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Evaluation of Barrier Dams to Adult Sea Lamprey Migration

by:

William D. Youngs[2]

[2]Department of Natural Resources
NYS College of Agriculture and Life Sciences
Cornell University
Ithaca, New York 14853

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Report on

Evaluation of barrier dams to adult sea lamprey migration

William D. Youngs
Department of Natural Resources
NYS College of Agriculture and Life Sciences
Cornell University
Ithaca, New York 14853

Abstract

The object of the experimentation was to determine vertical height migrating adult sea lamprey could ascend. This report summarizes work done at the experimental spawning channel at Myers Point on Cayuga Lake, New York, during 1978. Water flow was varied from 1-10 cfs with different height vertical barriers of nominally 35, 53 and 72 centimeters forming the barriers. Pool depth below a barrier varied with flow and was a contributing factor. Approximately 1,000 adult lamprey, trapped at Cayuga Inlet and transferred to the channel were used in the tests. Of 1,900 lamprey challenged (some lamprey were used more than once), no lamprey was able to negotiate a 30 cm difference between pool surface and weir crest, regardless of flow; only 13 lamprey were able to negotiate a height greater than 15.7 cm. There was indication of a lamprey size-vertical barrier height relationship but flow and temperature were confounding factors. A sample of 866 lamprey which were sexed consisted of 555 males and 311 females. Mean lengths were 44.22 cm and 42.99 cm for males and females based on samples of 411 and 270, respectively. The overall length-weight relationships were weight = 0.0036, length 2.8566 and weight = 0.0082, length 2.6578 for males and females respectively. General observations of behavior for this group of lamprey

is presented. It is recommended that further trials be conducted with barriers of 30 cm vertical height with exposure to the entire migration period. Other trials should be conducted simultaneously using various barrier designs such as inclined plane and ogive shaped surfaces.

Introduction

There is relatively little information reported in the literature concerning physical barriers to sea lamprey migration and, in particular, to vertical height that may be ascended. Applegate (1950) reported spawning migrant lampreys were able to pass falls of 4.5 and 6 feet high. He also reports migrants were able to pass an irregularly constructed logging dam but does not mention exact height. With regard to jumping, Applegate (loc cit) states "Observations on the Ocqueoc and at several high dams, such as those on the Cheboygan and Manistique rivers, indicate that sea lampreys can seldom "jump" vertically more than two feet although they have been occasionally observed leaping as much as four feet in a forward and slightly upward direction at the base of a natural falls." He also reported that sheer mass accumulation at some barriers was sufficient to allow passage of some uppermost individuals. Searching behavior of lamprey and its ability to find holes and cracks in barriers were also noted by him.

Wigley (1959) observed the behavior of sea lamprey on spawning migration in Cayuga Inlet. A low concrete dam resulting in a water level drop of 1 foot was reported by Wigley to form at least a partial barrier to migrating lamprey. He also observed that water flow was an important factor affecting upstream movement of lamprey.

The objective of this study was to determine the vertical distance that could be negotiated by adult lamprey on spawning migration.

Methods and Materials

The general procedure in testing vertical height as a barrier to migrating adult lamprey was to challenge a number of lamprey with a vertical barrier such that the desired test height was the difference between the elevation of the downstream pool and the crest of the barrier. Tests were conducted at the New York State Department of Environmental Conservation artificial spawning channel located at Myers Point on Cayuga Lake, New York. The design and operation of this structure has been described by Webster and Otis (1973) [Appendix A].

This facility consists of six channels, each 100 feet in length by six feet wide and five feet in depth. The channels are constructed to allow water flow in series or parallel. Water is supplied from Salmon Creek through a settling basin by means of a battery of four pumps of 2.5, 7.5, 10 and 15 horsepower and 1, 2, 3 and 4 cfs respectively. Maximum flow with all pumps is ten cubic feet per second.

The first tests were conducted using two channels: one for control and the other with a series of vertical barriers made from 2" x 6" lumber. The crest of the weir was covered with a 6 cm wide strip of sheet metal so that a 1 cm overhang was provided. Weir crest heights were 35, 60 and 79 cm. Pool depths varied with water flow. This arrangement is shown schematically in Figure 1. A V-type trap was placed at the upstream end of the control channel and on the upstream side of each barrier. An 8-foot section of cover was provided immediately downstream from the barrier. A downstream view of one test structure is pictured in Figure 2.

Equal numbers of lamprey were released at the downstream end of the test channel and of the control channel. Subsequent tests were altered to the extent of removing the blocking screen between the control and test channel and releasing all lamprey at the downstream end of the control chanel. This allowed more lamprey to be challenged to the barriers while still retaining the test for upstream migration per se. Lamprey were left in the test situation for a minimum of 24 hours for all tests and up to 96 hours in some cases, eg., over weekends and holidays.

A second series of tests were run near the end of the migration period for lamprey in Cayuga Inlet. During this set of tests various heights were set up as a single barrier in a channel with the lamprey released immediately below the barrier. These tests were done primarily with large flow, i.e., 10 cfs. In addition to vertical barriers some preliminary tests were conducted with inclined planes and Cipolletti weirs.

Test animals were collected and held at the fishway on Cayuga Inlet until transported to the channel. Cayuga Inlet is the tributary where the major spawning run of lamprey occurs and is approximately 12 miles from the channel. Lamprey were placed in a screened-off section of a channel until used for tests. Uncertainty as to numbers of lamprey available for tests necessitated the reuse of some of the early run migrants. As number of lamprey available increased those used in the tests were sacrificed. Lengths and sex were observed for all killed lamprey; weights were measured for a portion of some samples to provide estimates of length-weight relationships. Lamprey were anesthetized with an aqueous solution of ethyl ether before measurement and sacrifice. Trials consisted of 100 or 200 lamprey per test.

Pool depths were measured for the various pump combinations. Temperature was recorded at the head of the channel containing the barrier structures.

Measurement of water velocity over the weir crests was attempted but was not successful due to limitation of equipment available at the time.

Results

Nineteen hundred lamprey, counting those used in more than one trial, were challenged to vertical barrier heights* ranging from 2-30 cm. Only sixteen lamprey successfully moved upstream over barriers of 16.4 cm and greater; no lamprey passed a 30 cm barrier. Table 1 summarizes results of 1978 experiments. Water flow and mean temperature for the duration of a trial are also given in Table 1.

Of 1,239 lamprey challenged in the multiple weir trials, 91 did not show any upstream movement, 842 were stopped by the first weir with heights ranging from 9.2 to 19.8 cm, and only 306 lamprey were successful in migrating upstream over any barrier. The information for this group is shown as follows:

Height of barrier:	9.2	10.2	11.9	13.2	13.2	15.2	15.7	18.2	19.8
% stopped:	11	12	66	73	92	78	83	100	100

There is a strong suggestion that larger lamprey were the ones successfully ascending barriers (Table 2). Mean length of lamprey in pool 3, when lamprey were successful in passing weir 1, always exceeded mean length of lamprey in pool 1 after trial runs. Differences were not statistically significant (α = .05) in eight of eleven cases. Mean lengths of lamprey in the release channel, i.e., those not migrating, were equally divided

*Barrier height was defined as the difference between the height of a weir crest and the height of the pool surface immediately downstream from the weir.

between being greater and being less than those present in pool 1. Length measurements were not taken at all trials since many lamprey were run through multiple trials and the necessity to anesthetize them before measurement might have affected their migration behavior.

Two trial runs with a Cipolletti weir as a barrier resulted in no successful upstream movement by lamprey. Water flow was 3 and 10 cfs for the two trials respectively.

A trial conducted with a 20 cm overhanging metal lip on the barrier crest, a flow of 3 cfs and heights of 9.4, 13.2 and 21.5 cm proved no more effective as a barrier than did the normal set up, i.e., a metal crest with approximately 1 cm overhand. Lamprey were successful in attempting all the above heights.

The overall length-weight relationship for lamprey sampled in this study was determined for male and female animals separately with the following least squares fit to the logarithmic transformation of data:

$$\text{Male:} \quad \text{weight} = 0.0036 \ \text{length}^{2.8566}$$

$$\text{Female:} \quad \text{weight} = 0.0082 \ \text{length}^{2.6578}$$

The reuse of some lamprey and the pooling of lamprey in holding precluded doing any seasonal analysis of size data.

Eight hundred sixty-six lamprey were sexed and found to consist of 555 males and 311 females. This sample taken over the entire migration period of the Cayuga Inlet run consisted of approximately 50% of the total number trapped at the Inlet fishway.

General Observations

In virtually all cases, lamprey showed upstream movement and attempts at barriers when placed in the test situation. This activity was generally almost an immediate response, i.e., within five minutes. Even those lamprey recently transported from the fishway and placed in holding pens at the channel showed this activity.

The attempts by lamprey against the barriers might best be described as an exerted swimming rather than as jumping. The first attempts appear as strong swimming against the barrier surface or directed into the water flow coming over the weir. Generally the upper third to half of the lamprey would be out of water and the animal would very rapidly move in a lateral direction across the face of the barrier. Swimming into the water flow would generally occur at the side of the channel and if the lamprey could not ascend the barrier, it would skitter across the face of the water fall. On many occasions a lamprey would have the anterior third or half of its body beyond the crest of the weir and clearly in the upstream pool only to be swept back downstream. Undirected jumping was observed to occur in the pool below a barrier but this effort was generally nearly vertical in nature.

Attempts against barriers very frequently resulted in the lamprey attaching by its mouth to a vertical surface. This occurred in particular at the corners formed by barrier and channel walls. Lamprey would hang out of water for extended periods of time, i.e., many minutes, before releasing and falling back into the downstream pool. This same behavior was noted in lamprey that had succeeded in moving partially over a barrier where they would latch on to the metal lip of the barrier and remain for many minutes. In all cases observed there was no indication that a lamprey was able to move upstream by sucking its way along. The behavior observed in these situations was a release suction held by the mouth and a simultaneous swimming effort. A similar behavior pattern was noted for lamprey successfully going over a barrier. The swimming effort appeared exerted and demanding going over a barrier followed by the almost immediate attachment to some object upstream. This same pattern of swim-attach-rest-release-swim was also noted for lamprey in some preliminary trials with inclined barriers.

Bright direct sunlight did not appear to lessen the activity although lamprey would generally go to a shaded area if available. Activity did not increase with darkness but rather tended to become less on the occasion when observations extended into darkness. There is a possible interaction with temperature since water temperature decreased with decreasing light.

The upstream activity of lamprey did not persist for any extended period; at the end of a 24-hour period nearly all lamprey in a test situation would have moved back downstream as far as possible generally being in the corners of the V-traps. The change of water flow would induce a movement reaction from the lamprey which was of interest mainly because of the difference that occurred over the course of the migratory period. Early run migrants moved downstream when the water flow was reduced. Late run migrants showed the opposite reaction by moving upstream on a decreased flow. An increase in flow generally stimulated upstream movement.

Small streams of water, eg., spurts from cracks, attracted lamprey and many would spend considerable effort in examining such flow in apparent attempts to find an opening large enough to work through. One specific observation is worth reporting: A board used in damming water had a 2-inch hole to pass water into a holding area. A lamprey, released above this area in the process of cleaning out the release channel during a period of decreasing flow, without error and at a fast rate of speed went through the hole in its attempt to escape from the channel.

The current patterns formed by the discharge through a Cipolletti weir resulted in some confusion to migrating lamprey. As placed in the channel, the Cipolletti weir caused a strong midstream, downstream current with side current in the upstream direction. Lamprey searching the wall were swimming into the current but away from the barrier. Those in the midstream current swimming against the current, i.e., swimming upstream tended towards the walls with the result of entering a current in the opposite direction. It would be worthwhile to run further experiments with similar structures perhaps in conjunction with a velocity barrier.

Approximately 100 lamprey which had been held for three weeks were placed in a channel with a gravel bottom. Nest building attempts were started within an hour and, although the experiment was terminated and the channel dried, it appeared that spawning would have taken place. During this observation two male lamprey were observed fighting. Open-mouth rushes and attempts to attach to the opponent were noted.

Discussion

These experiments suggest that the Cayuga Lake sea lamprey may effectively be prevented from upstream migration by relatively low vertical barriers. The important factor to be considered is the height between barrier crest and downstream pool elevation which is in most cases a function of water flow. A high water barrier of at least 30 cm would be necessary unless velocity became a limiting factor. A height, so defined, of 30 cm can be tentatively used as a minimum requirement for a barrier dam. An interaction between lamprey length and height which is a barrier most certainly exists but is undoubtedly also related to the animal stage of maturity and probably to water temperature. In these experiments water temperature did not have a demonstrated effect. This may be an important area for future work in situations where lamprey size is expected to vary considerably.

The velocity barrier work being done by others for the Commission is also of extreme importance in the consideration of a suitable physical barrier to lamprey. In all likelihood some combination of these two factors will have to be incorporated in the design of some barriers. Other areas such as surface texture should be tested at some point in time.

The general behavior seen in this study by and large corroborate the observation of Applegate (1950) and Wigley (1959) with one possible exception. Wigley felt an overhanging lip was an essential factor to incorporate in a barrier design; this study does not categorically support this idea. Again further testing of this might prove of value.

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Proposed Work for 1979

The scope of work that could be proposed is very large; the extent of future work would in large measure be dependent upon the support from the Commission and others. The low end of the spectrum may be represented by what I feel is a minimum that should be done: testing the 30 cm height barrier against a representative migration. At the other end of the spectrum would be a complete evaluation of integrated lamprey control and the consequences of such control on fish stocks. The price range is on the order of $1,000-$150,000, using Cayuga Lake as a test case. I leave this open for your consideration.

Work I feel should be done as logical follow up to the 1978 study is to test the 30 cm height using a variety of flow conditions and barrier designs. By decreasing channel width (barrier width), flows greater than 10 cfs can be simulated. Barrier designs would include vertical, inclined plane and ogive types. This work would be done at the Myers Point spawning channel. If possible and dependent upon compatibility with management work, a number of tests could be conducted at the Cayuga Inlet fishway. These tests would be the 30 cm barrier and some velocity tests. Conducting tests at the fishway would allow observations on the reaction of other species to the barrier, eg., white suckers, alewife, smelt, smallmouth bass, bluegill, rainbow trout, tec. This part would have to have prior approval of the New York State Department of Environmental Conservation.

Cost for the above outlined work would be on the order of $6,500, broken down as follows: Electricity - $2,000; Supplies, Equipment, Rental - $1,000; Travel - $500, and Principal Investigator - $3,000.

Table 1. Summary of success-failure tests of vertical height as a barrier to migrating adult sea lamprey, 1978.

Height (cm)	Success + Failure -	Flow (cfs)	Temp. °C**
2.0*	+	10	17.8
3.9	+	7	20.7
8.1	+	4	22.9
9.2*	+	2	17.1
9.4	+	3	17.2
9.4	+	3	18.6
9.4	+	3	21.6
10.0*	+	7	15.0
10.2	+	4	22.9
11.9*	+	2	13.9
11.9	+	2	17.1
11.9	+	3	16.7
13.2	+	3	17.2
13.2	+	3	18.6
13.2	+	3	21.6
15.2	+	3	13.9
15.7	+	2	16.7
16.4	-	7	20.7
18.2*	-	2	14.6
19.8	-	2	13.3
20.2	+(2)	4	22.9
21.5	-	3	17.2
21.5	-	3	18.6
21.5	+(1)	3	21.6
22.0*	-	10	15.0
24.0	-	2	17.1
24.0	-	2	16.7
25.3	-	3	13.9
26.0*	+(13)	10	19.7
26.0*	-	4	12.8
30.0*	-	10	12.4

*Trials involved 200 lamprey; other heights in trials were with 100 lamprey.

**Mean temperature for test period.

Table 2. Mean lengths of lamprey in pools 1 and 3 of the multiple barrier tests, 1978.

Date	Flow (cfs)	Pool 1		Pool 3	
		Depth	$\bar{\ell}$(n)s^2	Depth	$\bar{\ell}$(n)s^2
			MALE		
5/22	2	19.5	43.41 (86) 12.2936	55.0	47.68 (27) 12.5639
5/24	3	22.0	44.54 (51) 8.9501	57.5	47.45 (6) 7.8510
5/25	3	22.0	44.26 (41) 12.3000	57.5	47.74 (20) 5.4341
5/26	3	22.0	43.12 (26) 16.3368	57.5	44.86 (33) 12.8118
5/30	4	25.0	38.45 (2) 9.2450	58.8	44.20 (54) 10.1373
6/1	7	–	39.68 (6) 4.6497	62.6	42.86 (24) 11.5443
			FEMALE		
5/22	2	19.5	43.02 (80) 13.1463	55.0	47.15 (6) 21.9670
5/24	3	22.0	44.20 (32) 10.6277	57.5	(0)
5/25	3	22.0	43.65 (21) 14.7186	57.5	47.84 (5) 19.7380
5/26	3	22.0	43.08 (22) 14.9780	57.5	44.70 (6) 5.1000
5/30	4	25.0	40.61 (9) 16.0711	58.8	43.24 (24) 9.7860
6/1	7	–*	41.19 (14) 11.1798	62.6	42.79 (15) 8.6284

*Missing value.

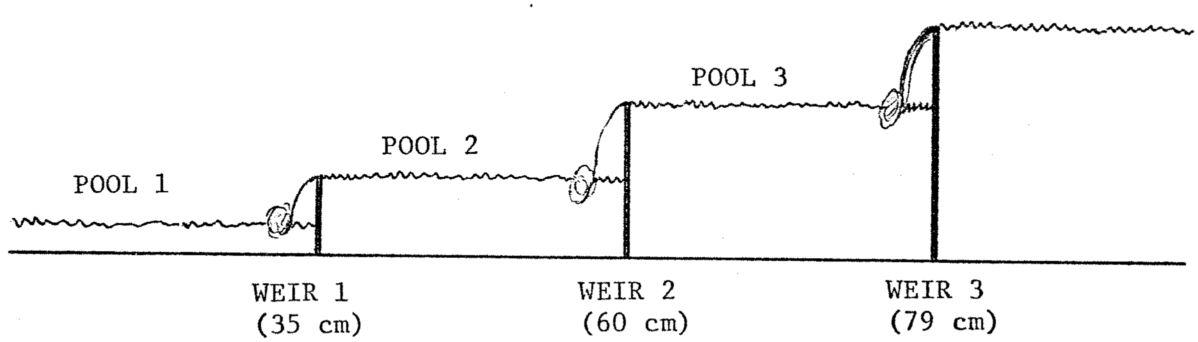

Figure 1. Schematic diagram of test structure.

Report on

Evaluation of barrier dams to adult sea lamprey migration - 1979

William D. Youngs

Abstract

Adult migrating sea lamprey were challenged by vertical barriers of 30, 45 and 60 cm heights at the Myers Point spawning channel. Pool depth below barriers was maintained at a depth of at least 30 cm. Water flow was varied from 0.02832 m^3/s to 0.2832 m^3/s (1-10 cfs). Straight, trapezoidal and shallow vee weirs were tested. Approximately 1,500 adult lampreys were challenged. No lamprey was successful in passing any of the weirs.

Barrier tests were also conducted at the fishway on Cayuga Inlet using a straight weir. Vertical height could not be maintained at the desired 30 cm due to low water conditions in the stream which resulted in low operating head. The barrier had to be removed for periods of time in order to allow migrating white suckers to pass. Barrier heights ranged from 15-25 cm depending on water flow in the Inlet. No lamprey was successful in passing the barrier when it was operational but the experimental set-up was less than desired.

Preliminary work for a means of conducting velocity tests at the spawning channel was conducted. A dam with orifices in its face was constructed such that velocity through the openings could be controlled by manipulation of the head above the openings. Lamprey oriented to the flow and from an experimental standpoint appeared to be attempting to swim through the openings.

Introduction

The general experimental approach for work done at the spawning channel and results of the first year's work were given in last year's report (a copy is appended). Those experiments concluded that a vertical height of 30 cm was sufficient to block migration of adult sea lamprey from Cayuga Inlet.

Studies reported on here were to more extensively test the 30 cm height with additional heights of 45 and 60 cm being tested at the spawning channel. Other studies at Cayuga Inlet fishway were conducted to test the 30 cm barrier against the natural run of migrating lamprey undisturbed by handling.

Hunn and Youngs (1979 ms) have reviewed the literature relative to mechanical barriers in general.

Methods and Materials

Spawning channel experiment. The spawning channel at Myers Point on Cayuga Lake is a concrete structure of six 100-foot channels with a pumped water supply. Water is pumped to the channel by any combination of four pumps of 2.5, 7.5, 10 and 15 hp which supply 1, 2, 3 and 4 cfs respectively. Flow may be of any amount up to 10 cfs.

Weirs were placed in series in the channel with the downstream weir having a 30 cm vertical barrier; the 45 cm barrier was next upstream followed upstream by the 60 cm barrier. Barrier height was measured as the distance between the surface of the immediately downstream pool and the weir lip. A minimum depth of 30 cm was maintained in any downstream pool.

Weirs were constructed of 2" x 6" lumber with a tin lip on the weir crest to provide a clean break edge. Straight, trapezoidal and shallow vee weirs were tested under water flows ranging from one to ten cfs. V-traps were placed immediately upstream of the barrier to prevent any successful lamprey from dropping downstream. The barrier was also covered to exclude bright sunlight. Depth of water over the weir for any given flow was also varied by reducing the weir crest length. Daily temperature was recorded.

A straight weir was placed in the trap area of the fishway to challenge unhandled lamprey to a 30 cm vertical barrier. This barrier was constructed by fastening keyways to the vertical sidewall of the fishway and using 2" x 6" lumber as flash boards to control barrier height. An upstream trap above the weir prevented drop back in the event any lamprey passed the barrier.

Adult lampreys trapped at the Cayuga Inlet fishway were transported to the channel and placed downstream of the 30 cm barrier. All lamprey collected throughout the season were placed together in the downstream pool. Samples of lamprey were taken on a nearly daily basis and measured for length and weight.

Preliminary experiments, primarily feasibility studies, were conducted to test velocity as a barrier to migrating lamprey. This work was conducted at the channel by simply forming a dam of 2" x 6" lumber and placing holes near the bottom of the dam. The holes opened into a downstream pool in which lamprey were held. A v-trap was placed on the upstream side of the dam. Velocity can be controlled by adjustment of the head of water above the dam.

Results

No lamprey was successful in passing any vertical barrier tested. Mean lengths of lamprey were 47.05 and 46.02 cm for male and female lampreys respectively. Water temperature varied from 10-23°C over the course of the experiments.

Experiments at the fishway were unsuccessful in the sense that the 30 cm barrier could not be attained, and the barrier had to be removed on a number of occasions in order to allow white suckers to migrate upstream. Vertical height of the fishway barrier ranged from 15 to 25 cm depending upon water flow but even these heights blocked lamprey migration; none passed the barrier. Adult migrating white suckers were not totally blocked from moving upstream but it appeared that 70-80% of the run was held back due to the barrier.

Lamprey behavior was essentially as described in last year's report. Movies were taken in both years in an attempt to document some of the behavior previously described. Changing flow stimulated activity from the lamprey. Generally there was nearly immediate attempts at the barrier when flow changed and when lampreys were placed in the channel. Activity was much reduced when water temperature was below 15°C.

Reducing the width of the weir in the channel experiments to increase the depth of water over the weir for any given flow did not result in any particular benefit to the lamprey. As water depth over the weir increased so did water velocity resulting in somewhat of a tradeoff. Again no lamprey was successful in any of these trials.

Preliminary velocity tests showed that lampreys would orient to and attempt to swim through openings in a vertical barrier. Holes of approximately 10 cm discharging just under the surface of the holding pool attracted lampreys. Two lampreys successfully moved upstream when water velocity through the openings was approximately 2 m/sec but none was successful at a velocity of approximately 3 m/sec. These tests were conducted at the end of the experimental period and the lampreys were undoubtedly under physiological stress. However, the feasibility of the experimental procedure was demonstrated.

Discussion

Experiments conducted over the last two years quite convincingly demonstrate that the sea lamprey in Cyauga Lake cannot pass a vertical barrier of 30 cm or greater in height. No lamprey successfully passed this height during these experiments with some 3,000 lampreys. Only 16 lampreys were successful in moving upstream over barriers of 16.4 cm and greater (1978 experiments).

Lamprey size was not demonstrated to be a factor although the 1978 trials suggested larger lampreys were the ones passing the barriers. However, the lampreys in 1979 were significantly larger than those used in 1978 tests but the 30 cm remained a barrier. 1979 lampreys averaged 47.05 and 46.02 cm for male and female respectively as compared to 44.05 and 43.36 cm for male and female lamprey respectively in 1978.

Weirs of various types appeared to have little effect on lamprey behavior with the possible exception of a trapezoidal type weir. Under conditions in the channel, e.g. straight, even sides and uniform flow, a trapezoidal type weir discharging in the center of the channel caused counter currents along the sides. This reverse flow had the effect of disorienting the upstream swimming of lampreys. A rectangular center cut weir would have the same effect.

Under natural stream conditions a straight weir having a 30 cm drop should prove to be a lamprey barrier. The problem is maintaining the height under varying flows normally found in streams. It seems that some amount of ponding may be necessary to maintain upstream water level to provide vertical height under flood conditions.

Studies to determine what velocity blocks lamprey migration seem necessary. It should be possible in many situations to design a barrier such that vertical height may be a barrier at low flow while velocity becomes a barrier under high flow conditions.

The studies done at the spawning channel should be conducted using other sources of lamprey or repeated at other locations where lamprey are available. The 30 cm barrier to Cayuga lamprey may not be to other populations of lamprey.

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