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DECLINE OF THE LAKE TROUT FISHERY IN LAKE MICHIGAN

By RALPH HILE, PAUL H. ESCHMEYER, and GEORGE F. LUNGER

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By RALPH HILE and PAUL H. ESCHMEYER, *Fishery Research Biologists,* and GEORGE F. LUNGER, *Statistician*

Collapse of the fishery for lake trout, *Salvelinus* [=*Cristivomer*] *namaycush*, of Lake Huron has been treated in detail in a recent publication by Hile (1949). In the present paper we take up the unpleasant task of describing the decline of the lake-trout fishery in yet another of the Great Lakes, Lake Michigan. Lake Superior now stands as the only significant center of commercial production of that species yet remaining in the United States.

In this, as in the earlier paper mentioned, treatment will be limited to a statistical account of the changes that have taken place in the lake-trout fishery. We offer no extended argument on the role of the sea lamprey in this most recent debacle, other than to express the considered opinion that on the basis of currently available evidence this parasite must be held the major cause of the catastrophes that have overtaken both Lake Huron and Lake Michigan.

MATERIALS AND METHODS

The statistics on the production of lake trout in the individual States over the period 1879–1940, incorporated in table 1, were adapted from Gallagher and Van Oosten (1943) and are from the sources listed in that publication. Our annual totals, however, are in agreement with those of Gallagher and Van Oosten only for those years in which statistics were available for all four States bordering the lake. In a number of years statistics were at hand for Michigan and Wisconsin but not for Illinois and Indiana; in such situations those authors recorded the yields from the first two States as the totals for Lake Michigan. Our totals in the same situations include estimates of the Illinois-Indiana catch. On the basis of the actual distribution of the take among the States in the 8 years with complete data from 1885 through 1917 and in the 6 years [1] from 1922 through 1929 we derived the correction factors 1.0291 and 1.0683. The former factor was applied to the combined Michigan-Wisconsin catch to give an adjusted grand total in years lacking Illinois-Indiana data through 1919; the latter factor was used for years after 1919. To be sure, the percentage contribution of Illinois and Indiana varied within each of the two periods, but the derivation of a greater number of factors would not have been profitable. We have not considered it advisable to estimate the Lake Michigan total in any year for which we had data for only one State.

Statistics on production after 1940 were compiled directly from commercial fishermen's reports in the Ann Arbor offices of the Fish and Wildlife Service (Michigan) or supplied by State conservation agencies (Wisconsin, Illinois, and Indiana).

The data on the yield of lake trout in the several statistical districts of the State of Michigan waters of Lake Michigan for 1891–1908 were tabulated in the Service's Great Lakes offices from original records supplied by the Michigan Department of Conservation.[2]

The detailed information on production, fishing intensity, and estimated availability of lake trout in the State of Michigan waters in 1929–49 is based on analyses of monthly reports of commercial fishermen licensed by the State of Michigan. These reports, which were supplied by the department of conservation, contain data on fishing locality, kind and amount of gear fished, and kinds and quantities of fish captured for each day of fishing by each licensee.

The methods employed in estimating the abundance of the principal species and the intensity of the fishery in the State of Michigan waters of the Great Lakes have been described in detail in earlier publications (Hile 1937; Hile and Jobes

[1] For this purpose the 1925 data were usable since the Indiana-Illinois catch was included in the total; statistics for the two States individually, however, were not available.

[2] The Works Progress Administration gave valuable assistance in this work.

1941; Van Oosten, Hile, and Jobes 1946). The boundaries of the eight statistical districts, M–1 to M–8, are given in figure 2.

PRODUCTION TRENDS IN LAKE MICHIGAN, 1879–1949

The trends of production of lake trout from 1879 through 1949 perhaps can be brought out best through comments on the yield over certain periods of years (tables 1 and 2; fig. 1).

The take in 1879, the first year for which we have a record, was comparatively low (2,659,000 pounds). Catches were higher in 1885 (6,431,000 pounds) and 1889 (5,580,000 pounds) but the take in each of those years and the mean for the two (6,006,000 pounds) were far below the level that characterized the period beginning with 1890. It may be assumed that the fishery was in the process of development in 1879–89.

The interval 1890–1911 was one of rather consistently high production. The take exceeded 8 million pounds in 7 of the 11 years for which lake totals are recorded and was more than 9 million pounds in 1 of these 7 (9,282,000 pounds in 1896). Of the remaining 4 years, 2 had yields between 7 and 8 million pounds, 1 between 6 and 7 million, and 1 less than 6 million. The two lowest catches (6,624,000 pounds in 1892 and 5,286,000 pounds in 1899) both deviated sharply from the general level for the period and both can be attributed to the low yields recorded for Wisconsin. The grand average catch [3] for 1890–1911 was 8,230,000 pounds or 2,224,000 pounds greater than for 1885–89. Every State but Indiana shared in the increase; the rise was greatest, however, in Wisconsin (1,950,000 pounds).

The production of lake trout in Lake Michigan was at a decidedly lower level in 1912–26 when the average yield of 7,007,000 pounds was 1,223,000 pounds below that of 1890–1911. Of the 14 years for which there are totals (see footnote 1 to table 1 concerning the exclusion of data for Wisconsin in 1921) 5 had catches between 7 and 8 million pounds, 8 between 6 and 7 million pounds, and 1 less than 6 million pounds. The highest yield was 7,928,000 pounds in 1915 and the lowest was 5,979,000 pounds in 1918. Declines from the preceding period of 932,000 pounds in Wisconsin and 459,000 pounds in Michigan, were compensated to a small degree by increases of 132,000 pounds in Indiana and 36,000 pounds in Illinois.

[3] To obtain full use of the data of table 1, the means in the body of table 2 were determined from all records of yield for each State during the indicated periods and these State means were added to obtain the totals at the right.

TABLE 1.—*Production of lake trout in Lake Michigan, 1879–1949*

[In thousands of pounds]

Year	State				Total
	Michigan	Wisconsin	Illinois	Indiana	
1879					2,659
1880					
1881					
1882					
1883					
1884					
1885	3,725	2,668	4	34	6,431
1886					
1887					
1888					
1889	2,950	2,455	25	150	5,580
1890	4,674	3,464	72	155	8,364
1891	3,686				
1892	3,616	2,821			6,624
1893	3,122	5,404			8,774
1894	2,668	5,865			8,781
1895	2,392	5,304			7,920
1896	3,020	6,000			9,282
1897	2,872	4,711	219	21	7,823
1898	2,540				
1899	2,370	2,804	77	35	5,286
1900	2,016				
1901	2,844				
1902	4,337				
1903	4,055	4,613	199	76	8,943
1904	4,254				
1905	4,456				
1906	5,103				
1907	4,271				
1908	4,023	4,328	150	130	8,631
1909		4,371			
1910		4,337			
1911	3,526	4,640			8,404
1912	3,003	3,588			6,752
1913	2,544	3,761			6,488
1914	2,711	4,126			7,036
1915	3,853	3,851			7,928
1916	2,805	3,195			6,174
1917	2,866	3,745	169	123	6,904
1918	2,456	3,354			5,979
1919	2,735	3,849			6,776
1920	3,143	3,840			7,461
1921	3,107	[1] 8,642			[1] 12,551
1922	3,264	3,801	203	272	7,540
1923	2,757	3,419			6,599
1924	3,472	3,752			7,717
1925	3,422	3,101			[2] 6,894
1926	3,352	2,762	165	250	6,530
1927	2,900	2,379	167	253	5,699
1928	1,831	2,029	172	187	4,819
1929	2,198	3,817	247	132	6,394
1930	2,556	2,316	383	186	5,441
1931	2,652	2,673	202	106	5,632
1932	2,746	2,345	281	98	5,470
1933	2,379	2,481	262	90	5,212
1934	2,053	2,590	225	88	4,957
1935	2,451	2,042	260	120	4,873
1936	2,127	2,232	274	130	4,763
1937	2,264	2,353	271	100	4,988
1938	2,480	1,940	311	174	4,906
1939	2,778	2,358	318	205	5,660
1940	2,780	2,492	814	179	6,266
1941	3,189	2,747	705	146	6,787
1942	2,641	2,695	1,111	38	6,484
1943	2,814	2,825	1,193	28	6,860
1944	2,609	2,852	1,036	[3]	6,498
1945	2,228	2,516	694	[3]	5,437
1946	1,908	1,650	416	1	3,974
1947	914	1,178	333	1	2,425
1948	589	542	65	[3]	1,197
1949	223	115	4		342

[1] The recorded yield of 8,642,000 pounds in Wisconsin in 1921 is so badly out of line with data for neighboring years as to be held unreliable. It was not plotted in fig. 1 or employed in the computation of any means or percentages.

[2] No breakdown available of the 371,000 pounds taken in Indiana and Illinois.

[3] Less than 500 pounds.

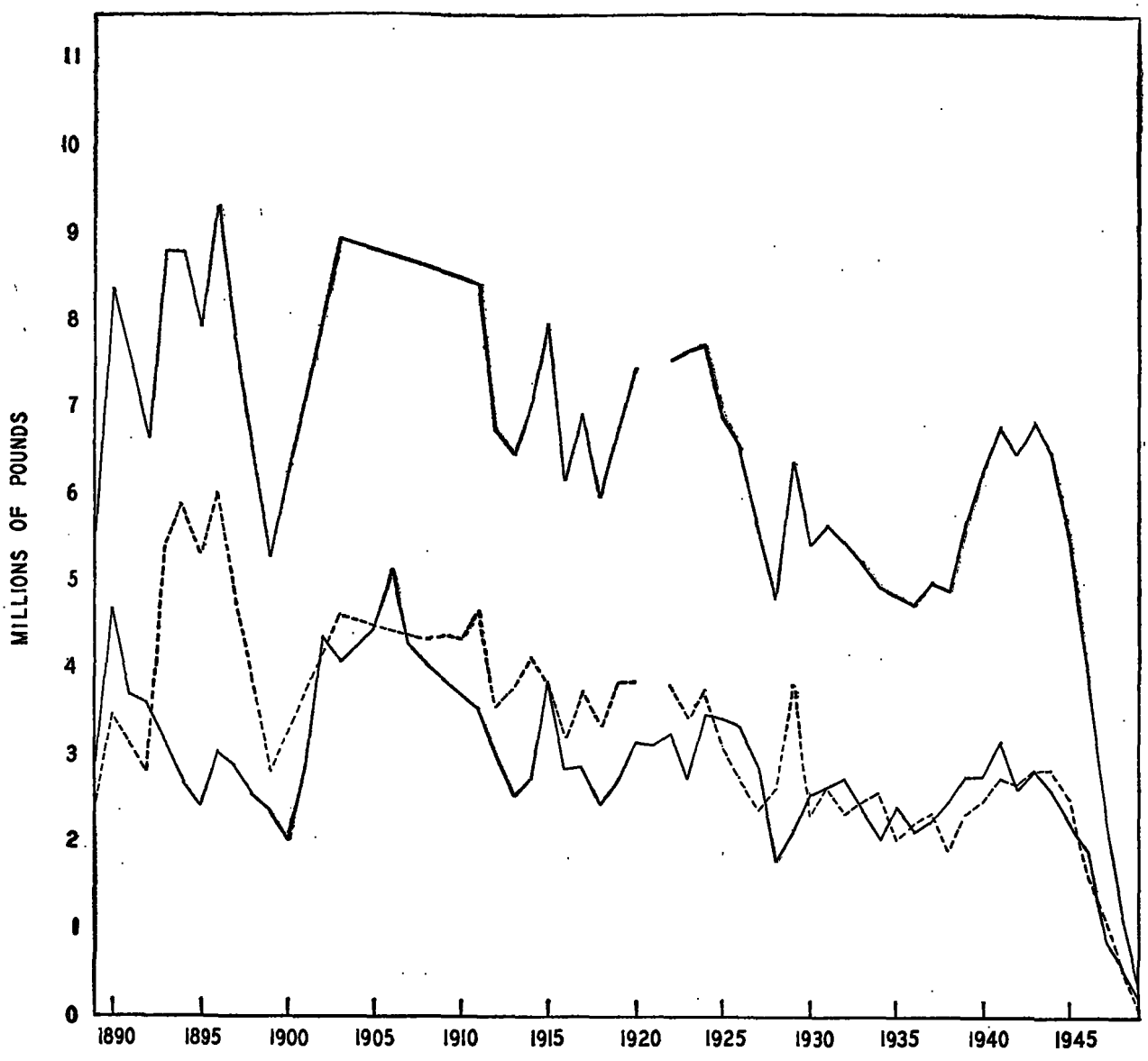

FIGURE 1.—Production of lake trout in Lake Michigan, 1889–1949. Upper solid line=entire lake; broken line=Wisconsin; lower solid line=Michigan.

The take of lake trout fluctuated about a still lower level in 1927–39 when the average total for the lake was 5,293,000 pounds, 1,714,000 pounds below the mean for 1912–26 and 2,937,000 pounds less than that for 1890–1911. The catch exceeded 6 million pounds only once in 13 years (6,394,000 pounds in 1929—again a sharp deviation of the Wisconsin figure from the characteristic level was responsible for the extreme); it was between 5 and 6 million pounds in 6 years, and less than 5 million pounds in 6 years. The lowest catch of the period was 4,763,000 pounds in 1936. Michigan, Wisconsin, and Indiana contributed to the decline from 1912–26 to 1927–39 with decreases of 616,000, 1,107,000, and 71,000 pounds, respectively. The Illinois catch, on the contrary, was increased by 80,000 pounds in the latter period.

The lake-trout fishery of Lake Michigan enjoyed a brief period of heightened productivity in 1940–44 when the take exceeded 6 million pounds in every one of the 5 years and averaged 6,578,000 pounds, or 1,285,000 pounds above the 1927–39 mean. To a considerable extent the improvement can be attributed to the large increase of 713,000

TABLE 2.—*Average production of lake trout in Lake Michigan, by periods*

[In thousands of pounds]

Period	Number of years [1]	Item	State				Total
			Michigan	Wisconsin	Illinois	Indiana	
1879	1	Production					2,659
1885–89	2	Mean annual production	3,338	2,562	14	92	6,006
		Percentage of total	55.6	42.7	0.2	1.5	100
1890–1911	22	Mean annual production	3,492	[2] 4,512	143	83	8,230
		Percentage of total	42.4	54.8	1.8	1.0	100
1912–26	15	Mean annual production	3,033	[3] 3,580	179	215	7,007
		Percentage of total	43.3	51.1	2.5	3.1	100
1927–39	13	Mean annual production	2,417	[4] 2,473	259	144	5,293
		Percentage of total	45.7	46.7	4.9	2.7	100
1940–44	5	Mean annual production	2,807	2,722	972	78	6,578
		Percentage of total	42.7	41.4	14.7	1.2	100
1945–49	5	Mean annual production	1,172	1,200	302	0	2,674
		Percentage of total	43.8	44.9	11.3	0	100

[1] Number of years for which statistics were available in at least 1 State or for the entire lake.

[2] The reported Wisconsin production for the years 1892 and 1899 was far below the level characteristic of the period. If these years are excluded, the Wisconsin mean becomes 4,822 and the percentages and total change accordingly.

[3] Excluding 1921 for which year the reliability of the Wisconsin data appears questionable.

[4] The reported Wisconsin production for 1929 was considerably above the level characteristic of the period. If this year is excluded, the Wisconsin mean becomes 2,362 and the percentages and total change accordingly.

pounds in Illinois, a rise exceeding the combined increases in Michigan (390,000 pounds) and Wisconsin (249,000 pounds). Indiana alone experienced a decline (66,000 pounds).

The sharp drop in the recorded Indiana take to a lower level during the 1940–44 interval probably reflects improvement in the collection of statistics more than a decrease in output. Indiana producers, who traditionally take the bulk of their catch of lake trout in State of Michigan waters, have to our best knowledge customarily reported their entire production to both Indiana and Michigan. There is considerable evidence, therefore, that part of the take of Indiana fishermen in earlier years was reported in duplicate. In view of the relatively small production of these operators, the effects on the statistics for the entire lake were not particularly damaging, but the figures for Indiana before about 1942 must be viewed with some skepticism.

The period 1940–44 is exceptional for its brevity. Statistics for the preceding three periods demonstrated a tendency for the productivity of the lake-trout fishery to fluctuate closely about a characteristic level for from 13 to 22 years. In view of this tendency, it might well be expected that the new high level reached in 1940 would be maintained longer than 5 years. That it was not maintained suggests that some disruptive factor intervened. The sea lamprey qualifies well as that factor.

Although the downward trend of production actually started a year earlier, 1945 can be set a the beginning year of the recent disastrous decline. In this year the catch dropped by more than a million pounds and fell distinctly below the level of 1940–44. Once the decline started, its progress was spectacular. In 1946 the take was under 4 million pounds for the first time since 1879, and each of the years 1947 to 1949 set a new record low. It is the high rate of decrease rather than the average of 2,674,000 pounds that makes the 1945–49 period significant.

The collapse of production in the lake-trout fishery of Lake Michigan resembles closely that described for Lake Huron by Hile (1949). Indeed, the decline appears to have been even more rapid in Lake Michigan than in the United States waters of Lake Huron. This point can be brought out by a comparison of the number of years required for a 90-percent or greater decline from the last year with the take above the "modern" average. In Lake Michigan this average can be set at 5,651,000 pounds (the mean for 1927–44), and the last year in which the take exceeded that figure was 1944 (6,498,000 pounds); only 5 years later the catch had dropped by 94.7 percent (to 342,000 pounds in 1949). In the United States waters of Lake Huron the "modern normal yield" was set by Hile at 1,685,000 pounds (the mean for 1895–1939), and the last year with an output above this figure was 1935 (1,743,000 pounds); 10 years were required for the catch to decline 90.1 percent (to 173,000 pounds in 1945).

PRODUCTION IN STATE OF MICHIGAN WATERS, 1891–1908 AND 1929–49

Records of the annual take of lake trout in the several statistical districts [4] of the State of Michigan in 1891–1908 (table 3) make possible the comparison of the actual productivity of various regions and of their percentage contributions to the total for the lake [5] in that period with conditions in recent years (table 4). Despite the considerable fluctuations in annual yield in the different districts to be seen in table 3, comments on the 1891–1908 data [6] will be restricted to the averages; we are without the information on fluctuations in the availability of lake trout, in the intensity of the fishery, and in other conditions, that we need for an intelligent treatment of the matter. Attention should be called, however, to the distinct similarity of trends in production in the several districts.

TABLE 3.—*Production of lake trout in Michigan statistical districts, 1891–1908*

[In thousands of pounds]

Year	District								Total
	M–1	M–2	M–3	M–4	M–5	M–6	M–7	M–8	
1891	171	349	1,554	130	346	228	395	513	3,686
1892	35	390	1,691	77	379	290	257	496	3,616
1893	174	144	1,392	98	311	318	360	324	3,122
1894	142	249	1,285	86	255	224	185	243	2,668
1895	109	57	1,312	118	267	185	165	180	2,392
1896	119	392	1,529	151	307	207	160	155	3,020
1897	176	411	1,456	76	212	200	174	167	2,872
1898	161	288	1,367	46	233	258	98	89	2,540
1899	127	264	1,160	47	298	190	130	154	2,370
1900	90	191	782	42	259	190	195	266	2,016
1901	168	361	1,073	78	330	344	212	279	2,844
1902	307	470	1,704	112	362	345	542	493	4,337
1903	380	598	1,534	94	422	246	368	412	4,055
1904	363	572	1,708	138	428	311	296	438	4,254
1905	382	538	1,903	158	443	380	238	412	4,456
1906	332	348	2,325	195	498	503	446	456	5,103
1907	299	298	1,670	170	437	446	503	448	4,271
1908	300	421	1,553	134	330	483	484	318	4,023
1891–1908 mean	213	352	1,500	108	340	297	289	325	3,425
Percentage of total	6.2	10.3	43.8	3.2	9.9	8.7	8.4	9.5	100

TABLE 4.—*Production of lake trout in Michigan statistical districts, 1929–49*

[In thousands of pounds]

Year	District								Total	Production index [1]
	M–1	M–2	M–3	M–4	M–5	M–6	M–7	M–8		
1929	182	153	912	68	273	291	146	174	2,198	86
1930	203	234	986	90	286	270	224	262	2,556	101
1931	220	300	1,020	102	321	291	249	148	2,652	104
1932	194	331	898	113	387	354	313	156	2,746	108
1933	134	298	692	102	449	303	206	196	2,379	94
1934	72	276	669	71	380	278	144	163	2,053	81
1935	77	242	771	89	432	306	234	300	2,451	96
1936	158	259	823	76	363	143	111	193	2,127	84
1937	236	296	738	88	447	147	131	180	2,264	89
1938	248	243	801	117	437	183	148	303	2,480	98
1939	157	234	1,047	100	407	266	195	370	2,778	109
1940	83	220	739	109	427	424	289	488	2,780	109
1941	75	354	910	141	449	413	414	432	3,189	126
1942	56	251	684	133	385	283	342	508	2,641	104
1943	91	299	837	122	453	274	216	523	2,814	111
1929–43 mean	146	266	835	101	393	282	224	293	2,540	100
Percentage of total	5.7	10.5	32.9	4.0	15.5	11.1	8.8	11.5	100	
1944	47	195	675	131	462	251	261	587	2,609	103
1945	29	145	599	96	299	227	247	586	2,228	88
1946	11	79	448	68	263	152	293	593	1,908	75
1947	46	25	219	38	126	71	155	234	914	36
1948	178	25	87	19	86	19	45	131	589	23
1949	149	3	23	13	21	5	2	6	223	9

[1] Percentage of 1929–43 mean.

[4] See figure 2 for the boundaries of the statistical districts.

[5] The term "lake" in this and the following sections has reference to State of Michigan waters only.

District M–3 strongly dominated the production of lake trout in the State of Michigan waters of Lake Michigan in 1891–1908, contributing 43.8 percent of the total output for the period. The percentages for five of the seven remaining districts exhibited only small differences, ranging from 10.3 percent for M–2 which held second position to 8.4 percent for M–7 which ranked sixth. The lowest average yields were in M–1 (6.2 percent) and M–4 (3.2 percent). In this early period, waters north of Grand Traverse Point (M–1, M–2, and M–3) accounted for 60.3 percent of the total output as compared with 39.7 percent for districts M–4 through M–8.

To facilitate comparisons between the production of lake trout in the statistical districts in 1891–1908 (table 3) and 1929–43, the "base period" for modern statistics (table 4), a summary (table 5) has been prepared. The principal features of the comparison are a generally lower level of take in the more recent period, a shifting of production toward the more southerly districts, and a lack of pronounced changes in the ranking of the districts with respect to the percentage of total yield.

Only M–5 exhibited a rise in average annual production from 1891–1908 to 1929–43 (an increase of 53,000 pounds). The remaining seven districts all suffered declines that ranged from 7,000 pounds in M–4 to the tremendous drop of 665,000 pounds in M–3. This latter decline accounted for most of the decrease of 885,000 pounds for the combined districts. In no other district did the take fall by more than 86,000 pounds (the decrease for M–2).

[6] The data for 1891–1908 provide a less reliable record of production in the individual districts than do those for 1929 and later. In the earlier period the annual catch of each fisherman was allocated to the district in which his home port was located, whereas in the recent period each day's catch was credited to the statistical district in which the gear actually was lifted. The extent to which fishermen operated outside their home districts in 1891–1908 is unknown, but records for recent years suggest that error from this source was not sufficiently great to affect the validity of comparisons based on tables 3 and 4.

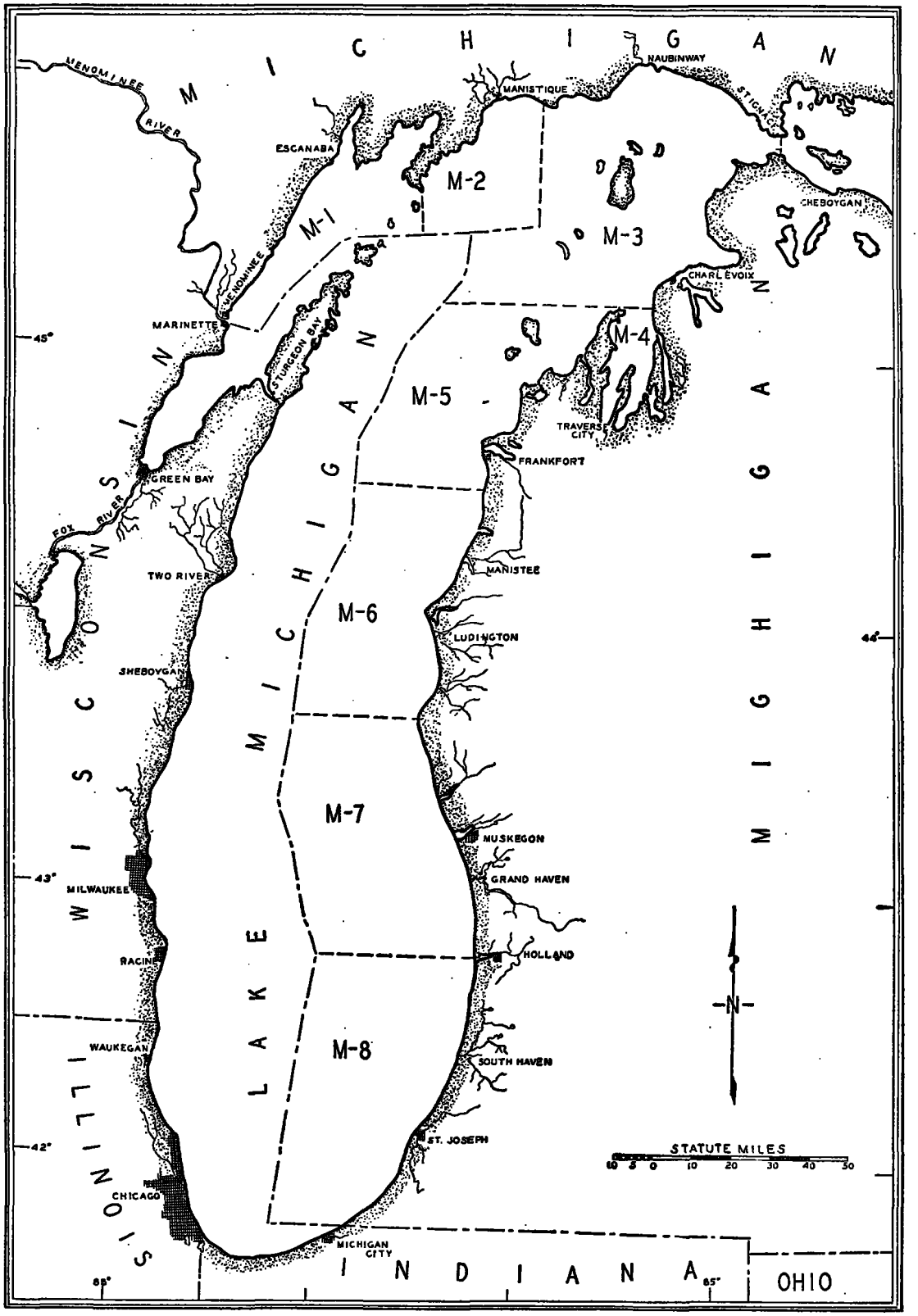

FIGURE 2.—Statistical districts in State of Michigan waters of Lake Michigan.

TABLE 5.—*Comparison of average production of lake trout in Michigan statistical districts, 1891–1908 and 1929–43*

District	1891–1908			1929–43			Change, 1891–1908 to 1929–43, in—		
	Average production [1]	Percentage of total	Rank	Average production [1]	Percentage of total	Rank	Average production [1]	Percentage of total	Rank
M–1	213	6.2	7	146	5.7	7	−67	−0.5	0
M–2	352	10.3	2	266	10.5	5	−86	+.2	−3
M–3	1,500	43.8	1	835	32.9	1	−665	−10.9	0
M–4	108	3.2	8	101	4.0	8	−7	+.8	0
M–5	340	9.9	3	393	15.5	2	+53	+5.6	+1
M–6	297	8.7	5	282	11.1	4	−15	+2.4	+1
M–7	289	8.4	6	224	8.8	6	−65	+.4	0
M–8	325	9.5	4	293	11.5	3	−32	+2.0	+1
Total	3,424	100		2,540	100		−885		

[1] Mean annual production in thousands of pounds.

The large drop in production in M–3 from 1891–1908 to 1929–43 was reflected in a decrease of 10.9 in the percentage contribution of the district to the total output of the State of Michigan waters (from 43.8 to 32.9 percent). The only other district in which the percentage decreased was M–1 (a drop of but 0.5). The remaining six districts experienced increases in percentage that ranged from 0.2 in M–2 to 5.6 in M–5. These changes in the various districts resulted in a noticeable shift of production toward the south. Districts M–1, M–2, and M–3, which, as noted earlier, contributed 60.3 percent of the total in 1891–1908, accounted for only 49.1 percent in 1929–43. The proportion for M–4 through M–8 rose correspondingly from 39.7 to 50.9 percent. A similar shift in production of lake trout toward the south was described for the State of Michigan waters of Lake Huron by Hile (1949).

Rather than burden the present section, which deals with production trends in 1929–49, with numerous unexplained exceptions to general statements, it is believed desirable to anticipate discussion that logically should appear later and describe at this time the peculiar situation in district M–1 that makes the data for that area so difficult to fit into a general account of the lake-trout fishery of the State of Michigan waters of Lake Michigan. This difficulty has its origin in the circumstance that M–1 is not true "lake-trout water" and that the commercial catches of the species are normally part of the production in a fishery aimed primarily at the taking of lake whitefish (*Coregonus clupeaformis*). As a result, the intensity of the fishery for lake trout, and consequently the production as well, are controlled to a large degree by the conditions of the whitefish fishery. This relation is brought out rather forcefully by the data of table 6 on the production, abundance, and fishing intensity for the two species in M–1 over the period 1929–49.

The salient features of table 6 are summarized briefly in the following sentences. First, the production of whitefish in M–1 normally is considerably greater than that of lake trout. In only 2 of the 15 years of the base period 1929–43 was the take of lake trout the greater, and the 15-year average for whitefish was nearly three times that for lake trout. In the years after 1943 the advantage of whitefish was much greater than in the earlier, more nearly normal period. Second, the availability of lake trout and the intensity of the fishery for that species did not exhibit the positive correlation that would be expected if abundance

TABLE 6.—*Comparison of lake-trout and whitefish fisheries in district M–1, 1929–49*

Year	Lake trout			Whitefish		
	Production [1]	Abundance index [2]	Fishing-intensity index [2]	Production [1]	Abundance index [2]	Fishing-intensity index [2 3]
1929	182	71	162	1,140	180	199
1930	303	65	198	1,076	145	238
1931	220	69	204	1,195	143	234
1932	194	80	155	910	120	187
1933	134	97	88	238	66	62
1934	72	92	49	263	91	46
1935	77	87	56	175	89	57
1936	158	137	72	90	75	42
1937	236	157	94	105	65	47
1938	248	112	139	354	104	120
1939	157	94	105	238	86	83
1940	83	105	49	123	74	37
1941	75	138	35	116	90	36
1942	56	96	37	93	80	44
1943	91	100	57	141	92	68
1929–43 mean	146	100	100	417	100	100
1944	47	53	56	232	114	90
1945	29	51	36	234	100	97
1946	11	32	22	514	148	139
1947	46	26	111	2,427	275	397
1948	178	44	253	3,066	221	629
1949	149	45	207	2,263	158	600

[1] In thousands of pounds
[2] Percentage of 1929–43 mean.
[3] Operations with large-mesh gill nets only.

TABLE 7.—*Correlations between abundance and fishing-intensity indices for lake trout and whitefish in district M–1*

Indices correlated	Period [1]		
	1929–41	1929–43	1929–49
Abundance of trout : Fishing intensity for trout	−0.611	−0.553	−0.316
Abundance of whitefish : Fishing intensity for whitefish	.888	.891	.800
Abundance of trout : Abundance of whitefish	−.710	−.690	−.745
Fishing intensity for trout : Fishing intensity for whitefish	.961	.955	.786
Abundance of trout : Fishing intensity for whitefish	−.736	−.704	−.250
Fishing intensity for trout : Abundance of whitefish	.779	.778	.561
Value of r at $p=0.05$	.553	.514	.433
Value of r at $p=0.01$	.684	.641	.549

[1] Data given for two earlier periods as well as for entire 21 years since wartime conditions disrupted normal trends in fishing intensity after 1941 and the extremely low abundance of lake trout introduced a disturbing factor after 1943.

were an important factor in determining the rate of fishing; the correlation that did exist is negative (table 7). It should be emphasized here that the estimate of fishing intensity for a particular species is based only on gear lifted on days when some quantity of that species was captured. Third, the fluctuations in fishing intensity for lake trout followed closely those of the gill-net fishery for whitefish (most lake trout are captured in gill nets), and fishing intensity for whitefish in turn was correlated closely with the fluctuations in the abundance of that species. The data of tables 6 and 7 thus offer rather conclusive evidence that the availability of whitefish is of primary significance in the determination of the intensity of the lake-trout fishery.

The situation just described for district M–1 is not entirely without parallel. Hile (1949) demonstrated that in three districts of Lake Huron in which lake trout and whitefish ordinarily were taken together in a "two-species fishery" (catches of other varieties in this type of fishery are usually unimportant) the fluctuations in the availability of whitefish exerted a readily detectable effect on the fishing intensity for lake trout. The conditions in M–1 merely represent an extreme because of the strongly predominant position of whitefish in the joint fishery and also because of the tremendous upturn in the abundance of whitefish and hence in fishing intensity for both whitefish and lake trout at a time when the availability of the latter species was far below normal.

Comments on the 1929–49 trends of production in the several statistical districts as recorded in table 4 will be based largely on the summary in the top section of table 8. Reference to the production curves of figures 3, 4, and 5 also should prove helpful.

A pronounced difference is to be detected between the "northern" districts (M–1, M–2, M–3) and the remaining or "southern" districts with respect to the calendar years of highest production of lake trout within the period 1929–49. Of

TABLE 8.—*Summary of production, abundance, and fishing intensity for lake trout in Michigan statistical districts, 1929–49*

Item	District								All districts combined
	M–1	M–2	M–3	M–4	M–5	M–6	M–7	M–8	
PRODUCTION:									
3 years of greatest production	1938	1941	1939	1941	1944	1940	1941	1946	1941
	1937	1932	1931	1942	1943	1941	1942	1944	1943
	1931	1931	1930	1944	1941	1932	1932	1945	1940
Last year with production average or greater	[1] 1939	1943	1943	1944	1944	1942	1946	1946	1944
First year of recent progressive decline	[2] 1944	1944	1944	1945	1945	1941	1947	1947	1944
First year with production less than half average	[3] 1944	1946	1947	1947	1947	1947	[4] 1948	1948	1947
ABUNDANCE:									
3 years of greatest abundance	1937	1936	1939	1943	1943	1940	1941	1942	1943
	1941	1933	1941	1935	1944	1941	1942	1943	1941
	1936	1931	1932	1934	1941	1943	1943	1944	1942
Last year with abundance average or greater	1943	1941	1943	1944	1945	1945	1947	1947	1944
First year of recent progressive decline	[5] 1944	[5] 1944	1944	1944	1944	[5] 1944	1942	1943	1944
First year with abundance below 70 percent	[6] 1944	1944	1946	[6] 1947	1948	1949	1949	[6] 1949	1947
FISHING INTENSITY:									
3 years of greatest intensity	([7])	1941	1930	1940	1933	1931	1931	1946	1930
	([7])	1943	1931	1930	1932	1932	1932	1940	1931
	([7])	1942	1938	1932	1937	1930	1930	1935	1932
Last year with intensity average or greater	([7])	1944	1945	1945	1939	1941	1946	1946	1941
First year of recent progressive decline	([7])	1944	1946	1945	1947	1942	1947	1947	[8] 1947
First year with intensity less than half average	([7])	1947	1948	1948	1947	1947	1948	1949	[9] 1949

[1] 1948 and 1949 production above average.
[2] Decline interrupted by increases in 1947 and 1948.
[3] First recent year; production less than half average in 1934 and 1942.
[4] First recent year; production less than half average in 1936.
[5] Decline interrupted by increases in 1948 (followed by further slight rise in 1949 in M–1).
[6] First recent year; abundance below 70-percent level in 1930 and/or 1931.
[7] Fishing intensity so closely linked with availability of whitefish that summary would be meaningless and possibly misleading; see p. 83.
[8] 1941 if irregularities in 1944 and 1946 are ignored.
[9] Intensity unquestionably would have been less than 50 percent of average in 1948 but for the abnormal situation in M–1; see p. 83.

the 9 "high-production" years listed in table 8 for the first three districts, 8 were earlier than 1940 (the 1941 production in M–2 provided the only exception) and 5 earlier than 1935. In districts M–4 through M–8, on the contrary, the highest yields usually came after 1939. Only 2 of the 15 high-production years listed for the southern districts were earlier than 1940 (1932 in M–6 and M–7) and 10 fell within the brief 4-year period 1941–44.

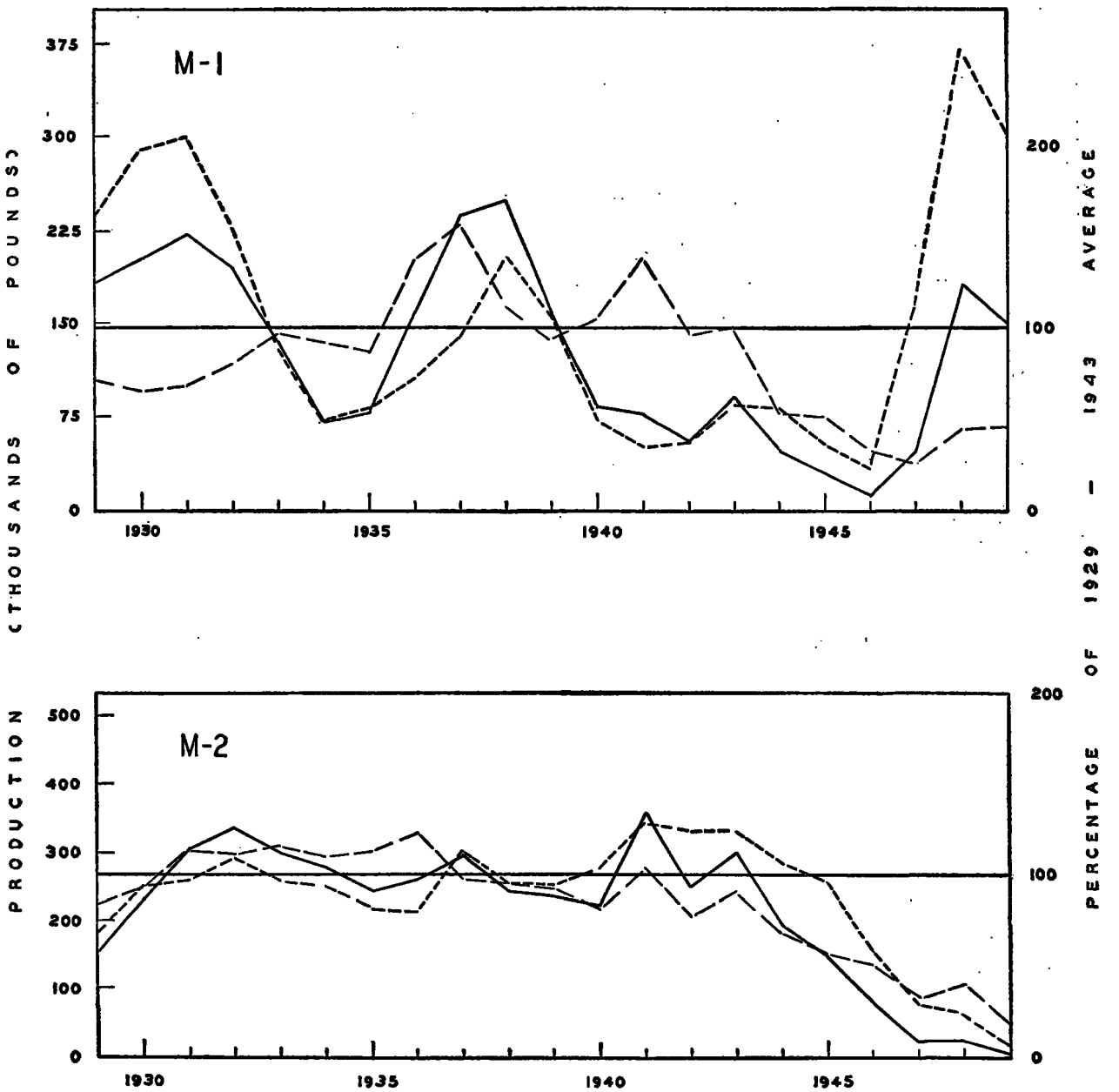

FIGURE 3.—Production, abundance index, and fishing-intensity index for lake trout in districts M-1 and M-2, 1929–49. Solid line = production; long dashes = abundance index; short dashes = fishing-intensity index. Scale at left (thousands of pounds) applies only to production; scale at right is in terms of 1929–43 mean for each item.

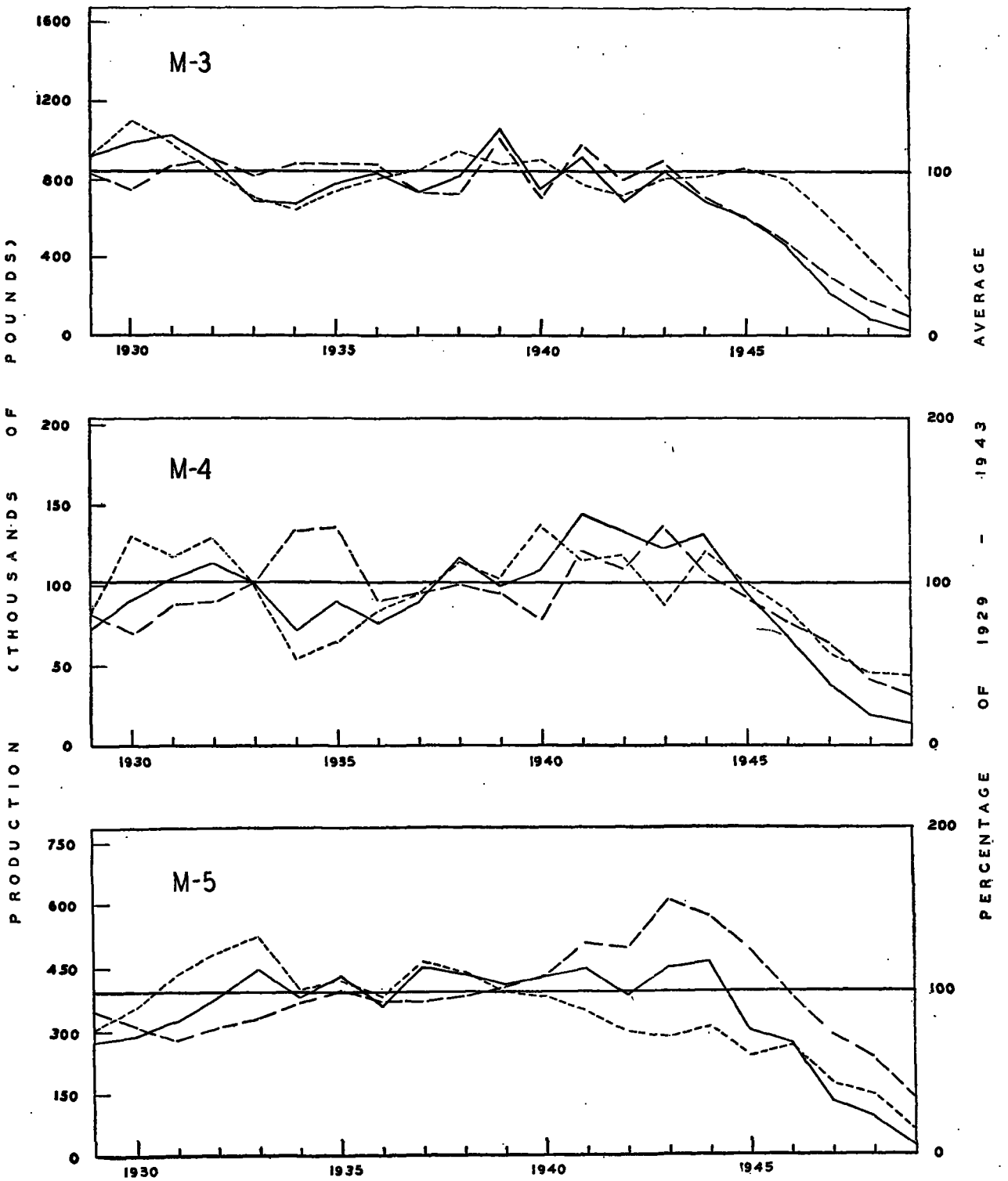

FIGURE 4.—Production, abundance index, and fishing-intensity index for lake trout in districts M–3, M–4, and M–5, 1929–42. Solid line=production; long dashes=abundance index; short dashes=fishing-intensity index. Scale at left (thousands of pounds) applies to production only; scale at right is in terms of 1929–43 mean for each item.

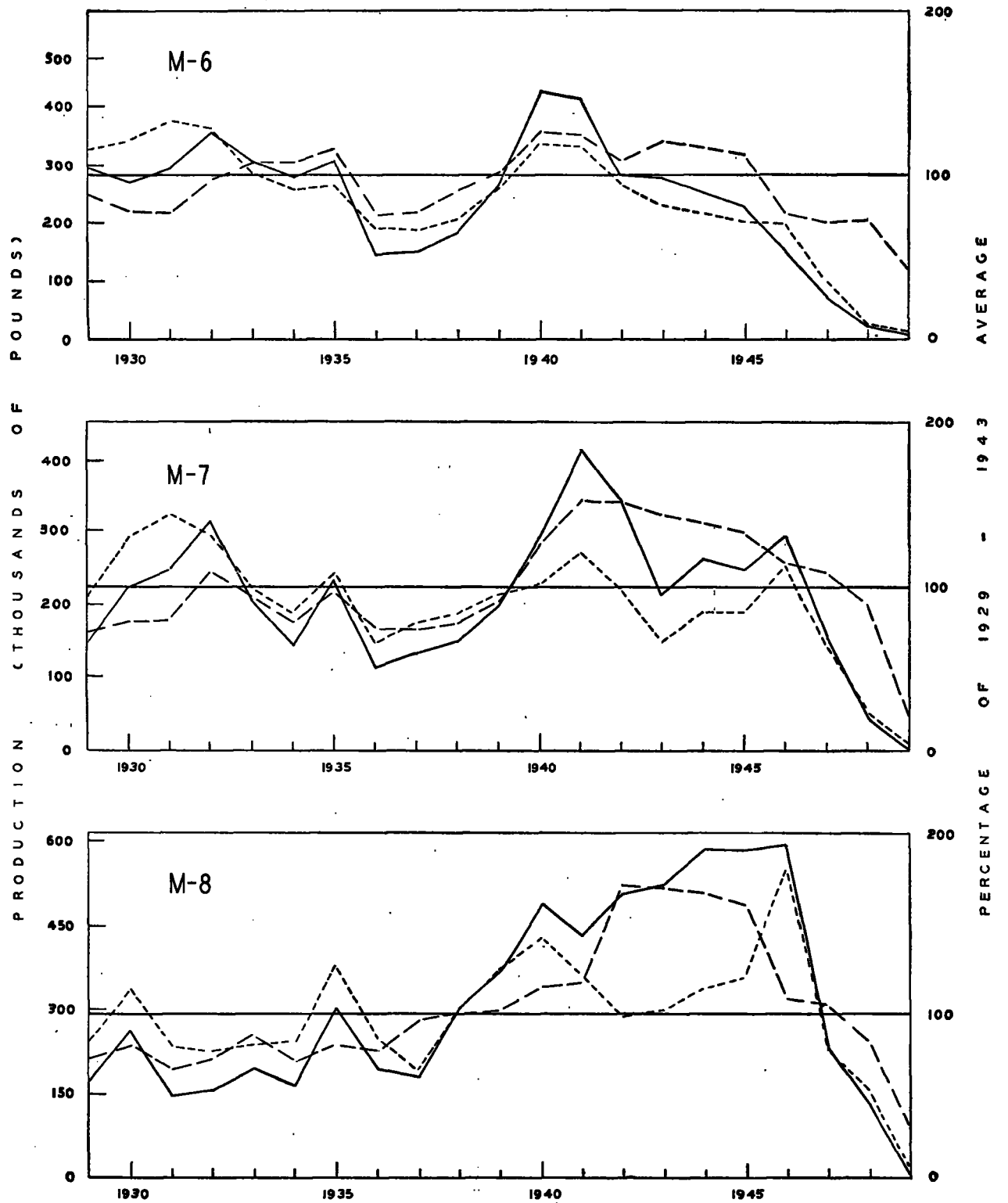

FIGURE 5.—Production, abundance index, and fishing-intensity index for lake trout in districts M–6, M–7, and M–8, 1929–49. Solid line=production; long dashes=abundance index; short dashes=fishing-intensity index. Scale at left (thousands of pounds) applies to production only; scale at right is in terms of 1929–43 mean for each item.

Despite the differences between the northern and southern waters just outlined, all districts agreed in showing production equal to or greater than the 1929–43 mean in relatively recent years. If we ignore the 1948–49 data for M–1, where, as explained, conditions were abnormal, the situation can be described by the statement that every district had average or better production in 1942 or later and in two districts (M–7 and M–8) the take was still above the mean in 1946.

The districts agreed further in that the onset of the progressive decline which has caused so much concern and the drop of production to less than half the average also were recent. In only one of the eight districts (M–6) did the recent progressive decrease get under way before 1944, and in the southernmost waters (M–7 and M–8) it did not start until 1947. With the exception of M–1 and M–2 (again 1948–49 data are ignored in the former district) the 50-percent level was not passed before 1947, and in M–7 and M–8 the take did not drop below half the mean until 1948. These data suggest a distinct north-to-south trend in the time at which the decline set in.

Despite the lateness of the decline, the speed with which it progressed was such that by 1949 the lake-trout fishery had practically come to an end in all districts but M–1. The 1949 total catch for districts M–2 through M–8 was only 74,000 pounds. These same waters had yielded more than 3 million pounds as recently as 1941 and in excess of 2 million pounds as late as 1945. The decline since the latter year represents a decrease of 96.7 percent.

The production data for the combined districts may be summarized as follows: Highest yields occurred in the early 1940's (1941, 1943, 1940); 1944 was the last year of above-average production and the first year of the recent decline; the output fell below 50 percent of the 1929–43 mean for the first time in 1947. Even when data are included for M–1 where the 1949 take was above the 1929–43 average, the decrease from 1944 to 1949 amounted to 90.6 percent.

ABUNDANCE IN STATE OF MICHIGAN WATERS, 1929–49

The estimates of the abundance or availability[7] of lake trout in the statistical districts of the State of Michigan waters of Lake Michigan beginning with 1929 (table 9; see also figs. 3, 4, and 5), are based principally on the records of the catch per unit lift of large-mesh gill nets (mesh sizes 4½ inches and greater, extension measure). During the base period 1929–43, large-mesh gill nets accounted for 88.1 percent of the total catch of lake trout. Set hooks were second (8.2 percent), and pound nets third (2.2 percent). The catch of other gears plus a small quantity of lake trout for which gear records were lacking made up the remaining 1.5 percent (presentation here of original data on gear composition of the catch is not considered necessary). Pound nets were of sufficient importance to be included in the estimation of abundance in only three districts (M–1, M–3, M–4).

Records of the catch per unit of fishing effort of large-mesh gill nets, set hooks, and pound nets in the several districts in 1929–49 are given in tables 10, 11, and 12.

In the listing of the years of highest abundance (middle section of table 8), as was true for the years of greatest production (top section), distinct

TABLE 9.—*Abundance indices for lake trout in Michigan statistical districts, 1929–49*

[Percentages of 1929-43 mean]

Year	Abundance percentage in district—								Average[1]
	M-1	M-2	M-3	M-4	M-5	M-6	M-7	M-8	
1929	71	84	99	80	88	89	72	74	87
1930	65	93	89	69	79	79	79	81	83
1931	69	114	103	86	71	77	79	66	87
1932	80	112	106	88	78	98	110	73	96
1933	97	115	98	100	83	107	94	88	97
1934	92	110	104	132	93	108	79	70	98
1935	87	112	104	134	101	116	98	81	102
1936	137	122	104	89	93	76	75	78	97
1937	157	98	88	92	94	78	74	96	93
1938	112	95	86	99	97	90	78	100	92
1939	94	93	120	93	102	102	91	101	105
1940	105	81	83	77	110	126	126	116	100
1941	135	104	116	119	129	125	153	119	123
1942	96	77	95	108	126	108	151	179	114
1943	100	90	105	134	156	121	143	178	126
1944	53	69	84	105	146	117	139	174	110
1945	51	56	71	91	125	113	132	166	98
1946	32	51	56	76	97	77	115	109	75
1947	26	33	36	63	73	72	108	105	60
1948	44	40	22	40	60	73	89	84	50
1949	45	19	12	30	35	43	31	33	26

[1] In the computation of the averages the abundance index for each district was weighted by the percentage contribution of that district to the total catch of all districts over the 15-year period 1929–43.

[7] Argument about which of the two words should be employed would constitute a futile quibbling over terminology. These estimates are based on the fishing experience of the fishermen—the records of their catch of legal-sized lake trout per standard unit of fishing effort. They offer no information on the abundance of undersized lake trout and are affected by such factors as meteorological conditions, annual differences in the time of spawning in relation to the fixed closed season, and annual differences in the distribution of fish. Yet, for all these obvious weaknesses they offer the best estimates of abundance to be had at the present time. Accordingly, we do not hesitate to use "availability" and "abundance" interchangeably.

TABLE 10.—*Catch of lake trout per lift of large-mesh gill nets in Michigan statistical districts, 1929–49*

[In pounds per lift of 10,000 linear feet of large-mesh gill nets 4½ inches and greater, extension measure]

Year	District							
	M–1	M–2	M–3	M–4	M–5	M–6	M–7	M–8
1929	66	126	131	83	84	98	99	85
1930	57	143	117	66	77	86	111	108
1931	63	175	140	90	72	84	139	92
1932	78	171	143	88	80	107	201	138
1933	106	169	122	88	86	119	140	138
1934	73	168	127	153	96	118	126	91
1935	79	166	136	138	103	127	188	128
1936	168	184	136	97	94	82	148	149
1937	189	146	113	92	95	85	143	163
1938	121	142	113	106	99	98	181	177
1939	96	142	161	101	103	113	189	184
1940	118	121	109	80	113	139	276	212
1941	134	161	155	126	131	137	264	196
1942	91	115	125	118	127	118	247	279
1943	94	136	138	143	158	130	234	260
1929–43 mean	102	151	131	105	101	109	179	160
1944	50	105	109	109	147	129	219	258
1945	48	81	92	92	126	124	212	239
1946	30	78	73	80	98	84	189	158
1947	24	49	47	65	73	79	189	150
1948	42	61	29	42	61	80	143	122
1949	44	28	16	31	35	47	34	48

TABLE 11.—*Catch of lake trout per lift of set hooks in Michigan statistical districts, 1929–49*

[In pounds per lift of 1,000 set hooks. Where no figures are given, few or no lake trout were taken with this gear]

Year	District							
	M–1	M–2	M–3	M–4	M–5	M–6	M–7	M–8
1929	223	173	133	137	356	131	239	252
1930	253	111	143	119	247	108	194	194
1931	201	187	118	123	208	122	132	145
1932	151	218	132	94	138	131	191	116
1933	197	290	229	172	165	72	201	132
1934	247	198	264	139	162	112	154	200
1935	237	259	161	147	202	120	143	162
1936	165	236	182	96	275	------	117	112
1937	154	215	114	191	218	------	122	133
1938	129	207	61	131	433	------	123	140
1939	138	158	111	83	117	------	153	161
1940	129	190	104	143	120	------	134	158
1941	------	91	102	73	------	56	137	176
1942	102	------	------	107	------	------	173	212
1943	------	------	------	------	------	265	249	323
1929–43 mean [1]	184	190	143	128	243	121	164	174
1944	------	------	------	140	------	------	346	73
1945	------	------	------	167	------	------	211	------
1946	------	------	------	------	------	------	185	208
1947	------	------	------	------	------	------	74	435
1948	------	------	------	------	------	------	------	65
1949	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)

[1] For each district for which data are not given for 1 or more years, the 15-year average is estimated by dividing the mean of the available annual averages by the mean of the abundance percentages for the same years. See Van Oosten, Hile, and Jobes (1946) for comments on the estimation of a normal catch when data are not available for all years.

[2] No fishing with set hooks in 1949.

differences are to be seen between the northern and southern areas of the lake. Of the 12 "high-abundance" years listed for districts M–1 through M–4,[8] 9 were earlier than 1940 and only 1 was later than 1941. The corresponding record for districts M–5 through M–8, on the contrary, shows all 12 years within the period 1940–44 and 9 within the still-shorter interval 1941–43.

[8] District M–4, assigned to the southern districts in the grouping with respect to production, has been assigned to the northern with respect to years of greatest abundance.

TABLE 12.—*Catch of lake trout per lift of pound nets in Michigan statistical districts, 1929–49*

[In pounds per lift of 1 pound net. Where no figures are given, few or no lake trout were taken with this gear]

Year	District			Year	District		
	M–1	M–3	M–4		M–1	M–3	M–4
1929	14	17	21	1941	13	12	19
1930	15	16	27	1942	------	8	23
1931	13	15	22	1943	2	12	18
1932	18	16	43				
1933	16	25	47	1929–43 mean [1]	14	15	28
1934	29	17	38				
1935	23	20	56	1944	4	13	9
1936	8	17	24	1945	------	16	------
1937	13	22	33	1946	------	10	10
1938	16	15	17	1947	9	4	2
1939	12	11	13	1948	8	3	7
1940	8	9	16	1949	5	1	------

[1] For each district for which data are not given for 1 or more years, the 15-year average is estimated by dividing the mean of the available annual averages by the mean of the abundance percentages for the same years. See Van Oosten, Hile, and Jobes (1946) for comments on the estimation of a normal catch when data are not available for all years.

Although the recent progressive decline in abundance appears to have started at much the same time in all districts (1942 in M–7, 1943 in M–8, and 1944 in all other districts) it proceeded much more rapidly in northerly than in southerly waters. The last year with abundance at average or greater was 1941 in M–2, 1943 in M–1 and M–3, 1944 in M–4, 1945 in M–5 and M–6, and 1947 in M–7 and M–8. The same north-to-south sequence exists in the first year in which abundance dropped below the 70-percent level,[9] 1944 in M–1 and M–2, 1946 in M–3, 1947 in M–4, 1948 in M–5, and 1949 in M–6, M–7, and M–8. This north-to-south progression resembles closely that described for production in the preceding section. The situation invites speculation about the possibility that a southward spread of the sea lamprey was a contributing factor.

Despite the differences in timing just described, the districts agreed in that all showed an extremely low level of availability of lake trout in 1949 (range of abundance percentages from 45 in M–1 down to 12 in M–3). Admittedly, the dependability of the estimates of abundance decreases rapidly as production falls to low levels. Nevertheless, the consistently low returns per

[9] The 70-percent level is considered preferable here to the 50-percent figure employed for analogous items in the data for production (and for fishing intensity, discussed later). Usually the fishery has all but disappeared by the time the 50-percent level of abundance is reached.

unit of fishing effort together with the very fact that production had all but ended in most areas must be accepted as conclusive evidence of the great scarcity of marketable-sized lake trout in the State of Michigan waters of Lake Michigan in 1949.

For the combined districts the level of abundance was highest in 1943 (126), 1941, and 1942. The last year with abundance above average and the first year of the recent progressive decline was 1944, and abundance first dropped below the 70-percent level in 1947. In 1949 the abundance had reached the low figure of 26 percent.

TABLE 13.—*Correlations between 1929–43 fluctuations in abundance indices for lake trout in Michigan statistical districts*

[Values of r corresponding to probabilities p of 0.05 and 0.01 are ±0.514 and ±0.641]

District	District							
	M–1	M–2	M–3	M–4	M–5	M–6	M–7	M–8
M–1	-------	0.113	−0.040	0.175	0.346	0.043	0.142	0.223
M–2	0.113	-------	.370	.181	−.460	−.255	−.374	−.617
M–3	−.040	.370	-------	.404	.181	.233	.201	−.037
M–4	.175	.181	.404	-------	.587	.591	.394	.365
M–5	.346	−.460	.181	.587	-------	.681	.786	.889
M–6	.043	−.255	.233	.591	.681	-------	.767	.526
M–7	.142	−.374	.201	.394	.786	.767	-------	.805
M–8	.223	−.617	−.037	.365	.889	.526	.805	-------

From earlier discussion and from the examination of table 9 and figures 3, 4, and 5, it is apparent that in certain districts the annual fluctuations in the abundance of lake trout followed similar trends. In the northern waters for example, it has been pointed out that most of the years of highest abundance fell before 1940, whereas the southern districts shared a period of high availability in the early 1940's. To provide a more precise measurement of the agreement in these trends, coefficients of correlation were computed for the abundance percentages for all pairs of districts over the period 1929–43. Data for years later than 1943 were excluded in order to minimize or possibly eliminate the distorting effects of the decline in abundance that followed the depredations of the sea lamprey in all districts. This restriction, we believe, has made the coefficients recorded in table 13 relatively reliable estimates of the correlations between fluctuations in the availability of lake trout in the different districts under approximately "normal" conditions.

The outstanding feature of the data of table 13 is the close positive correlation among the fluctuations in abundance in the four southern districts (M–5 through M–8). Of the six coefficients that could be computed for these districts, five exceeded the value ordinarily accepted as "highly significant" ($p<0.01$), and the sixth was above the level ordinarily termed "significant" ($p<0.05$). These high values, together with the consistency with which they occurred with all possible pairings, suggest strongly that the lake-trout fisheries to the south of Grand Traverse Point were based on a common stock or on stocks in which the factors controlling abundance in 1929–43 were the same or subject to similar annual fluctuations. Further speculation in the matter would be to little point until we have definite information on the nature of these factors and the methods by which they operate.

The fluctuations of abundance in M–4 exhibited positive significant correlation with those in the two districts immediately to the south (M–5 and M–6). The correlation with fluctuations in M–3 also was positive but the value of the coefficient ($r=0.404$) was well below the level of significance.

Of the 3 coefficients computed between districts M–1, M–2, and M–3, and the 15 calculated between those districts and the ones lying farther south, only one was significant ($r=-0.617$, M–2 and M–8). This single significant value in a group of 18 fails to fit the pattern. The weight of the evidence suggests that the fluctuations in the abundance of lake trout in each of the three northern districts were not correlated with those in the remaining ones.

FISHING INTENSITY IN STATE OF MICHIGAN WATERS, 1929–49

The records of the annual fluctuations in the intensity of the fishery for lake trout (table 14; figs. 3, 4, and 5; bottom section of table 8) fail to reveal the distinct separation with respect to trends that existed between northern and southern areas in production and abundance. With the exception of M–2 where all three years and M–8 where two of the three years of most intensive fishing occurred in the 1940's, the tendency was general for fishing operations to be heaviest in the early 1930's. Of the 21 "high-intensity" years listed in table 8 (see section on production in the

TABLE 14.—*Intensity of fishery for lake trout in Michigan statistical districts, 1929–49*

[In units corresponding to 1/1500 of total expected catch for all districts over 15-year period 1929–43]

Year	District								Tota
	M-1	M-2	M-3	M-4	M-5	M-6	M-7	M-8	
1929	10.1	7.1	35.8	3.4	11.9	12.7	8.3	9.5	98.8
1930	12.3	9.7	42.9	5.2	14.0	13.3	11.5	13.0	121.9
1931	12.7	10.1	38.3	4.7	17.3	14.6	12.7	9.1	119.5
1932	9.6	11.4	32.7	5.2	19.2	14.1	11.5	8.6	112.3
1933	5.4	10.0	27.3	4.1	20.9	11.1	8.9	9.1	96.8
1934	3.1	9.8	25.1	2.2	15.8	10.1	7.5	9.4	83.0
1935	3.4	8.4	28.9	2.6	16.7	10.3	9.5	14.5	94.3
1936	4.5	8.3	30.8	3.3	15.1	7.4	5.8	9.6	84.8
1937	5.8	11.8	32.8	3.8	18.6	7.4	6.9	7.3	94.4
1938	8.6	9.9	36.4	4.6	17.4	7.9	7.4	11.8	104.0
1939	6.5	9.8	33.9	4.2	15.6	10.1	8.4	14.3	102.8
1940	3.1	10.6	34.8	5.5	15.1	13.0	8.9	16.5	107.5
1941	2.1	13.3	30.3	4.6	13.5	12.9	10.6	14.1	101.4
1942	2.3	12.9	28.1	4.8	11.9	10.2	8.8	11.1	90.1
1943	3.6	13.0	31.0	3.5	11.3	8.8	5.8	11.4	88.4
1929–43 mean	6.2	10.4	32.6	4.1	15.6	10.9	8.9	11.3	100
1944	3.5	11.0	31.5	4.9	12.3	8.3	7.3	13.1	91.9
1945	2.2	10.0	32.8	4.1	9.3	7.8	7.3	13.7	87.2
1946	1.4	6.0	31.1	3.5	10.5	7.7	9.9	21.2	91.3
1947	6.9	3.0	23.9	2.4	6.3	3.8	5.6	8.7	61.1
1948	15.7	2.4	15.8	1.8	5.6	1.0	1.9	6.1	50.3
1949	12.8	.7	7.4	1.7	2.4	.4	.4	.7	26.5

various districts for an account of the unusual situation in M–1) 12 fell within the 4-year period 1930–33.

The last year of average or greater fishing intensity was 1939 in M–5, 1941 in M–6, and 1944 to 1946 in the remaining districts. The recent progressive decline started in 1942 in M–6 and in 1944 to 1947 in other areas. Fishing intensity first dropped below the 50-percent level in 1947 in M–2, M–5, and M–6, in 1948 in M–3, M–4, and M–7, and in 1949 in M–8.

For the combined districts the intensity of the lake-trout fishery was greatest in 1930, 1931, and 1932, and the last year of greater-than-average intensity was 1941. The recent progressive decline started in 1947, and in 1949 fishing intensity was only 26 percent of the 1929–43 mean.

The factors that influence the intensity of the fishery for lake trout are so numerous, so variable in their effects, and so difficult to appraise, that in most situations it is impossible to evaluate the effect of any one of them. Among these factors may be listed: Weather conditions; costs of operation; availability of and market for lake trout, for species taken along with lake trout, and for species produced alternatively. During the war years scarcities of equipment and supplies and manpower shortages also affected fishing intensity.

The availability of the lake trout itself well might be expected to exert an important influence on the intensity of fishing since good catches per unit of effort should stimulate fishing operations and poor lifts depress them. This expectation is not borne out, however, by the following tabulation of the coefficients of correlation between the abundance of lake trout and fishing intensity for the species in the various districts in 1929–41:[10]

	r		r
District M–1	−0.611	District M–5	−0.379
District M–2	.034	District M–6	.225
District M–3	−.378	District M–7	.357
District M–4	−.677	District M–8	.633

Of the eight coefficients calculated, four were positive and four negative, and of the three that were "significant" ($r=\pm 0.553$ at the 5-percent level of probability) one was positive and two negative. It is not to be concluded, of course, that a plenitude of lake trout is about equally likely to stimulate or depress fishing activity; rather, it should be stated that in many situations other factors are of greater importance.

The high negative correlation between fishing intensity and abundance of lake trout in M–1 has already been explained. The available statistical data do not suggest an explanation of the even higher negative figure for M–4. Perhaps this significant correlation was merely fortuitous. We are inclined to suspect, however, that the negative correlation can be attributed in part to changes of fishing grounds during the time of the great increase in the popularity of "deep-sea" trolling for lake trout in Grand Traverse Bay (identical with M–4) in the 1930's. Although we have no quantitative measure of the effect on the intensity of the fishery, we do know that certain fishermen, in an attempt to lessen friction between sport and commercial interests, avoided the sport-trolling grounds during the peak of the tourist season and moved their operations to grounds north of Grand Traverse Point (M–3) and near Cathead Point (M–5). Consequently, fishing intensity may have been lower than normally would be expected in some years when lake trout were relatively plentiful.

The significant positive correlation between fishing intensity and the abundance of lake trout in M–8 may reflect a true cause-and-effect rela-

[10] The elimination of years after 1941 in these computations makes possible the best estimate of relations under approximately "normal" conditions since bias from wartime shortages of manpower and materials and the effects of the general sharp deline in abundance that accompanied the increase in the population of sea lampreys in recent years are eliminated or minimized.

tion, but the lack of a similar correlation in the other districts throws some doubt on such an interpretation.

The general situation in the State of Michigan waters seems to be much the same as that in the United States waters of Lake Huron where Hile (1949) concluded that "indispensable as the lake trout may be to the conduct of a lake trout fishery, the abundance of that species is only one of the factors, and in some situations a subordinate factor, in the determination of fishing intensity."

RELATIONS OF PRODUCTION, ABUNDANCE, AND FISHING INTENSITY

Considerable information on the relations of production, abundance, and fishing intensity in the lake-trout fishery of the State of Michigan waters of Lake Michigan was given in the preceding sections. The discussion of the present section is restricted largely to the question of the extent to which production has served as an indicator of fluctuations in the abundance of lake trout and to changes in the fishery immediately preceding and during the recent collapse, with special reference to the possible role of overfishing as a factor in the decline in abundance of lake trout.

The accumulation of information on the degree of reliability of production statistics as indicators of changes in abundance or availability in the Great Lakes fisheries is of importance because in many areas data on the actual take per unit of fishing effort are not available or are at hand for only the more recent years.

The opinion was expressed by Van Oosten, Hile, and Jobes (1946) that "under normal conditions (without disruption in the methods or regulations of the fishery), over limited areas, and for short periods of years, large increases or decreases of production may serve as reliable indicators of increases or decreases in the abundance of fish on the grounds." A similar view was held by Doan (1942) who considered it valid to employ catch statistics for the estimation of the fluctuation in the abundance of several commercially important species in Lake Erie. Doan based his opinion largely on the agreement between trends in the catch of walleyes or yellow pikeperch (*Stizostedion v. vitreum*) per unit effort in the principal gear and the total production of the species in four fishing areas of Lakes Huron and Michigan (data for these two lakes adapted from Hile 1937) and in Lake Erie. More recently, Hile (1949) demonstrated a significant positive correlation between annual fluctuations in the production and abundance of lake trout for four of the six statistical districts of the United States waters of Lake Huron and for the six districts combined. In a fifth area the coefficient was positive with a value corresponding to the 10-percent level of probability, but a significant negative value existed in the sixth district. This negative correlation was explained as the result of the depressing effect of the collapse of the whitefish fishery on the intensity of operations with large-mesh gill nets during years of relatively high abundance of lake trout (note the similar situation described earlier in this paper for district M–1).

Of the coefficients of correlation between the production and abundance computed for Lake Michigan (table 15) those for the period 1929–41 most nearly reflect "normal" conditions. The coefficients for the base period 1929–43 were probably biased by the depressing effects of wartime scarcities of manpower and equipment and those for 1929–49 were affected by wartime conditions and more recently by the general collapse of the lake-trout fishery.

TABLE 15.—*Correlations between production and abundance of lake trout in Michigan statistical districts, for 3 periods*

Item	Period		
	1929–41	1929–43	1929–49
District M–1	−0.050	−0.028	0.337
District M–2	.614	.516	.914
District M–3	.431	.441	.937
District M–4	.065	.223	.712
District M–5	.577	.528	.708
District M–6	.775	.714	.802
District M–7	.904	.817	.802
District M–8	.874	.878	.872
All districts	.579	.596	.918
Value of r at $p=0.10$	.476	.441	.369
Value of r at $p=0.05$	.553	.514	.433
Value of r at $p=0.01$	.684	.641	.549

Actually, the differences between 1929–41 and 1929–43 were unimportant. In both periods the correlations between production and abundance were "highly significant" ($p<0.01$) for M–6, M–7, and M–8 and were "significant" ($0.05>p>0.01$) for M–2 and M–5 and for the combined districts. The positive coefficients for M–3 were moderately high but nevertheless fell short even of the 10-percent value in 1929–41 and barely attained that level in 1929–43. The 1929–41 and 1929–43 data

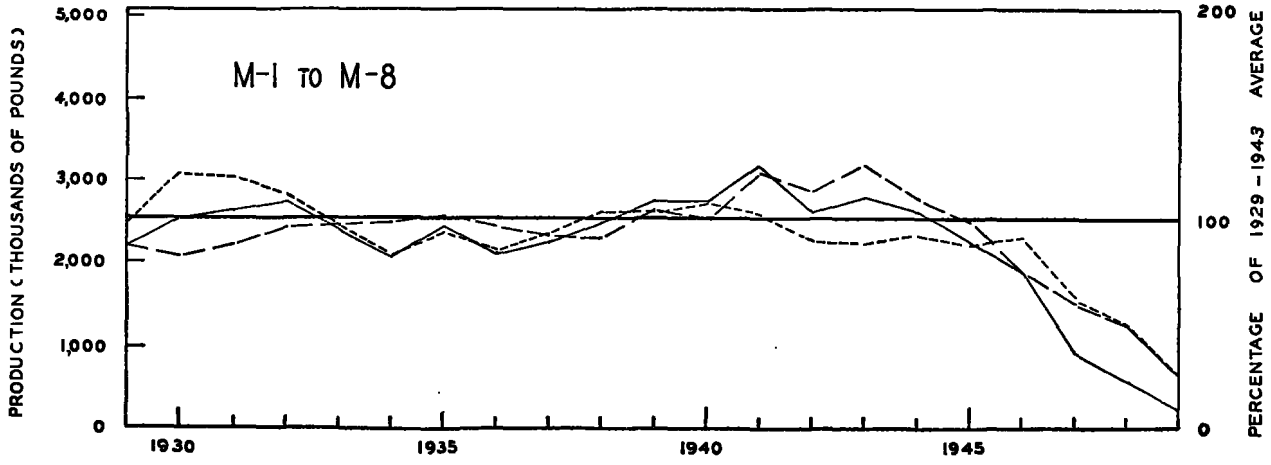

FIGURE 6.—Production, abundance index, and fishing-intensity index for lake trout in combined districts of State of Michigan waters, 1929–49. Solid line=production; long dashes=abundance index; short dashes=fishing-intensity index. Scale at left (thousands of pounds) applies to production only; scale at right is in terms of 1929–43 mean for each item.

offer no evidence for a correlation between the production and abundance of lake trout in M–1 and M–4. A negative correlation between abundance and fishing intensity in each of the two districts in 1929–41 (see preceding section) unquestionably was a major disturbing influence.

From the values of the coefficients for 1929–41 and/or 1929–43 it appears that production served as a more or less reliable indicator of at least the more significant fluctuations of abundance in five of eight districts and in the lake as a whole, was of highly limited value in one district and was completely undependable in two (see figs. 3, 4, 5, and 6). The failure of production and abundance to follow similar courses in M–1 and M–4 (to a considerable extent in M–3 also) brings out the importance of being constantly alert to identify and, if possible, evaluate disturbing factors in the use of production figures for detecting changes in abundance. It should be stressed also that catch statistics should be employed only to detect changes of abundance and not as measures of those changes.

The coefficients of correlation for 1929–49 had high positive values—far beyond the level accepted as highly significant—in districts M–2 through M–8 and in the combined districts. District M–1, where abnormally intensive fishing kept production high in later years, offered the single exception. These high values for districts M–2 through M–8 can be attributed to the enormous declines in both production and abundance that occurred in the later years of the period. Too much should not be made of the high coefficients for 1929–49 as an argument for the value of production statistics for following trends of availability. When a fishery suffers a decline as disastrous as the one that has overtaken the lake-trout fishery of Lake Michigan, statistical analyses are hardly required to prove that fish are too scarce to support commercial operations.

During the years of the decline in the lake-trout fisheries of Lakes Huron and Michigan we heard the opinion expressed both privately and publicly that the sea lamprey had not contributed significantly to the collapse, that the stocks of lake trout simply had dwindled away under the pressure of overfishing, that the distress of the fishing industry was but just retribution for a wanton despoliation of a valuable public resource. The facts given in an earlier study of the lake-trout fishery of Lake Huron (Hile 1949) demonstrated rather conclusively that excessive fishing intensity could not have brought about the collapse of the fishery in the United States waters of that lake. Corresponding data for the State of Michigan portion of Lake Michigan compel a similar conclusion for the lake-trout fishery of those waters.

The data of table 16 (see also fig. 6) fail completely to show a level of fishing intensity that would account for the recent decline in the lake-trout fishery of Lake Michigan. On the contrary, the most intensive fishing operations of the 21-year period, 1929–49, occurred in 1930–32 (112 to 122 percent of the 1929–43 mean—figures that do not indicate excessive fishing even at that time) whereas in the later years fishing intensity has

TABLE 16.—*Indices of production, abundance, and fishing intensity for lake trout in State of Michigan waters, 1929–49*

[Percentages of 1929–43 means]

Year	Production	Abundance	Intensity	Year	Production	Abundance	Intensity
1929	86	87	99	1940	109	100	108
1930	101	83	122	1941	126	123	101
1931	104	87	120	1942	104	114	90
1932	108	96	112	1943	111	126	88
1933	94	97	97	1944	103	110	92
1934	81	98	83	1945	88	98	87
1935	96	102	94	1946	75	75	91
1936	84	97	85	1947	36	60	61
1937	89	93	94	1948	23	50	50
1938	98	92	104	1949	9	26	26
1939	109	105	103				

been invariably below the 100-percent value since 1941. It is particularly significant that intensity was below average in 3 of the 4 years of highest abundance (1941–44) and was barely above the 15-year mean in the fourth. These same years saw production consistently above the mean and at a 21-year peak in 1941, but a high level of abundance, not intensive fishing, was the cause. Furthermore, the intensity percentage exceeded the abundance percentage in only 2 of the 9 years of the period 1941–49; in the remaining 7 years the two index figures were the same or fishing intensity was the lower. It is thus obvious that a rate of fishing that could bring the index of abundance from a record high figure of 126 in 1943 to a record low value of 26 in 1949 simply did not exist. Some factor other than overfishing caused the lake trout to disappear in Lakes Huron and Michigan. The best evidence points to the sea lamprey.

SUMMARY

After a developmental period from 1879 through 1889, the fishery for lake trout, *Salvelinus* [=*Cristivomer*] *namaycush*, in Lake Michigan entered on a 22-year period (1890–1911) of high and relatively stable production. The average annual output for this latter interval was 8,230,000 pounds. There followed two shorter intervals of 15 years (1912–26) and 13 years (1927–39) in which the annual yields were still moderately stable but had successively lower average values of 7,007,000 and 5,293,000 pounds. Production rose in 1940 but the heightened prosperity was short-lived. After 5 years (1940–44) in which the yield was consistently more than 6 million pounds and averaged 6,578,000 pounds, the lake-trout fishery suffered a calamitous decline which saw the annual catch drop from 6,498,000 pounds in 1944 to only 342,000 pounds in 1949.

Michigan and Wisconsin have always contributed the bulk of the production of lake trout in Lake Michigan. The contribution of Michigan for the periods listed in the preceding paragraph (excluding the developmental years for which only scattered data were available) ranged from 42.4 percent in 1890–1911 to 45.7 percent in 1927–39. In Wisconsin the range was from 41.4 percent in 1940–44 to 54.8 percent in 1890–1911. The percentages have been consistently small for Indiana (maximum of 3.1 percent in 1912–26) and were small for Illinois also in the earlier years. More recently Illinois contributed 14.7 percent of the total for the lake in 1940–44 and 11.3 percent in 1945–49.

Comparison of the annual yields of lake trout in the eight statistical districts of the State of Michigan waters of Lake Michigan in 1891–1908 with those of 1929–43 (the base period for our modern statistical analyses) revealed a lower level of productivity in more recent years for every district but M–5 and a slight southward shifting of the centers of production (the northerly districts M–1 through M–3 contributed 60.3 percent of the 1891–1908 total but only 49.1 percent of the 1929–43 yield). The ranking of the districts with respect to their percentage contribution to the lake total changed little, however.

Production statistics for the individual districts in 1929–49 showed that most of the years of relatively high production (the three best years for each district) fell before 1940 in northerly waters (M–1 through M–3) and after 1940 in southerly waters (M–4 through M–8). Although the recent progressive decline in production got under way earlier than 1944 in only one district and started as late as 1947 in M–7 and M–8, the catch had dropped to an insignificantly low level in all districts by 1949 (an exception must be made for M–1 where considerable quantities of lake trout were taken coincidentally in an abnormally intensive fishery for whitefish).

Records of the three years of greatest abundance or availability of lake trout (as computed from the data on the catch per unit of fishing effort of the principal gears) revealed that most of these years fell before 1940 in districts M–1 through M–4, whereas in the waters to the south (M–5 through M–8) they all fell within the period 1940–44. Figures on the last year with abun-

dance at or above the 1929–43 index of 100 and on the first year of abundance below 70 (a level of availability selected as critical in this study) give strong indication of a north-to-south progression in the timing of the recent decline (with the more northerly districts the first to drop below average and to pass the 70-percent level). This sequence suggests that the different areas may have been affected successively as the sea lamprey spread from the north to the south. Despite this progression, all eight districts agreed in exhibiting an extremely low level of abundance in 1949 (from 12 to 45 percent of average in the individual districts; 26 percent for the combined districts).

During the more nearly normal years preceding the recent general decline of the lake-trout fishery, the annual fluctuations in the abundance of lake trout in the four southern districts (M–5 through M–8) were closely correlated. The coefficient of correlation r was highly significant ($p<0.01$) for five of six possible pairings over the period 1929–43 and was significant ($p<0.05$) for the sixth. The fluctuations of abundance in M–4 also were correlated significantly with those in M–5 and M–6. The abundance in each of the northern districts, on the contrary, appeared to be independent of that in any other area.

In the majority of the statistical districts the years of most intensive fishing for lake trout fell in the early 1930's and for the combined districts the three years of greatest fishing intensity were 1930, 1931, and 1932. With the exception of M–1, where a recent upswing in the intensity of fishing for whitefish led to an increased pressure on lake trout, fishing intensity for the latter species entered on a progressive decline as early as 1942 and in no district later than 1947. By 1949, fishing intensity was far below 50 percent of the 1929–43 average in all districts but M–1 and amounted to only 26.5 percent for the eight districts combined. The abundance of lake trout seems to have had little influence on the intensity of the fishery under the normal conditions of 1929–41 (before World War II with its shortages of manpower and equipment and well before the general decline of the lake-trout fishery associated with the spread of the sea lamprey).

During the same normal 1929–41 period, fluctuations in production served as reasonably dependable indicators of major changes in abundance in five of the eight districts. These changes in production did not, however, provide reliable measures of the extent of the fluctuations in abundance.

Statistics on the production and abundance of lake trout and on the intensity of the lake-trout fishery refute the view sometimes advanced that overfishing has been the cause of the decline of the lake trout in the State of Michigan waters of Lake Michigan. The most intensive fishing of the 1929–49 period took place in 1930–32, and intensity has been consistently below the 1929–43 average since 1941. Some factor other than overfishing caused the lake trout to disappear. The best evidence points to the sea lamprey.

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