American Eel and Perched Culverts in the Hudson Valley

Final Report to

NYS Water Resources Institute at Cornell University and
Hudson River Estuary Program, NYS DEC
21 South Putt Corners Rd.
New Paltz, NY 12561

Dr. Robert E. Schmidt
Berkshire Environmental Research Center
Bard College at Simon's Rock
Great Barrington, MA 01230
schmidt@simons-rock.edu

and

Richard A. Brase
Environmental Science Program
Marist College
Poughkeepsie, NY 12601
rickybrase@yahoo.com

January 5, 2016

This report was prepared for NYS Water Resources Institute at Cornell University and the NYS Department of Environmental Conservation Hudson River Estuary Program, with support from the NYS Environmental Protection Fund.

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A Program of the New York State Department of Environmental Conservation

Preface

This document summarizes field work done in 2015 the status of American eel (*Anguilla rostrata*) populations in the vicinity of perched culverts in the Hudson Valley. Streams were sampled both downstream and upstream of the culverts to determine the presence and abundance of American eel.

Introduction

The American eel (*Anguilla rostrata*) is a catadromous fish with substantial historical commercial value in the Hudson Valley. Today, American eel cannot be sold commercially for human consumption due to PCB contamination. American eel is a very fatty fish (3-17% body weight, S. Mount, SUNY ESF, pers. comm.) and PCBs selectively bind to fats. Therefore, there is virtually no fishing mortality in the Hudson River American eel population.

American eel populations on the East Coast of the United States are in serious decline (Haro et al. 2000). A recent report addressing continent-wide American eel populations found that this species is drastically declining or extinct at the inland extremes of its range (Anon. n.d.). On the other hand, densities of American eel in the mouths of Hudson River tributaries are among the highest ever observed. Machut et al. (2007) reported up to 1.5 eels/m^2 in Hudson River tributaries, Schmidt et al. (2006) reported >1.3 eels/m^2 and 15-30 g/m^2 in the mouth of the Saw Kill (Annandale), and Frank et al. (In press) reported 1.2 eels/m^2 in the Klyne Esopus Kill, a tiny tributary south of Kingston. In contrast, Morrison and Secor (2004) estimated the mean density of American eel in the tidal Hudson River at 0.0095 eels/m^2 (0.005-0.018), however they could only catch large eels (28-67 cm TL) in their baited traps.

The disparity between observations at the extremes of its range and observations in Hudson River tributary mouths is due to the mode of migration of this species. Smogor et al. (1995) successfully modeled the decrease in American eel density with distance from the sea as a simple diffusion model:

$$Y = ae^{-X/c}$$

Where: **Y** = eel density, **X** = distance from the ocean, **e** is the base of the natural logarithm, and **a** and **c** are parameters from a linear regression. The researchers were able to explain up to 85% of the variation in American eel density with this equation. In fact, they stated, "For large scales, espousing or elaborating relations between American eel occurrence and habitat features … is unwarranted; distribution and abundance of American eels may be mostly functions of distance from the ocean …".

Conclusions drawn from the diffusion model are very important. The implication is that American eel migration is driven by high densities. much like diffusion is faster when concentrations of materials are very high. Thus in locations like the mouths of Hudson River tributaries, high densities should cause American eel to migrate upstream and higher densities should be correlated with more migrants moving upstream. Likewise, migrants should stop moving upstream when densities of American eel are low. If we then propose that American eel numbers overall are being reduced (by several human activities, Haro et al. 2000) then overall densities will be lower and fewer eels will migrate upstream. The result is that migrants no longer reach the farthest locations in the stream systems, and we perceive this as a decline in the populations at the edges of the range.

There may be two mechanisms occurring in American eel populations at high densities that produce this diffusion effect. One is the aggressive nature of the American eel. Ian Hetterich did an experiment with captive American eel several years ago at Bard College at Simon's Rock. He noticed that there were a large number of aggressive interactions among the three American eels in his tank and that the marginally largest of the three was dominant. In fact, one of the captives died due to *Saprolegnia* infection of wounds received from the dominant individual. American eel at high densities will probably be quite aggressive and it will be the small eels, subordinate individuals, who will migrate. Our data from the eel "ladder" on the lowest dam on the Saw Kill supports that the migrants are mostly small, 10-15 cm TL (Schmidt et al. 2009, and unpublished data).

Additionally, high densities of American eel may alter the availability of food that smaller eels depend on. There are some data from the Saw Kill that show a decrease in macroinvertebrate density where American eel are most dense. Reduced food availability could also be a trigger for small American eel to leave and move upstream.

Dams and American eel migration.

Really large dams, e.g. the Conowingo Dam on the Susquehanna River, are complete barriers to upstream movement of American eel. However, American eel are remarkably able to ascend or circumvent smaller dams. This ability is not perfect and the percentage of migrators that do manage to pass by a dam is relatively low. Machut (2006) and Machut et al. (2007) reported that, as a rule of thumb, density of American eel is reduced by 90% above each barrier and it does not seem to matter whether the barrier is large or small. Dams tend to artificially increase the density of American eel below them, because the majority of migrators do not pass the barrier, and artificially reduce the density of American eel upstream of them. Thus the number of American eel that will continue to migrate upstream is reduced. Goodwin and

Angermeier (2003) and Wiley et al. (2004) noted that eel densities increased just below barriers in streams.

It is doubtful that there are any dams in the Hudson Valley that are complete barriers to American eel migration. American eel has been collected upstream of the Croton Dam and the dam and falls on Esopus Creek, two of the Hudson Valley's largest structures. However, all dams, even the many small mill dams, impede upstream migration of American eel.

Impoundments, lakes, and American eel migration.

Once American eel pass by a dam, the fish encounter impoundments that vary from trivial to large. Large American eel do not seem to inhabit very small impoundments but can be collected upstream of them (Anderson and Schmidt 2006, Machut 2006). Large impoundments, however, can provide suitable habitat for large American eel and may be a highly significant source of female silver eels in the Hudson Valley. RES went electroshocking on Lake Taghkanic with Scott Wells, Region 4 DEC, in summer 2015. They observed ~15 very large American eel and measured one at 84 cm. Lake Taghkanic is a relatively shallow lake and eels are susceptible to boat electrofishing there. Other deeper lakes may well hold substantial numbers of large American eel but are extremely hard to sample. [Baited traps may be effective, but have not been tried to our knowledge].

It appears that once American eel gain access to large lakes, migration stops. This may well be a result of low densities of American eel in those lakes. The following observations seem to support this idea. Eels were collected by electrofishing in Croton Reservoir but an electrofishing survey of the streams tributary to the reservoir collected no American eel (RES and T. Baudanza, NYS DEP). Electrofishing in a stream tributary to Sleepy Hollow Lake on the Murderers Kill, Athens, turned up no American eel (J. Wright and B. Weatherwax, NYS

Museum, pers. comm.). RES and R. Kennedy (then Hudson River Fisherman's Association) electrofished a stream tributary to Chadwick Lake on Quassaic Creek and found no American eel. A recent survey of Rockefeller Preserve documented American eel downstream of Pocantico Lake, but none in a tributary to the lake (Schmidt 2015). RES has observed large American eel below the Red Mills Dam on Claverack Creek but American eel were not present in Hollowville Brook, a tributary to the impoundment formed by Red Mills Dam. RES (with J. Wright and B. Weatherwax) collected American eel below the Robinson Pond Dam on the Roeliff Jansen Kill, but RES has never seen American eel upstream of that impoundment.

Methods

Perched culverts were located by Andrew Meyer and Megan Lung, NYS DEC. Several additional perched culverts were discovered in drainages that were not surveyed by the DEC.

American eel was collected with a Smith-Root backpack electroshocker. At a given location, area to be sampled was determined by eye and was often dictated by the physiography of the stream. The plan was to sample below the perched culvert, above the culvert, and at the next barrier upstream where eels that may have passed the culvert were likely to concentrate. If none were found below the culvert, the site was assumed to contain no American eel. If the area upstream of the culvert and next barrier were close to each other, the two sampling areas were combined into one.

A two-pass sequential removal method was used to estimate the number of American eel at each location for those locations that had American eel. Stunned American eel were collected with dip nets and counted on site. American eel from the first pass were held in a bucket until the second pass was completed and then all individuals were returned to the stream. The length and width of the stream segment sampled was measured with a tape, and area sampled calculated from those measurements.

Eel population estimates were calculated using the following two-pass depletion equations where N = the population estimate, C_1 = the number of eels caught on the first pass, C_2 = the number of eels caught of the second pass and p = the probability of capture (Lockwood and Schneider 2000):

$$p = \frac{C_1 - C_2}{C_1} \quad [1]$$

$$N = \frac{C_1^2}{(C_1 - C_2)} \quad [2]$$

$$Variance\ of\ N = \frac{C_1^2 C_2^2 (C_1 + C_2)}{(C_1 - C_2)^4} \quad [3]$$

$$Standard\ Error\ of\ N = \sqrt{Variance\ of\ N} \quad [4]$$

$$95\%\ Confidence\ Limits = N \pm 2(Standard\ Error\ of\ N) \quad [5]$$

Population estimates were considered unbiased when $p \geq 0.80$ and unreliable when $p \leq 0.20$ (Lockwood and Schneider 2000).

An exception to the above methodology occurred in several small streams where visibility and accessibility to the American eel population was high. In those cases where very few eels were collected and it seemed highly unlikely that any more would be collected, only one pass was done and all the American eel present were assumed to have been caught. This was called a “Direct Count”. With very small numbers, especially if the second pass collected no American eel, the above calculations become superfluous.

In one instance, a three-pass calculation was done because the number of American eel collected did not decrease in the second pass. This method is also described in Lockwood and Schneider (2007). Instead of reproducing the complex formulae here, please refer to that publication.

Densities (number of American eel per m^2) were calculated from the two-pass or three-pass depletion data or a direct count. Those numbers were divided by estimates of the area sampled.

Longitude, latitude, and altitude of each sampling site were estimated from Google Earth. Total distance to the tidal Hudson River was measured with the Google Maps calculating tool, following the meanders of the streams. The number of dams or natural barriers (waterfalls) between the site and the tidal Hudson River was taken from several sources: Schmidt and Cooper (1996), the NYSDEC Inventory of Dams, culvert assessment field work done by the Dutchess County Soil and Water Conservation District, the Student Conservation Association and the NYSDEC/Water Resources Institute Hudson River Estuary Program, culvert prioritization work done by The Nature Conservancy (Brown and Cheeseman 2011) , and from reconnaissance. Presence or absence of a large impoundment between the site and the tidal Hudson River was determined from topographic maps or reconnaissance. Gradient between the collection site and the tidal Hudson River was calculated by dividing the altitude (m) by the distance (m).

Passability scores were determined for each of the perched culverts where American eel was present using the North Atlantic Aquatic Connetivity Collaborative (NAACC, n.d.) protocol. These scores provide information about which locations are most likely to increase aquatic connectivity if a given culvert is improved. The scores are derived by an algorithm that includes several field observations such as; height of culvert above the stream surface, diameter of the culvert, material used in construction, and others. Field data were gathered by Andrew Meyer and/or Megan Lung of the DEC. The final scores were supplied by them. A chi-square test was used to determine whether the scores could predict observations by comparing the number of sample sites for each passability category where American eels either had or had not gotten above the culvert with a random distribution, i.e. all culverts are the same.

Results

Some of the perched culverts identified by the DEC personnel were not sampled. In two instances, tributaries of the Krumkill along Rt. 85 (Albany County), the streams were inaccessible due to chain link fencing along the highway corridor. In one instance, a perched culvert on Stockport Rd. in Kinderhook (Columbia County), the stream was very turbid and visibility would have been too poor for effective collection of eels.

More commonly, streams with perched culverts identified by the DEC personnel were dry when visited. These locations were on very small streams in headwaters of a given watershed. Examples are; a tributary to Mud Creek on Fingar Rd., Columbia County (Roeliff Jansen Kill) and a tributary to Cedar Pond Brook on Rt. 100, Rockland County (Cedar Pond Brook).

The next category of perched culverts (seven data points) is where the streams were running and sampling was feasible. However, thorough electroshocking indicated that there were no American eel in that segment of the stream (Table 1).

Finally, we visited eleven perched culverts where American eel were present downstream and adjacent to the culvert (Table 2). Eels were encountered at those sites that were, in general (Table 3), at lower altitudes, closer to the tidal Hudson River, and, probably most significantly, had few or no barriers between the site and the tidal Hudson River. Given the diffusion model of American eel migration, one should expect fewer American eel at greater distances from the

Table 1. Characteristics of perched culvert sites in the Hudson Valley where no American eel were detected. Sampling was done with a backpack electroshocker in summer 2015.

Culvert Site	Latitude & Longitude	Altitude Meters	Distance to tidal Hudson R. (m)	Gradient %	Known Barriers Downstream	Total Barriers
Dock Hill Ave., Cornwall Tributary to tidal Hudson River	41.442914 N -74.006906 W	38	709	5.4	None	0
Continental Rd., Cornwall Canterbury Brk., Moodna Crk.	41.426912 N -74.034131 W	114	3,927	2.9	None	0
Norton Rd., Rhinebeck Tributary to Saw Kill	41.971315 N -73.864050 W	76	10,139	0.8	3 dams, 3 falls	6
Whalesback Rd., Red Hook Tributary to Saw Kill	42.021244 N -73.895081 W	61	4,265	1.4	2 dams, 3 falls	5
Hollowville Crk., Hollowville Tributary to Claverack Crk.	42.204748 N -73.697712 W	88	26,473	0.3	3 dams, 1 fall, 1 lake	5*
Rt. 217, Claverack Tributary to Claverack Crk.	42.225144 N -73.715266 W	53	22,965	0.2	2 dams	2
Widows Crk., Kinderhook Tributary to Claverack Crk.	42.333211 N -73.711733 W	49	7,500	0.6	2 dams	2

*The presence of a lake in this system automatically means no American eel would be found.

Table 2. Characteristics of perched culvert sites in the Hudson Valley where American eel were detected. Sampling was done with a backpack electroshocker in summer 2015.

Culvert Site	Latitude & Longitude	Altitude Meters	Distance to tidal Hudson R. (m)	Gradient %	Known Barriers Downstream	Total Barriers
1. Dinsmore Park, Staatsburg Tributary to Indian Kill	41.847515 N -73.929137 W	6.1	1,876	0.3	None	0
2. Enderkill Rd., Staatsburg Indian Kill	41.846295 N -73.928527 W	6.1	1,418	0.4	None	0
3. Rt. 85, North Germantown Camp Creek	42.166164 N -73.870718 W	15.2	614	2.5	None	0
4. Access Rd., Tivoli Dace Brook	42.035478 N -73.909583 W	15.2	683	2.2	None	0
5. Wayne Ave., Stony Point Cedar Pond Brook	41.240844 N -74.024855 W	68.6	5,440	1.3	None	0
6. Rt. 210, Stony Point Tributary to Cedar Pond Brook	41.231019 N -74.002844 W	30.5	2,897	1.1	None	0
7. Rt. 9, Hyde Park Bard Rock Creek	41.805110 N -73.937551 W	30.5	679	4.5	None	0
8. Rt. 117, Sleepy Hollow Gorey Brook, Pocantico River	41.107872 N -73.850643 W	45.7	3,573	1.3	1 dam, 1 fall	2
9. Dalesbridge Rd., Germantown Tributary to Roeliff Jansen Kill	42.146221 N -73.860948 W	61	6,356	1.0	None	0
10. Krumkill Rd., Albany Krumkill, Tributary to Normanskill	42.659279 N -73.828003 W	38	14,243	0.3	None	0
11. Knickerbocker Rd., Schodack Schodack Creek	42.497153 N -73.745406 W	43	2,913	1.5	None	0

Table 3. Summary of characteristics of locations below perched culverts that had no American eel (7) and those that did have American eel (11). Distance was measured from the culvert site to the tidal Hudson River following the meanders of the stream, and gradient was calculated as altitude divided by distance expressed as a percentage.

	Eels Absent		Eels Present	
	Mean	Range	Mean	Range
Altitude (m)	68.4	38-114	32.7	6.1-68.6
Distance (km)	10.8	0.7-26.5	3.7	0.6-14.2
Gradient (%)	1.7	0.2-5.4	1.5	0.3-4.5
# Barriers	2.9	0-6	0.2	0-2

source (the mouth of the stream in the Hudson River). Given our understanding of how barriers affect American eel movements, one should expect that streams with more barriers (natural or otherwise) should have a lower density of American eel. The difference in altitude of culvert sites (Table 3) may be due to misclassification of steep areas of streams which may actually be barriers rather than passages.

American eel was sampled at eleven perched culverts. Sampling below the culvert and directly above the culvert was always possible, but sampling at the next upstream barrier was only possible in three instances (Table 4). At most of the sites, the stream decreased in size upstream of the culvert, had no barriers, and ultimately disappeared. At two culverts, there was no access to the stream at the next barrier.

Densities of American eel downstream of the eleven perched culverts ranged from 0.001-0.98 eels/m^2. It should be noted that some of these values are underestimates because three of the

Table 4. Number and densities of American eel collected by electroshocking in the vicinity of perched culverts in the Hudson Valley, summer 2015. Population size of American eel (#) was either estimated by two or three-pass depletion methods (E) or by direct count (D). Densities are given in # American eel/m^2.

	Below Culvert			Above Culvert			Next Barrier		
Sample Site	#	Density		#	Density		#	Density	
Dinsmore Park[1]	21.3±32	0.01	E	0			0		
Enderkill Rd.	5.3±6	0.11	E	1	0.02	D	-[2]		
Clear Crk.	12.1±0.7	0.01	E	0			2	0.001	D
Dace Brk.[3]	5±0.9[4]	0.007	E	0			-		
Cedar Pond Brk.[3]	1	0.001	D	3	0.004	D	-		
Rt. 210[3]	1	0.003	D	0			-		
Bard Rock Crk.	23[4]	0.98	D	0			-[2]		
Gorey Brk.[3]	3	0.03	D	1[5]	0.005	D	-		
Dalesbridge Rd.	19±4	0.65	E[6]	0			-[7]		
Krumkill	2[4]	0.01	D	2	0.03	D	12±36	0.12	E
Schodack Crk.[3]	2[4]	0.04	E	0			-		

[1]The upstream area and the next barrier were close together and treated as one sample.
[2]The next barrier upstream was on private property and could not be accessed.
[3]There is no other barrier upstream of the culvert.
[4]The number of American eel below the culvert is an underestimate due to a deep pool.
[5]This datum from Schmidt (2015).
[6]Three-pass depletion method.
[7]Area upstream of the culvert is a vast swamp which could not be sampled.

sites had deep pools under the culvert that could not be sampled with a backpack shocker. These pools certainly contain American eel, and perhaps in substantial numbers. The highest density reported here is one of those underestimates (Bard Rock Crk.) and the actual density of American eel at this culvert may equal or exceed the high densities observed in tributary mouths. The densities observed spanned three orders of magnitude (or four, given that the density at Bard Rock Crk. is an underestimate) and therefore calculating a mean density would be uninformative.

At seven sites, no American eel was collected directly above the culvert. At two sites the density of American eel directly upstream of the culvert was an order of magnitude lower than the density downstream of the culvert. At two sites, the density of American eel was about the same downstream and upstream of the culvert (but at one of these sites, the Krumkill, the downstream numbers were underestimated). At the three locations where the next barrier upstream was accessible, the density of American eel at that upstream barrier was the same as the density above the culvert or higher.

Passability scores calculated for the eleven sites where American eel was collected fell into three categories; Moderate, Significant, and Severe. Therefore none of the sites would allow for unrestricted fish passage and those in the "Severe" category would essentially prohibit fish passage. American eel were not observed upstream of the three sites categorized as "Severe" (Table 5), but were observed upstream of some of the sites categorized as "Moderate" and all of the sites categorized as "Significant". The chi-square test showed that the distribution of sites among categories was not significantly different from a random distribution ($X^2 = 5.89$, $p = 0.32$).

Table 5. Relationship between the density of American eel downstream and upstream of perched culverts in the Hudson Valley and the Passability Score of the culverts. Numbers are American eel density (# eels/m^2) and the densities reported above the barrier are the higher of the densities just above the barrier or at the next barrier upstream. The Passability Score is rated from most to least likely to pass fishes: Moderate > Significant > Severe.

Sample Site	American Eel Density Below	American Eel Density Above	Passability Score
Dinsmore Park	0.01	0	Severe
Enderkill Rd.	0.11	0.02	Moderate
Clear Crk.	0.01	0.001	Significant
Dace Brk.	0.007	0	Moderate
Cedar Pond Brk.	0.001	0.004	Significant
Rt. 210	0.003	0	Moderate
Bard Rock Crk.	0.98	0	Severe
Gorey Brk.	0.03	0.005	Significant
Dalesbridge Rd.	0.65	0	Moderate
Krumkill	0.01	0.12	Significant
Schodack Crk.	0.04	0	Severe

Discussion

American eel can bypass or pass through perched culverts but with varying success. Five of the eleven perched culverts sampled had American eel upstream of the culvert (Table 4). It is likely that there are American eel above three more of the sites where sampling was not feasible. Thus the remarkable ability of American eel to get above dams applies to their ability to get above perched culverts as well.

However, American eel do not pass perched culverts very well. In two instances the density of American eel directly upstream of the perched culvert was the same order of magnitude as the density below the perched culvert. At all other perched culverts examined, the density of American eel directly upstream of the culvert was at least an order of magnitude lower than the density below the perched culvert. This is the same pattern that has been reported for dams on Hudson River tributaries (Machut 2006, Machut et al. 2007).

The density of American eel below the next barrier upstream of a perched culvert was higher than the density just upstream of the culvert in the two instances documented here. This observation gives some support to the hypothesis that once American eel pass an obstacle migration continues until they encounter the next obstacle and build up a denser population there.

Because American eel do pass around or through perched culverts, the Passability Scores are not useful for predicting whether a particular culvert is a barrier or not. Perched culverts are behaving just like dams in terms of their effects on American eel populations, although perched culverts are usually found on small streams and thus are probably affecting fewer American eel than dams.

Modifications of perched culverts will enhance the movement of American eel upstream. In many instances, the ideal modification would be to use and open-bottom culvert so that the stream substrate continues through the road crossing without interruption. For closed culverts, the upstream and downstream ends should be buried , so that the substrate of the stream is continuous and level with the stream bed at the inlet and outlet. Culverts should be wide enough so that there is minimal damming upstream and scouring downstream (> 1.25 bankfull width). The amount of light in the culvert can affect the ability of some organisms to pass through. Speed and depth of the water in the culvert can also be important and should match the speed and depth of the stream beyond the culvert. All of that costs money.

This study was limited to sampling perched culverts. The number of perched culverts that are close enough to the Hudson River and have few dams and falls between the culvert and the

Hudson River (and thus are likely to have American eel nearby) are relatively few. Not all Hudson River drainages have been surveyed, however. There are many culverts that are not perched and there are no data on whether American eel perceive these structures as barriers or not. The next hypothesis that needs to be tested is that all culverts act as barriers to upstream movement of American eel.

Conclusions

1. Upstream movement of American eel is greatly affected by population size and density and by the number of natural and artificial barriers that the migratory individuals encounter.
2. Perched culverts affect American eel migration in the same manner as dams. American eel can pass perched culverts, but they do not do so very well. Hudson River tributaries in the watersheds surveyed so far where American eel are present have few perched culverts.
3. Passability Scores were not able to predict whether American eel can or cannot pass a given perched culvert from the small sample available.
4. A next question to address might be whether perched culverts are any worse at allowing American eel passage than culverts that are not perched.

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