Climate-Aquatics Blog #72: The eDNA revolution & developing comprehensive aquatic biodiversity archives

Measuring & understanding the effects of climate change on aquatic life requires an accurate baseline status assessment that can serve as a benchmark for comparisons through time. But even where streams and lakes are heavily studied, those baselines typically exist only for the few large charismatic species we like to eat or play with by tethering ourselves to them via narrow strands of monofilament. We know very little that is very specific about where most aquatic species live, and even for those we think we know well, genetic techniques like DNA barcoding are sometimes revealing layers of unappreciated cryptic biodiversity and entirely new species (blog 53 and examples shown here by Hebert & colleagues). Sure, when we're forced to we can draw crude polygons on maps and say that that's the range of species x, y, or z (graphic 1). But that isn't nearly precise enough to be useful in meaningful conservation planning or strategic investing because it doesn't resolve the locations of individual populations or provide information at scales commensurate with those at which human activities alter landscapes. And because so much of conservation comes down fundamentally to choices about where to make investments, we need that granular level of biological information feeding into our decision making process. Compounding matters exponentially, we need high-resolution information for all species if we want to be serious about the biodiversity thing and not just give it lip service.

That's a fantastically tall order to fill so hasn't really been worth contemplating seriously until just the last few years. But with the revolution now being wrought by environmental DNA (eDNA) that vision is rapidly becoming a transforming reality. Most, by now, have heard about this seemingly magical new technology, but for those who haven't, it is possible to detect fragments of DNA that have been shed from their parent organisms and to use that information in reliable determination of species locations. eDNA technology is especially powerful in aquatic environments where simple water samples can be taken from streams, lakes, or wetlands and analyzed to determine what lives there. Collecting eDNA samples in the field requires only inexpensive equipment and a small water pump that fits easily into a daypack. Costs to collect and process lab samples are already much lower than traditional sampling techniques and will continue to fall as the technology matures. Moreover, first generation eDNA technologies limited analyses to single species determinations, but next generation technologies are already becoming available to do multispecies assessments simultaneously. And not all the DNA contained in samples are destroyed during an analysis so what's left over simply goes in the freezer where it can sit indefinitely to serve as a biodiversity archive for later queries if the need arises. Combine it all, and it's possible not just to contemplate, but to begin actuating, geographically broad sampling campaigns designed to map all of aquatic critter-dom at the resolutions needed for conservation and management.

For a thorough recent review about aquatic eDNA applications, Thomsen & colleagues provide a good place to start (study hyperlinked here: https://www.researchgate.net/profile/Philip_Thomsen). But for those wishing a full aquatic eDNA immersion, the bibliography below hyperlinks to 79 recent studies, of which only 1 was published prior to 2011. And before you literally wade out to start collecting eDNA, here are a few basic pointers to help minimize any missteps (but please consult the real experts and expertise of those cited in the bibliography rather than relying overly much on the simplifications of this blogger).

1) First, a species-specific eDNA marker has to be developed before you can use the technology to determine the presence/absence of a target species. But new markers are being developed for more species by various labs all the time so the odds that a marker already exists for a species of interest are continually increasing. AFS, AFWA, and USFS maintain this eDNA clearinghouse website to make it easy to see what's out there and to know who to contact: http://edna.fisheries.org/
2) If an eDNA marker doesn't exist, it costs about $5k to develop one. But you (or someone) need to collect tissues from the target organism across a representative portion of its range (a great excuse for those electrofishing rodeos blog 30!) and send them to the lab vendor for marker development.
3) Once a marker exists, you can start collecting eDNA samples and sending them to the lab for processing. The field sampling protocols for aquatic eDNA collection are straightforward and several are listed in the bibliography below. Consult with your lab vendor as they will have a preferred protocol.
4) Depending on the species, the detection efficiency of eDNA may or may not be well understood. If it's not well understood, you don't want to run around collecting samples willy-nilly until you've conducted field trials to determine detection rates under field conditions. Otherwise, it's impossible to determine what negative readings mean. It may be because the organism wasn't there that day, or because it wasn't close enough to where the sample was taken to put a detectable amount of DNA into the water. For some well-studied organisms, those detection efficiencies have been estimate (see studies below), but for most species they have not been. The general expectation, however, is

that eDNA will usually have higher detection efficiencies (often much higher) than traditional sampling techniques.

5) Finally, eDNA is a new and sexy way to collect species occurrence data but it will yield valuable information in direct proportion to the quality of questions driving its application. As with any sampling technique, those questions are the foundation upon which logical sampling strategies are designed to determine where in space & time samples are collected. So don't forget the basics!

As in any revolution, there will be abuses, overreaches, and unfulfilled promises, especially during these initial years as eDNA technology is being deployed and learned. But that will be worked through and those bits of DNA shrapnel floating through waterways around us will transform the way we do business and how we think about biology as surely as electricity brought day to night, the industrial revolution started warming the climate, and the internet and digital rivers of information now connect us. We'll ultimately find that eDNA gives us a really big hammer and reveals a world full of nails. I suspect that the quality and quantity of information built by the aquatics army with that hammer will be remarkable when we look back on it someday. And because it's so easy and inexpensive to collect eDNA samples, it presents a huge crowd-sourcing opportunity (blog 71) that can be used to engage school kids, anglers, grandpas, or your local congresswoman in discovering the joy of mucking around aqueous environments & uncovering underappreciated parts of nature. Before we know it, we will have constructed an accurate assessment of all aquatic critters everywhere and will have finished the maps started by the likes of Lewis & Clark, Jordan, and Evermann during the great geographical & fish expeditions of the 1800s (graphic 2). Those maps are the keys to designing comprehensive conservation strategies that allow us decide how to invest most cost effectively this century. Not surprisingly, we will be subject to a deluge of new data as this all unfolds and infrastructures capable of handling it will be needed—a topic that will be pondered next time in the pen-penultimate Climate-Aquatics blog.

Until then, best regards. Dan

Tweeting at Dan Isaak@DanIsaak

eDNA Bibliography (current as of yesterday, today there are probably 5 new studies…)

Barnes et al. 2014. Environmental conditions influence eDNA persistence in aquatic systems. *Environmental science & technology* **48**: 1819-1827. https://www.researchgate.net/profile/Matthew_Barnes8

Barnes & Turner. 2015. The ecology of environmental DNA and implications for conservation genetics. *Conservation Genetics* doi:10.1007/s10592-015-0775-4 http://link.springer.com/article/10.1007/s10592-015-0775-4

Biggs et al. 2015. Using eDNA to develop a national citizen science-based monitoring programme for the great crested newt (*Triturus cristatus*). Biological Conservation **183**: DOI: 10.1016/j.biocon.2014.11.029. https://www.researchgate.net/profile/Alice_Valentini

Bohmann et al. 2014. Environmental DNA for wildlife biology and biodiversity monitoring. *Trends in Ecology and Evolution* **29**:358-367. http://www.sciencedirect.com/science/article/pii/S016953471400086X

Carim et al. 2015. Protocol for collecting eDNA samples from streams [Version 2.1]. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Boise Aquatic Sciences Lab. 10 p. http://www.treesearch.fs.fed.us/pubs/48132

Collins et al. 2013. Something in the water: biosecurity monitoring of ornamental fish imports using environmental DNA. *Biological Invasions* **15**:1209–1215. http://link.springer.com/article/10.1007/s10530-012-0376-9

Darling et al. 2011. From molecules to management: adopting DNA-based methods for monitoring biological invasions in aquatic environments. *Environmental Research* **111**:978–988. http://www.invasivespecies.gov/global/ISAC/ISAC_Minutes/2011/PDF/Darling_Mahon_Article.pdf

Davy et al. 2015. Development and Validation of Environmental DNA (eDNA) Markers for Detection of Freshwater Turtles. *PLoS One* **10**: e0130965. http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0130965

Dejean et al. 2011. Persistence of environmental DNA in freshwater ecosystems. *PLoS One* **6**:e23398. http://www.environmental-dna.nl/Portals/7/Dejean%20et%20al,%202011.pdf

Deiner et al. 2015. Environmental DNA reveals that rivers are conveyer belts of biodiversity information. http://biorxiv.org/content/biorxiv/early/2015/06/11/020800.full.pdf

Deiner & Altermatt 2014. Transport distance of invertebrate environmental DNA in a natural river. *PLoS ONE* **9**:e88786. https://www.researchgate.net/profile/Kristy_Deiner

Deiner et al. 2013. Increased accuracy of species lists developed for alpine lakes using morphology and cytochrome oxidase I for identification of specimens. *Molecular Ecology Resources* **13**:820-831. http://knapplab.msi.ucsb.edu/pdfs/Deiner_MolEcolRes_2013.pdf

Deiner et al. 2015. Choice of capture and extraction methods affect detection of freshwater biodiversity from environmental DNA. *Biological Conservation* **183**:53-63. https://www.researchgate.net/profile/Kristy_Deiner

Doi et al. 2015. Use of Droplet Digital PCR for Estimation of Fish Abundance and Biomass in Environmental DNA Surveys. *PLoS One* **10**:e0122763. http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0122763

Doi 2015. Droplet digital PCR outperforms real-time PCR in the detection of environmental DNA from an invasive fish species. *Environmental Science and Technology* **49**:5601–5608. http://pubs.acs.org/doi/abs/10.1021/acs.est.5b00253

Egan et al. 2013. Rapid Invasive Species Detection by Combining Environmental DNA with Light Transmission Spectroscopy. *Conservation Letters* **6**:402–409. doi:10.1111/conl.12017

Eichmiller et al. 2014. The Relationship between the Distribution of Common Carp and Their Environmental DNA in a Small Lake. *PLoS One* **9**: e112611. http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0112611

Evans et al. 2015. Quantification of mesocosm fish and amphibian species diversity via environmental DNA metabarcoding. *Molecular Ecology Resources* doi: 10.1111/1755-0998.12433 http://onlinelibrary.wiley.com/doi/10.1111/1755-0998.12433/epdf

Farrington et al. 2015. Mitochondrial genome sequencing and development of genetic markers for the detection of DNA of invasive bighead and silver carp in environmental water samples from the United States. *PLoS One* **10**:e0117803. http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0117803

Ficetola et al. 2008. Species detection using environmental DNA from water samples: *Biology Letters* **4**:423–425. http://www.webalice.it/f.ficetola/Ficetola%202008%20Biology%20Letters.pdf

Fukumoto et al. 2015. A basin-scale application of environmental DNA assessment for rare endemic species and closely related exotic species in rivers: A case study of giant salamanders in Japan. *Journal of Applied Ecology* **52**:358-365. https://www.researchgate.net/researcher/2066469342_Sou_Fukumoto

Goldberg et al. 2015. Moving environmental DNA methods from concept to practice for monitoring aquatic macroorganisms. *Biological Conservation* (special issue) **183**:1-3. http://www.sciencedirect.com/science/journal/00063207/183/supp/C

Goldberg et al. 2011. Molecular detection of vertebrates in stream water: A demonstration using Rocky Mountain tailed frogs and Idaho giant salamanders. *PLoS One* **6**:e22746 https://www.researchgate.net/profile/Caren_Goldberg4

Goldberg et al. 2013. Environmental DNA as a new method for early detection of New Zealand mudsnails (*Potamopyrgus antipodarum*). *Freshwater Science* **32**:792-800. https://www.researchgate.net/profile/Caren_Goldberg4

Gustavson et al. 2015. An eDNA assay for Irish *Petromyzon marinus* and *Salmo trutta* and field validation in running water. *Journal of Fish Biology* doi:10.1111/jfb.12781 http://onlinelibrary.wiley.com/doi/10.1111/jfb.12781/

Huver et al. 2015. Development and application of an eDNA method to detect and quantify a pathogenic parasite in aquatic ecosystems. *Ecological Applications* **25**:991-1002. http://www.esajournals.org/doi/10.1890/14-1530.1

Iversen et al. 2015. Monitoring of animal abundance by environmental DNA—An increasingly obscure perspective: A reply to Klymus et al. 2015. *Biological Conservation*. doi:10.1016/j.biocon.2015.09.024. http://www.sciencedirect.com/science/article/pii/S0006320715301166

Jane et al. 2015. Distance, flow and PCR inhibition: eDNA dynamics in two headwater streams. *Molecular Ecology Resources* **15**:216-227. https://www.researchgate.net/profile/Stephen_Jane2

Janosik and Johnston. 2015. Environmental DNA as an effective tool for detection of imperiled fishes. *Environmental Biology of Fishes* doi:10.1007/s10641-015-0405-5 https://www.researchgate.net/profile/Alexis_Janosik

Jerde et al. 2011. "Sight-unseen" detection of rare aquatic species using environmental DNA. *Conservation Letters* **4**:150-157. http://www.anbiosci.com/protocols/Jerde_2011.pdf

Jerde and Mahon. 2015. Improving confidence in environmental DNA species detection. *Molecular Ecology Resources* **15**:461-463. http://onlinelibrary.wiley.com/doi/10.1111/1755-0998.12377/abstract?userIsAuthenticated=false&deniedAccessCustomisedMessage=

Jerde et al. 2013. Detection of Asian carp DNA as part of a Great Lakes basin-wide surveillance program. *Canadian Journal of Fisheries and Aquatic Sciences* **70**:522–526. http://people.cst.cmich.edu/mahon2a/MahonLab/Publications_files/2013%20CJFAS%20Jerde%20et%20al%20asian%20carp.pdf

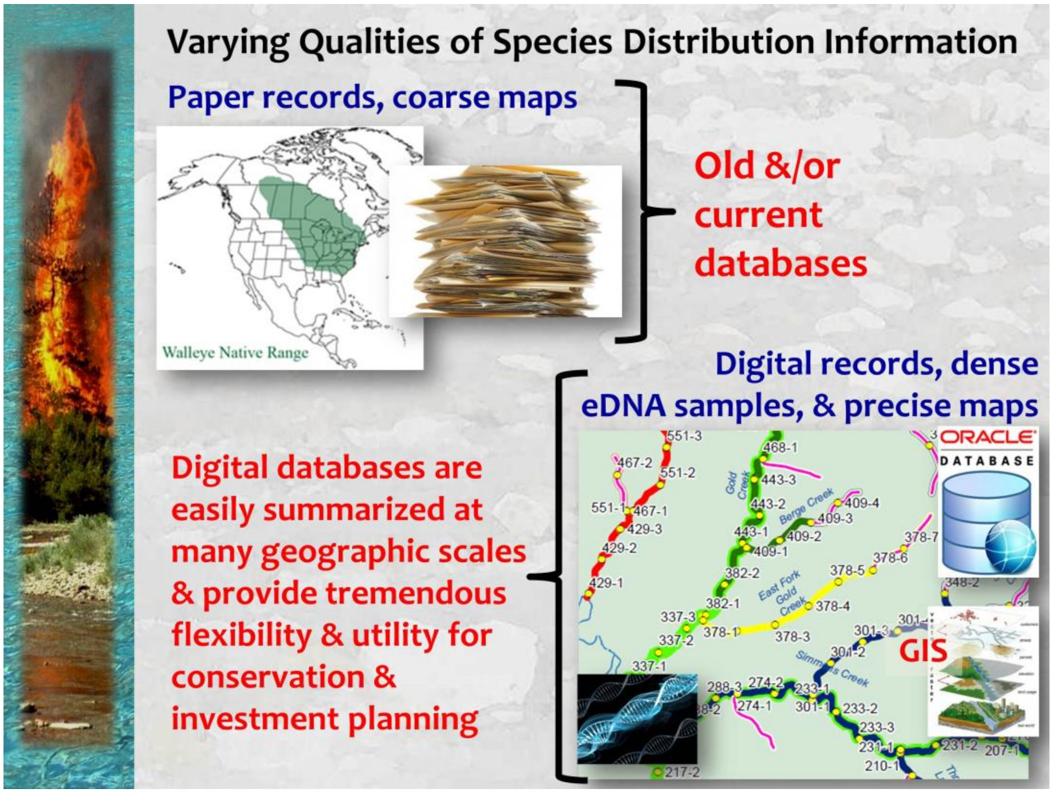
Keskin. 2014. Detection of invasive freshwater fish species using environmental DNA survey. *Biochemical Systematics and Ecology* **56**:68–74. http://www.sciencedirect.com/science/article/pii/S030519781400146X

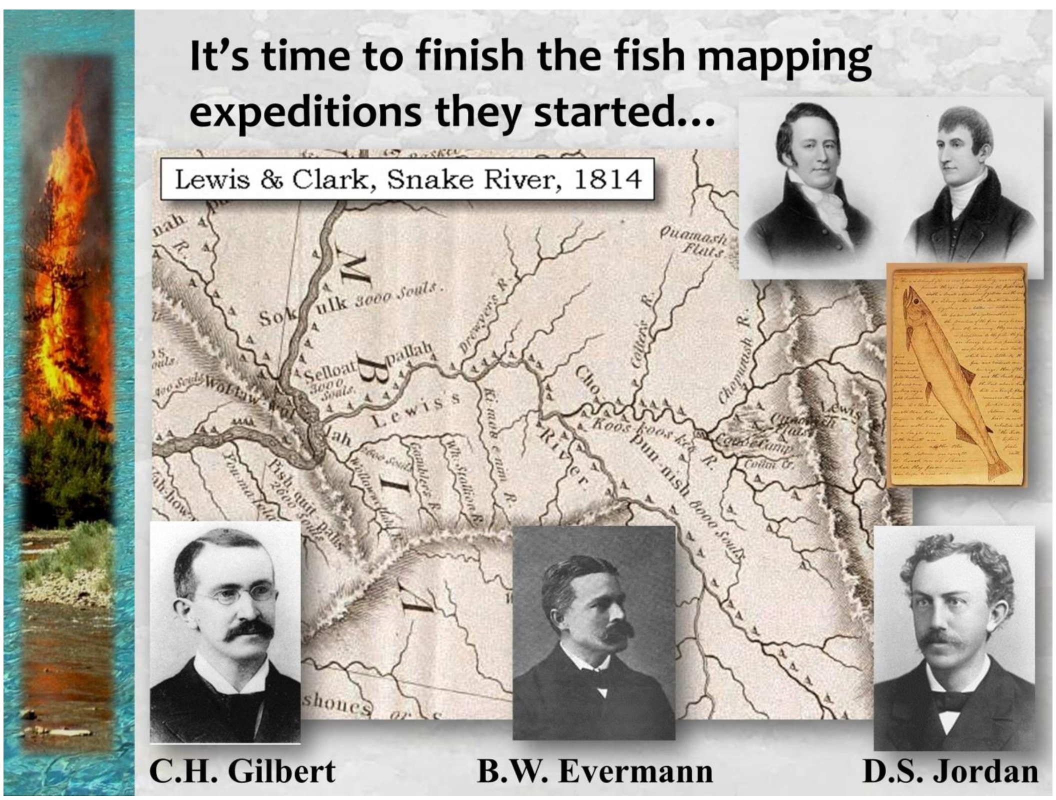
Klymus et al., 2015. Quantification of eDNA shedding rates from invasive bighead carp and silver carp. *Biological Conservation* **183**:77–84. http://www.sciencedirect.com/science/article/pii/S0006320714004455
Klymus et al., 2015. A reply to Iversen et al.'s comment "Monitoring of animal abundance by environmental DNA — An increasingly obscure perspective" *Biological Conservation* DOI: 10.1016/j.biocon.2015.09.025 https://www.researchgate.net/profile/Katy_Klymus
Laramie et al. 2015. Environmental DNA sampling protocol—Filtering water to capture DNA from aquatic organisms: U.S. Geological Survey Techniques and Methods, book 2, chap. A13, 15 p., http://dx.doi.org/10.3133/tm2A13 .
Laramie et al. 2015. Characterizing the distribution of an endangered salmonid using environmental DNA analysis. *Biological Conservation* **183**:29-37. https://www.researchgate.net/profile/Matthew_Laramie
Lodge et al. 2012. Conservation in a cup of water: estimating biodiversity and population abundance from environmental DNA. *Molecular Ecology* **21**: 2555-2558. http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3412215/
Mächler et al. 2014. Utility of environmental DNA for monitoring rare and indicator macroinvertebrate species. *Freshwater Science* DOI: 10.1086/678128 http://homepages.eawag.ch/~altermfl/Publications_files/Ma%CC%88chler.et.al_FreshwaterScience_2014.pdf
Mahon et al. 2013. Validation of eDNA Surveillance Sensitivity for Detection of Asian Carps in Controlled and Field Experiments. Liles MR, editor. *PLoS One*. **8**:e58316. http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0058316
Mahon et al. 2014. Meta-genomic surveillance of invasive species in the bait trade. *Conservation Genetics Resources* **6**:563–567. https://www.researchgate.net/profile/Lucas_Nathan
Maruyama et al. 2014. The release rate of environmental DNA from juvenile and adult fish. *PLoS One* **9**:e11463. http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0114639
McKelvey et al. In press. Sampling large geographic areas for rare species using environmental DNA (eDNA): a study of bull trout occupancy in western Montana. *Journal of Fish Biology*.
Merkes et al. 2014. Persistence of DNA in carcasses, slime and avian feces may affect interpretation of environmental DNA data. *PLoS One* **9**:e113346. https://www.researchgate.net/researcher/2058683182_Christopher_M_Merkes
Minamoto et al. 2012. Surveillance of fish species composition using environmental DNA. *Limnology* **13**:193–197. https://www.researchgate.net/profile/Toshifumi_Minamoto
Minamoto et al. 2011. Surveillance of fish species composition using environmental DNA. *Limnology* **13**: DOI: 10.1007/s10201-011-0362-4. https://www.researchgate.net/profile/Toshifumi_Minamoto
Minamoto et al. 2015. Techniques for the practical collection of environmental DNA: filter selection, preservation, and extraction. *Limnology* doi:10.1007/s10201-015-0457-4. http://link.springer.com/article/10.1007/s10201-015-0457-4
Miya et al. 2015. MiFish, a set of universal PCR primers for metabarcoding environmental DNA from fishes: detection of more than 230 subtropical marine species. *Royal Society Open Science* **2**:150088. https://www.researchgate.net/profile/Masaki_Miya
Moyer et al. 2014. Assessing environmental DNA detection in controlled lentic systems. *PLoS One* **9**:e103767. http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0103767

Nathan et al. 2015. The use of environmental DNA in invasive species surveillance of the Great Lakes commercial bait trade. *Conservation Biology* **29**:430-439. https://www.researchgate.net/profile/Lucas_Nathan
Nathan et al. 2014. Quantifying environmental DNA signals for aquatic invasive species across multiple detection platforms. *Environmental Science & Technology* **48**:12800-12806. https://www.researchgate.net/profile/Megan_Simmons2
Olson et al. 2012. An eDNA approach to detect eastern hellbenders (*Cryptobranchus a. alleganiensis*) using samples of water. *Wildlife Research* **39:**629–636. https://ag.purdue.edu/fnr/discover/HerpetologyLab/Documents/Olson_eDNAApproach.pdf
Olsen et al. 2015. An evaluation of target specificity and sensitivity of three qPCR assays for detecting environmental DNA from Northern Pike (*Esox lucius*). *Conservation Genetics Resources* **7**:615-617. http://link.springer.com/article/10.1007/s12686-015-0459-x
Pilliod et al. 2013. Estimating occupancy and abundance of stream amphibians using environmental DNA from filtered water samples. *Canadian Journal of Fisheries and Aquatic Sciences* **70**:1123–1130. https://www.researchgate.net/profile/David_Pilliod
Pilliod et al. 2014. Factors influencing detection of eDNA from a stream-dwelling amphibian. *Molecular Ecology Resources* **14**:109-116. https://www.researchgate.net/profile/David_Pilliod
Rees et al. 2014. The application of eDNA for monitoring of the Great Crested Newt in the UK. *Ecology and Evolution* **4**:4023-4032. http://onlinelibrary.wiley.com/doi/10.1002/ece3.1272/full
Rees et al. 2014. REVIEW: The detection of aquatic animal species using environmental DNA–a review of eDNA as a survey tool in ecology. *Journal of Applied Ecology* **51**:1450-1459. https://www.researchgate.net/profile/Helen_Rees6
Renshaw et al. 2014. The room temperature preservation of filtered environmental DNA samples and assimilation into a phenol-chloroform-isoamyl alcohol DNA extraction. *Molecular Ecology Resources* **15**:168–176. http://onlinelibrary.wiley.com/doi/10.1111/1755-0998.12281/full
Santas et al. 2013. Noninvasive Method for a Statewide Survey of Eastern Hellbenders Cryptobranchus alleganiensis Using Environmental DNA. *International Journal of Zoology* doi:10.1155/2013/174056 http://www.hindawi.com/journals/ijz/2013/174056/
Scriver et al. 2015. Development of species-specific environmental DNA (eDNA) markers for invasive aquatic plants. *Aquatic Botany* **122**:27-31. http://www.sciencedirect.com/science/article/pii/S0304377015000066
Sigsgaard et al. 2014. Monitoring the near-extinct European weather loach in Denmark based on environmental DNA from water samples. *Biological Conservation* **183** DOI: 10.1016/j.biocon.2014.11.023x: https://www.researchgate.net/profile/Philip_Thomsen
Simmons et al. 2015. Active and passive environmental DNA surveillance of aquatic invasive species. *Canadian Journal of Fisheries and Aquatic Sciences* Doi: 10.1139/cjfas-2015-0262 http://www.nrcresearchpress.com/doi/abs/10.1139/cjfas-2015-0262#.VhGPyiuZPfd
Smart et al. 2015. Environmental DNA sampling is more sensitive than traditional survey technique for detecting an aquatic invader. *Ecological Applications* **25**:1944-1952. http://www.esajournals.org/doi/abs/10.1890/14-1751.1
Spear et al. 2015. Using environmental DNA methods to improve detectability in a hellbender (*Cryptobranchus alleganiensis*) monitoring program. *Biological Conservation* **183**:38-45. http://www.sciencedirect.com/science/article/pii/S0006320714004418

Strickler et al. 2015. Quantifying effects of UV-B, temperature, and pH on eDNA degradation in aquatic microcosms. *Biological Conservation* **183**:85-92. https://www.researchgate.net/profile/Caren_Goldberg4
Takahara et al. 2013. Using environmental DNA to estimate the distribution of an invasive fish species in ponds. *PLoS One* **8**:e56584. http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0056584
Takahara et al. 2012. Estimation of fish biomass using environmental DNA. *PLoS One* **7**:e35868. http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0035868
Takahara et al. 2014. Effects of sample processing on the detection rate of environmental DNA from the Common Carp (*Cyprinus carpio*). *Biological Conservation* **183**:64–69. http://www.sciencedirect.com/science/article/pii/S000632071400439X
Thomsen et al. 2012b. Monitoring endangered freshwater biodiversity using environmental DNA. *Molecular Ecology* **21**:2565–2573. http://www.fugleognatur.dk/pdf/mec_5418_Rev_EV.pdf
Thomsen et al. 2015. Environmental DNA – An emerging tool in conservation for monitoring past and present biodiversity. *Biological Conservation* **183**: 4–18. https://www.researchgate.net/profile/Philip_Thomsen
Turner et al. 2014. Particle size distribution and optimal capture of aqueous macrobial eDNA. *Methods in Ecology and Evolution* **5**:676-684. http://biorxiv.org/content/biorxiv/early/2014/01/19/001941.full.pdf
Turner et al. 2015. Fish environmental DNA is more concentrated in aquatic sediments than surface water. *Biological Conservation* **183**:93-102. https://www.researchgate.net/profile/Cameron_Turner
Turner et al. 2014. Improved Methods for Capture, Extraction, and Quantitative Assay of Environmental DNA from Asian Bigheaded Carp (*Hypophthalmichthys spp.*). *PLoS One* **9**:e114329. http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0114329
Valentini et al. 2015. Next-generation monitoring of aquatic biodiversity using environmental DNA metabarcoding. *Molecular ecology* DOI: 10.1111/mec.13428 http://onlinelibrary.wiley.com/doi/10.1111/mec.13428/abstract
Wegleitner et al. 2015. Long duration, room temperature preservation of filtered eDNA samples. *Conservation Genetics Resources* doi.org/10.1007/s12686-015-0483-x. https://www.researchgate.net/profile/Benjamin_Wegleitner
Wilcox et al. In press. The dual challenges of generality and specificity when developing environmental DNA markers for species and subspecies of *Oncorhynchus*. *PLoS One*.
Wilcox et al. 2015. Environmental DNA particle size distribution from Brook Trout (*Salvelinus fontinalis*). *Conservation Genetics Resources* **7**:639-641. https://www.researchgate.net/profile/Taylor_Wilcox
Wilcox et al. 2014. A blocking primer increases specificity in environmental DNA detection of bull trout (*Salvelinus confluentus*). *Conservation Genetics Resources* **6**:283-284. http://www.fs.fed.us/rm/pubs_other/rmrs_2014_wilcox_t001.pdf
Wilcox et al. 2013. Robust detection of rare species using environmental DNA: the importance of primer specificity. *PLoS One* **8**:e59520. https://www.researchgate.net/profile/Taylor_Wilcox
Wilson et al. 2015. Tracking ghosts : combined electrofishing and environmental DNA surveillance efforts for Asian carps in Ontario waters of Lake Erie. *Management of*

Biological Invasions **5**:225-231.
http://www.reabic.net/journals/mbi/2014/3/MBI_2014_Wilson_etal.pdf





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 ~9,000 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
Blog #71: Harnessing social & digital network technologies to maximize climate effectiveness

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

Blog #68: Part 7, Identifying & protecting climate refugia as a strategy for long-term species conservation

Blog #69: Part 8, Building climate-smart conservation networks (metapopulations + biodiversity + refugia)

Blog #70: Part 9, Restoration success stories that improve population resilience to climate change