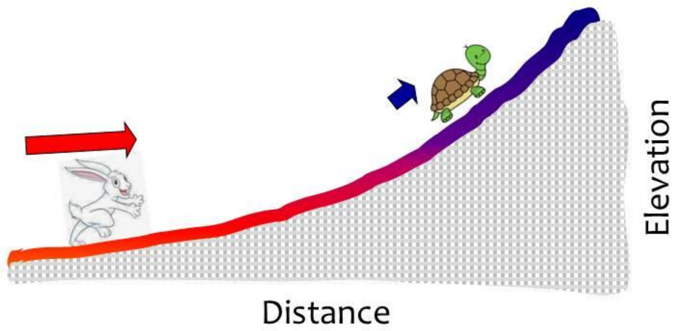
Climate-Aquatics Blog #36: The "velocity" of climate change in rivers & streams

If it's steep, it will slow the creep…



Hi Everyone,
Let me preface this week's blog by saying there are lots of things wrapped up in climate change that affect the distribution & abundance of species & their habitats, but at its most fundamental level, it's about temperatures increasing (they call it global warming for a reason). Moreover, with fish & the great majority of other aquatic critters, we're talking about ectotherms that are constrained to well-defined water bodies like lakes and stream networks. There's not much wiggle room for them to avoid the effects of warming and no one's going to evolve legs in the next few decades, climb out of the water, & walk to cooler habitats. Temperature very much is destiny for aquatic critters in a warming world and they'll have to either adapt in place (through phenological adjustments or greater temperature tolerances) or shift their distributions along the constraints posed by a stream network (or we'll have to find ways to cool those streams through restoration efforts, which we'll talk about later). Given those considerations, an important concept to understand is what's been described as the "velocity" of climate change. As per the usual definition, velocity implies something that's moving some distance per unit of time—and in the case of climate change, that thing is a temperature isotherm (graphic 1). Well, if you recall from a previous blog (#33), one of the main assumptions in bioclimatic models used to forecast species distribution shifts this century is that a critical isotherm delimits those distributions & that species and population boundaries will track that same isotherm through time.

Simple enough, but what if those isotherms move faster than a critter is able to move or otherwise adapt? Well, that's a problem, & it's one of the main reasons that it's feared global warming will cause mass extinctions this century. That being the case, it would be good to know what climate velocities are in different areas, and to match that information with biological distributions to better understand where key vulnerabilities may lie. And that's basically what the authors of our first study by Loarie and colleagues (attached) did for the Earth's terrestrial ecosystems (graphic 2). It turns out that calculating climate velocity is a simple calculation that involves dividing the long-term temperature warming rate by the local spatial gradient (often referred to as the lapse rate) in temperature (i.e., $°C\ yr^{-1}/°C\ km^{-1} = km\ yr^{-1}$). The data needed for this calculation are readily derived from global air temperature models and projections regarding climate change scenarios.

Lots of cool things in the Loarie study but one of the key take-homes is the dominant influence that topographic steepness has on climate velocity. If you look at that global map in graphic 2, it's apparent that the world's mountainous areas have much lower climate velocities than flat area like plains and coastal lowlands, & hence the tagline, "if it's steep, it will slow the creep…". In fact, velocity differences among different areas of the Earth's terrestrial landscapes vary by some two orders of magnitude! And this property emerges, even when all locations are subject to the same amount of temperature increase (e.g., +2˚C)—indicating that local topography will strongly mediate the biological consequences of global warming. Critters in flat areas will have to adapt and shift much more rapidly than their mountain brethren that may stroll relatively leisurely ahead of those nagging isotherms.

Applying the climate velocity concept to streams and river networks is straightforward and is the subject of the second paper by Isaak and Rieman (attached). The only hitch is that because spatially continuous data for stream temperatures don't yet exist in many places the way they do for air temperatures, it takes a bit more work to make it work. Four types of data are needed to do the velocity calculations for a stream (graphic 3), but the most critical piece of data is simply an estimate of the stream temperature lapse rate, which can be obtained through a few months of temperature monitoring at several sensor locations spread along a stream's longitudinal profile (another great excuse to do more temperature monitoring (blog's 3, 5, 8, and 9)!). With that lapse rate estimate, the other bits of data can be readily obtained from a GIS and the published literature, and one can then plug and chug through a simple set of trigonometry calculations to determine the rate at which an isotherm shifts as a stream warms from climate change (graphic 4). If you do that, you've literally done what it takes to make a stream-specific climate change scenario prediction, and one that's much more precise than what a coarse scale, global climate air temperature model will ever provide. Doing the calculations for more than one stream, however, becomes tedious, so Isaak & Rieman also developed a set of reference curves with the calculations summarized for a wide range of stream types (graphic 5). As was the case with Loarie's velocity predictions based on air temperature, the stream curves indicate that topographic steepness (stream slope in this case) has a dominant influence on climate velocity.

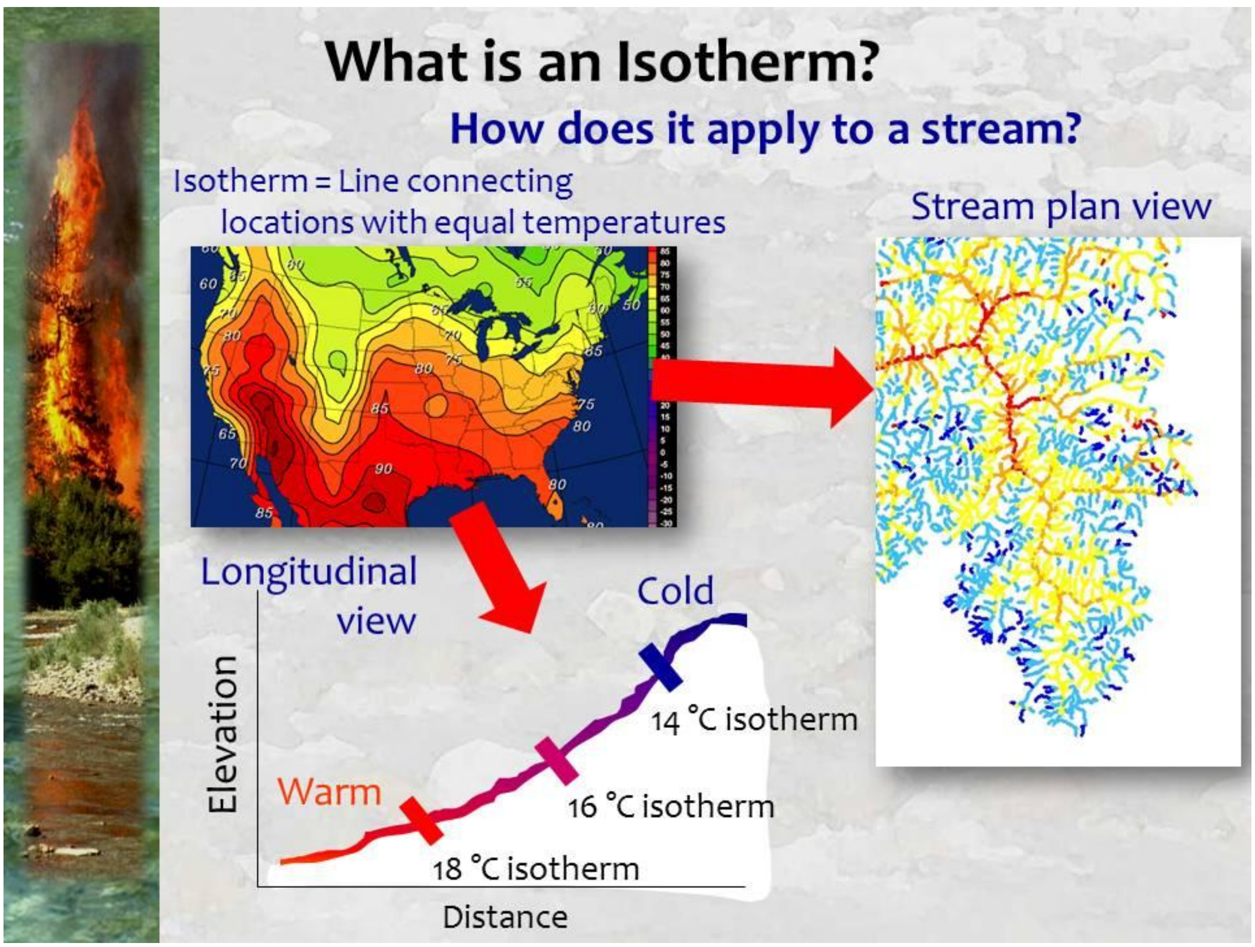
The velocity concept is a simple tool, but powerful, in that it yields a useful set of predictions that allow us to better anticipate, describe, and study how warming from climate change may affect stream thermal conditions and biotas this century. For example, the calculations can be used to determine whether or not an isotherm shift poses a problem for a particular fish species or population within a given stream (graphic 6). In many instances, fish populations will have upstream refugia to which they can retreat; whereas in other instances, populations will literally be trapped in small headwater habitats and threatened with thermal extirpation. The calculations may also be used to develop climate velocity maps (sensu Loarie) for entire river networks to provide strategic views regarding variation in isotherm shifts among streams (graphic 7). It is sobering to note that because isotherms shift most rapidly in the flattest streams, which always include the largest rivers within a region or river network (graphic 5 and 7), important commercial, recreational, and subsistence fisheries may be especially vulnerable to thermal disruptions this century. In particular, those fish populations in mainstem rivers that already show some evidence of thermal constraints are likely to be the first and most heavily impacted by climate warming (graphic 8).

So it appears that topography is going to be our frien-emy (i.e., both friend and enemy; graphic 9) this century in terms of having more/less time in some areas to deal with climate change as we work to find solutions and assist species through this transitional century. We can use this new understanding to help guide those efforts but can also use it to make specific predictions regarding where biomonitoring is best done to test, validate, and improve the bioclimatic models we'll ultimately have to rely on for strategic assessments and planning purposes. Next time out we'll begin discussing how climate-smart biomonitoring might be done, as well as some additional implications that the stream velocity calculations have for these monitoring strategies.

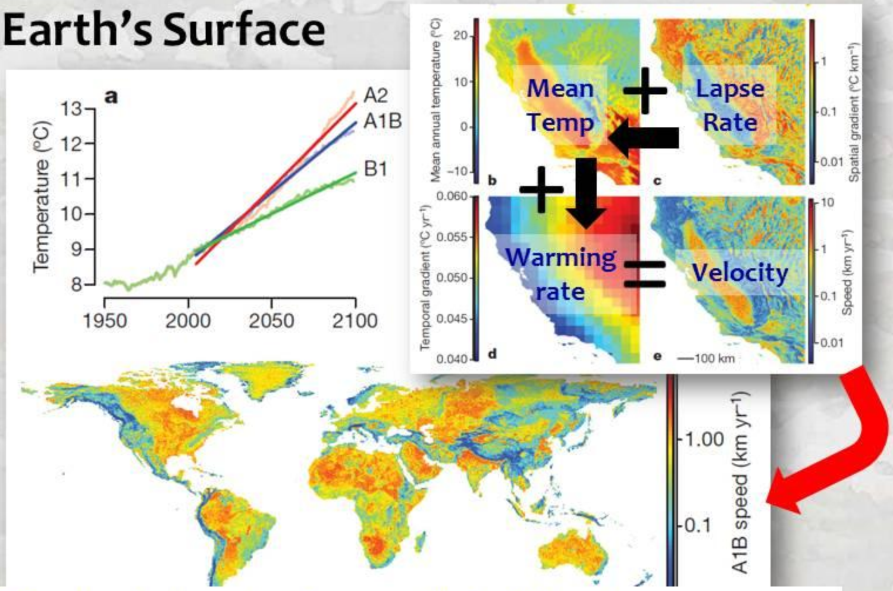
Until next time, happy holidays,

Dan

Now Tweeting at [Dan Isaak@DanIsaak]



The "Velocity" of Climate Change is the Rate at Which Isotherms Shift Across the Earth's Surface



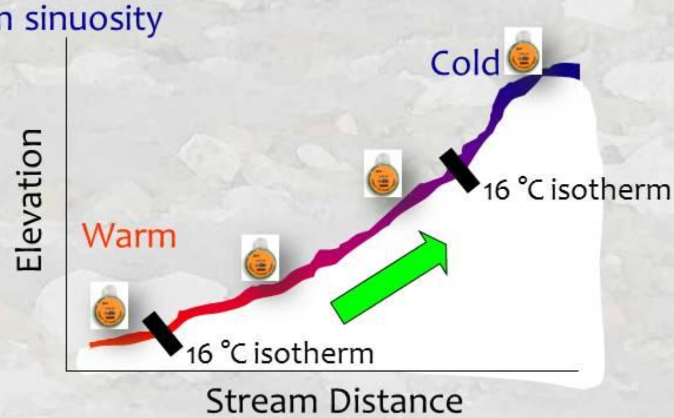
Climate velocity varies 100x across the Earth's surface…

Climate velocity is slow in steep areas and fast in flat areas

Loarie et al. 2009. *Nature* **462**:1052-1055.

Four Types of Data are Needed to Calculate the Climate Velocity (Isotherm Shift Rate) Within a Stream or River Network

1) Stream temperature lapse rate (°C / 100 m)
2) Long-term stream warming rate (°C / decade)
3) Stream slope (degrees)
4) Stream sinuosity



Isaak & Rieman. 2012. *Global Change Biology* **19**, doi: 10.1111/gcb.12073

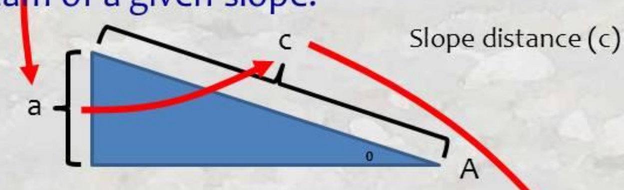
Finally, A Good Use for High School Trigonometry!

Step 1. Calculate vertical elevation displacement for a given stream lapse rate and long-term warming rate.

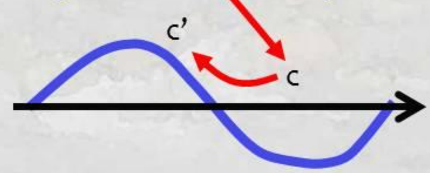
$$\text{Displacement (a)} = \frac{\text{Warming rate}}{\text{Lapse rate}} = \frac{0.2^{o}\text{C/decade}}{0.4^{o}\text{C/100m}} = +50\text{m/decade}$$

Step 2. Translate elevation displacement to distance along a stream of a given slope.

$$\text{Slope distance (c)} = \frac{a}{\sin A^{o}}$$

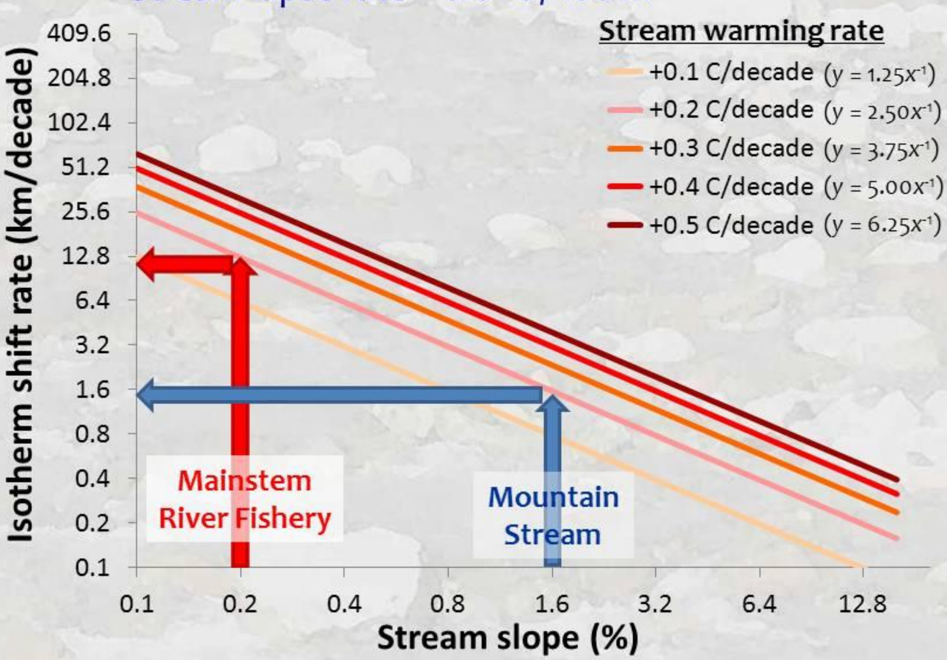


Step 3. Multiply slope distance by stream sinuosity ratio in meandering streams.



Isotherm Shift Rate Curves

Stream lapse rate = 0.8 °C / 100 m

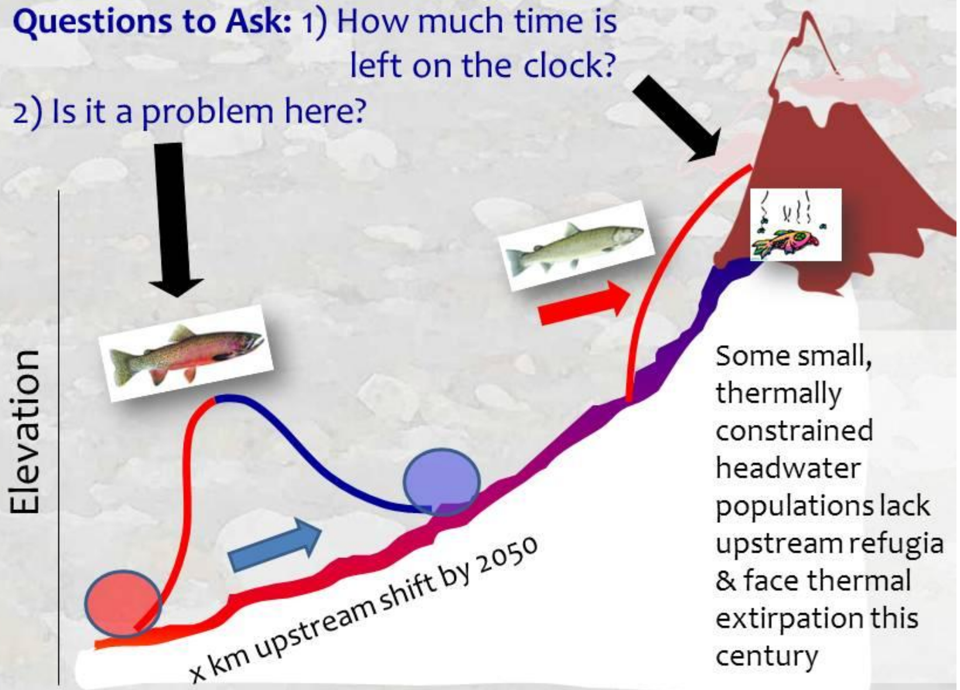


Isaak & Rieman. 2012. *Global Change Biology* **19**, doi: 10.1111/gcb.12073

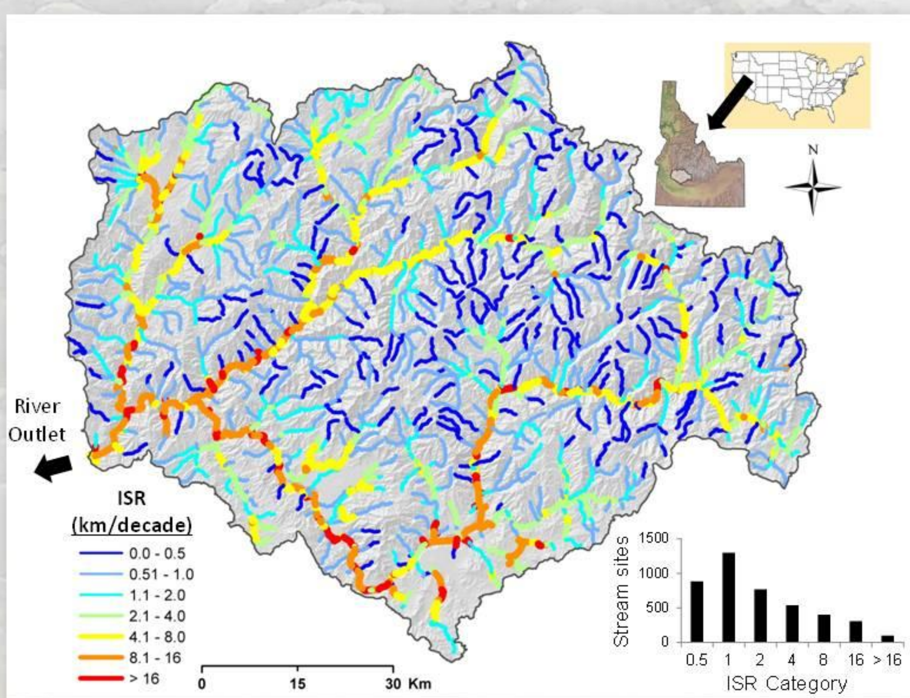
ISR Calculations Enable Stream-Specific Climate Change Scenario Predictions

Questions to Ask: 1) How much time is left on the clock?

2) Is it a problem here?



Climate Velocity Map for River Network



sensu Loarie et al. 2009. *Nature* **462**:1052-1055.

Fish Populations in Mainstem Rivers, Where Historical Evidence of Thermal Constraints Already Exists, Will Show the First & Most Pronounced Impacts from Climate Warming

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

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denverpost.com

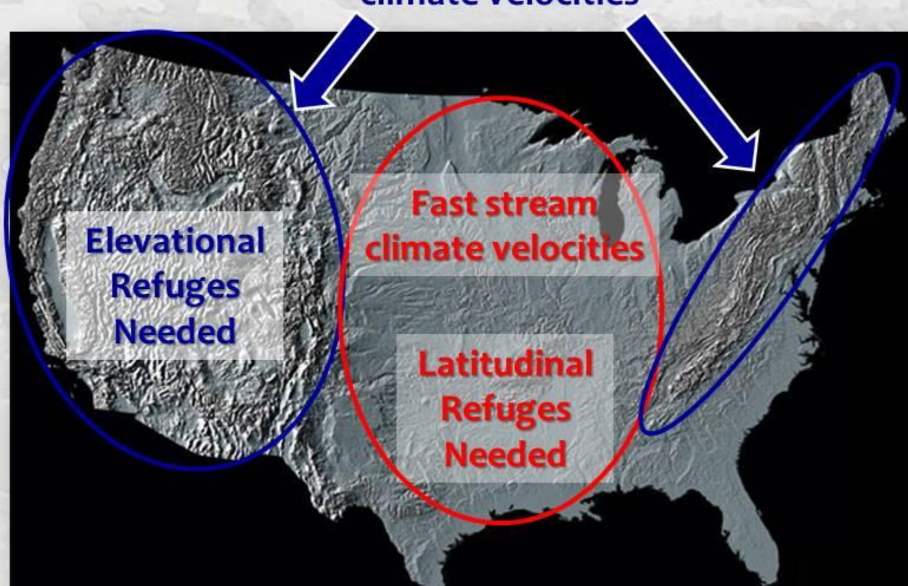
FISHING
Heat causing fishing closures

PRINT EMAIL 0 COMMENTS

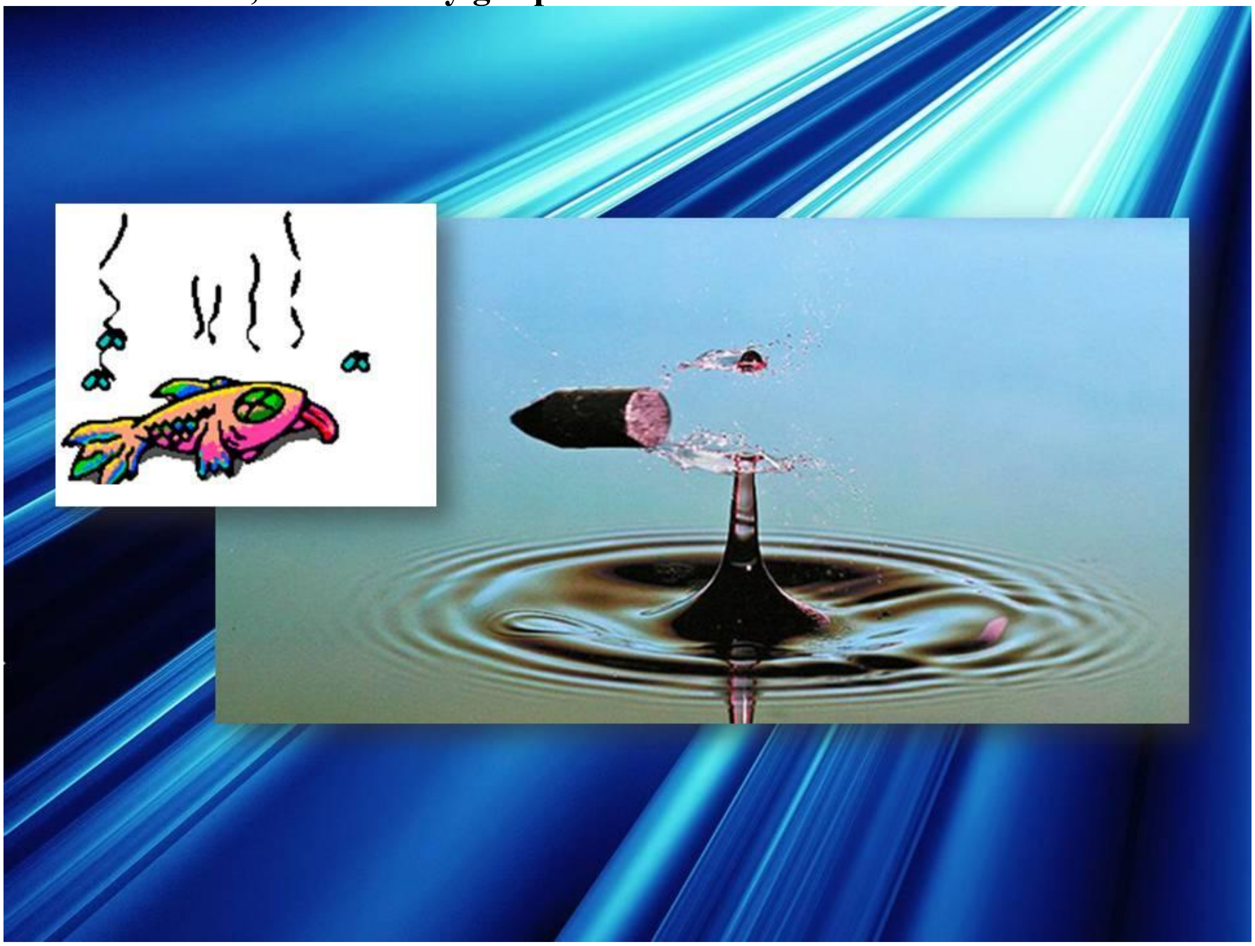
July 3, 2012

Topography & Climate Vulnerability

Slow stream climate velocities



…but if it's flat, the fish may go splat



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

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

Future topics…

Climate-Aquatics Management Module