Climate-Aquatics Blog #51:
Part 10, Mechanisms of change in fish populations: Extinction

It all begins with fish zombi-fication…

Hi Everyone,
It is often said that species have three options when dealing with climate change: move, adapt, or die. In the previous 9 blogs of this module, we've covered the science related to how those first two options may happen. But it's not realistic to think that there won't be some casualties from climate change as we progress through this century. Sometimes the habitat in an area will change so much that it's simply not habitat anymore or so fast that a critter's dispersal abilities can't match the velocity at which those habitats shift away from them (Blog #36). At other times, the changes wrought by climate change may facilitate invasions by alien invaders, or we inadvertently release these species into areas where they systematically outcompete the natives (Blog #49). When that happens, a fish-zombification process has occurred and our local native fish population has become a sort of walking dead. There's an extinction debt to be paid and the reaper will come. It's just a matter of time, & manner, by which he appears.

It has also often been said that we're living through the world's 6th great extinction event. The previous 5 being due to various natural calamities like super volcanoes, meteors impacting Earth, etc. The current extinction event, however, is caused by humans eating our way through the tree of life—either quite literally as we dispersed out of Africa over the last 50,000 years and consumed goodly numbers of megafaunas along the way; or figuratively, as our population has exploded the last two centuries and increasing development and consumption monopolize larger & larger shares of the Earth's resources. And we can see fish twigs being trimmed from the tree of life here during contemporary times. A recent review paper by Burkhead (Hyperlinked here: http://fl.biology.usgs.gov/pdf/Burkhead_2012_Extinction_rates_in_North_American_fishes.pdf) summarizes losses from the North American ichthyofauna over the last century (graphic 1). Rather sobering to note that that trend may be increasing & that the global rate of fish extirpations is estimated to be 200 times faster than the natural background rate. Moreover, fish extinctions are occurring 2x faster than those in other vertebrate taxa.

That's not good, but what role, if any, does climate change play in those numbers? Has anyone actually observed & documented the final outcome of the climate-fish-zombification process? Not really. The closest anyone's come at present is work like the study by Durance & Ormerod (attached) wherein they describe the loss of a cold-water planarian species (*Crenobia alpina*) from the headwaters of Welsh streams in recent decades (graphic 2). There, a series of poor climate years associated with a regional climate cycle (Blog #12) led to significant reductions in food resources. When coupled to competition with a closely related species, the two factors were too much for the cold-water populations and they disappeared from the study streams. The other planarian species has persisted and rebounded with the return to prior climatic conditions, but our cold-water friend has not reappeared.

It's a great study, made possible through dedicated long-term monitoring efforts, but it serves mainly to illustrate how the climate change endgame *might* look for a population because the extirpations were triggered by a climate cycle rather than a trend. Moreover, what does food and competition have to do with it? Where were the heat-waves and droughts and poor planarians perishing before our eyes?

Hmmm…zombies are messy creatures, so maybe this process of climate zombification is messy as well, with a more diverse set of contributing factors than we'd first guess? To get a better sense of those factors we'll have to cast our taxonomic net more broadly than planarians (or fish for that matter), which is what Cahill & colleagues have done (Hyperlinked here: http://www.wienslab.com/Publications_files/Cahill_et_al_2013_PRSL.pdf). The authors reviewed the global literature to ferret out the best case histories linking climate-change to population extirpations. They found 136 case histories related to this topic but only 7 of those demonstrated clear linkages to climate. And within those 7, there was a diverse array of proximate causes—the spread of pathogens, food reductions, loss of microhabitats, loss of symbiotes, dessication stress, extreme temperatures—that were cited as pushing populations over the brink (graphic 3). In most cases, too, there were interactions among multiple factors so clear attribution was difficult.

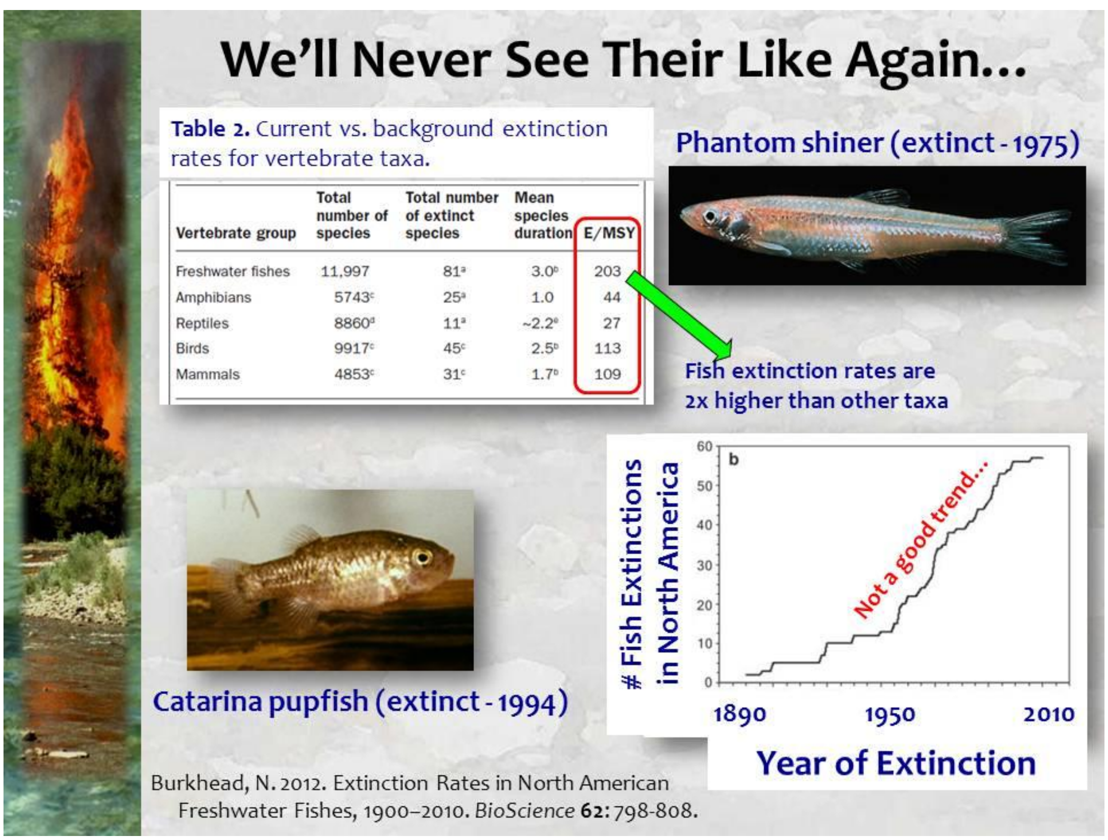
Messy indeed, but even with a tiny sample size of 7, it starts to give a sense of how complex the process of extinction is likely to be. In the mountain trout populations that I'm most familiar with an extirpation scenario would be equally messy (graphic 4). For example, many trout populations are already confined to the coldest headwater habitats by longterm, historic climate patterns & modern climate change is predicted to push them further upstream. A variety of non-native trouts & other species are abundant in warmer waters at lower elevations and these will push harder upstream to intensify competitive interactions. Longterm climate trends of decreasing summer flows reduce the volume of habitat in the headwater refuges, shrinking populations further. And finally, some stochastic environmental event like a wildfire, flood, or regional drought happens to deliver the population death blow.

In that scenario, was it temperature or an invasive species, or a disturbance that caused the extinction? You could say it was all of them, or none of them, and be equally right. And at least from a conservation/management perspective, I don't think we necessarily have to know the details regarding a population's final days to be effective. More important to understand the set of conditions that predisposes a population toward zombi-fication, so that we can minimize the number of zombies. There are, of course, many such conditions but probably the single most important is the size of a habitat and its population. Bigger habitats and populations can simply absorb more punishment and environmental variation than smaller ones, so will be less susceptible to climate related factors that increase population risks this century (Graphic 5).

So that's easy then right? All we have to do is keep populations from getting small! But much easier said than done because it's where human society's voracious appetite comes into play. If we can trim our diet in smart ways, however, & maybe do some proactive things in the smartest places, it could be instrumental to minimizing extirpation risks & preserving the maximum amount of native biodiversity through this transitional century. In the Climate-Aquatics Management blog module that we're about to begin, we'll explore those things and dietary options in more detail (funny, I thought the zombies were trying to eat us?). But next time out I wanted to summarize the road thus far traveled since we've been on it now for almost 3 years. Much has been learned in that time to advance our understanding regarding how climate change affects aquatic systems, but key questions remain yet to be resolved & I'll attempt to highlight what we do, don't, & need to know before blogging on.

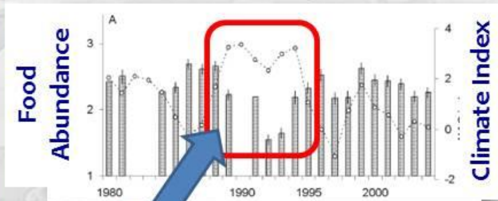
Until next time, best regards,
Dan

Now Tweeting at [Dan Isaak@DanIsaak]

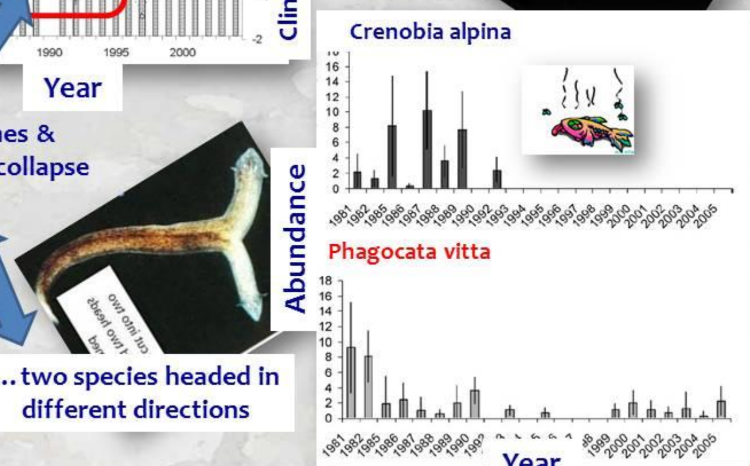


Vertebrate group	Total number of species	Total number of extinct species	Mean species duration	E/MSY
Freshwater fishes	11,997	81[a]	3.0[b]	203
Amphibians	5743[c]	25[a]	1.0	44
Reptiles	8860[d]	11[a]	~2.2[e]	27
Birds	9917[c]	45[c]	2.5[b]	113
Mammals	4853[c]	31[c]	1.7[b]	109

Case History Describes Climate-Related Loss of Planarian Species from Welsh Streams



Climate extremes & food resource collapse translates to…



… two species headed in different directions

Durance & Ormerod. 2010. Evidence for the role of climate in the local extinction of a cool-water triclad. *Journal of the North American Benthological Society* **29**: 1367-1378.

How Does Climate Change Cause Extinctions?

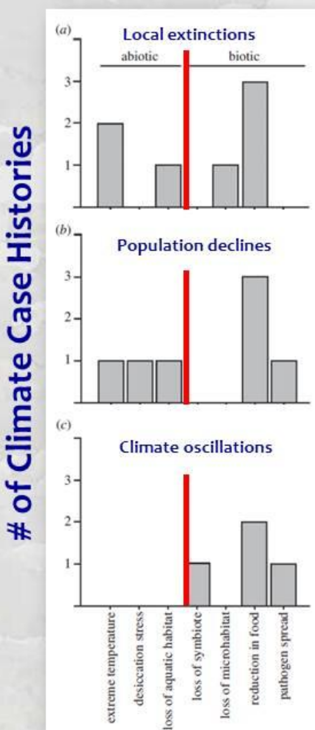


Table 1. Studies documenting the proximate causes of local extinction due to climatic change.

species	location	hypothesized proximate cause of local extinction
American pika (*Ochotona princeps*)	Great Basin region, USA	limited tolerance to temperature extremes (both high and low)
planarian (*Crenobia alpina*)	Wales, UK	loss of prey as result of increasing stream temperatures
desert bighorn sheep (*Ovis canadensis*)	California, USA	decrease in precipitation leading to altered plant community (food)
checkerspot butterfly (*Euphydryas editha bayensis*)	San Francisco Bay area, CA, USA	increase in variability of precipitation corresponding with reduction of temporal overlap between larvae and host plants
fish (*Gobiodon* sp. A)	New Britain, Papua New Guinea	destruction of obligate coral habitat due to coral bleaching caused by increasing water temperatures
48 lizard species (genus *Sceloporus*)	Mexico	increased maximum air temperature approaches physiological limit, seemingly causing decreased surface activity during the reproductive season
Adrar Mountain fish species	Mauritania	loss of water bodies due to drought

7 case histories is a small sample, but a disturbing number of these (3 of 7) are aquatic species. Hopefully that's not a trend within this trend…

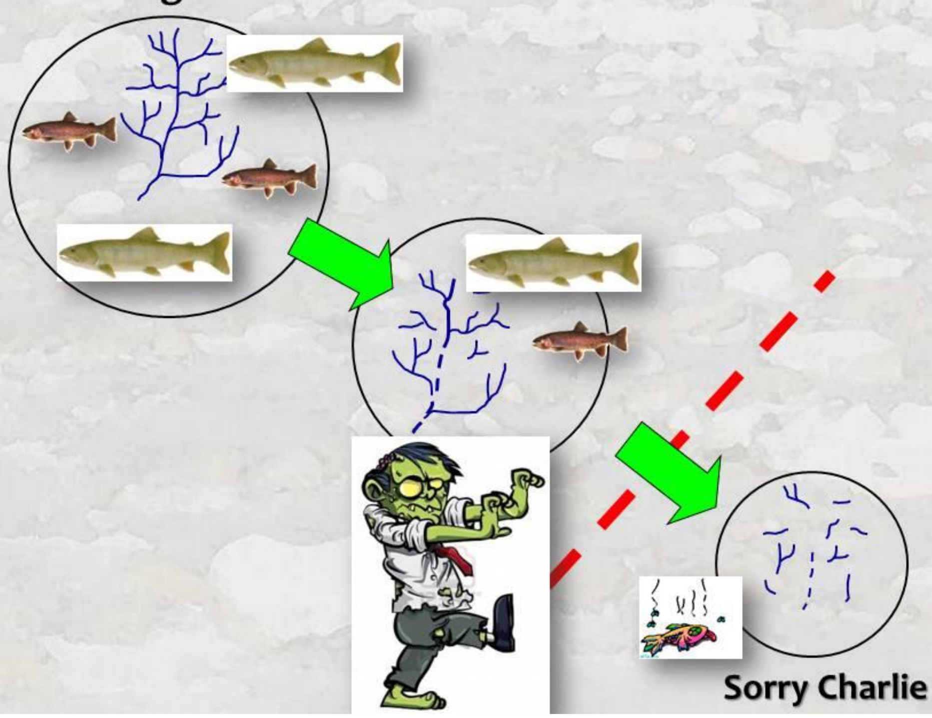
Cahill et al. 2013. How does climate change cause extinction? *Proceedings of the Royal Society B: Biological Sciences* **280**(1750).

Hypothesized Extirpation Scenario for Headwater Trout Population in a Mountain Stream

1) Warming temperatures reduce downstream habitat & isolate population in headwaters
2) Presence of non-native invader exacerbates population constriction
3) Decreasing summer flows reduce the amount of upstream habitat
4) Stochastic "event" like wildfire & debris flow, winter floods, or regional drought extirpates population

The Mountain Trout Vise

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



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

Future topics…
Climate-Aquatics Management Module

Climate-Aquatics End Game