Importance of Tributaries to the Hudson River Eel Population: Implications for Restoration and Management

A Proposal to the Hudson River Foundation

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Introduction

The American eel, *Anguilla rostrata*, is a catadromous species that is of considerable commercial importance (Tesch 1977; Haro et al. 2000). It colonizes the rivers, estuaries, and many inland water bodies in eastern North America, including the Great Lakes. The eel is a highly adaptive fish in terms of its habitat use, being able to survive a range of conditions and also capable of overland travel for short distances (Tesch 1977). After hatching in the Sargasso, the leptocephalus larvae drift to the continent, where they metamorphose into glass eels in estuaries. Glass eels migrate upstream and develop pigment (yellow phase) and may remain in rivers, or move into tributaries and connected lakes and ponds. Both American and European (*A. anguilla*) eels exhibit variable growth (Holmgren 1996; Morrison and Secor 2002b), and sex determination appears to be geographically based, with males predominating in lower reaches of estuaries and females farther upstream (Tesch 1977; Holmgren 1996; Krueger and Oliviera 1999; Oliviera 1999).

On both sides of the Atlantic, anguillid eels are in decline (Dekker et al. 2002; Haro et al 2000). Depressed landings in North America have stimulated calls for increased studies of eel biology and life history, better to understand and manage for fisheries (ASMFC 2000; Haro et al. 2000). In New York State, catches declined from a decadal average of 244,240 metric tons in the 1950s to 9.29 metric tons in the 1990s (data from the National Marine Fisheries Service). Although some of this decline was due to a fisheries closure on PCB-contaminated Hudson River eels, the most recent decline is from 1995 and is dramatic (Figure 1).

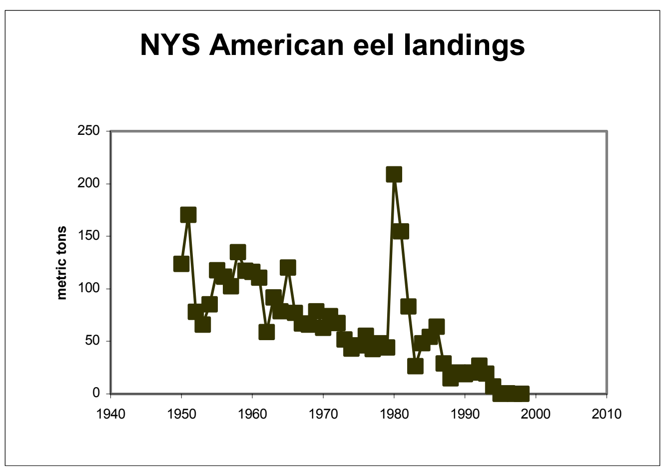

Figure 1. Landings of American eels in New York State since 1950. Source: National Marine Fisheries Service.

Recently, David Secor and Wendy Morrison undertook studies of American eel use of the tidal mainstem of the Hudson River. Their findings (Morrison and Secor 2002a,b; Morrison et al. 2002) indicate that (1) mainstem eels are mostly composed of females, (2) growth rates in the brackish portion of the estuary were far greater than in the tidal freshwater zone, and (3) eels that were marked and released were fairly stationary over the course of two years.

To date, little formal study of eel use of the tidal Hudson's tributaries has been carried out, even though survey data (Schmidt unpublished data from Quassaick Creek, Saw Kill, and Stony Creek; Limburg unpublished data from the Wappingers and Fishkill Creeks) indicate that tributaries could serve as major portions of the eel "population reservoir" within the drainage. **Thus, we propose to extend the studies of Secor and colleagues into Hudson River tributaries, and in particular intend to address: recruitment of glass eels and their predation; age structure, growth rates, and production in tributaries; lifetime habitat use of tributary-caught eels; sex ratios and maturation indices; *Anguillicola* burdens; and penetration into tributaries as a function of dams and distance from the sea.**

Research Questions

We propose to study the life stages of American eels that use tributaries of the Hudson, to answer the following questions:

1. Is glass eel recruitment into tributaries a function of distance from the ocean?

2. What are the levels of glass eel predation by other fish?

3. Is eel abundance and penetration into tributaries limited by distance from the sea, by numbers of dams, or both?

4. Do tributary-dwelling eels exhibit similar north-south variations in growth and production as mainstem eels?

5. Do eels move into tributaries only as glass eels, remaining there until spawning maturity, or do they exhibit complex movements between fresh, brackish, and marine waters, as exhibited in European eels studied by Limburg et al. (2002)?

6. What are the sex ratios of eels in Hudson tributaries, and what is their maturation status as indicated by gonadal state, eye diameter, and lipid content?

7. How do tributary eels compare in these characteristics to mainstem eels, what are their burdens of the parasite *Anguillicola*, and how do Hudson stocks compare to others, particularly the depleted stocks in the Great Lakes?

Approach

Site selection – two streams, Hunter Brook and Saw Kill, have already been selected for glass eel monitoring (see below). We will select an additional four to six tributaries for study, based on distance from the Hudson's mouth and degree of damming (accounting for both numbers of dams and their heights). Each question's approach is described:

1. *Is glass eel recruitment into tributaries a function of distance from the ocean?*

Glass eel recruitment will be monitored intensively in two tributaries. This will be conducted under a separate grant to RES, funded by the New York State Department of Environmental Conservation (NYS DEC), and will run for three years. In that study, we will be sampling glass eels from February through July in two Hudson River tributaries, the Saw Kill in Annandale, Dutchess County (river kilometer 167) and Hunters Brook in Wappingers Falls, Dutchess County (river km 105). Daily collections will be made, tracking relative abundance over time. Although the exact gear is yet to be determined, we have consulted with other research groups in Connecticut and Nova Scotia on various trapping methods. The expected results will be catch-per-unit-effort indexes from the two tributaries (counts per day per trap).

Once a fortnight, samples (up to 30 glass eels) will be preserved from each stream for morphometrics and diet analysis. Eels will also be examined for presence of the swim-bladder parasite, *Anguillicola crassus*, which has been shown to be capable of infecting even this young stage (Nimeth et al. 2000).

This study will serve as a funding match to the other tasks we lay out in our current proposal to HRF; its narrative is included as Appendix A to this proposal.

2. *What are the levels of glass eel predation by other fish?*

Studies on glass eel predation will be done in conjunction with the DEC-sponsored glass eel immigration study. We propose to sample predatory fishes in each area once a week throughout the glass eel migration period and determine the magnitude of consumption.

We have documented the presence of several species of predatory fishes in Hudson River tributaries especially in the spring (Schmidt and Lake, 2000 for example). At some times, these predators are found spawning in the tributaries, but frequently we take white perch (*Morone americana*), for example, in substantial numbers in early spring well before their spawning period. Perhaps these fishes are seeking warmer water in the early spring and are feeding in the tributary mouths. T. Lake (Hudson River Estuary Program, *pers. comm*.) has reported finding large numbers of glass eels packed into white perch stomachs in tributary mouths in the early spring.

Potentially, glass eels entering tributary mouths and moving upstream may be highly vulnerable to predation, more so than in the open Hudson River estuary. Glass eels may be present in high densities in tributary mouths and have fewer places to hide from predators than in other parts of the Hudson River system.

We propose to sample predators in the Saw Kill and Hunters Brook with gill nets. We have had success deploying 50 ft long monofilament nets with 1.25 inch and 0.75 inch bar mesh in sampling fishes in these habitats. The smaller mesh net does catch relatively small fishes, but glass eels are only 6 cm total length and predators would not have to be large to have a significant effect on the eels. We also propose to fish a gill net with larger mesh, 1.75-inch mesh to catch the (probably) few very large individuals that are present.

We will sample each tributary once a week on an incoming tide. Nets will be set and tended for a period of up to four hours per day. Logistically, we will not be able to sample both tributaries on the same day. Fishes collected will be returned to the laboratory. They will be identified, measured (total length in cm), weighed to the nearest 0.1 g, and their stomachs will be excised. Stomach contents will be identified as far as is practical and counted. Glass eels will be measured (total length, or in cases where only partial remains are present, we will develop and use regressions to estimate total lengths from the remains).

We will compare the presence and abundance of glass eels in fish stomachs with the relative abundance data collected in each tributary, and will express this with an electivity index (e.g., Ivlev 1961). We seek a correlation between glass eel abundance and fish predation (all species combined). In addition to determining the level of predation on the species of interest, we will be accumulating further data on tributary use by Hudson River fishes and something about their feeding behavior.

3. *Is eel abundance and penetration into tributaries limited by distance from the sea, by numbers of dams, or both?*

Turbines in hydroelectric dams have been implicated in adult mortality (Montén 1985, EPRI 1999, Haro et al. 2000, McCleave 2001), but less is known about the barrier effect of dams on immigrating glass eels, elvers, and older life stages. White and Knights (1997) and Feunteun et al. (1998) documented reductions in upstream eel migration in European rivers as a function of dams, and Wiley et al. (2002) calculated percent reductions in eel presence in Maryland streams as a function of dam height.

Hudson River tributaries have numerous dams (Schmidt and Cooper 1996) built over the past 300+ years. Although some serve to magazine water, many are no longer in active use. Glass eels are known to be able to scale vertical surfaces (Tesch 1977, Moriarity 1978), but not necessarily very large structures (Legault 1988). Furthermore, only glass eels less than 100-120 mm appear to be capable of scaling vertical walls (Jellyman 1977, Legault 1988). If eels grow as they move upriver, then we might expect fewer to be able to recruit into dammed tributaries if they exceed 12 cm when reaching the stream.

Alternatively, eels of all sizes may crawl out of the water into moist grass and skirt obstructions in that manner (Moriarity 1978). If moist ground conditions were unavailable, as may be the case in urbanized streams, then we would expect eels to be prevented from overland access.

We will select tributaries draining into the lower, middle, and upper tidal Hudson River for population and demographic analysis of eels. Although it is likely that all tributaries have dams, the numbers and sizes differ, and we will search for systems that reflect high and low incidence of dams. Dam locations will be quantified via GPS and logged into a geographic database; we can estimate dam heights through standard methods (geometry).

Standing stocks of yellow eels (numbers and biomass) will be estimated in at least five locations within each tributary, by dividing the system up into reaches from near the estuarine confluence up into the headwaters. A standard procedure will be adopted for each reach. A fixed distance of stream (e.g., 100-150 m) will be blocked off with nets and electrofished. A repeated sampling scheme will be used, in order to estimate population size within the reach via a depletion method (King 1995). We may need to adapt the method to the particulars of eel behavior: that is, once shocked, if an eel is not captured, it will likely burrow or wedge itself under a rock and will not be vulnerable to a second pass with an electroshocker. A solution would be to complete the repeated samples on successive days.

A classic, three-pass reduction estimator such as that described by DeLury (1947) may need to be revised to accommodate low population sizes (Sullivan and Boomer, *manuscript in preparation*). We will consult with Patrick Sullivan, Cornell University, on Bayesian estimation methods if necessary.

We will compute means and variances of population sizes of eels within each sampling site. Within each tributary system, we will map the population sizes and geographically correlate their penetration into each tributary watershed as a function of obstructions.

4. *Do tributary-dwelling eels exhibit similar north-south variations in growth and production as mainstem eels?*

Morrison et al. (2002) and Morrison and Secor (2002b) documented dramatic differences in growth and production of eels in the Hudson River mainstem as a function of distance to the mouth. Specifically, upstream eels' growth and production (the latter defined as the evolution of biomass over time accounting for both growth and mortality; Chapman 1978) are much lower than for brackish water eels. Growth in Haverstraw Bay averaged > 10 cm/year in 1999-2000, but only around 3 cm/year between Newburgh and Albany.

As a pilot study, one of us (KEL) collected four yellow eels in August 2002 from the Quassaick Creek in Newburgh (river KM 97) and assayed their otoliths for growth and retrospective habitat use. Otoliths were removed, ground in the sagittal plane to expose the core, and increments enumerated and measured under transmitted light. Campana's (1990) method of back-calculating age at length was applied and is shown in Figure 2. Growth of these haphazardly chosen four eels shows the typical variability reported by other eel researchers. Moreover, mean growth of these eels (3.1 ± 0.04 cm/yr) is much slower even than the tidal freshwater sites in Morrison and Secor's study.

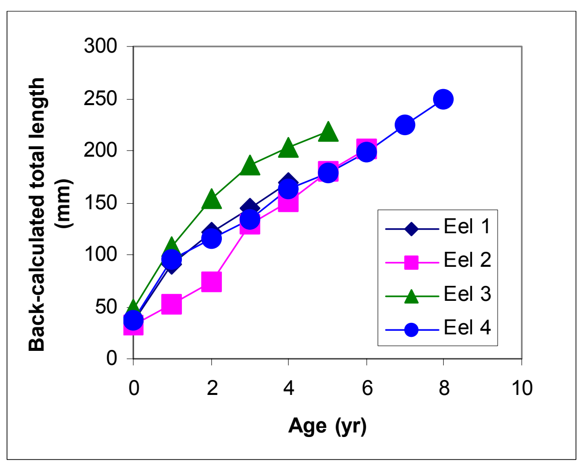

Figure 2. Back-calculated lengths-at-age of four yellow eels collected in Quassaick Creek, Newburgh, in August 2002. Note that "0" denotes a growth check attributed to the metamorphosis from leptocephalus larva to glass eel.

For the assessment of production, we will need to make at least two censuses, in order to estimate numbers of eels and their mean weights at two different time intervals. We will select sites within each tributary for this estimation procedure, based upon such factors as catch efficiency and relative abundance during the first census.

We will collect eels by electrofishing (see previous section), and will narcotize them for data collection. Numbers and sizes (lengths and weights) will be recorded, and sub-samples of up to 60 yellow eels per tributary will be collected (frozen) for laboratory analysis. Otoliths will be used for age and growth estimations, as well as for retrospective habitat use (see next section). We will follow Morrison and Secor's protocols for otolith preparation and age determination, which are slightly different than the way age data are presented here (that is, a distinctive growth check in the inner otolith, representing metamorphosis, is counted by them as Age 1, because in general, American eels should be Age 1 at this time). Loss rates (Z) will be calculated through standard catch curve analysis (King 1995) and production will be estimated with Ricker's equation (Ricker 1975, Chapman 1978):

$$\overline{B} = \frac{B_0(e^{G-Z} - 1)}{G - Z},$$

where $\overline{B}$ is mean biomass (weight per individual, times number of individuals) over some interval of time, B_0 is the biomass at the beginning of the time interval, G is the instantaneous growth rate of the population, and Z is the loss rate (we assume, as did Morrison and Secor, that we will not be able to distinguish mortality from emigration).

As part of the growth assessment, we will check our laboratory-archived eels for infestations of the swim-bladder parasite *Anguillicola crassus*. This debilitating import from Japan has moved rapidly through eel populations on both sides of the Atlantic, having been first identified in Italy in the 1980s (Wickström 2001) and in South Carolina in 1995 (Moser et al. 2001). Morrison and Secor (2002b) documented increasing infection rates in Hudson mainstem eels from 1997-2000, particularly in upriver sites. Like those researchers, we will dissect and check swimbladders for presence and burden (numbers) of *A. crassus*.

5. *Do eels move into tributaries only as glass eels, remaining there until spawning maturity, or do they exhibit complex movements between fresh, brackish, and marine waters, as exhibited in European eels studied by Limburg et al. (2002)?*

Lifetime habitat use by diadromous fishes can often be tracked by mapping the changes in strontium-to-calcium ratios (Sr:Ca) in otoliths (e.g., Secor 1992, 1999; Limburg 1995, 2001; Limburg et al. 2001, 2002; Campana 1999; Tzeng 2002). Briefly, strontium concentrations tend to be nearly an order of magnitude higher in marine vs inland waters (Ingram and Sloan 1992, Limburg 1995), so Sr:Ca ratios may serve as proxies for salinity both in water and in otoliths. However, Sr:Ca can vary inland due to local geological conditions (Odum 1957, Durum and Haffty 1963, Skougstad and Horr 1963, Kraus ad Secor 2002), in which case other ancillary tracers must be employed. Recently, Limburg and Siegel (*manuscript in preparation*) documented that Sr:Ca levels in the tidal freshwater Hudson River are uniformly low (2.7 mmol/mol vs values around 9 mmol/mol for marine waters), confirming that good Sr:Ca end-members exist in the Hudson.

Using the Sr:Ca approach, Morrison and Secor (2002a) documented that mainstem eels could be separated into "contingents" (Secor 1999) of upriver and downriver residents, plus eels that moved from upriver to downriver areas. Mark-recapture studies (Morrison and Secor 2002b) showed low rates of movement over the timescale of one year. Nevertheless, examination of their graphs shows that variations occur within individual fishes, indicating movements within the river. Similar movements over the course of many years were recorded by Limburg et al. (2002) for European eels (*A. anguilla*) in the Baltic Sea. There, eels displayed a wide variety of lifetime habitat uses, sometimes moving repeatedly between brackish (Baltic Sea) and inland waters, or between marine and brackish areas.

The pilot study on four Quassaick Creek eels included probing transects along the main axis of growth (posterior) and Sr and Ca concentrations were measured (Figure 3). A JEOL 8900 electron microprobe at Cornell University was used. Accelerating voltage was 20 kV and current 30 nA; spot size was 20 microns. Counting times were 30 sec for Sr and 10 sec for Ca; background corrections were made every third point analysis. The Sr:Ca "life history transects" showed a rapid decline in Sr:Ca below 2 mmol/mol for three eels, and values declining below 2 mmol/mol only in the third post-metamorphic year for the fourth eel. Morrison and Secor (2000a) defined freshwater residents as fish with Sr:Ca values around 2 mmol/mol, but clearly, variation occurs, and some waters, such as the Quassaick, apparently have even lower Sr:Ca than the freshwater tidal Hudson.

We will use electron microprobe methods to analyze otoliths of the eels we preserve to reconstruct past habitat use. In order to make comparisons with present habitats, we will collect and analyze water chemistry at each collection site (using the Perkin-Elmer ICP Optical Emission Spectrometer at SUNY-ESF), and we will make several point analyses (several are necessary, due to lattice irregularities) along the outer growing margin of the otolith. We prefer to collect water during base flow conditions, but ratios should not vary too much even during other times of the year (Limburg and Siegel, in preparation).

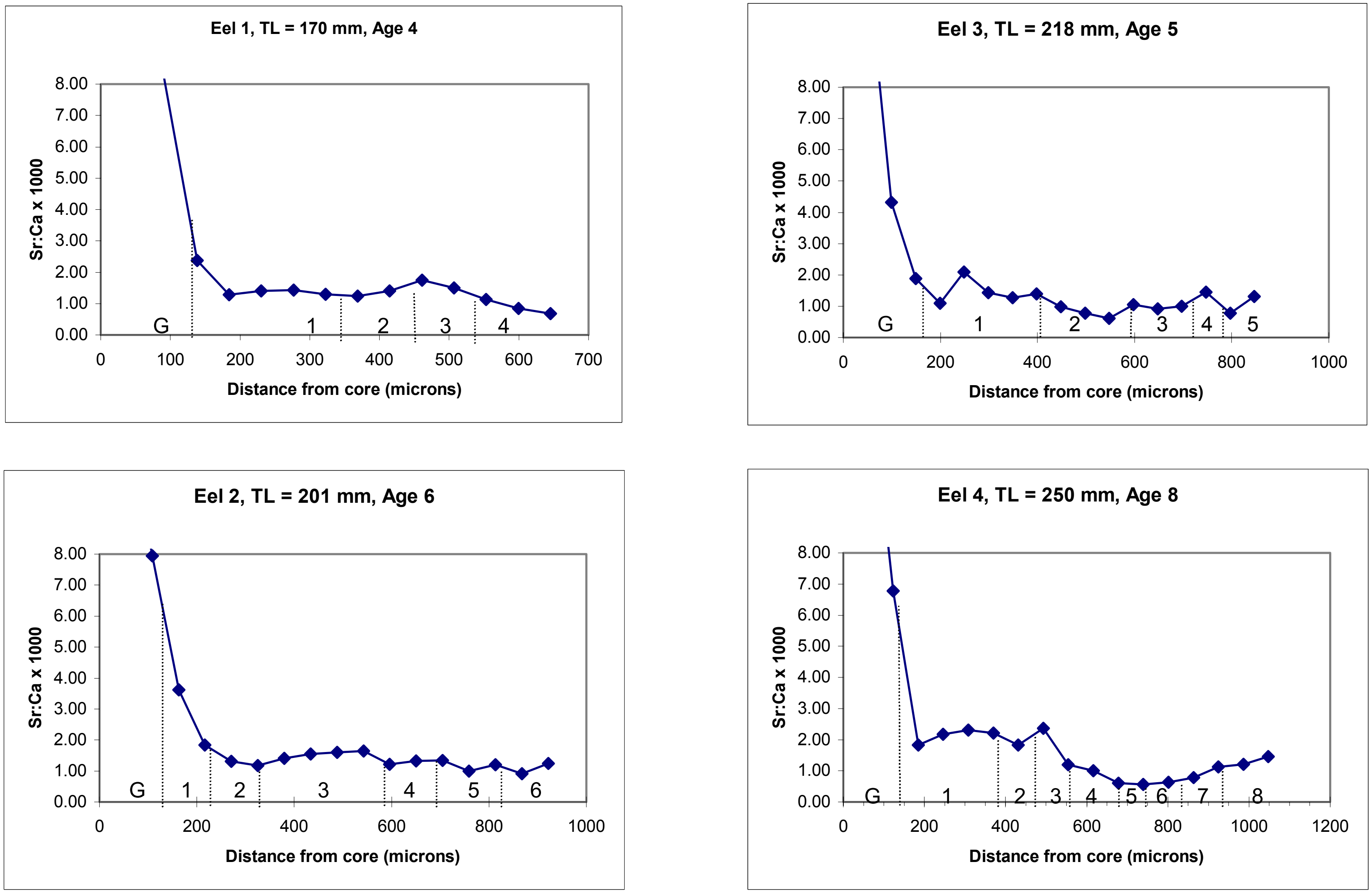

Figure 3. Strontium:calcium ratios (mmol/mol) measured by wavelength-dispersive electron microprobe spectrometry in sagittal otoliths from four yellow eels collected in Quassaick Creek (river KM 97), August 2002. Dotted lines and numbers indicate ages. “G” represents transition to glass eel phase.

6. *What are the sex ratios of eels in Hudson tributaries, and what is their maturation status as indicated by gonadal state, eye diameter, and lipid content?*

Eel sex determination appears to be a function of crowding, growth rates, and latitudinal distance from the Sargasso spawning grounds (Tesch 1977; Holmgren 1996; Krueger and Oliviera 1999; Oliviera 1999). In our previous studies, we have noted high densities of eels in tributary mouths and sparser numbers upstream. Morrison and Secor (2002b) found 97% of mainstem eels to be female, with the few males found at downriver sites. We hypothesize that females will be found both in tributaries to the upper tidal Hudson and in upper portions of downriver tributaries, and that if males are found, they will be located in crowded conditions at the lower end of the tributaries.

In the eels collected for laboratory analysis, the entire gonad will be excised and weighed to the nearest gram to calculate a gonadosomatic index. For sex identification, a small portion of the gonad will be observed on a microscope slide. Gonads will be classified according to the descriptions in Beullens et al. (1997).

A small piece of the gonad will be collected for histological examination. Each piece will be preserved in 10% buffered formalin, embedded in paraffin, sectioned, and stained with hematoxylin and eosin. The proportion of the oocytes in various maturity stages will be determined following Couillard et al. (1997).

During our surveys, we will assess the maturation potential of eels. Typically this is measured by external characters (Pankhurst 1982, Cottrill et al. 2002) and lipid content (Svedäng et al. 1996, van Ginneken and van den Thillart 2001, Limburg et al. 2002). We will use these methods on our archived eels. Additionally, we will assess the usefulness of a method developed by Kevin Friedland at the University of Massachusetts and already used by one of us (KEL) to assess fecundity. In this method, a small amount of ovary is excised and placed in Gilson's solution to dissolve the connective tissue. After several weeks, the supernatant is decanted, the eggs are rinsed and plated into agarose, and the plates are imaged with a flatbed scanner. Eggs are then enumerated and sized with an image processing program (OPTIMAS in our case). This works very well for American shad eggs (K. Friedland, pers. comm.) and even for smaller eggs of blueback herring (I.R. Blackburn, SUNY-ESF, pers.comm..)

7. *How do tributary eels compare in these characteristics to mainstem eels, and how do Hudson stocks compare to others, particularly the depleted stocks in the Great Lakes?*

We will be able to compare our results to Morrison and Secor's studies of mainstem eels. In addition, we will collaborate with Dr. Dawn Dittman of the U.S. Geological Survey, in making comparisons between Hudson River eel demographics and demographics of Great Lakes/St. Lawrence eels. This will take the form of a synthesis of data collected, and also information in published reports and journal articles.

Significance

The proposed research falls within the mission of the Hudson River Foundation, in the context of Resource and Key Species, scientific importance, and policy. The basic information on eels will greatly enhance the value of previous HRF-funded work by Morrison and Secor on mainstem populations of American eels, by building a more complete picture of the stocks within the watershed. We should be able to estimate the fraction of the population supported by tributaries, and highlight the impact (or lack of impact) caused by dams. Furthermore, the study will provide much needed basic information on eel biology and ecology in Hudson River tributaries, in keeping with the goal of the Hudson River Estuary Program to understand the linkages between the tidal and non-tidal portions of the Hudson watershed. The information will serve as a basis for continued improvements of tributaries for diadromous species. It will also enable us to compare Hudson eel dynamics to other estuaries, including the Saint Lawrence/Great Lakes.

Related research

Both Limburg and Schmidt have extensive experience working on projects, some of them together, in the Hudson River ecosystem. RES has visited every major tributary (and many minor) in the Hudson River estuary and has sampled migratory fishes in a substantial subset of these tributaries, as well as in many of the tidal marshes. An abbreviated list of the publications and reports produced from these activities are listed on his CV (attached). Most of these activities have been funded by the Hudson River Foundation. KEL has conducted many ecological studies in the Hudson, including food web dynamics of larval fish (*Morone* spp.) and zooplankton, ecology of Tivoli Bays, zebra mussel trophic effects on pelagic fish (shad and blueback herring), life history and migration of American shad, and effects of land use change on the ecology of Hudson River tributaries and their fishes. In addition she has studied European eel migration and thus has experience with a sister species to *A. rostrata*.

List of specific tasks

- Deploy gill nets in the mouths of Saw Kill and Hunters Brook during the glass eel migration.
- Measure, weigh, determine gender, and remove stomachs from predators collected in gill nets.
- Determine presence and number of glass eels in each predator's stomach.
- Relate the relative abundance of predators and amount of glass eels consumed to abundance of glass eels in DEC-funded study.
- Conduct electrofishing surveys for population estimation and yellow eel collections in Hunters Brook, Saw Kill, and 4-6 other tributaries to be determined.
- On all eels: measure lengths and weights (or develop length/weight relationship and measure lengths), enumerate.
- On collected eels: extract otoliths, determine sex, inspect for parasites, measure lipid content, quantify maturation status.
- Otoliths: determine age and growth rates, Sr:Ca ratios (also measured in water).
- Calculate population sizes, loss rates, production.
- Determine population characteristics in relation to dams and distance of tributaries from the ocean.
- Write report and disseminate information through conference presentation, scientific journal articles, and outreach (e.g., to DEC watershed coordinator and other concerned parties).

Timetable

The proposed project will start in May 2003 and run for two years:

- Conduct glass eel studies: February –August 2003-2005
- Glass eel predation studies: April – August 2003-2004
- Synoptic survey of yellow eels: June – September 2003, supplemental sampling in 2004
- Laboratory analyses: September 2003 – December 2004
- Data analyses: ongoing, terminating in winter 2005
- Write final report: spring 2005

List of Current and Pending Research Grants and Contract Support

Karin Limburg:

SUPPORTING AGENCY AND AGENCY ACTIVE AWARD/PENDING PROPOSAL NUMBER	TOTAL $ AMOUNT	EFFECTIVE AND EXPIRATION DATES	% OF TIME COMMITTED	TITLE OF PROJECT
Active:				
Rensselaer Polytechnic Institute	$103,545	6/1/00 – 6/30/03	10% AY	Modeling and Measuring the Process and Consequences of Land Use Change: Case Studies in the Hudson River Watershed
Hudsonia Limited	$7,048	$7/11/02 – 6/30/03	5% AY	Assessment of the Current Status of Quassaick Creek
Normandeau Associates	$10,000	2/1/01 – 1/31/03	10% AY	Analysis of Blueback Herring in the Mohawk River System
Pending:				
Hudson River Foundation	$39,002	5/1/02 – 4/30/04	1% AY	Ecosystem-Level Responses to Land-Use Change: An Addendum to "Modeling and Measuring the Processes and Consequences of Land-Use Change in the Hudson Watershed
National Science Foundation	$616,165	1/1/03 – 12/31/06	10% AY	Career: Watersheds & Fisheries as Foci of Human Impacts and Ecological Responses: A Research and Teaching Agenda
University of Connecticut	$7,279	6/1/03 – 5/31/05	3% AY 2 Wks. Summer	*Anchoa mitchilli* in the Hudson River: Analyses of Early Life-State Migration and the Function of Estuarine Residency
This Proposal: Hudson River Foundation	$146,868	5/1/03 – 4/30/06	8% AY 2 Wks. Summer	The Importance of Tributaries to the Hudson River Eel Population: Implications for Restoration and Management

Bob Schmidt:

Current-

Study of Glass Eel Immigration in Two Hudson River Tributaries funded by the New York State Department of Environmental Conservation for a period of three years (beginning Spring 2003) and a total of $91,847.34. Sampling is daily in this project but my time commitment is minimal during the field season. I need to be available for emergencies and gather samples from the field crews twice a week. My intention is to collect the predators in the same tributaries being sampled for glass eel immigration.

Pending-

I am part of a National Science Foundation proposal to study the ecosystem effects of anoxia in water chestnut beds in the Hudson River. This proposal is being submitted by the Institute of Ecosystem Studies. This project would begin in summer 2003, probably after the field work for the glåssol migration is over. This is a three year project that requires about 12 days of field work per year. The total amount for my part of the project is $47,629.03 (for all three years). There is no overlap with the currently proposed research, conceptually or temporally.

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Curriculum Vitae – Karin E. Limburg

Faculty of Environmental and Forest Biology
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Education:
Ph. D. Cornell University, Ithaca, NY; Ecology & Evolutionary Biology, 1994
M.S. University of Florida, Gainesville, FL; Systems Ecology, 1981
A.B. Vassar College, Poughkeepsie, NY; Ecology-Conservation + Biology, 1977

Professional Experience (since receipt of PhD):

1999-present	Assistant Professor, Biology, SUNY College of Environmental Science and Forestry, Faculty of Chemistry
1997- 1999	Research Assistant Professor, Dept. of Systems Ecology, Stockholm University (Sweden)
1994- 1997	Postdoctoral associate, Institute of Ecosystem Studies, Millbrook, NY

Professional Affiliations:
AAAS, AIBS, Ecol. Society of America (ESA), American Fisheries Society (AFS), Estuarine Research Federation (ERF), International Society of Ecological Economics, Sigma Xi

Honors and Awards:
Promotion to Docent (roughly equivalent to Associate Professor) in Marine Systems Ecology, Stockholm University (1999); EPRI Graduate Fellowship - Program in Fish Biology (1991-93); Cooperative Education Internship - U.S. Fish and Wildlife Service (1991); Hudson River Foundation Graduate Fellowship (1988); T.T. Polgar Fellowship (1987, 1990).

Synergistic Activities (last 2 years):
National & International:
- Organizer, "Ecological Economics Approaches to Ecosystem Health, June 2002, International Society of Ecosystem Health conference, Washington, DC;
- Co-organizer, "SHAD 2001: a Conference on the Status and Conservation of Shads Worldwide" Baltimore, May 2001 (book in progress, to be published by American Fisheries Society);
- Organizer, "Analysis, Interpretation and Applications of Fish Otoliths and Other Hard Parts: the State-of-the-Art" June 2001 (reviewed in *TREE*, November 2001);
- Organizer, thematic session on Ecological Economics of Estuaries, ERF meeting, 1999;
- Participant, workshop on aquatic ecosystem conservation in the Adirondacks, The Nature Conservancy, June 2002;
- Participant, workshop on Research Agenda for A Rivers and Estuaries Institute (G. Likens and R. Bell, conveners), West Point, NY, February 2001;
- Participant, "Valuing the World's Ecosystem Goods and Services" (R. Costanza and S. Farber, PI's), National Center for Ecological Analysis and Synthesis, Santa Barbara, CA.

Regional: Co-convener of a workshop on sustainable development in Dutchess County, NY (March 2001).

<u>*On campus*</u>:
Co-convener of two seminar series; developing interdisciplinary courses in Watershed Ecology; member of Center for Watershed Science and Engineering; member of Urban Ecology Initiative. In addition, I teach Fisheries Biology and graduate seminars.

Recent Grants (not including travel grants)

2002	Grant award, New York State Department of Environmental Conservation: "Ecology of the Quassaick Creek prior to dam removal" (with Hudsonia, $24,868)
2001	*Conference support*: raised $15,000 in support of "SHAD 2001: A Conference on the Status and Conservation of Shads Worldwide", and $5,750 in support of a workshop "Analysis, Interpretation, and Applications of Fish Otoliths and Other Hard Parts: State-of-the-Art"
	Grant approved, Great Lakes Research Consortium, funding subject to NYS budget: "Silica mediation of food web biochemical structure in the Great Lakes" ($23,506)
2000	Grant award, Hudson River Foundation: "Modeling and Measuring the Process and Consequences of Land Use Change: Case Studies in the Hudson River Watershed" ($296,750 6/00-6/03, with RPI)
1999	Grant award, Hudson River Foundation: "Blueback Herring: Trophic Links to the Watershed?" ($96,960, through 12/01)
	Grant award, New York Sea Grant: "Ecological Constraints on Establishment of a Freshwater-Resident Population of Blueback Herring in the Mohawk/Hudson Drainage" (2 years, $74,377)
	Grant award, Ax:son Jonsson Foundation (Sweden): "Building linkages between natural and social sciences" (approx. US $13,000)
1998	Grant award, Swedish Agricultural and Forestry Research Council: "Revealing Complex Life Histories of Fishes Through Natural Information Storage Devices: Case Studies of Diadromous Events as Recorded by Otoliths" (approx. US $90,000)

Five publications relevant to this proposal:

Limburg, K.E., H. Wickström, H. Svedäng, M. Elfman, and P. Kristiansson. 2002. Do stocked freshwater eels migrate? Evidence from the Baltic suggests "yes." ***Biology, Management and Protection of Catadromous Eels*** (American Fisheries Society Symposium Series, in press).

Limburg, K.E., M. Elfman, P. Kristiansson, K. Malmkvist, and J. Pallon. 2002. New insights into fish ecology via nuclear microscopy of otoliths. *Proc. Conf. on Applications of Accelerators in Research and Industry* (in review).

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Five Other Publications:

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Limburg, K.E. 1998. Anomalous migrations of anadromous herrings revealed with natural chemical tracers. *Canadian Journal of Fisheries and Aquatic Sciences* 55: 431-437.

CURRICULUM VITAE

Robert Edward Schmidt, Ph.D.
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Birth date: 26 Sept. 1946

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Bard College
Annandale, NY 12504
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Present Position:
Professor of Zoology and Environmental Studies and director of nonprofit environmental research corporation. Responsible for grant proposals, field research, report writing, and undergraduate and graduate instruction.

Education:
University of Rhode Island, Kingston, RI – BS in Zoology, 1969.
University of Connecticut, Storrs, CT – MS in Fisheries Biology, 1971.
Texas A&M University, College Station, TX – Ph.D. program, 1972-73.
University of Connecticut, Storrs, CT – Ph.D. in Zoology (Ichthyology), 1976.

Distinctions:
Phi Kappa Phi national honor society, Phi Sigma zoological society.
Member: American Fisheries Society, American Society of Ichthyologists and Herpetologists, Biological Society of Washington, Estuarine Research Federation, American Institute of Fisheries Research Biologists
Board of Directors: Berkshire Environmental Research Center, Hudsonia Limited, Northeastern Naturalist
Reviewer: National Science Foundation, Systematic Zoology, Hudson River Foundation, CUNY Research Award Program, J. Freshwater Ecology, Wildlife Conservation Society, Ichthyological Explorations of Freshwaters, Northeastern Naturalist, Polish Archives of Hydrobiology, Fishery Bulletin
Associate Curator: New York State Museum (Fishes)

Positions Held:
Assistant Professor, Biology Dept., Fordham University, 1976-80.
Fisheries Research Biologist, Texas Instruments (Hudson River Survey), 1980.
Adjunct Assistant Professor, Borough of Manhattan Community College, 1981; Mercy College, 1981-83; County College of Morris, 1983; Upsala College, 1981-84.
Biological Consultant, Natural Resources Dynamics, 1981.
Director, Hudsonia Limited, 1981-89; Associate Director, 1990-present.
Faculty, Bard College Graduate School of Environmental Studies, 1988-2002.
Professor, Simon's Rock College of Bard, 1984-present.
Director, Berkshire Environmental Research Center, 1986-present.

Research Experience:
Life history of bluefish, Sandy Hook Marine Lab, NJ.
Fisheries and limnological survey of Thames River system, CT.
Coho salmon stocking and American shad restoration program, Thames River, CT.

Life history of estuarine white catfish population.
Impact of thermal effluent on fishes in Galveston Bay, TX.
Snorkeling as a stream fish assessment technique in New England.
Parasite and disease survey of largemouth bass and white suckers in CT.
Biogeography and biology of swamp darters in New England.
Water quality surveys of New York streams.
Use of daily growth rings on fish otoliths.
Ichthyological collecting in the US and Guyana, SA.
Distribution and movements of important Hudson River fishes.
Analysis of discharger compliance with water quality limits, NY.
EIS to establish Estuarine Sancuaries on the Hudson River.
Curation of Hudson River larval fishes, AMNH and NYSM.
Larval fish descriptions and dynamics in the Hudson River.
Fish community structure in tidal freshwater marshes.
Role of tributaries in Hudson River ecology.
Documentation of anadromy and potamodromy in Hudson River tributaries.
Restoration of dammed streams in Hudson River basin.

College Teaching Experience:
I have taught organism through ecosystem level courses primarily animal-oriented including environmental sciences and paleontology. These courses have served non-science majors and beginning biology majors through graduate courses.

Graduate Advising:
Systematics, biology and behavior of the cutlips minnow.
Population dynamics of largemouth bass/redbreast sunfish pond.
Pathogenicity of *Aeromonas* to trout.
Biogeography and taxonomy of *Etheostoma olmstedi* and *E. nigrum.*
Systematics of Centrarchidae.
Zoogeography of Connecticut herptiles.
Discrimination of American shad stocks on the East Coast.
Inshore transport of larval Labridae in the New York Bight.
Population fluctuations of larval smelt in the Hudson River.
Development of an IBI for the Hudson Valley.
Development of HIS for skinks in Connecticut.
Comparison of macroinvertebrate indices in detecting water quality degradation.
Fish communities in water chestnut stands in the Hudson River.
Use of macroinvertebrate indices to detect a non-point source of pollution.
Computerization and modification of a Hudson Valley IBI.

MS Thesis:
Life history of the white catfish (*Ictalurus catus*) in the lower Thames River System, Connecticut.

Ph.D. Thesis:
Distribution and habitat of *Ethestoma fusiforme* with emphasis on southern New England.

Major grants received (as principal investigator):

- Ecology of stream fishes- NIH Biomedical Research grant and Fordham University Research Council, 1976-78
- Fish survey of the Bronx River- Exxon Corp. and Bronx River Restoration, 1979
- Water Quality of the Bronx River- Eppley Foundation, 1980
- Fishes of Great Brook, NJ- Timber Properties, Inc., 1981
- SPDES permit compliance- Hudson River Sloop Clearwater, Inc., 1982
- Curation of Hudson River larval fish collection at AMNH- Hudson River Foundation, 1984
- Survey of biota and water quality of Fishkill Creek, NY- Hudson River Fisherman's Assoc., 1985
- Fish community structure in Tivoli North Bay, NY- NOAA, Office of Oceans and Coastal Resources Management, 1985
- Assessment of aluminum deposition in Crum Elbow Crk., Hyde Park, NY- Hyde Park Fire and Water Dist., 1986
- Larval fish communities in water chestnut stands- Hudson River Foundation, 1987
- Assessment of anadromous fish runs in Quassaick Crk., Newburgh- Hudson River Foundation, 1987
- Estimate of the value of non-tidal portions of Hudson River tributaries for anadromous fish spawning- Hudson River Foundation, 1988
- Baseline assessment of tributaries to the Hudson- Hudson River Improvement Fund, 1988
- Water quality assessment of the Saugus River, MA- NE Natural Resources Research Center & Mass. NYPIRG, 1990
- Fishes in Manitou Marsh, Hudson River- Museum of the Hudson Highlands, 1992
- Drift of fish larvae in Stockport Creek, NY- Hudson River Foundation, 1993
- Survey of barriers to anadromous fishes in Hudson River tributaries- Hudson River Foundation, 1995
- Alewives in Hudson River tributaries- Hudson River Foundation, 1998-99
- Survey of fishes in Schenob Brk., MA- Sweetwater Trust, 1999
- Survey of crayfish and mussels in Schenob Brk.- Sweetwater Trust, 2000
- Monitoring program for fishes in Tivoli Bays, NY- NYS DEC, 2001-02
- Identification of larval fishes in the Neversink R., NY- The Nature Conservancy, 2001
- Macroinvertebrates in Berkshire-Taconic streams- The Nature Conservancy, 2001

Relevant and Recent Publications- Robert E. Schmidt

Schmidt, R.E. 1975. Barriers to anadromous fishes and stream bank use in the Thames River watershed, Connecticut. p. 101-110. *In* R.L. Hames (Ed.). An evaluation of the fishery resources of the Thames River watershed, Connecticut. Storrs Agr. Exp. Sta. Bull. 435.

Schmidt, R.E. 1986. Fish community structure in Tivoli North Bay, a Hudson River freshwater tidal marsh. Rept. to NOAA, Estuarine Sanctuary Program, 47 p.

Schmidt, R.E. and E. Kiviat. 1988. Communities of larval and juvenile fishes associated with water-chestnut, watermilfoil, and water-celery in the Tivoli Bays of the Hudson River. Rept. to Hudson River Foundation, 36 p.

Klauda, R.J., R.E. Moos and R.E. Schmidt. 1988. Distribution and movements of Atlantic tomcod in the Hudson River estuary and adjacent waters. p. 219-251. *In*. C.L. Smith. (Ed.). Fisheries Research in the Hudson River. SUNY Press, Albany, NY.

Schmidt, R.E., R.J. Klauda and J.M. Bartels. 1988. Distribution and movements of the early life stages of three *Alosa* spp. in the Hudson River estuary, with comments on mechanisms that reduce interspecific competition. p. 193-215. *In*. C.L. Smith. (Ed.). Fisheries Research in the Hudson River. SUNY Press, Albany, NY.

Klauda, R.J., J.B. McLaren, R.E. Schmidt and W. Dey. 1989. Life history of white perch in the Hudson River, New York. p. 69-88. *In*. L.W. Barnthouse, R.J. Klauda, D.S. Vaughan and R.L. Kendall. (Ed.). Science, Law and the Hudson River Power Plants: A Case Study in Environmental Impact Assessment. American Fisheries Society, Monograph #4.

Limburg, K.E. and R.E. Schmidt. 1990. Patterns of fish spawning in Hudson River tributaries: Response to an urban gradient? Ecology 71(4): 1238-1245.

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Schmidt, R.E., A.B. Anderson and K.E. Limburg. 1992. Dynamics of larval fish populations in a Hudson River tidal marsh. p. 458-475. *In*. C.L. Smith. (Ed.). Estuarine Research in the 1980[s]. Seventh Symposium on Hudson River Ecology, Hudson River Environmental Society. SUNY Press, Albany.

Schmidt, R.E. and S. Cooper. 1996. A catalog of barriers to upstream movement of migratory fishes in Hudson River tributaries. Rept. to Hudson River Foundation, 184 p.

Lake, T.R. and R.E. Schmidt. 1997. Seasonal presence and movement of fish populations in the tidal reach of Quassaic Creek, a Hudson River tributary (HRM 60): Documentation of potamodromy, anadromy, and residential components. Section VII, 36 p. *In*. W.C. Nieder and J.R. Waldman. (Ed.). Final Reports of the Tibor T. Polgar Fellowship Program, 1996. Hudson River Foundation, NY.

Lake, T.R. and R.E. Schmidt. 1998. The relationship between fecundity of an alewife (*Alosa pseudoharengus*) spawning population and egg productivity in Quassaic Creek, a Hudson River tributary (HRM 60) in Orange County, New York. Section II, 26 p. *In*. W.C. Nieder and J.R. Waldman. (Ed.). Final Reports of the Tibor T. Polgar Fellowship Program, 1997. Hudson River Foundation, NY.

Schmidt, R.E. and T. Stillman. 1998. Evidence of potamodromy in an estuarine population of smallmouth bass (*Micropterus dolomieu*). J. Freshwater Ecol. 13(2): 155-163.

Horn, E. and R.E. Schmidt. 1999. Health Consultation: 1996 Survey of Hudson River Anglers. NYS Dept. Health, Public Review Draft: NYD 980763841, 48 p.

Waldman, J.R., J.R. Young, B.P. Lindsay, R.E. Schmidt and H. Andreyko. 1999. A comparison of alternative approaches to discriminate larvae of striped bass and white perch. N.A.J. Fish. Mgt. 19(2): 470-481.

Schmidt, R.E. and T.R. Lake. 2000. Alewives in Hudson River tributaries, two years of sampling. Rept. to Hudson River Foundation, NY. 37 p.

Kiviat, E. and R.E. Schmidt. 2001. Vegetation and fish sampling in six Hudson River tidal marshes, 1999. Rept. to Hudson River National Estuarine Research Reserve and NY State Dept. Environmental Conservation, 31 p.

Limburg, K.E., I. Blackburn, R.E. Schmidt, T.R. Lake, J. Hasse, M. Elfman and P. Kristiansson. 2001. Otolith microchemistry indicates unexpected patterns of residency and anadromy in blueback herring, *Alosa aestivalis*, in the Hudson and Mohawk Rivers. Bull. Fr. Pêche Piscis. 362/363: 931-938.

Schmidt, R.E. and T.R. Lake. 2001. A benthic juvenile scrawled cowfish (*Acanthostracion quadricornis*) from the lower Hudson River estuary. NE Nat. 8(3): 343-346.

Schmidt, R.E., E. Griffin-Noyes and A. Lavine. 2002. Monitoring fish populations in the Tivoli Bays Hudson River National Estuarine Research Reserve: Year one. Rept. to Hudson River National Estuarine Research Reserve, 20 p.

Schmidt, R.E. and T.R. Lake. 2002. Migratory fishes in the tidal Pocantico River. Rept. to Habitat Restoration Prog., Hudson River National Estuarine Research Reserve, 7 p.

APPENDIX A –

Project Description of Recent DEC Award to R.E. Schmidt
"Study of Glass Eel Immigration in Two Hudson River Tributaries"

A. Relevant Experience

I have over 20 years of experience studying fishes in the Hudson River. I began working with Texas Instruments in 1981 on the Hudson River Ecological Survey and have subsequently been doing fish and fisheries research with Hudsonia Limited. I published 18 papers on Hudson River fishes (3 more now in review) and written 38 major reports to funding agencies including the Hudson River Foundation, New York State DEC, New York State Dept. of Health, NOAA, and others. My full CV is available on request.

I have not worked specifically with eels. I have surveyed all major and most minor tributaries to the tidal Hudson River for presence of barriers to migratory fishes and therefore I have considerable first-hand knowledge of those areas. I have sampled fishes in many of these tributaries with seines, gill nets, drift nets, and electrofishing. I have observed glass eels on many occasions and I have taken them in drift nets- an incidental catch since these nets are supposed to collect fishes drifting downstream not those swimming upstream. When I have electrofished in Hudson River tributary mouths, eels are the most abundant species present.

I am familiar with use of a variety of gear and I have caught glass eels and yellow eels frequently. I just haven't done it quantitatively yet.

B. References

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C. Methods

Site Selection

There are over 60 tributaries to the tidal Hudson River and potentially they all have runs of glass eels. I propose to sample two tributaries in different areas of the Hudson River to examine the possibility that glass eel migration may differ in at least pattern and timing.

The considerations I used to select these two sites were (not necessarily in order of importance): ease of access from the shore, security from tampering, distance apart in the Hudson, and sampling convenience to control travel costs. The Saw Kill in northern Dutchess County (River Mile 99- measured north from the southern tip of the Battery in Manhattan) and Hunters Brook, a tributary to the tidal mouth of Wappingers Creek in southern Dutchess County (RM 67), seem to be the best choices. I am open to discussion on this point.

The Saw Kill is bordered by Bard College and Montgomery Place, both of whom monitor public access to the stream. In addition, Hudsonia Limited has its office and the Hudson River National Estuarine Research Reserve has its headquarters in a building adjacent to the Saw Kill making research access simple. Hunters Brook is a tributary of similar size to the Saw Kill, seems to hold little public interest for local people, and is very close to home for our prospective field worker.

I have sampled yellow eels and glass eels from the Saw Kill. Hunters Brook has a fairly dense population of yellow eels (K. Limburg, SUNY ESF, *pers. comm.*) and therefore probably has a glass eel run.

Gear Selection and Placement

Given the three choices of gear in the IFB, I prefer the Sheldon eel trap. It appears to be less complicated to set and tend than the other options and simpler to repair. This trap has certainly been used with great success in areas similar to those I am proposing. If possible, I would like to discuss using the glass eel sampler that the Connecticut DEP is deploying on its glass eel surveys (T. Wildman, CT DEP, *pers. comm.*). There may be some value in using gear directly comparable to that used in their surveys.

The gear will need to be fished upstream of tidal influence. Reversing tidal flows will reduce effectiveness of the gear half the time and may disturb the set requiring constant monitoring and frequent resetting. Both proposed streams have adequate area upstream of tidal influence to set and manage the gear.

I will have two extra sets of gear available to replace the ones in use.

Sampling Effort

I will be ready to place two gear units on February 1 but I doubt that it will be possible. Last winter, it probably would have been feasible to set gear that early, but I think it is unlikely this year. The CT DEP sets their gear on March 1 hoping to see zero catches (thus assuring that they sample the whole run- S. Gebhard, CT DEP, *pers. comm*.). Sometimes they catch glass eels immediately. Therefore, it is wise to have gear fishing as soon as possible in the spring. I will also be prepared to take gear out if spring runoff threatens to damage the gear.

Although a minimum of 10 weeks of sampling is specified in the IFB, I do not think that is adequate time to sample the entire run of Hudson River glass eels. I have taken glass eels in drift nets well into early June (and they were the same size as glass eels taken earlier in the season, ~60 mm). Therefore I have budgeted this proposal for 15 weeks (about March 1-June 15).

Field and Laboratory Procedures

The field and laboratory data to be gathered was spelled out very clearly in the IFB and I will gather the required data in its specified manner.

Generally, this means checking traps daily, counting or estimating glass eel numbers by counting three weighed subsamples, and releasing the eels as a specified distance from the sampling site. Any bycatch will be identified, counted, and measured. (I have documented spring tributary runs of many Hudson River fishes and certainly some will be collected.)

Measuring, weighing, and staging (Haro and Krueger 1988) up to 60 glass eels twice a week will have to be done in the laboratory. I don't think the accuracy required, especially in staging, is reasonably attainable in the field. Specimens will be collected soon after sampling and transported to the lab. Eels will be anaesthetized, measured with a digital caliper, weighed to 0.01 gr on a benchtop electric balance, and staged under a dissecting microscope. Specimens will then be preserved and archived at the New York State Museum (I am an Associate Curator of Fishes). These specimens could be a valuable resource for further studies, such as feeding habits.