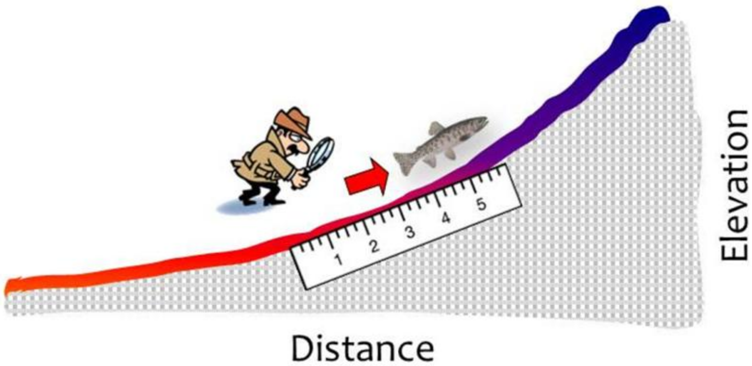
Climate-Aquatics Blog #37: Part 1, Monitoring to detect climate effects on fish distributions: Sampling design and length of time

What will it take?



Hi Everyone,
So simple question. If one were to design a monitoring strategy for measuring the effects of climate change on fish populations, how would it be done? Well, since climate's everywhere & affecting biological processes all the time, that's probably too broadly phrased. Let's constrain the question, therefore, to describing the effects of climate change on the spatial distribution of a population or species because that's what we've most recently focused on in the bioclimatic model blogs (#'s 33, 34, 35). Given that one of the primary assumptions in those models is that distributions are delimited by critical isotherms, a good start would be focusing where population boundaries are thermally mediated (typically at the margins of a distribution) and things are either a bit too warm or too cold to be prime habitat. In these areas, we'd want to estimate the location where a population boundary actually occurs & one straightforward way of doing this is to sample a series of sites along a transect & determine the presence/absence of a target species relative to the local temperature gradient (graphic 1). Key to this sampling design is covering a wide range of temperatures that exceed some portion of the target species' thermal niche (i.e., either too warm or too cold). And…sampling multiple sites where a species didn't occur along a transect due to thermal limitations (somewhat ironically, one needs to sample where a species *isn't* to most reliably estimate where it *is* (at least for statistical purposes)).

Simple enough, but transect sampling to determine the location of thermally-mediated species boundaries is a very different sort of sampling than we've traditionally done, which has more often consisted of trend monitoring of abundance at sites that were often initially chosen for having lots of the target species. For a variety of reasons, those traditional abundance sites may be some of the last places we'd expect to see the biological effects of climate change (although data from these sites still are invaluable assets because of their long timespans & we'll discuss ways of teasing a bioclimate signal from these in part 4 of this mini-module). That said, the transect/boundary approach isn't necessarily that different from another type of traditional sampling design that has involved longitudinal stream surveys. Lots of these studies have been published, but they've typically been done for a variety of reasons other than climate change assessments. A good example is the study by Rieman & colleagues (attached) that estimated how far upstream invasive brook trout have pushed the distributions of native bull trout. Longitudinal samples of bull trout populations were done in 12 streams with & without brook trout and statistical comparisons made between the two types of streams to measure the difference in boundary locations of the bull trout distributions. Extending this traditional sampling design to make it work for climate change assessments requires only adding a temporal dimension by resurveying the same sites periodically, deriving new estimates of the population boundaries, and comparing those estimates to measure the amount of shift (graphic 2). Tingley & Bessinger (attached) wrote a great general ecology paper on the subject a few years ago that explores the statistical nitty-gritty & other considerations in these sorts of assessments (graphic 3).

Two important questions that will come up in bioclimatic monitoring designs are how frequently sites should be resampled? & how long will it take for a distribution shift to occur that could be attributable to climate change? For the former, a rule of thumb might be to not sample at frequencies less than the generation time of the critter being studied (for those interested, Morris et al. *Ecology* **89**:18-25 provide a nice synthesis regarding how generation time affects species' climate tracking abilities). And for relatively short-lived critters like most fishes, it makes sense & ensures that some inter-generational dispersal/colonization processes occur between sampling efforts that are relevant to determining the locations of population boundaries. So, for example, with the efforts I'm involved in to monitor distributions of inland trout, we're resurveying our sites once each decade and plan to keep doing it as long as we need to. Which leads to question 2—How long will it take for a distribution shift to occur? It would be nice if we had at least a general idea so we could be sure to sample long enough that the effects of climate change were truly assessed…and because hiking electrofishers up steep mountain trails to torture fish with electricity isn't easy…and will get harder I suspect each decade. So will we be doing those hikes for another decade, 2 decades, or will I be an 80 year old with a bad back and still no end in sight? And if it might take many decades, then it's probably smart to know before my back gives out so I can be working to secure the funding necessary to continue the monitoring, and more importantly, engaging a younger scientist with a stronger back to continue the work after I hang it up.

But back to the question at hand—How long? In the absence of good empirical data from fish case histories that describe the details of multi-decadal range shifts, it's difficult to address the question directly. But we can make an educated guess through extension of what was discussed last time in the "velocity" blog (#36). That discussion focused exclusively on the rate at which isotherms shifted during climate change but ignored the natural, short-term variability that would accompany these shifts. And that short-term variability (i.e., inter-annual and decadal timescales) is huge relative to the tiny annual increments that comprise the global warming signal. So the other important aspect of the Isaak & Rieman paper from last time addressed this variability question and calculated how long it would take an isotherm to move a statistically significant distance while exhibiting short-term variation (graphic 4). It was reasoned that biological distribution shifts from climate change wouldn't be expected until that isotherm shift had occurred because short-term thermal "noise" would mask the warming signal at short timesteps.

Turns out that that calculation can be made with the same set of equations that are used for the velocity calculations but rather than going through another mind-numbing trigonometry session, we'll just skip ahead to the results (graphic 5). As we'd expect, the faster an isotherm shifts & the less short-term variability in stream temperatures, the quicker a statistically significant shift occurs. But we also have to constrain the range of isotherm shift rates considered (x-axis in graphic 5) to something that's realistic for current and anticipated stream warming rates; and associate that with specific stream slope & lapse rate conditions. That done, the calculations suggest it will take 2 – 6 decades for a stream isotherm to shift to a statistically different place along a stream's course. This time span varies slightly for streams with different slopes & lapse rates, but only slightly—so in most instances it seems we're looking at a fairly prolonged period over which thermal shifts manifest. Moreover, fish distribution shifts would be expected to lag behind these shifts, which would make these estimates conservative.

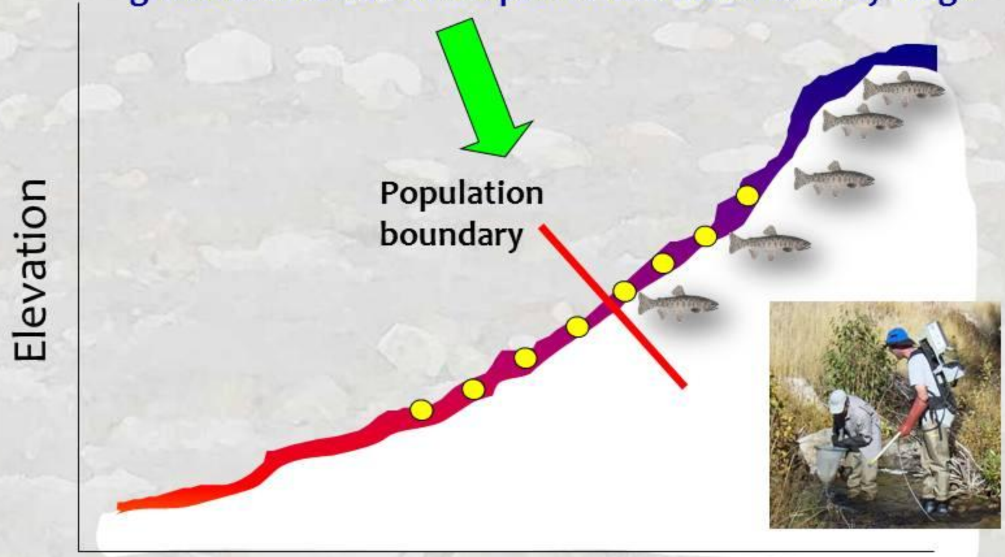
If that's truly the case, then I'd argue it's going to be game over if we start implementing new bioclimatic monitoring programs now & then wait multiple decades before getting the all-important estimates of fish distribution shift rates. We simply don't have the luxury of waiting given the rate of global temperature increase. Indeed, the final data are in for 2012 and the U.S. just set a new record for the warmest year (by a lot) since direct instrumental records were initiated 117 years ago in 1895 (graphic 6). We need good estimates of fish responses in the next few years so they can be used to validate, refine, and improve the bioclimatic models to the point that decision makers have the scientific backing they need to start making tough calls. Until those biological estimates exist to "prove" that it's happening to fish, I suspect we'll continue to suffer from an "inertia of inaction" regarding tough choices because the "climate thing" will seem too abstract. But at the same time, until we've documented the biological effects and used them to calibrate the bioclimatic model projections, we run the risk of making poor decisions and misallocating scarce conservation resources if the model predictions prove to be inaccurate.

So a rock & a hard place be where we be at present. If only we could fish-warp back in time somehow to set up the necessary monitoring transects several decades ago, then we'd be in business. Actually, there is a way & we'll talk about it next time….

Until then, best regards,
Dan

Sampling Design to Determine the Location of Thermally Mediated Fish Distribution Boundary

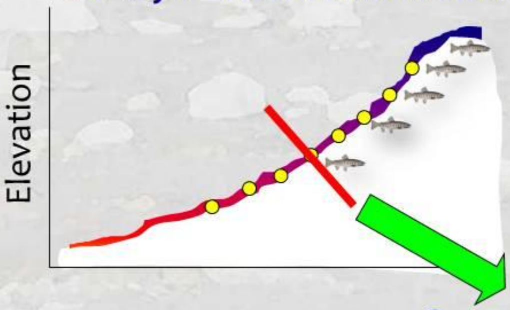
Species occurrence data collected along a temperature gradient that exceeds a species' thermal suitability range



Rieman et al. 2006. Have brook trout displaced bull trout along longitudinal gradients in central Idaho streams? *Canadian Journal of Fisheries & Aquatic Sciences* **63**:63-78.

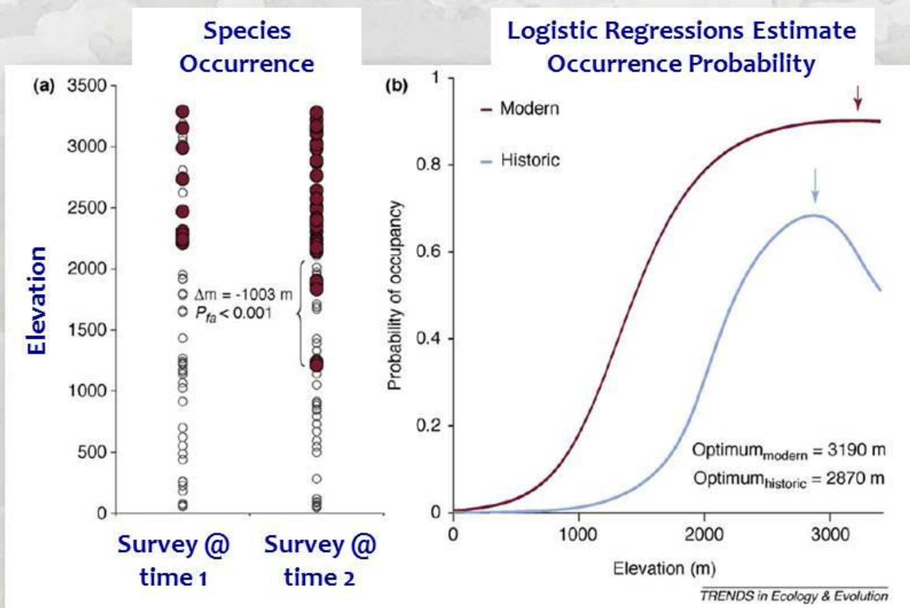
Resurvey periodically to assess possible distribution shifts

Survey 1 = Establishes baseline



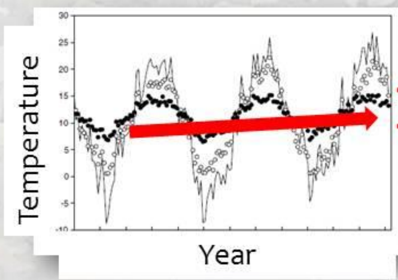
Survey 2 = Change assessment

Measure Amount of Shift Between Surveys With Statistical Techniques



Tingley & Bessinger. 2009. Detecting range shifts from historical species occurrences. *Trends in Ecology & Evolution* **24**:625-633.

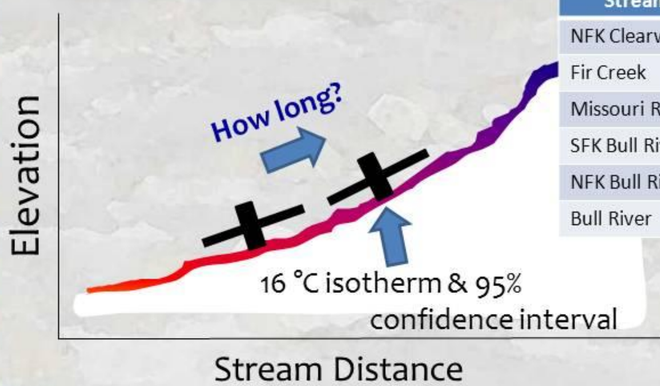
How long does it take for an isotherm shift to occur that could presage a biological shift?



Short-term thermal variation in streams masks isotherms shifts due to climate change from fish populations for extended periods

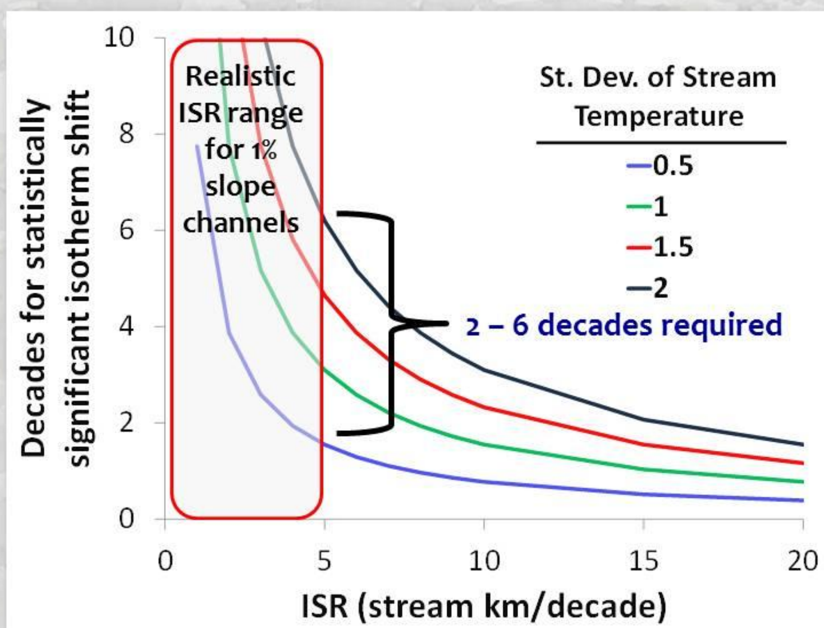
Temperature Variation

Stream	Summer SD	Annual SD
NFK Clearwater	1.41	0.70
Fir Creek	0.82	0.51
Missouri R.	1.17	0.64
SFK Bull River	0.86	0.55
NFK Bull River	0.36	0.44
Bull River	0.82	0.58

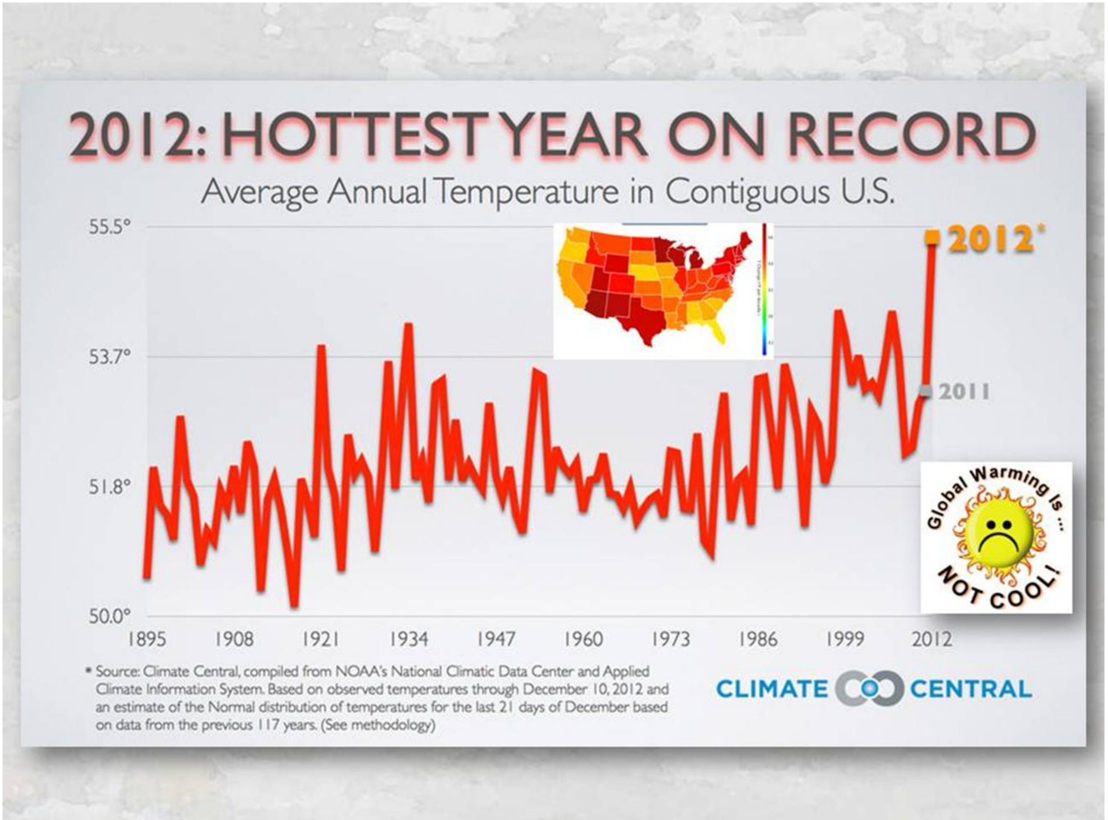


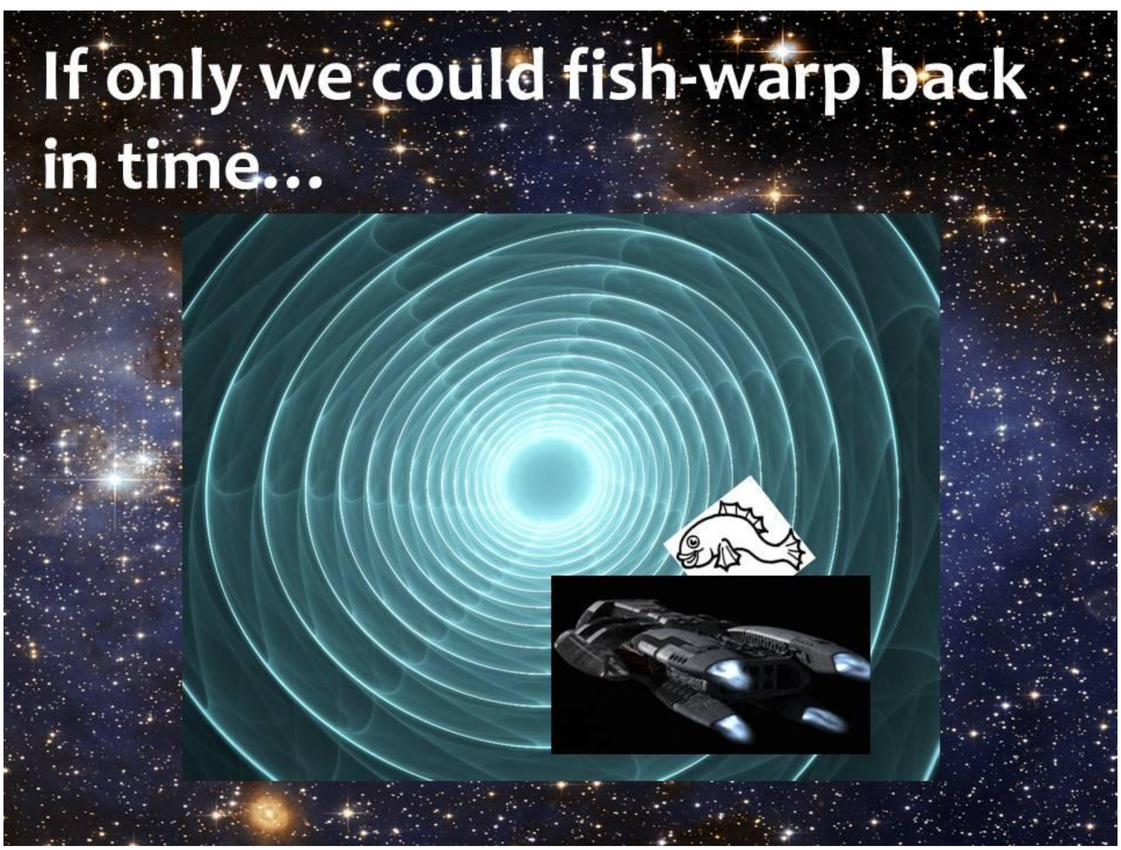
Isaak et al. 2012. *Climatic Change* **113**:499-524.

Power Curves for Isotherm Shifts



Isaak & Rieman. 2012. Stream isotherm shifts from climate change & implications for distributions of ectothermic organisms. *Global Change Biology* **19**, doi: 10.1111/gcb.12073


2012: HOTTEST YEAR ON RECORD
Average Annual Temperature in Contiguous U.S.
55.5°
53.7°
51.8°
50.0°
1895
1908
1921
1934
1947
1960
1973
1986
1999
2012
2012*
2011
Global Warming Is ... NOT COOL!
* Source: Climate Central, compiled from NOAA's National Climatic Data Center and Applied Climate Information System. Based on observed temperatures through December 10, 2012 and an estimate of the Normal distribution of temperatures for the last 21 days of December based on data from the previous 117 years. (See methodology)
CLIMATE CENTRAL


If only we could fish-warp back in time…

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 4,381 (& 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 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

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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

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

Future topics…
Climate-Aquatics Management Module