SEA LAMPREY CONTROL ON THE GREAT LAKES 1953 AND 1954

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1953 and 1954

by

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ABSTRACT

Development of electromechanical devices permitted practical application of sea-lamprey control in Great Lakes streams. The barriers were energized by 110-volt, 60-cycle, alternating current.

Sea lampreys were effectively blocked in their upstream spawning migration. Traps were installed in the control structures to pass migratory fish upstream. The extent of fish mortality at the electrical barriers was influenced by stream velocities, conductivity of the water and stream bottom, and size and location of the traps.

Biological data on the sea lampreys were collected at the control structures.

Each stream appeared to have its own electrical characteristics. Several factors influencing the electrical fields were determined. Present information indicates limited possibility of improving the electrical field to reduce fish mortality.

CONTENTS

SEA LAMPREY CONTROL ON THE GREAT LAKES 1953 AND 1954

The use of electricity to control the sea lamprey (Petromyzon marinus) was undertaken on Lake Superior and northern Lake Michigan in 1953 and 1954 as a result of 3 years of development research on control methods by the Great Lakes Fishery Investigations of the Fish and Wildlife Service.

The initial project was a pilot control program, operated during the spring of 1953 in several streams tributary to Lake Superior, to test the practicability of the electromechanical devices as barriers to the movement of sea lampreys to their spawning grounds. After this test proved the effectiveness of the devices, a comprehensive control program was launched in 1954. Control structures were operated in streams along 500 miles of the south shore of Lake Superior. In anticipation of the expansion of the control program to Lake Michigan, several control devices were also installed and operated in streams tributary to northern Green Bay. The areas of the Great Lakes currently covered by the program are shown in figure 1.

Numerous species of fish are mentioned in this report. Their common and scientific names are as follows:

Sea lamprey	Petromyzon marinus
Silver lamprey	Ichthyomyzon unicuspis
American brook lamprey	Lampetra lamottei
Bowfin	Amia calva
Rainbow trout	Salmo gairdneri
Brown trout	Salmo trutta
Lake trout	Salvelinus namaycush
Brook trout	Salvelinus fontinalis
Round whitefish	Prosopium cylindraceum
Smelt	Osmerus mordax
White sucker	Catostomus commersoni
Longnose sucker	Catostomus catostomus
Hog sucker	Hypentelium nigricans
Silver redhorse	Moxostoma anisurum
Golden shiner	Notemigonus crysoleucas
Creek chub	Semotilus atromaculatus
Pearl dace	Semotilus margarita nachtriebi
Emerald shiner	Notropis atherinoides
Common shiner	Notropis cornutus
Spottail shiner	Notropis hudsonius
Lake chub	Hybopsis plumbea
Blacknose dace	Rhinichthys atratulus
Longnose dace	Rhinichthys cataractae
Redbelly dace	Chrosomus eos
Carp	Cyprinus carpio
Brown bullhead	Ictalurus nebulosus
Black bullhead	Ictalurus melas
Northern pike	Esox lucius
Central mudminnow	Umbra limi
Burbot	Lota lota
Trout-perch	Percopsis omiscomaycus
Ninespine stickleback	Pungitius pungitius
Yellow perch	Perca flavescens
Walleye	Stizostedion v. vitreum
Logperch	Percina caprodes
Johnny darter	Etheostoma nigrum
Smallmouth bass	Micropterus dolomieui
Pumpkinseed	Lepomis gibbosus
Rock bass	Ambloplites rupestris
Black crappie	Pomoxis nigromaculatus
White bass	Roccus chrysops
Freshwater sculpins	Cottus bairdi
	Cottus cognatus

Electromechanical control structures

Three types of electromechanical weirs were used in the pilot control project (Applegate, Smith, and Neilsen, 1952). Each barrier was designed to meet the particular requirements of certain streams. All types included a shielded trap (or traps) to capture and protect the migrating fish. The type of structures used in the control

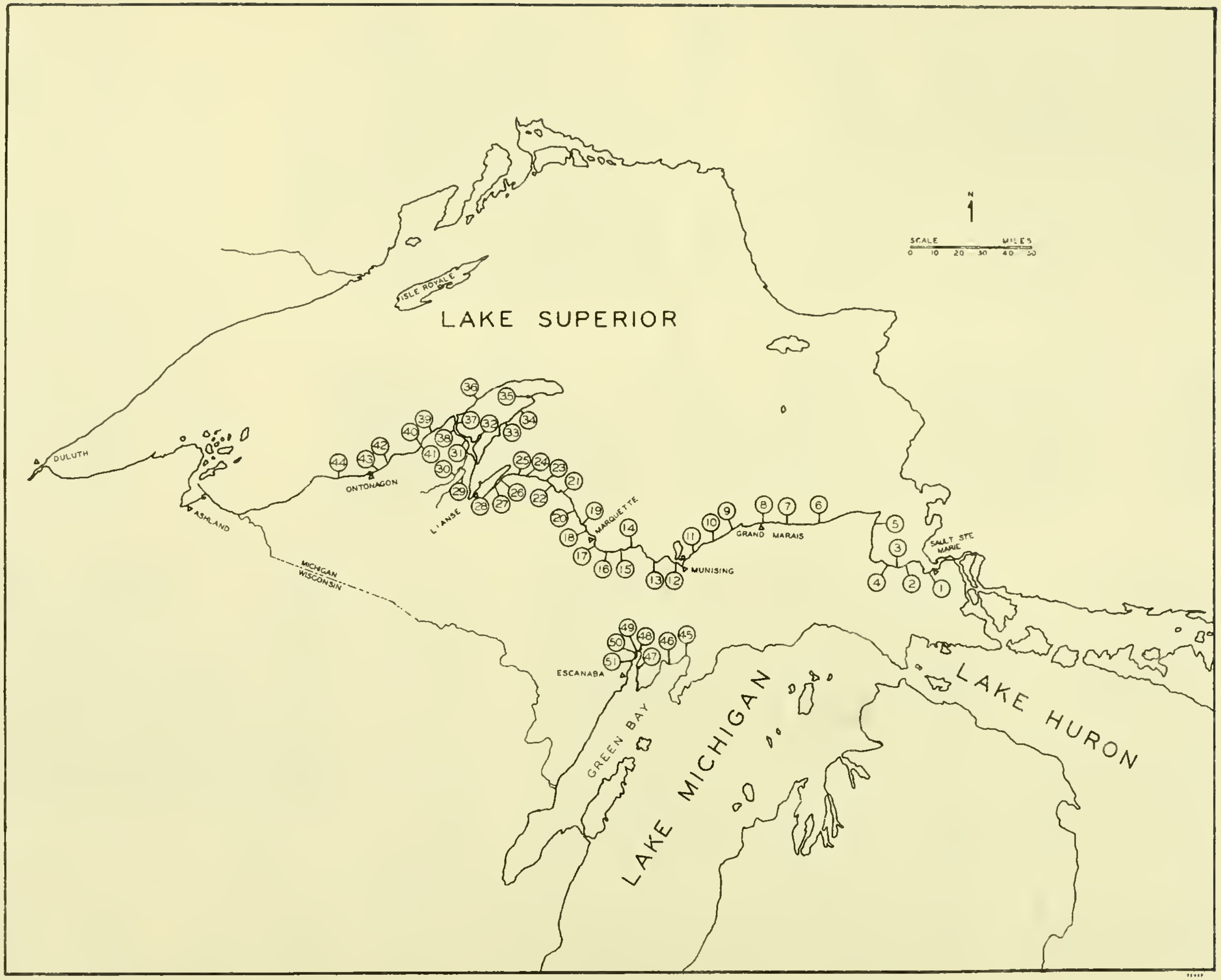

Figure 1.--Map of Lake Superior and northern Lake Michigan showing locations of sea-lamprey control devices. The names of the streams are given in tables 1, 3 and 4.

work are described briefly as follows:

Type A.--Two parallel rows of hanging electrodes suspended across the stream by a catenary cable (fig. 2).

Type B.--A single row of suspended electrodes and a horizontal submerged electrode parallel to the suspended electrodes (fig. 3).

Type C.--Two horizontal, submerged electrodes lying parallel across the stream bed (fig. 4).

The kind of device used was determined by the physical characteristics of each stream. Type A was installed in deep, soft-bottomed streams, where water velocities were low. Type B structures were used in streams having moderate depths, relatively firm bottoms, and reasonably fast water velocities. Type C barriers were installed in shallow, rapid-flowing streams. All installations were energized by 110-volt, 60-cycle, alternating current, which was supplied from commercial lines or by gasoline-powered generators.

The streams were grouped by operational zones, each of which contained as many streams as a service crew could handle in a day. The devices were visited by a two-man crew at least once a day. The men removed the live sea lampreys from the traps and the dead or disabled lampreys from the electrical field below and destroyed them. All fish in the traps were counted and recorded by species and were released upstream. Generators were checked and refueled as needed. Only two zones were operated on Lake Superior in 1953; in 1954, the number was increased to seven zones on Lake Superior, and one zone was established on Lake Michigan.

Sea lampreys and fish caught or killed

Ten electrical control devices were operated in 1953 along the south shore of Lake Superior between Sault Ste. Marie and Marquette, Mich., during most of the sea-lamprey migration period. Operations began April 4 and ended August 14. Original plans called for 23 devices in streams selected for the pilot project on the basis of surveys of 1950-51 (Loeb and Hall 1952), but considerable delay was encountered in obtaining leases or easements on lands needed for the placement of the structures. Consequently, only 10 of the proposed 23 were completed in time for operation. Nine more units were installed by June 1, but owing to the lateness of the season and the lack of manpower occasioned by official recruitment restrictions they were not operated.

In 1954, the 19 electrical control structures that had been installed by the end of the preceding season, plus 24 additional devices, were operated on the south shore of Lake Superior, thus expanding the area of control to Porcupine Mountain State Park, Mich. In addition, a large mechanical weir was constructed on the Chocolay River near Marquette, Mich. Seven more barriers were constructed and operated in streams tributary to Big Bay de Noc and Little Bay de Noc of northern Lake Michigan.

Sea lamprey.--Although the operation of the pilot project in 1953 was incomplete, it proved that sea lampreys could be blocked effectively in their upstream migration. Lampreys were taken in 9 of the 10 streams under control in 1953. The electrical barriers in these streams captured

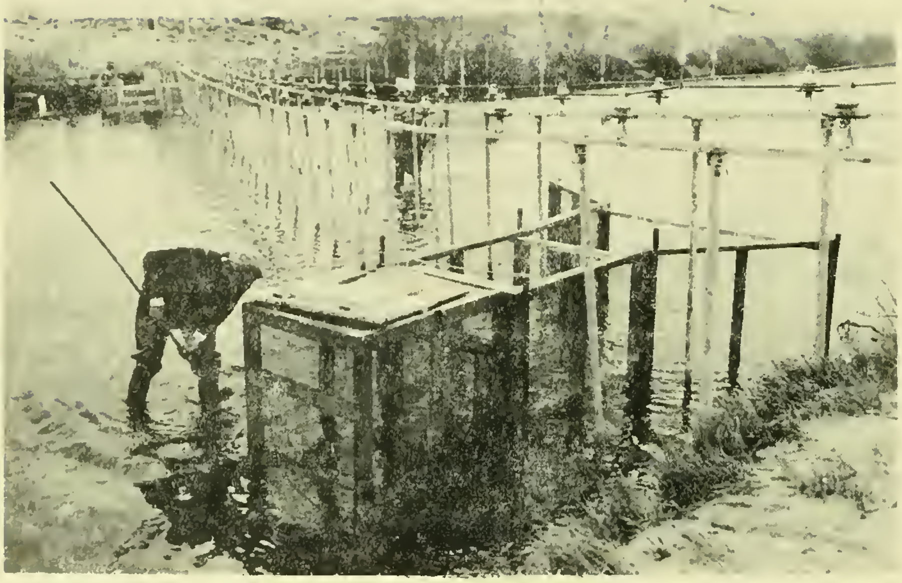

Figure 2.--Electromechanical sea-lamprey control device (Type A) in the Two Hearted River, Luce County, Mich.

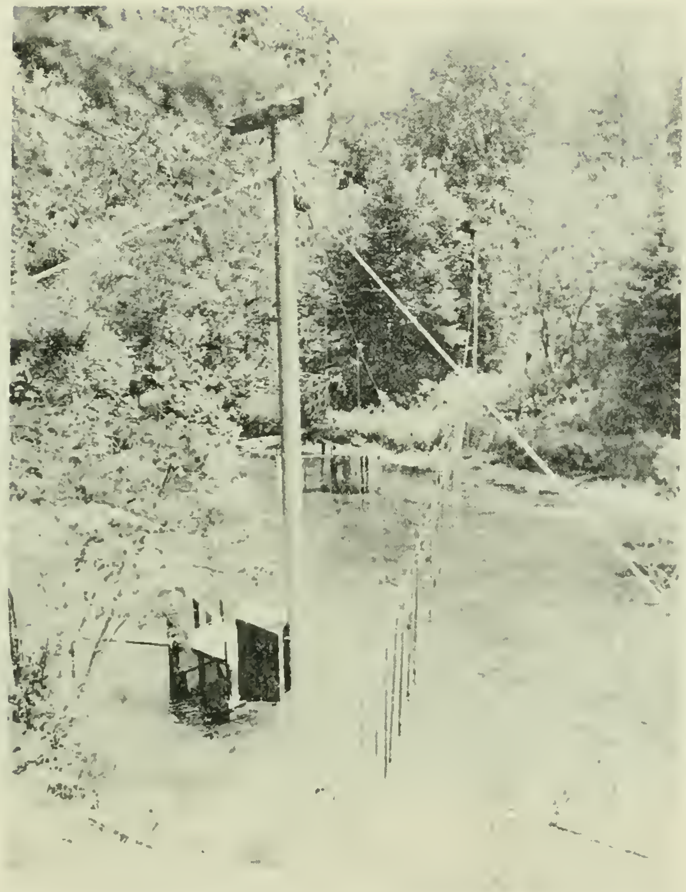

Figure 3.- Electromechanical sea-lamprey control device (Type B) in the Iron River, Marquette County, Mich.

Figure 4.--Electromechanical sea-lamprey control device (Type C) in Harlow Creek, Marquette County, Mich.

or killed 1,668 sea lampreys (table 1). The traps included in the control structures to protect migrating fish captured the large majority (90.6 percent) of the sea lampreys; the rest were killed by the electrical field.

Expansion of the pilot project in 1954 resulted in almost complete control along the south shore of Lake Superior. Operations began March 19 and ended August 18. Of the 44 Lake Superior streams--14 of them west of Marquette, Mich.--18 failed to yield lampreys. The remaining 26 streams produced a total catch of 4,922 lampreys (tables 2 and 3). Again the major part (86.9 percent) of the catch was taken from the traps. Of the 26 streams, 7 had large sea-lamprey runs that produced 4,485 lampreys, or 91.1 percent of the total. It is entirely possible that as the sea-lamprey population in Lake Superior increases, these more productive streams will develop spawning runs that are too large to be accomodated and the surplus spawners may have to utilize the less suitable streams.

In anticipation of the extension of controls to Lake Michigan, and to obtain information on the problems to be encountered, 7 electrical devices were operated in streams tributary to northern Green Bay. All 7 streams had sea-lamprey runs. A total of 7,367 lampreys was taken, of which 89.2 percent were captured in the traps (tables 2 and 4). The Sturgeon River produced 55.8 percent of the total catch in the zone. Observations of sea-lamprey behavior in the stream gave evidence that many lampreys were diverted downstream by the electrical field, and that they returned to the lake to find other streams or died without spawning.

Comparison of the data for the 10 Lake Superior streams that were under control in both years demonstrated that over comparable periods of operation the catch of sea lampreys increased from 1,624 in 1953 to 2,479 in 1954--a gain of 53 percent. Further evidence of increase was observed from the incidence of scarring among the large, sexually mature lake trout caught in the commercial fishery at Marquette, Mich. Of 1,073 lake trout (average weight 8.1 pounds) examined in early November 1954, 232 (21.6 percent) were scarred. In the same period in 1953, 793 lake trout (average weight 8.6 pounds) included 105 (13.2 percent) scarred individuals. These data indicate an increase in the sea-lamprey population in Lake Superior similar to the increases that took place in Lake Huron and Lake Michigan. If this increase is not halted, the lampreys will destroy the lake-trout fishery of Lake Superior within the next few years.

The spawning population of sea lampreys in Lake Superior is not large at present in comparison with populations in Lake Huron and Lake Michigan, but the outlook for the next several years is poor. It is significant that the present controls serve only to prevent the spawning of future generations. The streams already contain several year classes from past spawnings. Control may have been instituted in time to avert extermination of the lake trout, but unless some means is discovered of destroying larval lampreys in the streams a serious decline of lake trout is almost certain.

Nor has early control been complete. Some upstream escapement occurred in 1954 because of a power breakdown on the Two Hearted River, because of flooding of the mechanical weir on the Chocolay River, and because of a late start on the Huron River. Control is believed to have been complete in all other streams with barriers. Extensive checks of streams above the structures failed to reveal signs of sea lampreys or their nests. Surveys of streams in the control area without electrical barriers disclosed only two streams with sea-lamprey runs. The Misery River, west of Keweenaw Peninsula, had several lamprey nests. Rock River, with a 5-foot concrete dam that was

Table 1.--Catch of fish and sea lampreys in traps of control structures, and numbers found dead in the electrical field, 1953 (Streams can be located in fig. 1 by the numbers in parentheses)

	In Zone S-1					In Zone S-2					
	Pendills Creek (2)	Betsy River (5)	Two Hearted River (6)	Dead Sucker River (7)	Sucker River (8)	Beaver Lake Creek (10)	Miners River (11)	Furnace Creek (12)	Au Train River (13)	Laughing Whitefish River (14)	Totals
Sea lamprey:											
From traps	23	187	257	0	748	6	64	14	204	9	1,512
Dead in field	0	34	114	0	2	2	0	4	0	0	156
Native lamprey:											
From traps	9	5	0	0	0	0	0	2	1	0	17
Dead in field	0	40	0	1	26	0	0	395	0	10	472
Rainbow trout:											
From traps	39	0	209	0	27	6	15	161	4	10	470
Dead in field	2	0	31	5	8	2	6	27	0	16	97
Brook trout:											
From traps	111	4	25	8	23	9	13	139	2	3	337
Dead in field	1	3	1	12	2	4	0	10	0	0	33
Brown trout:											
From traps	109	0	0	1	0	0	0	0	0	0	110
Dead in field	0	0	0	0	0	0	0	0	0	0	0
Round whitefish:											
From traps	0	0	521	0	0	2	0	0	0	0	523
Dead in field	0	0	39	1	0	0	0	0	0	0	40
Smelt:											
From traps	6	1	0	0	0	0	0	4,977	924	0	5,908
Dead in field	0	0	0	0	0	0	0	173	0	0	173
White sucker:											
From traps	15	435	274	2	528	53	42	197	173	31	1,750
Dead in field	1	299	33	45	117	130	4	62	11	35	737
Longnose sucker:											
From traps	1,319	356	198	0	9	0	16	129	4	253	84
Dead in field	15	2,122	31	0	14	5	8	154	5	537	2,891
Miscellaneous[1/]											
From traps	941	459	46	39	470	1,876	708	2,710	1,303	145	8,597
Dead in field	0	25	0	2	3	82	16	294	7	55	484

1/ Miscellaneous includes 535 yellow perch, 52 northern pike, 7 walleye, 3,329 longnose dace, 41 creek chubs, 1,966 trout-perch, 595 sculpins, 52 mudminnows, 663 rock bass, 1,769 spottail shiner, 2 lake chubs, 2 smallmouth bass, 1 emerald shiner, 22 logperch, 12 bullhead, 2 redbelly dace, 7 burbot, 4 stickleback, 3 golden shiner, 7 common shiner, 4 blacknose dace, 3 johnny darters, and 1 pearl dace

Table 2.--Total number of sea lampreys and fish trapped and electrocuted at control devices, 1954

Fish	In Lake Superior			In Lake Michigan		
	Number trapped	Number electrocuted	Total	Number trapped	Number electrocuted	Total
Sea lamprey	4,277	645	4,922	6,569	798	7,367
Native lamprey	530	1,831	2,361	526	370	896
Rainbow trout (large)[1/]	364	307	671	8	8	16
Rainbow trout (small)	2,363	2,725	5,088	9	19	28
Brook trout	1,564	645	2,209	98	53	151
Smelt	12,041	1,512	13,553	10,022	4,404	14,426
White sucker	15,090	11,638	26,728	1,540	948	2,488
Longnose sucker	35,945	10,966	46,911	267	91	358
Northern pike	60	84	144	11	219	230
Brown trout	102	36	138	1	0	1
Round whitefish	191	45	236	0	0	0
Yellow perch	1,191	81	1,272	10	13	23
Walleye	93	32	125	4	96	100
Longnose dace	3,977	1,017	4,994	264	147	411
Trout-perch	61,399	7,277	68,676	10,326	1,273	11,599
Sculpin	623	308	931	23	63	86
Spottail shiner	2,473	144	2,617	948	154	1,102
Bullhead	1,795	24	1,819	1,441	22	1,463
Logperch	1,448	3,806	5,254	1,336	46,200	48,536
Miscellaneous[2/]	3,947	1,455	5,402	3,298	1,503	4,801

1/ Over 12 inches, total length

2/ Miscellaneous includes: common shiner, smallmouth bass, pumpkinseed, rock bass, burbot, white bass, creek chub, stickleback, mudminnow, silver redhorse, lake chub, bowfin, hog sucker, and carp

Table 3.--Catches of sea lampreys and fish at 44 control devices on streams of Lake Superior, 1954

(Streams can be located in fig. 1 by the numbers in parentheses)

Fish	In Zone S-1					In Zone S-2			
	Waiska River (1)	Pendills Creek (2)	Halfaday Creek (3)	Ankodosh Creek (4)	Betsy River (5)	Two Hearted River (6)	Dead Sucker River (7)	Sucker River (8)	Hurricane River (9)
Sea lamprey:									
From traps..........	16	36	10	0	531	541	0	1,288	6
Dead in field.........	16	4	2	0	36	97	0	21	2
Native lamprey:									
From traps..........	121	29	5	0	10	1	0	2	0
Dead in field.........	6	0	2	65	2	0	1	0	0
Rainbow trout (large)[1/]:									
From traps..........	0	8	22	0	0	62	1	6	15
Dead in field.........	0	0	32	0	0	18	3	16	9
Rainbow trout (small):									
From traps..........	0	32	66	0	0	570	1	18	37
Dead in field.........	0	0	18	0	0	13	4	1	5
Brook trout:									
From traps..........	0	188	104	59	3	13	1	80	28
Dead in field.........	0	1	9	49	1	2	4	10	0
Smelt:									
From traps..........	0	334	3	0	7	39	8	73	0
Dead in field.........	0	0	0	0	12	2	5	13	0
White sucker:									
From traps..........	440	9	2	0	374	3	22	397	0
Dead in field.........	1,275	0	0	0	128	62	34	71	0
Longnose sucker:									
From traps..........	0	414	20	0	883	1,749	1	19	3
Dead in field.........	0	0	3	0	619	111	0	17	13
Miscellaneous[2/]:									
From traps..........	2,974	757	220	314	355	226	3	373	7
Dead in field.........	55	1	4	135	17	43	18	0	0

(continued)

Table 3.--(Continued)

Fish	In Zone S-3						
	Beaver Lake Creek (10)	Miners River (11)	Furnace Creek (12)	Au Train River (13)	Laughing Whitefish River (14)	Sand River (15)	Chocolay River (16)
Sea lamprey:							
From traps..........	9	53	29	339	11	0	1,227
Dead in field.........	10	0	18	11	14	0	0
Native lamprey:							
From traps..........	0	0	0	0	0	0	10
Dead in field.........	1	0	945	0	1	0	0
Rainbow trout (large)[1/]:							
From traps..........	0	9	4	1	6	7	46
Dead in field.........	11	1	4	0	6	42	0
Rainbow trout (small):							
From traps..........	6	64	16	0	22	57	188
Dead in field.........	7	1	16	0	19	75	0
Brook trout:							
From traps..........	31	18	75	0	3	14	53
Dead in field.........	9	0	12	0	0	7	0
Smelt:							
From traps..........	0	0	3,872	164	1	0	10
Dead in field.........	0	0	470	0	0	0	0
White sucker							
From traps.........	79	168	116	109	230	64	3,126
Dead in field.........	76	8	61	19	35	337	0
Longnose sucker							
From traps..........	0	253	6	4	1,056	10	26,023
Dead in field.........	0	12	123	0	277	96	0
Miscellaneous[2/]							
From traps..........	2,022	140	410	1,009	163	727	229
Dead in field.........	191	2	155	29	13	50	0

(continued)

Table 3.--(Continued)

Fish	In Zone S-4						
	Carp River (17)	Harlow River (18)	Little Garlic River (19)	Big Garlic River (20)	Iron River (21)	Salmon Trout River (22)	Pine River (23)
Sea lamprey:							
From traps..........	0	1	0	54	30	1	1
Dead in field.........	0	0	0	0	37	0	9
Native lamprey:							
From traps..........	0	3	0	0	53	2	2
Dead in field.........	0	4	0	0	3	0	8
Rainbow trout (large)[1/]:							
From traps..........	3	17	87	2	0	4	3
Dead in field.........	1	0	5	1	1	7	2
Rainbow trout (small):							
From traps..........	22	139	61	4	1	9	2
Dead in field.........	2	6	12	0	2	7	3
Brook trout:							
From traps..........	7	124	36	5	2	119	2
Dead in field.........	2	4	2	0	4	14	4
Smelt:							
From traps..........	0	0	1	19	13	0	1,393
Dead in field.........	0	0	0	7	96	0	431
White sucker:							
From traps..........	65	134	41	211	63	190	88
Dead in field.........	12	26	12	37	112	137	63
Longnose sucker:							
From traps..........	25	81	125	754	851	685	308
Dead in field.........	33	17	40	34	2,024	1,176	301
Miscellaneous[2/]:							
From traps..........	13	512	247	95	174	1,042	155
Dead in field.........	3	38	209	61	422	113	343

(continued)

Table 3.--(Continued)

Fish	In Zone S-5						
	Little Huron River (24)	Huron River (25)	Ravine River (26)	Slate River (27)	Silver River (28)	Sturgeon River (29)	Otter River (30)
Sea lamprey:							
From traps..........	0	20	0	0	45	1	0
Dead in field..... ...	0	127	1	0	202	0	0
Native lamprey:							
From traps..........	0	0	1	0	24	41	0
Dead in field.........	1	1	1	0	17	8	0
Rainbow trout (large) 1/:							
From traps..........	11	5	2	9	2	0	1
Dead in field.........	49	15	9	3	8	0	0
Rainbow trout (small):							
From traps..........	18	103	20	16	5	2	3
Dead in field.........	52	52	259	0	26	0	9
Brook trout:							
From traps..........	44	27	9	27	10	1	6
Dead in field.........	46	12	18	0	51	0	0
Smelt:							
From traps..........	11	16	1	0	0	1	0
Dead in field.........	22	7	0	0	0	1	1
White sucker:							
From traps..........	3	111	33	220	1,501	25	82
Dead in field.........	2	174	191	69	4,919	15	32
Longnose sucker:							
From traps..........	0	392	373	363	59	10	0
Dead in field.........	11	2,706	124	101	84	7	1
Miscellaneous 2/:							
From traps..........	22	8,800	646	5,173	2,503	615	3,874
Dead in field.........	49	13	99	20	26	10	3

(continued)

Table 3.--(Continued)

Fish	In Zone S-6							
	Pilgrim River (31)	Traprock River (32)	Traverse River (33)	Tobacco River (34)	Little Gratiot River (35)	Gratiot River (36)	Boston-Lily Creek (37)	Schlotz Creek (38)
Sea lamprey:								
From traps..........	0	0	1	0	0	1	0	0
Dead in field.........	0	0	2	0	0	0	0	0
Native lamprey:								
From traps..........	17	12	34	0	36	5	2	0
Dead in field.........	219	1	74	4	186	2	0	0
Rainbow trout (large)[1/]:								
From traps..........	1	1	9	0	0	1	0	1
Dead in field.........	5	0	6	0	1	8	3	0
Rainbow trout (small):								
From traps..........	55	4	47	30	3	49	17	191
Dead in field.........	258	0	157	7	7	38	175	5
Brook trout:								
From traps..........	109	6	12	4	8	13	61	189
Dead in field.........	102	4	3	0	13	2	229	6
Smelt:								
From traps..........	3,811	601	1	0	266	33	39	10
Dead in field.........	296	30	0	0	39	2	2	0
White sucker:								
From traps..........	828	3,626	51	15	613	42	56	174
Dead in field.........	1,572	477	88	12	335	27	545	39
Longnose sucker:								
From traps..........	0	0	543	44	167	389	1	0
Dead in field.........	0	2	211	90	101	39	0	0
Miscellaneous[2/]:								
From traps..........	169	893	35	16	38,501	43	724	678
Dead in field.........	1,545	26	65	0	5,795	80	3,793	20

(continued)

Table 3.--(Concluded)

Fish	In Zone S-7					
	Graveraet River (39)	Elm River (40)	S. Branch Elm River (41)	Firesteel River (42)	Flintsteel River (43)	Union River (44)
Sea lamprey:						
From traps..........	0	0	0	26	0	0
Dead in field.........	0	0	0	34	2	0
Native lamprey:						
From traps..........	0	0	0	116	19	35
Dead in field.........	0	0	0	166	11	52
Rainbow trout (large)1/:						
From traps..........	2	10	3	2	0	1
Dead in field.........	5	9	11	3	0	13
Rainbow trout (small):						
From traps..........	166	138	111	44	0	26
Dead in field.........	16	2	797	63	6	605
Brook trout:						
From traps..........	24	10	31	4	3	1
Dead in field.........	4	0	18	0	2	1
Smelt:						
From traps..........	0	0	0	0	0	11
Dead in field.........	0	0	0	0	0	0
White sucker:						
From traps..........	3	5	5	321	85	50
Dead in field.........	0	2	14	321	151	148
Longnose sucker:						
From traps..........	0	40	0	34	25	235
Dead in field.........	0	7	0	1,491	509	586
Miscellaneous2/:	157	15	48	902	1,165	208
	9	0	47	326	60	421

1/ Over 12 inches, total length

2/ Miscellaneous includes brown trout, round whitefish, yellow perch, northern pike, walleye, longnose dace, trout-perch, sculpin, spottail shiner, golden shiner, common shiner, logperch, brown bullhead, smallmouth bass, pumpkinseed, rock bass, black crappie, burbot, creek chub, stickleback, mudminnow, silver redhorse, lake chub, and johnny darters. The largest number of any species was 68,676 trout-perch.

Table 4.--Catches of sea lampreys and fish at 7 control devices on streams of Lake Michigan, 1954
(Streams can be located in fig. 1 by the numbers in parentheses)

Fish	Big Fishdam River (45)	Sturgeon River (46)	Squaw Creek (47)	Whitefish River (48)	Rapid River (49)	Tacoosh River (50)	Days River (51)
Sea lamprey:							
From traps..........	377	3,949	280	1,312	552	7	92
Dead in field.........	315	164	3	177	22	4	113
Native lamprey:							
From traps..........	59	215	0	213	24	2	13
Dead in field.........	151	99	1	54	2	7	56
Rainbow trout (large) 1/:							
From traps..........	0	0	0	3	3	0	2
Dead in field.........	0	0	0	4	2	0	2
Rainbow trout (small):							
From traps..........	0	1	0	4	3	0	1
Dead in field.........	0	1	0	6	4	1	7
Brook trout:							
From traps..........	1	3	1	14	37	25	17
Dead in field.........	3	0	0	2	5	40	3
Smelt:							
From traps..........	4,037	0	3,963	0	1	321	1,700
Dead in field.........	907	1	100	2,339	0	36	1,021
White sucker:							
From traps..........	204	674	13	68	333	71	177
Dead in field.........	237	119	6	53	69	368	96
Longnose sucker:							
From traps..........	157	61	1	0	29	7	12
Dead in field.........	91	0	0	0	0	0	0
Miscellaneous 2/:							
From traps..........	2,192	888	1,260	632	1,113	112	11,454
Dead in field.........	39,249	41	3,018	2,652	744	779	2,988

1/ Over 12 inches, total length

2/ Miscellaneous includes brown trout, yellow perch, walleye, longnose dace, trout-perch, sculpin, spottail shiner, common shiner, logperch, brown bullhead, black bullhead, smallmouth bass, pumpkinseed, rock bass, burbot, white bass, creek chub, stickleback, mudminnow, silver redhorse, lake chub, johnny darters, bowfin, hog sucker, and carp. The largest number of any species was 47,536 logperch presumed to be a barrier to sea-lamprey migration, had a considerable escapement; 40 nests and several lampreys were observed in a quarter-mile section of the river.

Migratory fish.--Forty species of fish were captured in the traps during the sea-lamprey control operations. A spawning run of at least one species occurred in each stream with an electrical barrier. In order to take these fish and pass them upstream, one or more traps were included in the electrical control structures. In small streams, the trap is usually located at the upstream end of the diagonal array of electrodes so that the fish are diverted into it by the fringe field of electricity (fig. 4). Occasionally fish protection was improved by locating the trap along the electrode array at a point where it intersected the natural route of migration. At larger installations, a second trap is placed at the lower end of the electrode array (figs. 2 and 3).

Counts were made, by species, of fish entering the traps and also of those that were electrocuted. Table 1 gives a record of fish handled during the initial operation in 1953, and tables 2, 3, and 4 present the data for 1954.

The rainbow trout is the most important game species among the fish ascending the Lake Superior streams in the spring. They begin their spawning migration after the spring breakup. At several of the principal trout streams, many rainbow trout were above the electrical barriers before operations were started. The time of the spawning migrations of rainbow trout and sea lamprey overlap, however. The degree of overlap each year may depend on meteorological conditions.

In several streams, many mature rainbow trout were blocked by the control devices, and some were electrocuted. In 1953, rainbow-trout mortality occurred at 9 of the 10 installations and totaled 97 fish (table 1). The barriers in the same streams electrocuted 120 rainbow trout in 1954. Total mortality of rainbow trout by electrocution in Lake Superior streams in 1954 was 307 mature and 2,725 immature fish (table 2). Movement of rainbow trout in 1954 was insignificant in the 7 streams with control devices along northern Green Bay, Lake Michigan (tables 2 and 4).

The white suckers and the longnose suckers are the principal nongame species with spawning runs concurring with that of the sea lamprey. Relatively large numbers of both species of suckers were electrocuted in the deep, low-velocity streams (tables 1, 2, and 3). The highest mortality was incurred by the logperch in the tributary streams of northern Green Bay (table 2).

Factors of fish mortality.--The extent of fish mortality at a device is controlled by several factors, such as stream velocity at various volumes of flow, conductivity of the water and bottom of the stream, and size and location of the trap or traps. The importance of each of these factors is difficult to evaluate, because they are interrelated. For example, a device in a stream with fast water velocities ordinarily does not kill many fish. If, however, the electrical characteristics of the stream produce a high voltage gradient at normal electrode spacing, and if fish movement is not restricted to a well-defined channel where the trap is installed, high mortality may result. In a stream where such conditions prevail, the voltage gradient may be diminished by moving the electrodes farther apart, but this change may so increase the area of the field that fish moving downstream die from long exposure to the electrical current. Such conditions existed in the South Branch of the Elm River, where 797 fry and fingerling rainbow trout were killed in the field, despite changes made in the electrode spacing. In Harlow Creek, a trout stream of similar size and with the same type of control structure (Type C), only 6 small rainbow trout were found dead in the field. Low water velocities in Elm River and sufficiently high velocities in Harlow Creek account for the difference in number of fatalities.

Stream velocity is probably the most important physical characteristic affecting fish mortality from electrocution. Generally, an excessive kill occurs when water velocities are low, unless the pattern of fish movement is restricted to a section of the stream where the fish can be trapped before they enter the electrical field. In the Pilgrim River, the flow is sluggish after the spring runoff, and since the white sucker did not have a well-defined upstream route of migration 1,572 were killed in the electrical field.

In the selection of control sites, every effort has been made to place the devices in locations harmless to the migrating fish. The most important consideration, however, has been the blocking of the sea lampreys from spawning grounds. If the site must be selected where conditions will cause some fish kill, the mortality should be considered part of the cost of operations.

Although fish losses were high at some barriers, we believe they were generally insignificant in relation to the total runs and to the benefits of lamprey control. Among the 10 important species, including the suckers, the total mortality was only 29.8 percent. This figure includes individuals taken alive in the trap and those found dead in and below the field. It was not possible to determine the number of fish and lampreys that were blocked and turned back by the barriers to enter other streams. Observations indicate that certain species, such as suckers and smelt, spawn in some of the streams below the barriers.

Biological characteristics of the lamprey spawning runs

To supplement the original study on the sea-lamprey spawning runs in Michigan (Applegate 1950), the collection of data has been continued with the control program.

Over the present range of the species in the Great Lakes basins, the seasonal spawning migrations extend from March through August. Early migrants enter a few streams with estuarine waters in March, and upstream movement begins about mid-April, when water temperatures rise and remain above 40° F. As water temperatures increase, the upstream movement gains momentum and usually reaches a peak about the end of May or the first week of June. In the weekly record for 1954 (table 5 and fig. 5), we have combined the number of sea lampreys captured in each period from the productive streams of Lake Superior and northern Lake Michigan. In Lake Michigan, 54 percent of the total run in the 7 streams with electrical barriers had been captured by May 21; the corresponding figure for 15 streams in Lake Superior was 28 percent. By July 9, the spawning migration of sea lampreys in the streams of northern Green Bay had ended. On Lake Superior, the spawning runs in a few streams continued into August.

Several index streams were selected in 1953 and 1954 as sources of information on the biological characteristics of the spawning runs. The data on the sex of sea lampreys in these streams showed that the percentage of males increased from 1953 to 1954. (table 6). In the 5 index streams observed in 1953, the sex composition of 1,777 lampreys was 99 males to 100 females. In 1954 (when the number of index streams on Lake Superior was increased to 9), the sex ratio was 140 males to 100 females for 3,939 sea lampreys. The sex ratio of 3,530 sea lampreys sampled in 1954 in the 5 index

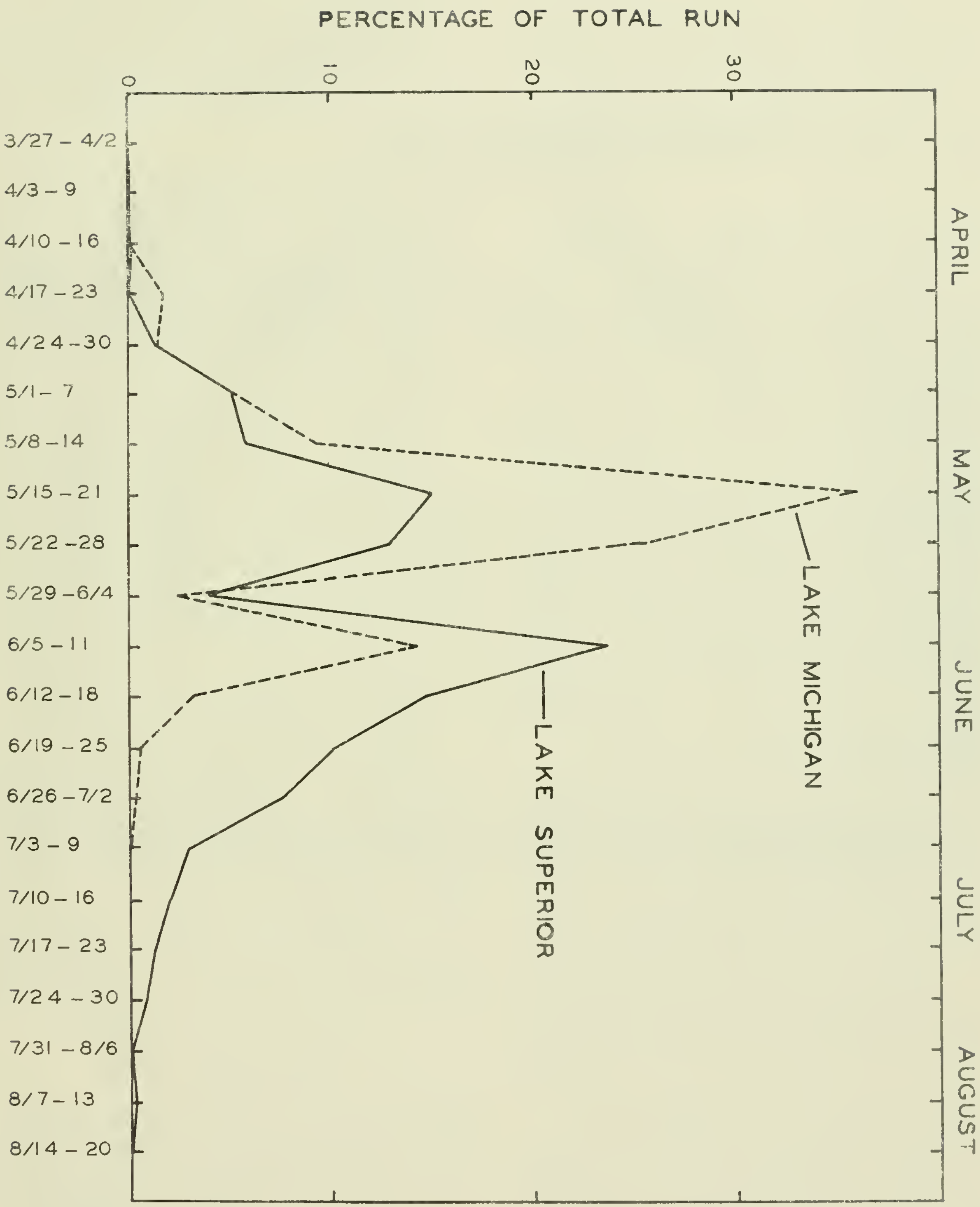

Figure 5.--Weekly total catch of sea lampreys in streams under control in Lake Superior and Lake Michigan, 1954.

Table 5.--Weekly record of total number of sea lampreys captured at electrical barriers in streams of Lake Superior and Lake Michigan, 1954

Period	Lake Superior			Lake Michigan		
	Number of streams producing lampreys	Number of lampreys	Percentage of total run	Number of streams producing lampreys	Number of lampreys	Percentage of total run
Mar. 29 - Apr. 2	1	1	0.02	...	...	...
Apr. 3 - 9	2	2	.04	2	6	0.08
Apr. 10 - 16	2	11	.2	4	8	.1
Apr. 17 - 23	4	20	.4	6	123	1.7
Apr. 24 - 30	7	63	1.3	6	109	1.5
May 1 - 7	10	248	5.1	6	380	5.2
May 8 - 14	10	280	5.8	7	694	9.4
May 15 - 21	13	724	15.0	7	2,662	36.1
May 22 - 28	15	616	12.8	7	1,854	25.2
May 29 - June 4	16	189	3.9	6	183	2.5
June 5 - 11	22	1,146	23.7	7	1,055	14.3
June 12 - 18	18	567	11.7	6	232	3.1
June 19-25	16	390	8.1	5	41	.6
June 26 - July 2	14	290	6.0	3	15	.2
July 3 - 9	14	112	2.3	2	5	.06
July 10 - 16	17	75	1.6	0	0	.0
July 17 - 23	12	1/ 48	1.0	...	...	...
July 24 - 30	7	30	.6	...	...	...
July 31 - Aug. 6	1	3	.06	...	...	...
Aug. 7 - 13	1	10	.2	...	...	...
Aug. 14 - 20	1	1	.02	...	...	...
Total	...	4,826	100.0	...	7,367	100.0

1/ 96 additional sea lampreys recovered from nests above Chocolay River barrier during this period streams observed in 1953 was 143 males to 100 females. In the first year of operation in northern Lake Michigan streams, the sex ratio of 6,559 lampreys was 219 males to 100 females (table 6).

Lengths and weights of sea lampreys in spawning runs entering index streams of Lake Superior and from one stream on Lake Michigan (tables 7 and 8) permit a number of comparisons. The average total length for 3,939 Lake Superior specimens (sexes combined) was 18.1 inches in 1954--0.4 inch above the mean 17.7 inches for 263 lampreys measured in 1953. The average length of 572 lampreys taken in 1954 from Rapid River, tributary to Lake Michigan, was 17.7 inches. In 1954, the mean weight of 2,474 lampreys from Lake Superior streams was 225.6 grams (7.9 ounces), which was closely similar to the average weight of 226.8 grams (8.0 ounces) for 279 lampreys from the Chocolay River in 1953. The average weight of 572 specimens from Rapid River on Lake Michigan was 174.2 grams (6.1 ounces).

The differences in weight of the sea lampreys from the two lake basins is probably due to the loss of the principal food species (lake trout) in Lake Michigan. The abundance of lampreys in Lake Michigan has reached the point where lack of food prohibits maximum growth of the lamprey. This phenomenon was noted in Lake Huron in 1951 (Applegate, Smith, and Patterson, 1952). As the population of sea lampreys increases in Lake Superior, a reduction in their size should become apparent.

Electrical features of streams and related problems

Each stream appears to have its own electrical characteristics, and problems of control vary accordingly. These characteristics affect the power consumption, the intensity of the electrical field, and the dispersion of the field relative to the electrodes and the trap. They do not prohibit the establishment of an effective barrier in the water with one of the three standard types of electrode arrays. In all of the streams, the electrical field remained an absolute barrier to the upstream passage of sea lampreys regardless of changes or fluctuations in the electrical characteristics.

Information collected to date on electrical fields at the barriers has added little to the data discussed by Applegate, Smith, and Nielsen (1952). The same equipment (as described by them) was used to obtain the information. Electrical data from 31 streams included measurements of current flow around and between electrodes, intensity of the field, ratio between resistivities of the stream bottom and of the water, conductivity of water, and power consumption. Preoccupation with problems of installation and operation of structures during the season prevented a scheduling of measurements at selected index streams. Failure to obtain these periodic measurements makes it necessary to speak only in generalities.

Fluctuations of temperature, volume, conductivity of the water, and immersed surface area of electrodes influence the electrical field in the streams. Changes in these factors appear usually to compensate for one another. For example, as water levels decrease in streams with Type A and Type B electrode arrays, the conductivity of the water increases; but the intensity of the electrical field remains nearly constant because of reduction in the surface area of the immersed electrode.

The change in water conductivity also results in a change in the ratio between bottom and water resistivities. It would seem best to install a control device where the bottom resistance exceeds that of the water. Information obtained to date, however, indicates that a satisfactory electrical

Table 6 — Sex ratios of sea lampreys in index streams of Lake Superior and Lake Michigan, 1953 and 1954

Stream	1953			1954		
	Males	Females	Males per 100 females	Males	Females	Males per 100 females
Lake Superior						
Betsy River	101	101	100	295	270	109
Two Hearted River	180	178	101	330	273	121
Sucker River	371	379	98	588	429	137
Au Train River	101	85	128	194	150	129
Chocolay River 1/	132	149	89	668	333	201
Big Garlic River 2/	...	...	...	32	19	174
Iron River 2/	...	...	...	37	27	137
Silver River 2/	...	...	...	120	115	104
Firesteel River 2/	...	...	...	32	27	119
All streams	885	892	99	2,296	1,643	140
Lake Michigan 2/						
Rapid River	...	...	...	357	215	166
Sturgeon River	...	...	...	2,789	1,097	254
Whitefish River	...	...	...	930	479	194
Fishdam River	...	...	...	426	266	160
All streams	...	...	...	4,502	2,057	219

1/ 1953 data obtained from operation of Burkey Electric Fish Screen
2/ No installations in 1953

Table 7 --Average lengths (in inches) of sea lampreys from five index streams of Lake Superior, 1953

Stream	Males		Females		Sexes combined	
	Number	Length	Number	Length	Number	Length
Au Train River - - - - - - -	101	17.5	85	18.1	186	17 8
Beaver Lake Outlet - - - - -	3	16.3	4	17.4	7	16.9
Miners River - - - - - - - -	22	17.1	31	17.6	53	17.4
Furnace Creek - - - - - - -	6	17.7	5	17.5	11	17.6
Laughing Whitefish River - -	3	17.2	3	17.7	6	17.4
All streams	135	17.4	128	17.9	263	17.7

Table 8.--Average lengths (in inches) and weights (in grams) of sea lampreys from index streams of Lake Superior and Lake Michigan, 1954

Stream	Males		Females		Sexes combined		Males		Females		Sexes combined	
	Number	Length	Number	Length	Number	Length	Number	Weight	Number	Weight	Number	Weight
Lake Superior:												
Betsy River......	295	18.4	270	18 3	565	18.3	...	...	...	...	...	...
Sucker River....	588	18.1	429	17.9	1,017	18.0	587	229	426	227	1,013	228
Au Train River..	194	17.6	150	17.9	344	17.7	188	207	148	223	336	214
Chocolay River..	668	18.1	333	18.2	1,001	18.1	668	223	333	233	1,001	226
Big Garlic River.	32	18.5	19	19.1	51	18.7	32	230	18	240	50	234
Iron River.......	37	17.8	27	17.8	64	17.8	37	226	27	231	64	228
Silver River.....	120	18.0	115	17.9	235	17.9	115	224	111	238	226	231
Firesteel River..	32	17.9	27	17.8	59	17.9	30	249	27	230	57	225
All streams	1,966	18.1	1,370	18.0	3,336	18.1	1,657	223	1,090	229	2,747	226
Lake Michigan:												
Rapid River......	357	17.7	215	17.8	572	17.7	312	172	188	178	500	174

field can be established over a conductive bottom. The principal disadvantage is a greater power consumption. Because of a large and unexplained variation in power consumption from stream to stream, it is difficult to determine the actual correlation between power consumption and the ratio of bottom resistivity to water resistivity.

During the early part of the operational season, when water temperature was low and the volume of runoff water was large, the water resistance was sufficiently high that a ratio (bottom to water resistance) of 1 : 8 was recorded for Harlow Creek. A drop in this ratio to 1 : 1.5 by mid-July indicated that the conductivity for that particular stream had increased considerably. To be sure, a change in the ratio of water resistivity to bottom resistivity does not provide an exact means of determining the change in conductivity of the water. A rise in power consumption on the Au Train River, which had a controlled water level, indicates a more than twofold increase in the water conductivity of that stream.

Comparisons of water conductivity between streams were checked by measuring dissolved solids in parts per million with a Nalcometer. The water resistance was determined by using the same equipment and essentially the same procedure as that used for finding the ratio of bottom resistivity to water resistivity. The values obtained by this method of measuring water resistance are relative and can be used only for comparisons. Inasmuch as other factors influence water conductivity, the amount of dissolved solids alone, as measured by the Nalcometer, did not give an accurate indication of water resistance; however, a negative correlation between dissolved solids and measured resistance for the water in the 10 streams was evident.

The effects of increases in the conductivity of the water cannot be discussed in detail, because we were unable to obtain sufficient data to judge the importance of all the influencing factors. Changes of water level, especially, conceal the effects of changes in conductivity by decreasing or increasing the immersed area of the electrodes. In general, the increase in water conductivity is disadvantageous. The most obvious difficulties are as follows:

1. Increased water conductivity increases power consumption, with resulting greater costs.

2. Increased conductivity increases the intensity of the electrical field in most streams. This increase is especially great where there is no loss of area of submerged electrodes, as in streams that have the bottom-type electrodes. Low water, comparatively large electrode area, and increased water conductivity combine to give an intense electrical field that may in turn cause excessive mortality or injury.

3. Perhaps the most important result of increased water conductivity is the increase in the size of the electrical field. A fringe field may gradually extend downstream until it envelops the trap entrances. Although the isolation of the trap entrances offered a problem in some streams at the time of installation, the problem became more serious as the season progressed. This problem has been minimized by extending a bare copper conductor from the trap wings to a stake in the stream bed below the downstream edge of the fringe field. Generally, the angle of extension from the end of the wings has been greater than the angle of the opening formed by the wings. In shallow water (up to 18 inches), one such conductor has been sufficient. In water deeper than 18 inches, two have been installed--one a few inches from the bottom and the second near the surface. At two installations, small-diameter rods, clamped to the end of the wings, served the same purpose satisfactorily.

Another problem of isolation of the trap entrance develops when current flows from a control device to a point not associated with it. On occasion, the current leaves the downstream extremity of the intended field and flows to one of the banks. In one stream, this path became comparatively narrow and extended some 50 feet below the control device to a point on the shore opposite the one on which the power supply was located. In other streams, the path remained broad. It is assumed that this phenomenon results from the presence of a highly conductive material. This problem became more acute during the latter part of the season, but it caused difficulty only when the unexplained current crossed ahead of the trap entrances. For the most part, this problem was overcome by providing a conductor, or a series of conductors, to pick up and carry the current across the area that affected the entrance to the trap.

The data collected have led to few recommendations for changes in the electrical equipment. In a few of the deeper streams equipped with a single suspension, the mortality may be reduced by moving the bottom electrode upstream from the suspended electrode. In deep water, the surface field above the bottom electrode may be weak enough to allow fish swimming near the surface to approach the suspended electrodes. When water velocities are low, the fish may become paralyzed and sink close to the bottom electrode, where they may be killed.

Few effective changes of equipment can be made in streams in which conductivity increases greatly and there is no compensating reduction of the surface area of the immersed electrodes. The voltage gradient can be reduced by the installation of a voltage-dropping device (variable transformer), by increasing the distance between the electrodes, or by decreasing electrode surface area. All of the preceding means have limitations. A disadvantage in a voltage-dropping device is the impossibility of providing for sudden fluctuations in water levels. An increase of distance between electrodes which would be large enough to reduce mortality of fish moving upstream and which still would maintain an electrical field strong enough to stop sea lampreys, could produce an energized stretch of stream that would be too long for the downstream migrant fish to pass safely. Decreasing the area of the immersed electrodes would require the more expensive installation of a suspension, but this appears to offer the most effective procedure.

On the basis of our present knowledge, it is believed that the physical characteristics are so varied and play such an important part in the operation of the control devices that modifications cannot completely solve all existing problems. The solution to the major problem, that of excessive mortality of useful fish, will depend on a careful study of physical factors of individual streams so that control devices may be properly designed to meet local conditions.

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