Original: Fish Division
cc: Education-Game
Inst. for Fish. Res.
Marquette Fish. Res. Station
T. M. Stauffer

INSTITUTE FOR FISHERIES RESEARCH
DIVISION OF FISHERIES
MICHIGAN DEPARTMENT OF CONSERVATION
COOPERATING WITH THE
UNIVERSITY OF MICHIGAN

GERALD P. COOPER PH.D.
DIRECTOR

ADDRESS
UNIVERSITY MUSEUMS ANNEX
ANN ARBOR, MICHIGAN

January 21, 1963

Report No. 1653

AN EXPERIMENTAL SEA LAMPREY BARRIER 1950-1957

By Thomas M. Stauffer

The sea lamprey, Petromyzon marinus, may be vulnerable to control during its upstream spawning migration. Three devices have been used to block spawning runs: (1) the mechanical weir, which consists of 1/2-inch mesh screening installed across a stream so that the entire stream flow passes through the screens (Applegate and Smith, 1950); (2) the electro-mechanical weir, which blocks upstream migrating sea lampreys by means of an impenetrable alternating-current electrical field across the stream (Applegate, Smith and Nielsen, 1952); and (3) the barrier dam, that creates a fall of water or "head" which sea lampreys cannot surmount (Stauffer, 1951, 1952 and 1954). This paper evaluates the third type, which was constructed to block upstream-migrating sea lampreys and to permit the upstream passage of other fish, principally rainbow trout.

Black River, Mackinac County, where the investigation was carried out, flows into northern Lake Michigan at a point 30 miles west of the Straits of Mackinac. From October 1, 1951 to September 30, 1952, it had an average flow of 33 cubic feet per second with extremes of 12 to 154 c.f.s. (measured 2 1/2 miles upstream from the mouth). The water is stained but carries little suspended material. Resident fish species include: American brook lamprey, *Lampetra lamottei*; brown trout, *Salmo trutta*; and brook trout, *Salvelinus fontinalis*. Migrant species include: (1) sea lampreys; (2) rainbow trout, *Salmo gairdneri*; (3) white suckers, *Catostomus commersoni*; (4) longnose suckers, *Catostomus catostomus*; and (5) American smelt, *Osmerus mordax*.

Construction of barrier dam

Initial construction was of wood, except for a curved steel lip, and was completed on May 15, 1950. Essential features of the barrier were described by Applegate and Smith (1950) and Stauffer (1951). The bulkheads were constructed with 1 1/4-inch sheet piling driven 4 feet into the river bottom; at their extreme upstream and downstream ends, they turned and extended into the bank. The bulkheads were back-filled with sand and clay to the top of the sheet piling. The face of the dam was built of two rows of 1 1/4-inch sheet piling (3 feet apart) driven 4 feet into the river bottom. For added strength, a platform was constructed on top of the two rows of sheet piling. The plates that constituted the lip of the dam were bolted to the downstream side of the platform. The plates were 1/4-inch steel, curved into a half circle (18-inch diameter), and were adjustable over a vertical range of one foot. Immediately downstream and partially under the curved steel lip was a floored pool from which food and game fish could jump. An upstream trap adjoined the jumping pool on the east bank and could be converted into a bypass by removing the upstream and downstream walls.

Because severe undercutting occurred soon after construction had been completed, the barrier was rebuilt in the winter of 1950-1951 (Fig. 1). To reinforce the dam, interlocking steel sheet piling (12 feet long) was driven into the river bottom along the upstream face of the dam and 10 feet into the bank on either side. To facilitate passage of water, the face of the dam was extended into the area formerly occupied by the bypass and the east bulkhead was relocated. In addition, the bulkheads were packed with clay, which added greatly to the stability of the structure. These modifications made the dam physically sound and no undercutting occurred during the 1951 season.

On October 29, 1951, an upstream trap (Fig. 2) was installed in the jumping pool next to the east bulkhead. Essentially the trap was a wooden box (approximately 4 by 6 1/2 by 3 1/2 feet) with a removable screen liner which could be hoisted out of the water for easy removal of fish. The trap adjoined the curved lip, and splash boards were installed on top of the platform to control the amount of water entering it. To prevent escapement of sea lampreys, 1/2-inch wire mesh was placed on the platform above the splash boards to screen the flow entering the trap over the splash boards.

In 1952, the barrier dam was unchanged except that the steel lip was raised 9 inches to compensate for the lowered head caused by the high level of Lake Michigan.

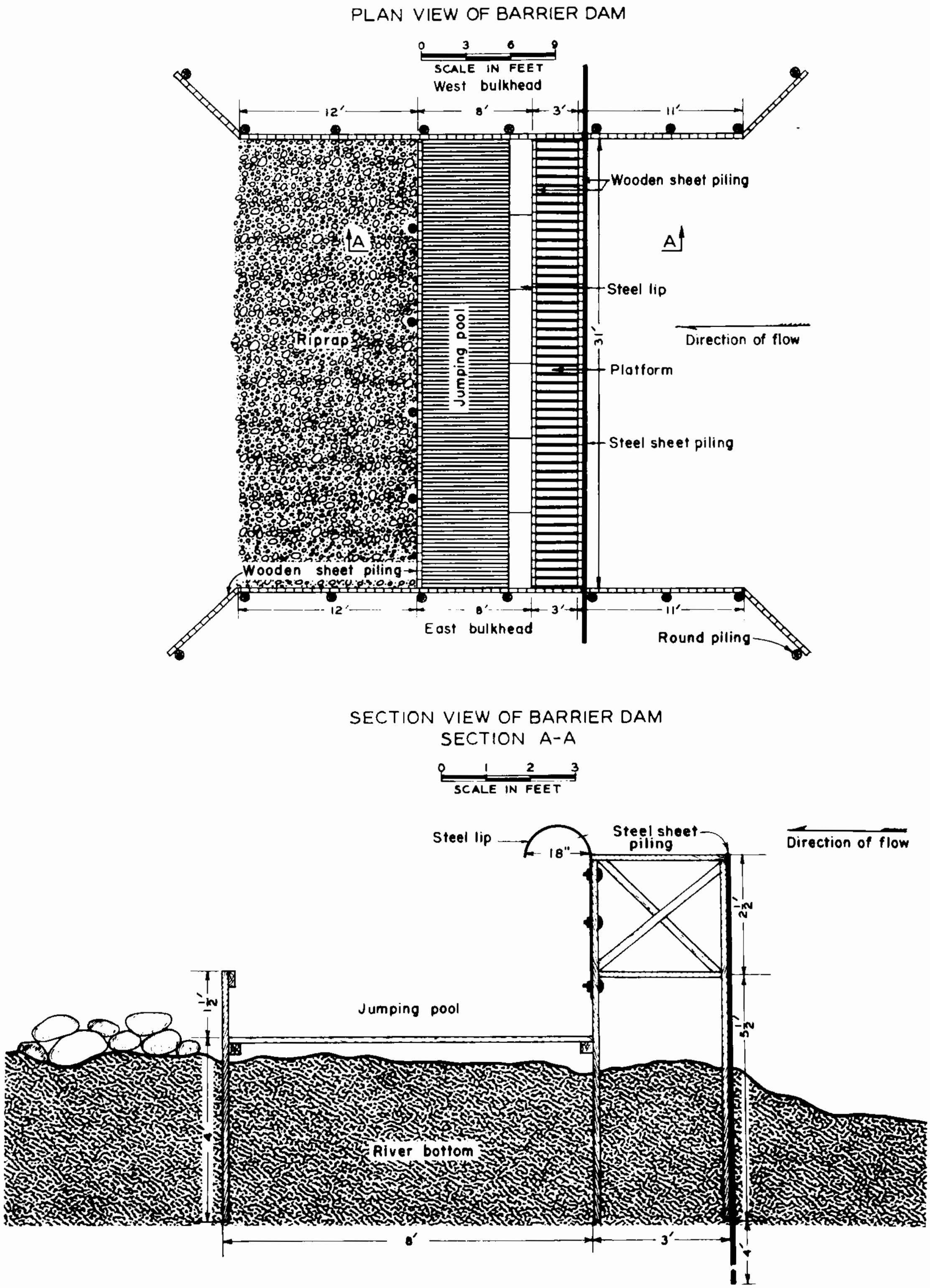

Figure 1.--Plan and section view of the barrier dam, April, 1951.

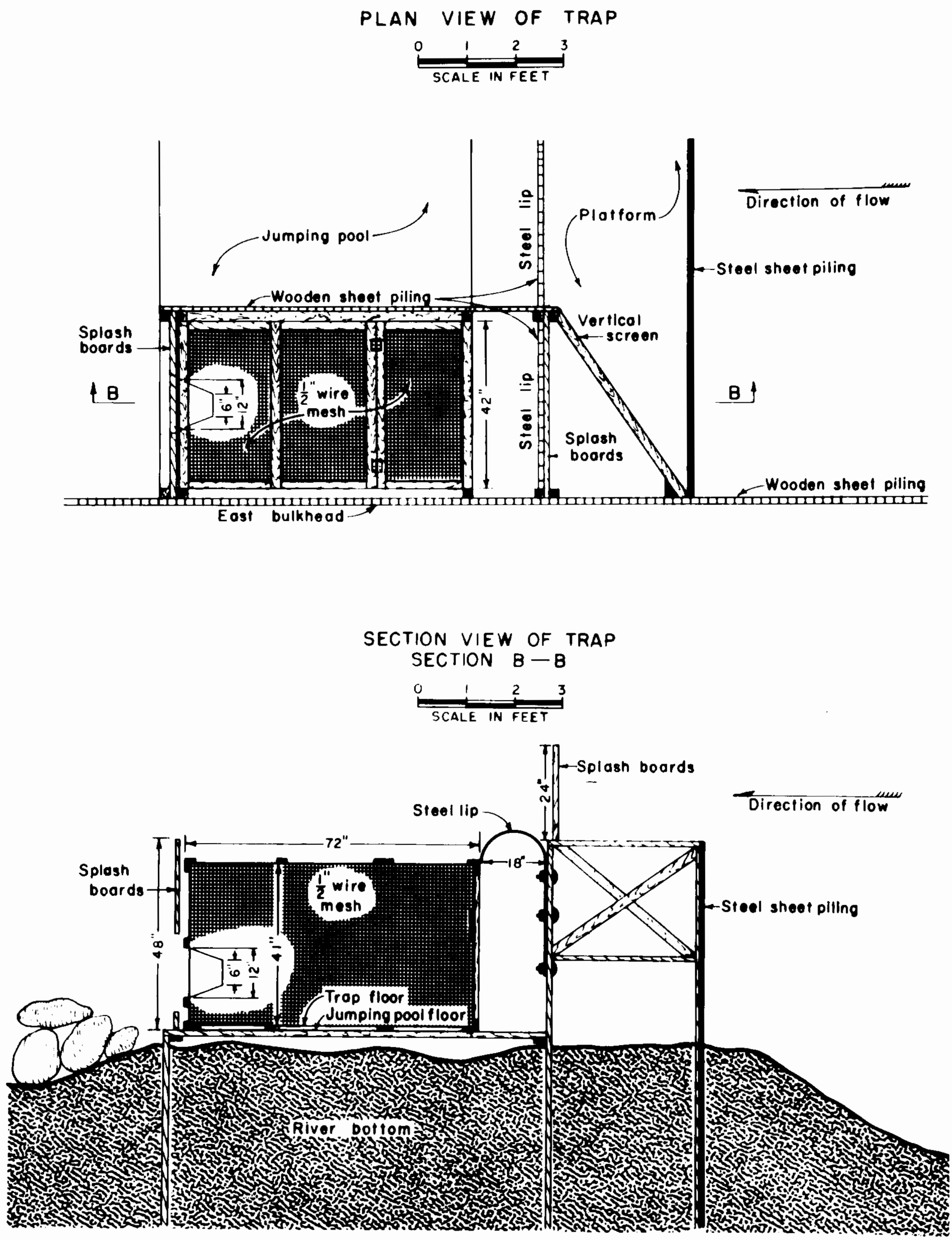

Figure 2.--Plan and section view of the dam trap.

A different type of lip was tested in 1953. The "new" lip was straight rather than curved. The lip was 19 inches long and projected upward at a 150° angle from the downstream face of the dam. To reduce the resultant increase in head, the downstream wall of the jumping pool was raised 18 inches on May 8 and an additional 6 inches on June 9. This created a small difference in water level between the jumping pool and river. However, this small waterfall was no barrier to upstream migrating fish.

In 1954, the spring runoff buckled the downstream wall of the jumping pool. The wall was straightened on May 20. Throughout the 1954 operation, structural weakness was indicated by the cave-ins which occurred behind both bulkheads. These cave-ins occurred downstream from the steel piling and may have been caused by leakage from the jumping pool rather than by leakage from the river above.

Little structural change was made in 1955, although cave-ins similar to those mentioned for 1954 necessitated the use of gravel fill. In October, the lower wall of the jumping pool was strengthened by the addition of a heavy A-frame, the apex of which fitted against the middle of the lower jumping pool wall with the ends braced against the downstream bulkheads.

No major structural changes were made in 1956, although the cave-ins behind the bulkheads continued.

On April 20, 1957, a severe spring runoff overtopped the bulkheads, swept away the superstructure, and washed away much of the fill behind the bulkheads. The superstructure and fill were replaced shortly after this flood. Subsequent floods on May 15 and 26 continued to wash away the fill. These floods broke the floor of the jumping pool and spread the abutting steel plates of the lip. The resulting gaps in the lip were sealed on June 3. A severe flood on July 4-5 removed much of the fill from behind the bulkheads and buckled the face of the dam slightly. Because of the poor condition of the dam, it was removed from the river in August.

Methods

The barrier dam, located 1/2 mile upstream from the mouth (Fig. 3), was in operation from May 15 to June 25, 1950 and from March 12, 1951 to August 5, 1957. Periods of study (except for collection of ammocoetes, see below) of the barrier dam coincided with the inclusive dates of operation of the barrier dam trap (Table 1) except in 1951, when the study periods extended from April 9 to July 5 and September 6 to November 14. An electrical weir with an alternating current blocking field and a direct current "diversion device" (McLain, 1957) was operated during the sea lamprey spawning run in 1958-1959. No barrier to upstream migrating sea lampreys was present in 1960-1961.

To discover escape routes (if any), the barrier dam was inspected at each visit. In addition, the barrier was carefully observed for 274 hours[1] during the upstream migration of rainbow trout and sea lampreys.

---

[1] Observation time (hours) was as follows: 1950, 65; 1951, 98; 1952, 37; 1953, 38; 1954, 5; 1955, 12; 1956, 19; and 1957, 0.

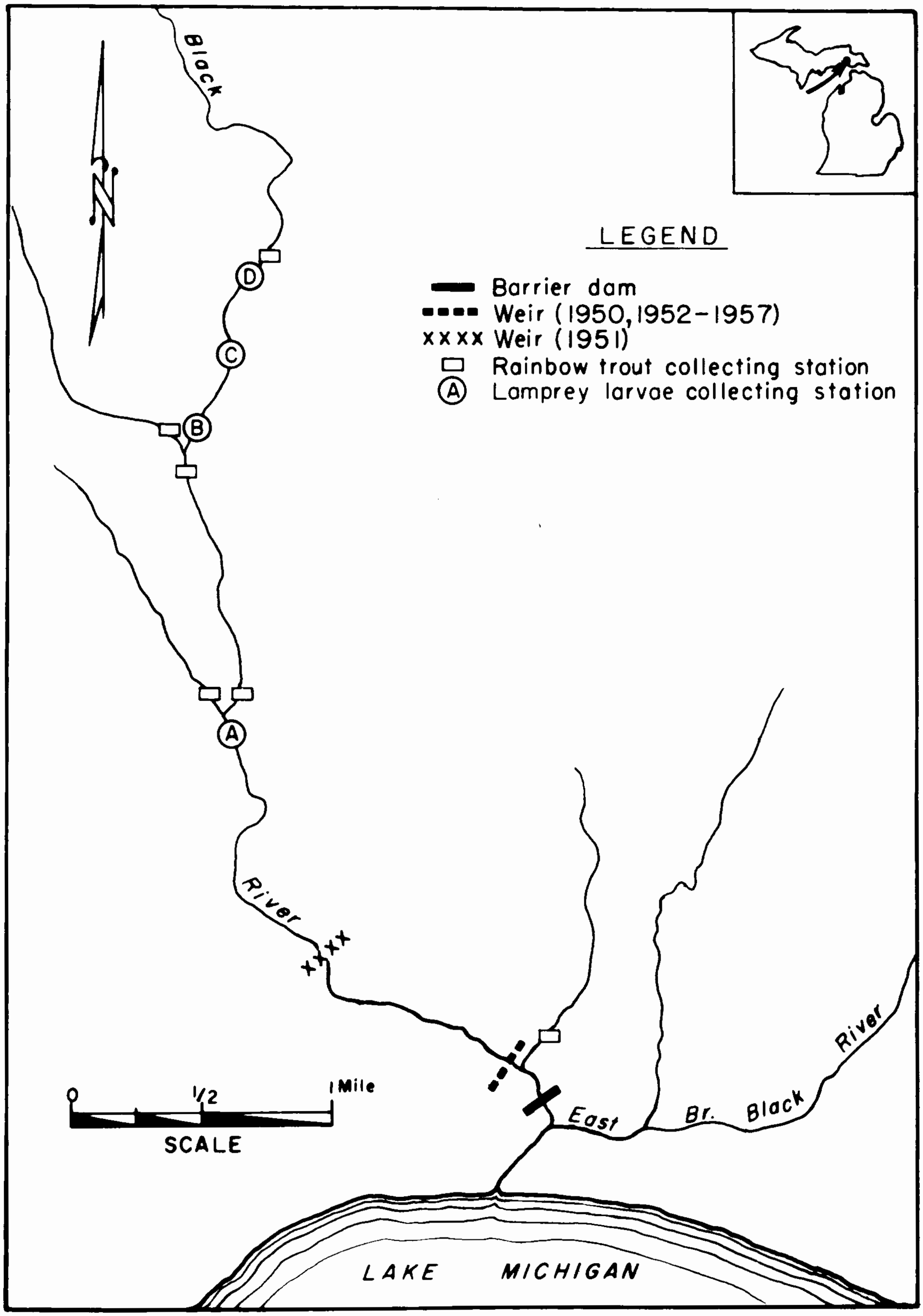

Figure 3.--Lower portion of Black River, Mackinac County, showing location of barrier dam, weir(s) and collecting stations.

Table 1.--Inclusive dates of operation of the traps in the barrier dam and weir, Black River, 1950-1957

Year	Barrier dam trap[1]		Upstream and downstream traps of weir[2]	
	From	To	From	To
1950	May 24	June 25	May 27	November 23
1951	October 29	November 15	May 8	July 5
1952	April 8 August 30	August 1 November 24	May 9 September 2	July 22 November 14
1953	April 1 August 31	July 26 November 15	May 4 August 31	July 26 November 13
1954	March 27 September 4	July 16 November 14	May 13 September 4	July 16 October 27
1955	April 1 August 29	July 15 November 14	April 27 August 30	July 15 November 13
1956	April 2 September 2	July 14 November 14	May 5	July 13
1957	April 2	August 5	May 1 September 22	July 4 November 24

[1] Incomplete or no operation during June 19-21, 1950; September 10-12, 1952; April 28-May 4, 1953; April 15-16, 27-28, 1954; October 25-26, 1955; April 9-10, 1956; and April 19-22, July 20-August 5, 1957.

[2] Incomplete or no operation during July 16-September 7, 1950; September 30-October 1, October 12-22, 1954; October 31-November 7, 1955; May 14-17, 19-20, July 8-10, 1956; and May 26-29, November 8-11, 15-21, 1957.

During periods of observation, the lip and jumping pool of the barrier were under constant scrutiny except for periodic checks of other possible avenues of escape. Since sea lampreys are most active at night, most of the observations were made under artificial light.

The upstream trap in the barrier was operated to obtain data on the runs of fish entering the river. A weir, upstream from the dam (Fig. 2), was operated each year (Table 1) to assess escapement of fish past the barrier. This weir consisted of 1/2-inch mesh screening extending diagonally across the stream with a downstream trap at the lower end and an upstream trap at the other. Escapement of fish under the screening and traps was prevented by a sheet-piling foundation.

As a rule, the barrier dam trap and weir traps were visited three times daily (8-10 AM, 4-6 PM and 9-11 PM). The number of lampreys and fish in the traps was recorded at each visit. Sea lampreys were destroyed and other fish were released in the direction of travel (except as otherwise noted). Measurements of head (difference between the jumping pool water level and that of the dam impoundment) and jumping pool depth (which was uniform at any given time) were recorded at each morning visit. The head measurements are presented in Table 2.

To determine the effect of the barrier dam on sea lamprey reproduction, a direct-current shocker was used to collect large samples of ammocoetes (P. marinus, L. lamottei) above the barrier in 1955-1961. As a further check, the main stream above the barrier was inspected for sea lamprey redds in 1956-1957. To determine the success of rainbow

Table 2.--Range and average (in parentheses) "head" measurements (inches) at the Black River barrier dam, 1950-1957

Period	Year							
	1950	1951	1952	1953	1954	1955	1956	1957
April 1-15	-	-	22-26 (25)	36-49 (40)	24-29 (25)	25-28 (27)	23-28 (26)	26-28 (27)
April 16-30	-	-	20-24 (22)	37-45 (41)	28-29 (28)	24-27 (26)	25-29 (28)	25-36 (29)
May 1-15	-	26-30 (29)	16-29 (22)	31-43 (36)	28-32 (30)	26-29 (27)	24-28 (27)	27-29 (27)
May 16-31	36-38 (37)	28-29 (29)	16-26 (22)	28-32 (30)	26-30 (28)	27-35 (30)	25-28 (27)	26-28 (27)
June 1-15	29-36 (33)	28-30 (29)	22-26 (24)	24-34 (30)	25-34 (29)	27-31 (29)	27-31 (29)	28-29 (28)
June 16-30	26-31 (30)	24-30 (28)	16-27 (23)	23-28 (25)	24-34 (29)	30-32 (31)	26-30 (29)	29-41 (35)
July 1-15	-	27-29 (28)	19-26 (23)	20-26 (25)	30-36 (34)	29-34 (32)	25-30 (28)	26-45 (36)
September 1-15	-	-	10-27 (19)	24-25 (24)	23-38 (31)	28-35 (32)	28-30 (30)	-
September 16-30	-	-	13-36 (27)	23-25 (24)	21-23 (22)	28-33 (29)	27-29 (28)	-
October 1-15	-	-	30-40 (34)	24-24 (24)	21-23 (22)	26-29 (27)	27-28 (28)	-
October 16-31	-	-	31-43 (37)	23-24 (24)	22-24 (23)	26-28 (27)	27-28 (28)	-
November 1-15	-	-	28-44 (37)	22-24 (23)	22-24 (23)	27-27 (27)	27-28 (28)	-

trout reproduction above the barrier, young-of-the-year rainbow trout were collected in 1952-1957 with an alternating-current shocker at six different locations above the barrier.

Sea lamprey

Behavior at the barrier.--Observation by Applegate (1950) indicated that sea lampreys are uniquely adapted to surmounting low and irregular dams, even though they could seldom jump vertically more than 2 feet. Dams were negotiated by short wriggling thrusts and use of the oral disc to secure each gain. He also noted that sea lampreys, congregated below a weir, searched incessantly for some small aperture through which to escape upstream. These openings need not be much wider than 1/2 inch to permit smaller individuals to escape (Applegate and Smith, 1950).

At the Black River, during periods of active migration, sea lampreys gathered in the jumping pool near the west bulkhead just below the steel lip and, to a lesser degree, in the vicinity of the dam trap. Few were seen near the center of the lip. Most of the sea lampreys seen were attached to some object, usually the bulkhead walls or to the steel plates underneath the lip. Lampreys were not observed to climb more than 16 inches above the water surface. Sea lampreys clinging at or near the surface of the water would release their hold and attempt to swim or jump vertically but could seldom clear the water. In addition to attempts to surmount the barrier by jumping up the bulkhead walls and plates under the lip, a few sea lampreys attempted a direct assault on the fall of water over the lip. In these attempts, their take-off was usually within 1 foot of the falls. Seldom did they jump more than halfway up the falls. Those which landed on or in the falls were immediately swept downstream. Their sense of direction was poor and many times their leap would carry them downstream. The searching behavior noted by Applegate (1950) also was apparent on the Black River. Sea lampreys explored all parts of the barrier and were especially attracted by small currents of water issuing from the bulkhead walls. That they were able to utilize a small opening to escape upstream was demonstrated by the discovery of an aperture (under the splash boards of the bypass in 1950) about 1/2 inch wide in which four adult sea lampreys were found tightly wedged. Undoubtedly some small specimens were able to utilize this crack as an avenue of escape.

Escapement of spawning migrants.--The years of operation have been divided into three groups (1950-1952, 1953-1954, 1955-1957) based on type of lip and different heads. Periods of sea lamprey movement were determined by the catch of the upstream weir trap (1950), observations of sea lampreys at the barrier (1951), the catch of the dam trap (1952-1955), and by observations[2] and the daily catch of the dam trap (1956-1957). The number of sea lampreys caught in the dam and weir traps is presented in Table 3. Most of the migration occurred within the period May 15 to July 15. Each year there was an average of five periods of accelerated migration—each period averaged

---

[2] Because the trap fished poorly in 1956-1957 (see Table 3), visual observations supplemented the data provided by the trap.

Table 3.--Number of adult sea lampreys caught in traps of the barrier dam and weir, Black River, 1950-1957[1]

Year	Barrier dam trap		Weir			
			Upstream		Downstream	
	March-August	August-November	April-July	August-November	April-July	August-November
1950	69	-	1,655	1	475	0
1951	-	0	0	-	0	-
1952	696	0	17	0	2	0
1953	1,552	5	26	0	0	0
1954	915	8	17	0	0	0
1955	712	1	0	0	0	0
1956	35[2]	0	1	-	0	-
1957	27[2]	-	3	0	2	1

[1] See Table 1 for exact dates of operation.

[2] The trap fished much less efficiently in 1956-1957 because of a reduced water level below the barrier.

4 days in length. Since practically all escapement occurred during periods of accelerated migration (as shown by the weir catch), the head given in the text is the range of morning measurements recorded during these periods. The morning head readings were not always representative, since seiches and precipitation within the daily periods, caused sizable variations.

The curved lip was tested in 1950-1952 and was operated at heads of 26 to 38 inches (1950), 27 to 29 inches (1951), and 16 to 27 inches (1952). Escapement, as judged by the weir catches, was nearly total in 1950, nil in 1951, and at least 19 (escapement occurred through the weir) in 1952. Escapement in 1950 was due to structural failure of the barrier and, in 1952, was no doubt due to seiches which, at times, nearly submerged the curved lip. Observations at the barrier in 1950 (65 hours) and in 1951 (98 hours) strongly suggested that sea lampreys were unable to get over the curved lip at the head used. In 1952, although no sea lampreys were observed negotiating the lip, escapement over the curved lip probably occurred when the head was much reduced by seiches. Thus, a curved lip and tight structure, as in 1951, appeared to block spawning sea lampreys at a head of 27 to 29 inches.

In 1953-1954, a straight overhanging lip was tested at heads of 20-36 and 24-35 inches, respectively. The catch at the weir showed that 26 sea lampreys escaped upstream in 1953 and 17 in 1954. Observations during the nightly visits suggested that sea lampreys escaped over the lip, near the west bulkhead, in 1953. Three sea lampreys were observed on June 21, 1953, attached to the west bulkhead, immediately upstream from the lip. No avenues of escape, other than over the lip, were seen. Hardware cloth, which screened all water passing over the lip near the bulkhead, was installed on the lip and apparently prevented subsequent escapement. Escapement in 1954 may have been due to an opening under the splash boards just upstream from the dam trap through which sea lampreys may have entered the screened enclosure on the wooden platform. At times the screening extended only 6 to 12 inches above the water and sea lampreys may have jumped over and escaped upstream. In both years, cave-ins of fill occurred behind the bulkhead, indicating subterranean channels through which lampreys may have escaped. The cause of escapement in 1953 and 1954 is uncertain, but circumstantial evidence indicates that sea lampreys were able to surmount the straight lip in 1953 at a head of 20-36 inches.

In 1955-1957, the straight lip was operated with slightly greater heads of 26-35 inches (1955), 26-30 inches (1956), and 28-40 inches (1957). There was no known escapement in 1955, one sea lamprey escaped in 1956 (no redds were found, suggesting that this was the only escapee), and a minimum (seven sea lamprey redds were found upstream from the weir) of five escaped in 1957. Escapement in 1956 of one individual was believed due to a seiche which greatly reduced the head. Escapement in 1957 was probably the result of undercutting of the barrier dam. The study in 1955-1957 suggests that, in the absence of structural defects and seiches, sea lampreys were unable to surmount the straight lip at heads of 26-35 inches.

Escapement of fall migration.--In September, October, and November, feeding sea lampreys follow large migratory rainbow trout into the Black River. Whether or not sea lampreys make a serious attempt to surmount the barrier at this time is questionable. However, if they are unimpeded (as in 1950 and 1957), individuals may go upstream as far as the weir (Table 3). In 1952-1955, when the barrier dam and weir were operated in September-November, no sea lampreys were taken in the weir, suggesting that the dam was a barrier to sea lampreys.

Reproduction above the barrier.--Escapement of large numbers of spawning migrants was apparently prevented by the combined effects of the barrier and weir in 1952-1954 and 1957 and by the barrier in 1951 and 1955-1956. Thus, the barrier alone cannot be deemed responsible for changes occurring in the population of sea lamprey ammocoetes. However, the barrier was at least partially responsible for certain changes in the population.

Larvae[3] were collected with a direct-current shocker (usually at four stations, Fig. 2) above the barrier in 1955-1961 to follow trends in the population. In late June or early July and in October, large numbers of ammocoetes were collected at station A in 1955-1961 and at stations B, C, and D in 1957-1961. Ammocoetes were collected with

---

[3] "Ammocoete" and "larva" refer to P. marinus and L. lamottei unless stated otherwise.

no effort to select by size or species. However, it was difficult to see larvae shorter than 1 inch and these small individuals were not caught in proportion to their numbers. Although collections were made in the same areas each year, such areas are soon repopulated by sea lamprey ammocoetes (Stauffer and Hansen, 1958). The data of Stauffer and Hansen also indicated that American brook lamprey larvae soon moved into depopulated areas, although it was not mentioned in their report. In addition to the shocker collections, larvae killed by a larvicide treatment in June, 1961, were collected at stations A, C, and D. The collections provided three indices of relative abundance of sea lamprey larvae: the percentage in the collection, the catch per hour with the shocker, and the average length.

Use of the percentage of sea lampreys in the collections as an index of abundance (Table 4) entailed the assumption that populations of sea lamprey and American brook lamprey larvae were not subject to wide fluctuations. If this assumption is true, the interruption of annual recruitment to the sea lamprey population by the barrier (which presumably did not inhibit American brook lamprey reproduction) should be reflected by a decrease in the percentage of sea lamprey ammocoetes in the collections. At station A, the percentage of sea lamprey larvae in the collections decreased more or less progressively from 1955 to 1961. Although this trend was not so evident at stations B, C, and D, the percentage was considerably higher in 1957-1959 than in 1960-1961.

Table 4.--Percentage and catch per hour of larval sea lampreys in electrofishing collections,[1] Black River, 1955-1961

Station and date of collection[2]	Number of larvae collected (two species)	Sea lamprey larvae		
		Number	Percent of collection	Catch per hour
A				
1955 (O)	652	78	12.0	62.4
1956 (J, O)	2,433	207	8.5	31.1
1957 (J, O)	745	45	6.0	7.5
1958 (J, O)	2,256	160	7.1	28.7
1959 (J, O)	1,555	10	0.6	2.0
1960 (J, O)	1,456	2	0.1	0.3
1961 (J)	726	2	0.3	0.7
B, C, D (combined)				
1957 (J, O)[3]	2,036	10	0.5	0.7
1958 (J, O)	4,108	35	0.9	2.5
1959 (J, O)	2,401	18	0.7	1.7
1960 (J, O)	1,807	1	<0.1	0.1
1961 (J)	846	1	0.1	0.2

[1] Sea lamprey larvae, that could be identified as resulting from recruitment after the end of the barrier dam operation (1957), were not included.

[2] J = June or July, O = October.

[3] Station D was not sampled in October.

The catch per hour of sea lamprey ammocoetes (Table 4) was not a completely satisfactory index of abundance; it was probably influenced by such factors as: (1) the experience and number of collectors, (2) visibility, which was affected by turbidity, water level, time of day, and weather conditions, and (3) the portion of the station that was sampled. Although the figures for the catch per hour were somewhat beclouded by the varying collecting conditions, there was a sharp drop in catch per hour at station A in 1959 and at stations B, C, and D in 1960. These reductions in catch per hour corresponded with the drops in percentages of sea lampreys present.

An analysis of the length distribution of sea lamprey larvae was helpful in determining if recruitment had occurred during the study. Applegate (1950) and Wigley (1959) have studied the relation of length to age. Although the older age groups could not be identified with any degree of certainty, they concluded that age groups 0 and I could be identified.

In the Black River, no sea lamprey larvae shorter than 2 inches (age-group 0 or I) were taken in the shocker collections (Table 5) in 1955-1958, although 1,038 American brook lampreys of this size were collected. In the fall of 1959, 1 sea lamprey larva, 1.6 inches long, and presumably of the 1958 year class was caught; in 1960, 2 sea lampreys, 0.5 and 0.8 inch long, of the 1960 year class were collected; and in 1961, 23 sea lampreys, 0.5-1.1 inches long, either of the 1959 or 1960 year class were taken with the shocker or larvicide. Thus, no recruitment was detected in 1955-1957 (when the barrier was operated), but there was recruitment

Table 5.--Length distribution of sea lamprey larvae collected by electrofishing[1] in the Black River, 1955-1961

[Percentage in parentheses]

Date of collection[2]	Station	Length group (inches) 0.0-0.9	1.0-1.9	2.0-2.9	3.0-3.9	4.0-4.9	5.0-5.9	Number collected	Average length (inches)
1955 (O)	A	0	0	55 (71)	22 (28)	1 (1)	0	78	2.8
1956 (J, O)	A	0	0	125 (60)	79 (38)	3 (2)	0	207	2.8
1957 (J, O)	A-D[3]	0	0	2 (4)	43 (78)	7 (13)	3 (5)	55	3.6
1958 (J, O)	A-D	0	0	12 (6)	140 (72)	28 (14)	15 (8)	195	3.7
1959 (J, O)	A-D	0	1 -	1 (3)	7 (25)	10 (36)	10 (36)	29	4.4[4]
1960 (J, O)	A-D	2 -	0	0	1 (33)	2 (67)	0	5	4.4[4]
1961 (J)	A-D	19 -	4 -	0	0	2 (25)	6 (75)	31	5.2[4]

[1] The 1961 collections include 25 specimens that were taken during the larvicide treatment in June, 1961.

[2] J = June or July, O = October.

[3] Station D was not sampled in October.

[4] Sea lamprey larvae that could be identified as resulting from recruitment after the end of the barrier dam operation (1957) were not used for this average. Thus, the average for the 1959 collections was based on 28 specimens, the 1960 average on 3 specimens and the 1961 average was based on 8 specimens.

from the 1958 and 1959 spawning runs (when an electric barrier was operated) and the 1960 run (no barrier). Further evidence of the lack of appreciable recruitment in 1955-1957 was an irregular, but continuous, increase in average length of sea lamprey larvae from 1955 to 1961 (Table 5). In 1955-1956, most sea lamprey larvae were in the 2.0- to 2.9-inch group; in 1957-1958, most were in the 3.0- to 3.9-inch group; and in 1959-1961, most (excluding recruitment after 1957) were in the 4.0- to 4.9-inch or 5.0- to 5.9-inch group.

The downward trend in the population of sea lamprey larvae as shown by the ratio of sea lampreys to American brook lampreys, catch per hour of shocking, the lack of detectable recruitment in 1955-1957, and the increase in average length from year to year strongly suggest that the barrier dam (assisted by the weir in 1952-1954 and 1957) appreciably inhibited reproduction of sea lampreys.

Rainbow trout

Behavior at the barrier.--The author and two assistants observed 198 attempts (22 in 1950, 176 in 1951) by rainbow trout to surmount the curved lip and 295 attempts (225 in 1953, 55 in 1955, 15 in 1956) to surmount the straight lip. In general, rainbow trout attempted to negotiate the barrier by jumping over or swimming up through the falls. In 1950-1951, 1953, and 1956, most of the rainbow trout that were observed attempted to surmount the barrier by jumping. In 1955, however, most of the observed attempts were made by swimming. The observations in 1951, which occurred over a relatively long period of time and at different rates of flow, indicated that swimming attempts were more frequent than jumping attempts during periods of relatively high flow. Observations in 1955 were made during a period of relatively high flow, which may have accounted for the high percentage of swimming attempts. Apparently rainbows surmounted the barrier with equal facility by either jumping or swimming.

In 1951 and 1953, when such observations were recorded, most of the observed attempts to ascend the falls were made near the west bulkhead; the remainder of the observed attempts occurred more or less evenly over the rest of the falls (1951) or near the east bulkhead (1953). Although the greater number of attempts at the west bulkhead was associated with a smaller volume and higher head than elsewhere along the lip,[4] other factors, that were unknown, may have made this a preferred location. In the 2 years of observation, the location of attempts had no discernible effect on rate of success.

Rainbow trout that could surmount the barrier included practically all size groups in the spawning run. In 1952 fish captured in the dam trap were measured, marked with individually numbered tags, and released below the barrier (see below). The average length of tagged trout recaptured upstream from the barrier was 22.5 inches (range, 13.8-28.4) and was 22.7 inches (range, 15.4-28.9) for those not recaptured upstream. In 1955-1957, when fish were given identical

---

[4] The lip of the dam was 3 inches higher at the west bank than at the east bank during 1951-1957.

marks, the average size of all fish marked at the dam trap and released below was compared with the average size of these fish that were recovered above the barrier. The average size in inches was as follows: 1955, released below, 20.4, recaptured above, 21.3; 1956, released below, 17.4, recaptured above, 17.0; and 1957, released below, 18.4, recaptured above, 18.5. Thus, the ability to surmount the barrier was apparently not dependent on size.

Effect of the barrier on spawning migration.--Various methods were used to determine how successfully rainbow trout could surmount the barrier. Because these methods and conditions at the dam varied, the migration of 1950-1953 is discussed separately and the migrations of 1954-1957 as a group. Generally, the main spawning migration occurred in late April and early May and lasted from 9 to 35 days. Periods of active migration were determined by observation in 1951 and the catch in the dam trap in 1952-1957 (Table 6). The head measurements mentioned are the range of daily head (morning reading) measurements during the period of heavy migration for each year.

To determine if the barrier dam was blocking spawning migrants, adult lake-run trout caught in the dam trap were marked with jaw tags or fin clips and returned downstream in 1952-1957. The number of these fish recovered above the barrier, by anglers or in the weir, would then indicate the percentage of the total run that surmounted the barrier. Most (73 percent) of the fish were marked before installation of the weir.[5] Few marked rainbow trout were caught in the upstream trap of the weir because many of the marked fish could surmount the barrier and migrate

[5] The weir could not be operated during the spring runoff when the majority of rainbow trout migration occurred.

Table 6.--Number of lake-run rainbow trout caught in traps of the barrier dam and weir, Black River, 1950-1957[1]

Year	Barrier dam trap		Weir			
			Upstream		Downstream	
	March-August	August-November	April-July	August-November	April-July	August-November
1950	12	-	14	167	71	0
1951	-	14	21	-	163	-
1952	81	35	24	3	107	0
1953	59	113	34	3	34	0
1954	97	44	10	27	48	0
1955	46	15	44	1	65	0
1956	59	20	12	-	17	-
1957	63	-	39	61	37	0

[1] See Table 1 for exact dates of operation.

to the spawning grounds without being caught. Although some of these fish were recovered in the downstream trap of the weir when returning to Lake Michigan after spawning, the number was no doubt reduced by spawning and angling mortality upstream from the weir site. To determine the recovery rate in the weir of fish that had surmounted the barrier, 83 and 15 marked rainbow trout were released above the barrier in 1954 and 1955 before the weir was installed. Only 36 and 33 percent were subsequently caught above the barrier (mostly in the downstream trap). Small numbers caught in the barrier dam trap, after the weir was installed, were also marked and returned downstream. However, observations indicated that these late-run fish were reluctant to enter the upstream trap of the weir, suggesting that the recovery rate of the marked late migrants was also minimal.

Observations of rainbow trout jumping at the barrier also provided an indication of their ability to surmount the dam. Observations were conducted in the same manner as for sea lampreys, except that most of the observations occurred during daylight hours. Individuals usually could not be distinguished, so the number of observed attempts represents an unknown number of fish.

In 1950, 6 (27 percent) of 22 observed attempts to jump the barrier were successful. Severe undercutting of the structure permitted many rainbows to proceed upstream unimpeded.

Between April 12 and 26, 1951, 9 (11 percent) of 85 attempts by rainbows to negotiate the curved lip were successful. These fish were jumping from a pool containing 2 1/2 to 3 feet (estimated) of water, and were attempting a head of some 2 1/2 to 3 feet (estimated). On April 27, the head was reduced to 24-30 inches by raising the downstream wall of the jumping pool 8 inches. Subsequently, 24 (26 percent) of 91 observed attempts to jump the curved lip were successful. Overall, the percentage of successful attempts was greater than in 1955 and 1956 when escapement was judged to be good (see below), suggesting that little blocking action occurred in 1951.

In 1952, 77 adult rainbow trout (70 before the weir was installed and 7 after) were marked and released below the dam. The marked fish were jumping from a pool whose depth varied between 28 and 44 inches and were attempting a head of 20 to 26 inches. A total of 33 percent of those marked before weir installation and 43 percent of those marked after weir installation were recaptured above the barrier. The relatively high percentage of recovery of those marked at the barrier indicates that the barrier with a curved lip had little blocking effect on upstream-migrating rainbow trout. No observations were made of behavior at the barrier.

In 1953, when the straight lip was installed, the head ranged from 33 to 49 inches and the depth of the jumping pool varied between 23 and 36 inches. Three fish were marked and released below the dam before weir installation (May 4) and two thereafter. None of these fish were recovered above the dam. Of 225 observed attempts of rainbow trout to jump the barrier, only 4 percent were successful. The straight lip with the relatively high head and/or the observed extreme turbulence in the jumping pool presumably interfered considerably with the upstream passage of rainbow trout.

In 1954-1957, the head measurements ranged from 24 to 28 inches (1955) to 25 to 36 inches (1957) and the jumping pool depth from 36 to 46 inches (1956 and 1957) to 43 to 53 inches (1955). The total number of fish trapped and marked at the dam trap and released below was as follows (number marked after weir installation in parentheses): 10 (2) in 1954, 31 (8) in 1955, 33 (17) in 1956, and 50 (19) in 1957. Fish marked in 1954 after weir installation were marked differently than those marked before installation, but in 1955-1957 all fish were given identical marks. Recovery of the marked fish above the barrier was: 1954, before, 25 percent, after, nil; 1955, 39 percent; 1956, 33 percent; and 1957, 58 percent. There were no observations of rainbow trout at the barrier in 1954 or 1957, but 55 (14 percent success) and 15 (13 percent success) attempts to surmount the barrier were observed in 1955 and 1956. The relatively high percentage of recovery of marked fish above the barrier and (in 1955-1956) the percentage of successful attempts strongly suggest that the barrier, with a straight lip and head of 2 to 3 feet, did not block significant numbers of upstream-migrating rainbow trout.

Effect of the barrier on fall migration

In September-November, both immature and mature rainbow trout entered the Black River from Lake Michigan. When the barrier was out of operation in August-November of 1950 and 1957, many of these fish migrated past the dam site as evidenced by the capture of 228 in the upstream trap of the weir (Table 6). When the barrier was operated during August-November of 1952 to 1955, 207 were caught (and returned downstream) at the dam trap but only 34 were taken in the weir. Of those taken in the weir, 27 were caught in 1954. The larger number of trout surmounting the barrier in 1954 than in 1952, 1953, 1955, was associated with a lower head (Table 2) and a larger flow of water.

In the autumns of 1953 and 1954, 27 mature fish were caught in the dam trap, tagged, and returned downstream. None of these were recovered above the barrier in the autumn of the year they were tagged; six were recovered below the dam in April of the next year, and four were recovered above the barrier in May or June of that year. These data suggest that the fall migrants have a lesser urge to move upstream and if prevented from so doing may remain below the barrier until the next spring.

Effect of the barrier on reproduction.--In September or October, 1952-1957, young rainbow trout were collected with an alternating-current shocker at three stations in the Black River and at three stations in small tributaries (Fig. 1). These stations were

360 to 720 feet long and about 1 1/2 hours were spent collecting rainbow trout at each station. The yearly catch per hour of young-of-the-year rainbow trout (average, 12; range, 3 to 40), although variable, demonstrated that reproduction from lake-run fish[6] occurred each year. Reproduction was poor in 1953 when rainbow trout had the greatest difficulty at the barrier, but was little better in 1954 and 1957 when rainbow trout apparently had little difficulty at the barrier. It is suspected that factors other than the barrier dam are the cause of the wide fluctuation in the catch per hour.

Miscellaneous fish

Each spring, large spawning runs of common suckers, longnose suckers, and smelt enter the Black River from Lake Michigan. Resident brook and brown trout also spawn in the Black River. The blocking effect of the barrier on these species was studied, but there was no investigation of reproduction.

White and longnose suckers.--Relatively large numbers of white and longnose suckers were caught at the dam trap (Table 7). The sucker migration usually occurred in May and the first part of June. At that time, in 1951-1957, the average semi-monthly head ranged from 22 to 37 inches (Table 2). All (except 222 returned downstream in 1952) suckers caught in the dam trap were passed upstream in 1950 and 1952-1955, but none were passed upstream in 1951, 1956, and 1957. In 1950,

---

[6] A study (1950-1959) of rainbow trout life history on the Black River, indicated that reproduction from stream resident fish was negligible.

Table 7.--Number of white and longnose suckers and smelt caught in traps of the barrier dam and weir at the Black River during the spawning runs in 1950-1957

Year	White sucker			Longnose sucker			Smelt		
	Barrier dam	Upstream weir	Downstream weir	Barrier dam	Upstream weir	Downstream weir	Barrier dam	Upstream weir	Downstream weir
1950	399	441	77	750	534	473	0	0	0
1951	-	0	0	-	0	0	-	0	0
1952	1,156	511	570	2,116	527	814	1,877	0	0
1953	573	483	421	397	363	322	4,523	0	0
1954	190	180	135	72	42	40	47	0	1
1955	69	62	52	752	594	558	4,397	94	80
1956[1]	77	0	0	9	0	0	0	0	0
1957[1]	35	1	0	0	0	0	0	0	0

[1] The small number of suckers and smelt taken in 1956-1957 was due to low water which made it difficult for these species to enter the trap. In 1958, when a more efficient trap was operated, large numbers of these species were again caught.

escapement of white suckers occurred, since more were taken in the upstream trap of the weir than were passed over the dam. This escapement is believed to have resulted from the severe undercutting of the barrier which occurred that year. In 1952, 222 suckers caught in the barrier dam trap were marked by the removal of the dorsal fin and were released below the barrier. Five were subsequently trapped at the weir. However, these may have been inadvertently released upstream when recaptured in the dam trap. In 1953-1955, the observed poor jumping ability of suckers, plus the fact that the number taken in the upstream trap of the weir did not exceed the number that was caught in the dam trap and passed over the dam, indicated that suckers were blocked.

In 1951, 1956, and 1957, when suckers caught in the trap were returned downstream, the dam was a virtually complete barrier to white and longnose suckers since only one adult sucker was taken in the weir.

Smelt.--Smelt usually migrated upstream during the last half of April and the first half of May. In 1954-1957, when the escapement of smelt was studied, the average semi-monthly head ranged from 27 to 30 inches (Table 2). The catch of the weir in 1954-1957 during the later part of the smelt runs demonstrated that smelt were unable to surmount the barrier. In 1954-1955, a few smelt were caught in the weir (Table 7) after being lifted over the dam, but they were not caught in 1956-1957 when they were not transferred over the barrier.

Observations of large concentrations of smelt below the dam and their weak jumping ability also indicated that smelt were blocked by the barrier.

Brook and brown trout.--Few data on escapement of brook and brown trout are available for 1950-1955. However, in July 1951, two lake-run brown trout (17.8 and 19.9 inches) which had presumably jumped the barrier, were caught in the upstream trap of the weir. In March-August of 1956-1957, brook and brown trout caught in the barrier dam trap were fin-clipped and returned downstream. Two (10.1 and 11.4 inches) of 51 marked brook trout (4.0-11.4 inches) and two (9.7 and 11.8 inches) of 23 marked brown trout (8.2-21.5 inches) were recaptured in the weir.

Suggested improvements for barrier dam

The barrier dam, as constructed, was not an entirely satisfactory structure for sea lamprey control. The wooden portion necessitated many repairs and it is doubtful that it was always tight enough to prevent sea lampreys from escaping through cracks and crevices. A concrete and steel structure would undoubtedly be tighter and preclude continual maintenance. This improved structure should have: (1) a larger and deeper jumping pool to eliminate turbulence; (2) a wider spillway to accommodate flood waters; and (3) a location above the effect of lake seiches. The dam trap can be eliminated unless it is desirable to pass smelt and suckers upstream.

Comparison of the dam with other control methods

The electro-mechanical weir (McLain, 1957) and a larvicide (Applegate, et al., 1961) have been extensively used to control sea lampreys. The former was designed to block sea lampreys from their spawning grounds and the latter was used to kill larvae in streams.

Even if it is assumed that the electrical weir blocks all sea lampreys during its operation and the larvicide kills all larvae in the stream, shortcomings of these two methods are apparent. The barrier dam can be operated throughout the year but the electrical weir can be operated economically only during the sea lamprey spawning season. In some streams, sea lampreys enter the stream at other times of the year and have free access to the spawning grounds. Larval sea lampreys migrate out of the stream (Hansen and Hayne, 1961) into lentic environments where they are not vulnerable to treatment with larvicide.

The cost of building an improved dam on the Black River is estimated at $10,000; maintenance would involve only an occasional visit and probably not more than $200 per year. The initial cost of an electrical weir on the Black River was $1,500 and maintenance and servicing cost approximately $1,000 per year.[7] A larvicide treatment of the Black River in 1961 cost $4,100. Costs, however, are best compared if they are prorated for 10-, 20-, and 30-year periods. Prorated over a 10-year period, costs of the three methods of control are

[7] This cost is difficult to establish because electrical weirs are operated in groups by one crew. A rough estimate of cost was found by dividing the total cost by the number of weirs in this particular group.

approximately the same, assuming that a larvicide treatment would be made every 4 years. On a 20- and 30-year basis, however, costs of electrical weir operation or larvicide use were approximately 1 1/2 and 2 times more than the cost of operating a barrier dam during the same periods.

Summary

Spawning sea lampreys were unable to escape over the curved or straight lip when a head of 26 inches or more was maintained (as in 1951, 1955, and 1956). When the minimum head was less (16 and 20 inches in 1952 and 1953) escapement over both lips apparently occurred. The effectiveness of the two lips was not discernibly different. Escapement of spawning sea lampreys in 1950, 1954, and 1957 was no doubt due to structural failure. The dam blocked lampreys in the late summer and fall when feeding sea lampreys entered the stream. Although minor escapement of spawning migrants occurred, the barrier dam was at least partially responsible for a severe curtailment of recruitment to the larval population as evidenced by a sharp reduction in numbers of sea lamprey larvae above the barrier and increases in their average size.

Except in 1953, rainbow trout were not blocked by the barrier. They could surmount the barrier at a head of at least 30 inches, a head which blocked sea lampreys. However, at heads of 33 to 49 inches, it was difficult for rainbow trout to jump over the barrier. The type of lip had no discernible effect on the ability of rainbow trout to surmount the barrier. The majority of rainbow trout migrating upstream in August-November were blocked by the barrier until the following spring. Reproduction, above the barrier, occurred each year.

White suckers, longnose suckers, and smelt were blocked by the barrier. At least some brook and brown trout were able to negotiate the barrier.

The barrier dam was not entirely satisfactory. A concrete and steel structure, with certain modifications, would no doubt prevent escapement of sea lampreys. An improved barrier dam may be a cheaper and more efficient method of control than an electric weir or larvicides in certain small streams.

Literature cited

Applegate, Vernon C. 1950. Natural history of the sea lamprey, *Petromyzon marinus*, in Michigan. U. S. Dept. of Int., Fish and Wildl. Serv., Spec. Sci. Rept., Fish. 55, 237 p.

Applegate, Vernon C., and Bernard R. Smith. 1950. Sea lamprey spawning runs in the Great Lakes, 1950. U. S. Dept. of Int., Fish and Wildl. Serv., Spec. Sci. Rept., Fish. 61, 49 p.

Applegate, Vernon C., Bernard R. Smith, and Willis L. Nielsen. 1952. Use of electricity in the control of sea lampreys: Electromechanical weirs and traps and electrical barriers. U. S. Dept. of Int., Fish and Wildl. Serv., Spec. Sci. Rept., Fish. 92, 52 p.

Applegate, Vernon C., John H. Howell, James W. Moffett, B. G. H. Smith, and Manning A. Smith. 1961. Use of 3-trifluormethyl-4-nitrophenol as a selective sea lamprey larvicide. Great Lakes Fishery Commission Tech. Rept. 1, 35 p.

Hansen, Martin J., and Don W. Hayne. 1962. Sea lamprey larvae in Ogontz Bay and Ogontz River, Michigan. Jour. Wildl. Mgt., 26 (3): 237-247.

McLain, Alberton L. 1957. The control of the upstream movement of fish with pulsated direct current. Trans. Am. Fish. Soc., 86: 269-284.

Stauffer, Thomas M. 1951. Experimental operation of Black River sea lamprey barrier dam, 1950. Mich. Dept. Cons., Inst. Fish. Res. Rept. No. 1280 (unpublished).

__________ 1952. Experimental operation of the Black River sea lamprey barrier, 1951. Mich. Dept. Cons., Inst. Fish. Res. Rept. No. 1314 (unpublished).

__________ 1954. Operation of Black River barrier dam, 1952-53. Mich. Dept. Cons., Inst. Fish. Res. Rept. No. 1411 (unpublished).

Stauffer, Thomas M., and Martin J. Hansen. 1958. A preliminary report of the migration of sea lamprey ammocoetes in Michigan. Mich. Dept. Cons., Inst. Fish. Res. Rept. No. 1535 (unpublished).

Wigley, Roland L. 1959. Life history of the sea lamprey of Cayuga Lake, New York. U. S. Dept. of Int., Fish and Wildl. Serv., Fish. Bull. 154: 561-617.

INSTITUTE FOR FISHERIES RESEARCH

Thomas M. Stauffer

Report approved by W. R. Crowe

Typed by M. S. McClure