FACTORS ASSOCIATED WITH FLUCTUATIONS IN ABUNDANCE OF HUDSON RIVER SHAD

BY GERALD B. TALBOT

FISHERY BULLETIN 101

UNITED STATES DEPARTMENT OF THE INTERIOR, Douglas McKay, *Secretary*

FISH AND WILDLIFE SERVICE, John L. Farley, *Director*

ABSTRACT

A study of the Hudson River shad (*Alosa sapidissima*) was undertaken during 1950 and 1951 as part of a shad investigation carried out by the Fish and Wildlife Service to supply information to the Atlantic States Marine Fisheries Commission for fishery regulation along the Atlantic coast. Catch and effort statistics were obtained for the years 1915 through 1951, from various sources, for the gill-net fishery which catches more than 95 percent of the shad in the Hudson River. A tagging program during 1951 gave estimates of the total shad population entering the river that year. The total run and the escapement (since the catch was known) were then calculated for each year from 1915 through 1950. Age analysis of a sample of the catch of 1950 and 1951 showed that most shad returned as adults to the river at 4 and 5 years of age. Also, about 50 percent of the fish had previously spawned.

It was shown that about 85 percent of the variation in size of the run between 1920 and 1951 could be attributed to the size of the escapement from the fishery. No correlation was found between the size of the run each year and such factors as stream flow, water temperatures, channel improvements, ship traffic, or hatchery operations. No evidence of natural cycles of abundance was found. Catches of Hudson River shad in waters outside the river were shown to be large, and these catches may affect the expected size of the run. Using the methods outlined, the size of run can be predicted 1 year in advance, and by controlling the fishing efforts, the desired number of shad can be allowed to escape so that future runs can produce maximum sustained yields of shad from this river.

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FACTORS ASSOCIATED WITH FLUCTUATIONS IN ABUNDANCE OF HUDSON RIVER SHAD

By Gerald B. Talbot, *Fishery Research Biologist*

The commercial yield of Atlantic-coast shad (*Alosa sapidissima*) reached a peak of 50 million pounds in 1896 and thereafter declined until in 1950 it was less than a sixth of the 1896 catch. Alarmed by the continued decline of this valuable food fish, the Atlantic States Marine Fisheries Commission initiated action which resulted in special Congressional appropriations for a 6-year study of shad in the Atlantic Coast States. The Fish and Wildlife Service, as the primary research agency of the Commission, began this study in 1950. The basic purposes of the investigation were to discover the underlying causes of the decline, to determine conditions favoring recovery, and to provide basic information for scientific management of the fishery to obtain a maximum sustained yield.

Since funds and personnel were not sufficient for a study of all the major shad runs simultaneously, it was necessary to limit the field work each year to small areas. Work was begun on the Hudson River in the spring of 1950 and was continued in 1951. Plans were formulated to study other areas simultaneously and in succeeding years. This report covers only the studies made on the Hudson River.

The following members of the Fish and Wildlife Service assisted in this project: R. A. Fredin, to whom special acknowledgements are due for his help in the statistical analyses, C. E. Atkinson, J. P. Cating, R. H. Eggleston, J. H. Finucane, B. A. Lehman, John Parkin, T. Penny, C. L. Perkins, Jr., J. E. Sykes, and C. H. Walburg, of the Beaufort Fishery Laboratory staff, as well as Henry Bearse and R. H. Wilson of the Market News Service, Branch of Commercial Fisheries.

We are also grateful to W. C. Senning, J. R. Greeley, A. W. Bromley, J. Skain, Cecil Heacox, Alfred Tucker, and J. R. Westman (now with Rutgers University) of the New York Conservation Department, to F. W. Gilcreas and B. F. Pfeil, of the New York Department of Health, and to A. Heaton Underhill, A. E. Sullivan, and H. P. Hartmann, of the New Jersey Department of Fish and Game, for their help and cooperation during this study.

In addition, we greatly appreciate the help of the fish wardens of both States and the many commercial fishermen who helped us in every way possible to ensure success of our project.

DESCRIPTION OF THE RIVER AND ITS SHAD FISHERY

The Hudson River has its source in the Adirondack Mountains, flows generally southward about 300 miles, and empties into Upper New York Bay at the Battery, New York City. The river is tidal from its mouth upstream to Troy, a distance of about 160 miles (fig. 1). A dam at Troy is the upper limit of shad migration. The original wooden dam at Troy was finished in 1826, and this was later replaced by a masonry structure. From the dam at Troy to Peekskill the river ranges from 200 yards to 2,500 yards in width. Below this it broadens into Haverstraw Bay where the width ranges from 3 to 4 miles. The lower section of the river, from Dobbs Ferry to the Battery, averages about a mile in width.

The fresh-water section of the river extends downstream to a few miles below Poughkeepsie, where the intrusion of salt water begins. The degree of salinity at any particular place, and the position of the division between fresh and brackish water depends upon the tide and river run-off. The average weekly surface salinity at Bear Mountain Bridge (about 25 miles below Poughkeepsie) from July through October 1951 was 0.69‰ with a maximum of 2.39‰ and a minimum of 0.0‰. At Piermont Pier, about 20 miles below Bear Mountain Bridge, the average of the weekly samples for the same period was 6.81‰, with a maximum of 8.50‰ and a mini-

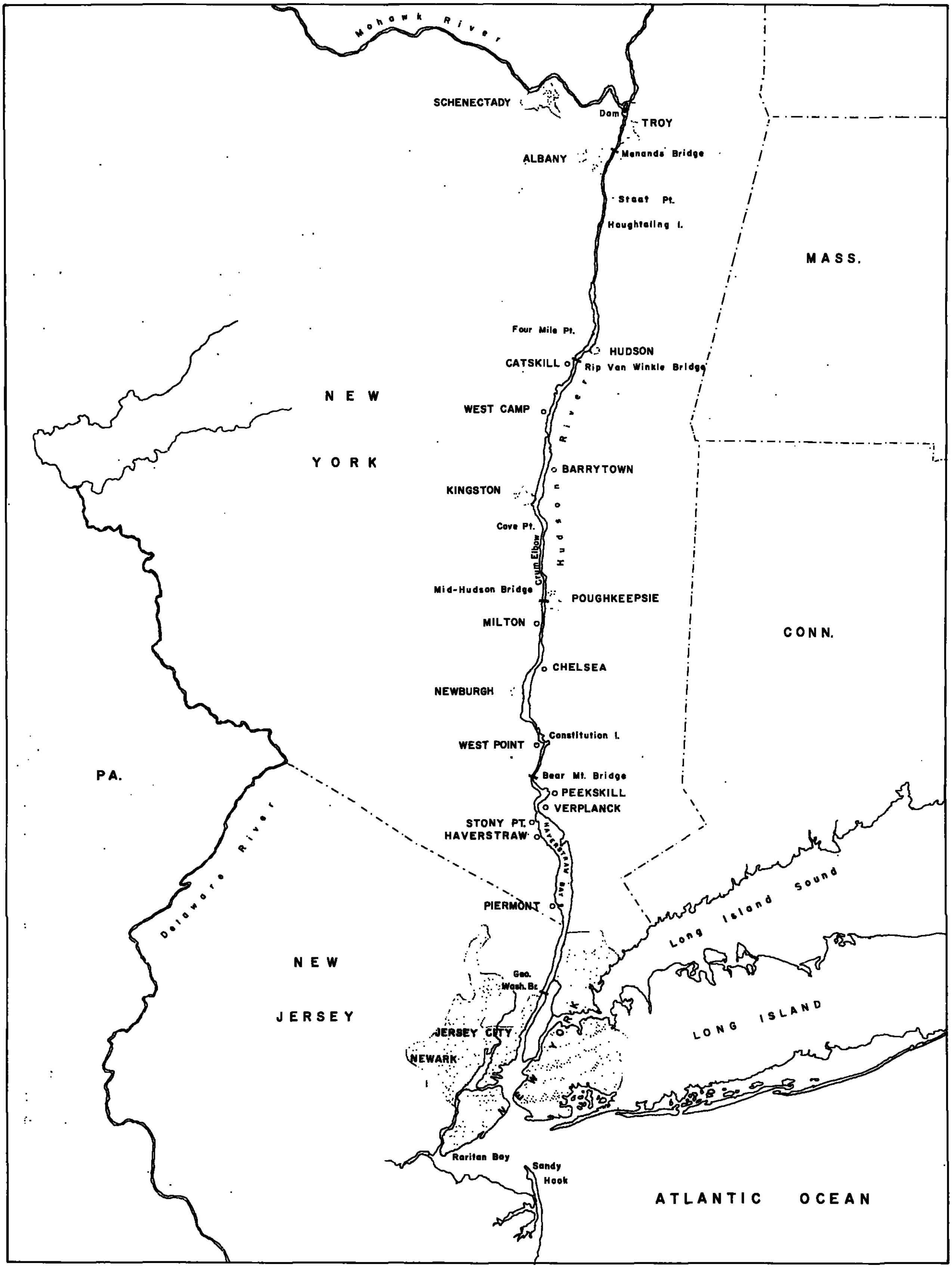

FIGURE 1.—Hudson River from Troy to the Atlantic Ocean.

mum of 2.09°/₀₀ (unpublished data, U. S. Fish and Wildlife Service and New York Department of Health).

The shad is the largest member of the family Clupeidae in the United States. It is anadromous, usually ascending streams in the spring of the year to spawn. Shad begin their run into the Hudson River the last of March or the first of April, and the run is usually over by the end of June. The bulk of the catch is made in a 6- or 7-week period. The adult shad normally do not die after spawning, and if they survive natural and fishing hazards they return to spawn in successive years.

The average number of eggs laid per female is approximately 250,000 (Lehman 1953). Eggs are about 3 mm. in diameter, are nonadhesive, and are deposited free in the water. After the eggs absorb water, their specific gravity is slightly greater than that of water and they sink to the bottom and are carried along by river and tidal currents.

On the basis of egg sampling by Cable (New York Conservation Department, 1943), the present major spawning area in the Hudson River appears to be between Port Ewen and Coxsackie, with the greatest concentration of eggs occurring just below the town of Catskill. The eggs hatch into a larval stage in 6 to 8 days at 17° C., and in another 4 or 5 days at the same temperature develop into their final form (Leim 1924). The young shad stay in the river until October or November, attaining a length of from 3 to 5 inches, and then migrate to sea.

The shad fishery in the Hudson was at a low level of production during the early years of the century (fig. 2) and continued at a low level until 1934. Then, contrary to the general trend of the shad fishery along the Atlantic coast, production increased tremendously and for the next 10 years the catches equaled those of the best years on record. After 1945 a decline set in, and at the present time the catch is nearing the previous low level of production.

Gill nets are the principal type of commercial gear used in the Hudson River shad fishery. Haul seines and other miscellaneous gear account for small catches, but these are inconsequential compared to the gill-net landings. There is no sport fishery.

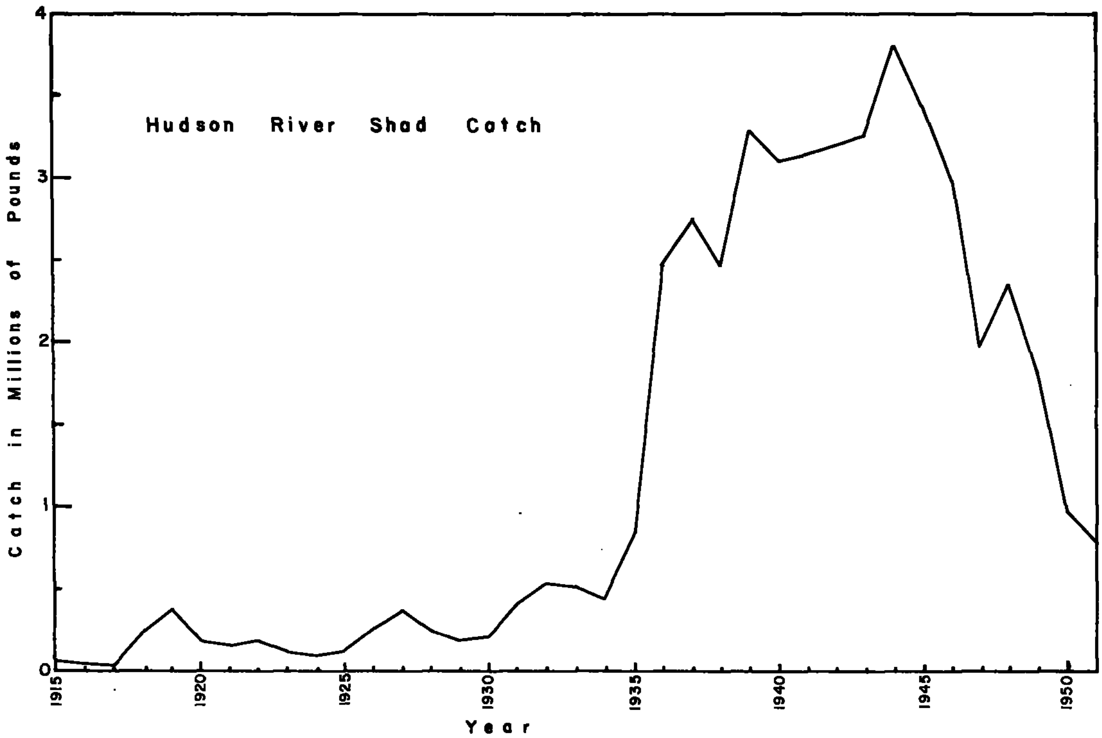

FIGURE 2.—Hudson River shad catch, 1915 through 1951. (Statistics from U. S. Fish and Wildlife Service, 1915–49; from New York and New Jersey conservation agencies, 1950–51.)

The gill nets are operated as drift nets and stake nets, and because of the physical character of the river the fishery can be divided into three natural classifications, New Jersey stake-net, New York stake-net, and New York drift-net areas. In the lower section of the river, which is bounded by both New York and New Jersey, stake gill nets are used almost exclusively. Nearly all of these are set and operated from the New Jersey side of the river and are licensed by the State of New Jersey. For an occasional net that extends beyond the middle of the river into New York waters, a license from New York is required for that portion of the net in New York.

The nets in this area are suspended from long poles, spaced about 30 feet apart, which are driven into the river bottom. These nets are usually fished only on the flood tide. The fish are removed just before high slack water, and the net is removed or fastened above water level until the next low slack water occurs. Because of navigational difficulties in the lower part of the river, the U. S. Army Corps of Engineers since 1940 has designated areas and lengths of nets that can be used so that channels for shipping are unobstructed. These nets are installed and operated during the shad season only.

In Haverstraw Bay, shad fishing is accomplished mainly by means of stake gill nets. These are set in shallow areas of the bay. Since the river velocity is not so great here as in the lower part, the nets in Haverstraw Bay can be fished on both the flood and ebb tides. Because of the greater width of the river, however, stake nets in Haverstraw Bay occupy a smaller proportion of the river width than the stake nets below, and catch fewer fish per net.

Above Haverstraw Bay and extending to the city of Hudson, the fishing is done almost entirely by drift gill nets. These are placed in the river during flood or ebb tides from skiffs usually carrying two men, and are set so that the net will not encounter snags or other obstructions during the drift. The nets are usually removed from the water at slack tide and hauled into the skiffs. Fishing is carried out at night if the water is clear,

TABLE 1.—*Hudson River shad catch and units of gear fished annually in New York, 1915–49*

[Data from U. S. Fish and Wildlife Service]

Year	Drift gill nets			Stake gill nets			Haul seines			Caught incidentally		Total New York catch	
	Number of nets	Catch		Number of nets	Catch		Number of nets	Catch		Number of fish	Pounds	Number of fish	Pounds
		Number of fish	Pounds		Number of fish	Pounds		Number of fish	Pounds				
1915	79	11, 333	47, 333				2	62	298	211	933	11, 606	48, 564
1916	76	7, 536	31, 670				3	191	1, 008	60	245	7, 787	32, 923
1917	213	9, 535	34, 420				13	1, 080	3, 924			10, 615	38, 344
1918	272	61, 583	214, 196				15	1, 821	6, 406			63, 404	220, 602
1919	359	75, 060	296, 259				12	1, 441	5, 047			76, 501	301, 306
1920	190	37, 821	150, 658				10	1, 871	7, 057			39, 692	157, 715
1921	159	27, 991	101, 465				5	747	2, 603	210	815	28, 948	104, 883
1922	133	34, 763	123, 469				5	1, 348	4, 855			36, 111	128, 324
1923	110	27, 245	93, 503				2	669	2, 100	722	2, 260	28, 636	97, 863
1924	95	22, 002	70, 159				2	625	1, 760	187	600	22, 814	72, 519
1925	90	32, 509	104, 063	13	1, 144	3, 644	4	825	2, 375	90	277	34, 568	110, 359
1926	96	61, 625	184, 059	11	4, 544	14, 443	8	6, 963	20, 102			73, 312	219, 183
1927	123	85, 174	283, 041				5	4, 337	15, 023	473	1, 629	89, 984	299, 693
1928	118	53, 477	169, 557	16	4, 100	14, 291	2	2, 350	6, 640	1, 152	3, 693	61, 079	-194, 181
1929	104	43, 430	149, 328	10	2, 550	8, 567						45, 980	157, 895
1930	105	44, 817	148, 372	14	3, 979	15, 298				445	1, 334	49, 241	165, 004
1931	104	92, 353	303, 563	15	9, 975	33, 795	2	1, 270	3, 815	445	1, 438	104, 043	342, 611
1932	110	107, 753	347, 354	10	13, 032	48, 950	2	535	1, 350	38	100	121, 358	397, 754
1933	118	96, 411	314, 693	14	8, 300	31, 293	2	576	1, 670	1, 655		105, 287	347, 656
1934	126	102, 281	302, 900	14	1, 142	3, 500	10	1, 020	3, 000		4, 800	106, 098	314, 200
1935	281	137, 487	434, 500				28	3, 592	10, 200	2, 898	8, 600	143, 977	453, 300
1936	124	253, 562	683, 800	551	42, 299	133, 100	14	7, 884	16, 800	269	700	304, 014	834, 400
1937	185	279, 780	932, 600	26	7, 110	23, 700	15	5, 900	19, 700			292, 790	976, 000
1938	232	283, 700	946, 000	301	4, 470	14, 900	18	3, 480	11, 600			291, 650	972, 500
1939	230	442, 291	1, 442, 600	139	4, 302	14, 200	13	18, 062	59, 600			464, 655	1, 516, 400
1940	145	270, 390	865, 400	380	130, 446	416, 400	12	4, 970	15, 900			405, 806	1, 297, 700
1941	146	257, 112	822, 800	129	156, 603	513, 600	6	1, 422	4, 600			415, 137	1, 341, 000
1942	125	275, 463	805, 200	353	166, 416	485, 600	8	995	2, 900	381	1, 100	443, 255	1, 294, 800
1943	155	368, 786	1, 032, 600	78	219, 481	592, 000	13	4, 223	11, 400	1, 331	4, 000	593, 821	1, 640, 000
1944	128	351, 500	1, 056, 000	317	188, 700	566, 900	12	9, 400	28, 300			549, 600	1, 651, 200
1945	173	358, 315	1, 072, 700	122	.314, 535	941, 200	10	16, 633	48, 800	9, 507	28, 600	698, 990	2, 091, 300
1946	189	283, 500	849, 600	155	192, 000	574, 000	18	7, 700	23, 300			483, 200	1, 446, 900
1947	231	162, 000	602, 800	148	82, 917	307, 100	35	11, 590	42, 900	1, 242	4, 600	257, 749	957, 400
1948	223	203, 178	612, 400	155	147, 396	443, 700	37	22, 010	65, 500			372, 584	1, 121, 600
1949	191	135, 694	441, 500	102	71, 835	264, 000	43	13, 030	43, 300			220, 559	748, 800

but if the water is turbid, fishing is also done during the day. All the river above the New Jersey stake-net area is entirely within New York State, and licenses are issued by that State for shad fishing in Haverstraw Bay and above. In recent years little or no fishing has been done between the city of Hudson and the dam at Troy.

Most of the shad catch in the New York section of the river is made by fishermen holding special shad licenses good only for the legal shad-fishing season extending from March 15 to June 15 each year. A small part of the catch is made by fishermen holding regular gill-net licenses which are valid throughout the year for other species of fish in addition to shad.

STATISTICS OF THE FISHERY

The U. S. Fish and Wildlife Service and its predecessor, the Bureau of Fisheries, have published yearly statistics of the Hudson River shad fishery in Fishery Statistics of the United States and in Fishery Industries of the United States. From 1915 through 1949, these reports give the numbers and pounds of shad caught, as well as the amount and kinds of gear making the catch. The data are presented in tables 1 and 2.

Also available are the New York Conservation Department's annual reports listing the total shad catches made by New York fishermen in the Hudson River, the number of licenses and catch by special stake and drift gill net licenses first issued in 1924, and the number of regular gill-net licenses issued each year. There is no way of determining at the present time how many of the regular gill-net licenses were used to fish for shad or what their shad catches were. We have therefore presented here only the data for the special gill-net licenses. These are shown in table 3. These data were furnished by the New York Conservation Department from original material in files and contain several corrections of small errors found in previously published data.

TABLE 2.—*Hudson River shad catch and units of gear fished annually in New Jersey, and total catch for New York and New Jersey, 1915–49*

[Data from U. S. Fish and Wildlife Service]

Year	Drift gill nets			Stake gill nets			Total New Jersey catch		Total Hudson River catch, New York and New Jersey	
	Number of nets	Catch		Number of nets	Catch		Number of fish	Pounds	Number of fish	Pounds
		Number of fish	Pounds		Number of fish	Pounds				
1915	...	...	...	7	4,249	20,104	4,249	20,104	15,855	68,668
1916	...	...	...	3	1,500	7,250	1,500	7,250	9,287	40,173
1917	...	...	...	2	1,400	5,040	1,400	5,040	12,015	43,384
1918	...	...	...	1	3,999	14,000	3,999	14,000	67,403	234,602
1919	...	...	...	14	13,800	73,668	13,800	73,668	90,301	374,974
1920	...	...	...	10	9,623	42,129	9,623	42,129	49,315	199,844
1921	...	...	...	8	6,500	25,920	6,500	25,920	35,448	130,803
1922	...	...	...	8	12,225	46,862	12,225	46,862	48,336	175,186
1923	...	...	...	5	6,450	23,865	6,450	23,865	35,086	121,728
1924	...	...	...	4	5,980	21,850	5,980	21,850	28,794	94,369
1925	...	...	...	4	4,300	13,975	4,300	13,975	38,868	124,334
1926	...	...	...	4	11,150	46,237	11,150	46,237	84,462	265,420
1927	...	...	...	7	20,300	58,362	20,300	58,362	110,284	358,055
1928	...	...	...	7	17,950	52,050	17,950	52,050	79,029	246,231
1929	...	...	...	5	10,500	38,850	10,500	38,850	56,480	196,745
1930	...	...	...	7	12,200	41,500	12,200	41,500	61,441	206,504
1931	...	...	...	4	21,900	72,000	21,900	72,000	125,943	414,611
1932	...	...	...	6	38,000	132,000	38,000	132,000	159,358	529,754
1933	1	150	524	13	49,000	170,500	49,150	171,024	154,437	518,680
1934	...	...	...	14	35,360	123,800	35,360	123,800	141,458	438,000
1935	...	...	...	26	116,003	394,100	116,003	394,100	259,980	847,400
1936	...	...	...	672	393,211	1,633,500	393,211	1,633,500	697,225	2,467,900
1937	1	1,000	3,000	87	584,400	1,753,200	585,400	1,756,200	878,190	2,732,[illegible]00
1938	1	70	200	65	420,079	1,494,500	420,149	1,494,500	711,799	2,467,000
1939	1	1,014	5,000	47	517,597	1,549,300	518,511	1,754,300	983,166	3,270,700
1940	4	11,941	49,700	55	512,525	1,767,000	524,466	1,816,700	930,272	3,114,400
1941	2	812	3,100	55	517,609	1,789,400	518,421	1,792,500	933,558	3,133,500
1942	2	1,293	4,800	47	580,651	1,886,300	581,944	1,891,100	1,025,199	3,185,900
1943	2	2,123	7,450	40	525,493	1,577,900	527,616	1,585,350	1,121,437	3,225,350
1944	3	2,318	8,700	41	640,203	2,149,500	642,521	2,158,200	1,192,121	3,809,400
1945	4	(1)	8,700	84	(1)	1,377,200	(1)	1,385,900	...	3,477,200
1946	...	...	...	182	437,689	1,525,243	437,689	1,525,243	920,889	2,972,143
1947	...	...	...	154	282,121	1,024,392	282,121	1,024,392	539,870	1,981,792
1948	6	500	1,500	92	338,513	1,231,300	339,013	1,232,800	711,597	2,354,400
1949	14	16,865	51,156	161	257,678	917,414	274,543	978,570	495,102	1,727,370

[1] Not available.

TABLE 3.—*Number of licenses issued and shad catch for special gill nets in New York State, 1924–51*

Year	Number of licenses	Catch in pounds	Year	Number of licenses	Catch in pounds
1924	97	55,546	1938	261	922,285
1925	[1] 98	87,700	1939	254	1,384,527
1926	99	165,920	1940	216	1,268,723
1927	136	226,388	1941	231	1,322,521
1928	129	146,241	1942	220	1,278,064
1929	122	100,798	1943	230	1,606,751
1930	121	91,025	1944	263	2,025,811
1931	120	195,293	1945	242	2,167,540
1932	123	246,995	1946	357	1,749,193
1933	146	224,582	1947	366	1,021,617
1934	144	249,174	1948	357	1,229,641
1935	140	425,332	1949	315	1,064,854
1936	162	623,122	1950	295	471,068
1937	200	901,585	1951	215	423,473

[1] No record; estimated.

Since 1940 the New York Conservation Department has differentiated between the numbers and catches by special drift-net licenses and special stake-net licenses. These are presented in table 4.

Beginning in 1937, the New Jersey Board of Fish and Game Commissioners, later the Division of Fish and Game, has published in its annual report various data relating to the Hudson River shad fishery. These data include the number and pounds of shad landed, the number of nets and boats used, and the number of men engaged in the fishery. The shad landings agree closely with those shown for New Jersey in table 2. Unfortunately, the data given for the number of nets used in the fishery in the New Jersey reports refer to number of nets owned by the fishermen (since 1947, number licensed) and not to the actual number of stake nets fished during the season; hence they cannot be used for determining fishing effort.

TABLE 4.—*Special drift and stake net licenses issued, and catch by each type of net in New York State, 1940–51*

Year	Total number of licenses	Drift gill nets		Stake gill nets	
		Number of licenses	Catch, in pounds	Number of licenses	Catch, in pounds
1940	216	153	917,665	63	351,058
1941	231	146	822,778	85	499,743
1942	220	132	804,687	88	473,377
1943	230	133	1,015,137	97	591,614
1944	263	159	1,110,155	104	915,656
1945	242	150	1,080,188	92	1,087,352
1946	357	231	891,885	126	857,308
1947	366	235	571,130	131	450,487
1948	357	219	661,333	138	568,308
1949	315	189	403,521	126	661,333
1950	295	172	239,866	123	231,202
1951	215	125	280,020	90	143,453

An analysis of the data in tables 1 and 2 for the purpose of combining catch and effort data for all gear for all parts of the river has disclosed some irregularities which we have been unable to reconcile with known facts. Beginning with 1936, the numbers of stake gill nets operating in New York, as shown in table 1, are unusually high on alternate years. The numbers of special gill-net licenses issued by New York during the same period, as shown in table 3, do not show these fluctuations, and neither do the total number of licenses issued for regular and special gill-net licenses as shown in the New York Conservation Department's annual reports.

In addition to these discrepancies, the number of stake nets operated in New Jersey in 1936 is listed as 672. Since the area in which stake nets can be set in that part of the Hudson River bounded by New Jersey is only about 16 miles in length, and since by law the nets must be 1,500 feet apart, there can be a maximum of approximately 56 stake nets in the river at any one time. It is probable that the figure of 672 is a typographical error, but the numbers listed for the New Jersey stake nets for 1937 and from 1945 through 1948 also are unreasonably large. It may be possible that the figures for the latter years were erroneously recorded as the number of nets owned, rather than the number of stake nets set in the river. Since none of the original data are available from which to check these figures, we have viewed the data in tables 1 and 2 with suspicion, especially for the amount of gear used after 1935.

During the field seasons of 1950 and 1951 there was ample opportunity to observe the various types of gear and their operation. It was found that the few drift gill net operators in the New Jersey area fished very irregularly and hence no measure of their fishing effort was available for past years. The same was true of the haul seines operated in the New York area. On the other hand, the special drift gill net and stake gill net operators in New York, and the stake gill net operators in New Jersey, usually fished all season, or at least through the peak of the season, if they fished at all. It was therefore necessary to limit this study to those types of gear. As these nets usually catch more than 95 percent of all the shad caught in the Hudson, little error is introduced by disregarding the catch and effort of the other types of gear.

In compiling a table of catch and effort data for the Hudson River shad fishery we have used the U. S. Bureau of Fisheries and the U. S. Fish and Wildlife Service statistics as shown in tables 1 and 2, for the years 1915 through 1935 for the

State of New Jersey, and for 1915 through 1923 for New York State, since these are the only data available. From 1924 through 1951 we have used the New York special gill-net license and catch data for New York State since these appeared to be the most accurate. The number of special gill-net licenses issued in 1925 was not available, so this was estimated.

The total number of stake nets operated in the New Jersey section of the Hudson River in 1935 is listed as 26 in Fishery Industries of the United States (U. S. Bureau of Fisheries, 1938). In the breakdown by counties, however, the number of stake nets listed for Bergen County is 15 and there is none listed for Hudson County (the only other county bordering the Hudson River), and so we have used 15 stake nets as perhaps being more nearly correct. For the years 1936 through 1951 there are no published records of the number of stake nets operating in the New Jersey area of the river. Fortunately, the Corps of Engineers has made a survey of this fishery each year since 1938 in connection with the regulation of the channels of the Hudson River, and through correspondence they have supplied us with the number of nets operating each year from 1938 through 1951. We have used these data along with the catches of shad given in reports of the Fish and Wildlife Service (tables 1 and 2), since they agree closely with data for the same period obtained from the New Jersey Fish and Game Department. The numbers of stake nets fished in New Jersey in 1950 and 1951 were verified by our field crew while working on the river. The only years for which usable effort data were not available for New Jersey were 1936 and 1937. We have estimated these as indicated in table 5, after talking with fishermen, fish buyers, and others, and believe that they are approximately correct figures. These data, taken from the several sources mentioned, as shown in table 5 are the Hudson River catch and effort statistics used in the analyses in this report.

Since 1915, New York has instituted closed weekends, also called "lift periods," as a conservation measure, during which shad fishing is not permitted. From 1915 through 1917 the weekly closure was 2½ days, but the closure applied only to fishing downriver as far as Verplanck Point. After 1917 it included all the river under the supervision of New York. We have assumed that fishing effort was uniform throughout the New York part of the Hudson River and have corrected the closure on a geographical basis by using only 2 days of closure for the first 3 years to make these closures more comparable to those after 1917. The State of New Jersey did not establish closed days until 1940, and since then by cooperative action the number of closed days each year in the two States has been uniform. The number of days of closure each year by each State is shown in table 5.

TABLE 5.—*Hudson River shad catch, units of gear, and closed days for drift and stake gill nets, by years, 1915–51*

[Data from various sources]

Year	New York			New Jersey			Total catch, in pounds
	Number of gill nets	Catch, in pounds	Closed days per week	Number of stake gill nets	Catch, in pounds	Closed days per week	
1915	79	47,333	[2] 2	7	20,104	0	67,437
1916	76	31,670	[2] 2	3	7,250	0	38,920
1917	213	34,420	[2] 2	2	5,040	0	39,460
1918	272	214,196	2½	1	14,000	0	228,196
1919	359	296,259	2½	14	73,668	0	369,927
1920	190	150,658	2½	10	42,129	0	192,787
1921	159	101,465	2½	8	25,920	0	127,385
1922	133	123,469	2½	8	46,862	0	170,331
1923	110	93,503	2½	5	23,865	0	117,368
1924	97	55,546	2½	4	21,850	0	77,396
1925	[1] 98	87,700	2½	4	13,975	0	101,675
1926	99	165,920	2½	4	46,237	0	212,157
1927	136	226,388	2½	7	58,362	0	284,750
1928	129	146,241	2½	7	52,050	0	198,291
1929	122	100,798	2½	5	38,850	0	139,648
1930	121	91,025	2½	7	41,500	0	132,525
1931	120	195,293	2½	4	72,000	0	267,293
1932	123	246,995	2½	6	132,000	0	378,995
1933	146	224,582	2½	13	170,500	0	395,082
1934	144	249,174	2½	14	123,800	0	372,974
1935	140	425,332	2½	15	394,100	0	819,432
1936	162	623,122	2½	[1] 36	1,633,500	0	2,256,622
1937	200	901,585	2½	[1] 36	1,753,200	0	2,654,785
1938	261	922,285	2½	52	1,494,500	0	2,416,785
1939	254	1,348,527	2½	43	1,754,300	0	3,102,827
1940	216	1,268,723	1½	46	1,767,000	1½	3,035,723
1941	231	1,322,521	1½	46	1,789,400	1½	3,111,921
1942	220	1,278,064	1½	48	1,886,300	1½	3,164,364
1943	230	1,606,751	0	32	1,577,900	0	3,184,651
1944	263	2,025,811	0	38	2,149,500	0	4,175,311
1945	242	2,167,540	1½	35	1,377,200	1½	3,544,740
1946	357	1,749,193	1½	52	1,525,243	1½	3,274,436
1947	366	1,021,617	1½	52	1,024,392	1½	2,046,009
1948	357	1,229,641	1½	44	1,231,300	1½	2,460,941
1949	315	1,064,854	1½	46	972,857	1½	2,037,711
1950	295	471,068	1½	40	520,958	1½	992,026
1951	215	423,473	3	25	331,523	3	754,996

[1] No record; estimated.
[2] In 1915, 1916, and 1917, the 2½ days closure extended only down to Verplanck Point; see text.

In this study the catches are listed in pounds of fish caught rather than numbers of fish because most of the landings are recorded in pounds. Where numbers of fish are given in published records these have usually been empirically converted to pounds by some such figure as 2.5 pounds each for male shad and 3.5 pounds for females. Since many of the published landings do not list the weight by sexes, it is impossible at this time to calculate the numbers of each sex for all years with the data available. While it might be more desirable to have the figures in numbers of fish rather than pounds, the magnitude of the changes in the catch would not differ greatly, because the conversion factors remain about the same.

TAGGING STUDIES

During the shad runs of 1950 and 1951, shad were tagged at the mouth of the Hudson River to estimate the total shad population entering the river. Captures of shad for tagging were made by drifting a commercial gill net below the New Jersey stake-net area. Fishing was carried out uniformly throughout the season in 1951, so that as nearly as possible the tags were affixed in proportion to the number of shad migrating upstream. Petersen disk tags were used and were affixed just below the dorsal fin. During the fishing season the shad fishermen were interviewed each week to collect the tags they had recovered and to obtain a record of their daily catches. Catch-record or log books were furnished to a representative number of those fishermen who normally kept no records of their shad catch. With few exceptions, the fishermen cooperated wholeheartedly in this study.

In 1950 the tagging experiment was late in getting started, and it was not possible to canvass all of the fishermen for tag returns. For this reason a sample was selected to provide an estimate of the ratio of tagged fish to fishermen's total catch. This ratio in turn was applied to the total catch reported to the State agencies to obtain estimates of the fishing rate and total population in pounds. This appears to be a valid method since the log-book records showed that fishing effort was uniform throughout the 6- or 7-week season when the bulk of the catch is made. The information obtained is as follows:

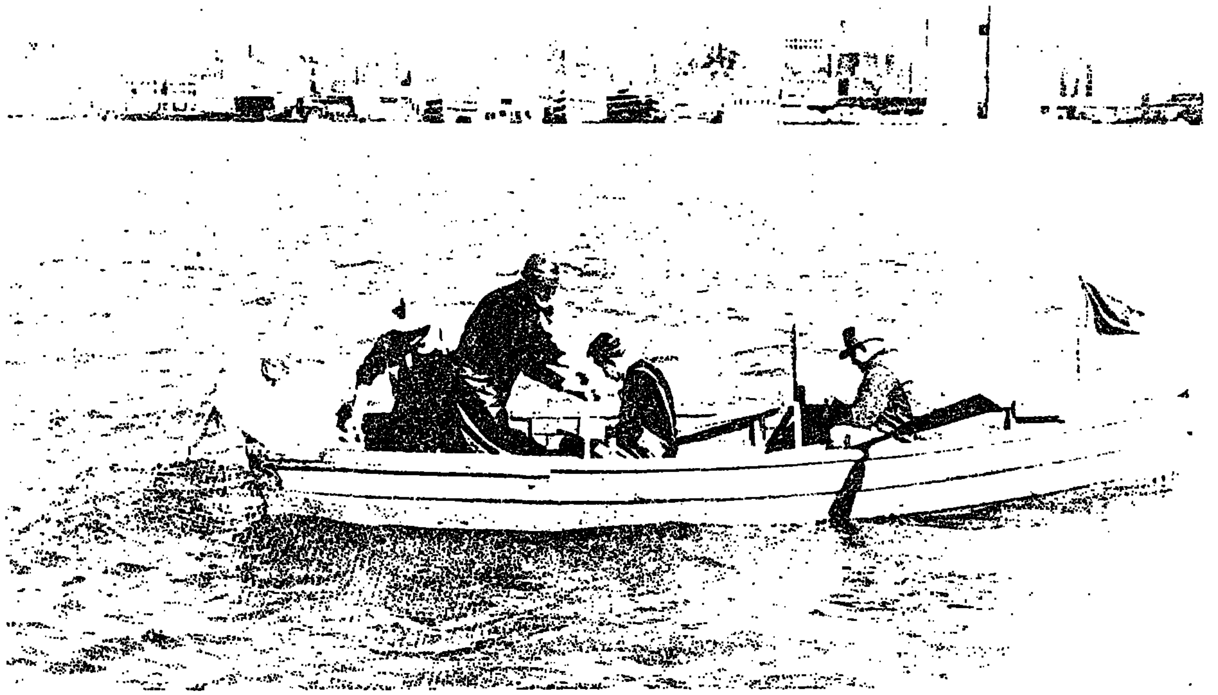

FIGURE 3.—Tagging shad near the mouth of the Hudson River.

Number of shad tagged at mouth of river, 1950	242
Number of tagged shad recovered by sample fishermen	57

Quantity of shad caught by sample fishermen ---------- pounds--	355, 000
Total quantity of shad caught by all fishermen (C) ---------- pounds--	992, 000
Estimated number of tagged fish recovered by all fishermen $\left(=57 \times \frac{992{,}000}{335{,}000}\right)$ ----------	159
Estimated fishing rate $\left(=\frac{159}{242}\right)$ ----- percent--	65. 7
Estimated total size run $\left(N=\frac{C}{0.657}\right)$ pounds-	1, 510, 000
Limits of confidence (95 percent) pounds---- [1] 1,383, 000 to 1, 619, 060	
Estimated escapement (E) -------- pounds----	518, 000

[1] Chapman 1948; Schaefer 1951.

During the shad run of 1951, shad were tagged throughout the fishing season. The fishermen were fully aware of our program and were canvassed regularly, and in almost every instance cooperated enthusiastically. We were able to use the total catch and total tags recovered, in our analysis, and hence we feel that the 1951 experiment gave us more reliable information than was obtained in 1950. The data from the 1951 experiment are as follows:

Number of shad tagged at mouth of river------	524
Number of tagged shad recovered in entire river fishery----------	241
Best estimate of fishing rate $\left(=\frac{241}{524}\right)$ percent-	46
Total catch (C) ---------- pounds--	755, 000
Estimated size of run (N) ---------- do----	1, 641, 000
Limits of confidence (95 percent) pounds---- [1] 1, 530, 000 to 1, 740, 000	
Estimated escapement (E) --------- pounds----	886, 00

[1] Chapman 1948; Schaefer 1951.

In a study of shad on the Umpqua River, Gharrett (1950) found that Petersen-disk type tags made the tagged fish more susceptible to capture because the tag became entangled in the gear; hence, a disproportionate number of tags were returned, and a correction for tag selectivity was necessary. We have examined this matter of tag selectivity in our tagging program by comparing the proportion of tags recovered in the New Jersey fishing area with that in the New York area. It can be reasoned that if the tagged fish were more susceptible to capture than untagged fish, there should be a higher proportion of tagged shad in the New Jersey catch than in the New York catch. Chi-square tests of the actual and expected numbers of tags returned from each area disclosed that there was no significant difference between the proportions of tagged fish in the catches of the two areas in either year. We have therefore concluded that a correction for tag selectivity was not necessary in our tagging experiment.

The reason for the difference between Gharrett's results and ours probably can be ascribed to the fact that in the Umpqua River the legal minimum stretched-mesh size of nets is 6 inches while in the Hudson River the stretched-mesh size ranges from 5 inches to 5¾ inches and averages about 5½ inches. An examination of shad caught in the Hudson River showed that in most cases the fish were gilled just behind the head, and only rarely did the mesh slip back to the dorsal fin where the tag might be a factor in retention of the fish by the net. The reverse was probably true in the Umpqua River where the mesh size was larger.

Other known sources of error which may affect the accuracy of population estimates based on tagging experiments are mortality of shad resulting from the tagging operations, shedding of the tags before capture, and natural mortality by predation, disease, or other hazard. Since our experiments were of such short duration, errors caused by predation and disease should be small. Mortalities attributable to the tagging procedure were considered, but are difficult to determine. During the tagging operations the condition of the shad after tagging was noted on the tagging records. When shad were caught during rough weather they were in extremely poor condition as a result of being jerked up and down in the gill net by wave action. Because of this it was thought at the time that all fish caught and tagged on some days would surely die after being returned to the water. No difference in the percentage or time of return was found in these tagged shad, however, when compared with tagged shad which appeared to be in good condition when returned to the river. Although proof is lacking, it appeared from these comparisons that Hudson River shad had remarkably good recuperative ability and that mortality from the tagging operations was not great. It is of course possible that some delayed action such as fungus growths on the fish from handling might have caused equal mortality on both groups of fish, but evidence of such was not found on any of the tagged fish examined after capture. In any event we have used the results of the tagging data as the best estimates of the populations available.

COMPARISON OF GEAR EFFICIENCY

The number of net-fishing days fished each season by New York and New Jersey fishermen was calculated by multiplying the number of nets fished by the number of days of fishing in a 6-week season each year (table 6). In these calculations we have limited the season to 6 weeks, since about 90 percent of the fish are caught during that period and practically all of the fishermen are fishing regularly. At the beginning and end of the season, fishing is done by only a few fishermen, and some of them fish intermittently, but when the run arrives in volume almost all of the fishermen fish consistently until the run diminishes.

From the records of catches made by the New York special drift and stake gill nets (table 4), it would appear that these two types of gear may not be comparable, so far as capturing shad is concerned. The stake nets caught slightly more shad per net on the average than did the drift nets. This may result because the stake nets get their catch first, while the drift nets fish on what is left. Since records for numbers and catch by each type are not available for the years before 1940, in this study the two types of gear are combined.

To obtain the total fishing-effort figure for the whole river, it is necessary to combine the fishing effort of both the New York and the New Jersey fishing gear. It can be seen from table 5 that the New Jersey nets catch more shad per net than do the New York nets. Actually, they average about six times as much per net. Part of this difference undoubtedly results from the fact that the New Jersey nets are located nearer the mouth of the river than the New York nets, which fish only on those shad that escape the New Jersey fishery. It is necessary, therefore, to determine whether the greater catches by New Jersey gear reflect a greater fishing power by that gear.

It can be seen that theoretically the first net set in the river has a better chance of catching fish than the next one upstream, and the second net a better chance than the third. In this paper, however, we are concerned only with the average fishing power of the New Jersey nets as compared with the average fishing power of the New York nets.

We are able to estimate the average fishing power of nets fished in New Jersey and New York by using a technique described by Fredin (1954). A comparison of the fishing powers of the nets enables us to standardize fishing effort. First, we will define "fishing power" to mean the ability of 1 unit of gear to capture a certain fraction of the fish present in the river in 1 day's fishing. We will call this fraction p, and it should be constant for a given type of gear in a given location within a season and between seasons provided (1) there is no change in design or manipulation of the nets to make them more or less efficient as a means of catching shad, (2) fishing effort is uniform in a given season, and (3) the migration pattern of shad is similar each year.

Stevenson's description of the Hudson River shad fishery illustrates that fishing was carried out in the same manner in 1896 as is done now. The use of outboard motors rather than oars has lessened the work of the fishermen in later years, but the time and manner in which the nets are fished and the nets themselves appear to have changed little. Nylon nets rather than linen were used by so few fishermen in 1950 and 1951 that our results would not be biased because of them, should nylon prove to be more efficient.

Since the shad-fishing season is short, most of the fishermen earn their livelihood by other occupations and either take their vacations or lay off work to fish. Once the run begins, they usually fish every legal day possible during the short season. Fishing effort, therefore, tends to be uniform during the main part of the run. Since there is no evidence that the shad, once in the river, behave or migrate differently in different seasons, it has been assumed that the above-listed provisions hold for the Hudson River shad fishery.

All the shad which enter the river are susceptible to capture by the New Jersey nets. If we consider the run as a whole and denote its size by N, the number of pounds of shad removed in 1 net-day's fishing in the New Jersey area is pN. The number of pounds remaining after 1 net-day's fishing is qN, where $q=1-p$. The fish escaping the first net-day are susceptible to capture the second net-day during which pqN are removed. The number of pounds removed and the number remaining after successive net-days are as follows:

Fishing period:	*Pounds removed*	*Pounds remaining*
First net-day	pN	qN
Second net-day	pqN	q^2N
Third net-day	pq^2N	q^3N
Fourth net day	pq^3N	q^4N
...	.	.
...	.	.
...	.	.
$n-1$ net-day	$pq^{n-2}N$	$q^{n-1}N$
nth net-day	$pq^{n-1}N$	q^nN

After the nth net-day of fishing by the New Jersey nets, there remain q^nN pounds of fish. This represents the escapement from the New Jersey nets. From our tagging experiment of 1951, we found that the total population (N) entering the river was 1,641,000 pounds. The catch (C) by the New Jersey nets as shown in table 5 was 332,000 pounds (to the nearest thousand pounds); hence the escapement (E) from the New Jersey nets was 1,309,000 pounds. Now, since the escapement (E) equal q^nN, as shown above, $q^n=\frac{E}{N}$, and since there were 600 net-days fished in New Jersey in 1951 (table 6), we have for the New Jersey nets:

$$q^{600}=\frac{1{,}309{,}000}{1{,}641{,}000}$$

from which we find that $q=0.999623$ and therefore $p=0.000377$. This is an estimate of the average fishing power of a New Jersey net that fishes 1 day. In 1 net-day of fishing a New Jersey net removes an average of 0.0377 percent of the fish available.

TABLE 6.—*Net-days fished in 6-week season for New York and New Jersey, and total catch, by years, 1915–51*

Year	Number of nets fished		Number of fishing days		Number of net-days		Total catch, in thousands of pounds
	New York	New Jersey	New York	New Jersey	New York	New Jersey	
1915	79	7	30	42	2, 370	294	67
1916	76	3	30	42	2, 280	126	39
1917	213	2	30	42	6, 390	84	39
1918	272	1	27	42	7, 344	42	228
1919	359	14	27	42	9, 693	588	370
1920	190	10	27	42	5, 130	420	193
1921	159	8	27	42	4, 293	336	127
1922	133	8	27	42	3, 591	336	170
1923	110	5	27	42	2, 970	210	117
1924	97	4	27	42	2, 619	168	77
1925	98	4	27	42	2, 646	168	102
1926	99	4	27	42	2, 673	168	212
1927	136	7	27	42	3, 672	294	285
1928	129	7	27	42	3, 483	294	198
1929	122	5	27	42	3, 294	210	140
1930	121	7	27	42	3, 267	294	133
1931	120	4	27	42	3, 240	168	267
1932	123	6	27	42	3, 321	252	379
1933	146	13	27	42	3, 942	546	395
1934	144	14	27	42	3, 888	588	373
1935	140	15	27	42	3, 780	630	819
1936	162	36	27	42	4, 374	1, 512	1, 257
1937	200	36	27	42	5, 400	1, 512	2, 655
1938	261	52	27	42	7, 047	2, 184	2, 417
1939	254	43	27	42	6, 858	1, 806	3, 103
1940	216	46	33	33	7, 128	1, 518	3, 036
1941	231	46	33	33	7, 623	1, 518	3, 112
1942	220	48	33	33	7, 260	1, 584	3, 164
1943	230	32	42	42	9, 660	1, 344	3, 185
1944	263	38	42	42	11, 046	1, 596	4, 175
1945	242	35	33	33	7, 986	1, 155	3, 545
1946	357	52	33	33	11, 781	1, 716	3, 274
1947	366	52	33	33	12, 078	1, 716	2, 046
1948	357	44	33	33	11, 781	1, 452	2, 461
1949	315	46	33	33	10, 395	1, 518	2, 038
1950	295	40	33	33	9, 735	1, 320	992
1951	215	25	24	24	5, 160	600	755

The shad that escape the New Jersey nets are available to the New York nets. We can determine the fishing power of a net that fishes in the New York area by the same method that we used for determining p for the New Jersey nets. Of the 1,309,000 pounds of shad available to the New York nets, 423,000 pounds were removed in 5,160 net-days (tables 5 and 6). The escapement from the New York nets as shown in the 1951 tagging data was 886,000 pounds which is the total escapement from the entire Hudson River fishery in 1951.[1] From these data:

$$q^{5160}=\frac{886{,}000}{1{,}309{,}000}$$

from which $q=0.999924$ and $p=0.000076$.

The estimated fishing power (p) of an average New Jersey net was found to be 0.000377. Dividing this by 0.000076 (the fishing power of an average New York net) gives:

$$\frac{0.000377}{0.000076}=4.96$$

Or in other words, the fishing power of an average New Jersey stake net is 4.96 times that of an average New York net.

Now that a measure of the fishing power of the nets in each area has been obtained, it is possible to convert the total fishing effort for the Hudson River to standard units. A standard-fishing-unit (s. f. u.) day will be defined as 1 New York net that fishes 1 day. A New Jersey net-day, therefore, is equivalent to 4.96 standard-fishing-unit days, or about 5 s. f. u. days. The second column of table 7 has been computed by multiplying the total net-days in New Jersey (table 6) by 5 and adding the net-days for New York (table 6). These are entered in table 7 as total s. f. u. days for each year. The catch is also given in thousands of pounds and the catch per unit of effort for each year is given as catch per s. f. u. day in pounds. These data are shown graphically in figure 4.

It can be seen that fishing effort, with the exception of that for 1919, was comparatively low

[1] Strictly speaking, the spawning population may be slightly larger than this, since some fish may spawn, or partially spawn, before being caught, but these are few in number, as the fishermen usually stop fishing when many spawned-out fish are caught, since they have low market value.

between 1915 and 1936. In 1936 the large catches attracted more fishermen, and fishing effort increased that year and remained high until 1950. Since it was apparent in the latter year that the shad runs had declined from their previous abundance, both New York and New Jersey increased the closed period to 3 days (table 5) as a conservation measure to reduce fishing intensity. This in itself greatly reduced the fishing effort, and the restriction to 4 days' fishing per week discouraged

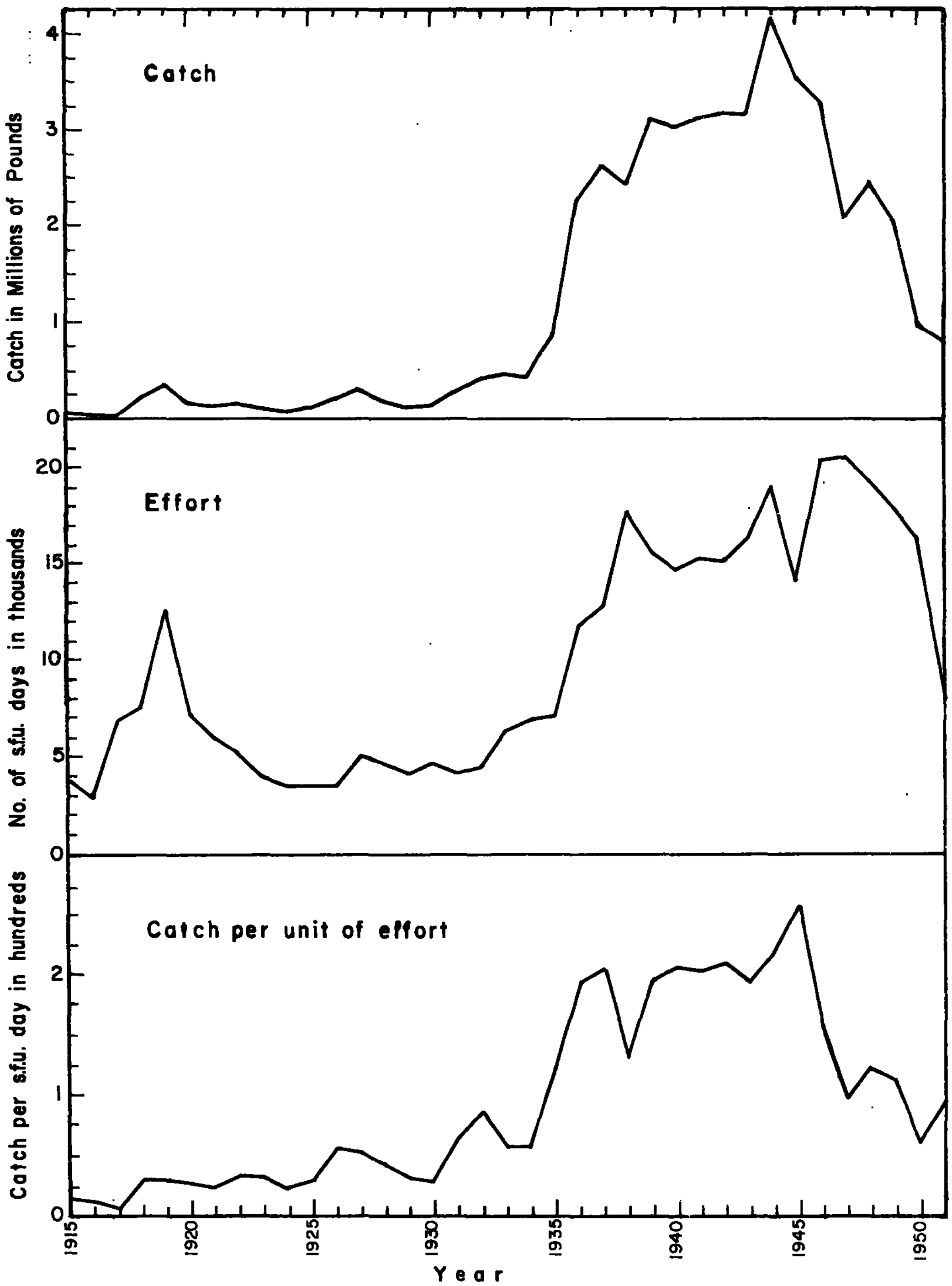

FIGURE 4.—Hudson River shad catch, total fishing effort of New York special gill nets and New Jersey stake nets, and catch per unit of effort, from 1915 through 1951.

some fishermen from operating that year. As a result the fishing effort in 1951 dropped to half that of the previous year.

The 1950 tagging experiment, although starting after the fishing season began and not carried out in as comprehensive a manner as in 1951, and therefore not considered to be so accurate, does give an independent estimate of the fishing power of the nets in the two areas. In that experiment the total population was estimated at 1,510,000 pounds, of which New Jersey caught 521,000 pounds (table 5), and the escapement from the New Jersey nets was 989,000 pounds. As shown in table 6, the number of New Jersey net-days of fishing in 1950 was 1,320, thus,

$$q^{1320}=\frac{989,000}{1,510,000}$$

and $q=0.999679$ and $p=0.000321$.

TABLE 7.—*Total fishing effort, total catch, and catch per unit of effort, by years, 1915–51*

Year	Total s. f. u. days	Total catch	Catch per s. f. u. day
		1,000 pounds	*Pounds*
1915	3, 840	67	17
1916	2, 910	39	13
1917	6, 810	39	6
1918	7, 554	228	30
1919	12, 633	370	29
1920	7, 230	193	27
1921	5, 973	127	21
1922	5, 271	170	32
1923	4, 020	117	29
1924	3, 450	77	22
1925	3, 486	102	29
1926	3, 513	212	60
1927	5, 142	285	55
1928	4, 953	198	40
1929	4, 344	140	32
1930	4, 737	133	28
1931	4, 080	267	65
1932	4, 581	379	83
1933	6, 672	395	59
1934	6, 828	373	55
1935	6, 930	819	118
1936	11, 934	2, 257	189
1937	12, 960	2, 655	205
1938	17, 967	2, 417	134
1939	15, 888	3, 103	195
1940	14, 718	3, 036	206
1941	15, 213	3, 112	204
1942	15, 180	3, 164	208
1943	16, 380	3, 185	194
1944	19, 026	4, 175	219
1945	13, 761	3, 545	258
1946	20, 361	3, 274	161
1947	20, 658	2, 046	99
1948	19, 041	2, 461	129
1949	17, 985	2, 038	113
1950	16, 335	992	61
1951	8, 160	755	92

As before, the fish that escaped the New Jersey nets were available to the New York nets. In 9,735 net-days of fishing, the New York nets took 471,000 pounds of shad, and the escapement from the New York nets, which is the ultimate spawning population, was 518,000 pounds. From this,

$$q^{9735}=\frac{518,000}{989,000}$$

from which $q=0.999934$ and $p=0.000066$. In 1950 the relative power of an average New Jersey net as compared with an average New York net was $\frac{0.000321}{0.000066}=4.86$. This figure is less than the figure obtained from the 1951 tagging data, but as previously mentioned our field work was late in starting in 1950 and we therefore place more reliance on the 1951 estimate. The two estimates, however, are not widely divergent, and the two years, 1950 and 1951, represent extremes both in the amount of fishing effort expended and in weather conditions which might have affected the movements of fish. We have therefore felt justified in using the numeral 5 to relate the efficiency of the New Jersey stake gill nets to the New York gill nets.

Since the fishing power of a New York gill net was taken as the standard unit of measure of fishing effort, the fraction of fish that is removed in 1 standard-fishing-unit day is the same as that previously found for the fishing power of the New York gill net, that is, $p=0.000076$. The total standard-fishing-unit days, by seasons from 1915 through 1950, have been calculated (table 7). Now pN is the number of pounds of shad removed in the first s. f. u. day, pqN is the number of pounds removed the second s. f. u. day, pq^2N is the number of pounds removed the third s. f. u. day, and so forth. It can be seen that in any season the total catch is as follows:

$$C=pN+pqN+pq^2N+pq^3N+ \cdot\cdot\cdot\cdot\cdot +pq^{n-1}N$$

Factoring,

$$C=pN(1+q+q^2+q^3+ \cdot\cdot\cdot\cdot\cdot q^{n-1})$$

Since the expression in the parentheses is a geometric progression, its sum can be expressed by the formula

$$\frac{1-q^n}{1-q}.$$

Substituting, we have:

$$C=pN\frac{(1-q^n)}{(1-q)}$$

and, therefore,

$$N=\frac{C}{p\left(\frac{1-q^n}{1-q}\right)}$$

or, since

$$p=(1-q),$$

$$N=\frac{C}{1-q^n}.$$

Since p and q are assumed constant from year to year, and C (catch) and n (s. f. u. days) are known (table 7), we can estimate the total population for each year from 1915 through 1950, by the above formula. These estimates, along with the estimated annual fishing rate and escapement, are shown in table 8. In figure 5 the total population, catch, and escapement (spawning population) are shown graphically.

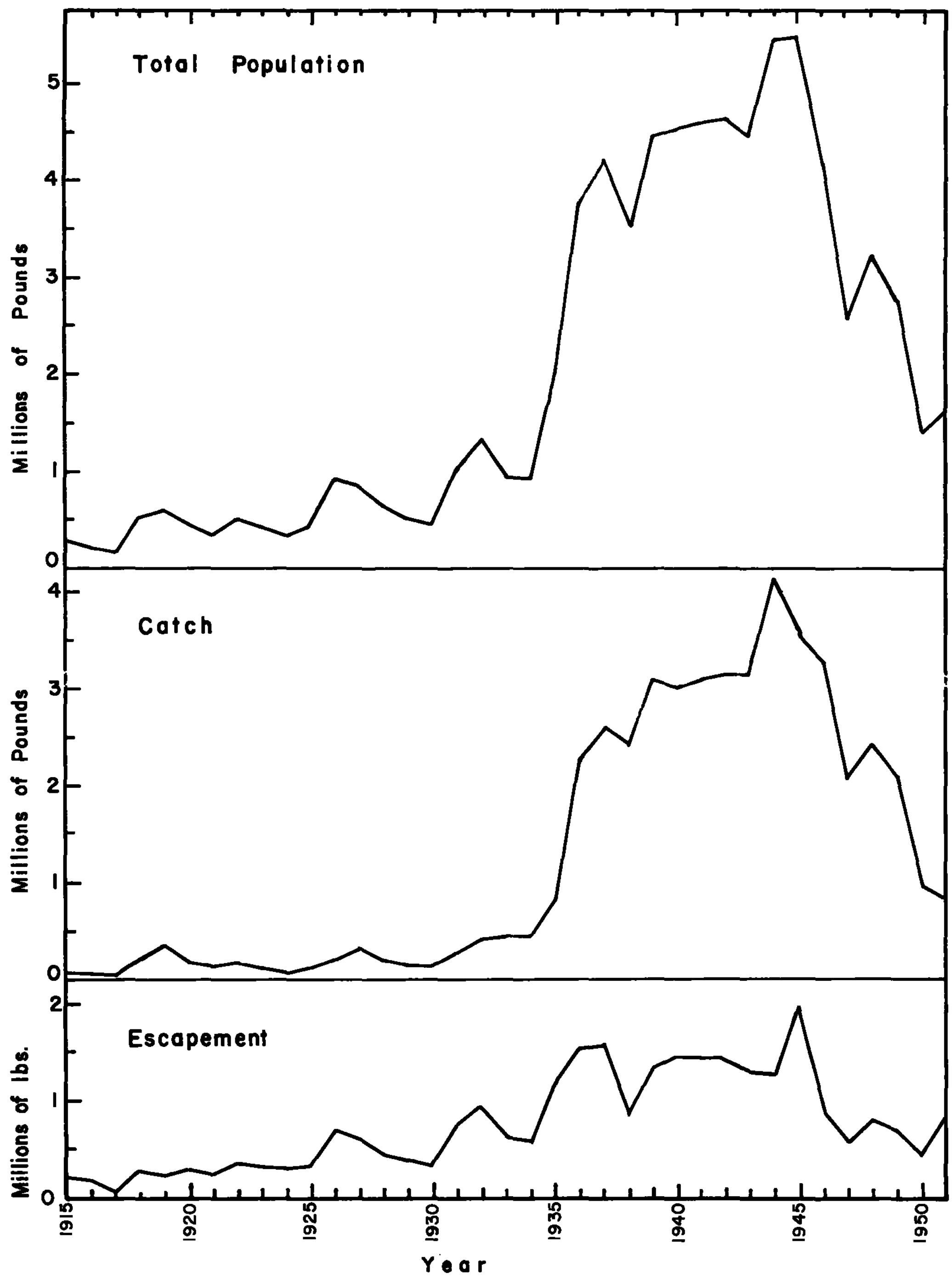

FIGURE 5.—Total calculated Hudson River shad population, catch, and escapement from fishery, from 1915 through 1951.

CALCULATION OF POPULATIONS, 1915–50

It has been demonstrated by several authors that under certain conditions it is possible to estimate the total population present for one of two years, provided the total population is known for the other year and total catch and effort are known for both (Baranov 1918; Ricker, 1940, 1944, 1948). It is possible to use the method presented by these authors, using instantaneous fishing rates (Ricker 1948), to calculate the total Hudson River shad population for each year from 1915 through 1950 with the data presented in table 7 and the 1951 tagging data. As has been shown by Fredin (1954) it is also possible to estimate total populations for years for which fishing effort and catch are available, if the total population and effort are known for one year, by the procedure used here to determine the fishing power of the New York and New Jersey nets. We have used Fredin's method since it does not involve the concepts of instantaneous mortality rates, the theory of which is more difficult for many readers to follow. The results using either method will be practically identical.

TABLE 8.—*Catch, effort, fishing rate, and calculated total population and escapement of shad in the Hudson River, by years, 1915–51*

Year	Catch	Effort	Fishing rate	Total population	Escapement
	1,000 pounds	*s. f. u. days*	*Percent*	*1,000 pounds*	*1,000 pounds*
1915	67	3, 840	25. 2	266	199
1916	39	2, 910	19. 8	197	158
1917	39	6, 810	40. 2	97	58
1918	228	7, 554	43. 5	524	296
1919	370	12, 633	61. 5	601	231
1920	193	7, 230	42. 1	458	265
1921	127	5, 973	36. 3	349	222
1922	170	5, 271	32. 9	517	347
1923	117	4, 020	26. 2	446	329
1924	77	3, 459	23. 0	334	257
1925	102	3, 486	23. 2	440	338
1926	212	3, 513	23. 3	908	696
1927	285	5, 142	32. 2	884	599
1928	198	4, 593	31. 2	634	436
1929	140	4, 344	28. 0	500	360
1930	133	4, 737	30. 1	442	309
1931	267	4, 080	26. 6	1, 006	739
1932	379	4. 581	29. 3	1, 294	915
1933	395	6, 672	39. 6	997	602
1934	373	6, 828	40. 3	925	552
1935	819	6, 930	40. 8	2, 008	1, 189
1936	2, 257	11, 934	59. 4	3, 796	1, 539
1937	2, 655	12, 960	62. 5	4, 249	1, 594
1938	2, 417	17, 967	74. 3	3, 253	836
1939	3, 103	15, 888	69. 9	4, 437	1, 334
1940	3, 036	14, 718	67. 2	4, 521	1, 485
1941	3, 112	15, 213	68. 4	4, 552	1, 440
1942	3, 164	15, 180	68. 3	4. 634	1, 470
1943	3, 185	16, 380	71. 0	4, 484	1, 299
1944	4, 175	19, 026	76. 3	5, 473	1, 298
1945	3, 545	13, 761	64. 7	5, 480	1, 935
1946	3, 274	20, 361	78. 6	4, 167	893
1947	2, 046	20, 658	79. 0	2, 588	542
1948	2, 461	19, 041	76. 3	3, 225	764
1949	2, 038	17, 985	74. 3	2, 741	703
1950	992	16, 335	70. 9	1, 398	406
1951	755	8, 160	46. 0	1, 639	884

It should be noted that in calculating the population and fishing rate for 1950 by the above method, the estimated fishing rate is 70.9 percent, whereas from our tagging experiment the fishing rate was estimated to be 65.7 percent. The population calculated from the 70.9-percent fishing rate is well within the limits of confidence as shown previously in the 1950 tagging data, and considering the limited nature of the tagging work the agreement appears about as good as might be expected.

FACTORS ASSOCIATED WITH FLUCTUATIONS IN HUDSON RIVER SHAD RUNS

Many factors have been suggested as the cause of the decline of the Hudson shad fishery at the turn of the century, its subsequent dramatic recovery beginning in 1936, and the decline beginning in 1945. These include ship traffic in the river, pollution, hatchery operations, dredging, overfishing, and weather. These are difficult to evaluate on the basis of catch data alone (the only figures previously available) since it is known that the total catches of fish depend not only upon the number of fish present, but also upon the amount of effort expended to catch the fish. The calculations in the previous section permit a direct comparison between factors suspected of affecting the runs and the total populations entering the river each year.

Before any relations can be evaluated we must take into account the age of the fish in the run, since the effect of a factor that influences the spawning population, eggs, or young shad of any one year will not appear until the fish of that year-class return to the river as adults and enter the fishery.

Scales were taken from a sample of the commercial catch of shad during the field work in 1950 and in 1951. These were read for total age, age at first spawning, and number of times the fish had previously spawned, for each sex, using the method developed by Cating (1953). The results are shown in table 9. The readings for the two years were then combined by weighting each year's catch in numbers according to sex and gear used. The results are expressed in percentages in table 10. It can be seen that shad which are 4, 5, 6, and 7 years old make up the bulk of the catch, that these fish enter the river for the first time predominantly at 4 and 5 years of age, and that during

TABLE 9.—*Distribution, by age at capture, by age at first spawning, and by number of times previously spawned, as read from scale samples, of shad caught in the New Jersey stake nets and the New York special gill nets in 1950 and 1951*

Group	Number of specimens							
	New Jersey stake nets				New York special gill nets			
	1950 sample [1]		1951 sample [2]		1950 sample [3]		1951 sample [4]	
	Females	Males	Females	Males	Females	Males	Females	Males
Total age at capture:								
2 years	0	1	0	0	1	7	0	0
3 years	2	3	3	1	5	20	1	10
4 years	43	12	89	53	66	17	141	70
5 years	70	18	58	49	130	53	117	109
6 years	31	18	37	45	89	87	80	184
7 years	6	11	24	61	32	56	51	212
8 years	2	5	15	29	10	8	19	88
9 years	2	2	9	8	5	4	5	17
Over 9 years	7	0	9	0	3	0	3	1
Total	163	70	244	246	341	252	417	691
Age at first spawning:								
2 years	0	1	0	0	1	9	0	5
3 years	4	8	3	4	9	44	5	104
4 years	66	32	103	126	124	128	256	440
5 years	74	22	89	88	177	61	135	123
6 years	17	7	41	28	30	10	18	18
Over 6 years	2	0	8	0	0	0	3	1
Total	163	70	244	246	341	252	417	691
Number of times previously spawned:								
None	108	28	166	91	177	48	231	108
1 time	34	12	35	41	98	72	59	97
2 times	9	24	18	56	50	82	80	179
3 times	5	4	15	42	6	43	38	199
4 times	1	1	5	13	6	6	6	86
5 times	5	1	2	3	2	1	2	20
6 times	0	0	1	0	1	0	1	1
7 times	1	0	2	0	1	0	0	1
Total	163	70	244	246	341	252	417	691

[1] Total 1950 catch: 152,216 females, 74,712 males.
[2] Total 1951 catch: 85,145 females, 58,511 males.
[3] Total 1950 catch: 36,625 females, 42,601 males.
[4] Total 1951 catch: 35,625 females, 59,375 males.

this period at least 49 percent of the shad in our sample were entering the river for the first time. Most of the shad caught that were over 5 years old entered the river for the first time as 4- or 5-year-olds and escaped the fishery until caught in later years.

It would be highly desirable to have representative scale samples from each year's catch so that the age compositions could be determined and age classes could be assigned to the year of their origin. Scale samples were not available for all the years covered by this study, so it was necessary to use the averages shown in table 10 as the best estimate obtainable of the age classes, or groups that make up the catch for each year.

FISHING EFFORT

Many men connected with the shad fishery of the Hudson River, including the fishermen themselves, believe that overfishing is the cause of the recent decline in the Hudson River catches. The drift netters in the upper fishing areas blame the stake-net operators in the lower areas. The

TABLE 10.—*Percentage distribution, by age at capture, by age at first spawning, and by number of times previously spawned, as read from scale samples, of 2,424 shad in the commercial catch of 1950 and 1951*

[Weighted according to catch by sex, gear, and year]

Group	Percentage in group
Total age at capture:	
3 years	2
4 years	23
5 years	29
6 years	22
7 years	14
8 years	6
9 years	2
Over 9 years	2
Total	100
Age at first spawning:	
2 years	+
3 years	6
4 years	47
5 years	36
6 years	10
Over 6 years	1
Total	100
Number of times previously spawned:	
None	49
1 time	19
2 times	18
3 times	10
4 times	2
5 times	2
6 times	+
7 times	+
Total	100

New York stake-net operators blame the New Jersey stake-net operators below them, while the New Jersey operators blame the ocean pound nets or the New York drift netters because the latter fish on the spawning grounds. If the fish are caught before they spawn, and nearly all of them are, it makes no difference where they are caught. The run is diminished by the same amount.

In table 8 the estimated spawning escapement for each year is listed, as well as the total population entering the river each year. As previously shown, the catchable population of shad each year appears to be made up mainly of the progeny of shad which spawned 4 and 5 years earlier. The fish that escaped the fishery the previous year are very important (table 10), since 51 percent of the shad sampled had spawned previously. The effect that the escapement 5 years earlier, 4 years earlier, or 1 year earlier has on the population of any one year can be evaluated by multiple-regression analysis. This has been done.

TABLE 11.—*Regression of calculated populations* Y (N_i) *and escapement 5 years earlier* X_1 (E_{i-5}) *and 4 years earlier* X_2 (E_{i-4}) *and 1 year earlier* X_2 (E_{i-1})

Year i	X_1 (E_{i-5})	X_2 (E_{i-4})	X_3 (E_{i-1})	Y (N_i)	Year i	X_1 (E_{i-5})	X_2 (E_{i-4})	X_3 (E_{i-1})	Y (N_i)
1920	199	158	231	458	1936	739	915	1, 189	3, 796
1921	158	58	265	349	1937	915	602	1, 539	4, 249
1922	58	296	222	517	1938	602	552	1, 594	3, 253
1923	296	231	347	446	1939	552	1, 189	836	4, 437
1924	231	265	329	334	1940	1, 189	1, 539	1, 334	4, 521
1925	265	222	257	440	1941	1, 539	1, 594	1, 485	4. 552
1926	222	347	338	908	1942	1, 594	836	1, 440	4, 634
1927	347	329	696	884	1943	836	1, 334	1, 470	4, 484
1928	329	257	599	634	1944	1, 334	1, 485	1, 299	5, 473
1929	257	338	436	500	1945	1, 485	1, 440	1, 298	5, 480
1930	338	696	360	442	1946	1, 440	1, 470	1, 935	4, 167
1931	696	599	309	1, 016	1947	1, 470	1, 299	893	2, 588
1932	599	436	739	1, 294	1948	1, 299	1, 298	542	3, 225
1933	436	360	915	997	1949	1, 298	1, 935	764	2, 741
1934	360	309	602	925	1950	1, 935	893	703	1, 398
1935	309	739	552	2, 028	1951	893	542	406	1, 639

$$\hat{Y} = -558.18326 - 0.06055X_1 + 1.55549X_2 + 2.07915X_3$$

Tests of significance of regression coefficients:

$t_{b_1} = -0.1467$ d. f. = 28 $p > 0.5$

$t_{b_2} = 3.678$ d. f. = 28 $p < 0.01$

$t_{b_3} = 5.865$ d. f. = 28 $p < 0.01$

Analysis of variance

Source	d. f.	SS	MS
Total	32	264, 197, 481	....
Means	1	165, 524, 464	165, 524, 464
Regression	3	83, 838, 733	27, 946, 244
Error	28	14, 834, 284	529, 796

$$F = \frac{27,946,244}{529,796} = 52.749 \text{ with 3 and 28 d. f.} \qquad P < 0.01$$

$$R^2 = 1 - \frac{14,834,284}{264,197,481 - 165,524,464} = 0.8497 = 85 \text{ percent}$$

$R = 0.92$ $P < 0.01$

In table 11, the total estimated population (N) for each year (i) from 1920 to 1951 has been entered in column 5, and this is designated as Y. In the second column the estimated escapement 5 years earlier or E_{i-5} is listed; this column is designated as X_1. Columns 3 and 4 are similar except that they are the escapements 4 years earlier and 1 year earlier; they are designated as X_2 and X_3 respectively. Also shown in table 11 are the regression equation, an analysis of variance for the multiple regression, and the multiple correlation coefficient R. Both the F value and R value are highly significant at the 1-percent level, and it can be inferred that 85 percent of the variations in total populations studied can be accounted for by changes in the escapement 5 years, 4 years, and 1 year earlier.

It can be seen in table 11 that the regression coefficient for the escapement 5 years earlier (b_1) does not differ significantly from zero, while the other two are highly significant. This indicates that the escapement 1 year earlier and 4 years earlier produce the high correlation value shown. This is not what might be expected from the age analysis of the scales. Since the proportion of 4- and 5-year-old fish in the catch may vary in different years, especially with changes in fishing intensity, the data in table 10 were divided into two parts. These were the period from 1920 through 1934, when the population sizes were gradually increasing and fishing effort was comparatively low, and the period from 1935 through 1951, when population sizes increased rapidly and then declined, and fishing intensity for most of the years was high. Multiple-regression analyses were calculated for each of these sets of data. The regression equations, tests of significance of the regression coefficients, analyses of variance for the multiple regressions, and the multiple-correlation coefficients R, are as follows:

1920–34 data:

$$\hat{Y} = 97.670 + 0.95366X_1 + 0.04262X_2 + 0.58702X_3$$

$t_{b_1} = 2.078$ d. f. = 11 $p \sim 0.06$

$t_{b_2} = 0.104$ d. f. = 11 $p > 0.50$

$t_{b_3} = 0.106$ d. f. = 11 $p \sim 0.06$

Analysis of Variance

Source	d. f.	SS	MS
Total	15	8, 112, 492	....
Mean	1	6, 860, 049	....
Regression	3	856, 613	285, 538
Error	11	395, 830	35, 984

$F = 7.935$ d. f. = 3 and 11 $p < 0.01$

$R^2 = 0.684$

$R = 0.827$ $p < 0.01$

1935–51 data:

$$\hat{Y} = -742.061 - 0.50115X_1 + 1.16810X_2 + 1.90083X_3$$

$t_{b_1} = -0.894$ d. f. = 13 $p \sim 0.40$

$t_{b_2} = 1.962$ d. f. = 13 $p \sim 0.075$

$t_{b_3} = 3.761$ d. f. = 13 $p < 0.01$

Analysis of Variance

Source	d. f.	SS	MS
Total	17	256, 185, 929	....
Mean	1	230, 994, 248	....
Regression	3	15, 223, 774	5, 074, 591
Error	13	9, 967, 907	766, 762

$F = 6.618$ d. f. = 3 and 13 $p < 0.01$

$R^2 = 0.604$

$R = 0.772$ $p < 0.01$

It can be seen from the two sets of data that for both periods there is a highly significant correlation value R. Of further interest, however, is the fact that for the early set of figures the regression coefficient for the escapement 5 years earlier approaches significance at the 5-percent level, while that for the escapement 4 years before is not significant. The data for the later period show that the regression coefficient for the escapement 4 years earlier approaches significance while that for the escapement 5 years earlier does not. In other words the escapements the year before and 5 years before produced the high correlation for the early data while the escapements the year before and 4 years before produced the high correlation for the later data. This is what might be expected since, when the fishing effort is low and the runs are increasing, the catch of fish tends to be of older stock than when the fishing effort is high. Obviously, what is needed to prove the point for this particular case is scale samples from both periods. As was previously mentioned, samples are only available for some of the years during the latter period. We felt justified, therefore, in using the data in table 10, since these data are the best available, keeping in mind that more accurate analyses can be made when scale samples are available for every year.

Using the appropriate escapement data in the regression equation in table 11, we have predicted the total population for each year from 1920 through 1951. The predicted populations based on escapements are shown in table 12, along with the population estimates from table 8, which were calculated from catch and effort data and the tagging studies. These data are shown graphically in figure 6 which shows also the percentage difference between the two population estimates. The deviations from regression shown in table 12 and figure 6 represent changes in the total populations not accounted for by escapements. In other words, they reflect the effects of other factors.

TABLE 12.—*Comparison of calculated total runs with runs predicted from regression equation, by years. 1920–51*

Year	Calculated run N_i	Predicted run $\hat{Y}$	Deviation $N_i - \hat{Y}$	Year	Calculated run N_i	Predicted run $\hat{Y}$	Deviation $N_i - \hat{Y}$
1920	458	156	302	1936	3, 796	3, 292	504
1921	349	73	276	1937	4, 249	3, 523	726
1922	517	360	157	1938	3, 253	3, 578	−325
1923	446	505	−59	1939	4, 437	2, 996	1, 441
1924	334	524	−190	1940	4, 521	4, 537	−16
1925	440	305	135	1941	4, 552	4, 916	−364
1926	908	671	237	1942	4, 634	3, 640	994
1927	884	1, 380	−496	1943	4, 484	4, 522	−38
1928	634	1, 067	−433	1944	5, 473	4, 533	940
1929	500	858	−358	1945	5, 480	4, 290	1, 190
1930	442	1, 252	−810	1946	4, 167	5, 664	−1, 497
1931	1, 006	974	32	1947	2, 588	3, 230	−642
1932	1, 294	1, 620	−326	1948	3, 225	2, 509	716
1933	997	1, 878	−881	1949	2, 471	3, 962	−1, 221
1934	925	1, 152	−227	1950	1, 398	2, 175	−777
1935	2, 008	1, 720	288	1951	1, 639	1, 075	564

Records of the shad catches previous to 1915 are sketchy and will be discussed later. The figures that are available for the early years show good catches during the period from 1879 through 1901, after which there was a drastic decline.

Unfortunately, the only year for which we know the amount of gear used in making the catches is 1896—in the report of Stevenson (1899). In that paper the number of stake nets is listed as individual nets hung between poles rather than in rows of nets set in the river as has been done since 1915. In New Jersey there were 1,518 individual stake nets listed, and Stevenson states that on the average there were 25 or 30 stake nets to the row. On the basis of 30 nets to the row, there were about 50 rows of nets in the New Jersey section of the Hudson River similar to the nets listed for recent years. In addition, there were 12 rows of pole nets which are the same as stake nets except that the webbing is in one piece. This makes a total of approximately 62 nets equivalent to the stake nets used in recent records.

For New York, Stevenson lists 337 drift nets fishing for shad in the Hudson River and 1,099 of the individual stake nets. No figure is given of the number of nets to the row for the stake nets, but using the figure of 30 as given for the New Jersey stake nets, there would be about 33 stake nets in New York. In addition to these there were 2 pole nets, giving a total of 35 stake nets equivalent to those we have used in our previous calculations.

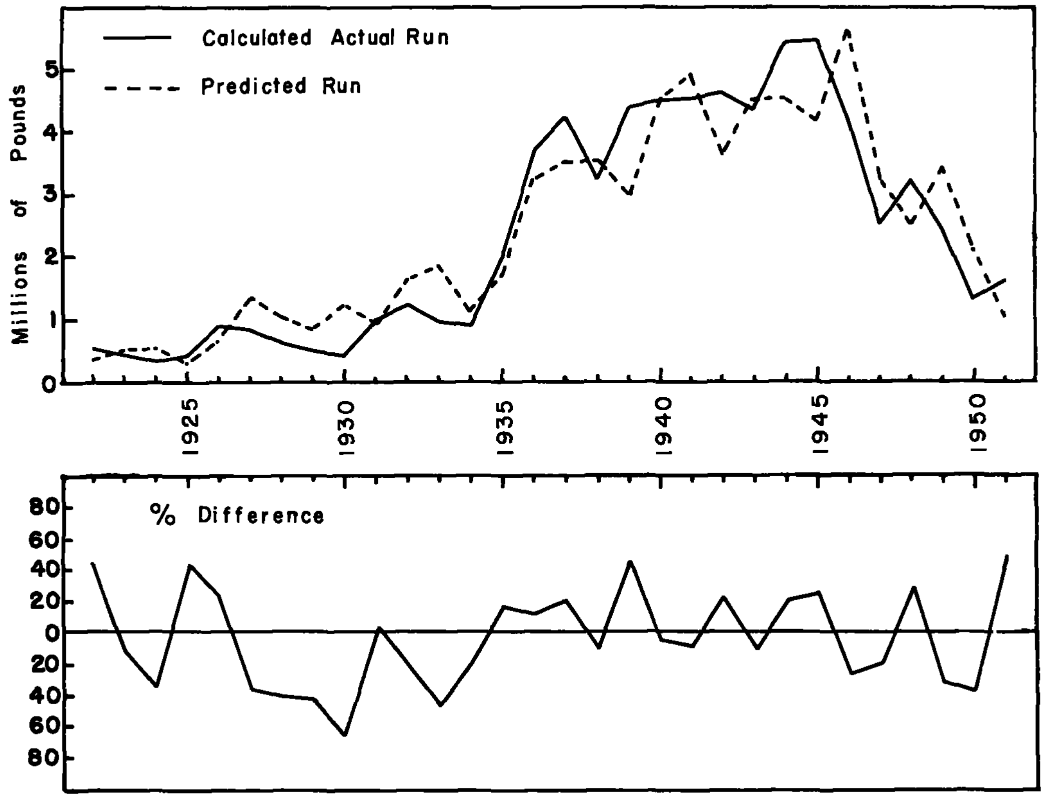

FIGURE 6.—Comparison of calculated actual Hudson River shad runs and predicted shad runs, and percentage difference between them.

The fishing power of the New Jersey stake nets has been shown to be equivalent to approximately 5 New York drift gill or stake nets. Therefore, there was a total of 722 ($62\times5+377+35$) standard fishing units of gear operating in the Hudson River in 1896. Stevenson states that fishing was closed 1½ days each week; therefore, 33 days were available for fishing during the 6-week season upon which we have based our calculations. This gives a total of 23,826 s. f. u. days for the fishing season. The catch by this gear was 519,853 shad which averaged about 4 pounds each (U. S. Fish and Wildlife Service, Fishery Statistics for 1945, p. 166) which gives a catch of approximately 2,079,412 pounds. Using the methods previously employed, the total population of shad in 1896 was estimated to have been 2,490,000 pounds, leaving a spawning population of 411,000 pounds. The fishing rate was therefore 83.5 percent.

The calculations for 1896 may be slightly in error since the conversion to gear equivalent to that used presently may not be strictly correct. The error should not be great, however, and the fishing rate of 83.5 percent is higher than any during the past 37 years as shown in table 8. If it is indicative of the fishing intensity at the turn of the century, the low productivity during the early 1900's probably resulted from too few shad being allowed to spawn.

It would appear from available data that the most important factor in the fluctuations in shad runs during the past 37 years, and possibly during earlier years, was the number of shad escaping to spawn each year. Other factors were investigated during the present study, however, to determine whether they had any influence on the shad runs, or whether they were the cause of the deviations from regression as shown in table 12.

STREAM FLOW

The water-discharge records of the Hudson River were examined to determine whether there was any correlation between stream flow and the size of shad runs. Discharge data were compiled for the Hudson River at Troy for each year from 1919 to 1948 from the records of the U. S. Geological Survey. These were computed by adding the Hudson River discharge at Mechanicville to the discharge of the Mohawk River which drains into the Hudson below Mechanicville. The Mohawk River discharges were recorded at Crescent Dam from 1919 to 1925, and at Cohoes from 1925 to 1948. Beginning in October 1948, the Hudson discharges at Troy were obtained directly from a gage at Green Island, just above the Troy Dam.

Figure 7 is a composite graph showing the water discharge for the Hudson River at Troy for the years 1919 to 1948. The discharges each year fluctuated greatly almost every month of the year except July, August, and September. In general, most of the high discharges occurred in March and April, but relatively high discharges occurred every month but August.

For a river the size of the Hudson, the most unusual situation brought out by an examination of the water records was the low flows occurring during the summer months. Every year, flows below 5,000 second-feet were recorded for part of the season, and during 1941 the flow was below 2,000 second-feet for 24 days. In this respect the Hudson River below Troy is not a river in the truest sense of the word, but a river valley into which the sea has been admitted by subsidence of the land, or an estuary. Tidal action, particularly during low flows, has more effect on the river velocity than does runoff.

It was considered that fluctuations in water discharge might directly affect the eggs or young shad while they were in the river, or indirectly affect them in some manner such as diluting or flushing out the pollutants in the river. To examine this possibility, multiple-regression analyses were made between the size of run of shad each year and the peak water discharges 4 and 5 years earlier for each of the months of April, May, and June for the years 1924 through 1951. No significant correlations were found. Similar multiple-regression analyses were made between the size of run each year and the average monthly discharges 4 and 5 years earlier for each of the months of May through July. Again no significant correlations were found. As previously shown, the size of run each year depends on the escapement of the previous year as well as on the progeny of the runs 4 and 5 years earlier. This would tend to obscure any correlation should it exist. It is not possible to make corrections in these calculations for the escapement in the previous year until scale samples are available for the years being checked so that the age composition of the runs can be determined. It was concluded that if variations in river discharge have

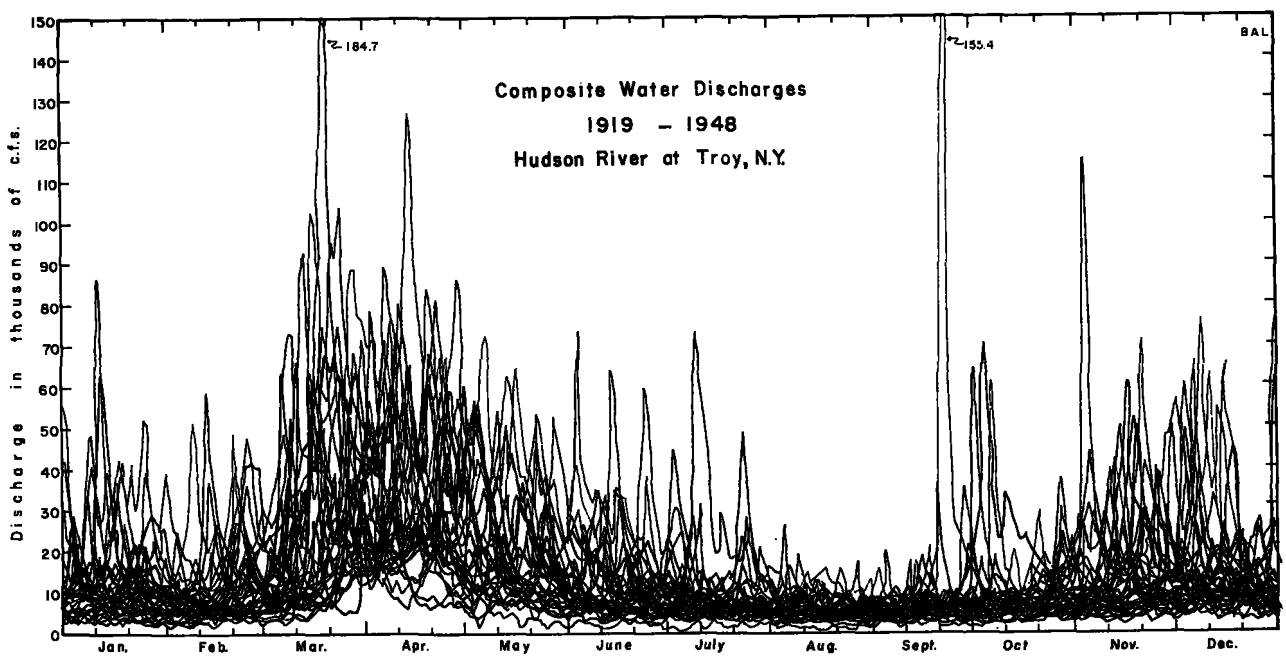

FIGURE 7.—Composite of Hudson River discharges at Troy, 1919 through 1948.

any effect on the shad runs the effect is obscured by other factors.

WATER TEMPERATURES

Water temperatures of the Hudson River at Poughkeepsie have been recorded for many years by the water works department of that city, which utilizes the Hudson River for its water supply. These temperatures are taken each day at 8 a. m. Many of the early records have been lost, but we were able to obtain the mean monthly temperatures from 1908 through 1919, and from March 1929 through 1949, from Thomas Cole, who was superintendent of the water-treatment plant before his retirement in 1949. The 1950 records were obtained at the Poughkeepsie water-treatment plant and are shown in figure 8. The monthly mean temperatures from March 1929 through 1950 are shown in table 13. The means of the monthly temperatures for these years are shown in figure 9, and the approximate time that the adults and young shad are in the river is also indicated.

The temperatures shown in table 13 and figures 8 and 9 are lower than mean daily temperatures since they were taken at 8 a. m. each day. Maximum and minimum daily temperatures were taken from April through August of 1951 and it was found that the greatest difference between maximum and minimum daily temperatures during this time was 7° F., while the average difference was 3.1° F. The average differences between the temperatures taken at 8 a. m. and the daily average of maximum and minimum was 1.4° F. It is probable that the mean temperatures as shown in table 13 and figures 8 and 9 during spring and summer should be approximately 1.4° higher to represent the average daily temperatures.

The shad runs in the Hudson River usually start around the first of April (fig. 9), at which time the interpolated average water temperature at 8 a. m. is about 40° F. In 1950, the temperature was 38° F. on April 1 (fig. 8). According to individual records of fishermen and landing reports (U. S. Fish and Wildlife Service, Fishery Products Report, 1938–51), the peak of the run, as judged from the catch, occurs between the middle of April and the middle of May, at which time the temperature averages 45° F. to 57° F. (table 13), but the temperature was colder than this in April 1950 (43° F. to 56° F., fig. 8). No conclusive data were obtained during this study as to the specific dates of spawning, but these probably occur primarily during the month of May in the Hudson River, at which time the fishermen obtain ripe fish and a few spawned-out fish. During this period the average 8 a. m. temperatures were between 51° F. and 62° F. (fig. 9). In 1950, they ranged between 45° F. and 60° F., and in 1951 (not shown) they were between 51° F. and 63° F. The daily average temperatures were probably

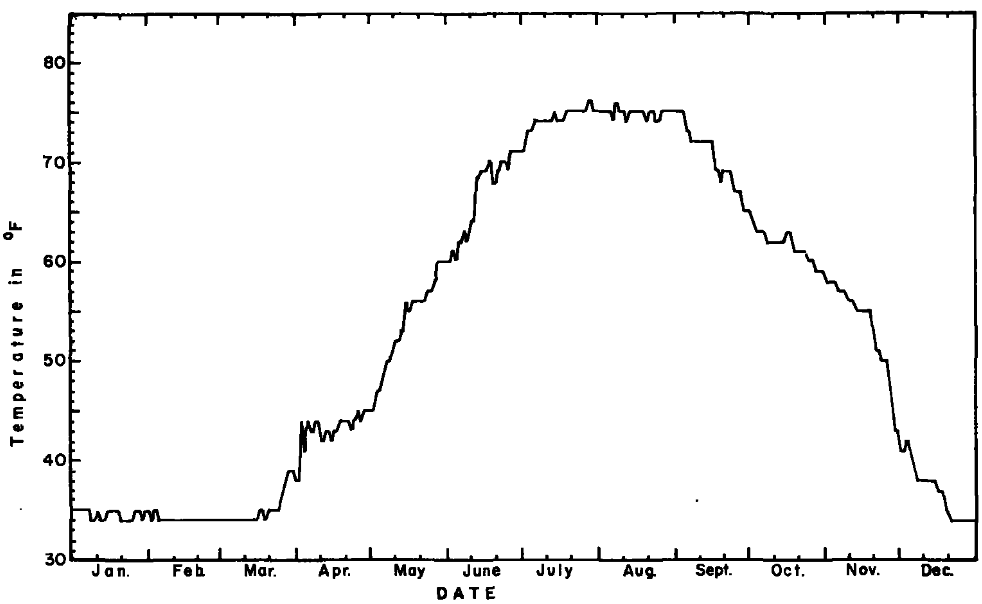

FIGURE 8.—Hudson River water temperatures at 8 a. m. at Poughkeepsie, for 1950.

about 1.4° F. higher than those listed, as previously explained. Massman (1952) has shown that in Virginia streams the greatest catches of shad eggs in plankton nets were at temperatures between 12° C. and 20° C. (53.6° F. and 68° F.). Cable (unpublished data) made good catches of shad eggs in plankton nets in the Hudson River at temperatures ranging from 57° F. to 68° F. during the last of May and first week of June in 1940 and 1941. Spawning had probably begun before she started sampling, and since she sampled during the afternoon and evening, the temperatures recorded may be near maximum for the day rather than average.

It is conceivable that variations in water temperature might affect the survival of eggs, larvae, or juveniles, and hence affect the size of the run 4 and 5 years later. No trends in water temperature could be found, however, which might have accounted for the great fluctuations in shad production, nor were any variations in average temperatures found that might have caused the devia-

TABLE 13.—*Monthly mean water temperatures of the Hudson River at Poughkeepsie, 1929–50*

[Temperatures in ° F.]

Year	January	February	March	April	May	June	July	August	September	October	November	December
1929				44.0	54.0	67.0	74.0	73.0	70.0	59.0	48.0	37.0
1930	33.0	33.0	36.0	43.5	55.0	65.0	74.0	75.8	71.7	63.7	50.4	34.9
1931	32.6	32.6	35.3	48.5	57.1	68.5	76.6	77.9	73.0	65.6	52.7	35.0
1932	34.3	33.6	34.2	42.7	56.1	67.3	73.3	75.8	72.5	60.5	46.3	34.5
1933	36.6	35.5	36.6	45.6	57.8	69.9	73.9	76.0	70.2	61.0	41.8	35.0
1934	33.0	33.0	33.0	42.6	55.5	65.8	72.2	71.5	66.4	57.8	46.4	35.0
1935	33.0	33.0	34.7	43.5	56.5	66.6	74.8	75.7	68.3	56.6	49.5	35.0
1936	33.0	33.0	36.6	43.4	58.8	68.9	75.6	77.4	71.2	60.5	44.0	34.0
1937	33.7	33.0	34.4	41.0	58.3	67.9	70.7	76.2	68.2	54.9	40.9	35.0
1938	33.0	34.0	36.5	47.0	59.9	68.3	74.1	76.8	68.0	56.2	49.2	35.6
1939	33.0	33.0	32.9	42.3	56.4	70.9	75.5	77.4	71.4	60.9	45.0	34.9
1940	33.0	33.0	34.0	40.0	58.0	70.0	75.0	77.0	70.0	61.0	47.0	37.0
1941	33.5	32.9	33.3	46.8	60.4	67.6	74.8	76.5	72.0	64.2	50.9	36.0
1942	33.6	34.0	37.0	45.4	59.0	70.4	75.6	77.1	72.1	59.2	47.3	35.6
1943	33.0	33.0	35.0	41.0	54.0	70.2	76.8	77.9	72.4	60.6	47.7	35.4
1944	33.4	35.1	36.0	40.4	57.7	68.9	76.1	78.2	73.2	62.1	48.6	35.3
1945	34.0	34.1	38.8	50.8	55.2	64.2	73.9	73.9	71.1	54.4	43.6	35.0
1946	33.4	33.2	38.6	47.8	55.4	64.5	73.2	74.1	71.3	63.2	52.9	39.5
1947	34.1	34.2	35.7	45.3	54.4	64.1	73.0	76.3	74.5	60.1	49.9	35.8
1948	33.0	33.0	35.6	47.1	55.4	64.3	75.0	76.2	74.5	62.9	52.1	41.8
1949	34.4	34.2	36.2	48.4	59.5	68.4	76.8	78.2	73.2	64.2	52.7	37.0
1950	34.6	34.1	35.2	43.4	54.1	66.8	74.2	74.8	70.4	61.6	53.5	36.9
Mean	33.6	33.5	35.5	44.6	56.8	67.5	74.5	76.1	71.2	60.5	48.2	36.0

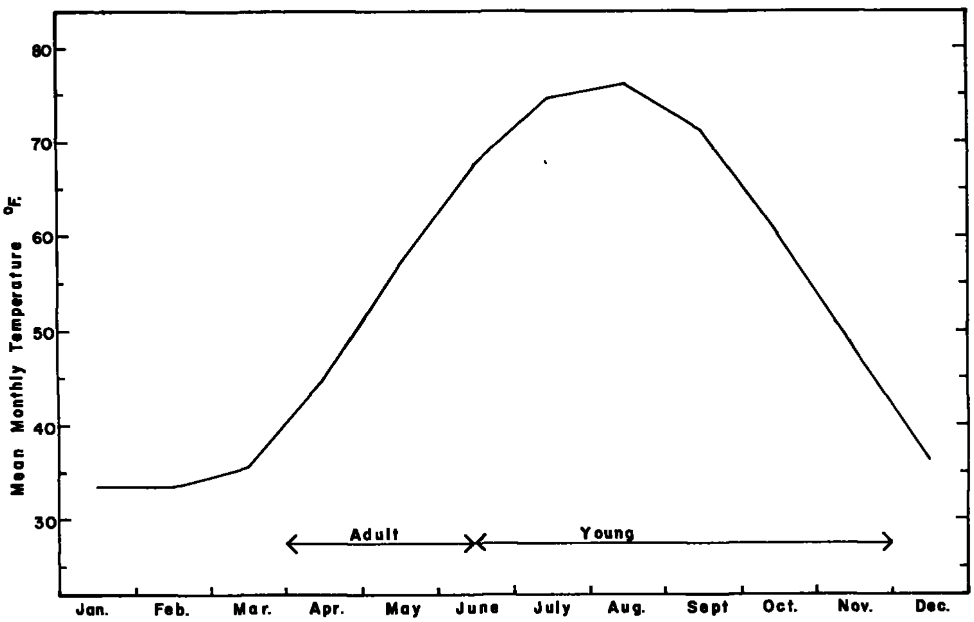

FIGURE 9.—Hudson River monthly mean water temperatures in °F., taken at 8 a. m., at Poughkeepsie, for 1929 through 1950, and periods when adult and young shad are in the river.

tions between predicted and calculated populations as shown in table 12. The only period of any duration when deviations from average water temperatures occurred was from June through October in the years 1939 through 1944. During this period 28 of the 30 monthly average temperatures shown in table 13 were above the mean for the monthly temperatures for 1929 through 1950. So far as could be determined, this had no effect on subsequent shad runs to the Hudson River. Variations in daily temperatures (records of which are not now available) may have occurred during critical periods of development of the eggs and larvae of the shad, which might have affected production. It is not likely, however, that they would have occurred in such a manner as to cause the fluctuations in total shad catches as shown in figure 2, but they might have been partially the cause of the deviations from predicted populations shown in table 12, either directly or indirectly as temperature affects other factors such as pollution. Since the only records available at this time are the mean monthly temperatures, which obscure daily variations, no examination can be made of this possibility.

Fishermen and others acquainted with the shad fishery believe that when a warm spring occurs the shad run is earlier than when cold weather prevails. To check on this statistically, a regression analysis was run using the mean water temperature for April from 1938 through 1951 and the week of peak catch in New York as measured by the landings in Fulton Market in New York City. The regression coefficient was not quite significant at the 5-percent level. In general, it can be said from an examination of the data that the Hudson River shad runs tend to be earlier when the spring is warmer than average, but the regression of time of the runs on water temperatures is not statistically significant. This same result has also been noted for the Columbia River shad runs (Talbot 1953). If better indexes than were used here were developed for water temperatures, and for time of run, a significant relation might be found.

CHANNEL IMPROVEMENTS

The Hudson River channel has undergone improvement for navigation purposes since 1789 (U. S. Army, Pt. I, 1920). Originally there was a 25-foot channel (with the exception of a few shoals which restricted the minimum depth to 19 feet) from New York City to Hudson. Above Hudson the river was obstructed by sandbars, making a tortuous and unstable channel. After partial improvement by the State of New York between 1797 and 1831, a narrow, crooked channel existed with a navigable depth of 3½ to 11 feet between Coxsackie and Waterford. From 1834 to 1892, improvement work was carried on by the State of New York in conjunction with the Federal Government, and legal control was given to the United States Government in 1891. A project initiated in 1899 called for a 12-foot channel from Coxsackie to Waterford. This was later increased to a projected depth of 27 feet between Hudson and Albany, as well as for the section between New York City and Hudson. By 1931 the river was dredged to minimum depths of 27 feet between New York City and Hudson and 26 feet to Albany. By the next year there was a 27-foot channel to Albany.

Deepening the channel has caused an increase in the mean tidal range in the upper part of the river between New Baltimore and Troy (U. S. Army, Pt. I, 1920). In 1831 the mean range of the tide at Albany was 2.09 feet. In 1910 the mean range was 2.9 feet, and the present project increased the mean range about 0.4 feet, or an increase in mean range of about 1.21 feet since 1831.

In addition to the change in tidal effect, many of the shallow sandbars have been removed in the upper section from areas which may have been former spawning grounds. What effect, if any, this may have had on the runs of earlier years cannot now be ascertained. Since the shad runs of the Hudson have made a dramatic recovery and again declined in recent years, the dredging records of the river were examined to determine whether the removal of this material has influenced the abundance of shad since 1920. Records of the amount of material in cubic yards removed from the upper Hudson for each year between 1920 and 1948 were obtained from the Corps of Engineers (U. S. Army, Pt. I, 1920–49). These amounts are shown in figure 10 and include both soft material and rock removed.

It can be seen in figure 10 that the greatest amount of material was removed between 1926 and 1934. The shad runs, however, increased in later years (1936–46) to somewhere near their greatest former abundance as shown in figure 15.

and since have declined. It must be concluded, therefore, that whatever effect the deepening of the upper reaches of the river has had on the shad runs, the fishery has still been able to produce at a high level, and the dredging operations in recent years have had no measurable adverse effect on the abundance of shad.

SHIP TRAFFIC

The Hudson River is one of the most important highways of commerce in the United States. It is open to navigation to Albany for a period of 8 to 10 months a year. During the past 10 or 15 years from 200 to 1,800 steam and motor vessels have visited the port of Albany each year, as well

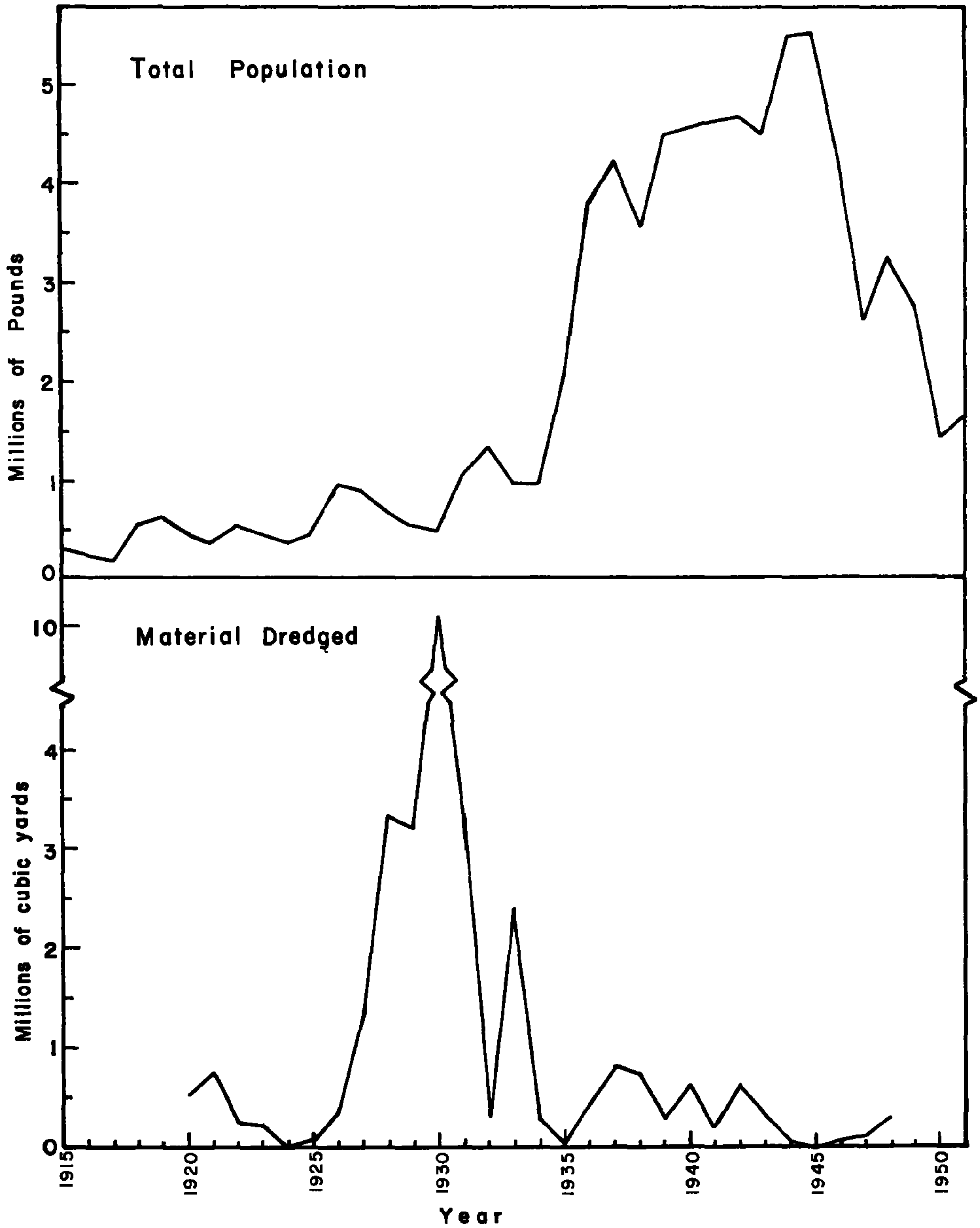

FIGURE 10.—Cubic yards of soft and hard material removed from Hudson River by dredging, 1920 through 1948, compared with total shad populations during the same years.

as approximately the same number of barges (U. S. Army, Pt. II, 1920–49). In addition, there is much traffic in the river that is bound for points below Albany. This congestion of shipping in the river represents a hazard to fishing operations, particularly to the drift-net fishermen in the upper fishing areas. Often the operators of the ships and barges make no effort to avoid either the fishermen's boats or their nets, as required by law, with the result that fishing is interrupted many times each season and loss of nets is common. In addition, the wakes of large ships cause large waves which make the anchoring of small boats difficult and cause damage to small wharves and boats along the shores.

Because of this, many fishermen are understandably antagonistic towards the captains or pilots of the ships and blame many of their difficulties on river traffic. During the course of our field work in 1950 and 1951, many fishermen informed us of the damage caused by shipping and also told of large numbers of eggs, presumably of shad, which had been washed up on the beaches by the waves caused by passing ships. In addition, some of the fishermen believe that the waves from passing ships and the turbulence caused by ships' propellers stir up shad eggs, sand, and silt from the river bottom, and that the eggs are smothered when all of these settle to the bottom again.

The hazards of ship traffic while shad fishing on the Hudson were experienced many times by the field crews working with the fishermen, but no evidence was ever found of shad eggs being washed ashore by the waves of passing ships. Nevertheless, records of ship traffic on the Hudson were examined in an attempt to determine whether variations in river traffic could be the cause of fluctuations in the shad populations.

Records of the numbers of trips made by ships and barges on the Hudson River are available from the report of the Chief of Engineers (U. S. Army, Pt. II, 1920–49), for various sections of the river. From these we have compiled the numbers of trips (one way only) by steamers and motor vessels between New York City and ports along the river to Waterford, for the years 1920 through 1949. The statistics for 1920 list all shipping above New York City. Between 1921 and 1933 the records are for trips between Tarrytown and Waterford, and after 1933 the records are for trips between Harlem River and ports along the river up to Waterford. These are shown in figure 11 (solid line) along with the estimated shad population 4 years later.

With the exception of the year 1923, when traffic was extremely high, there was a gradual though irregular decline in river traffic of steam and motor vessels from 1921 to 1944. During this time the shad population increased tremendously and then declined again. Obviously there is no correlation between the total number of trips made by steamers and motor vessels and shad production during this period.

On the assumption that larger ships could possibly do more damage than smaller ships, the number of trips (one way) by vessels of more than 20-foot draft between New York City and places along the Hudson River up to Waterford was compiled. These are shown as the broken line in figure 11, and depict a trend much different from that of all shipping on the river. The increase in traffic by larger and more heavily laden vessels beginning in the 1930's resulted, undoubtedly, from the deepening of the channel to 27 feet for the whole river between New York City and Albany in 1931 and 1932. The heavy ship traffic increased to a peak in 1939, but then decreased again to a low in 1942 because, as a result of World War II, the railroads handled most land freight, leaving the ships for ocean hauling. After 1945 the heavy hauling on the river again increased, reaching a peak in 1947. The peak of traffic by these vessels from 1935 to 1939 had no noticeable effect on the shad runs 4 and 5 years later, and the decrease in traffic during the war years and subsequent increase after the war compares with an overall decline during this time in the shad run 4 and 5 years later. We have concluded that, although shipping in the river is detrimental to fishing gear and constitutes a hazard to fishing, there is no evidence to show that it is detrimental to the shad runs.

HATCHERIES

For many years a shad hatchery was operated on the Hudson River in the vicinity of Catskill. In addition to the shad hatched at this station, the U. S. Fish and Fisheries Commission furnished shad fry for distribution in the Hudson River during the years between 1882 and 1904. More recently the practice of artificially hatching shad eggs has not received support, and the Hudson

River shad hatchery, along with many others on the Atlantic coast, has ceased operations.

Many fishermen and others associated with the fishing industry have insisted that the closure of the Hudson River hatchery has been the cause of the present decline in the Hudson River shad fishery. To examine this possibility, the records of shad eggs hatched or fry stocked each year have been compiled from available records (New York Fisheries Commission; New York Forests, Fish and Game Commission; New York Conservation Department; U. S. Fish Commission). These

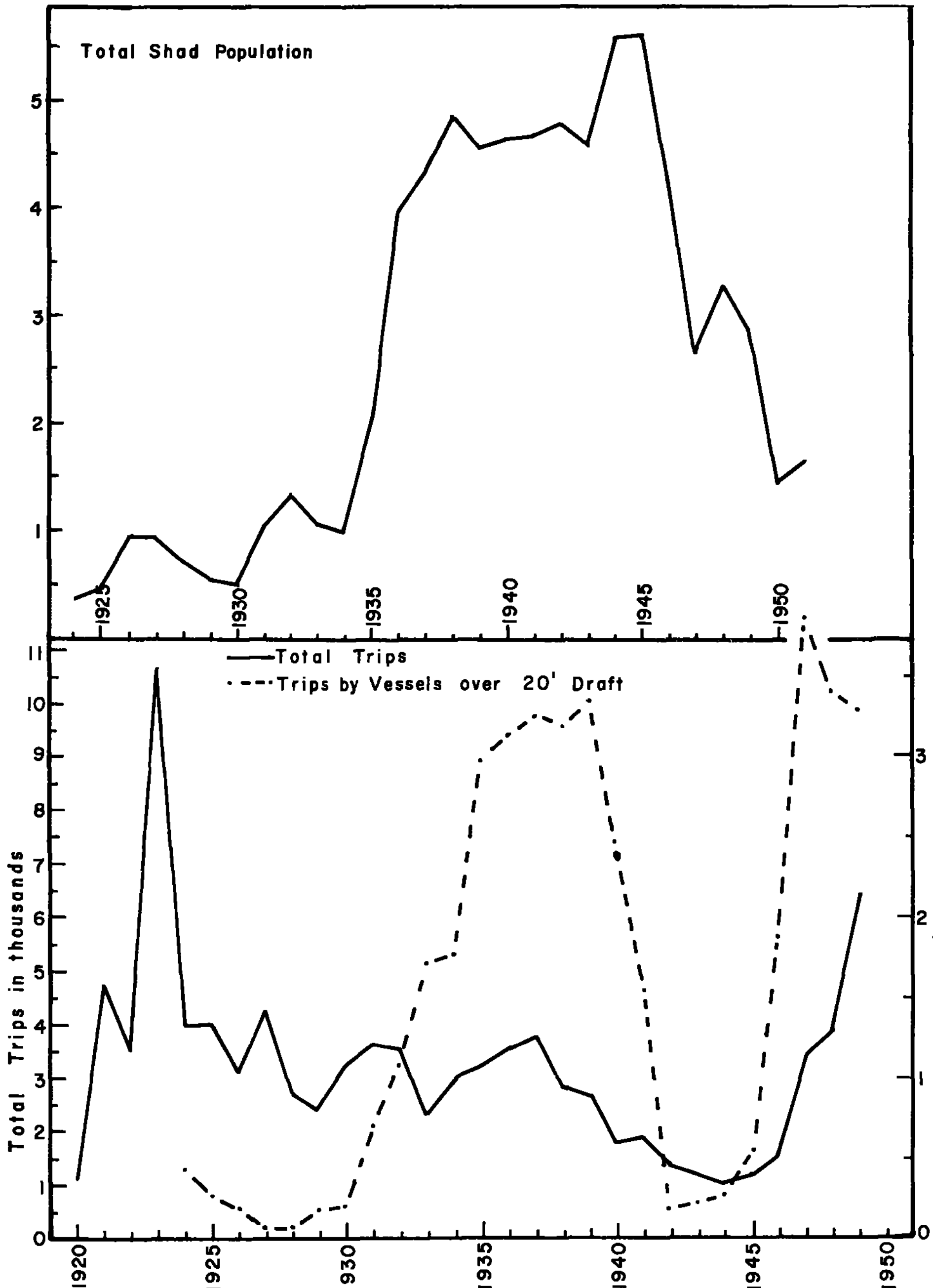

FIGURE 11.—Total number of 1-way trips by steam and motor vessels of more than 20-foot draft compared with total shad populations 4 years later.

show that artificially hatched fry were stocked in the Hudson almost every year from 1869 through 1944 (table 14 and fig. 12).

Early records of the shad catches from the Hudson River are fragmentary and will be discussed later, but it is known that the catches were large in some years between 1870 and 1902, and particularly between 1885 and 1901 (see fig. 15). These catches indicate large runs of shad, which appear to be reflected in the numbers of eggs that were obtained, hatched, and stocked each year. The greatest hatchery production occurred between 1887 and 1903. What part the hatchery played in shad production during early years is hard to assess at present, but it can be stated definitely that the peak hatchery production in 1899, 1900, and 1901 (fig. 12) did not maintain the runs, for the shad catch dropped from 3,432,472 pounds in 1901 (the peak year of hatchery production) to 573,399 pounds in 1904 (U. S. Bureau of Fsheries, 1907) and did not recover to anywhere near its former abundance until 32 years later, beginning in 1936.

TABLE 14.—*Hatchery shad released in Hudson River, 1869–1944*

Year	By U. S. Fish Commission	By New York State	Total
1869		15,000,000	15,000,000
1870		2,604,000	2,604,000
1871		8,295,000	8,295,000
1872		7,489,000	7,489,000
1873		5,041,000	5,041,000
1874		5,020,000	5,020,000
1875		4,580,000	4,580,000
1876		1,850,000	1,850,000
1877		3,584,000	3,584,000
1878		4,705,000	4,705,000
1879		6,459,000	6,459,000
1880		3,972,900	3,972,900
1881			
1882	963,000		963,000
1883	1,700,000	1,925,000	3,625,000
1884	1,477,000	1,467,000	2,944,000
1885	1,250,000	1,728,000	2,978,000
1886	2,412,000	2,279,000	4,691,000
1887	2,779,000	3,822,000	6,601,000
1888	4,200,000	3,924,500	8,124,500
1889	5,893,000	6,000,000	11,893,000
1890	6,366,000	2,025,000	8,391,000
1891	9,348,000	2,224,000	11,572,000
1892	5,199,000	2,436,000	7,635,000
1893	1,573,000	2,215,000	3,788,000
1894	5,414,000	190,000	5,614,000
1895	4,900,000	3,087,000	7,987,000
1896	4,595,000	4,095,000	8,690,000
1897	7,125,000	3,018,000	10,143,000
1898	5,500,000	6,579,400	12,079,400
1899	11,470,000	2,113,800	13,583,800
1900	10,280,000	2,870,200	13,150,200
1901	13,156,000	4,806,600	17,962,600
1902	2,123,000	3,911,150	6,034,150
1903		3,119,900	3,119,900
1904	3,000,000	1,518,500	4,518,500
1905		2,361,900	2,361,900
1906		400,000	400,000
1907		566,000	566,000
1908		881,000	881,000
1909		1,016,500	1,016,500
1910		6,126,500	6,126,500
1911		4,807,250	4,807,250
1912		6,603,695	6,603,695
1913		6,420,000	6,420,000
1914		1,403,000	1,403,000
1915		1,246,418	1,246,418
1916		1,411,000	1,411,000
1917		122,665	122,665
1918		2,054	2,054
1919		2,160,000	2,160,000
1920		1,776,279	1,776,279
1921		703,125	703,125
1922		1,056,875	1,056,875
1923		1,406,000	1,406,000
1924		1,282,500	1,282,500
1925		1,064,000	1,064,000
1926		2,014,722	2,014,722
1927		3,032,875	3,032,875
1928		2,455,750	2,455,750
1929		2,619,625	2,619,625
1930		1,781,250	1,781,250
1931		2,965,187	2,965,187
1932		2,755,000	2,755,000
1933		3,769,125	3,769,125
1934		3,075,625	3,075,625
1935		2,797,750	2,797,750
1936		2,999,625	2,999,625
1937		2,812,000	2,812,000
1938		3,222,875	3,222,875
1939		2,983,000	2,983,000
1940		[1] 1,000,000	[1] 1,000,000
1941		1,498,750	1,498,750
1942		997,500	997,500
1943			
1944		1,539,000	1,539,000

[1] Estimated.

Since the effect of hatchery operations on the 1936 to 1946 increase in shad production is of more immediate interest, because figures are available for both hatchery production and size of run each year, recent records have been examined closely. To determine whether hatchery production affects the size of runs in later years, a multiple-regression analysis was calculated between the size of the run each year from 1915 through 1946 and hatchery production 4 and 5 years before each year's run. No significant correlation was found. Here again the size of the escapement of the year before would tend to obscure any correlation that might exist, and there is no way possible at this time to make corrections for this factor.

It is not surprising that no correlation exists between the hatchery output and the sizes of subsequent runs. The average number of eggs obtained per female shad by fish culturists is between 20,000 and 30,000 (New York Fish. Comm. Rept. for 1899; Brice, 1898) but recently it has been shown (Lehman, 1953) that the actual number of eggs per female spawned naturally each season is between 100,000 and 500,000, depending on the age of the fish. Some of the eggs may be spawned in advance of stripping, but many are not ripe when the fish are stripped, and since the fish are usually killed in the process many of the eggs are lost. Since 1914, the number of eggs hatched artificially in the Hudson River hatchery each year has usually been between 1 and 3 million. From 40 to 120 female shad were stripped to obtain these eggs (at 25,000 per female), and if each of the females contained an average of 250,000 eggs it is possible that between 10 million and 30 million eggs were wasted in the process. The added protection given artificially hatched eggs can hardly be expected to compensate for the waste of eggs inherent in the process.

In some cases, the eggs for hatchery operations were obtained from commercial fishermen who stripped ripe eggs from the fish before selling them. In these cases no wastage occurs, but in any event the number of eggs handled each year is comparatively very small. For instance, the eggs handled in 1914 are equivalent to the total production of only 4 or 5 averaged-sized female shad, and the greatest hatchery output in 1901 of almost 18 million eggs is equivalent to the total egg production of only about 72 fish. Furthermore, the lowest calculated escapement shown in table 8 was 58,000 pounds in 1917. If females made up half the poundage, there were 29,000 pounds of female shad, and converting pounds to fish by a factor of 4 pounds to the female gives a figure of over 7,000 female shad spawning naturally that year. The hatchery production in the same year (table 14) was only about half that produced by 1 average-sized fish. Similarly, the greatest hatchery production in recent years was in 1933 and is equivalent to the production of approximately 15 female shad. In that same year the calculated natural escapement was 602,000 pounds which, on the basis of a fifty-fifty sex ratio, and an average weight of 4 pounds, amounts to more than 75,000 females spawning naturally. Obviously, the number of eggs that it has been possible to obtain for hatchery operations is only an extremely small fraction of the amount spawned naturally, and the increased survival

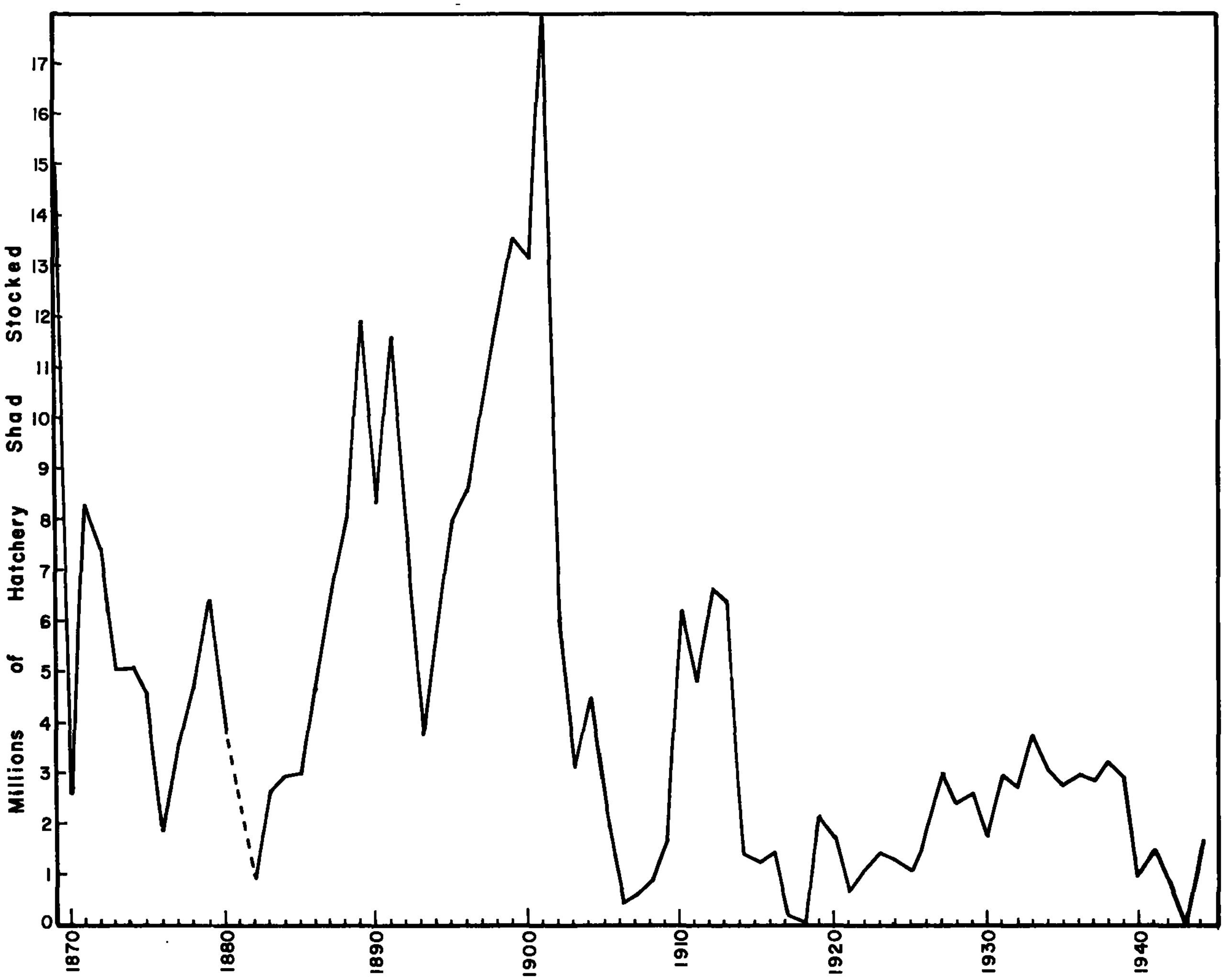

FIGURE 12.—Artificially hatched shad stocked in the Hudson River, 1869 through 1944.

rate, if any, resulting from current shad-hatchery practices has not produced, and cannot be expected to produce, an increase in shad production.

POLLUTION

Industrial and domestic pollution has been a serious problem in the Hudson River for many years, as a result of unrestricted discharge of raw sewage into the river for two centuries. Until recently very little was done about this situation, and then only in the lower reaches of the river. Complaints concerning the effects of pollution on the fisheries were voiced before the turn of the present century. Marshal McDonald in 1887 mentions that the Hudson fisheries were standing up remarkably well despite the gross pollution of the river by sewage, and the refuse of paper, calico, and other factories in operation along its banks.

In the eleventh annual report of the New York Forest, Fish and Game Commission (1906) there is mention of the serious pollution problem confronting the Commission. It is stated that, "Formerly, shad were caught up to the Troy Dam . . . It would seem as if, year after year, the run of fish was retarded by an invisible line which annually stretched further and further down the river and beyond which the fish would not pass . . . At present, the fish do not seem to run much above Hudson."

The annual report of the Torresdale hatchery (Pennsylvania Dept. Fish. 1914) states that at the Linlithgo hatchery on the Hudson River eggs are hatched in pond water since the Hudson River water is badly polluted.

One of the greatest difficulties in evaluating pollution data arises from the fact that there are no generally accepted standards of water quality which are recognized as constituting a good fish habitat. References dealing with this problem are almost innumerable. As pointed out by the California Water Pollution Control Board (1952), various investigators have been individualistic in their approaches to the problem, and the conditions under which they conducted their experiments varied widely and were seldom standardized. This has led to confusion and a lack of agreement in standards prescribed by different agencies dealing with water-quality criteria.

Listed in table 15 are standards for dissolved oxygen, biochemical oxygen demand (B. O. D.), and coliform-bacteria counts which have been adopted by several State or interstate agencies for water considered as a good fish habitat. While there is no overall agreement, it can be seen that these criteria call for an average for any month for dissolved oxygen of not less than between 6.0 p. p. m. and 6.5 p. p. m. The minimum for any day shall not be less than between 4.0 p. p. m. and 75-percent saturation (7.5 p. p. m. at 60° F.). The standards for these agencies for biochemical oxygen demand state that the average for any month shall not be more than between 1.5 to 2.5 p. p. m., and the maximum for any month shall not be more than between 3.0 to 3.5 p. p. m. Standards for coliform-bacteria counts range from 50 per 100 ml. to a maximum of 2,000 per 100 ml.

A great deal of work on water-quality problems is now in progress, and it is probable that more

TABLE 15.—*Dissolved oxygen, biochemical oxygen demand, and bacteria count standards of several States and agencies for water considered as good fish habitat*

[Data from California Water Pollution Board (1952)]

State or agency	Class	Dissolved oxygen p. p. m.		5-day B. O. D. at 20° C. p. p. m.		Most probable number of coliform bacteria per 100 ml.	
		Average any month not less than—	Minimum any month not less than—	Average any month not over—	Maximum any month not over—	Average any month, not over—	Maximum any sample not over—
Maryland Water Pollution Control Board	A	6.0	5.0	2.5	3.5	2,000	
West Virginia State Water Commission	A	6.5	5.0	2.5	3.5	1,000 or 2,000 in agricultural area.	
New York Dept. of Health, Water Pollution Control Board.	C		Trout waters 5.0; non-trout waters 4.0.				
Interstate Commission on the Potomac River Basin.	B	6.5	5.0	1.5	3.0	50 to 500	1,000.
Interstate Sanitation Commission New York, New Jersey and Connecticut.	A		50-percent saturation (5.0 at 60° C.).				100 in 50 percent of samples during bathing season only.
New England Interstate Water Pollution Control Commission.	C		(5 p. p. m.)				
New Hampshire Water Pollution Commission.	C		5.0				

definite and hence more uniformly acceptable standards based on standardized and controlled experiments will be formulated in the future for various types of waters and various species of fish. The above criteria, however, appear reasonable at present for judging the water quality of the Hudson River.

Very little continuous factual information concerning water quality of the Hudson River is available except for that portion of the river adjacent to New York City. Here, by the late 1800's, sewage disposal had overtaxed the capacity of the surrounding water to assimilate it, and beginning about 1900 the problems of sewage disposal were studied by various State and municipal bodies. In 1909 the Metropolitan Sewage Commission began making systematic dissolved-oxygen measurements and other water-quality determinations during the summer months (when conditions were at their worst) in the various waters surrounding the city, and these have been continued by other agencies until the present time. Dissolved-oxygen determinations were made at 5 stations in the Hudson River between Mount St. Vincent and the Battery. The annual (June through September) average and the minimum determination for the station opposite the Battery, where usually the lowest oxygen sag occurs, are shown in figure 13. These data were furnished by the New York City Department of Public Works. They show a downward trend from 1909 to 1926 and then a continuation of low levels averaging around 37 percent saturation of oxygen. The minimum oxygen saturation found throughout any season has been low since 1912, and since 1919 has averaged only 19 percent.

The dissolved-oxygen values as shown in figure 13 are indicative of gross pollution and are so far below any generally recognized minimum standard for fish life that shad could probably not survive to spawn, or the eggs and young could not survive, in water conditions such as those existing in this part of the river. These values, however, represent conditions during summer months, when low stream flows and high temperatures prevail, which cause fast oxidation of the sewage and subsequent lowering of the dissolved-oxygen content of the water. Fortunately, most of the adult shad migrate upstream to spawn and return to the ocean during April and May, when river discharge is

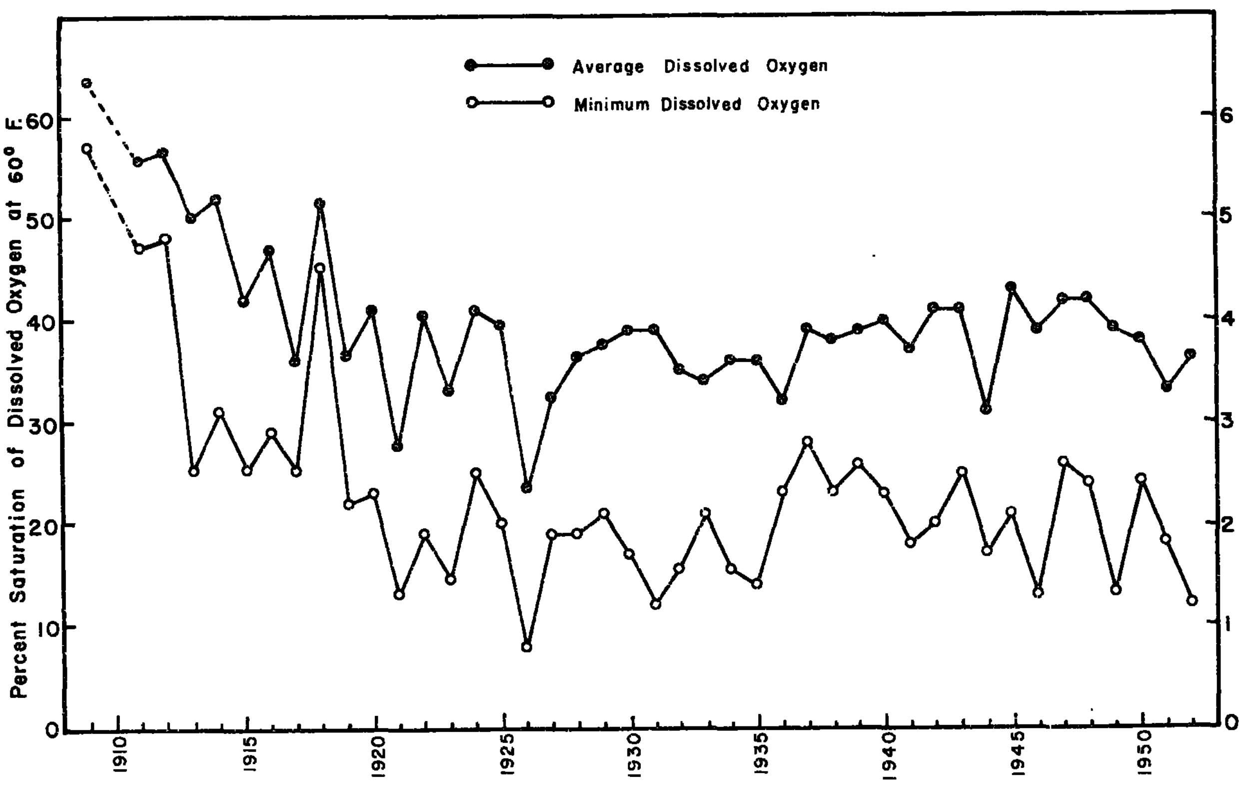

FIGURE 13.—Average dissolved oxygen and minimum dissolved oxygen in the Hudson River at the Battery, from 1909 through 1952.

greater and water temperatures lower than in the summer, and hence oxygen depletion is less severe; consequently, most adult shad probably escape the oxygen sags which have been observed in this area during the summer months. Similarly, the young shad leave the river in October or November, when cold weather again reduces oxygen depletion, and probably most of them do not encounter lethal conditions. While it is probable that during some years mortalities of late-migrating adults and early-migrating young may occur in this section of the river, they do not appear to have affected fluctuations in shad production, or at least there is no correlation between average oxygen content of the water as shown in figure 13 and shad production during the period between 1915 and 1951. Any effect that pollution in this area has had on the runs of shad may well have been uniform each year since about 1919, as there appears to be little overall change in water quality, as measured by oxygen content, since that time.

Since 1937, the Interstate Sanitation Commission, representing the States of New Jersey, New York, and Connecticut, has been working successfully to clean up the marine waters around New York City, Long Island, and the Hudson River to Bear Mountain Bridge. Good progress has been made, despite a setback during the war years, and sewage-treatment plants have been installed at Bear Mountain and in several communities located on Haverstraw Bay. No sewage-treatment plants have yet been constructed to eliminate pollution which New York City dumps into the Hudson River. These are contemplated in the near future, however, and by 1959 practically all pollution in the area under the jurisdiction of the interstate compact should be ended.

In 1951 the Fish and Wildlife Service in cooperation with the New York State Department of Health carried out a water-quality study of the Hudson River during the months of July through October. Weekly samples (except during the week of September 25–30 when a mechanical breakdown occurred) were taken at 5 locations at each of 17 stations located between Troy and Piermont. The stations chosen were those previously designated by the New York Health Department, plus two more below Bear Mountain Bridge. The positions of these stations are shown in table 16. The 5 locations at each station where samples were taken were also those designated by the New York Health Department and are: East shore, west shore, center of channel at 5-foot depth, center of channel at mid-depth, and center of channel 5-feet off bottom. The following determinations were made and recorded, with other data, from each sample: Color, odor, turbidity, temperature, pH, dissolved oxygen, B. O. D., and coliform-bacteria count.

TABLE 16.—*Hudson River sampling stations, 1951*

Station No.	Place	Miles above the Battery, New York City
00	Piermont Pier	25.0
0	Stony Point	39.5
1	Bear Mountain Bridge	48.0
2	Constitution Island (north end)	55.0
3	Breakneck Point, Storm King Mountain	57.5
4	Chelsea, Low Point, Roseton	67.0
5	Milton Railroad Station	74.5
6	North of Crum Elbow (200′ north of Light 26)	83.0
7	Cave Point (½ mile south of Esopus Light)	89.0
8	Barrytown (Buoy 34A)	100.5
9	West Camp (Light 37)	111.0
10	Catskill (Light 50)	120.0
11	Four Mile Point (Light 59)	126.5
12	Houghtaling Island (Light 72)	135.5
13	Staat Point (Light 90)	146.0
14	Menands Bridge	157.0
15	Troy Lock	161.0

The average dissolved oxygen of the 5 samples at each station for each week during the course of the study are shown in table 17. Also shown are the monthly averages, season minimums, and dates of their occurrence for each station. As shown in this table, weekly averages of less than 5 p. p. m. of dissolved oxygen occurred at all stations one or more weeks during the sampling, and below 4 p. p. m. at 7 of the 17 stations. Season minimums below 4 p. p. m. were recorded at 10 of the 17 stations. All the minimum values were found during July and August when water temperatures were at their highest. The lowest values were found below the Troy, Rensselaer, and Albany area (stations 11, 12, and 13) and they undoubtedly result from the large amount of raw sewage dumped into the river by those cities. Below this, minimum values were somewhat higher, reaching 4.2 p. p. m. at station 7 located between Kingston and Poughkeepsie. At station 5, which is below Poughkeepsie, another oxygen sag is apparent resulting undoubtedly from raw sewage from that city. Below this, the minimum dissolved oxygen was somewhat better but dropped again at the two lowest stations.

In table 18 are shown the average biochemical oxygen demand (B. O. D.) determinations for the

TABLE 17.—*Dissolved oxygen at 17 stations in the Hudson River, by weeks, July–October 1951*

[Average, in parts per million, of samples from 5 locations at each station]

Week of—	At station No.—																
	00	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
July 2-6	7.0	4.5	5.6	5.6	5.7	5.0	4.2	4.1	4.4	3.8	3.8	3.6	4.1	5.0	6.2	7.0	7.6
July 9-13	7.6	5.8	5.6	6.1	6.1	5.8	4.2	4.3	5.6	6.6	6.5	8.2	7.2	4.5	5.8	7.4	7.6
July 16-20	5.5	4.8	5.0	5.2	5.2	4.3	4.0	4.0	4.8	4.3	4.5	5.4	6.1	5.4	5.6	6.0	6.7
July 23-27	6.1	5.2	4.6	4.5	4.6	4.8	3.8	4.0	4.6	4.2	5.1	6.3	5.5	4.7	4.4	5.8	7.0
Average for month	6.6	5.4	5.2	5.4	5.4	5.0	4.0	4.1	4.8	4.7	5.0	5.9	5.7	4.9	5.5	6.5	7.2
July 30—Aug. 3	4.8	4.2	4.8	5.0	5.1	4.2	3.3	4.1	5.1	5.1	4.3	4.1	4.1	3.3	4.3	6.1	6.8
August 6-10	5.0	5.6	4.8	5.9	6.1	5.5	4.1	4.5	5.3	5.6	5.0	3.9	3.7	2.2	2.6	4.8	7.0
August 13-17	4.5	4.6	5.0	5.7	6.0	5.2	4.2	5.2	6.0	5.7	5.3	3.4	2.9	2.3	1.3	4.3	4.9
August 20-24	4.9	5.4	5.4	5.7	5.8	5.7	4.8	5.4	5.6	4.2	4.7	4.8	4.4	3.0	4.8	6.7	7.7
August 27-31	7.0	5.8	5.0	5.5	6.0	5.2	4.8	5.2	5.8	5.3	5.5	4.8	4.4	3.8	4.2	6.0	6.8
Average for month	5.2	5.1	5.0	5.6	5.8	5.2	4.2	4.9	5.6	5.2	5.0	4.2	3.9	2.9	3.4	5.6	6.6
Sept. 3-7	5.1	5.1	5.1	5.8	5.9	5.9	4.9	4.8	5.3	5.2	4.6	3.6	4.1	4.9	4.9	7.1	8.2
Sept. 10-14	5.1	5.5	5.8	6.3	6.3	5.6	4.6	5.7	6.8	6.5	6.3	6.0	5.4	5.4	5.3	6.4	7.7
Sept. 17-22	6.3	5.8	6.2	6.6	6.6	5.9	5.2	6.3	6.6	7.2	5.5	4.4	4.7	3.2	3.6	5.9	7.0
Average for month	5.5	5.5	5.7	6.2	6.3	5.8	4.9	5.6	6.2	6.3	5.5	4.7	4.7	4.5	4.6	6.5	7.6
Oct. 1-5	6.5	6.4	6.1	6.7	7.1	6.2	5.9	6.2	7.0	7.1	7.1	4.9	4.5	3.8	4.5	7.3	7.9
Oct. 8-12	6.9	7.0	7.0	7.4	7.4	6.7	6.8	7.4	7.8	7.3	5.9	5.1	6.2	7.6	7.9	10.0	10.2
Oct. 15-19	7.5	7.3	7.4	7.7	7.8	7.7	7.6	8.1	8.0	9.0	8.1	8.2	8.6	8.4	8.1	9.7	10.2
Oct. 22-26	6.9	7.4	7.6	8.0	8.3	8.0	7.6	8.0	8.8	9.4	8.9	7.4	6.8	5.9	7.4	9.7	10.2
Average for month	7.0	7.0	7.0	7.4	7.6	7.2	7.0	7.4	7.9	8.2	7.5	6.4	6.5	6.4	7.0	9.2	9.6
Season minimum [1]	3.6 (Aug. 2)	4.0 (Aug. 2)	4.4 (July 24)	4.4 (July 24)	4.4 (July 24)	3.8 (Aug. 1)	3.2 (Aug. 1)	3.8 (July 25, July 31)	4.2 (July 4, July 31)	3.6 (July 3)	3.6 (July 3)	3.4 (July 3, Aug. 15)	2.6 (Aug. 15)	2.0 (Aug. 14)	1.2 (Aug. 14)	4.0 (Aug. 14)	4.2 (Aug. 14)

[1] Date in parentheses.

TABLE 18.—*Biochemical oxygen demand determinations at 17 stations in the Hudson River, by weeks, July–October 1951*

[Average, in parts per million, of determinations for 5 locations at each station]

Week of—	At station No.—																
	00	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
July 2–6	1.4	0.8	1.0	0.6	0.8	0.7	-----	-----	-----	-----	-----	-----	-----	-----	2.1	3.1	3.0
July 9–13	1.0	0.4	0.3	0.6	0.6	0.7	-----	-----	1.3	1.8	2.6	2.8	2.0	-----	2.3	2.3	2.2
July 16–20	0.9	0.4	0.4	0.4	0.6	0.6	0.4	0.7	1.0	1.0	1.3	3.2	1.9	1.6	1.8	1.9	2.0
July 23–27	0.7	0.2	0.0	0.2	0.2	0.6	0.4	0.6	0.9	1.0	1.1	1.6	1.5	1.4	1.7	2.2	2.6
Average for month	1.0	0.4	0.4	0.4	0.5	0.6	0.4	0.6	1.1	1.3	1.7	2.5	1.8	1.5	2.0	2.4	2.4
July 30–Aug. 3	0.9	0.2	0.4	0.4	0.4	0.6	0.2	0.6	0.9	1.0	0.7	1.3	1.3	1.2	1.2	1.5	1.8
Aug. 6–10	0.7	0.7	0.5	0.7	0.8	0.7	0.4	0.4	0.7	0.8	0.8	1.0	1.0	1.2	2.0	3.5	2.8
Aug. 13–17	0.7	0.4	0.4	0.6	0.6	0.5	0.2	0.6	0.9	0.9	0.8	1.3	1.2	1.1	1.0	2.2	3.6
Aug. 20–24	0.5	0.7	0.5	0.5	0.6	0.7	0.3	0.7	0.9	1.0	1.2	1.4	1.3	1.0	2.1	3.4	2.9
Aug. 27–31	2.4	0.9	0.4	0.6	0.9	0.5	0.4	0.6	1.0	0.9	1.1	1.5	1.6	-----	1.7	2.0	2.4
Average for month	1.0	0.6	0.5	0.6	0.7	0.6	0.3	0.6	0.9	0.9	0.9	1.3	1.3	1.1	1.6	2.5	2.7
Sept. 3–7	0.6	0.6	0.4	0.5	0.4	0.6	0.4	0.4	0.6	0.9	0.8	1.2	1.4	1.4	2.0	3.7	3.0
Sept. 10–14	0.6	0.2	0.4	0.4	0.5	0.6	0.6	0.7	1.2	1.0	1.0	1.4	1.4	1.6	2.5	2.9	2.4
Sept. 17–22	0.8	0.6	0.8	0.4	0.3	0.3	0.4	0.8	0.8	1.0	1.0	1.4	1.7	1.3	2.2	3.1	4.0
Average for month	0.7	0.5	0.5	0.4	0.4	0.7	0.5	0.6	0.9	1.0	0.9	1.3	1.5	1.4	2.2	3.2	3.5
Oct. 1–5	0.4	0.5	0.4	0.4	0.4	0.4	0.3	0.5	0.6	0.8	0.9	1.9	1.9	2.0	2.0	3.5	3.4
Oct. 8–12	0.7	0.6	0.4	0.4	0.5	0.5	0.4	0.5	0.7	1.0	1.7	2.0	1.7	2.0	3.7	1.7	1.4
Oct. 15–19	0.6	0.6	0.3	0.5	0.5	0.6	0.8	1.1	1.1	1.7	1.7	1.8	1.8	2.2	3.8	1.8	1.8
Oct. 22–26	0.7	0.5	0.4	0.4	0.5	0.7	0.8	1.1	1.1	1.0	1.7	1.4	1.5	2.1	4.0	4.0	3.4
Average for month	0.6	0.5	0.4	0.4	0.5	0.5	0.6	0.8	0.9	1.4	1.5	1.8	1.7	2.1	3.4	2.8	2.5
Individual sample maximum [1]	5.4 (Aug. 31)	1.4 (Aug. 31, Sept. 18)	3.0 (Sept. 18)	0.9 (Aug. 7)	1.2 (July 5, Aug. 31)	2.0 (July 10)	1.0 (Oct. 18, Oct. 23)	1.6 (Oct. 17)	1.8 (Sept. 12)	2.0 (July 11, Oct. 24)	2.8 (July 12)	3.0 (July 12)	2.4 (July 12)	2.2 (Oct. 2, Oct. 11, Oct. 16, Oct. 25)	4.2 (Oct. 25)	4.4 (Sept. 7)	4.2 (Sept. 22, Oct. 26)

[1] Date in parentheses.

5 locations at each of the 17 stations for each week of the water-quality study. In addition, the monthly averages and maximum B. O. D.'s for any individual sample are shown with the dates of occurrence. Individual B. O. D. determinations higher than those considered satisfactory for a good fish habitat (3.0 to 3.5 p. p. m.) were found at stations 00, 13, 14, and 15, where the determinations were 5.4, 4.2, 4.4, and 4.2 p. p. m., respectively. Monthly averages higher than those considered tolerable for a good fish habitat by the Interstate Commission on the Potomac River (1.5) were found at stations 9, 10, 11, 13, 14, and 15 in July; at stations 14 and 15 in August; at stations 13, 14, and 15 in September; and at stations 10 through 15 in October. Using the higher value of 2.5 p. p. m. as listed by Maryland and Virginia, averages considered too high were found at station 15 in August, stations 14 and 15 in September, and stations 13 and 14 in October.

Table 19 gives the average coliform-bacteria counts of the 5 samples taken at each station each week for the 17 stations. Also given are the monthly averages for each station and the maximum individual bacteria counts for each station with the dates of occurrence. The highest bacteria count considered as a good fish habitat from the criteria examined and shown in table 15 was that of Maryland which specifies a monthly average of not more than 2,000 coliform bacteria per 100 ml. The largest maximum individual count allowable is 1,000 as given by the Interstate Commission on the Potomac River Basin. Using these as a basis for examining the 1951 Hudson River bacteria counts shown in table 19, it can be seen from the maximum individual samples that every station sampled in the Hudson River had at some time during the season a coliform-bacteria count above that considered as a good fish habitat. Furthermore, every station, with the exception of stations 6, 7, 8, and 9, had above-allowable individual average bacteria counts every month throughout the season. The highest monthly average bacteria counts were found at stations 10 through 15 in the upper part of the river area studied, but individual determinations just as large were found at the two lowest stations.

Based on the limits set up in table 15 the pollution records indicate that the entire area of the Hudson River studied cannot be considered a good habitat for fishes. The section most polluted is that between the Albany-Troy-Schenectady metropolitan area and Hudson, N. Y. (stations 10–15). This section of the river at one time supported a considerable shad fishery (New York Fish. Comm., 1890) and probably was also a good spawning area. In recent years few if any shad have been caught above Hudson, and sampling for shad eggs by the New York Conservation Department (1943) in 1940, 1941, and 1942, and by our staff in 1951 showed that little if any of this area is now used by shad for spawning purposes.

The effect that pollution has had on shad production in the Hudson River is difficult to ascertain since no records comparable to those just presented are available for previous years. The New York Department of Health in 1949 made examinations of water samples from the same 5 locations at stations 1 through 15 during the week of August 22 to 26 and again during the week of November 14 to 18 (unpublished records). The minimum oxygen determinations during the week in August were lower than the season minimums for the 1951 survey at stations 13, 14, and 15, while at the other stations the minimums were somewhat higher than for those in 1951. Biochemical oxygen demand determinations and bacteria counts showed pollution conditions similar to those in 1951. Their survey made from November 14 to 18 showed conditions similar to those shown for the week of October 22 to 26 in 1951.

The only other water-quality survey covering this part of the Hudson River was that done by the New York Conservation Department in 1934 and 1936 (Faigenbaum, 1935, 1937) in connection with the Department's biological survey of the Mohawk-Hudson watershed in 1934 and the biological survey of the lower Hudson River in 1936. The water-quality studies on the Hudson River in 1934 covered that section of the river between the Troy Dam and Hudson from August 28 to September 6. The 1936 survey was carried out between Hudson and Yonkers from June 18 to September 5.

In this survey, samples were usually taken only once during the season at each location. The work was begun in the upper areas and was gradually shifted downstream as the season progressed; consequently, no direct comparisons between the 1934–36 survey and our 1951 survey are possible. In addition, the surface samples in

TABLE 19.—*Average of most probable number of coliform bacteria at 17 stations in the Hudson River, by weeks, July–October 1951*

[Average, in thousands per 100 ml., of counts at 5 locations at each station]

Week of—	At station No.— 00	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
July 2–6	3.5	2.6	1.7	2.7	2.9	1.5	0.9	0.2	0.7	0.4	0.6	2.1	3.8	2.6	12.4	32.3	39.2
July 9–13	0.4	1.4	0.5	4.4	2.8	1.3	3.1	0.8	0.4	0.5	1.0	1.7	1.4	6.0	50.0	22.5	16.9
July 16–20	6.3	3.9	0.7	1.3	4.1	1.3	1.4	3.8	0.4	0.4	0.9	5.0	5.4	1.7	18.1	18.7	11.4
July 23–27	3.0	1.0	0.6	2.9	2.6	2.2	2.4	1.2	0.3	0.8	1.0	5.1	8.0	3.5	54.4	32.8	23.8
Average for month	3.3	2.2	0.9	2.8	3.1	1.6	2.0	1.5	0.4	0.5	0.9	3.5	4.6	3.4	23.7	26.6	22.8
July 30–Aug. 3	0.7	1.3	0.3	1.1	0.9	2.3	4.1	0.5	0.3	0.2	1.4	25.6	2.7	3.7	26.2	32.8	18.1
Aug. 6–10	2.4	1.6	0.4	0.8	3.5	1.2	1.1	0.7	0.6	0.2	0.3	3.1	5.7	4.1	65.7	88.8	46.1
Aug. 13–17	14.0	35.8	0.9	3.4	3.7	1.5	8.4	0.4	0.4	0.4	0.8	2.9	5.6	1.9	20.2	13.8	24.9
Aug. 20–24	1.8	4.5	1.5	4.8	3.1	3.7	2.4	1.1	1.3	0.3	2.0	28.1	2.6	4.6	14.6	80.0	16.3
Aug. 27–31	55.3	13.4	1.7	8.6	5.1	1.6	12.5	0.8	0.3	0.6	0.4	2.1	13.6	8.2	31.1	31.0	43.8
Average for month	14.8	4.9	1.0	3.6	3.3	2.1	5.7	0.6	0.6	0.3	1.0	12.4	6.0	4.5	31.6	49.3	29.8
Sept. 3–7	2.6	192.5	2.3	25.4	4.2	9.7	1.9	0.5	0.3	0.2	0.7	6.6	2.7	5.1	67.2	76.0	10.2
Sept. 10–14	3.8	2.1	0.5	12.9	1.6	10.0	3.1	0.4	0.5	0.1	0.3	3.7	4.3	4.5	93.2	91.4	26.6
Sept. 17–22	0.9	3.0	0.8	2.3	2.3	3.7	3.7	0.2	0.4	0.1	0.6	13.5	30.4	5.2	3.5	58.8	41.7
Average for month	2.4	81.2	1.2	5.9	2.7	7.8	2.9	0.4	0.4	0.1	0.5	8.0	12.5	4.9	54.6	75.4	26.2
Oct. 1–5	0.6	1.4	1.7	2.4	1.7	0.6	2.7	6.9	0.2	1.0	0.4	4.1	11.4	4.9	80.9	31.0	79.8
Oct. 8–12	9.3	4.3	0.9	4.3	15.0	0.9	15.0	4.3	0.9	2.3	2.3	24.0	24.0	24.0	24.0	110.0	24.0
Oct. 15–19	9.3	2.3	4.3	6.4	9.3	4.3	4.3	4.3	0.4	2.3	4.3	4.6	4.6	110.0	110.0	110.0	110.0
Oct. 22–26	24.0	4.3	3.9	2.3	4.3	2.3	2.3	0.8	0.2	0.4	4.3	46.0	24.0	24.0	158.0	110.0	46.0
Average for month	10.8	3.1	2.7	3.8	7.6	4.1	6.1	4.1	0.5	1.5	2.8	30.0	26.4	40.7	95.2	90.2	65.0
Individual sample maximum [1]	[2] 240.0 (Aug. 31)	[2] 240.0 (Sept. 4)	4.3 (Sept. 5, Oct. 4, Oct. 18)	24.0 (Aug. 31)	15.0 (Oct. 9)	46.0 (Sept. 5)	24.0 (Aug. 16)	12.0 (Oct. 3)	4.3 (Aug. 23)	4.3 (Oct. 3)	4.3 (Aug. 23, Aug. 28, Oct. 17, Oct. 24)	110.0 (July 31, Aug. 23)	110.0 (Sept. 20)	110.0 (Oct. 16)	[2] 240.0 (Aug. 10, Oct. 1, Oct. 12, Oct. 25)	[2] 240.0 (Aug. 10, Sept. 17)	[2] 240.0 (Oct. 1)

[1] Date in parentheses.
[2] These samples were recorded as "greater than 240,000." The figure 240,000 was used in calculating averages.

the 1934–36 survey were taken just below the surface, and the bottom samples just off the bottom, while in the 1951 survey samples were taken 5 feet below the surface and 5 feet above the bottom.

No B. O. D. determinations or bacteria counts were made in the 1934–36 surveys; dissolved-oxygen determinations were made, however, and these are shown by the solid line in figure 14 for all mid-depth determinations made during the 1934–36 survey. These are given here because they are more comparable with the mid-depth samples taken in 1951 than are the top and bottom samples. Included in figure 14 are the season mid-depth minimum dissolved-oxygen determinations from the 1951 study for comparison. Both of these oxygen profiles show that gross pollution occurs in the area below Albany and that at least partial oxygen recovery takes place by the time the water reaches the city of Hudson. Both profiles indicate an increase in pollution around Poughkeepsie. The lower values shown for 1951 cannot be definitely interpreted to mean that pollution was worse in 1951 than during the 1934–36 survey, since the 1951 data are the mid-depth minimums of the season while the 1934–36 data are usually for one determination only at each location during the season. It is possible, however, that industrial pollution was somewhat less during the 1936 survey than in 1951, for the New York census of manufacturers for 1929, 1939, and 1947 (U. S. Bureau of the Census, 1929, 1939, 1947) shows that, based on the number of wage earners, industrial activity was greatly curtailed after 1929, undoubtedly as a result of the depression, and then increased again to even greater activity by 1947.

One source of serious pollution that none of the water-quality studies have taken into account is oil dumped in the river. As pointed out by Nelson (1925), "Oil is, gallon for gallon as thrown out, the most destructive to aquatic life of all foreign substances now entering our coastal waters." During our studies on the Hudson in 1950 and 1951, large quantities of oil were observed in several areas in the river, and traces of oil were in evidence almost everywhere. The boats and sam-

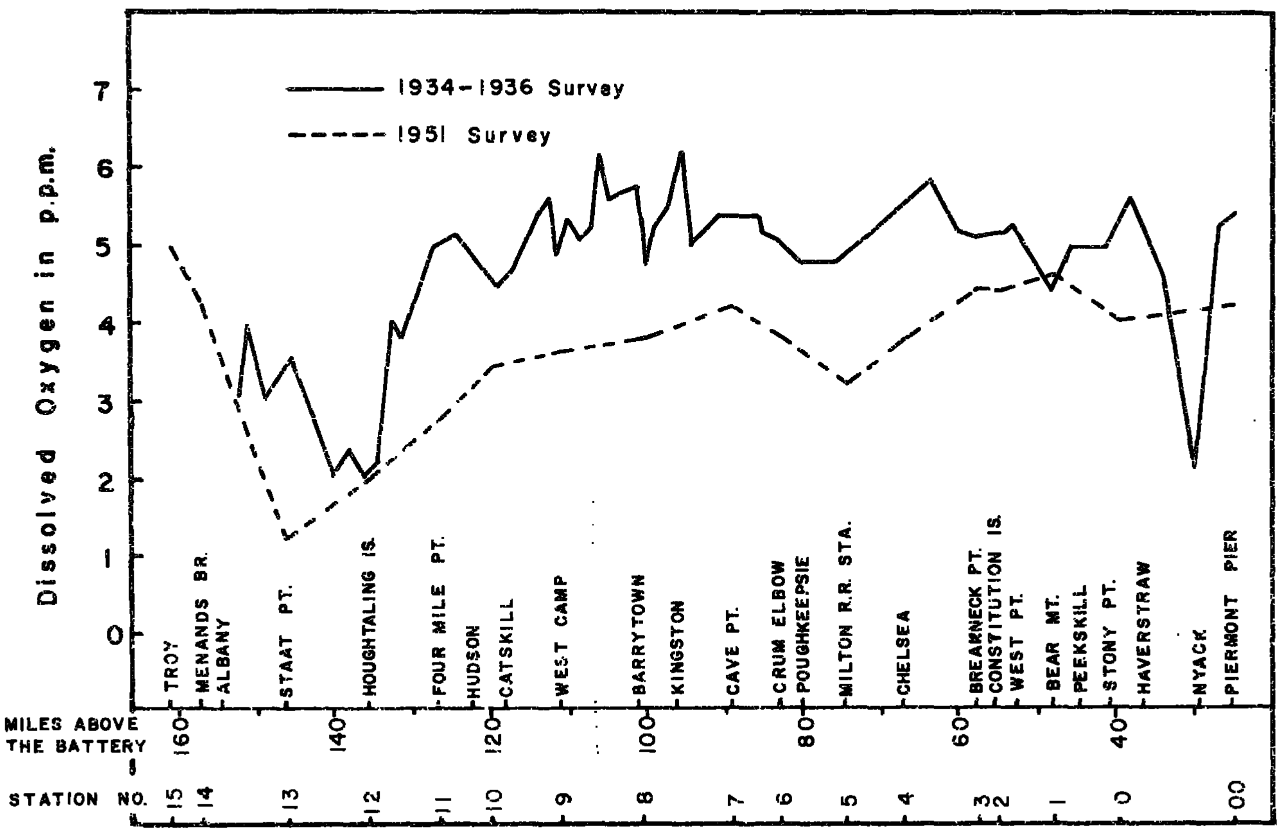

FIGURE 14.—Mid-depth minimum dissolved-oxygen determinations in 1951 and all mid-depth dissolved-oxygen determinations in 1934–36 at various stations between Troy and Piermont.

pling equipment became covered with it after short use in many areas, though not too evident visually. From observations made, it was apparent that some of this oil entered the water through spillage while oil tankers unloaded at shore installations, but most of it apparently came from tankers and oil barges illegally pumping their bilges and tanks into the river on the downstream run after delivering products, such as gasoline, lumber, fuel oil, and kerosene to upriver ports. In recent years the greatest percentage of freight transported on the Hudson River has been that of oil products, and the total tonnage hauled has increased tremendously. Pollution from this source, according to fishermen, sportsmen, and others, also has greatly increased during the past few years.

As pointed out by Chipman and Galtsoff (1949), the toxicity of oil in water has been demonstrated many times experimentally, using fishes and marine invertebrates, and these authors present data showing the toxicity of various oils to several forms of marine life. The toxic effect of oil appears to result from a substance or substances leached from the oil by water. Since no measure of this pollutant is available, it is not possible at this time to estimate its effect on the shad runs.

With the increase in oil pollution there have come many complaints about the flavor of shad from the Hudson River. Organoleptic tests by our field staff disclosed that these complaints were well founded. In 18 out of 20 shad tested there was a definite off flavor which could best be described as tasting like gasoline or kerosene. In some fish this was barely discernible, but in others it was strong, and in several the smell of kerosene was detected while cooking the fish. Apparently the off flavor of the resident fishes is worse than that of the anadromous shad, for Hudson River carp, catfish, perch, and some others are no longer acceptable on New York City markets.[2] Some fishermen transport Hudson River carp to fresh-water ponds where they are artificially fed until the off flavor disappears before marketing. Obviously, if the Hudson River is to produce edible fish in quantity, regulations concerning oil pollution should be rigidly enforced, and failure to do so may not only curtail the run, but make the fish unsalable.

[2] Personal communication from Henry Bearse, Market News Service, U. S. Fish and Wildlife Service, New York City.

From the data available, it can be concluded that parts of the Hudson River used, or formerly used, by shad are grossly polluted and that all parts of the river used by shad are polluted to such an extent as to be considered a poor fish habitat. The effect of pollution on shad production cannot be determined because records are not available to show changes in pollution. It is known, however, that pollution in the river below Troy Dam has been severe enough to cause comment before the beginning of the present century and even fish kills are noted in recent years (New York Conservation Dept. 1942). It is possible, therefore, that variations in predicted and calculated shad production as shown in table 12 have occurred because of different degrees of pollution resulting from the pollution load itself, variations in river runoff, water temperatures, wind, and rain. It is probably safe to conclude, although factual proof is lacking, that productivity and certainly quality of the shad would increase if pollution were diminished in this river.

CATCHES OUTSIDE THE RIVER

Returns of tagged shad from our enumeration work in 1950 and 1951 after termination of the fishing season in the river, were received from Long Island, the coast of Massachusetts, and Maine. The spring after tagging, tags were returned from North Carolina, Virginia, Maryland, Delaware, and New Jersey. These were comparatively few, but indicate that Hudson River shad during their migrations may be captured at least from Maine to North Carolina. The greatest percentage of outside returns came from the fishery along the New Jersey coast in the spring.

The results of unpublished tagging experiments (Hollis, Fish and Wildlife Service) conducted along the New Jersey coast and Staten Island, indicate that a large proportion of the shad caught in this region as well as some caught off Long Island are bound for the Hudson River, while lesser numbers are headed for the Connecticut River, Chesapeake Bay, and elsewhere. Table 20 shows the pound-net catches from these areas. The shad catches shown for Long Island include only the unspawned fish caught before June. The spawned-out fish caught in June and July have no market value as edible fish and are not recorded. The volume of shad caught in these areas is large enough to noticeably affect the catches in the

Hudson River should most or a large proportion of them be Hudson River fish (table 20). Fluctuations in these catches, as well as changes in the percentage of Hudson River shad in them, and catches of Hudson shad made elsewhere in waters outside the river, may well have produced a large part of the differences between calculated and predicted populations as shown in table 12. A study of the outside catches, particularly those made along the coast of New Jersey, to determine the composition or racial origin of the fish will be necessary if a more precise measurement is desired of the shad production of the Hudson River than was obtained in this study.

TABLE 20.—*Shad catches by New Jersey pound nets, Staten Island pound nets, and pound nets off Long Island from Jones Beach to Bellport Coast Guard Station, Great South Bay, Gardiner Bay, and Peconic Bay*

[In pounds. Statistics for Staten Island and Long Island from Bureau of Marine Fisheries, New York Conservation Department; those for New Jersey from New Jersey Department of Fish and Game]

Year	New Jersey Coast and Raritan Bay	Staten Island	Long Island	Total
1946	499, 877	175, 555	119, 306	794, 738
1947	303, 081	253, 168	36, 009	592, 258
1948	572, 521	223, 637	47, 659	843, 817
1949	411, 314	94, 556	54, 972	560, 842
1950	480, 435	204, 631	8, 930	693, 996
1951	150, 617	36, 200	12, 534	199, 351

CYCLES OF ABUNDANCE

It has been suggested (Burkenroad 1946) that cyclical fluctuations in abundance of Hudson River shad have occurred which may not be associated with human activities or random in period. In an attempt to determine whether definite natural cycles of abundance have occurred, we have examined the population curve in figure 5 and the deviations from regression in table 12. Clearly, no periodic cycles of abundance are reflected in the population curve, and the deviations from regression appear to be randomly distributed. Since it has already been shown that about 85 percent of the fluctuation in size of runs since 1920 was a function of fishing effort and related spawning escapement, cyclical changes in population size, if any, must have been small and would be entirely obscured by changes in fishing effort and spawning escapements.

Since natural cycles of abundance may have occurred over a longer period than the past 37 years, we have attempted to obtain data for the years previous to 1915. Catch data are available for some years as far back as 1880, but no comparable effort data are available previous to 1915 except for 1896. Therefore, we are unable to construct a true population curve covering a greater period of time because the size of the catch depends on fishing effort as well as on the actual size of the population. As a result, catch data alone are often misleading and the formulation of cyclic theories therefrom is, to a considerable degree, pure speculation. For lack of better information, however, and because we wish to obtain some indication of the size of the shad runs for a long period of time in which natural cycles might be more evident, we shall use catch records and adjective estimates of the size of the catches available for some years as far back as 1834. These have been obtained from several sources (New York Fish Comm., 1869–96; New York Forest, Fish and Game Comm., 1895–1910; U. S. Comm. Fish and Fisheries, 1884–1905; U. S. Bur. Fish., 1907, 1921–41; U. S. Bur. of the Census, 1911; and Stevenson 1899). Devoe (quoted in Burkenroad 1946) noted the condition of the Hudson shad fishery as early as 1824, but his remarks pertain only to the fyke-net fishery in or near New York Harbor and not to the river as a whole.

Adjective estimates are a poor indication of the condition of the fishery, since a slight decline after several good years is usually referred to as a "poor" year, whereas a catch of the same magnitude after a series of worse years may be referred to as "average" or "good." Newspaper articles in 1948, for instance, reported that the Hudson shad run was the poorest in 50 years, and in 1951 the run was reported as the poorest on record. Neither of these statements is in agreement with the catch records (fig. 2). We have therefore used only those adjective estimates from publications having a particular interest in the Hudson River shad fishery, and these estimates we do not consider as irrefutable. Another source of error is the fact that for some of the early years the catch figures attributed to the Hudson include catches in New York Bay, or sometimes for the whole State of New York, whereas for other years only the catches actually made in the river are included. These errors are probably not great enough to obscure the general magnitude of the catches since almost all the shad caught in New York are from the Hudson River. The data collected are presented in figure 15. Where actual figures for the size of the catch were available they were plotted according to the right-hand scale in pounds caught. When numbers rather than pounds of fish were given they were roughly converted to pounds by a factor of three. Where adjective estimates only were available they were plotted according to the adjective scale shown on the left of figure 15.

Two definite peaks of abundance are approximately centered in the years 1887 and 1942, which are 55 years apart. If the adjective estimate of 1855 is disregarded and it is assumed that the run was good for a period around 1832, it would appear that there might be evidence of a 55-year cycle of abundance of shad on the Hudson. The records indicate, however, that the run of 1855 was good. Furthermore, the records show that the runs were, in general, good between 1877 and 1901. The runs of 1881, 1884, and 1892, listed as "poor" during this period, were in all probability better than is shown in figure 15, since the reference "poor" probably inferred that the runs were poor compared with the years immediately previous which were good. In any event, there were a series of fairly good runs from 1877 through 1901, or for a period of 25 years. No records are available for a similar period around 1832, but the last period of abundance from 1936 to 1949 is only for 14 years. This is not what would be expected, if the runs were fluctuating at a regular 55-year natural cycle of abundance.

Since there is no reason for discarding the indicated "good" catch of 1855, there is no evidence from the available records to indicate that the Hudson River shad runs are following any natural cycle of abundance, or that cyclic fluctuations produce the deviations from regression as shown in table 11.

SUMMARY AND CONCLUSIONS

The shad fishery of the Hudson River was at a low level of production during the early years of this century until 1934. Then, unlike that of most shad streams along the Atlantic coast, its production increased tremendously, and for the next 12 years the catches almost equaled those of the best years on record. After 1945, a decline in catches occurred, and at present the catch is nearing the previous low level of production.

The Fish and Wildlife Service, acting as the primary research agency of the Atlantic States Marine Fisheries Commission, began a study of the Hudson shad fishery in 1950 as part of an investigation of the Atlantic-coast shad to seek the underlying causes of the decline, to determine

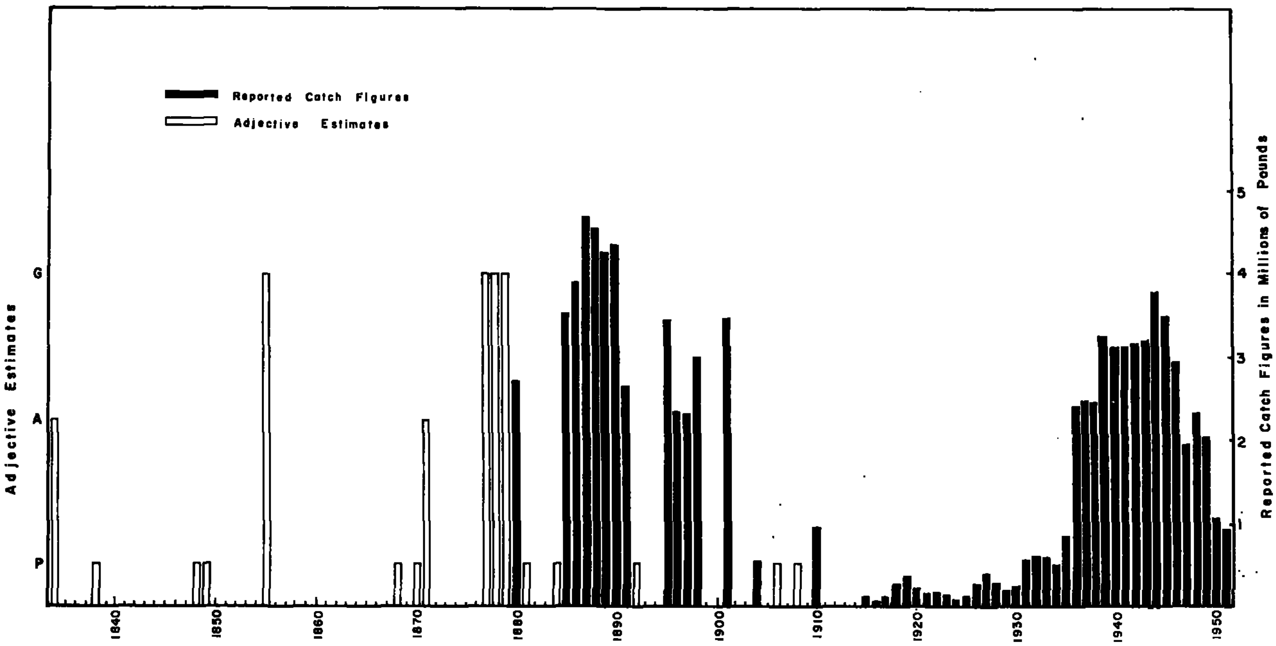

FIGURE 15.—Hudson River shad catches and adjective estimates for some years between 1834 and 1951. *G* indicates good catch, *A*, average catch, and *P*, poor catch.

conditions favoring recovery, and to provide basic information for proper scientific management of the fishery for obtaining a maximum sustained yield.

Catch statistics for the Hudson River shad fishery were compiled from all available sources. Only the drift and stake gill net fishermen in New York and the stake gill net fishermen in New Jersey fish consistently throughout the fishing season or through the peak of the season. The study of the Hudson shad fishery was therefore limited to these gears, and since effort data were available only for the nets fishing under special gill-net licenses in New York, only these were used for the New York fishery. Since these types of gear usually catch more than 95 percent of the shad caught in the Hudson, little validity is lost by the restriction. Catch and effort data were obtained for each year from 1915 through 1951. The total shad populations entering the river in 1950 and 1951 were enumerated by tagging experiments. Using the method developed by Fredin, the shad population and escapement for each year back to 1915 were calculated from the catch and effort data.

According to scale readings from a sample of the catch of 1950 and 1951, Hudson River shad spawn for the first time predominantly at 4 and 5 years of age. Of the shad caught, 51 percent had spawned previously; the ages of those caught were preponderantly 4, 5, and 6 years. Therefore, since the catch of any year depends on the progeny of the shad that spawn 4 and 5 years earlier and the fish that escape the fishery the year previous to any year's catch, the effect these have on the run of any year was evaluated by means of a multiple-regression analysis. This disclosed that approximately 85 percent of the fluctuation in the size of runs each year can be accounted for by changes in the escapement 5, 4, and 1 year earlier than the year of individual runs.

By using the regression equation, populations predicted from the escapements 5, 4, and 1 year earlier were calculated. The differences between these predicted populations and the actual populations calculated from catch and effort data illustrated the effect of factors other than escapement on the populations.

Several factors which have been blamed for the decline in shad production have been examined. No correlation was found between stream flows, water temperatures, channel improvements, ship traffic, hatchery operations and the production of shad.

From the available data there was no evidence that the shad runs fluctuated in natural cycles of abundance.

Pollution of the Hudson River is a serious problem and may be an important factor in shad production, but there are no records available to show changes in pollution on the spawning and rearing grounds so that cause-and-effect relations can be shown, if they exist.

Limited tagging studies have indicated that Hudson River shad are caught outside the river from Maine to North Carolina, but are taken in large numbers only along the New Jersey coast, and off Staten and Long Islands. A study of these fisheries is necessary to determine what percentage of the catch is Hudson River shad, if more precise data on Hudson River shad production is desired than has been presented here.

This study has shown that within the limits of the populations studied, the largest factor in the fluctuations of shad in the Hudson River is that of the number of shad escaping the commercial fishery to spawn. While pollution and catches outside the river may have an important effect on this fishery, on the average about 85 percent of the variations in the size of the run each year is dependent on the size of the escapement 5, 4, and 1 year earlier. By using the methods outlined in this paper it is possible to predict the size of the shad run one year in advance within desired confidence limits. By controlling the fishing effort with days closed to fishing, as has previously been done, the desired number of shad can be allowed to escape so that the size of future runs can be regulated to produce maximum sustained yields of shad.

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