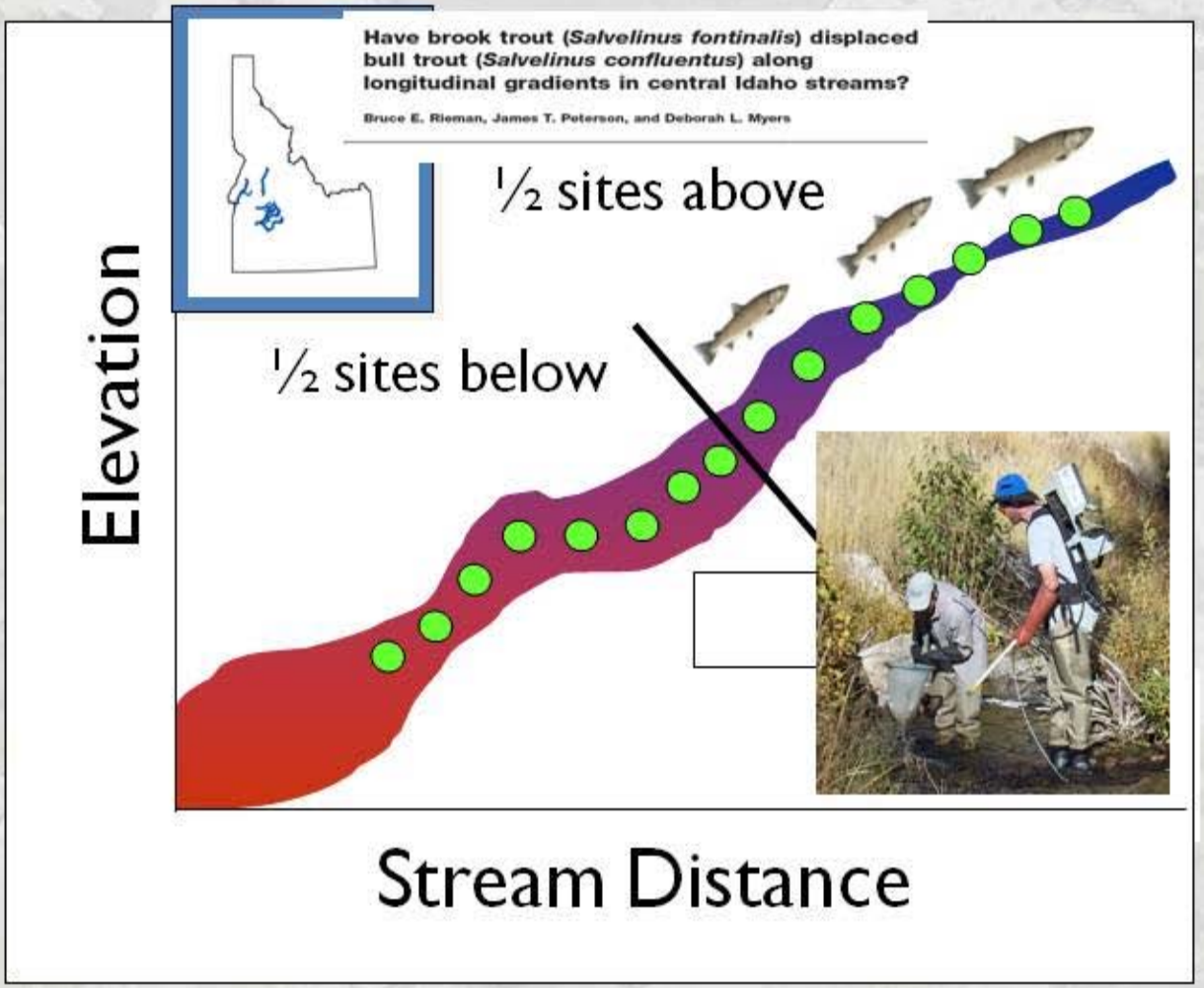
Isaak et al., In press

Are Populations Shifting in Space or Time?



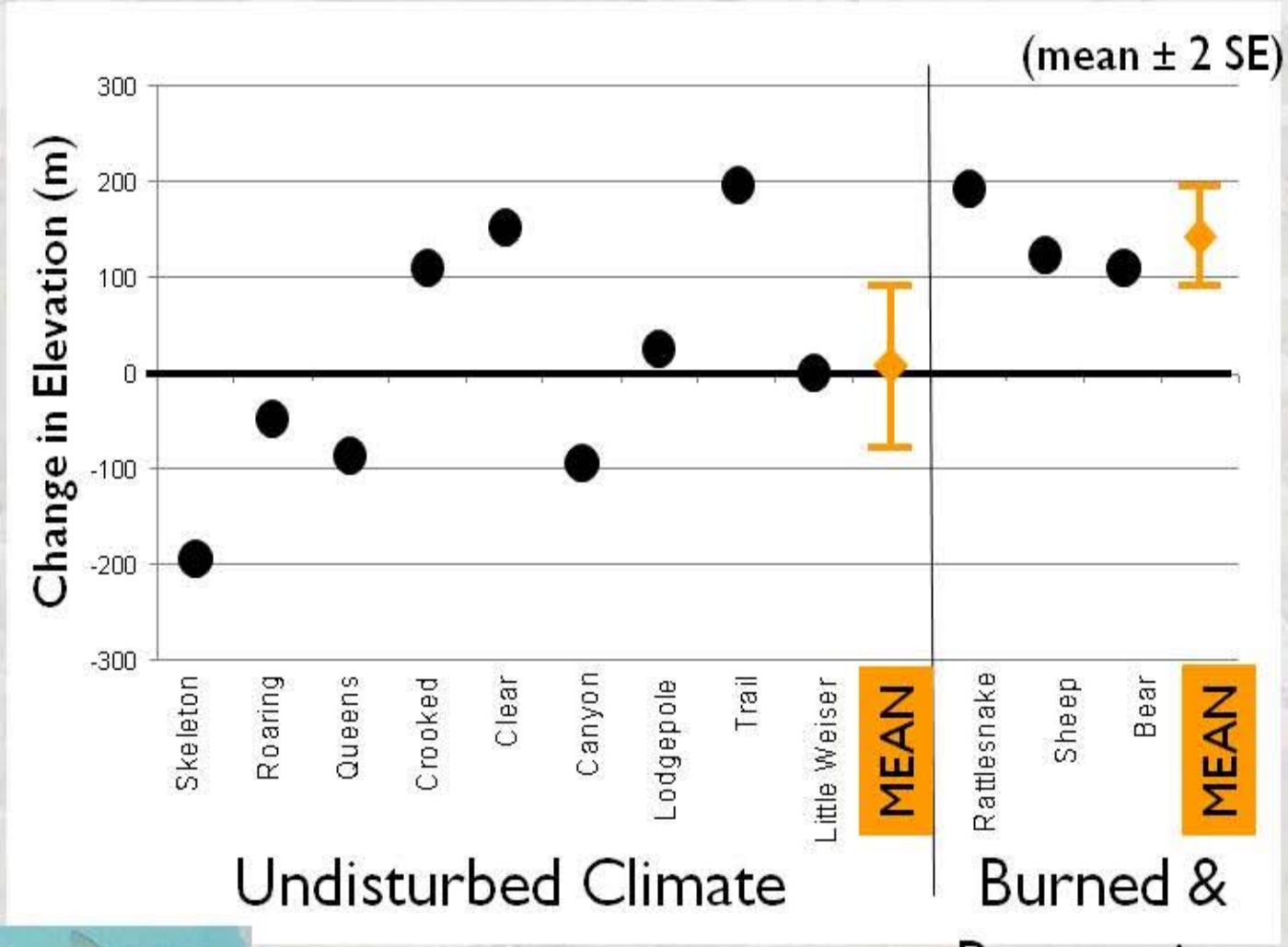


Monitoring Stream-Scale Distributions



Bull Trout Distribution Shifts

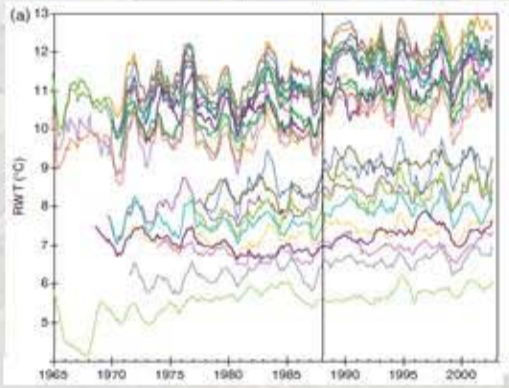
Lower Elevation Limit (1997-2007)



Brown Trout Distribution Shifts

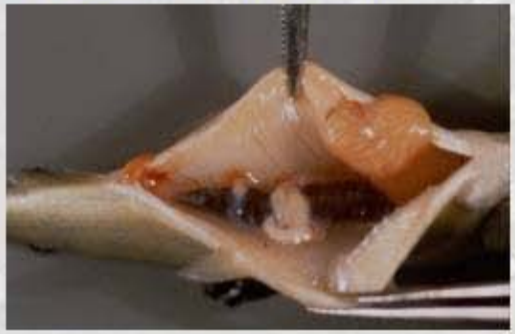
Switzerland (1978-2002)

Stream Temp Increases

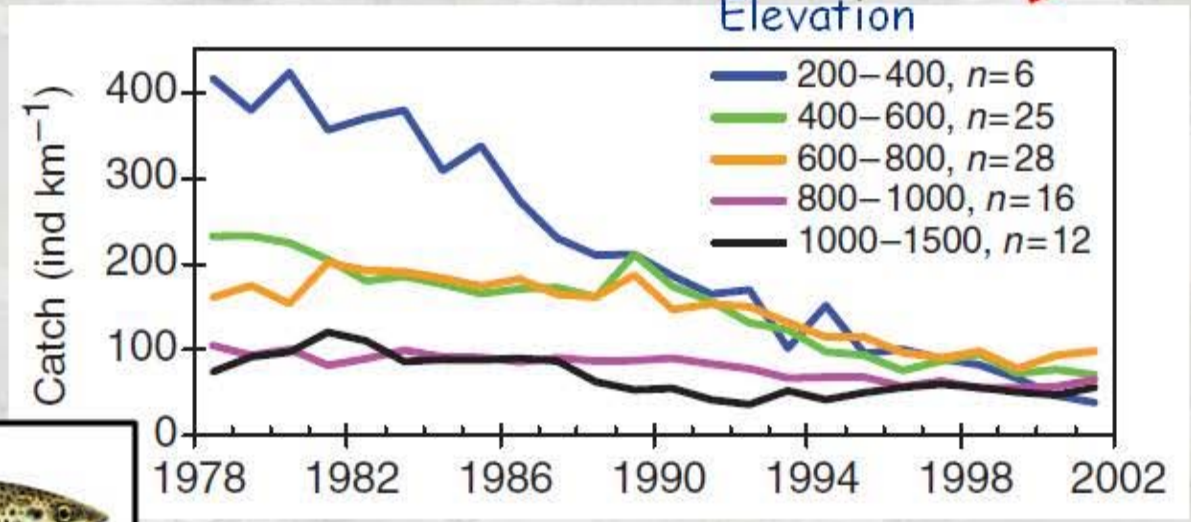


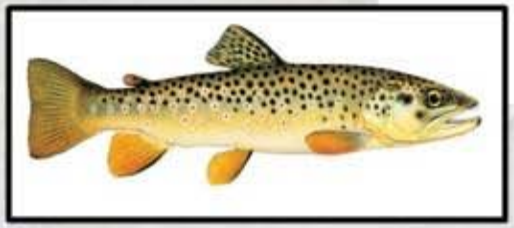
+

Disease Outbreaks



=

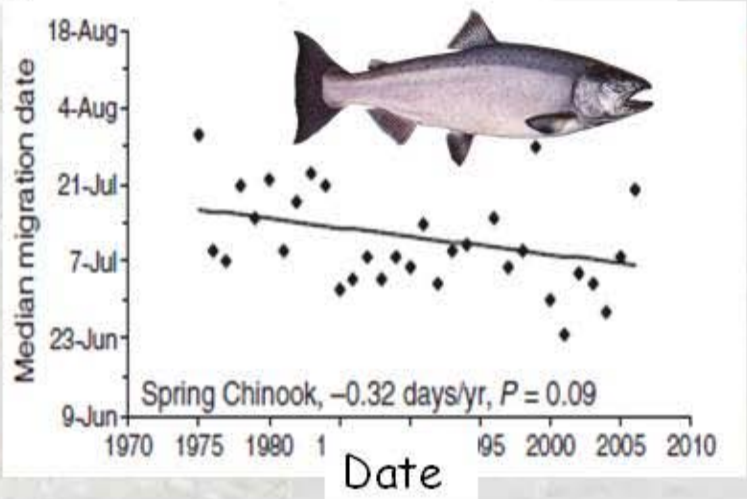




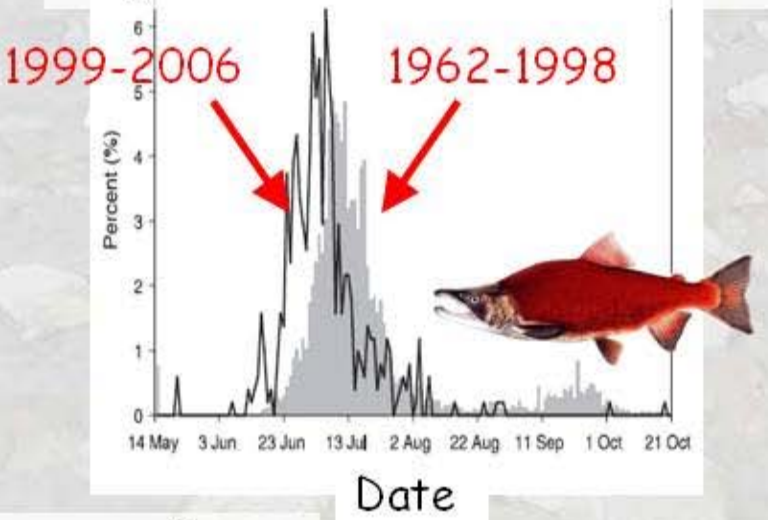
Hari et al. 2006

Shifts in Salmon Migration Timing

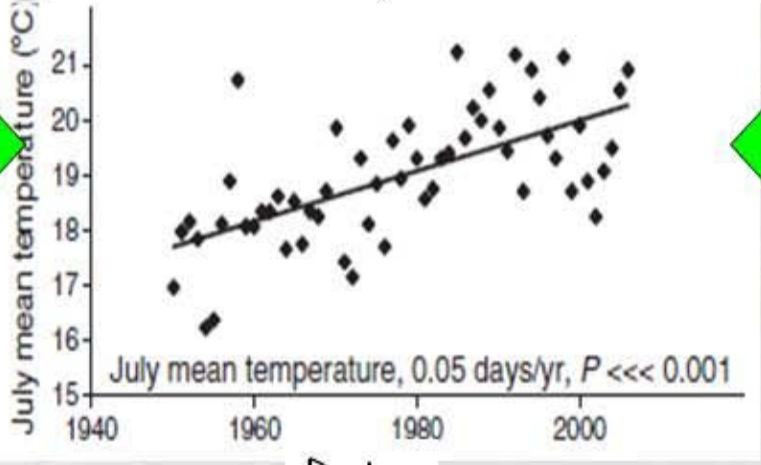
Median Spring Chinook Migration Dates at Bonneville



Distribution of Sockeye Migrations at Lower Granite



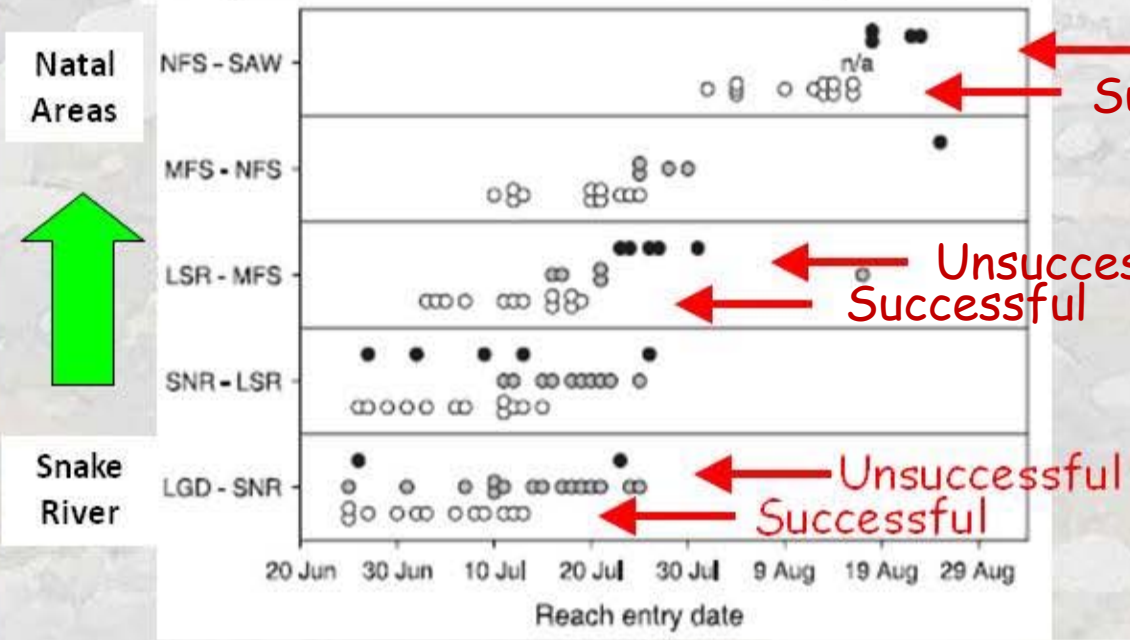
July Stream Temps at Bonneville



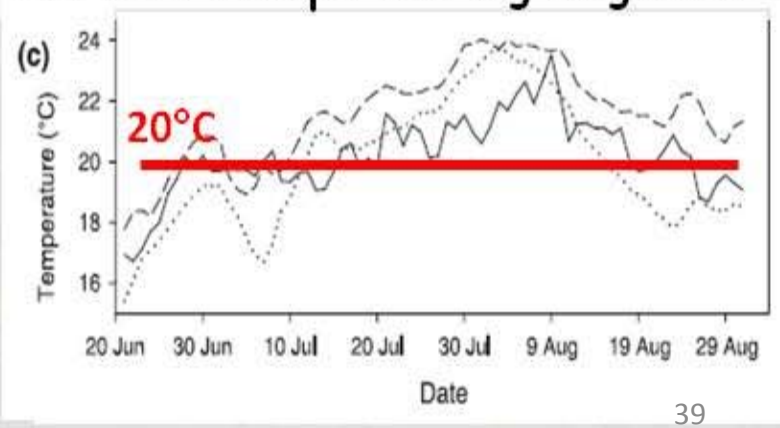
Crozier et al. 2008;
Keefer et al. 2009

Sockeye Salmon Migration Mortality

Migration Success vs. Timing



Stream Temps During Migration



Keefer et al. 2009

Fish Can Bend, But May Also Break

Thermal "Events" Will Increase

High Water Temperature In Grande Ronde Kills 239 Adult Spring Chinook
Columbia Basin Bulletin, August 14, 2009 (PST)

Saturday, October 26, 2002

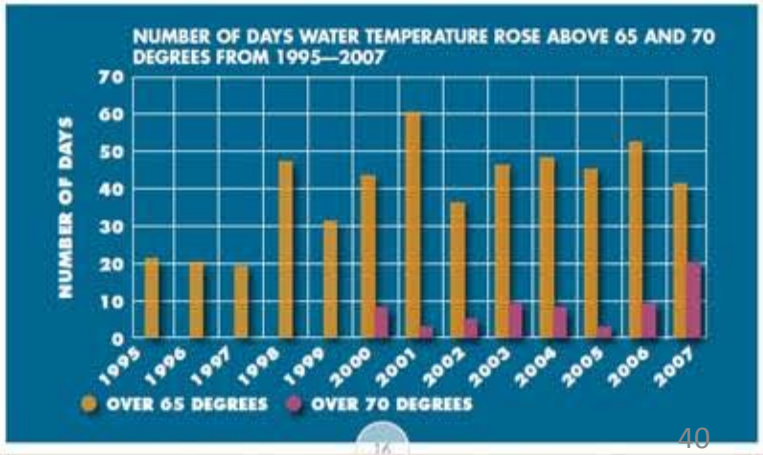
Klamath River fish kill estimates rise to 33,000

By JEFF BARNARD
THE ASSOCIATED PRESS

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

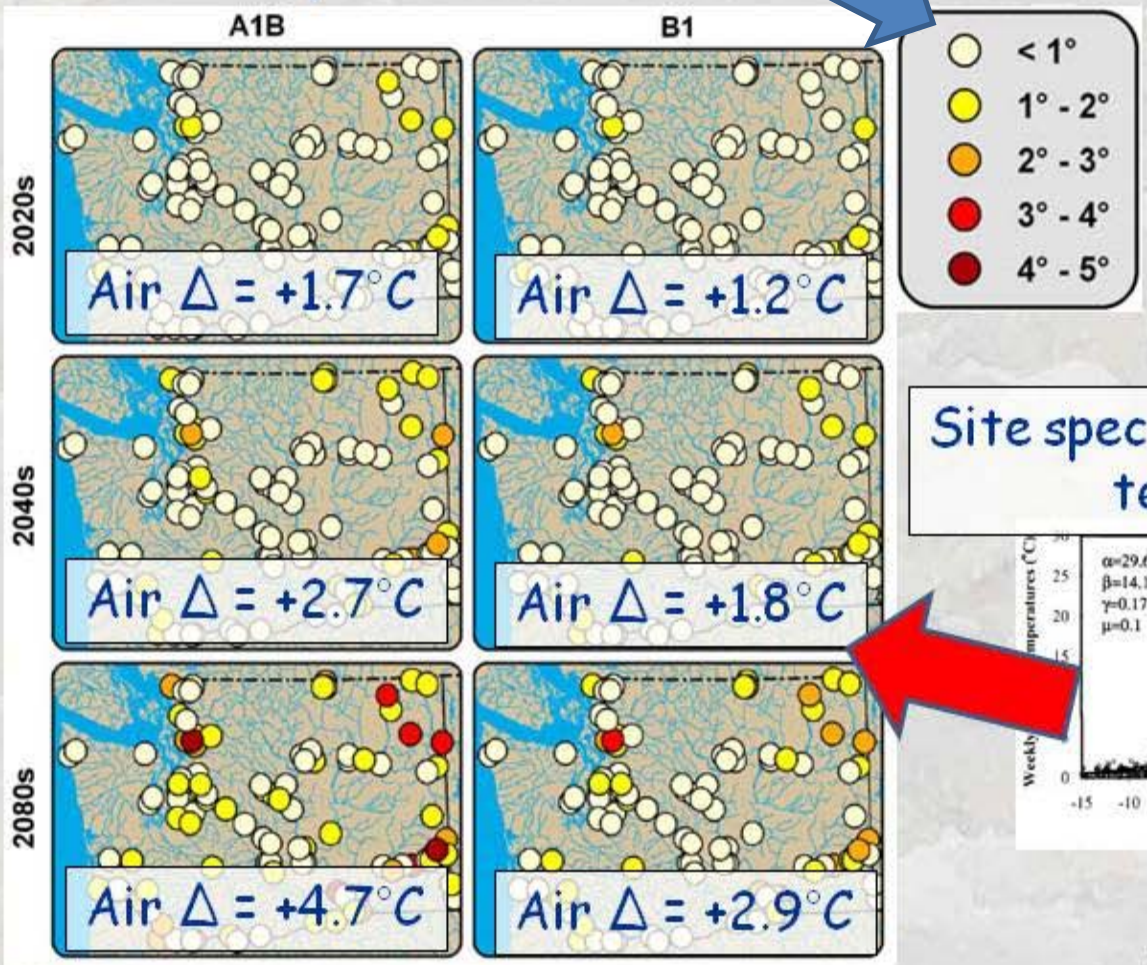
Wednesday, September 29, 2004
Fishing

HOT WATER IN ROCK CREEK

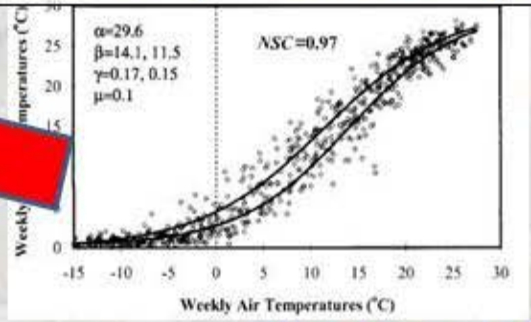


Projected Stream Temperature Increases

Maximum Weekly Stream Temperature Increases



Site specific air-stream temp relationships



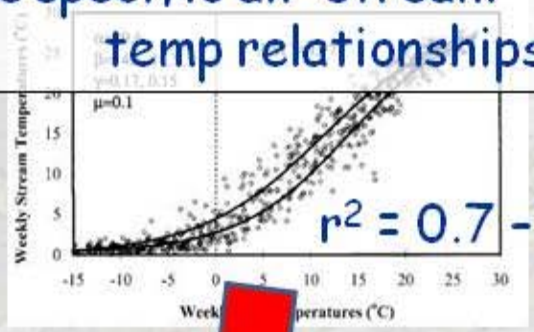
$r^2 = 0.7 - 0.9$

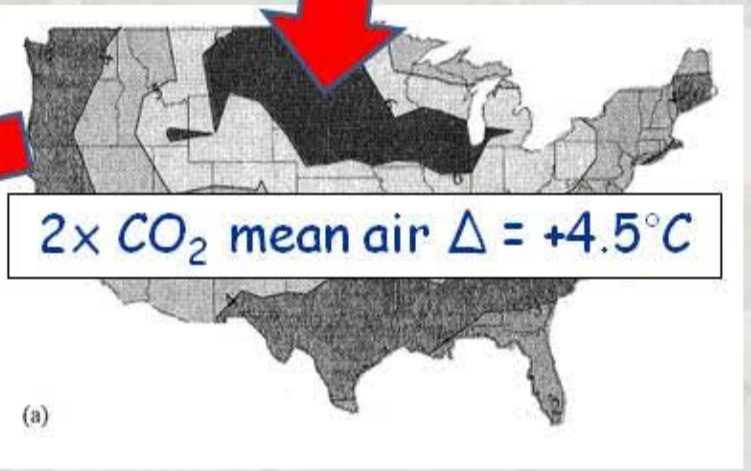
Mantua et al. 2009

Projected Stream Temperature Increases

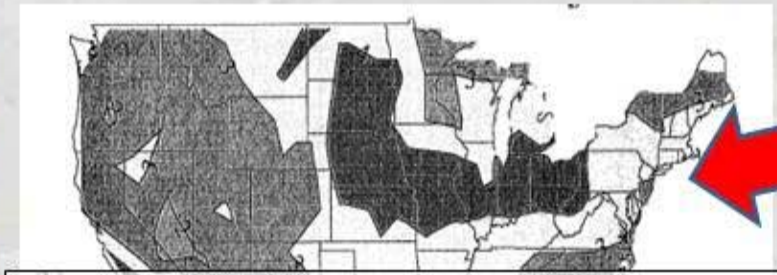
Stream temps @ USGS Gages

Site specific air-stream temp relationships





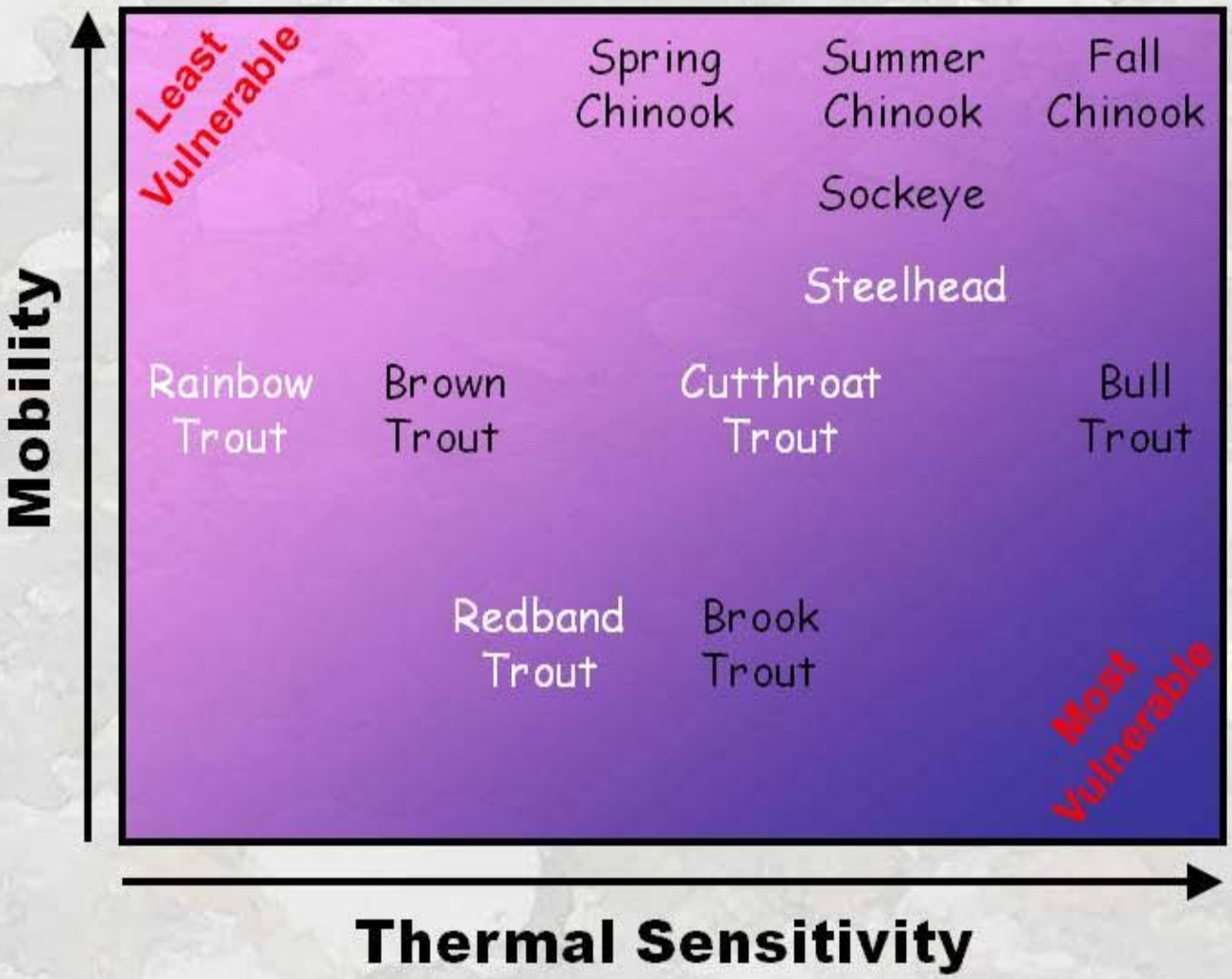
2x CO_2 mean air Δ = +4.5°C



Mean stream Δ =
+3.1°C (national, 0.67% of air)
+2°C (western US, 0.44% of air)

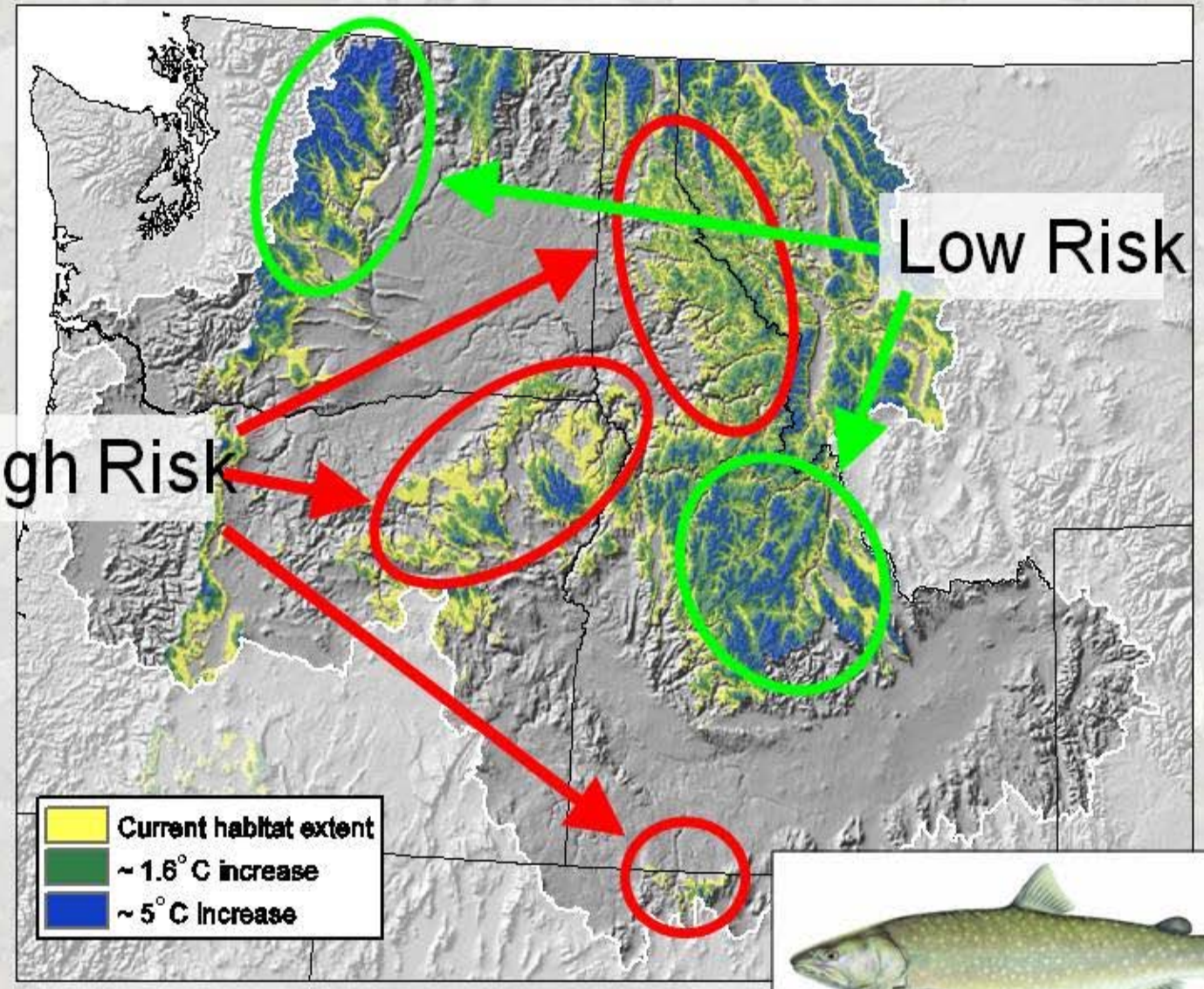
Mohseni et al. 1999, 2003

Context = Species of Concern



Black = fall spawner

Context = Spatial Domain



Rieman et al. 2007

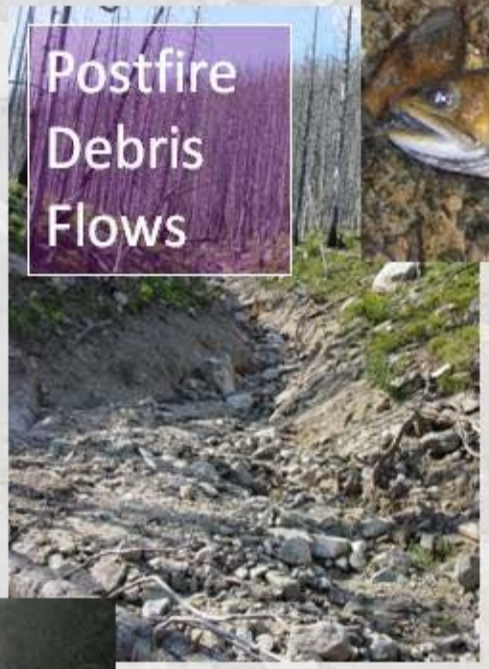
Context = Restoration Opportunities

Potential to offset warming

- Maintaining/restoring flow
- Maintaining/restoring riparian
- Restoring channel form/function

Context = . . .


Future Fires &
Riparian
Conversion


Postfire
Debris
Flows


Brook trout
invasions


Road
barriers


Midwinter Floods


Summer Flow
Reductions

Key Points:

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

2) Theory & empirical evidence suggest streams are warming in response to climate change. Warming rates are heterogeneous due to variation in climate forcing, geomorphic factors, and human/vegetative response.

3) General expectation is that warming will be deleterious to most coldwater species of concern, but case histories of bio-thermal effects in wild populations are relatively rare.

4) Population sensitivity to warming will depend on the context. This context is set by species physiology, habitat amount, quality, and connectivity, disturbance regimes, presence of non-native competitors, and other climate-related changes to streams.

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

BOISE AQUATIC SCIENCES LAB
RMRS - AWAE

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