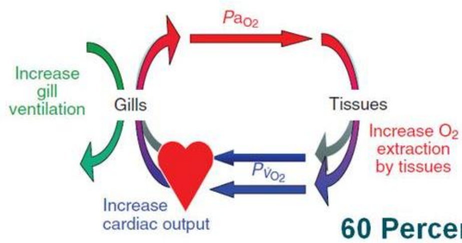
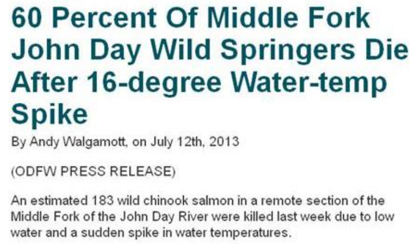
Climate-Aquatics Blog #46:
Part 5, Mechanisms of change in fish populations: Exceedance of thermal thresholds




60 Percent Of Middle Fork John Day Wild Springers Die After 16-degree Water-temp Spike

By Andy Walgamott, on July 12th, 2013

(ODFW PRESS RELEASE)

An estimated 183 wild chinook salmon in a remote section of the Middle Fork of the John Day River were killed last week due to low water and a sudden spike in water temperatures.

It's a heart-breaking phenomenon…

Hi Everyone,
As the drought and record breaking temperatures continue across many parts of the western U.S., they provide a natural segue to our next blog topic describing thermal mechanisms of change in fish populations. And unfortunately, the timing is too good as we just witnessed a thermal "event" wherein high temperatures killed a bunch of adult Chinook salmon in an Oregon river. The fish had just migrated back from the ocean and were staging near their natal headwater streams prior to spawning when they were caught by a big stream temperature spike associated with a recent heat wave. Although it's impossible to attribute any 1 such event to climate change *per se*, an increased frequency of these events is one of the tell-tale signs we'd expect to see as global warming slowly changes the environment. Near the margins of fish distributions, in both space and time, there will simply be more times when previously suitable habitats aren't, due to temperatures, or flows, or other stream characteristics exceeding biological tolerances. Those changes have obvious implications for the BIDE processes of fish populations and will lead to changes in abundance or a species distribution if repeated through time. Usually the biological responses aren't as dramatic (& traumatic) as seeing big, beautiful fish keel over in a stream but are more subtle and virtually invisible (unless we're doing good long-term biomonitoring (blogs 37, 38, 39)) because it's a gradual, multigenerational process. These dramatic events, however, serve as stark reminders of the changes that are going on around us.

So what exactly happens when a fish gets too hot and dies? Many of us are familiar with the basic phenomenon having innocently fried a few fish due to poor temperature regulation in our childhood aquaria. And apparently it's an experience that marks one's psyche as more than a few of those kids have grown up to make it their life's work to invent clever new ways of cooking fish in laboratories. As such, there's a long and storied literature on the topic and today we'll focus on one especially comprehensive set of basic and applied research for sockeye salmon in the Fraser River of British Columbia. The sockeye runs in the Fraser are some of the world's largest, consisting of 100,000s of returning adults each year, and there are significant commercial fisheries associated with these populations. There are also good long-term temperature and flow monitoring records for the Fraser dating back 60+ years that show the expected long-term trends from climate change. So when it became the case in recent years that significant portions of upriver migrating adults were "disappearing" during especially warm years and not arriving at the spawning grounds, there was more than a little interest in finding out why.

Many studies concerning the thermal ecology of Fraser River sockeye have been done over the last decade or so (graphic 1) but the paper by Farrell and colleagues "Pacific salmon in hot water: Applying aerobic scope models and biotelemetry to predict the success of spawning migrations" (graphic 2; study hyperlinked here: http://faculty.forestry.ubc.ca/hinch/Farrell%20et%20al%202008%20PBZ.pdf) provides a nice synthesis of the physiological processes and relates them to field evidence to develop a mechanistic hypothesis explaining the disappearances. The basic idea, as explored in detail by Farrell in a subsequent paper (hyperlinked here: http://people.landfood.ubc.ca/anthony.farrell/pubs/p290-Farrell_et_al_2009b.pdf), is that the aerobic scope for activity, which is the difference between basal and maximum metabolic rates (graphic 3) declines to nil beyond some species-specific, optimal temperature. This occurs because basal oxygen demand increases exponentially with temperature but cardiac pumping capacity reaches a plateau and then collapses. No aerobic scope leads to anaerobic metabolism, exhaustion, and death if experienced over a sufficiently long period. Farrell and colleagues hypothesize, therefore, that some upriver migrating sockeye, during especially warm years in the Fraser, experience a collapse of aerobic scope caused by chronic exposure to high temperatures and significant mortality—sometimes involving 10,000s of fish—ensues. The technical terminology for what happens inside the fish is *hypoxic bradycardia*, but in real terms, it's akin to dying of a broken heart.

So what about those fish in Oregon or those long lost fish souls from our childhood aquaria? Well, given that aerobic scope is strongly temperature dependent, fish don't have to be doing anything nearly as exhausting or inspiring as swimming hundreds of miles for their aerobic scope to collapse. They just have to be in water that's too warm for too long. If that occurs and there's no place nearby for them to cool off, their hearts will also break.

The work from the Fraser helps us understand this process through what could be a generalizable mechanism but to broaden our understanding & address the topic proactively, it would be ideal to have stream temperature monitoring data (Blog# 3) from those locations where future thermal events are most likely to occur. In many cases, we already have a good sense of which stream reaches and fish populations are most vulnerable because they have already shown occasional heat stress and/or are where climate velocities are fastest (graphic 4; Blog# 36). By establishing temperature monitoring networks there now, it would be possible to compare temperatures to aerobic scope curves prior to a thermal event happening and determine how close a stream is to a biological threshold. Or, in the unfortunate case of doing a post-mortem analysis, we'd be poised for a rigorous assessment that enables us to learn from our fishy friend's demise.

Until next time, best regards,

Dan

Thermal Research on Fraser River Sockeye

Cooke et al. 2004. Abnormal migration timing and high en route mortality of sockeye salmon in the Fraser River, British Columbia. *Fisheries* 29: 22-33.

Cooke et al. 2006. Mechanistic basis of individual mortality in Pacific salmon during spawning migrations. *Ecology* 87: 1575-1586.

Crossin et al. 2008. Exposure to high temperature influences the behaviour, physiology, and survival of sockeye salmon during spawning migration. *Canadian Journal of Zoology* 86: 127-140.

Eliason et al. 2011. Differences in thermal tolerance among sockeye salmon populations. Science 332: 109-112.

Farrell, A. P. 2002. Cardiorespiratory performance in salmonids during exercise at high temperature: insights into cardiovascular design limitations in fishes. *Comp. Biochem. Physiol.* 132:797-810.

Farrell. 2007. Tribute to P. L. Lutz: a message from the heart – why hypoxic bradycardia in fishes? *J. Exp. Biol.* 210:1715-1725.

Hague, M. J., et al. 2011. Modelling the future hydroclimatology of the lower Fraser River and its impacts on the spawning migration survival of sockeye salmon. Global Change Biology 17: 87-98.

Healey. 2011. The cumulative impacts of climate change on Fraser River sockeye salmon and implications for management. Canadian journal of fisheries and aquatic sciences 68: 718-737.

Hinch, S. G., & Rand, P. S. 1998. Swim speeds and energy use of upriver-migrating sockeye salmon (*Oncorhynchus nerka*): role of local environment and fish characteristics. *Canadian Journal of Fisheries and Aquatic Sciences* 55:1821-1831.

Martins, et al. 2011. Effects of river temperature and climate warming on stock-specific survival of adult migrating Fraser River sockeye salmon. *Global Change Biology* 17: 99-114.

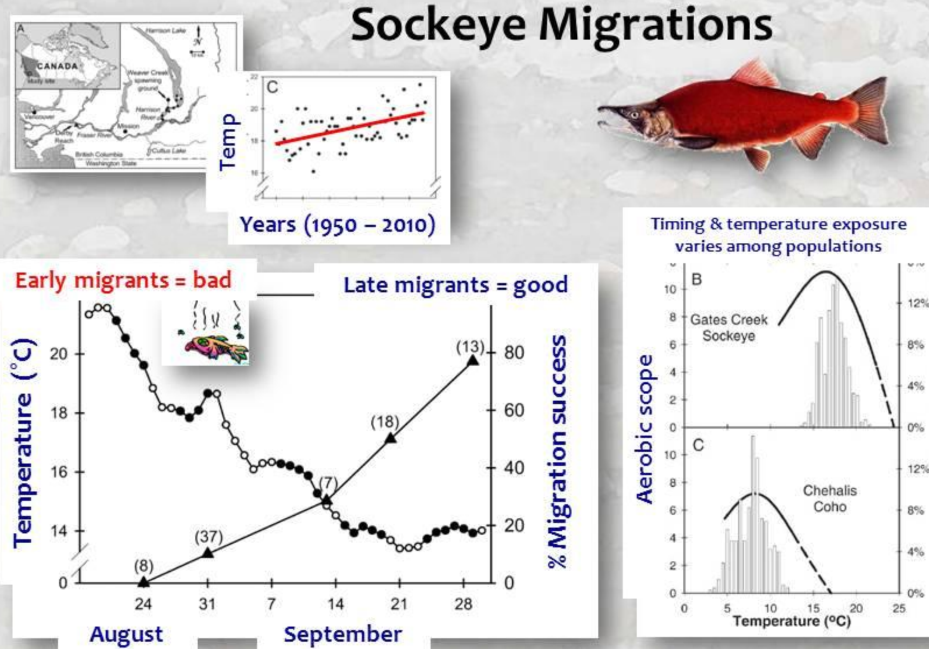
Morrison et al. 2002. Climate change in the Fraser River watershed: flow and temperature projections. *Journal of Hydrology* 263:230-244.

Rand & Hinch. 1998. Swim speeds and energy use of upriver-migrating sockeye salmon: simulating metabolic power and assessing risk of energy depletion. *Canadian Journal of Fisheries and Aquatic Sciences* 55:1832-1841.

Rand et al. 2006. Effects of river discharge, temperature, and future climates on energetics and mortality of adult migrating Fraser River sockeye salmon. *Transactions of the American Fisheries Society* 135:655-667.

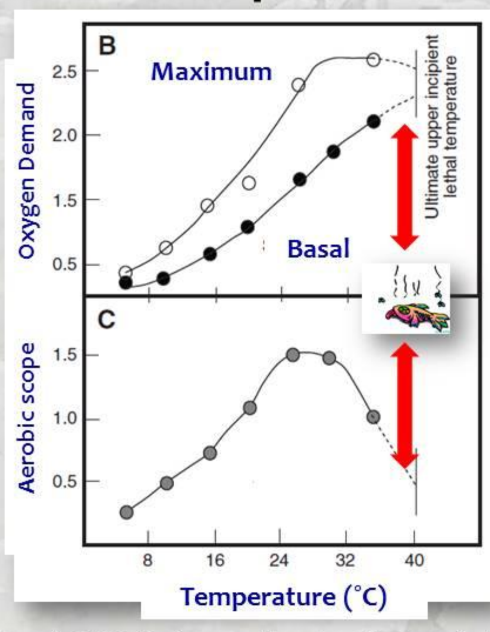
Reed, et al. 2011. Time to evolve? Potential evolutionary responses of Fraser River sockeye salmon to climate change and effects on persistence. PloS one 6.6: e20380.

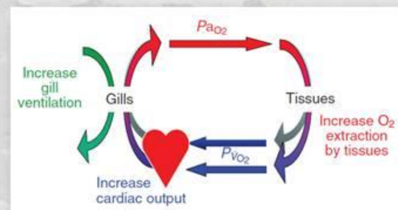
Thermal Sensitivity of Fraser River Sockeye Migrations



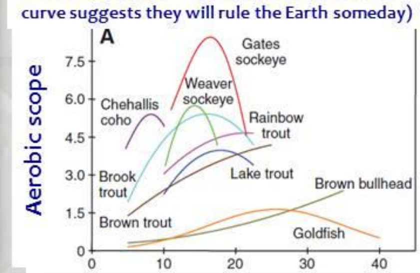
Farrell et al. 2008. Pacific salmon in hot water: Applying aerobic scope models and biotelemetry to predict the success of spawning migrations. *Physiological and Biochemical Zoology* **82**:697-708.

An Aerobic Scope Hypothesis Explaining Temperature Mortality in Fish



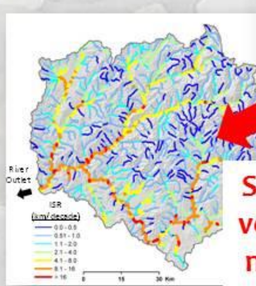


Varies by species (note that bullhead curve suggests they will rule the Earth someday)



Farrell. 2009. Environment, antecedents and climate change: lessons from the study of temperature physiology and river migration of salmonids. *The Journal of Experimental Biology* **212**:3771-3780.

Fish populations in low gradient streams (like mainstem rivers) that already show some historical evidence of thermal constraints will show the first & most pronounced impacts from climate change



Stream velocity map...

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

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

Wednesday, September 29, 2004
Fishing

PRINT SHARE

denverpost.com

FISHING
Heat causing fishing closures

PRINT EMAIL
0 COMMENTS

July 3, 2012

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 5,402 (& 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 these 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 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 to them. If you do not want to be contacted again in the future, please reply to that effect and you will be de-blogged.

Previous Blogs…

Climate-Aquatics Overviews

Blog #1: Climate-aquatics workshop science presentations available online

Blog #2: A new climate-aquatics synthesis report

Climate-Aquatics Thermal Module

Blog #3: Underwater epoxy technique for full-year stream temperature monitoring

Blog #4: A GoogleMap tool for interagency coordination of regional stream temperature monitoring

Blog #5: Massive air & stream sensor networks for ecologically relevant climate downscaling

Blog #6: Thoughts on monitoring air temperatures in complex, forested terrain

Blog #7: Downscaling of climate change effects on river network temperatures using inter-agency temperature databases with new spatial statistical stream network models

Blog #8: Thoughts on monitoring designs for temperature sensor networks across river and stream basins

Blog #9: Assessing climate sensitivity of aquatic habitats by direct measurement of stream & air temperatures

Blog #10: Long-term monitoring shows climate change effects on river & stream temperatures

Blog #11: Long-term monitoring shows climate change effects on lake temperatures

Blog #12: Climate trends & climate cycles & weather weirdness
Blog #13: Tools for visualizing local historical climate trends
Blog #14: Leveraging short-term stream temperature records to describe long-term trends
Blog #15: Wildfire & riparian vegetation change as the wildcards in climate warming of streams
Blog #23: New studies describe historic & future rates of warming in Northwest US streams
Blog #24: NoRRTN: An inexpensive regional river temperature monitoring network
Blog #25: NorWeST: A massive regional stream temperature database
Blog #26: Mapping thermal heterogeneity & climate in riverine environments
Blog #40: Crowd-sourcing a BIG DATA regional stream temperature model

Climate-Aquatics Hydrology Module
Blog #16: Shrinking snowpacks across the western US associated with climate change
Blog #17: Advances in stream flow runoff and changing flood risks across the western US
Blog #18: Climate change & observed trends toward lower summer flows in the northwest US
Blog #19: Groundwater mediation of stream flow responses to climate change
Blog #20: GIS tools for mapping flow responses of western U.S. streams to climate change
Blog #21: More discharge data to address more hydroclimate questions
Blog #22: Climate change effects on sediment delivery to stream channels

Climate-Aquatics Cool Stuff Module
Blog #27: Part 1, Spatial statistical models for stream networks: context & conceptual foundations
Blog #28: Part 2, Spatial statistical models for stream networks: applications and inference
Blog #29: Part 3, Spatial statistical models for stream networks: freeware tools for model implementation

Climate-Aquatics Biology Module
Blog #30: Recording and mapping Earth's stream biodiversity from genetic samples of critters
Blog #31: Global trends in species shifts caused by climate change
Blog #32: Empirical evidence of fish phenology shifts related to climate change
Blog #33: Part 1, Fish distribution shifts from climate change: Predicted patterns
Blog #34: Part 2, Fish distribution shifts from climate change: Empirical evidence for range contractions
Blog #35: Part 3, Fish distribution shifts from climate change: Empirical evidence for range expansions
Blog #36: The "velocity" of climate change in rivers & streams
Blog #37: Part 1, Monitoring to detect climate effects on fish distributions: Sampling design and length of time
Blog #38: Part 2, Monitoring to detect climate effects on fish distributions: Resurveys of historical stream transects
Blog #39: Part 3, Monitoring to detect climate effects on fish distributions: BIG DATA regional resurveys
Blog #41: Part 1, Mechanisms of change in fish populations: Patterns in common trend monitoring data
Blog #42: BREAKING ALERT! New study confirms broad-scale fish distribution shifts associated with climate change

Blog #43: Part 2, Mechanisms of change in fish populations: Floods and streambed scour during incubation & emergence
Blog #44: Part 3, Mechanisms of change in fish populations: Lower summer flows & drought effects on growth & survival
Blog #45: Part 4, Mechanisms of change in fish populations: Temperature effects on growth & survival

Future topics…
Climate-Aquatics Management Module