Climate-Aquatics Blog #64: **Building real-time river network temperature forecasting systems**

We can ~~re~~build ~~him~~ it...we have the technology…"

Hi Everyone,
For those who recall Lee Majors as the 70s era anti-hero cyborg undercover agent the opening sequence & soundtrack is no doubt indelibly etched in your mind (for a Youtube refresher: http://www.bing.com/videos/search?q=youtube+6+million+dollar+man+intro&qpvt=youtube+6+million+dollar+man+intro&FORM=VDRE#view=detail&mid=691A561821A665D62D79691A561821A665D62D79). Apropos then, as now, was the use of the latest technology to overcome limitations & solve important problems, whither it be for rebuilding crash-landed astronauts or, as in today's situation, building real-time temperature forecasting systems for river networks. Such systems would be overkill in many places, but in those with high-value resources—think riverine salmon fisheries or blue-ribbon trout fisheries—that are temperature sensitive & maybe already showing signs of thermal stress, having accurate short-term temperature forecasts will be critical. This then is one of our fish people generation's moonshots—a thing to be striven for even if it seems impossible or implausible. Luckily for us, most of the component parts to build such forecasting systems already exist and just need to be brought together synergistically.

Those components are:
A) High-resolution spatial inventories of river thermal conditions across broad areas. As Fullerton & colleagues showed recently, significant amounts of these data already exist in some places (graphic 1; study hyperlinked here: https://www.researchgate.net/profile/Aimee_Fullerton). And as Vaccaro & Maloy demonstrated earlier, there are also inexpensive ways of doing those inventories where they don't already exist or where budgets are smaller (graphic 2; study hyperlinked here: http://pubs.usgs.gov/sir/2006/5136/pdf/sir20065136.pdf). You can bet this will be a place that drone technology changes the game in future years.

B) Resurveys of river temperatures to measure how thermalscapes change through time as Dugdale & colleagues show (graphic 3; study hyperlinked here: https://www.researchgate.net/profile/Stephen_Dugdale). In this regard, let us also not forget the measurements that large & growing grassroots temperature monitoring networks now provide in many areas (graphic 4; dynamic map hyperlinked here: https://www.google.com/fusiontables/DataSource?docid=1rPY8Pe2Rfk2WfaeH7dQiDBPwet06oBZOPqvcUbNM#map:id=3).

C) Forecasting models to make accurate short-term predictions about stream temperatures based on weather forecasts & hydroclimatic conditions, a topic that Hague & Patterson explored in depth recently (graphic 5; study attached).

D) Analytical frameworks that let us scale river temperature forecasts throughout full river networks because fish swim and move throughout these networks. Achieving network scale forecasts, however, quickly puts us in the realm of big-data, so we'll need computationally efficient network estimation routines as Rushworth & colleagues discuss (graphic 6; study hyperlinked here: http://onlinelibrary.wiley.com/doi/10.1002/env.2340/epdf; & for a more general discussion of real-time networks in ecohydrology, see Krause & colleagues here: http://onlinelibrary.wiley.com/doi/10.1002/eco.1646/pdf

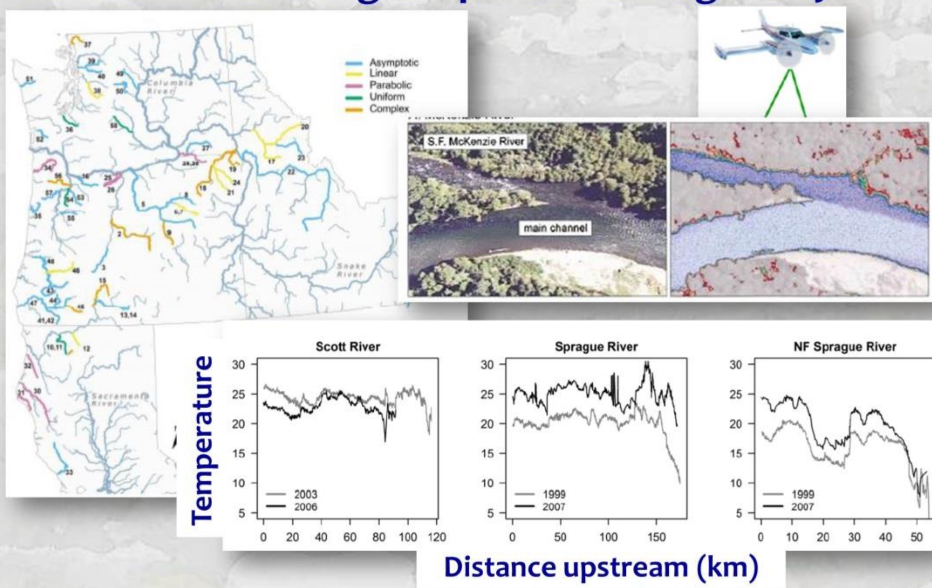
The good part about river temperature forecasting systems is that they won't cost 6 million dollars to develop, but they might save us many times that in terms of improved decision making & management that results from better information. So, for example, if we were to know days or weeks in advance precisely when/where fish were to become so thermally stressed that they might die, we could: a) temporarily close fisheries to avoid putting additional stressors on fish (a practice that's already commonly done in some areas), b) liberalize fisheries—why not catch more fish as a means of decreasing their density because it's often disease outbreaks among dense aggregations of fish under thermally stressful conditions that triggers die-offs, or c) do short-term water rights swaps during thermal bottlenecks to put as much water back in the channel as possible, which would reduce temperature & fish densities by adding additional water volume (a practice that would require advance agreements and generous compensation to the water rights holders no doubt). Sophisticated temperature network information systems would also allow us to identify places that presented chronically stressful conditions & those then might be specifically targeted for intensive restoration of riparian conditions, floodplains, or instream flows (blogs 55 and 58).

Or not. There will be some times & places where the degree of environmental change simply becomes too large & the local climate is going to move beyond the niche space of our favorite fish. Or in other cases, maintaining/restoring the habitat so that it continues to support that fish is so costly it exceeds what society is willing to bear. In both cases, better information and forecasting abilities will be critical to determining how close we are to those thresholds so that we can adapt accordingly. And part of that adaptation will mean, at times, redirecting resources elsewhere on the biodiversity battlefield to those places where we have better fighting chances.

Until next time, best regards,
Dan

Now Tweeting at Dan Isaak@DanIsaak

Component A: Thermal census of rivers to provide detailed accounting of spatial heterogeneity



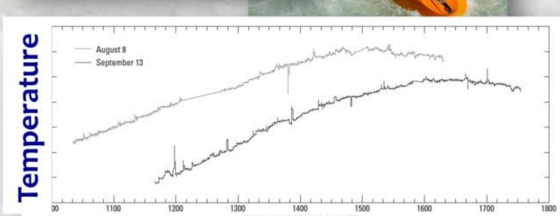
Fullerton et al. 2015. Rethinking the longitudinal stream temperature paradigm: region-wide comparison of thermal infrared imagery reveals unexpected complexity of river temperatures. *Hydrological Processes* DOI: 10.1002/hyp.10506

Go here for article: https://www.researchgate.net/profile/Aimee_Fullerton

Less Expensive (& More Fun) Alternatives for Thermal Censusing

Tow temperature sensors from a boat…

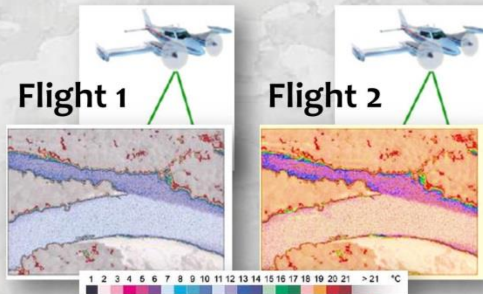
Or just wait for the attack of the drone mounted cameras soon…

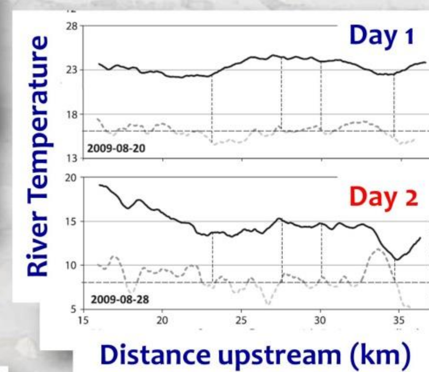


Vaccaro & Maloy. 2006. A thermal profile method to identify potential ground-water discharge areas and preferred salmonid habitats for long river reaches: U.S. Geological Survey Scientific Investigations Report 2006-5136.

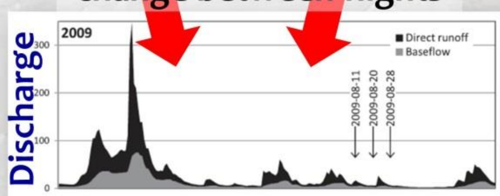
Go here for report: http://pubs.usgs.gov/sir/2006/5136/pdf/sir20065136.pdf

Component B(1): Repeat sampling to measure temperature variation through time





Air temp & discharge change between flights

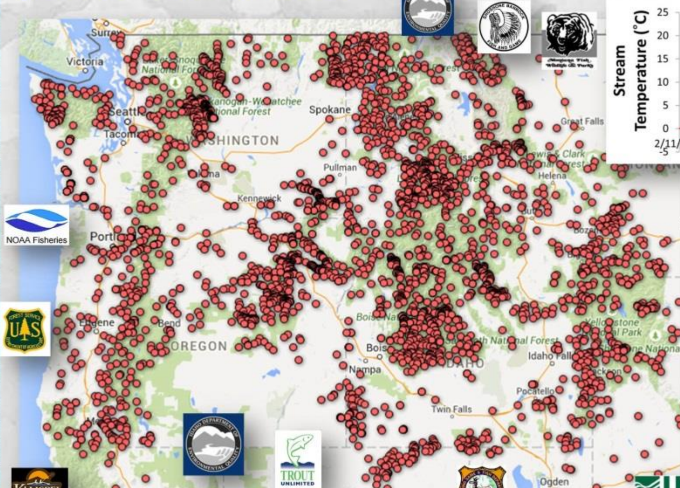


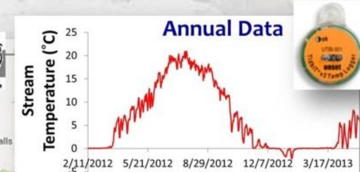
Which causes river temperature profiles to change…

Dugdale et al. 2013. Temporal variability of thermal refuges and water temperature patterns in an Atlantic salmon river. *Remote Sensing of Environment* **136**:358-373.

Go here for article: https://www.researchgate.net/profile/Stephen_Dugdale

Component B(2): The aquatic army's grassroots sensor network also measures hourly changes throughout the year at 1000s of sites





In the northwestern U.S., there are now >3,000 sites where full year temperatures are currently monitored. That's a 300% increase in 3 years!

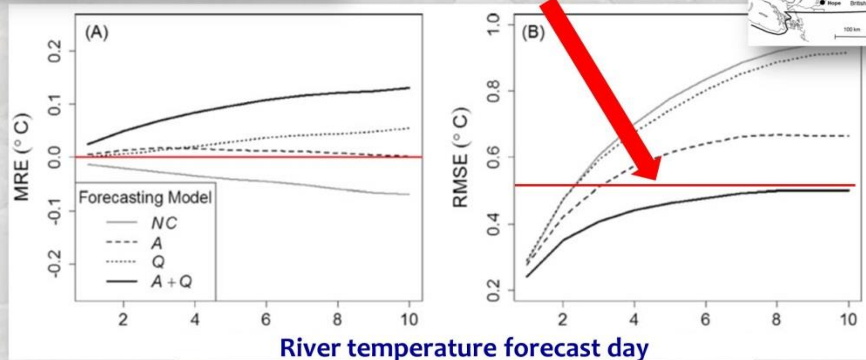
Go here to see a dynamic map viewer of these sites:

http://www.fs.fed.us/rm/boise/AWAE/projects/stream_temp/maps.html

Component C: Models making short-term "weather" forecasts of river temperatures based on forecasts of air temperature & river discharge

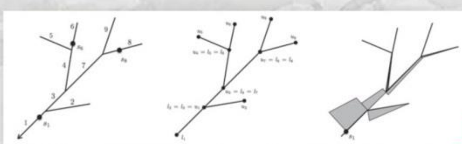
Fraser River prototype

Accurate river forecasts within +/-0.5°C possible one week in advance



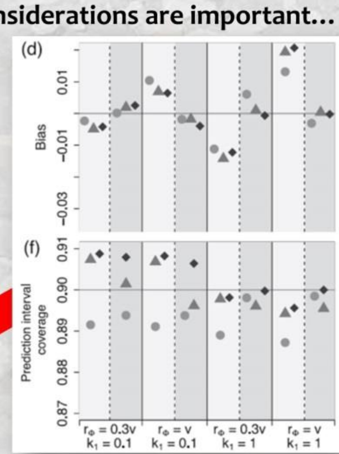
Hague & Patterson. 2014. Evaluation of Statistical River Temperature Forecast Models for Fisheries Management. *North American Journal of Fisheries Management* **34**:132–146.

Component D: Network models make interpolating broad river temperature forecasts a possibility

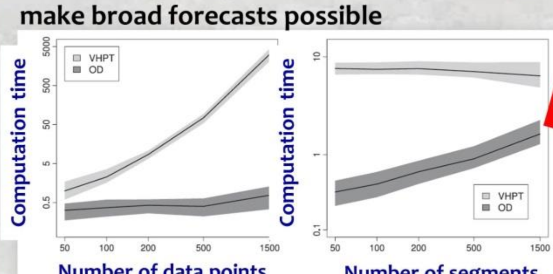


New types of statistical models for river networks…

work better than non-network models when spatial considerations are important…



& increasing computational efficiencies make broad forecasts possible



Rushworth et al. 2015. Validation and comparison of geostatistical and spline models for spatial stream networks. *Environmetrics* DOI: 10.1002/env.2340

Go here for article: http://onlinelibrary.wiley.com/doi/10.1002/env.2340/epdf

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 here: (http://www.fs.fed.us/rm/boise/AWAE/projects/stream_temp/stream_temperature_climate_aquatics_blog.html). The intent of the Climate-Aquatics Blog is to provide a means for the 9,214 (& growing) field biologists, hydrologists, anglers, students, managers, and researchers currently on this mailing list across North America, South 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 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 my colleagues & I have been conducting in the Rocky Mountain region, but attempts will be made to present topics & tools in ways that highlight their broader, global relevance. 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 occur to facilitate the rapid dissemination of knowledge among those concerned about climate change and its effects on aquatic ecosystems.

If you know 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
Blog #60: Bonus Blog: New report describes data collection protocols for continuous monitoring of temperature & flow in wadeable streams
Blog #61: Significant new non-American stream temperature climate change studies
Blog #62: More Bits about the How, What, When, & Where of Aquatic Thermalscapes
Blog #63: Navigating stream thermalscapes to thrive or merely survive

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
Blog #30: Recording and mapping Earth's stream biodiversity from genetic samples of critters
Blog #53: DNA Barcoding & Fish Biodiversity Mapping

Climate-Aquatics Biology Module
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 #56: New studies provide additional evidence for climate-induced fish distribution shifts
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
Blog #46: Part 5, Mechanisms of change in fish populations: Exceedance of thermal thresholds
Blog #47: Part 6, Mechanisms of change in fish populations: Interacting effects of flow and temperature
Blog #48: Part 7, Mechanisms of change in fish populations: Changing food resources
Blog #49: Part 8, Mechanisms of change in fish populations: Non-native species invasions
Blog #50: Part 9, Mechanisms of change in fish populations: Evolutionary responses
Blog #51: Part 10, Mechanisms of change in fish populations: Extinction
Blog #52: Review & Key Knowable Unknowns

Climate-Aquatics Management Module
Blog #54: Part 1, Managing with climate change: Goal setting & decision support tools for climate-smart prioritization
Blog #55: Part 2, Managing with climate change: Streams in channels & fish in streams
Blog #57: Identifying & protecting climate refuge lakes for coldwater fishes
Blog #58: Part 3, Managing with climate change: Maintaining & improving riparian vegetation & stream shade
Blog #59: Part 4, Managing with climate change: Keeping water on the landscape for fish (beaverin' up the bottoms)