Climate-Aquatics Blog #23: New Studies Describe Historic & Future Rates of Warming in Northwest US Streams

Climate's Cooking Along in Northwest U.S. Streams…

Hi Everyone,
So even though we in the northwest US have enjoyed a few years that are more "average" in terms of snowpack and temperatures recently as regional climate cycles do their thing (blog #12), the trends associated with long-term climate change are still in motion and it's important not to take our eyes off the ball. To keep abreast of emerging science regarding one of the fundamental climate-aquatics issues, that of rising stream temperatures (blogs #3 - #15), this week I wanted to highlight two new studies. The first describes how streams across the northwest US have been warming the last three decades; the second predicts how warm they could become by in the 21st Century.

Regarding the former and historical trends, there are numerous published accounts of streams warming the last several decades (blog #10) but these usually come from one or a few sites on larger rivers because these are where the longest temperature monitoring records exist (graphic 1). Hydroelectric dams, reservoirs, and urbanization alter the thermal regimes of most large rivers these days, however, so it's unknown whether trends in these systems are indicative of trends in unregulated streams, which often constitute the majority of stream kilometers throughout regional networks. Isaak & colleagues recently addressed these issues by querying the USGS National Water Information System database (website: http://waterdata.usgs.gov/nwis/) to extract temperature data on all streams and rivers in the northwest US that had been monitored most of the 30 years from 1980-2009. Their query turned up records from 18 sites at USGS gage locations where at least 21 years of daily temperature measurements were available (graphics 2). Unfortunately, 11 of those 18 records were on regulated streams, so only 7 were from unregulated streams, although these were spread across four states.

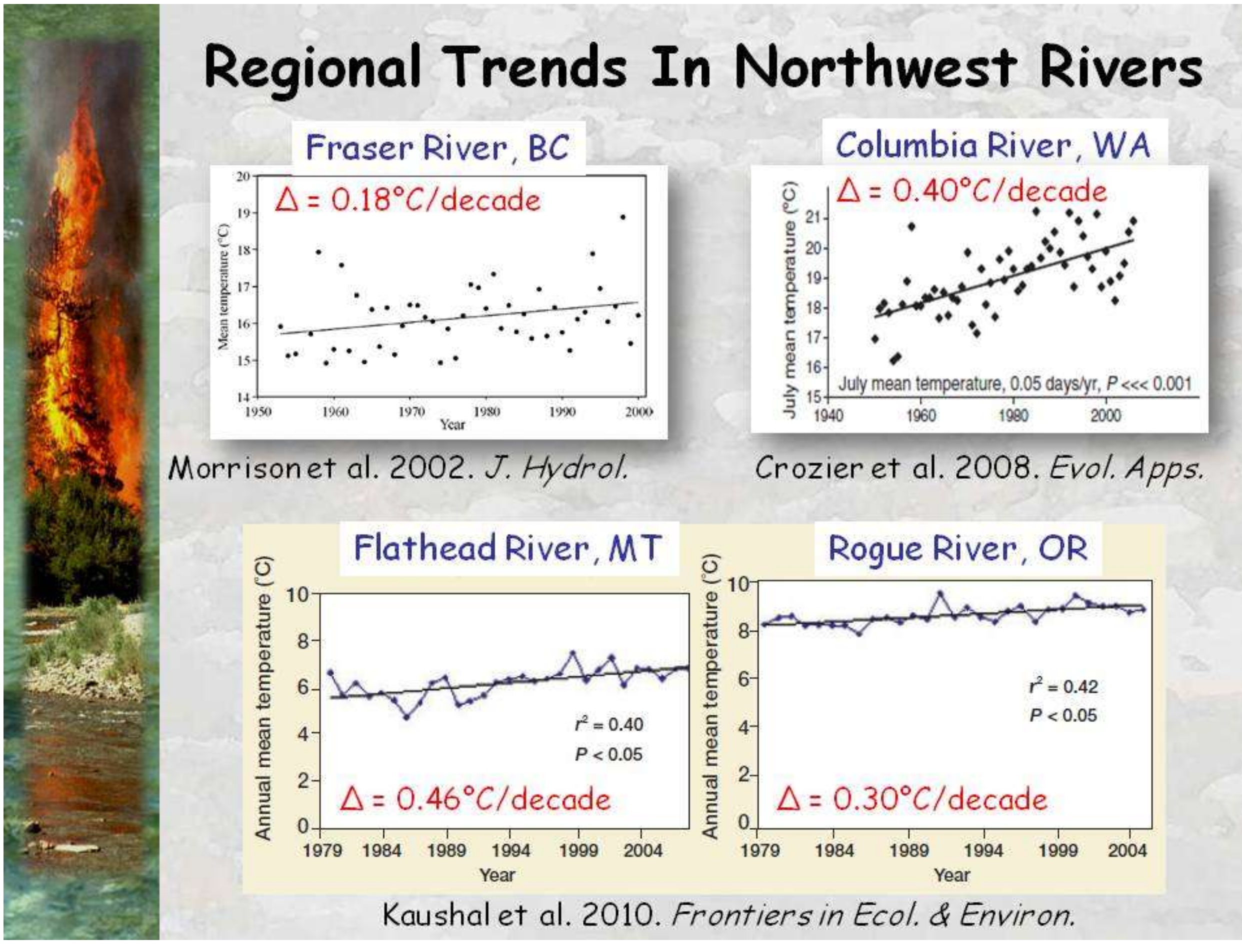
The data are limited but Isaak & colleagues could identify several important historical patterns in the monitoring records, including: 1) warming trends at both regulated and unregulated streams, with trends at unregulated sites being relatively consistent as these streams responded similarly to regional climate forcing. Inter-site variability was much higher among regulated sites, which precluded detection of a common, statistical trend across all sites; 2) warming trends at unregulated sites were most pronounced during the summer season (0.22 °C/decade) and smaller when averaged over the full year (0.11 °C/decade); and 3) seasonal temperature trends at unregulated stream sites closely tracked seasonal air temperature trends at nearby climate stations, which included a statistically significant cooling trend during the spring period (graphic 3). Perhaps the strongest conclusion from this study, however, is that long-term temperature monitoring efforts have been inadequate. A tiny number of sites currently exist on unregulated streams where historical climate trends can be directly described through examination of a monitoring record. Data from sites like these are much of what we have to provide unambiguous evidence of warming across approximately 350,000 kilometers of fish-bearing streams, despite, by some estimates, several billion dollars being spent on fish & wildlife restoration efforts in this region the last 30 years.

Hmmm…we should probably make sure we're not in the same boat 30 years from now. One would hope we'll eventually be swimming in long-term records since full year monitoring is so easy and inexpensive with modern temperature sensors (blog #3, #4, #8). That said, we don't have the luxury of waiting another 30 years for trends at new monitoring sites to manifest, so it's also good to know that a lot of useful information can be leveraged out of even short-term temperature records as described in previous blogs (#7, #14; graphic 4). The most important thing is to simply start collecting stream temperature data in places where it doesn't already exist &/or to pick a few sites and monitor these for as long as possible (then hand them off to someone else when you retire or move to a new job).

Our second study by Mantua & colleagues provides a good example of how short-term temperature records can provide inference over much longer time-spans. This study looked at thermal regimes in many of the big salmon rivers across the state of Washington and how these could respond to future climate forcing during the thermally stressful summer period. The model linking historical air temperatures to river temperature monitoring data was similar to one we described earlier (blog #14; graphic 4). Once the historical linkage was made, an air temperature increase representing an IPCC climate scenario (A1B, B1, etc) at a specific future date was simply substituted into the model to predict the future river temperature. Their results suggest that many of Washington's salmon streams could experience temperature increases of 1°C – 2°C by mid-century, and 2°C – 4°C by the 2080's (graphic 5). Mantua & colleagues also describe how the duration of thermally stressful temperatures for salmon is expected to increase at specific river locations in the future. That answer, of course, depends a lot on a stream's historic thermal regime because a cold stream has to warm up more than a warm stream before it's stressful to fish. Many of the warmest streams within a region are the largest rivers because they occur at the lowest elevations and also often have reservoirs that exacerbate warming. That's readily apparent in the temperature model projections (graphic 6), where thermally stressful temperatures already exist along the mainstems of major rivers like the Snake and Columbia, which also act as important migratory corridors for adult salmon that return from the ocean each year. Mid- to late-century projections for already warm rivers like these have the annual duration of stressful temperature increasing from historical averages of 2 – 3 weeks to 5 – 10 weeks (graphic 6).

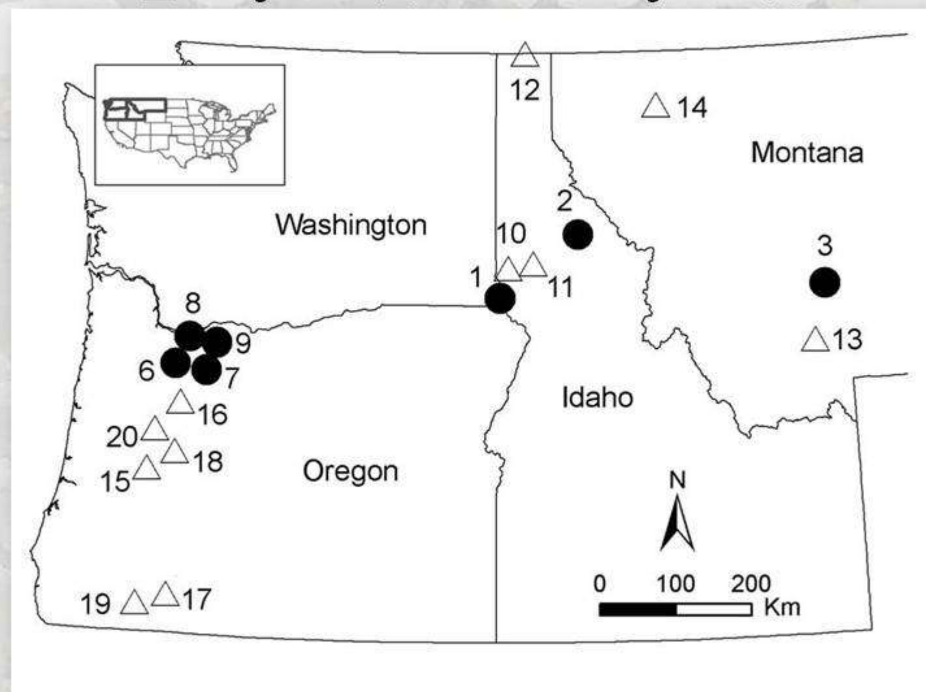
The warming Mantua & colleagues project in their scenarios generally implies higher rates than those described by Isaak & colleagues but that fits with most climate model projections that have air temperature increases accelerating during the first half of this century. Either way, it's likely to keep getting warmer for the rest of our lives and at least the next dozen or so fish generations barring some unforeseen breakthrough in clean energy to power the world's economies in the next decade. Understanding the implications of that warming for fish, identifying key population thresholds well in advance of their exceedance, and developing means of strategically allocating scarce conservation resources to maximize their impacts are going to be vitally important. Distributions of many native fish populations in the northwest are already fragmented and/or seasonally stressed by temperatures that are too warm, so any additional warming will only exacerbate these constraints (as we'll see in the biology module).

Until next time, best regards,
Dan


Regional Trends In Northwest Rivers
Fraser River, BC
Δ = 0.18°C/decade
Mean temperature (°C)
Year
Morrison et al. 2002. J. Hydrol.
Columbia River, WA
Δ = 0.40°C/decade
July mean temperature (°C)
July mean temperature, 0.05 days/yr, P <<< 0.001
Crozier et al. 2008. Evol. Apps.
Flathead River, MT
Annual mean temperature (°C)
r² = 0.40
P < 0.05
Δ = 0.46°C/decade
Year
Rogue River, OR
Annual mean temperature (°C)
r² = 0.42
P < 0.05
Δ = 0.30°C/decade
Year
Kaushal et al. 2010. Frontiers in Ecol. & Environ.

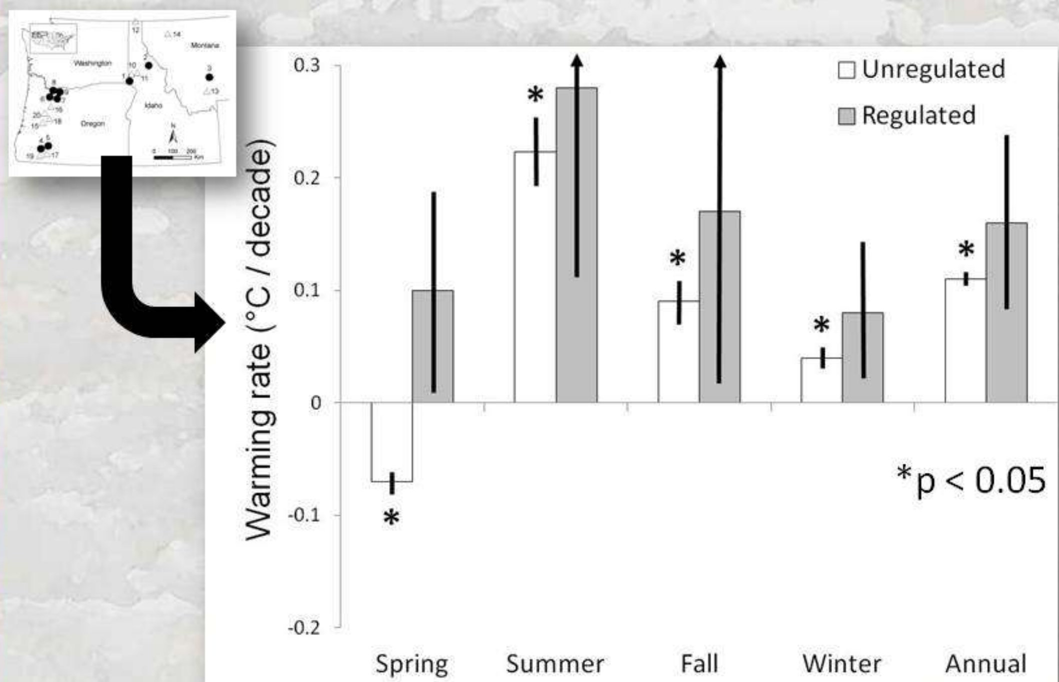
30 Year Monitoring Sites (1980-2009)

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

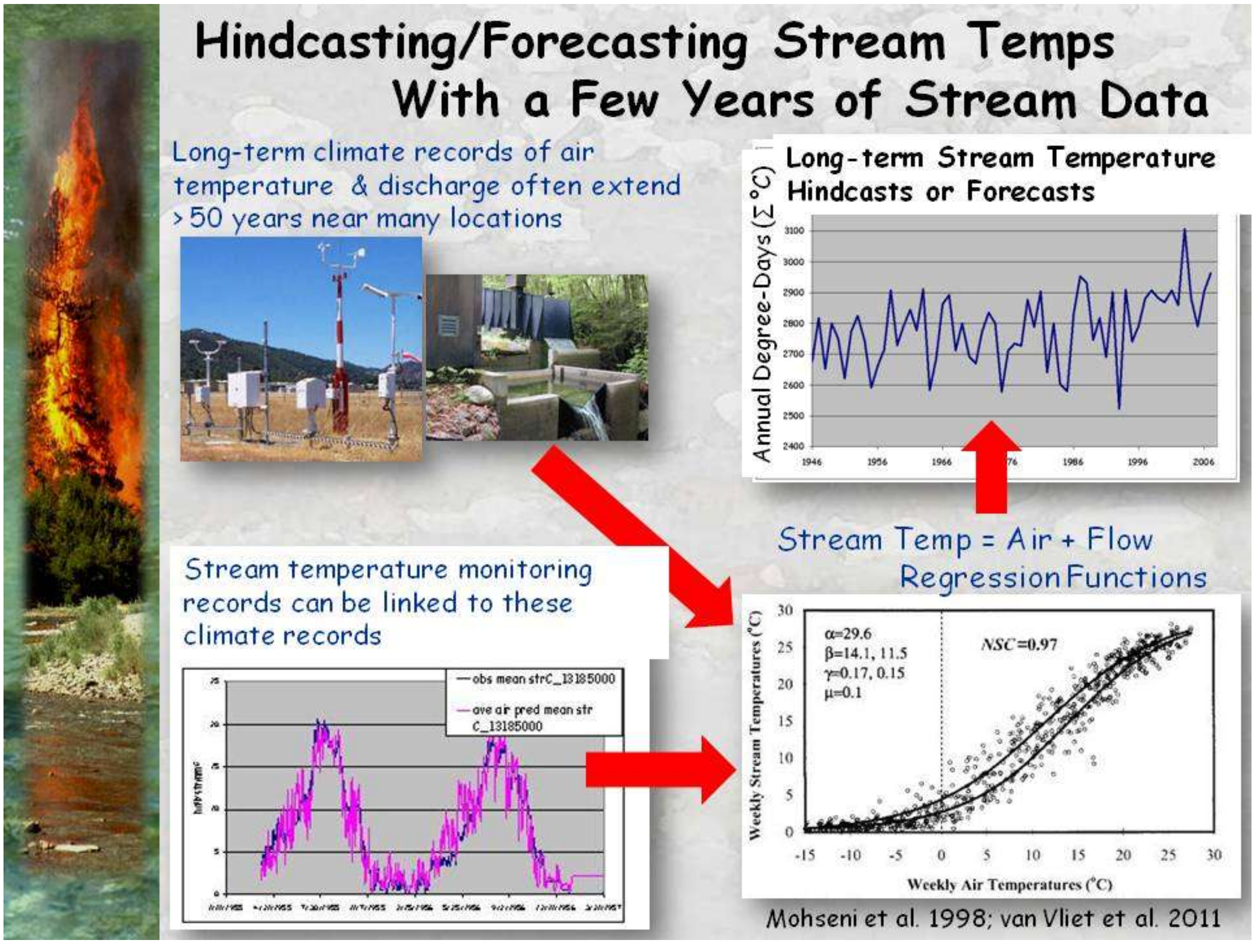


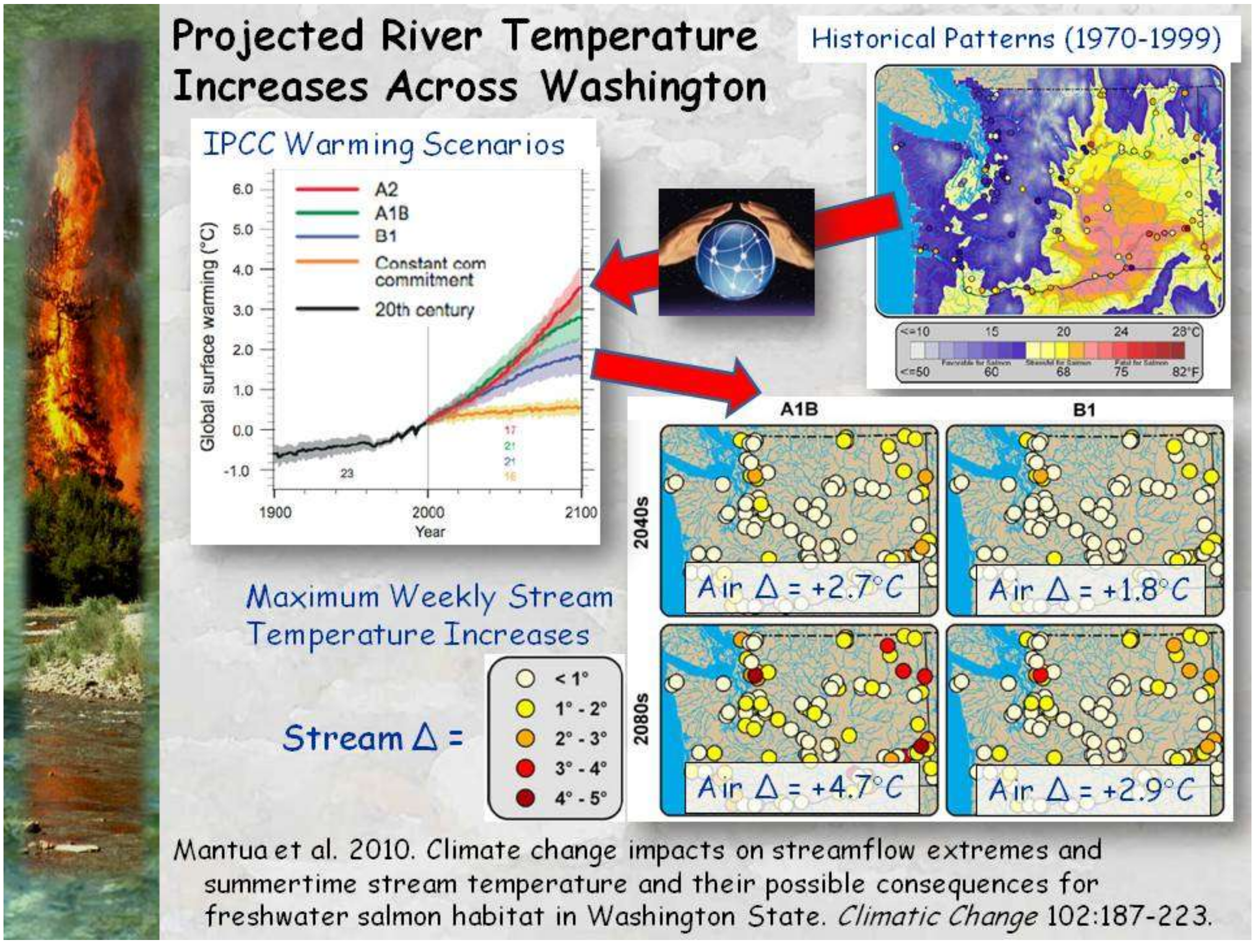
Data Source: USGS NWIS (http://waterdata.usgs.gov/nwis/)

Seasonal Stream Temperature Trends Across Northwest US From 1980-2009

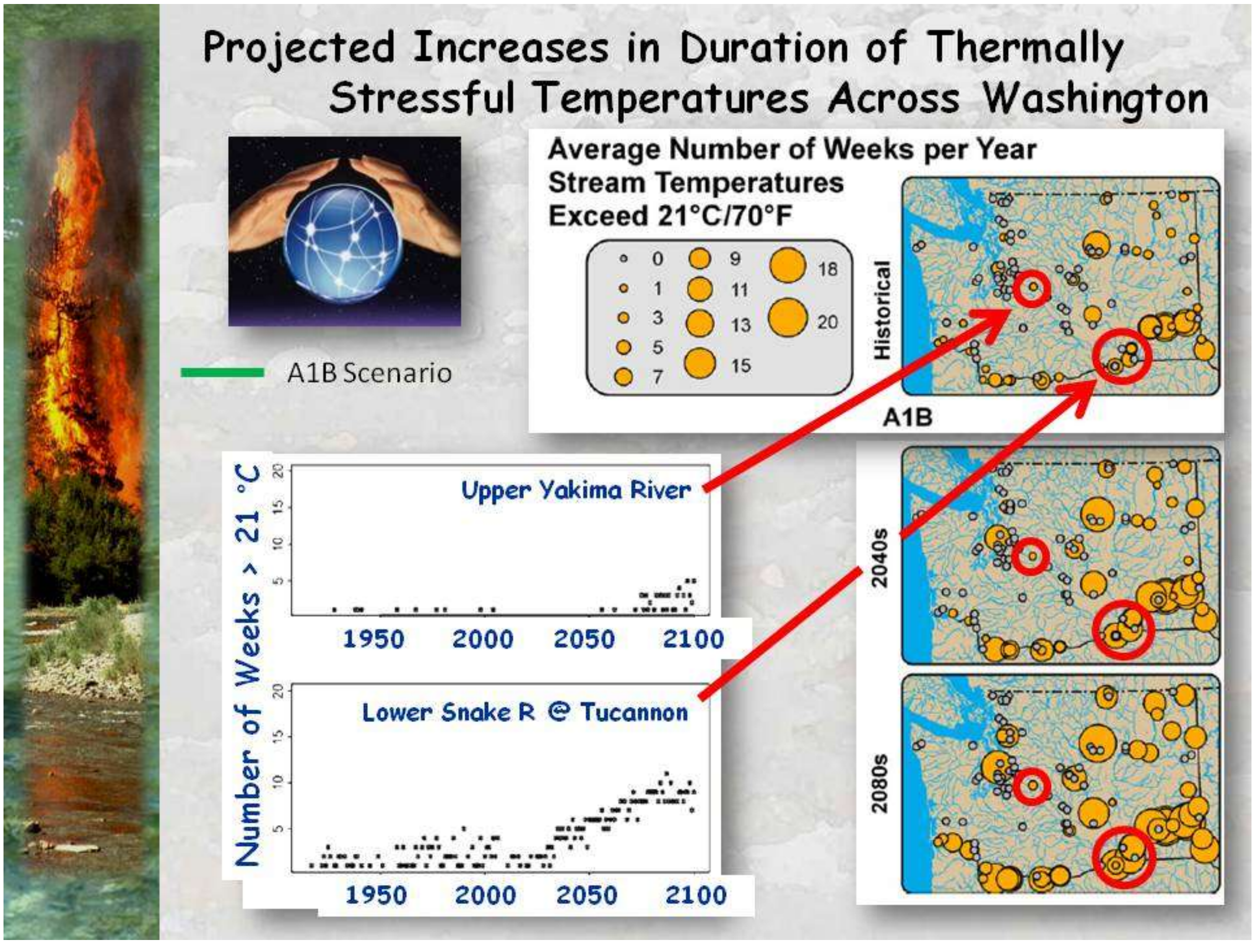


Isaak et al. 2011. Climate change effects on river and stream temperatures across the northwest U.S. from 1980-2009 and implications for salmonid fishes. *Climatic Change* doi:10.1007/s10584-011-0326-z.


Hindcasting/Forecasting Stream Temps
With a Few Years of Stream Data
Long-term climate records of air temperature & discharge often extend >50 years near many locations
Long-term Stream Temperature Hindcasts or Forecasts
Annual Degree-Days (Σ °C)
Stream Temp = Air + Flow Regression Functions
Stream temperature monitoring records can be linked to these climate records
obs mean strC_13185000
ave air pred mean str C_13185000
α=29.6
β=14.1, 11.5
γ=0.17, 0.15
μ=0.1
NSC=0.97
Weekly Stream Temperatures (°C)
Weekly Air Temperatures (°C)
Mohseni et al. 1998; van Vliet et al. 2011



Projected River Temperature Increases Across Washington
Historical Patterns (1970-1999)
IPCC Warming Scenarios
A2
A1B
B1
Constant com commitment
20th century
Global surface warming (°C)
Year
Favorable for Salmon
Stressful for Salmon
Fatal for Salmon
A1B
B1
2040s
2080s
Air Δ = +2.7°C
Air Δ = +1.8°C
Air Δ = +4.7°C
Air Δ = +2.9°C
Maximum Weekly Stream Temperature Increases
Stream Δ =
< 1°
1° - 2°
2° - 3°
3° - 4°
4° - 5°
Mantua et al. 2010. Climate change impacts on streamflow extremes and summertime stream temperature and their possible consequences for freshwater salmon habitat in Washington State. *Climatic Change* 102:187-223.



Welcome to the Climate-Aquatics Blog. For those new to the blog, previous posts with embedded graphics can be seen by clicking on the hyperlinks at the bottom or by navigating to the blog archive webpage on our Forest Service site at: (http://www.fs.fed.us/rm/boise/AWAE/projects/stream_temp/stream_temperature_climate_aquatics_blog.html). To discuss these topics with other interested parties, a Google discussion group has also been established and instructions for joining the group are also on the webpage. The intent of the Climate-Aquatics Blog and associated discussion group is to provide a means for the 3,624 (& growing) field biologists, hydrologists, anglers, students, managers, and researchers currently on this mailing list across North America, Europe, and Asia to more broadly and rapidly discuss topical issues associated with aquatic ecosystems and climate change.

Messages periodically posted to the blog will highlight new peer-reviewed research and science tools that may be useful in addressing this global phenomenon. Admittedly, many of the ideas for postings have their roots in studies I and my colleagues have been a part of in the Rocky Mountain region, but attempts will be made to present topics & tools in ways that highlight their broader, global relevance. Moreover, I acknowledge that the studies, tools, and techniques highlighted in future missives are by no means the only, or perhaps even the best, science products in existence on particular topics, so the hope is that this discussion group engages others doing, or interested in, similar work and that healthy debates & information exchanges will occur to facilitate the rapid dissemination of knowledge among those most concerned about climate change and its effects on aquatic ecosystems.

If you know of others interested in climate change and aquatic ecosystems, please forward this message and their names can be added to the mailing list for notification regarding additional science products on this topic. If you do not want to be contacted regarding future such notifications, please reply to that effect and you will be removed from this mailing list.

Previous Posts