Climate-Aquatics Blog #33: Part 1, Fish distribution shifts from climate change: Predicted patterns

The Sky is Falling!...(maybe?)

Hi Everyone,
So after dealing with time last time in fish phenologic responses to climate change, we'll look in the spatial dimension this time out. More specifically, we'll look at how fish species distributions are predicted to shift in response to climate change and what empirical support there may be that distributions are already shifting. It's a big deal if a species we're used to having in a certain stream or lake disappears from that system (especially if we're investing significant resources to keep it there as is the case with some protected species), so as you might imagine, this topic has sparked much interest in the fisheries literature over the last two decades. The topic is large enough, in fact, that we're going to split it into a mini-module of 3 – 4 related blogs. Today we'll focus on bioclimatic model predictions of changes in fish distributions this century. By my count, there are some 23 peer-reviewed manuscripts that have developed these models and used them to predict the future (full bibliography in graphics 1 – 3). These date back to the pioneering work of Don Meisner with eastern brook trout in the late 1980's/early 1990's and since then we've been applying similar approaches to a host of fishes in different parts of the globe.

For background, these bioclimatic models are really just another type of habitat suitability model that many of us may be more familiar with. A mathematical relationship is built that links the occurrence of a fish species to a set of habitat characteristics, but in bioclimatic models, we also throw in a few climatic predictors like temperature or stream flow to compliment the static habitat features that are traditionally used in suitability models. Once the relationship between the climate predictors and the historical fish distribution is described, the values associated with the climate predictors are adjusted to represent future climate scenarios and the associated distribution of suitable habitats remapped. The only other differences between the bioclimatic models and traditional habitat models then is the larger spatial scales that are usually addressed with bioclimatic models & maps are generated to show the model's habitat predictions spatially. A key assumption embedded in most bioclimatic models is that the habitat niches of species are conserved (i.e., constant through time), even if the distribution of these niches shifts in space. The most obvious example of this is the assumption that fish distributions are delimited by critical temperature isotherms (e.g., a temperature where it's too warm for a species to survive) and distributions will track these isotherms as they shift in response to warming (graphic 4).

There are many good examples of these sorts of models, but here we're highlighting a paper by Rieman and colleagues that predicts the distribution of bull trout habitats across the Columbia River Basin in the Northwest U.S. The first component of this study simply asked whether a relationship existed between climate patterns and the historical distribution of the fish. So longitudinal stream survey data were compiled for 76 streams from biologists across the river basin and the lower elevation limit of bull trout in these streams was modeled relative to latitude and longitude to describe spatial trends (graphic 5). The bull trout distribution dropped in elevation as one went north and west across the basin—closely matching the spatial trends in mean annual air temperature, so it was concluded that climate did indeed affect the fish's distribution. The second part of the study then simply remapped the locations of habitats by adjusting the elevation of the critical isotherm that delimited the historic bull trout distribution (5 ˚C) to represent future warming scenarios of +0.6 ˚C, +1.6 ˚C, etc. (graphic 6). Two things are apparent from the latter exercise; 1) even a relatively minor amount of warming could result in a significant loss of thermally suitable habitat (0.6 ˚C ~ 20% reduction) for this species, and 2) habitat losses would not be uniformly distributed. For the same 1.6 ˚C warming, for example, some areas were predicted to lose 70% of thermal habitat whereas others were predicted to lose only 20%. One thing to keep in mind with regards to a species like bull trout is that it has a very cold thermal niche, so often occurs as high in streams as is possible and lacks upstream refugia. Other species might be able to retreat upstream and not experience a net loss of thermal habitat…assuming, that is, nothing is in the way to block those movements.

In a second paper, Wenger and colleagues add several dimensions to the approach taken by Rieman. A huge fish database consisting of 10,000 unique survey locations was compiled from managers and researchers across the Rocky Mountains in the western U.S. (graphic 7). The occurrence probabilities of four trout species in this database were then modeled as a function of physical habitat characteristics, the occurrence of competitor species, and climatic attributes. Climate was represented not only by air temperature predictions from a global climate model (GCM), but also by a stream hydrology model linked to the GCM scenarios and tailored to predict flow changes within individual stream segments across the Rocky Mountains (described in Blog # 20; flow metrics archived online at: http://www.fs.fed.us/rm/boise/AWAE/projects/modeled_stream_flow_metrics.shtml). Here again, large reductions in the amount of future habitat for trout species were predicted to occur but there were also big differences among species in the amount of anticipated change. Habitats for brook trout, a fall-spawning species introduced to the Rocky Mountain region from the eastern U.S., were predicted to decline most (77%) by the year 2080 (graphic 8). Temperature increases, combined with an increasing frequency of winter flooding that negatively affected embryo and juvenile survival, were hypothesized to account for this large reduction. Rainbow trout habitats, in contrast, were predicted to decline only by 35%, in part due to a warmer thermal niche than the other species, but also because their spring spawning period renders them less vulnerable to alterations in winter flooding.

The main take home from these two studies and others like them is just how disruptive warming and other habitat perturbations associated with climate change may be for species distributions. Moreover, different things are likely to happen to different species for different reasons in different parts of their range. Even though climate change imposes a relatively consistent set of air temperature and precipitation changes across broad areas, complexity emerges from the interaction of these changes with local habitats and biology. Next time out we'll take a closer look at the empirical evidence supporting whether the distribution shifts predicted by the bioclimatic models have been occurring. We have, after all, been predicting these changes with dozens of models now for more than 20 years, & surely, with all that's on the line, someone has bothered to check whether the predictions are right…right?

As we'll see, however, space may turn out to be the final fishy frontier…

Until next time, best regards,
Dan

Those that have gone before…

Almodóvar A, Nicola GG, Ayllon D, Elvira B (2011) Global warming threatens the persistence of Mediterranean brown trout. *Global Change Biology* doi: 10:1111/j.1365-2486.2011.02608.x.

Battin J, Wiley MW, Ruckelshaus MH, Palmer RN, Korb E, Bartz KK, Imaki H (2007) Projected impacts of climate change on salmon habitat restoration. *Proceedings of the National Academy of Sciences (USA)*, **104**, 6720-6725.

Buisson L, Grenouillet G (2009) Contrasted impacts of climate change on stream fish assemblages along an environmental gradient. *Diversity and Distributions* **15**, 613-626.

Chu C, Mandrak NE, Minns CK (2005) Potential impacts of climate change on the distributions of several common and rare freshwater fishes in Canada. *Diversity and Distributions*, **11**, 299-310.

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Eaton JG, Schaller RM (1996) Effects of climate warming on fish thermal habitat in streams of the United States. *Limnology and Oceanography*, **41**, 1109-1115.

Flebbe PA, Roghair LD, Bruggink JL (2006) Spatial modeling to project southern Appalachian trout distribution in a warmer climate. *Transactions of the American Fisheries Society*, **135**, 1371-1382.

Keleher CJ, Rahel FJ (1996) Thermal limits to salmonid distributions in the Rocky Mountain region and potential habitat loss due to global warming: a geographic information system (GIS) approach. *Transactions of the American Fisheries Society*, **125**, 1-13.

Kennedy TL, Gutzler DS, Leung RL (2009) Predicting future threats to the long-term survival of Gila trout using a high-resolution simulation of climate change. *Climatic Change*, **94**, 503-515.

Lyons J, Stewart JS, Mitro M (2010) Predicted effects of climate warming on the distribution of 50 stream fishes in Wisconsin, U.S.A. *Journal of Fish Biology*, **77**, 1867-1898.

Matthews WJ, Zimmerman EG (1990) Potential effects of climate change on native fishes of the southern Great Plains and the Southwest. *Fisheries*, **15**, 26-32.

Meisner JD (1990) Effect of climatic warming on the southern margins of the native range of brook trout. *Canadian Journal of Fisheries and Aquatic Sciences*, **47**, 1065-1070.

…and a few more…

Mohseni O, Stefan HG, Eaton JG (2003) Global warming and potential changes in fish habitat in U.S. streams. *Climatic Change*, **59**, 389-409.

Nakano, S, Kitano, F, Maekawa, K (1996) Potential fragmentation and loss of thermal habitats for charrs in the Japanese archipelago due to climatic warming. *Freshwater Biology*, **36**, 711-722.

Rahel FJ, Keleher CJ, Anderson JL (1996) Potential habitat loss and population fragmentation for cold water fish in the North Platte River drainage of the Rocky Mountains: response to climate warming. *Limnology and Oceanography*, **41**, 1116-1123.

Rieman BE, Isaak D, Adams S, Horan D, Nagel D, Luce C, Myers D (2007) Anticipated climate warming effects on bull trout habitats and populations across the interior Columbia River Basin. *Transactions of the American Fisheries Society*, **136**, 1552-1565.

Ruesch AS, Torgersen CE, Lawler JJ, Olden JD, Peterson EE, Volk CJ, and Lawrence DJ (2012) Projected climate-induced habitat loss for salmonids in the John Day River Network, Oregon, U.S.A. *Conservation Biology*, **26**, 873-882.

Sharma S, Jackson DA (2008) Predicting smallmouth bass *Micropterus dolomieu* occurrence across North America under climatic change: a comparison of statistical approaches. *Canadian Journal of Fisheries and Aquatic Sciences*, **65**, 471-481.

Tisseuil C, Vrac M, Grenouillet G, Wade AJ, Gevrey M, Oberdorff T, Grodwohl JB, Lek S (2012) Strengthening the link between climate, hydrological and species distribution modeling to assess the impacts of climate change on freshwater biodiversity. *Science of the Total Environment*, doi:10.1016/j.scitotenv.2012.02.035.

Vorosmarty CJ, McIntyre PB, Gessner MO, Dudgeon D, Prusevich A, Green P, Glidden S, Bunn SE, Sullivan CA, Liermann CR, Davies PM (2010) Global threats to human water scarcity and river biodiversity. *Nature*, **467**, 555-561.

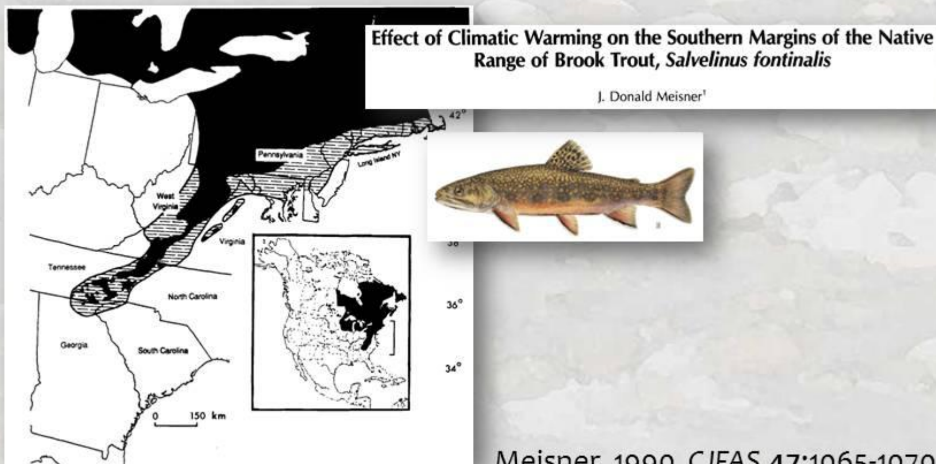
Wenger SJ, Isaak DJ, Luce CH, Neville HM, Fausch KD, Dunham JD, Dauwalter DC, Young MK, Elsner MM, Rieman BE, Hamlet AF, Williams JE (2011) Flow regime, temperature, and biotic interactions drive differential declines of trout species under climate change. *Proceedings of the National Academy of Sciences*, **108**, 1475-14180.

… and just a few more…

Williams JE, Haak AL, Neville HM, Colyer WT (2009) Potential consequences of climate change to persistence of cutthroat trout populations. *North American Journal of Fisheries Management*, **29**, 533–548.

Xenopoulos MA, Lodge DM, Alcamo J, Marker M, Schulze K, Van Vuuren DP (2005) Scenarios of freshwater fish extinctions from climate change and water withdrawal. *Global Change Biology*, **11**, 1557–1564.

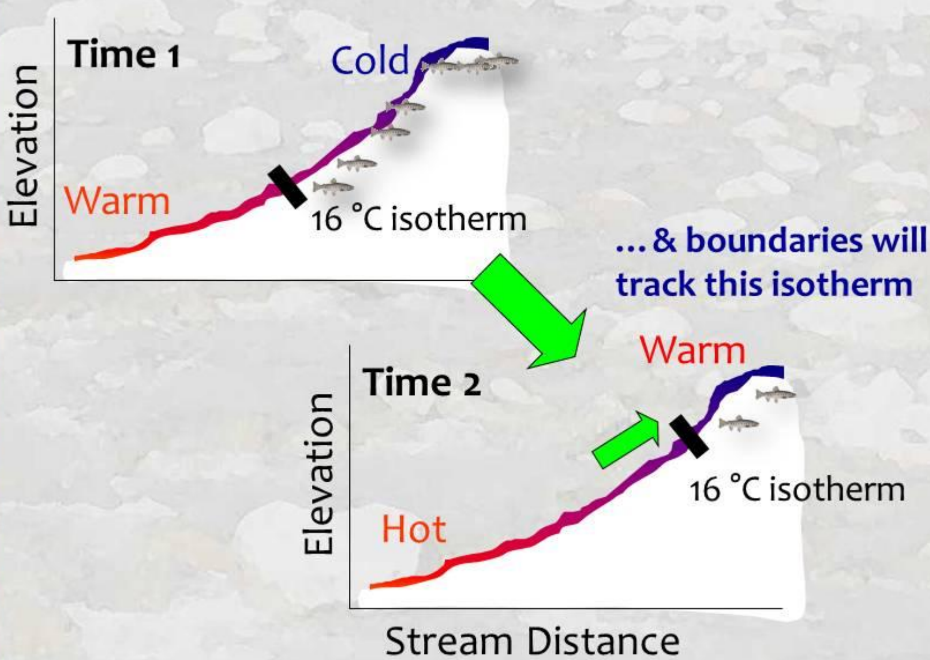
… but there was a first.



Meisner. 1990. *CJFAS* 47:1065-1070.

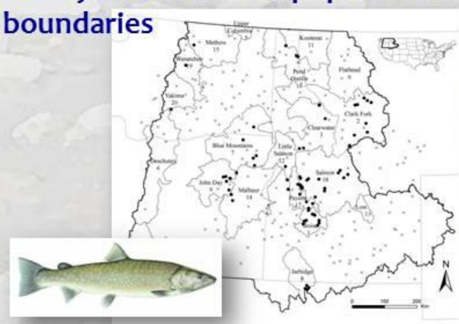
Key BioClimate Model Assumption:

Critical isotherm delimits species boundary…

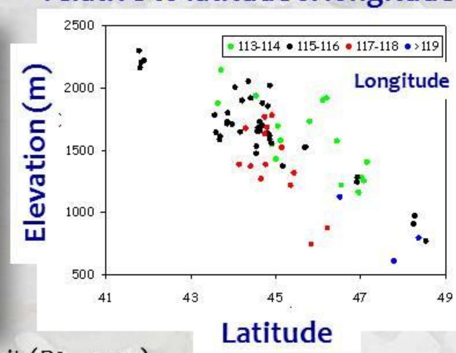


Does Climate Affect the Historic Distribution of Bull Trout?

76 streams with longitudinal surveys to determine population boundaries



Bull trout elevation boundaries relative to latitude & longitude



Juvenile Bull Trout Lower Elevation Limit ($R^2 = 0.74$)

Y = 18693 - 191(latitude) + 73.6(longitude)

1° lat = -191 m; 1° long = 73.6 m change in bull trout elevation limit

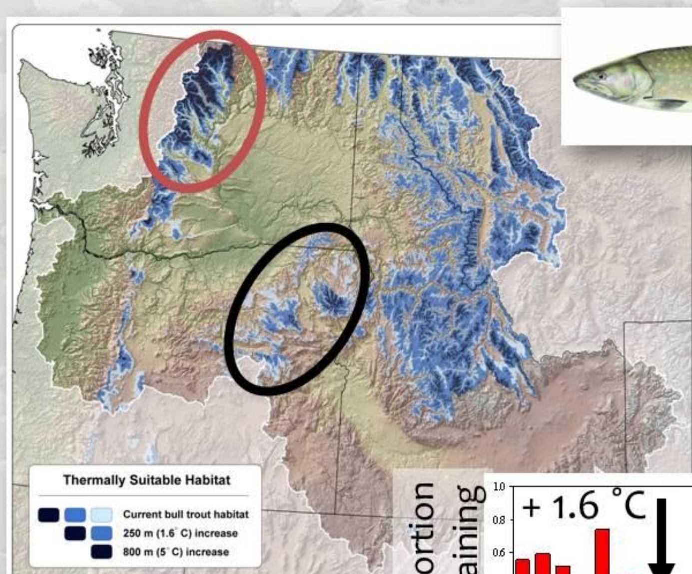
Mean Annual Air Temperature ($R^2 = 0.89$)

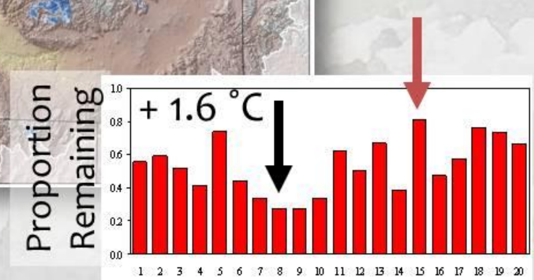
Y = 67 – 0.86(latitude) + 0.12(longitude) - 0.0062(elevation)

1° lat = - 138 m; 1° long = 88 m change in isotherm elevation

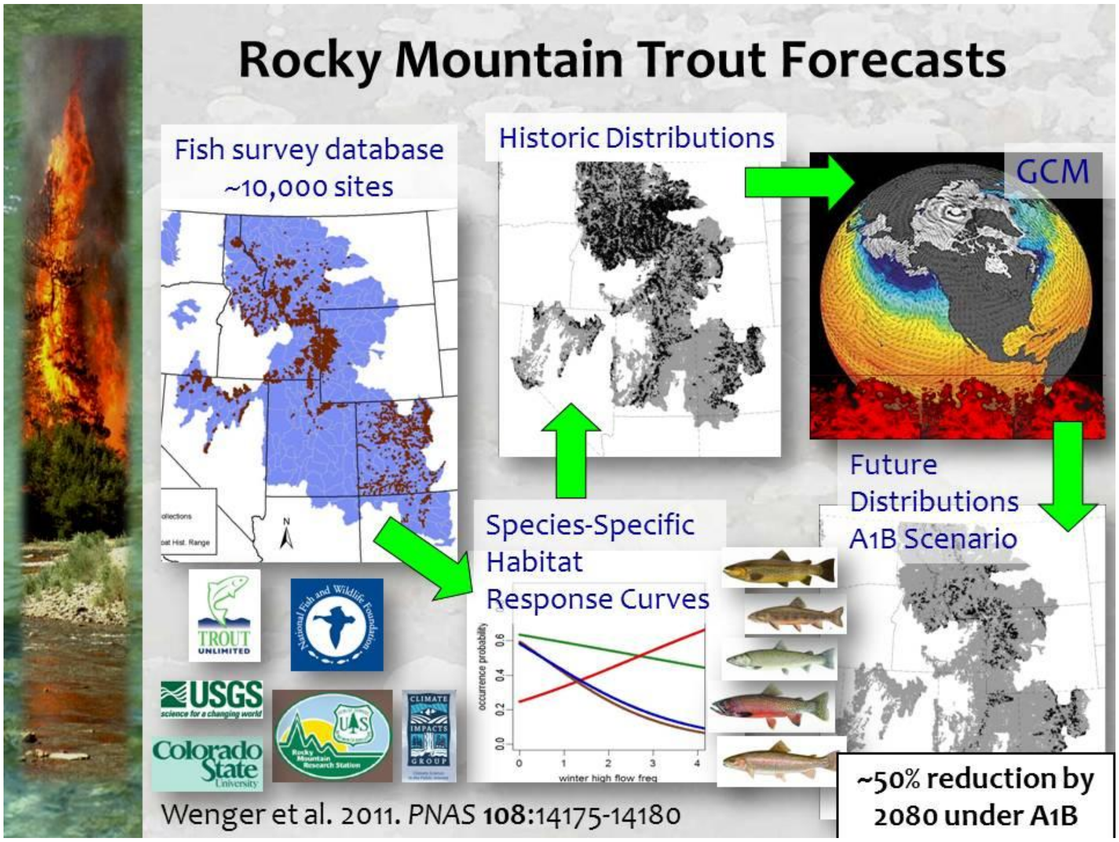
Rieman et al. 2007. *TAFS* **136**:1552-1565

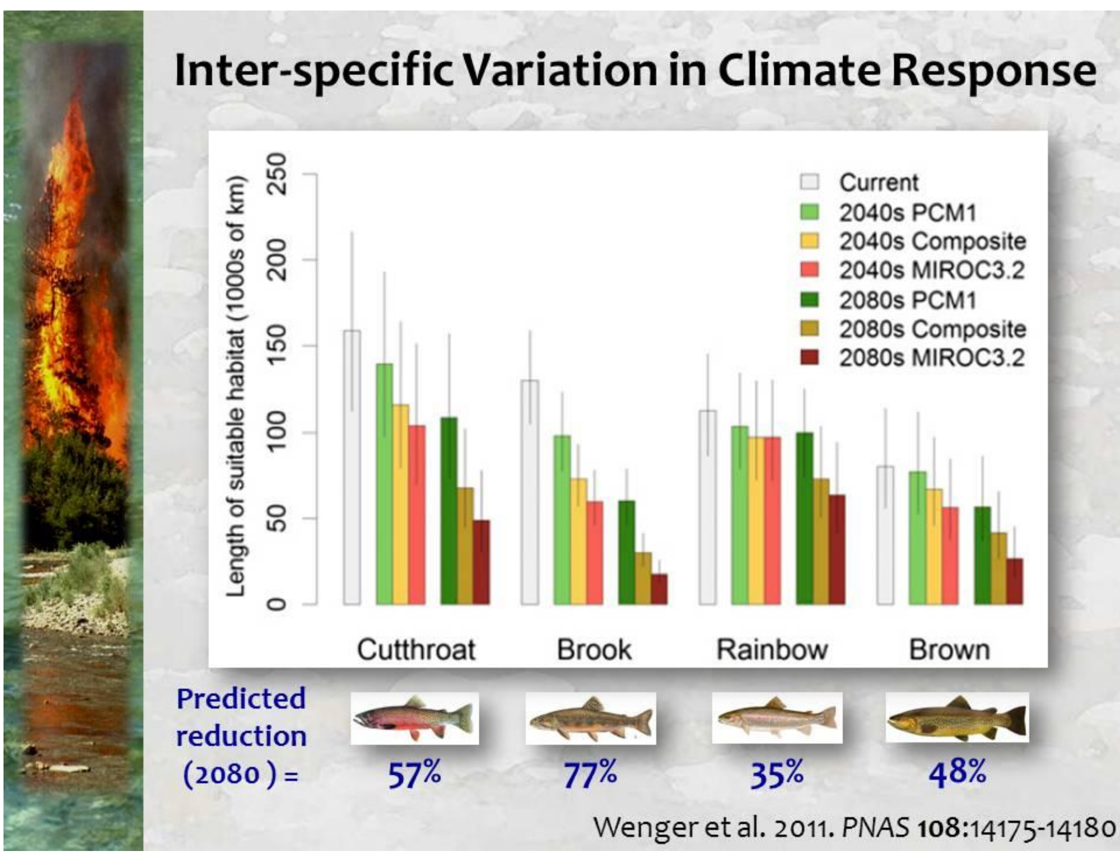
Spatial Variation in Future Changes





Rieman et al. 2007. *TAFS* **136**:1552-1565


Rocky Mountain Trout Forecasts
Fish survey database
~10,000 sites
Historic Distributions
GCM
Future
Distributions
A1B Scenario
Species-Specific
Habitat
Response Curves
occurrence probability
winter high flow freq
TROUT UNLIMITED
USGS
science for a changing world
Colorado State University
~50% reduction by
2080 under A1B
Wenger et al. 2011. PNAS 108:14175-14180


Inter-specific Variation in Climate Response
Length of suitable habitat (1000s of km)
0
50
100
150
200
250
Current
2040s PCM1
2040s Composite
2040s MIROC3.2
2080s PCM1
2080s Composite
2080s MIROC3.2
Cutthroat
Brook
Rainbow
Brown
Predicted
reduction
(2080) =
57%
77%
35%
48%
Wenger et al. 2011. PNAS 108:14175-14180

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 4,538 (& 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 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

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

Future topics…
Climate-Aquatics Management Module