State University of New York
COLLEGE OF ENVIRONMENTAL SCIENCE AND FORESTRY

Dr. Dennis Suszkowski
Hudson River Foundation
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3 February, 2005

Dear Dennis,

Please find herewith the results of our funded study, "Blueback herrings: links from the watershed to upper trophic levels?" This study extended beyond the original scoping of the project, because unexpected results carried us in new directions. However, I feel that we have accomplished what we set out to do, and hence can now conclude this project.

I enclose three manuscripts that resulted from this project:

I. Limburg, K.E., I. Blackburn, R. Schmidt, T. Lake, J. Hasse, M. Elfman, and P. Kristiansson. Otolith microchemistry indicates unexpected patterns of residency and anadromy in blueback herring, *Alosa aestivalis*, in the Hudson and Mohawk Rivers. *Bulletin Français de la Pêche et de la Pisciculture* 362/363:931-938.

II. Limburg, K.E., and D.I. Siegel. The geochemistry of connected waterways, and the potential for tracing fish migrations. *Geochemistry: Exploration, Environment, Analysis* (submitted, in review).

III. Limburg, K.E., F.R. Harvey, S.-J. Ju, N.F. Caraco, and R.E. Schmidt. Broadened trophic niche in juvenile blueback herring (*Alosa aestivalis*): response to zebra mussels and range expansion. Draft (to be submitted to *Canadian Journal of Fisheries and Aquatic Sciences*).

I will include a brief summary of the papers.

Sincerely,

Karin E. Limburg

Blueback herrings: links from the watershed to upper trophic levels?
Project Summary

Blueback herring (*Alosa aestivalis*) compose one of the key species of the tidal Hudson River, and increasingly, of the Mohawk River. In the 1980s and 1990s, larval and young-of-year (YOY) juveniles composed up to 80% of the fish biomass in the upper tidal Hudson (Limburg 1996). We were interested in how two factors – the invasion of zebra mussels and the range expansion of herrings into the Mohawk River through the lock and canal system – affected this species' trophic status and general population ecology. To this end, we undertook studies of both trophic status and residency status, since earlier studies (Limburg 1998) documented, with biogeochemical tracers, that some YOY overwinter in fresh water, somewhere in the Hudson watershed. We used a variety of approaches to attack these questions.

For residency status, we intended to use a method that has worked very well in the tidal Hudson, namely to measure Sr:Ca ratios in otoliths of fish. By measuring these ratios from the otolith core to the outer edge, one can detect changes such as abrupt increases in Sr:Ca that typically indicate movement from freshwater to marine environments. We analyzed otoliths of some 65 adult blueback herring that were collected in the tidal Hudson (Rondout Creek, Poesten Kill) and in the Mohawk River (near Lock 6 (rkm 259) and Rome (rkm 441). To our surprise, instead of finding evidence of single-season freshwater residency followed by migration to sea, we found highly irregular patterns of Sr:Ca. At first I thought these might have been caused by poor sample preparation and errors in the electron microprobe analysis; but subsequent analysis with microPIXE (proton-induced X-ray emission nuclear microscopy) that I conducted in Lund, Sweden confirmed the unusual patterns. I also noticed what seemed to be higher levels of Sr:Ca in the inner portions of otoliths from adults collected in the Mohawk; these inner portions corresponded to the first growing season of the fish. I analyzed otoliths from YOY from the Mohawk and Hudson respectively, and confirmed that they are statistically different: Mohawk River YOY collected down at Lock 6, near the confluence of the Mohawk with the Hudson River, were elevated in Sr:Ca compared to YOY otoliths from the Hudson. This suggested that there were unknown sources of

elevated Sr within the Mohawk drainage, or possibly westward in the connected waterways comprising the NYS Barge Canal (including the Erie Canal). These findings are detailed in Paper #1.

These results led me to initiate two more studies to identify the locations of sources of Sr within the drainage basin and westward, as blueback herring had been captured as far west as Lake Ontario. In 2000 (a wet year) and 2001 (a dry year) I collected water along transects from the lower Hudson (Tappan Zee in 2000, and Croton Point in 2001) all the way to Lake Ontario at Oswego, through all the connected waterways that blueback herring potentially could exploit because of their ability to lock through the NYS Barge Canal system. Together with geochemist Donald Siegel from Syracuse University, I analyzed major, minor, and trace elements in the water, including strontium and calcium, but also elements such as barium and manganese, which a growing body of literature demonstrates are also excellent for use as habitat markers in fish otoliths. We discovered that there are several geochemically distinct regional markers that can be identified by combinations of Sr:Ca, Mn:Ca, and Ba:Ca along this geographic transect, and that they were distinguishable in both the wet and the dry years. We confirmed not only the presence of high levels of Sr in the Mohawk, but also in sources to the west (southern tributaries of Oneida Lake, in particular). We found highest levels of Mn in sites around Rome, NY, and high levels of Ba in Oneida Lake. These geochemical markers should provide "signposts" in fish otoliths that would indicate use of several distinct habitats. I was able to measure Sr, Ca, Mn, and Ba in just two fish otoliths (due to my heavy teaching schedule and distance from a laser-ablation ICP mass spectrometer (LA-ICPMS)), but was able to confirm that an anadromous fish had elevated Sr:Ca without elevated Mn or Ba, while a herring collected at Rome showed the unique multi-elemental signature from Rome. These results are summarized in Paper #2.

Although not detailed in any of the enclosed manuscripts, the confounding of elevated Sr:Ca in the Mohawk part of the drainage caused me to embark on a multi-year search for means to detect trace elements in herring otoliths. I tried a variety of approaches, including LA-ICPMS, microPIXE, stable isotope analysis of oxygen and carbon, and more recently, a collaboration with physicists at the Cornell High Energy Synchrotron Source (CHESS). We discovered methodological problems with microPIXE which I am hoping that R&D will eventually overcome, but were successful at mapping out true trace elements with the synchrotron sourced x-ray analysis (we are preparing a manuscript for submission to Science magazine). We analyzed two more Mohawk blueback herring otoliths, confirming the patterns observed with ICPMS. The advantage of this and microPIXE analysis is that these methods do not destroy the otolith, whereas laser ablation does. The stable isotope analysis (conducted by micromilling several otoliths, and analyzing the powder with the help of Chris Wurster then at Syracuse University) also showed us that most of the Mohawk fish we analyzed had spent multiple years in fresh water, but ultimately emigrated to sea. This was confirmed by my student, Ian Blackburn, and myself later with stable isotope analysis of muscle tissue. It appears from these studies that blueback herring are capable of remaining in fresh water for multiple years, but do emigrate to sea at least one season before returning to spawn. This habitat use pattern was previously unreported, and presents new complexity in their life history repertoire.

The final part of this project (Paper #3), which has been equally thorny to decipher, was a trophic analysis of blueback herrings' role in Hudson and Mohawk food webs, with an eye to changes caused by zebra mussels. This part of the project was plagued by time lags in analyses of fatty acids, but in the end this did not hurt the project. We simply had not anticipated the extent to which blueback herrings' diets would have been altered, compared to pre-zebra mussel conditions, and consequently had to mount a number of further collections and studies in 2000-2003. Our collaborations with Rodger Harvey and Se-Jong Ju at the Chesapeake Biological Laboratory resulted in 41 analyses of fatty acid profiles (a large number) of larval to juvenile herring, many of their dietary items, and potential indirect sources of fatty acids that could be trophically transferred. We confirmed that copepods are a major vector of highly unsaturated fatty acids (HUFAs) which cannot be manufactured by animals, but are likely sourced from diatom production and which can be bioaccumulated. *Bosmina*, the formerly abundant prey food of YOY blueback herring, is low in DHA (C22:6 fatty acid), which is known to promote growth and survival of larval fishes. Copepods, larval herring, and Hudson River YOY were all enriched in DHA, whereas Mohawk YOY were depleted. Mohawk YOY consumed significant quantities of daphnids, which are rarely seen in the Hudson. A growing literature suggests that daphnids (and cladocerans in general) are depleted in DHA. Thus, we are left wondering about the nutritional status of larval fishes in the Mohawk (are they also depleted in DHA?), but note that the overall condition and growth of Mohawk YOY appears good.

However, the most striking results of that study come from comparison of traditional metrics of diet and fish growth and condition between our main study year, 1999, and studies I conducted as a Polgar fellow in 1987 (Limburg and Strayer 1988). We find that 1999 YOY fish ate less, shifted dramatically from pelagic to littoral/benthic species in the Hudson, and had worse condition and growth than prior to the invasion of zebra mussels. Although we only have two years for comparison, the results are consistent with the changes in the lower food web documented by researchers at the Institute of Ecosystem Studies (e.g., Caraco et al. 1997, Findlay et al. 1998, Pace et al. 1998, Strayer et al. 1999) and adds to the evidence of fish effects documented by Strayer et al. (2004).

Other effects that we documented consist of differences in food web isotopic signatures. In particular, we document a marked difference in nitrogen stable isotope ratios in the Mohawk (they are lower), and slightly lower carbon stable isotope ratios there as well (although these are more widely scattered). Not only does this mean that we can distinguish Mohawk and Hudson River fish isotopically, but it provides further evidence of elevated N cycling in the Hudson.

In summary, our studies revealed that blueback herring use of the Hudson and its major tributary is far more complex than we anticipated. Although our studies mainly describe status and trends, they suggest important questions about selective forces that shape the evolution of this species in the modern context. For example, why do blueback herring migrate in such large numbers from the Atlantic Ocean into the Mohawk, sometimes reaching Rome and points beyond? Such behaviors would only prevail if future generations benefited from this strategy. Yet we know very little about the Mohawk River as a nursery ground for this important species. The initial evidence from this project suggests it is very important, and that further investigations are warranted.

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