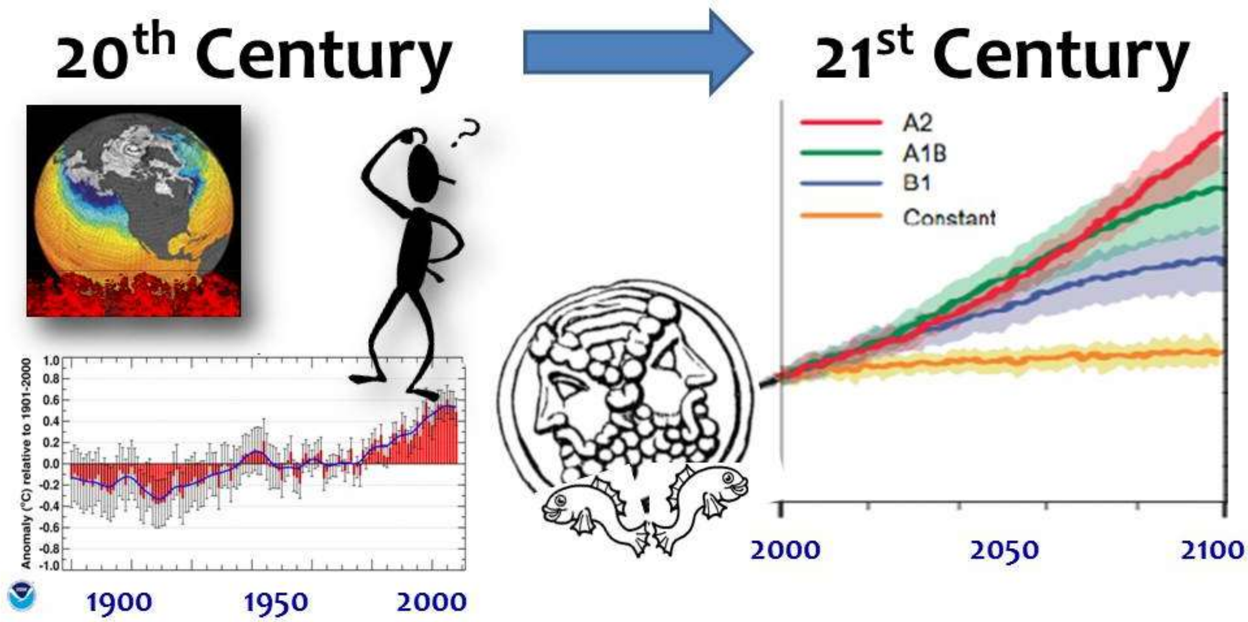
Climate-Aquatics Blog #52: Review & Key Knowable Unknowns



Hi Everyone,
So we're about 3 years into this climate-aquatics blog thing and slowly, but surely, working our way through to the end sometime next year. It's taken a lot longer to get here than I'd imagined because there's a gush of useful new information and tools the global aquatics community has been churning out in recent years and we're attempting to highlight a few of those while providing an overarching narrative. But that narrative is taking long enough that the ground has shifted somewhat beneath our feet, so as we close out the year, now seems to be a good time to do an appraisal of where things are, are going, and key questions yet to be resolved before starting on the penultimate climate-aquatics management module early next year.

As a basis for this appraisal, it's useful to point out that although there's a pretty clear consensus among the global climate models that things will get warmer, there isn't a clear consensus on how much, or how fast, things will warm (graphic 1). There's a range of prediction uncertainty at mid-century (the latest IPCC report is hyperlinked here: http://www.ipcc.ch/), which grows considerably by the end of the century because the uncertainties about future greenhouse gas emissions and the choices human societies make about energy systems come increasingly to bear. And those global uncertainties propagate down to lower levels to cast uncertainty onto the future of our local favorite fish population in our favorite stream (graphic 2). That's unfortunate, but it is what it is. It's a type of uncertainty that falls into a category that the eminently quotable Donald Rumsfeld once called, "Unknowable unknowns."

Adding to the uncertainty about the Earth's actual future warming trajectory are uncertainties associated with how gradual climate warming translates to effects on regional climate patterns, river network hydrology & thermal patterns, and biological response at the local scale. But this is also where significant opportunities lie, because those types of uncertainty fall more into the "knowable unknowns" category & are things the global aquatics community is well equipped to address. It's at that local & network/landscape scale where we often have a wealth of empirical data because this is the scale we're working & thinking day in and out to manage, conserve, & understand the things we care about. And it's here too that we also have a wealth of models and theory about how stream ecosystems operate and how fish populations are regulated by the environment. What we lack are the means of scaling up this local information & associated datasets into mesoscale models that are useful at larger scales and could be directly linked to the climate models to create an integrated system (graphic 3). So, for example, we often have lots of individual stream temperature measurements, but relatively few models that integrate these data properly and provide accurate predictions across full river networks where the information is needed by managers to make choices about where to prioritize habitat restoration projects (Blogs #7, #40). Or in a biological example, we have lots of thermal criteria for species, but these are usually derived from short-term laboratory trials on individual organisms rather than populations in nature where the relevant survival metric is measured across multiple generations as population growth rate (i.e., lambda, Blog #41).

The list could go on & on, but if we can develop the means of correctly scaling information to meet the climate models somewhere in the middle, we'd have taken a huge step towards addressing the *know*able unknowns and minimizing the overall level of uncertainty associated with climate change effects on aquatic ecosystems. Those *un*knowable unknowns associated with the planet's future warming trajectory will still exist, but at least we'll have minimized error propagation and specific trajectories can then be translated accurately to local conditions that facilitate better planning & adaptation responses.

So how to do that scaling to better resolve the knowable stuff? Conceptually, it's not that difficult—we just need lots of measurements of the most important things across space & time, feeding into accurate models, built from good theory, to interpolate among the measurements—but logistically it is. Because in reality, it's a tremendous amount of grunt work—organizing existing data into usable databases, supplementing these databases with new data to fill gaps, developing new protocols for collecting important data, developing the modeling systems that correctly scale information—that all takes time and effort. But it's something we have to do and we're kidding ourselves to think it's possible to create good information at scales and resolutions useful for conservation and management decision making any other way. And engaging in the process is by no means a bad thing. Having been immersed in many aspects of it now for several years (& likely for as many years as I can see into the future), I see it having a transformative effect in terms of fostering better collaborations and efficiencies among resource agencies. Equally important, going through the process greatly strengthens the social networks & communities of professionals that care about, and manage, aquatic resources within specific landscapes.

So before spelling out more specifically what I think the important knowable unknowns are, it's useful to discuss key data types because they constitute the foundation on which much else is built. And in this regard, stream temperature, flow, and various biological monitoring data are unto understanding what climate change is to aquatic resources as CO^2 monitoring is unto global warming research (graphics 4 and 5). You simply can't do much without good empirical measurements of them, or it. Briefly, then, here are the strengths/weaknesses of what we currently have for:

1) Stream temperature.–The development of accurate, inexpensive, miniature temperature sensors some 20 years ago has dramatically increased the amount of temperature data in some areas (graphic 6). But many other areas still lack even sparse temperature data or any semblance of monitoring programs. And even where much data exists, we usually monitor only for short periods of the year (e.g., summer months in the mountain streams and rivers I'm familiar with), and we rarely monitor the same site for many years (graphic 7). That makes it very difficult (or impossible) to describe long-term trends (Blogs #10, #23) and/or the characteristics associated with the full annual temperature cycle like we need to really understand thermal regimes. Although a lot can be done with existing temperature data (Blogs #7, #14, #25, #40), we obviously need to get serious about designing and establishing permanent, annual monitoring networks for stream and river temperatures (Blogs #8, #9, #24). Those networks might be piggybacked on the infrastructure that already exists for flow monitoring (see below), or established by themselves, but there's no excuse at this point for not doing so given the ease, cost effectiveness, and importance of annual temperature monitoring (Blog #3).

2) Stream flow.–The strengths & weaknesses of flow data are the inverse of those for temperature data. Long-term, annual monitoring data often exist, and these have proven their worth in many studies for describing & understanding trends associated with climate change over the last 60 years (Blogs #17, #18). But the flow monitoring network is also relatively sparse in most areas (graphics 8 & 9), and gradually becoming more so due to ongoing budgetary constraints (a good recent USGS report is hyperlinked here (warning, it's a big file): http://pubs.usgs.gov/sir/2013/5013/pdf/sir2013-5013.pdf). As with stream temperatures, however, new sensor technologies make it easier & less expensive to collect flow data (graphic 10; Blog #21), and this could, over time, increase the number of sites with data. Thought is needed, however, regarding how new monitoring efforts might best supplement existing long-term monitoring efforts.

3) Fish data.–There are many types of fish data that are relevant to understanding the effects of climate change on aquatic systems (growth, abundance, survival, etc.) and we've highlighted many of those in the blogs biology module (Blogs #32, #41, #44, #45, #47, #50). But the bread & butter stuff, the stuff that we legislate about & file lawsuits about, are species distributions (presence/absence data) and where different critters occur on the Earth's surface. And for that type of data, we're literally up to our eyeballs across most of the U.S. and Europe (graphic 11; Blogs #28, #39). Where lots of data exist, however, it's often the case that it's not as well organized as it could be, is spread across dozens of different agencies & not very accessible, or collected using different protocols that make comparisons difficult. Organizing those data will go a long way toward unlocking a wealth of new fish information, while standardizing future surveys will help ensure compatibility among different areas.

A key, & complimentary, addition to species distribution surveys in recent years has been genetic sampling. In fact, it was argued during an earlier blog (#30) that a tissue sample is the most important, & information rich, type of biological data we can collect (graphic 12). Moreover, fish tissue samples are easy to collect & store compactly, and dryly, on chromatography paper (no more messy alcohol vials!). And as costs to do genetic analysis continue to rapidly decrease, it will someday be possible to run hundreds or thousands of samples, even on tight fish budgets.

So there's a treasure trove of climate relevant biological information to mine from existing data, but those databases are also deficient in at least two important regards when it comes to climate questions. One, they're not very good about telling us specifically where the edges of species distributions occur because most fish monitoring has been done in the heart of species distributions with a focus on variation in abundance. As such, we have to apply modeling techniques to predict where the distributional edges occur & it would be useful, on occasion, to design & implement sampling strategies that specifically measured those edges more directly (graphic 13, Blogs #37, #38). Two, existing fish databases can't tell us much about how distributions are shifting in response to climate change (an exception occurs in the temporal domain where longterm records on fish migrations often show trends). So despite a whole bioclimatic modeling cottage industry developing in recent decades that predicts a lot of gloom and doom for many of our favorite fishes (Blog #33), there's very little biological proof that fish distributions are shifting in space the way the models say they should. That proof is common for many other plant & animal taxa (graphic 14, Blog #31), but with a few notable fish studies (graphic 15, Blogs #34, #35, #42), it's largely lacking for freshwaters. So we need to greatly expand our efforts to resurvey historical sites and determine if the same critters are swimming at sites today as was the case several decades ago (graphic 16). That means lots of electrofishing rodeos (Blog #30), which we all love, and it also provides a great excuse to take tissue samples from every critter we touch so that the genetic biodiversity archives we need today, and 100 years from now, will exist.

With good databases & monitoring networks for stream temperature, flow, and fish, we have the raw fuel that's needed to test hypotheses that help us resolve & understand those knowable unknowns while facilitating development of better models for scaling information. Broad efforts are underway in many areas to develop those sorts of data sources (graphic 17) and it's encouraging to see how much interagency collaboration there is spurring them and that much data is being digitally archived and made freely available (Blogs #21, #25, #40). Over time, those trends will benefit the aquatics community in several important ways. First & most obviously, they let us be more efficient in terms of how we invest limited resources because we can leverage across multiple agency partners. Second, they create stronger relationships between managers and researchers because managers constitute the bulk of the "army in the woods" and often contribute disproportionately to the large databases which are emerging. Moreover, my experience has been that the management community is eager to share data and have it used in research if it helps them address important issues and the outputs are packaged in useable formats. And I also know, as any researcher does, how time consuming it is to collect & organize datasets prior to the comparatively quick work of doing analyses & writing papers, so am always thankful to have help on the frontend. It becomes a win-win when people actually use the stuff that researchers publish, and that's far more likely when the information is developed from data contributed by the community of end-users. Third, open access to good data creates an environment wherein ideas, models, and tools can emerge more rapidly and be tested and compared based on their merits. There's much we need to learn in a short period of time, and anything that speeds the process of information development ultimately allows us to do more good things for more fish in more places. Though in previous blogs I've highlighted the new spatial statistical network models (graphic 18, Blogs #27, #28, #29) for their utility in developing useful information from aggregated databases at river network scales, many types of models and ways of developing new information are needed.

Now about those key "knowable unknowns" I see these as things that could be addressed or developed over the next 2 – 10 years that would greatly reduce overall uncertainties about how climate change affects aquatic ecosystems. In rough order, it would be useful to know…

a) Patterns of stream flow and temperature throughout full river networks (graphic 19, Blogs #20, #40). There are many models that provide this information at local scales but far fewer that do so at mesoscales where choices have to be made about which areas to prioritize. We need models for stream flow and temperature that can be used to create consistent, accurate, high-resolution scenarios (both historic and future) from the smallest headwater streams downstream to the mainstem rivers. Models that provide this information should be designed to interface with climate model outputs so that linked systems are created & error propagation minimized.
b) Distributions of aquatic species and genetic diversity throughout full river networks and throughout species' ranges. Like the cottage industry for bioclimatic models, there's one for species distribution models and genetic analyses and existing big fish databases & growing tissues archives could be mined to develop this information and the high-resolution, "smart maps" we need (Blog #26).
c) Climatic thresholds (too warm/cold, too much/too little flow) that mediate species distributional boundaries and climates that determine habitat quality (high/medium/low). Note: combining a & b from above once those pieces are built provides us with much of the answer and also highlights the way that a modular system could enable powerful synergies.
d) Habitat size/configurations/qualities that support the populations, species, and communities we're interested in. By knowing a, b, and c above, and by referencing that information against a consistent national or regional hydrologic layer, the parts are in place to make these calculations in standardized ways. In the U.S., for example, we often use the USGS NHDPlus digital hydrography layer (hyperlinked here: http://www.horizon-systems.com/nhdplus/) because it already exists any place we start a new project and has dozens, if not hundreds, of reach attributes already calculated (e.g., elevation, channel slope, watershed size, %landcover types, etc.). That saves us a lot of time, enables consistent comparisons among areas, and provides a backbone that stream climate scenario information can be added to. Then one can explore the habitat size/configuration questions in more detail and determine the environmental conditions associated with where different fishes thrive, just survive, or drop out. Good estimates of those habitat conditions where the drop-outs occur give a sense of where environmental tolerances are exceeded and/or the zombie-fication process is kicking in (graphic 20, Blog #51). And those estimates are needed to highlight where similar thresholds will be exceeded, and populations placed at risk, when we start to look at future habitat maps (below).

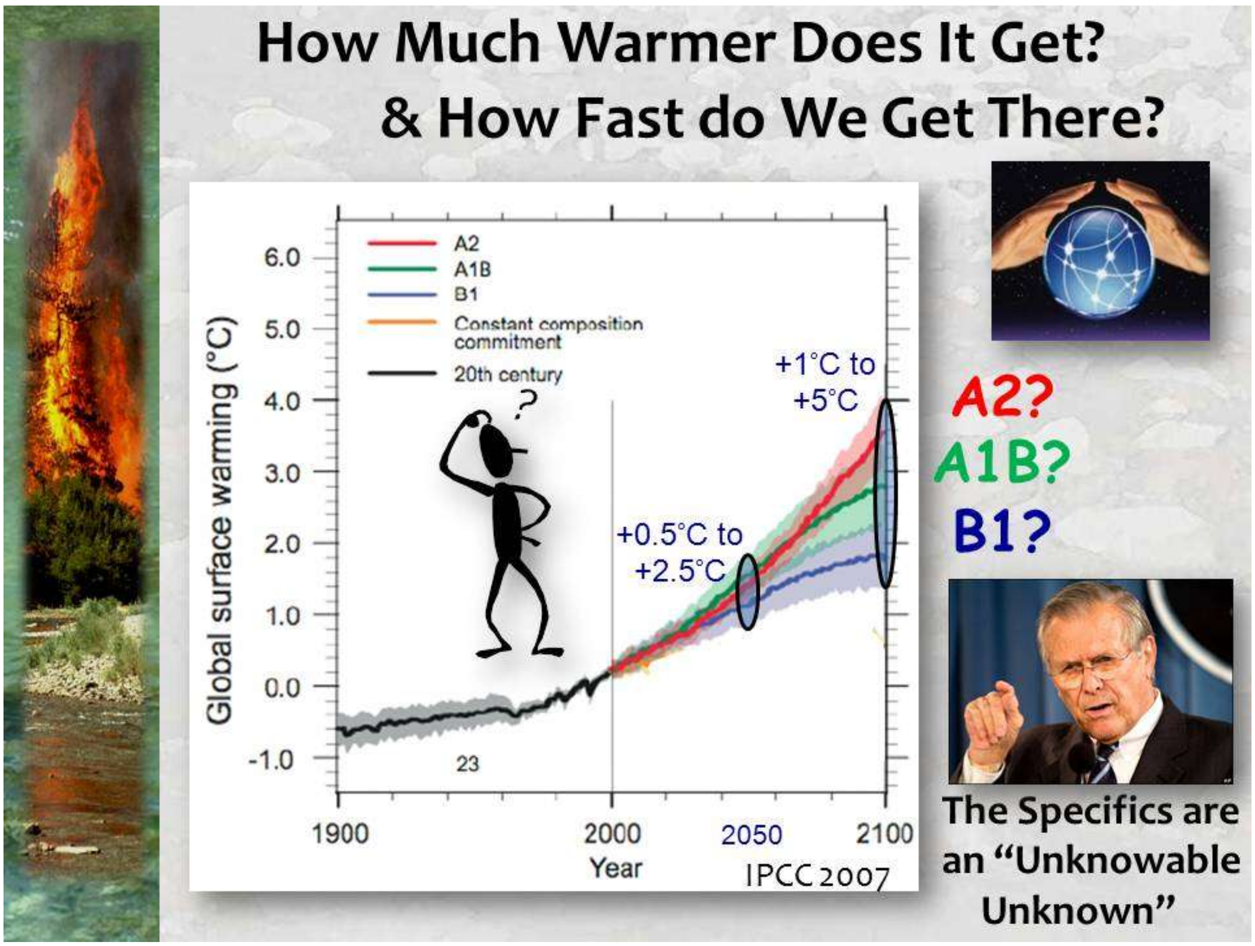
Notice that what's above rolls up to provide a consistent, accurate set of status maps, but there's no temporal/climate change dimension yet, which is where resolving the next set of knowable unknowns comes in…

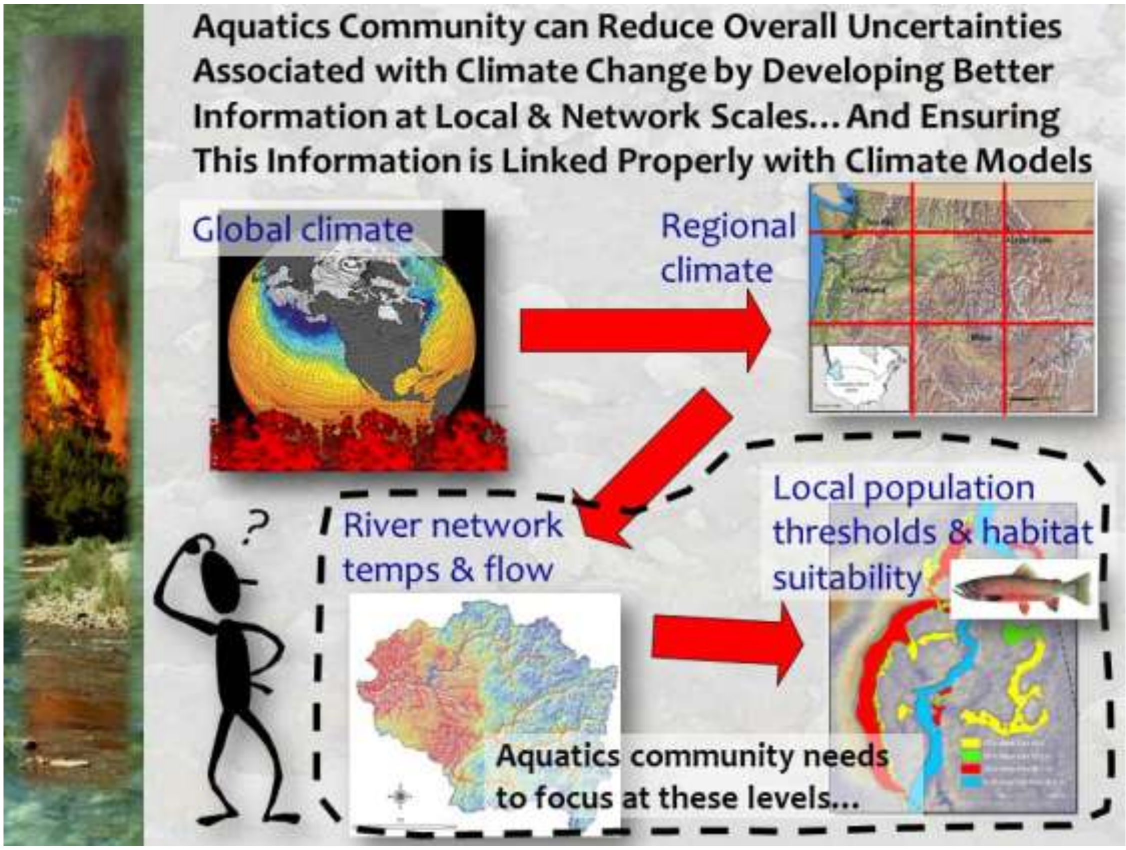
e) Determine the rates at which stream temperature and flow characteristics have been changing due to climate trends in recent decades. Some estimates exist (Blogs #18, #23), but we need more in more places and should explore means of doing historical reconstructions where longterm records are lacking. Those rates of change can then be translated to climate velocities (graphics 21, 22, Blog #36) to better understand the geographic rates at which the climate niches of species (as described in c above) are shifting.
f) Determine the rates at which fish distributions have been shifting in recent decades. Many ways of deriving those estimates, which leverage from existing data, were highlighted previously (Blogs #37, #38, #39, #42). Once estimates exist, determine whether biological shifts track climate velocities or if fish are lagging behind. If so, determine the factors that account for the lags and/or variation in the rates of distribution shifts (e.g., low dispersal rates, levels of habitat fragmentation, variation in climate velocity).
g) Determine the future projections from climate models, translate these to stream flow and temperature changes, translate these to species climatic niches and velocities. How do those projected velocities compare to historical rates?
h) Map where the habitats that supported populations/species/communities historically would occur in the future based on climate projections. Given observed distributional shift rates (f above), is it likely that fish will be able to track those habitats of their own accord or do we think about helping them move faster?
i) Map where the habitats that currently support populations/species/communities are projected to cross the zombification thresholds (as in d above). Those are vulnerable areas to be concerned about & might be good places to monitor as we seek to better understand the zombification process.
j) Combine all of the above—full maps of current/future suitable habitats, current species distributions/genetic structure—to get an accurate sense of what it looks like and where it could be headed if the climate projections come to fruition. Once we're to this point, we'll have at least a murky crystal ball wherein the overall uncertainty about climate change effects on aquatic systems is greatly reduced from the present condition wherein all our crystal balls are functionally opaque.

Adding to that last point, we then need to ask ourselves what we want those maps to look like 50 years from now, 100 years from now? And how do we most effectively influence the transition from the current maps to the desired future maps (graphic 23)? The farther into the future we look, the murkier the crystal ball becomes but it's still a powerful tool for plotting trajectories and understanding how our choices tilt the odds toward achieving more desired outcomes a century from now (graphics 24, 25). Understanding those trajectories & articulating goals about desired future outcomes then provides a context for how & where conservation efforts might be best employed to have a lasting impact. If we can develop the information, databases, monitoring networks, and analytical capacity described above, we'll have created an infrastructure that helps ensure those efforts are as effective as possible (Isaak & colleagues make these same basic points here: http://www.fs.fed.us/rm/pubs_other/rmrs_2012_isaak_d001.pdf). We'll begin to explore what some of those efforts could be in the next climate-aquatics management module, but for now, it's time to enjoy the holiday break.

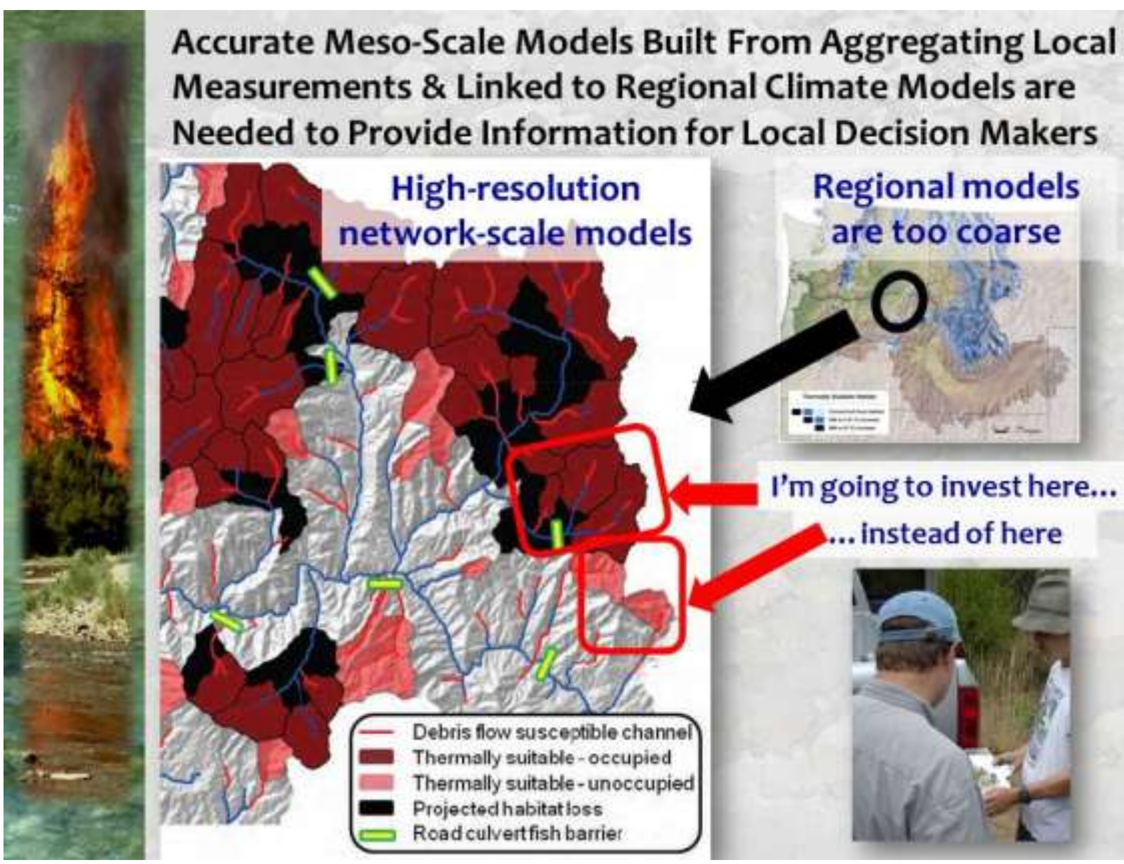
Best of holidays,
Dan

Now Tweeting at [Dan Isaak@DanIsaak]

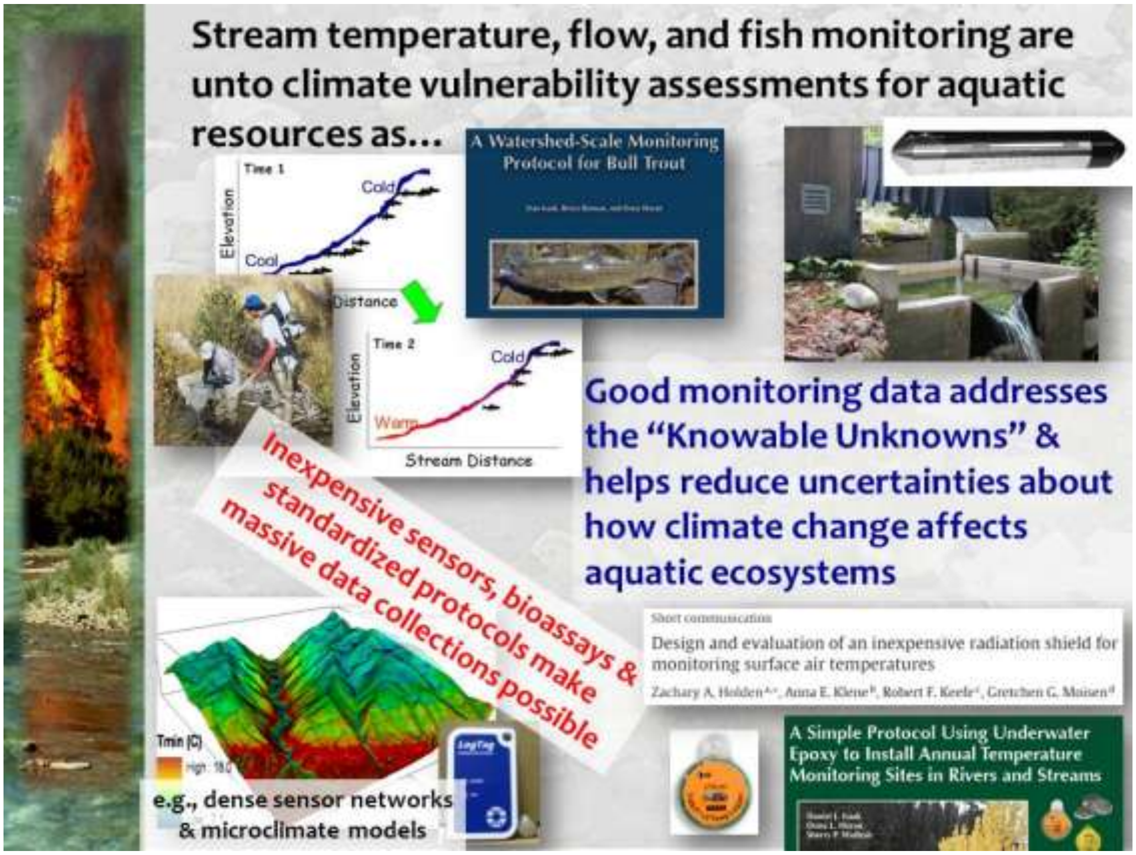


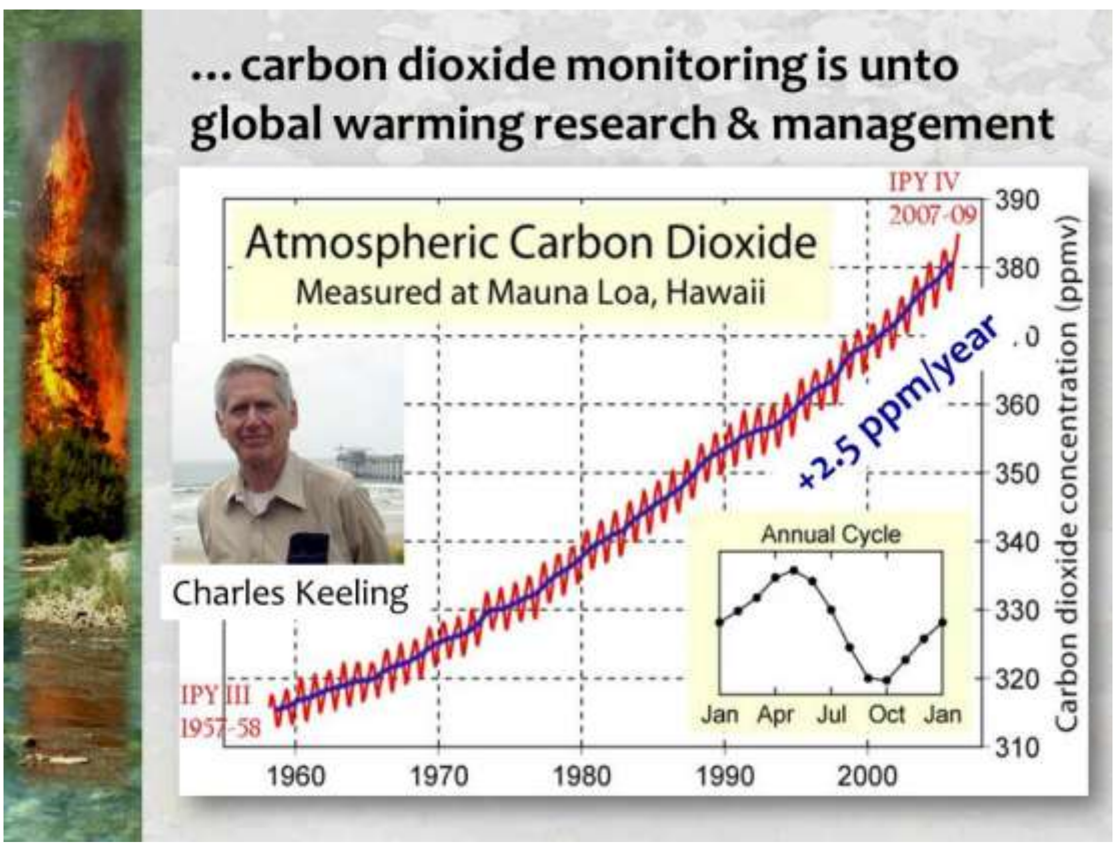


Aquatics Community can Reduce Overall Uncertainties Associated with Climate Change by Developing Better Information at Local & Network Scales… And Ensuring This Information is Linked Properly with Climate Models
Global climate
Regional climate
River network temps & flow
Local population thresholds & habitat suitability
Aquatics community needs to focus at these levels…

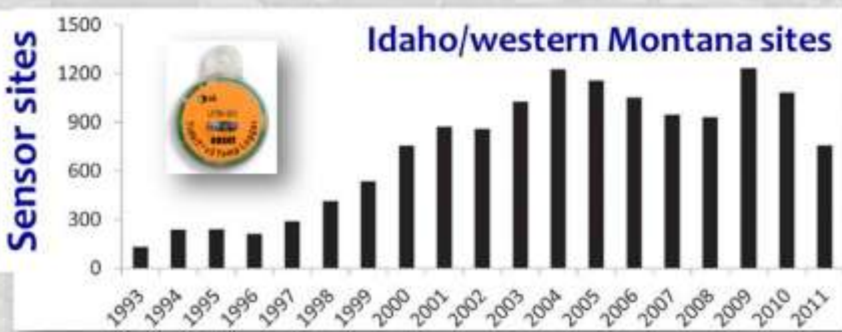


Accurate Meso-Scale Models Built From Aggregating Local Measurements & Linked to Regional Climate Models are Needed to Provide Information for Local Decision Makers
High-resolution network-scale models
Regional models are too coarse
I'm going to invest here…
… instead of here
Debris flow susceptible channel
Thermally suitable - occupied
Thermally suitable - unoccupied
Projected habitat loss
Road culvert fish barrier

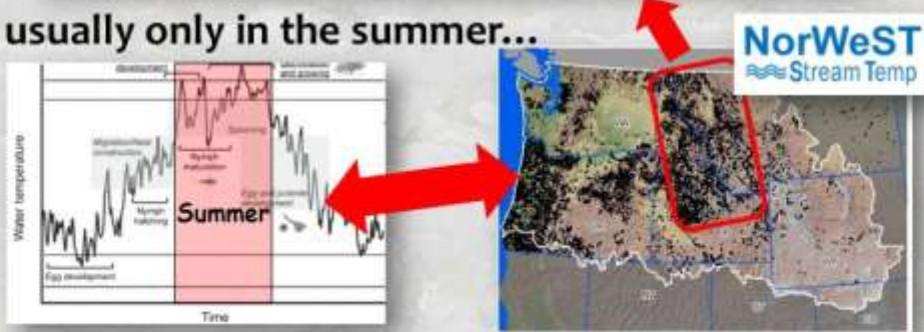

Stream temperature, flow, and fish monitoring are unto climate vulnerability assessments for aquatic resources as…
A Watershed-Scale Monitoring Protocol for Bull Trout
Time 1
Cold
Cool
Elevation
Distance
Time 2
Cold
Warm
Elevation
Stream Distance
Good monitoring data addresses the "Knowable Unknowns" & helps reduce uncertainties about how climate change affects aquatic ecosystems
Inexpensive sensors, bioassays & standardized protocols make massive data collections possible
Short communication
Design and evaluation of an inexpensive radiation shield for monitoring surface air temperatures
A Simple Protocol Using Underwater Epoxy to Install Annual Temperature Monitoring Sites in Rivers and Streams
Tmin (C)
e.g., dense sensor networks & microclimate models


… carbon dioxide monitoring is unto global warming research & management
Atmospheric Carbon Dioxide
Measured at Mauna Loa, Hawaii
IPY IV
2007-09
IPY III
1957-58
+2.5 ppm/year
Charles Keeling
Annual Cycle
Jan
Apr
Jul
Oct
Jan
390
380
360
350
340
330
320
310
Carbon dioxide concentration (ppmv)
1960
1970
1980
1990
2000

Stream Temperature: Many Sites Monitored, but…



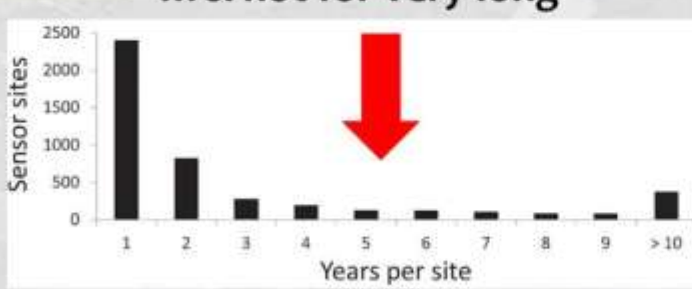
usually only in the summer…



Isaak et al. 2013. A simple protocol using underwater epoxy to install annual temperature monitoring sites in rivers and streams. USFS General Technical Report, 314.

Stream Temperature: Many Sites Monitored, but…

… & not for very long



Isaak et al. 2013. A simple protocol using underwater epoxy to install annual temperature monitoring sites in rivers and streams. USFS General Technical Report, 314.

Stream Flow: Few sites, but good long-term records

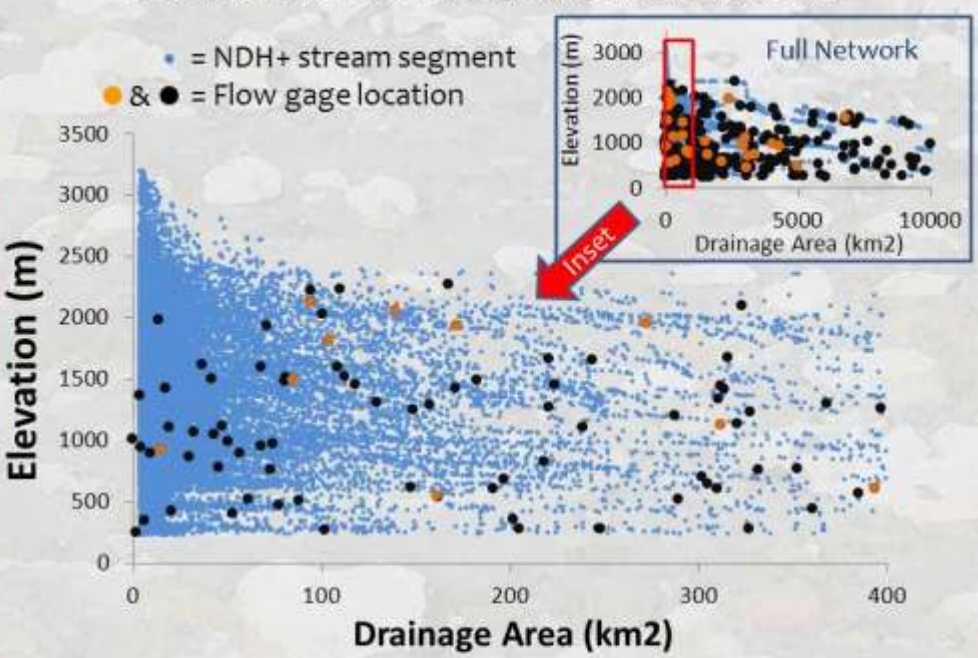
National USGS Stream Discharge Monitoring Network

Webtool for accessing USGS flow data:
http://wdr.water.usgs.gov/nwisgmap/

Database of USGS flow data that's already compiled:

Falcone et al. 2010. GAGES: A stream gage database for evaluating natural and altered flow conditions in the U.S. Ecology 91:621.

Stream Flow Monitoring vs. the Stream Network Universe



300,000+ stream kilometers comprise the drainage network across Montana and northern Idaho, yet only 400 gages actively monitor flows in the network.

New Sensors Could Expand Flow Monitoring Networks Cost-Effectively

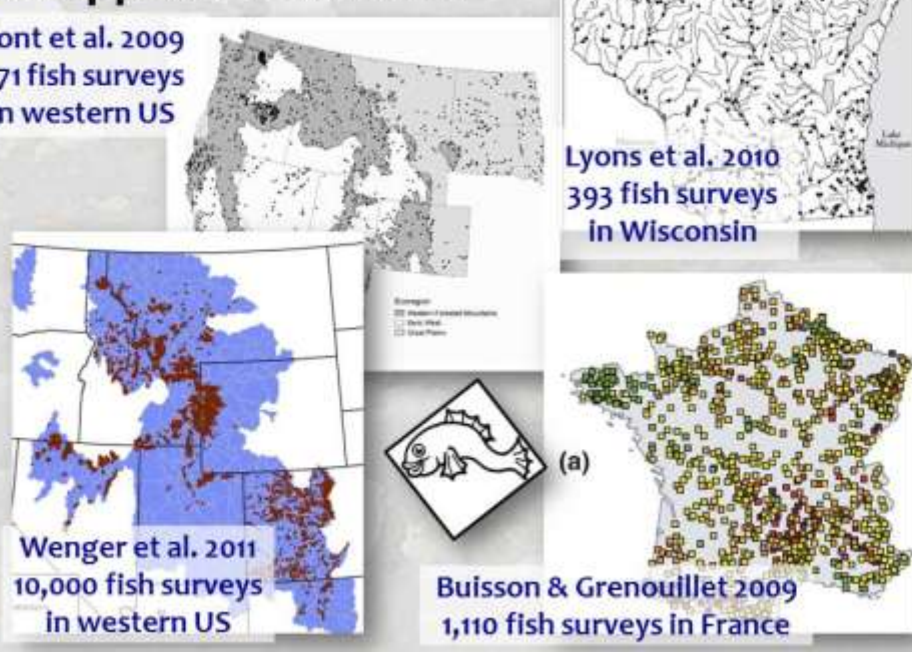
Traditional techniques
Useful, but also labor & capital intensive

Portable Doppler Velocimeter

Pressure Transducers

New techniques
Digital sensors facilitate accurate & inexpensive discharge measurements

Fish Survey Data is Abundant and Contains a Wealth of Untapped Information



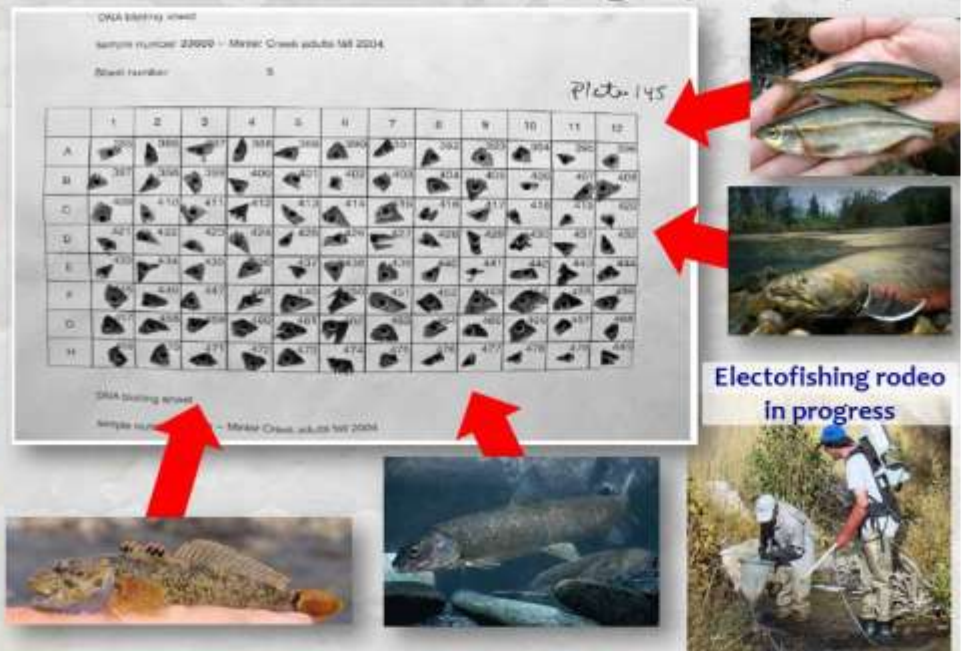
Pont et al. 2009
871 fish surveys in western US

Lyons et al. 2010
393 fish surveys in Wisconsin

Wenger et al. 2011
10,000 fish surveys in western US

Buisson & Grenouillet 2009
1,110 fish surveys in France

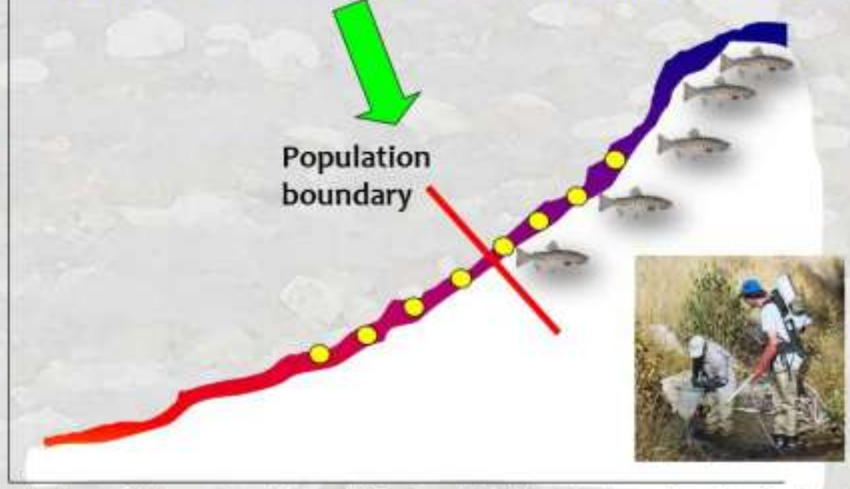
Fin Tissue Samples Conveniently Preserved on Chromatography Paper



LaHood et al. 2008. *Trans. American Fisheries Society* 137:1104-1107.

Sampling Could be Designed to Directly Measure the Edge of Species Distributions

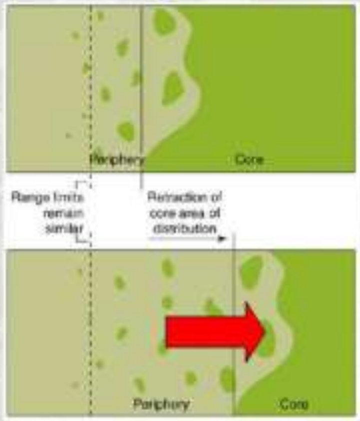
Species occurrence data collected along a temperature gradient that exceeds a species' thermal suitability range



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.

Species Distributions are Shifting

Spatial distribution shifts



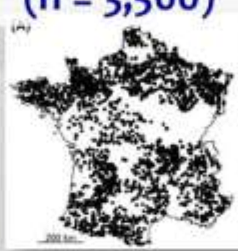
Average global rate of <u>distribution shift across taxa =</u> 6.1 km/decade poleward OR 6.1 m/decade higher

Parmesan and Yohe. 2003. *Nature* 421:37-42.

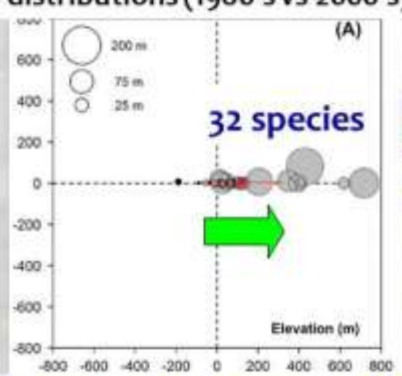
National Fish Resurveys Study Show Broad Distribution Shifts in Stream Fishes

French Fish Communities

Survey sites (n = 3,500)



Difference in stream fish distributions (1980's vs 2000's)

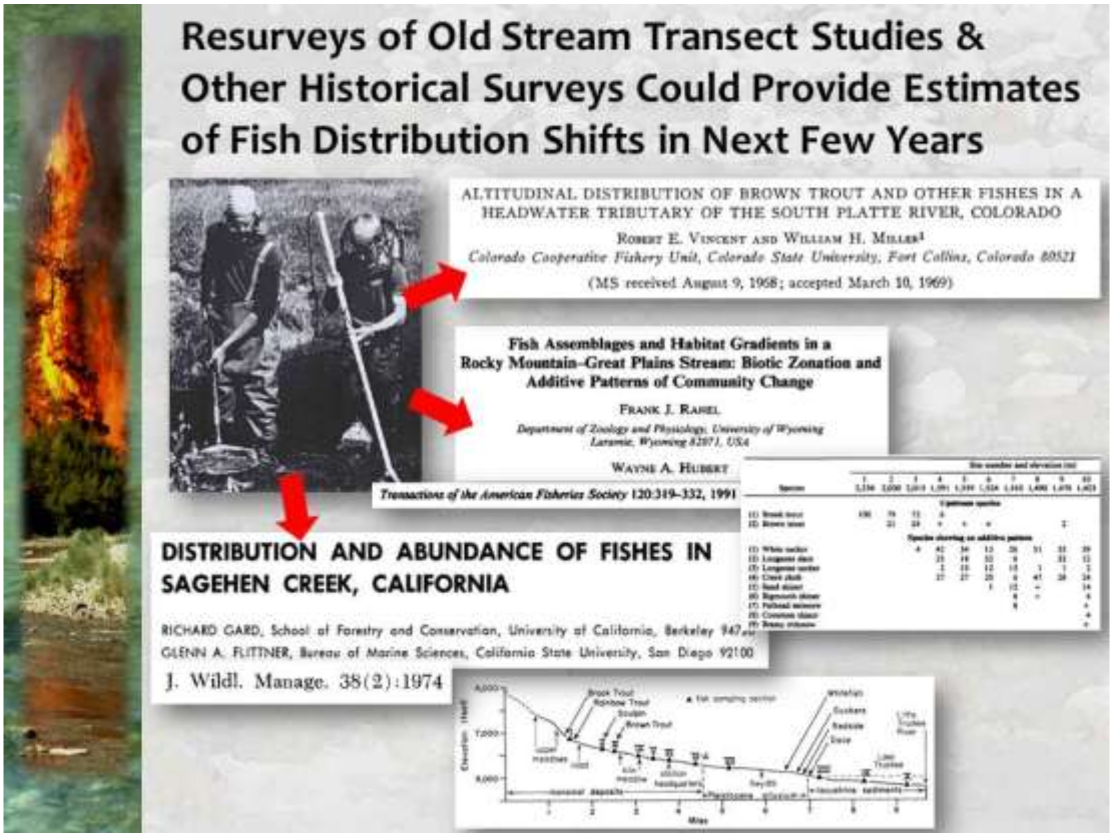


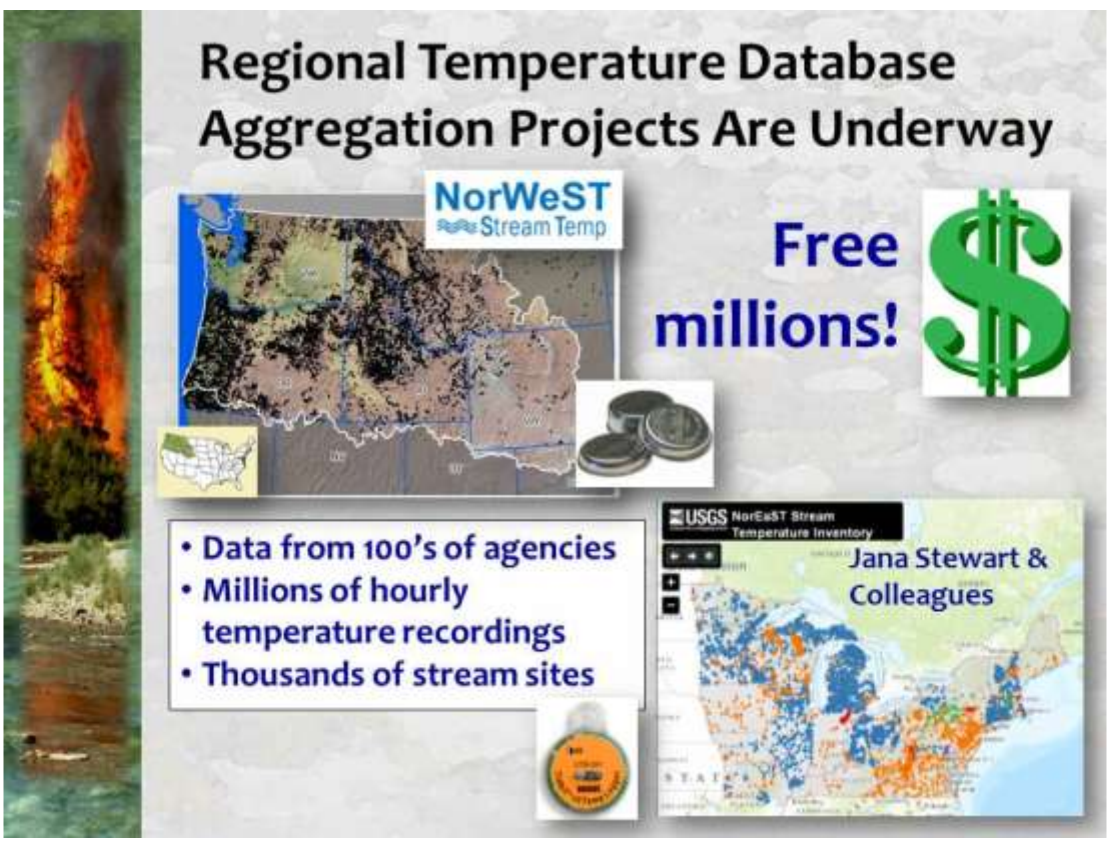
32 species

Change in Elevation (m)

March of the fishes...

Comte & Grenouillet. 2013. Do stream fish track climate change? Assessing distribution shifts in recent decades. *Ecography* doi: 10.1111/j.1600-0587.2013.00282.x

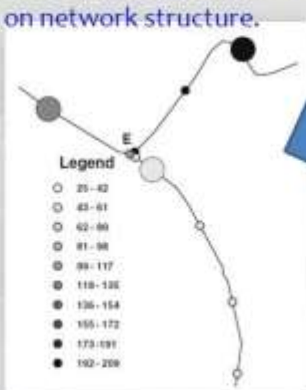

Resurveys of Old Stream Transect Studies & Other Historical Surveys Could Provide Estimates of Fish Distribution Shifts in Next Few Years
ALTITUDINAL DISTRIBUTION OF BROWN TROUT AND OTHER FISHES IN A HEADWATER TRIBUTARY OF THE SOUTH PLATTE RIVER, COLORADO
Robert E. Vincent and William H. Miller
Colorado Cooperative Fishery Unit, Colorado State University, Fort Collins, Colorado 80521
(MS received August 9, 1968; accepted March 10, 1969)
Fish Assemblages and Habitat Gradients in a Rocky Mountain–Great Plains Stream: Biotic Zonation and Additive Patterns of Community Change
Frank J. Rahel
Department of Zoology and Physiology, University of Wyoming Laramie, Wyoming 82071, USA
Wayne A. Hubert
Transactions of the American Fisheries Society 120:319–332, 1991
DISTRIBUTION AND ABUNDANCE OF FISHES IN SAGEHEN CREEK, CALIFORNIA
RICHARD GARD, School of Forestry and Conservation, University of California, Berkeley 947
GLENN A. FLITTNER, Bureau of Marine Sciences, California State University, San Diego 92100
J. Wildl. Manage. 38(2):1974

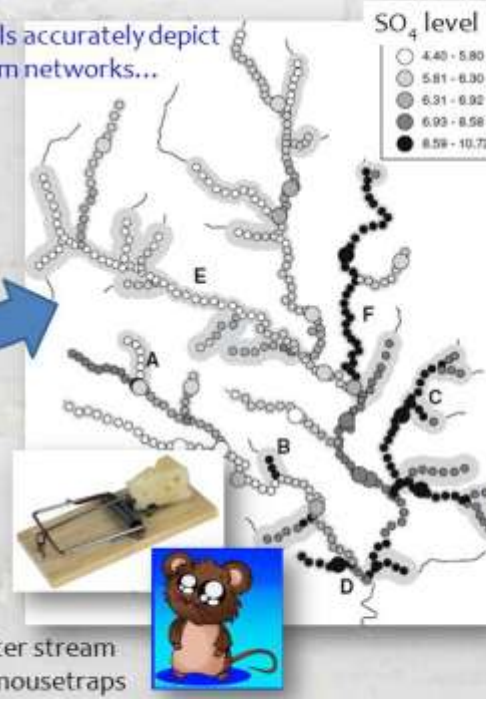

Regional Temperature Database Aggregation Projects Are Underway
NorWeST
Stream Temp
Free millions!
• Data from 100's of agencies
• Millions of hourly temperature recordings
• Thousands of stream sites
USGS NorEaST Stream Temperature Inventory
Jana Stewart & Colleagues

Spatial Statistical Network Models Can Develop Unbiased Information from Aggregated Databases & Work Better Than Traditional Statistical Techniques Applied to Stream Data

Spatial network models accurately depict gradients within stream networks…

… & account for abrupt changes at tributary confluences because of covariance structures based on network structure.



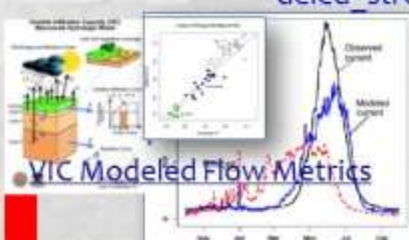


SSNMs are significantly better stream mousetraps than previous mousetraps

Stream Flow & Temperature Scenarios are Needed for Full River Networks

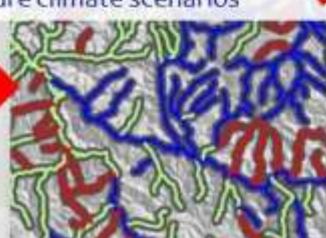
e.g., Western U.S. Flow Metrics Scenarios

Website: http://www.fs.fed.us/rm/boise/AWAE/projects/modeled_stream_flow_metrics.shtml



VIC Modeled Flow Metrics

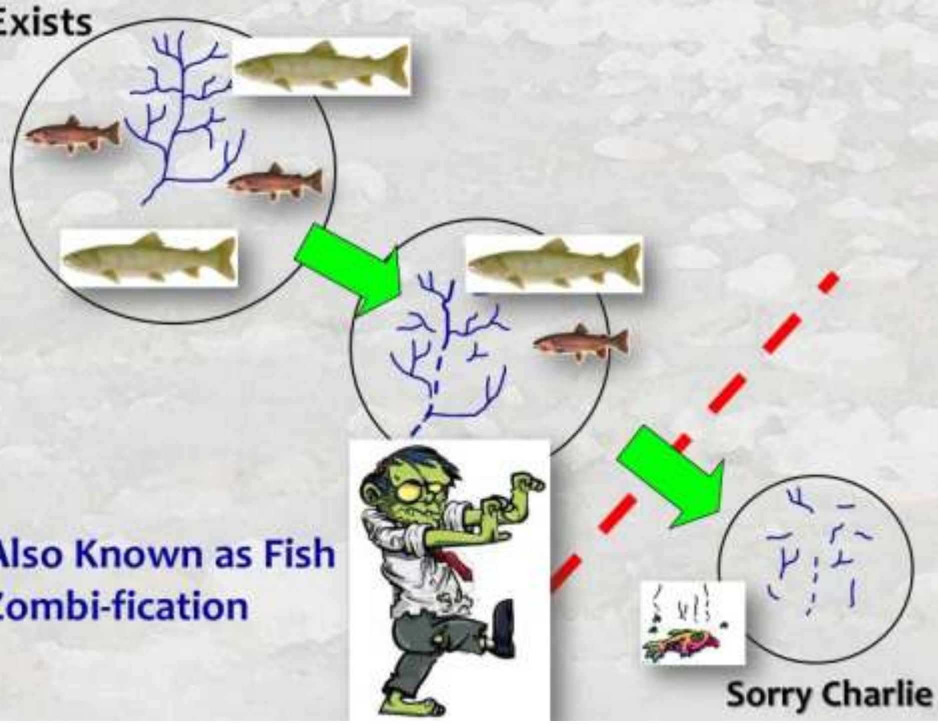
… are available for all NHD+ stream segments & historic or future climate scenarios



… across the western U.S.

to make apples-to-apples comparisons and climate assessments possible.

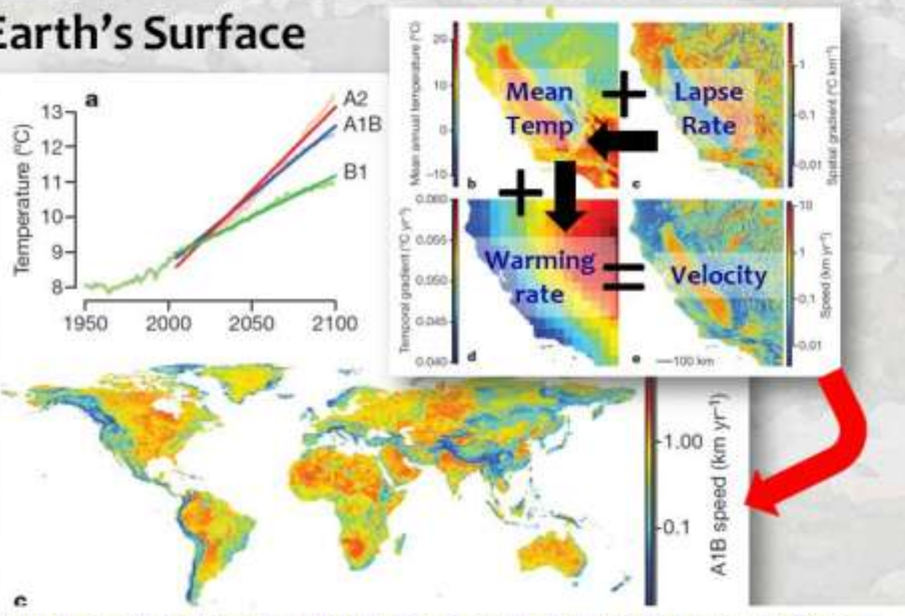
Habitat Thresholds Beyond Which Populations Become "Walking Dead" & an Extinction Debt Exists



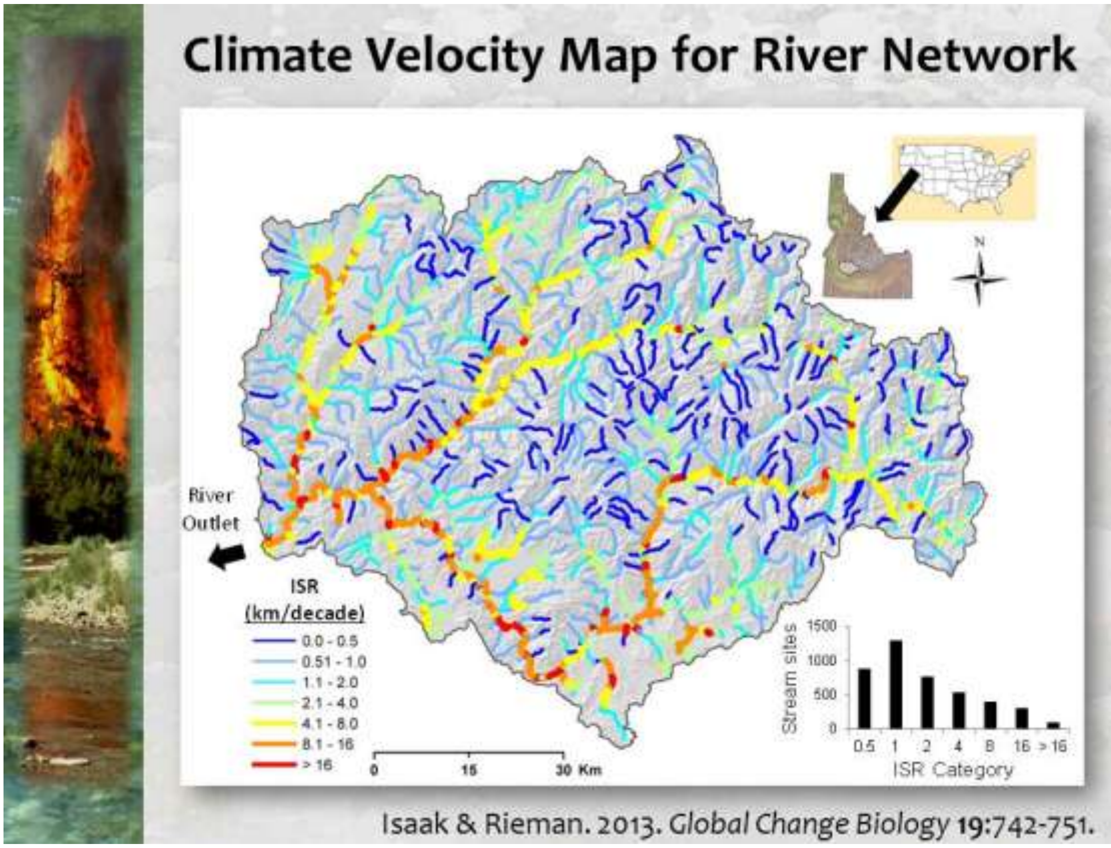
Also Known as Fish Zombi-fication

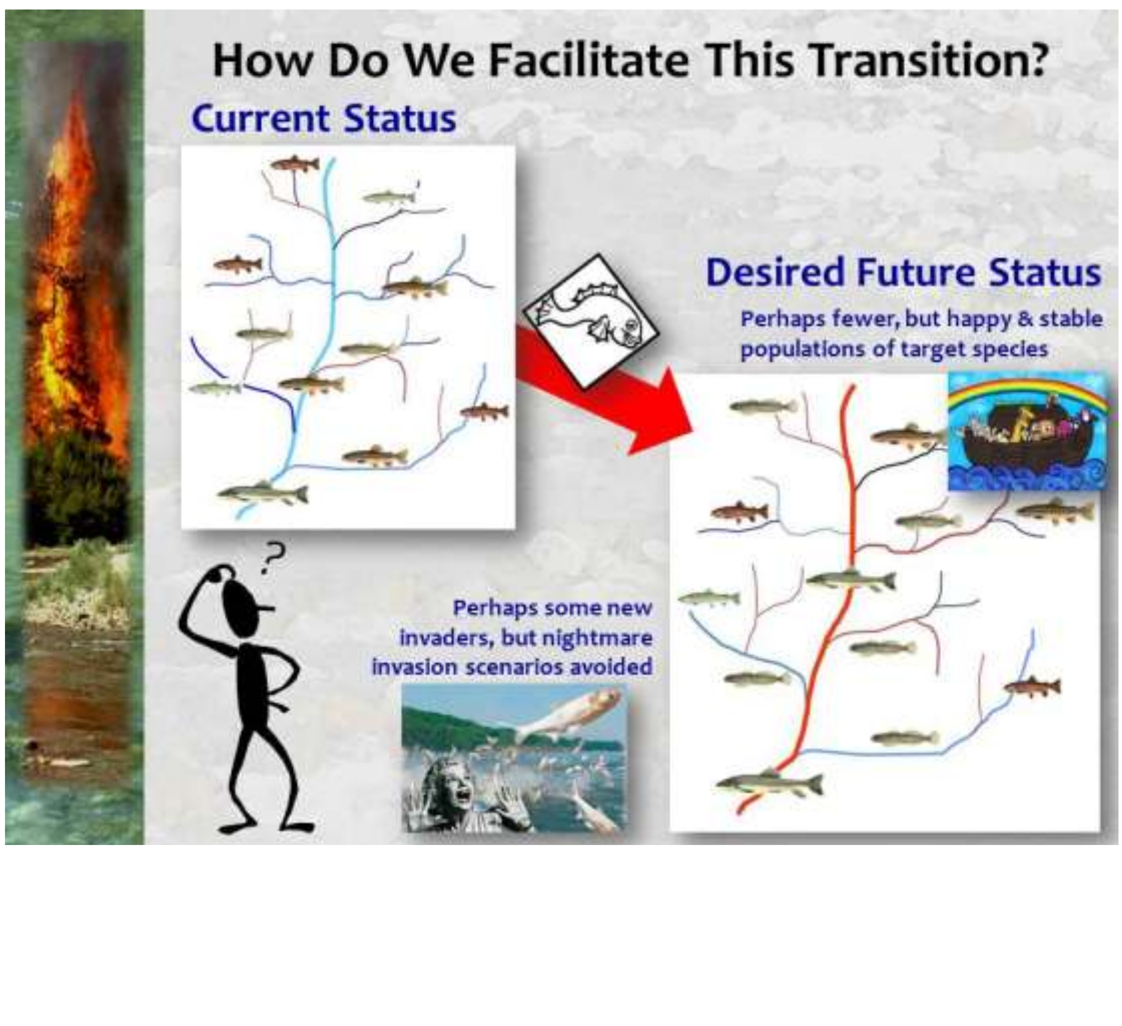
Sorry Charlie

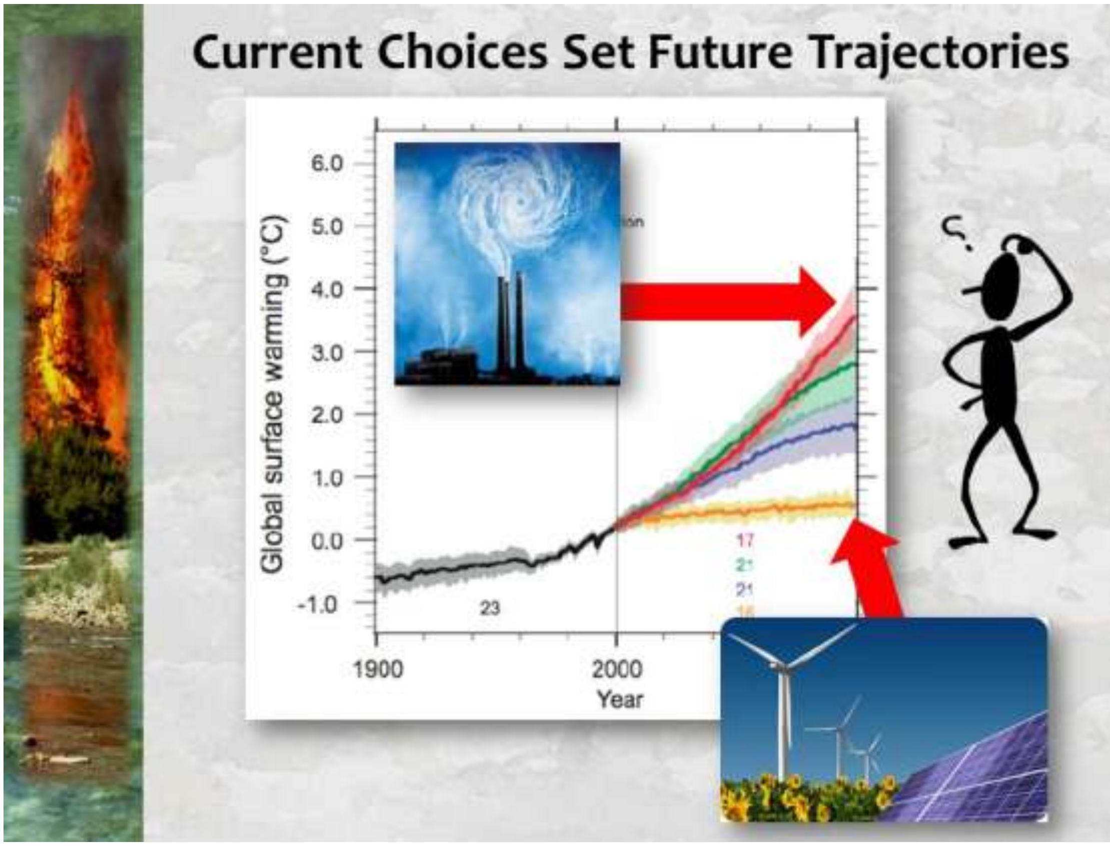
The "Velocity" of Climate Change is the Rate at Which Isotherms Shift Across the Earth's Surface

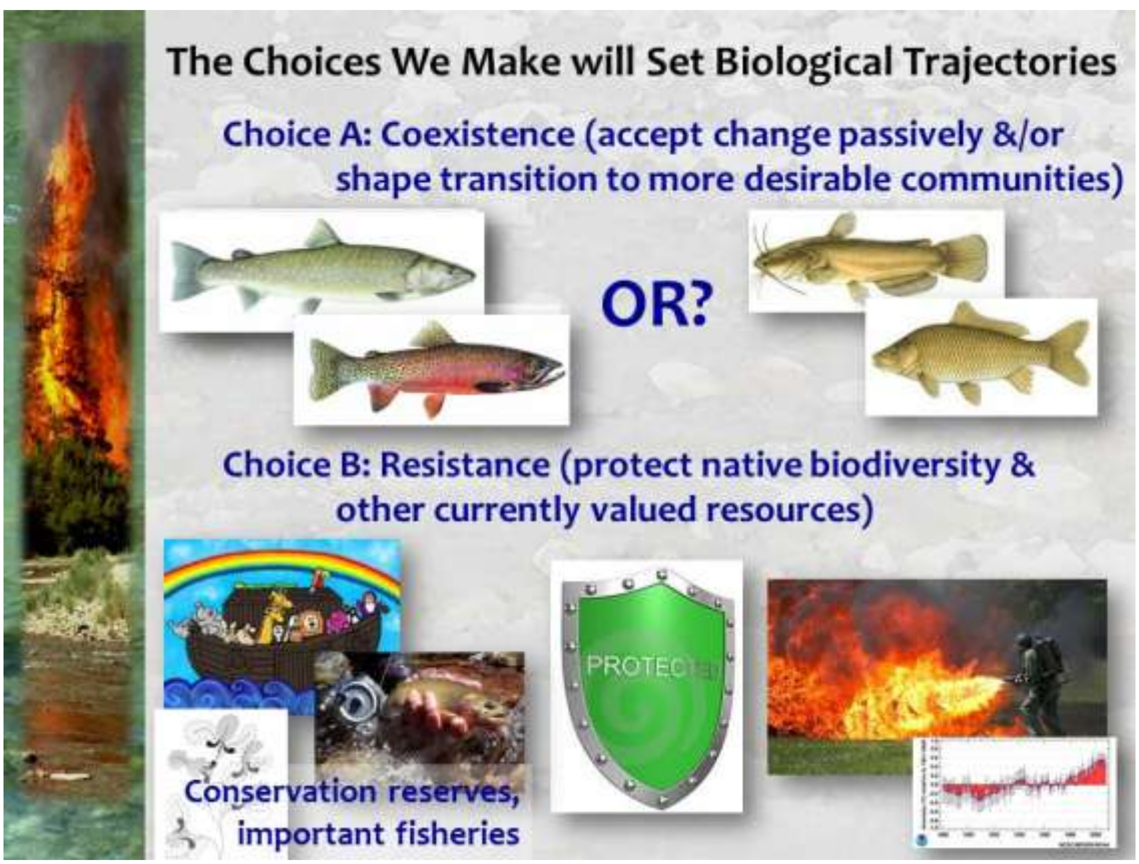


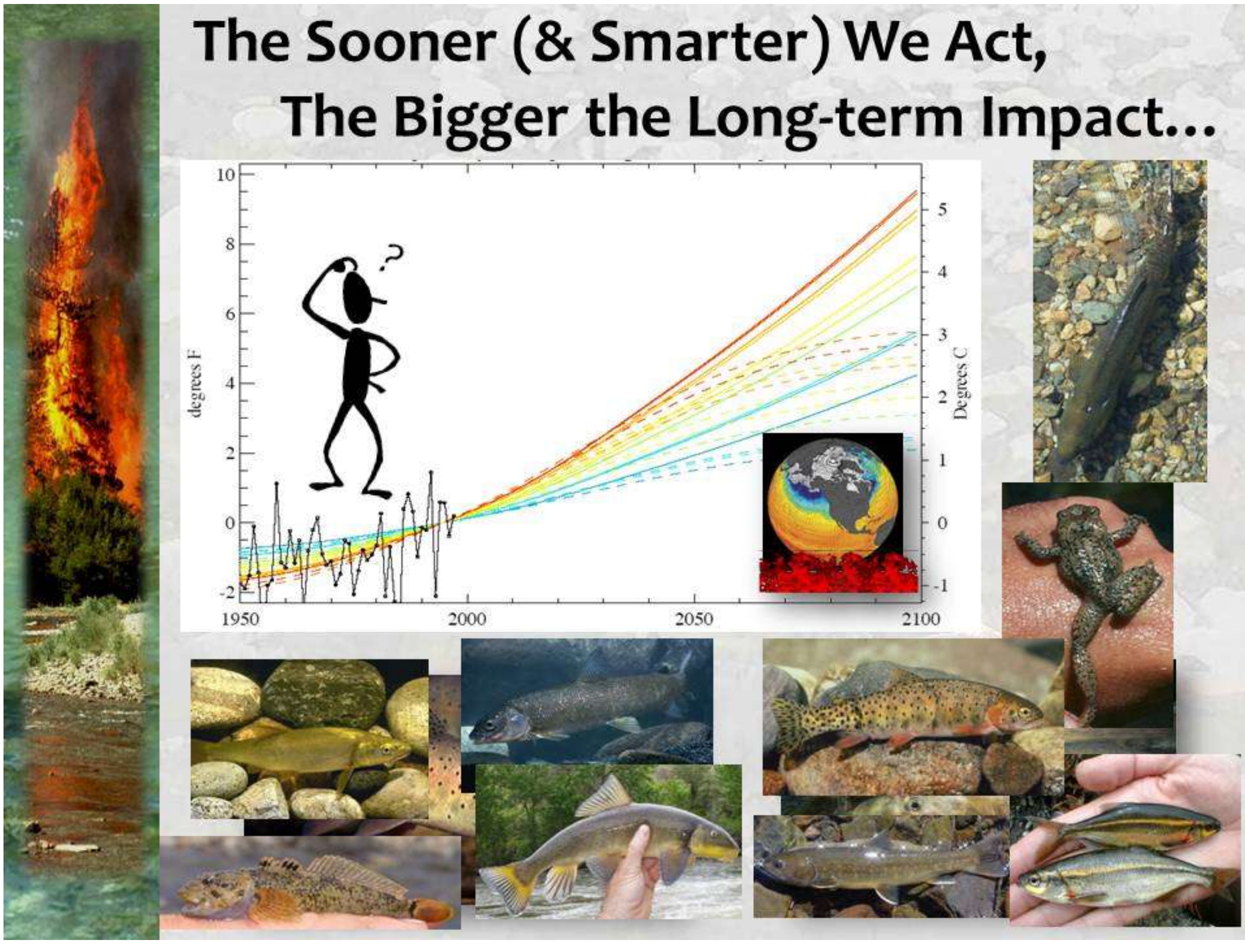
Thermally mediated species distribution boundaries need to move as fast as climate velocity to track climate change. Climate velocities are fast in flat areas and slow in steep areas. Loarie et al. 2009. *Nature* **462**:1052-1055.


Climate Velocity Map for River Network
River Outlet
ISR (km/decade)
0.0 - 0.5
0.51 - 1.0
1.1 - 2.0
2.1 - 4.0
4.1 - 8.0
8.1 - 16
> 16
0
15
30 Km
N
Stream sites
1500
1000
500
0
0.5 1 2 4 8 16 > 16
ISR Category
Isaak & Rieman. 2013. Global Change Biology 19:742-751.


How Do We Facilitate This Transition?
Current Status
Desired Future Status
Perhaps fewer, but happy & stable populations of target species
Perhaps some new invaders, but nightmare invasion scenarios avoided


Current Choices Set Future Trajectories
Global surface warming (°C)
6.0
5.0
4.0
3.0
2.0
1.0
0.0
-1.0
1900
2000
Year
23
17
21
21


The Choices We Make will Set Biological Trajectories
Choice A: Coexistence (accept change passively &/or shape transition to more desirable communities)
OR?
Choice B: Resistance (protect native biodiversity & other currently valued resources)
PROTECTED
Conservation reserves, important fisheries



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 6,151 (& 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 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

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
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 #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

Future topics…

Climate-Aquatics Management Module

Climate-Aquatics End Game