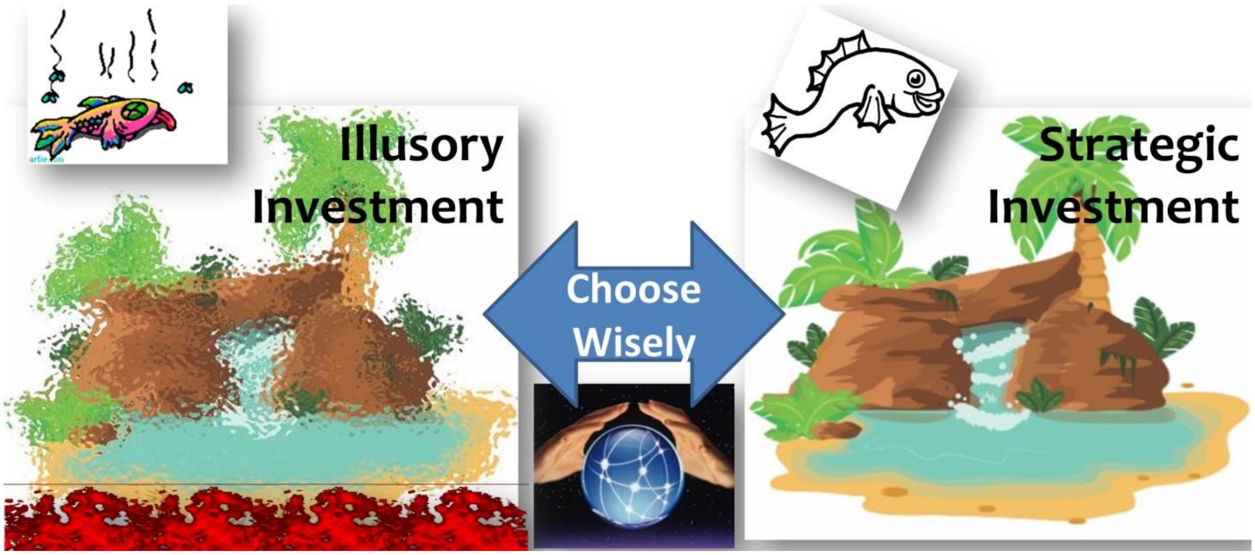
Climate-Aquatics Blog #68: Identifying & protecting climate refugia as a strategy for long-term species conservation



One of the great opportunities that combating climate change presents is a chance to revisit & sometimes address past ills visited upon aquatic environments. For by righting those wrongs and restoring habitat & the functioning ecosystems on which that habitat depends, we can sometimes mitigate the changes otherwise wrought by climate change & build more resilient fish populations in the process. That being the case, the astute observer has by now noticed that there aren't that many novel ideas in parts 1 – 6 of the management module we've been working through (Blogs 54, 55, 58, 59, 66 & 67). The real question isn't so much what to do, as where to do it & how to prioritize those "do's" given that the list of investment opportunities is really big (graphic 1).

Today we pick up where we left last time when asking "whither to shall we assist the fish?" (Blog #67) Assisted migration is fundamentally predicated on knowing where to move fish, and if there's going to be a useful where 50-100 years from now. It also takes a fair bit of time and money to move fish around—especially if the species being moved is rare or endangered. So we don't want to just be fish flowing & assisting species migrations willy-nilly without some sort of strategic plan to make the whole business more effective and cost efficient. Without a plan, we risk frittering away limited resources on short-term "feel-good" efforts that do little to maintain biodiversity in the long-run of this century. And before we get too amped up on moving things around, it's also important to realize that the most important thing we'll do for species conservation is to simply take care of them in the habitats they already occupy.

A conceptual & contextual solution that addresses many of these issues is the "climate refugia"—here defined as those habitats which will continue to have the capacity to support self-sustaining populations of a target species (or community) later this century. By identifying and protecting those areas—often a small subset of currently occupied habitats—we can ensure long-term species persistence at relatively low maintenance & management costs. Climate refugia could also then serve as foundational elements in the design and development of broader climate-smart conservation networks. A logical expansion beyond secured refugia, for example, could be investing to protect/restore lesser habitats that were proximate to refugia so that individuals could occasionally move between habitats. This would provide demographic support & help buffer populations in the network against stochastic disturbances (think climate flavored metapopulations) while minimizing the amount of human intervention needed to keep a particular critter on a landscape.

But before venturing further along this line of thought & discussing opportunities/challenges for operationalizing the climate refuge concept, let's first step back and look at a nice recent review by Gavin & colleagues (graphic 2; study hyperlinked here: http://carstenslab.org.ohio-state.edu/OSU/Publications_files/Gavin.etal.2014.pdf). The authors provide a broad discussion of past & present climate refugia, the roles they have served during previous periods of extreme climates, and various lines of paleoecological evidence that can be used for refuge discernment. The challenge during contemporary times, however, is that the future climates from whence flora and fauna need refuge are going to be much warmer than the cold climates associated with ice ages or the warmer interglacial periods that comprise much of the last 1,000,000 or so years. The past, in this instance, contains much useful information & lessons to be learned, but isn't likely a perfect prelude to a future wherein continental ice sheets & glaciers aren't grinding toward lower elevations & latitudes.

Moreover…identifying & protecting climate refugia during the Anthropocene requires a very precise understanding of species distributions, their environmental niches, & predictive abilities if the concept is to motivate meaningful efforts at biodiversity conservation this century. Imprecise model predictions about where to protect mean either that we don't protect the best places, we "overprotect" some areas, or combinations of both. And both are expensive errors in a zero-sum game wherein misallocated investments could have been used elsewhere to do more good. For today's discussion we won't go down the rabbit hole of species distribution modeling, which comprises a vast and growing literature (Elith & Leathwick provide a comprehensive review here: http://eurobasin.dtuaqua.dk/eurobasin/documents/Training%20ISM/Elith_and_Leathwick_2009.pdf), but instead focus on a more fundamental issue—the general lack of high-resolution, ecologically relevant climate information (Blogs 5, 6).

There are two means by which increased resolution can be achieved. The first I'll call "indirect" wherein environmental characteristics other than the desired climatic attributes are used to predict those attributes at locations distant from climate measurement locations. An example here is the common use of elevation from a DEM to predict temperature at higher or lower elevations than where measurements occurred. The indirect method is useful but the spatial extrapolations become large and create significant imprecision where the density of climate stations is sparse. When that occurs (& it occurs most of the time), there is simply no substitute for the "direct" method of resolution enhancement whereby additional climate measurements are obtained from more locations, which then provide local empirical calibration and support for climate model predictions. Minder & colleagues provide some specific examples (graphic 3; study hyperlinked here: http://www.atmos.albany.edu/facstaff/jminder/research/minder_et_al_lapse_published.pdf) & Potter & colleagues discuss the issue more generally within an ecological context (study available here: https://www.researchgate.net/profile/Kristen_Potter). The nice thing about climate data is that it's now so darn inexpensive to collect using a variety of proven protocols and reliable miniature sensors (graphic 4; Blogs 21, 60), which makes it possible to have data from many, many locations feeding into landscape climate models that minimize the distances over which extrapolations occur.

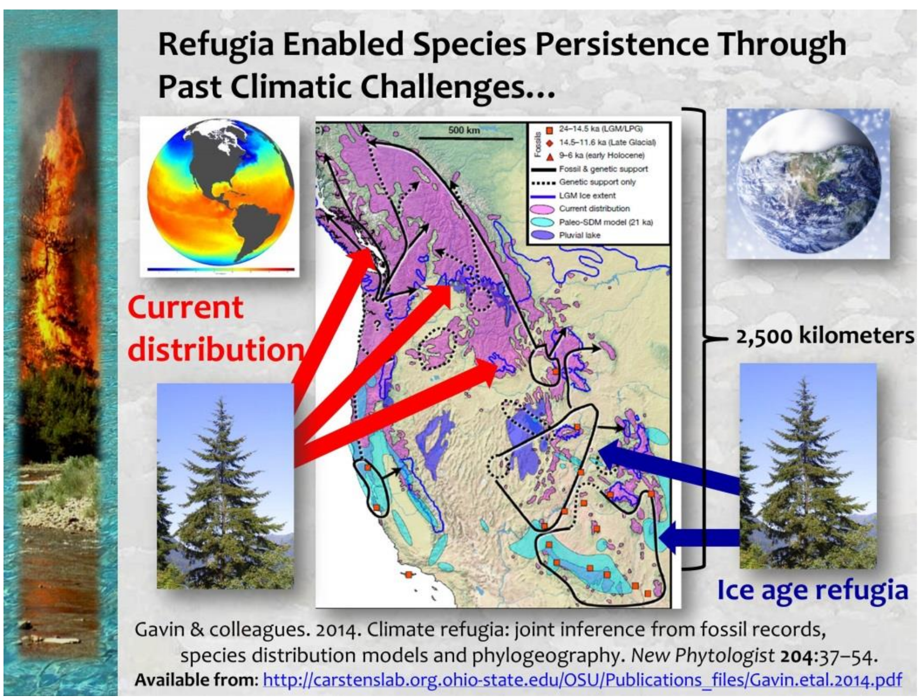
And so, fish people, having known all that 20 years ago, started collecting massive amounts of stream temperature data across Europe, the northeastern/northwestern US, and California (a country unto itself). Those same people, being a generally cooperative lot (& perhaps taking cues from how a fish in a school coordinates and collaborates with its neighbors) are now sharing those data and developing open-access databases that comprise 1,000,000s of hourly temperature recordings at 10,000s of unique sites (e.g., NorWeST website: http://www.fs.fed.us/rm/boise/AWAE/projects/NorWeST.html; NorEaST website: https://necsc.umass.edu/news/noreast-%E2%80%93-stream-temperature-web-portal-update). Those types of aggregated databases (which were previously a statistical nightmare because of non-independent sample locations & spatial autocorrelation) are perfect for use with the new spatial statistical network models described previously (blogs 27, 28, & 29; SSN/STARS website: http://www.fs.fed.us/rm/boise/AWAE/projects/SpatialStreamNetworks.shtml), which together provide the means of developing high-resolution climate scenarios supported by huge amounts of empirical data (graphic 5; Blog 40).

Once climate scenarios of sufficient resolution exist, it's then an easy matter to include the information just like any other predictor variable in species distribution models. Isaak & colleagues did just that using crowd-sourced fish datasets (which, by the way, often dwarf stream temperature databases in terms of unique sample sites) to develop models capable of predicting the occurrence of native trout populations within 1000s of streams across the northwestern US (graphic 6; study available here: https://www.researchgate.net/profile/Daniel_Isaak). The distribution models also served as tools to estimate the amount of habitat that reproducing populations required for persistence & which streams would be most likely to support populations in future climates. Climate refugia, in the final analysis, were simply those streams with the highest probabilities of future occupancy. To close the loop and ensure that the science & model predictions were accessible & useful for conservation planning purposes, Isaak & colleagues then packaged all the information as user-friendly digital maps & GIS databases that are distributed through a public website (graphic 7; Climate Shield website: http://www.fs.fed.us/rm/boise/AWAE/projects/ClimateShield.html). The precision of the information & its strategic extent complements the tactical knowledge managers have about individual streams so they are empowered when making on-the-ground decisions. And once the aquatics army is marching to protect & restore specific watersheds & streams, it's best to get out of the way because it will move mountains to do so...

Until next time, best regards. Dan

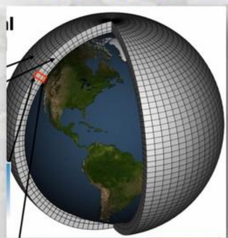
For even more fun related to this whole business, image you are a conservation biologist 10,000 years ago coming out of the last major glaciation & need to need to identify climate refugia to preserve critters through the global warming that occurred during the Holocene period...Williams et al. did in: The ice age ecologist: testing methods for reserve prioritization during the last global warming. *Global Ecology and Biogeography* **22**:289-301. (Study hyperlinked here: http://mvellend.recherche.usherbrooke.ca/Williams_etal_GEB2013.pdf)

Tweeting at Dan Isaak@DanIsaak

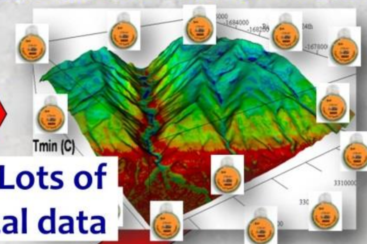


Dense Sensor Networks Enable Better "Downscaling" of Climate Information

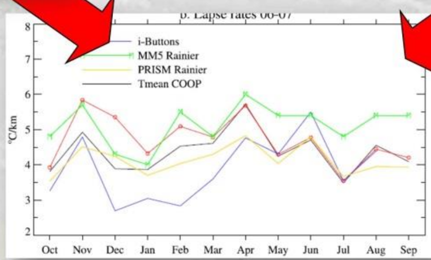
GCM Resolution: 10000s of meters



Landscape model Resolution: 100s of meters



Lots of local data

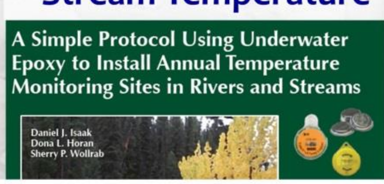


Temperature pattern differences due to model resolution

Minder & colleagues. 2010. Surface temperature lapse rates over complex terrain. Journal of Geophysical Research. **115,** D14122. **Available from:** http://www.atmos.albany.edu/facstaff/jminder/research/minder_et_al_lapse_published.pdf

Stream Climate Data are Easily & Inexpensively Collected Using a Variety of Standard Protocols

Stream Temperature


A Simple Protocol Using Underwater Epoxy to Install Annual Temperature Monitoring Sites in Rivers and Streams

Daniel J. Isaak
Dona L. Horan
Sherry P. Wollrab

$130 = 5 Years of Data

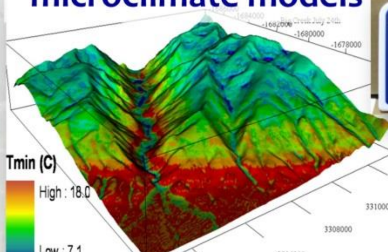
Stream discharge

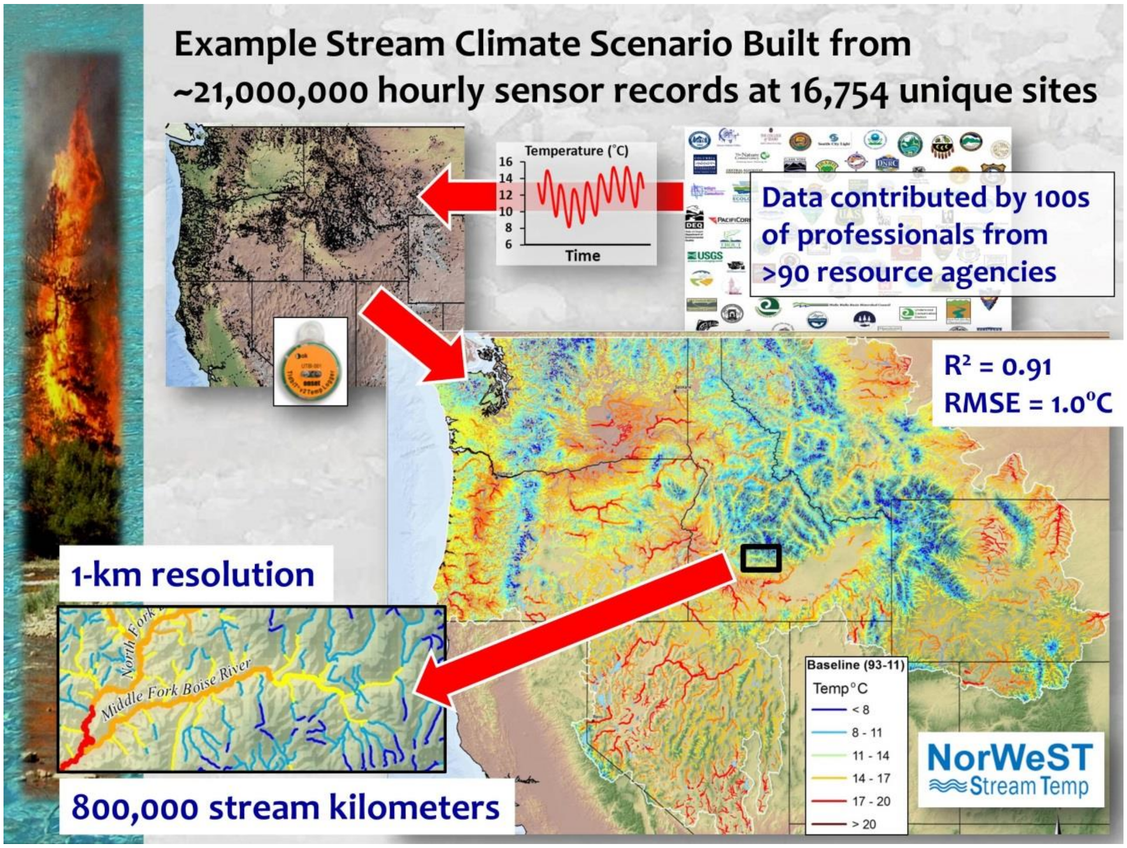
$299 sensor

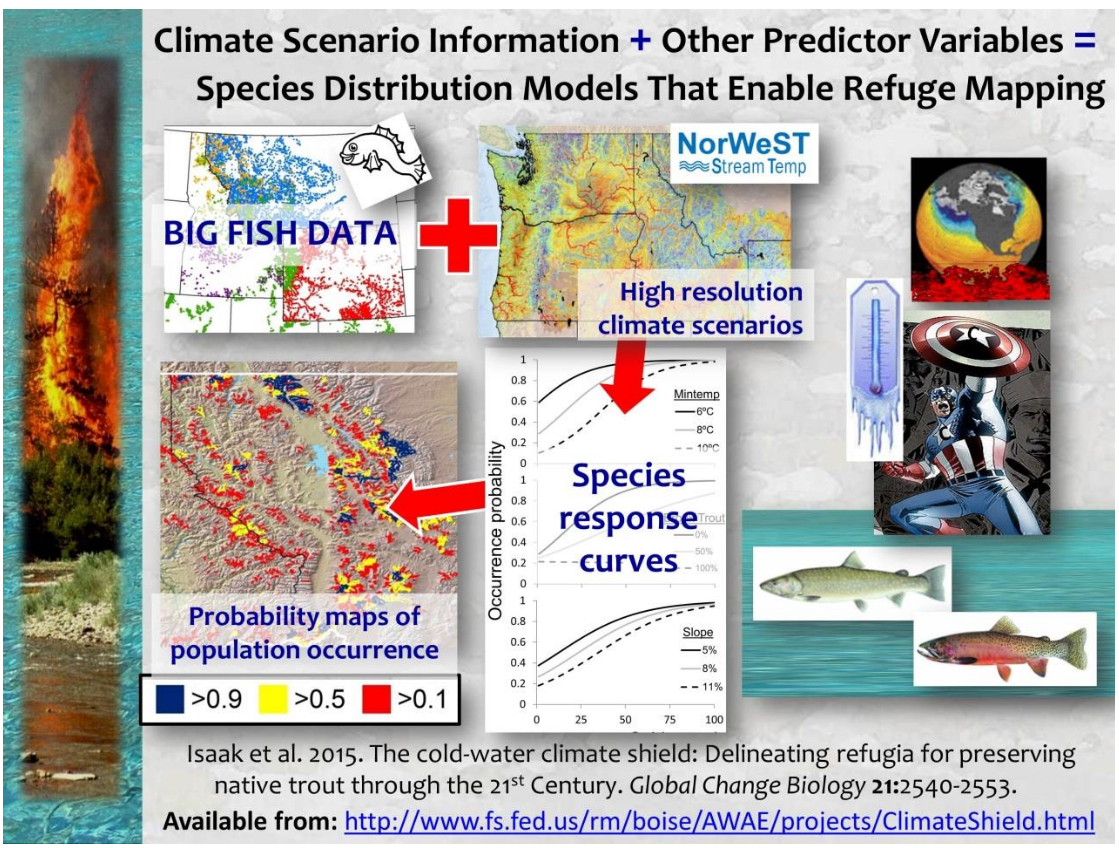

EPA United States Environmental Protection Agency

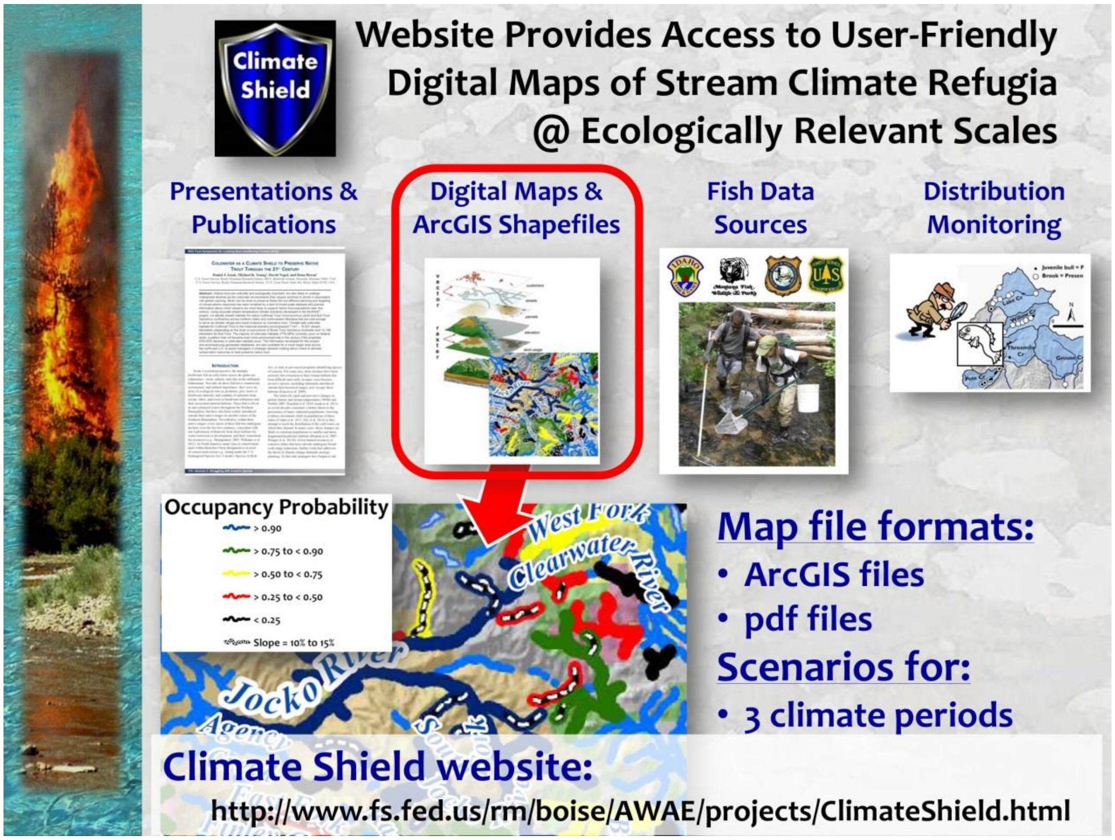
Best Practices for Continuous Monitoring of Temperature and Flow in Wadeable Streams

Air Sensors (~$50) for microclimate models




Example Stream Climate Scenario Built from
~21,000,000 hourly sensor records at 16,754 unique sites
Temperature (°C)
16
14
12
10
8
6
Time
Data contributed by 100s of professionals from >90 resource agencies
R² = 0.91
RMSE = 1.0°C
1-km resolution
North Fork
Middle Fork Boise River
800,000 stream kilometers
Baseline (93-11)
Temp°C
< 8
8 - 11
11 - 14
14 - 17
17 - 20
> 20
NorWeST
Stream Temp


Climate Scenario Information + Other Predictor Variables =
Species Distribution Models That Enable Refuge Mapping
BIG FISH DATA
NorWeST
Stream Temp
High resolution climate scenarios
Mintemp
6°C
8°C
10°C
Species response curves
Occurrence probability
Slope
5%
8%
11%
0
25
50
75
100
Probability maps of population occurrence
>0.9
>0.5
>0.1
Isaak et al. 2015. The cold-water climate shield: Delineating refugia for preserving native trout through the 21st Century. Global Change Biology 21:2540-2553.
Available from: http://www.fs.fed.us/rm/boise/AWAE/projects/ClimateShield.html


Climate Shield
Website Provides Access to User-Friendly Digital Maps of Stream Climate Refugia @ Ecologically Relevant Scales
Presentations & Publications
Digital Maps & ArcGIS Shapefiles
Fish Data Sources
Distribution Monitoring
Occupancy Probability
> 0.90
> 0.75 to < 0.90
> 0.50 to < 0.75
> 0.25 to < 0.50
< 0.25
Slope = 10% to 15%
West Fork Clearwater River
Jocko River
Map file formats:
• ArcGIS files
• pdf files
Scenarios for:
• 3 climate periods
Climate Shield website:
http://www.fs.fed.us/rm/boise/AWAE/projects/ClimateShield.html


Precise Information Empowers Local Decision Makers & The Aquatics Army Begins to March…
High-resolution landscape climate models
I'm going to invest here…
…instead of here
Debris flow susceptible channel
Thermally suitable - occupied
Thermally suitable - unoccupied
Projected habitat loss
Road culvert fish barrier
Because this population has a chance of persisting this century…
Coordinated stakeholder actions
NOAA Fisheries
USGS
science for a changing world
TROUT UNLIMITED

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…

Blog #62: More Bits about the How, What, When, & Where of Aquatic Thermalscapes
Blog #63: Navigating stream thermalscapes to thrive or merely survive
Blog #64: Building real-time river network temperature forecasting systems

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
Blog #65: The Fish Jumble as they Stumble along with the Shifting ThermalScape

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)

Blog #66: Part 5, Managing with climate change: Barrier placements to facilitate fish flows across landscapes

Blog #67: Part 6, Managing with climate change: Assisted migration to facilitate fish flows across landscapes