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SEMIANNUAL ESTIMATES OF NATURAL MORTALITY OF HATCHERY BROOK TROUT IN LAKES[1]

by

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[1] Contribution from Dingell-Johnson Project F-17-R, Michigan.

The rate and time of natural mortality in trout populations in lakes have been determined in only a few cases (Eipper, 1960; Alexander and Shetter, 1961). The causes of natural mortality cannot be readily assigned until the rate has been measured and time of occurrence is known. In Ford and Hemlock lakes, at the Pigeon River Trout Research Station, located near Vanderbilt, Michigan, the largest natural loss of hatchery brook trout (Salvelinus fontinalis) occurred during the first summer. The rate of natural mortality during summer decreased with a decrease in numbers stocked. The loss over winter was negligible. The causes of the mortality were unknown.

Ford Lake has about 10 acres and a maximum depth of 29 feet. Hemlock is about 6 acres, and has a depth of 59 feet. Both lakes have been described by geologists as limestone sinks, i.e., formed through the solution of underlying limestone by ground water and a settling of the surface layer of sand and gravel, producing a cone-shaped pot hole. (For a more complete physical and chemical description of each lake, see Eschmeyer, 1938, for Ford Lake; and Tanner, 1960, for Hemlock Lake.)

A permit-type creel census has been in operation at the station since 1949. All anglers are required to report their catch at the end of each trip to each lake, which guarantees a nearly complete record of the harvest. Semiannual estimates of the number of trout in Ford and Hemlock lakes were begun in the autumn of 1956 by Waters (1960). Estimates have been made in October and April each year since then.

Trout reproduction is unsuccessful in these lakes; the fishery is maintained by annual plantings of fingerling trout from the State hatchery at Oden, Michigan. The original stocking rate was 500 trout per acre; however, starting with the 1957 year class the rate was reduced to 100 per acre. Prior to 1957, Ford Lake received 5,850 and Hemlock 3,000 fingerling brook trout (age-group 0) each autumn. Presently, the lakes receive 1,170 and 600 fingerlings, respectively. Each year class is identified by a distinctive fin-clip combination made at the time of planting. Since 1956, trout 5 to 6 inches long (average about 5.5 inches total length) have been selected for each planting. Although both lakes were poisoned in the early 1950's, the mudminnow (Umbra limi) is present in Ford Lake and the bluntnose minnow (Pimephales notatus) in Hemlock Lake. Probably the mudminnow survived the poisoning, but the bluntnose minnow was introduced into Hemlock Lake after the poisoning, undoubtedly by an angler fishing illegally with minnows.

Regulations on trout fishing in Hemlock Lake include: a minimum size of 7 inches, a creel limit of 5 fish, and no restriction as to lure or bait except that minnows cannot be used. The same regulations have applied on Ford Lake with the addition, since 1955, of a flies-only restriction, i.e., only the commonly accepted wet or dry fly can be used as bait. An evaluation of the flies-only regulation will be made after the effects of the reduction in number of trout planted are no longer evident. The fishing season extends from the last Saturday in April through the second Sunday in September.

In general, Waters' (1960) procedure of using one gear to capture, and a different gear to recapture, was followed in making the "mark-and-recapture" estimates of population size. In most cases, this procedure provided the best estimate (judged on known populations and harvests). The estimates were calculated by Bailey's formula (a modification of the Petersen method) (Ricker, 1958), and the 95 percent confidence limits were calculated by use of Clopper and Pearson's (1934) chart. Fish were captured by angling, by netting with wire traps (Waters, 1960), and by shocking with direct current at night with underwater lights (Latta and Myers, 1961).

Because each year class was marked at planting with a distinctive fin clip, it was possible to estimate the number of fish in each year class, in the spring and autumn, before and after the fishing season, and identify in the creel census the number of fish from each year class caught by anglers during the fishing season. With these estimates and catch figures it was possible to calculate instantaneous mortality rates and conditional mortality rates for each year class (Ricker, 1958; see Widrig, 1954, and McCammon and LaFaunce, 1961, for origin of the term "conditional").

Population estimates

Methods of capture for marking and recovery, and the resulting estimates of population size for each April and October, 1958 through 1960, in Ford and Hemlock lakes are given in Tables 1-3. In general,

the procedure evolved into shocking in the spring for a sample of trout to be marked, and obtaining a recovery sample from the creel census for the ratio of marked to unmarked fish. Because a temporary clip (upper and/or lower tip of the caudal fin) was used to mark trout for the population estimate, the time for the recovery sample was limited to about three weeks. After this time, regeneration made the caudal clip obscure. The above procedure was used for all year classes that had grown to the legal size of seven inches or longer by spring. The last planting (made the previous fall) and, in some cases earlier plantings, had few fish of legal size by spring so that it was necessary to take the recovery sample by shocking and fishing rather than by creel census.

For the fall estimates, the general procedure was to take the sample for marking by fishing with flies, and the recovery sample by shocking. The lakes were not stocked with the next year class until the population estimates had been completed.

A summary of the number planted, the catch each year and the fall and spring estimates for each year class from 1956 through 1960 is given for Ford Lake in Table 4 and for Hemlock Lake in Table 5.

In some years, the estimate in the spring exceeded slightly the estimate for the previous fall. This happened at Ford Lake in April, 1959, and October, 1958, for the 1956 and 1957 year classes, and in April, 1960 and October, 1959 for the 1958 year class (Table 4). At Hemlock Lake, the April, 1958 estimate exceeded the October, 1957 estimate for the 1956 year class by 48 trout, the largest difference for

either lake; the April, 1959 estimate was slightly larger than the number planted in November, 1958 (Table 5). Some of these differences may be systematic errors associated with techniques or behavior of the trout (during the fall the trout are in spawning aggregations in the shallow water), or they may be chance occurrences noticeable because of the small change in population size over winter. In computing the instantaneous mortality rates in these cases, it was assumed that there was no decrease in the population from October to April and the population size was considered the mean of the two estimates.

Mortality

Instantaneous total mortality (i), fishing mortality (p) and natural mortality (q) were computed for each year class of brook trout in Ford and Hemlock lakes for the years 1956 through 1960 (Tables 6 and 7). The instantaneous mortality rates p and q were converted to conditional mortality rates m and n (Tables 8 and 9). The conditional fishing mortality rate m and the conditional natural mortality rate n represent the percentages of the fish present at the beginning of the season that would die from each cause on the condition that the other cause was nonoperative. Total mortality a for the winter, while there is no fishing, is equivalent to natural mortality n during the summer. Also the winter period was equal to the summer period in time because the fish were marked in April and October for semiannual estimates. Natural mortality, as represented by a for the winter and n for the summer, was plotted for each year class

for Ford and Hemlock lakes in Figures 1 and 2. Natural mortality was much greater during the summer than during the winter period. The variations from this pattern in the third and fourth years for trout in Hemlock Lake were the result of few fish being left in a year class after the second summer in the lake.

Natural mortality was greatest during the first summer in the lake. In Ford Lake, $\underline{n}$ during the first summer varied from 0.408 to 0.717, and in Hemlock Lake, from 0.519 to 0.795, for the years 1957-60 (Tables 8 and 9). Natural mortality was plotted for each year class by summers in the lake in Figure 3. The only exception to the above statement that natural mortality was greatest during the first summer in the lake occurred in the second summer of the 1958 year class in Ford Lake. This point continued an upward trend for natural mortality for the second summer in Ford Lake in opposition to the second summer in Hemlock Lake which had a downward trend and to other summers which had a general decline in mortality for each year class. The explanation for this upward trend is not apparent.

In 1957, the stocking rate was reduced from 500 to 100 trout per acre in both lakes. The decrease in the size of the population each spring is shown in Figure 4 and Table 10. With a decrease in the size of the population there has been a general decrease in the natural mortality rates for each summer as indicated in Figure 3.

Figure 1.--Semiannual estimates of natural mortality for each year class of brook trout during years of life in Ford Lake, 1956-60.

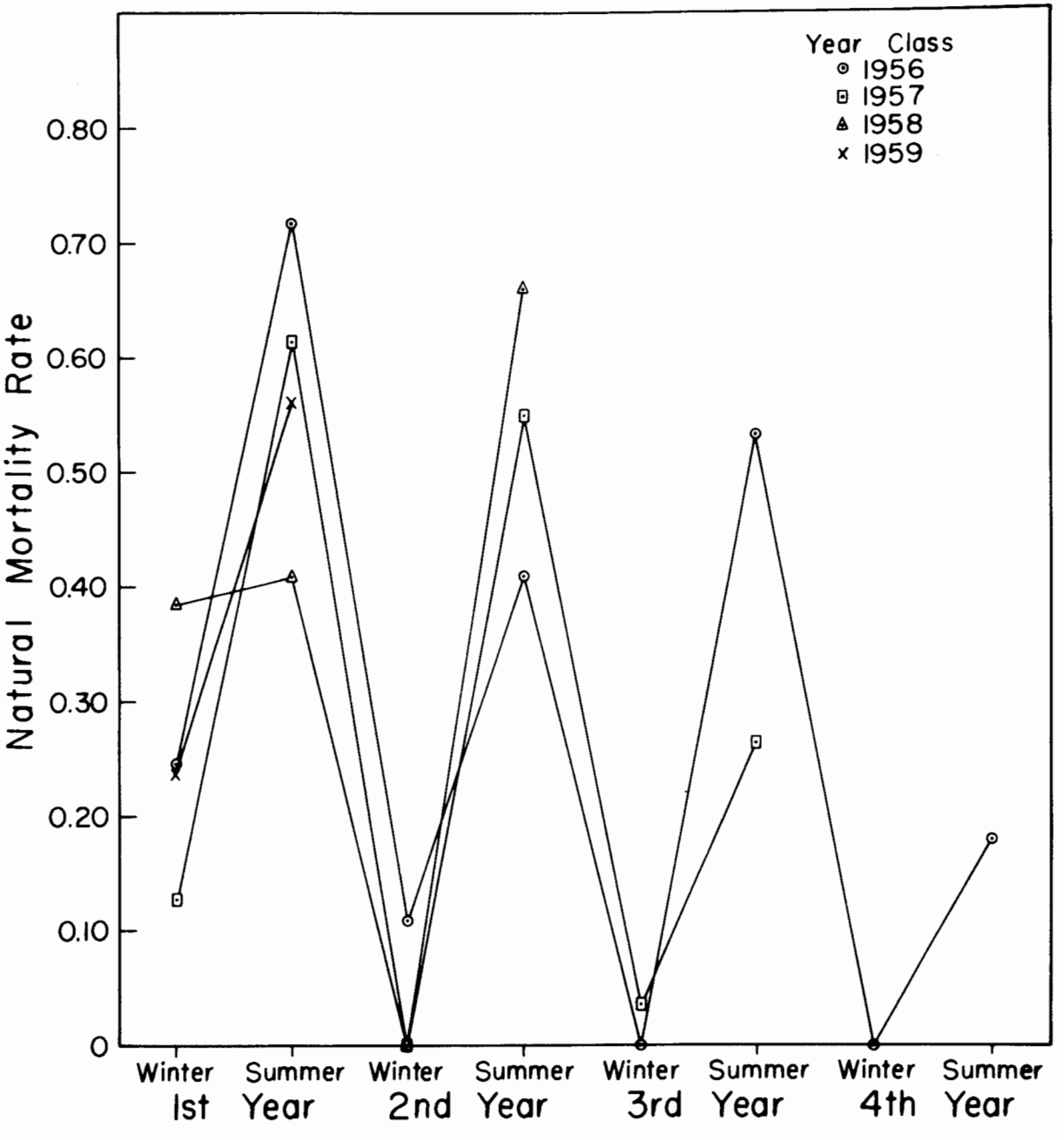
Year Class
1956
1957
1958
1959
Natural Mortality Rate
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0
Winter
Summer
Winter
Summer
Winter
Summer
Winter
Summer
1st Year
2nd Year
3rd Year
4th Year

Figure 1

Figure 2.--Semiannual estimates of natural mortality for each year class of brook trout during years of life in Hemlock Lake, 1956-60.

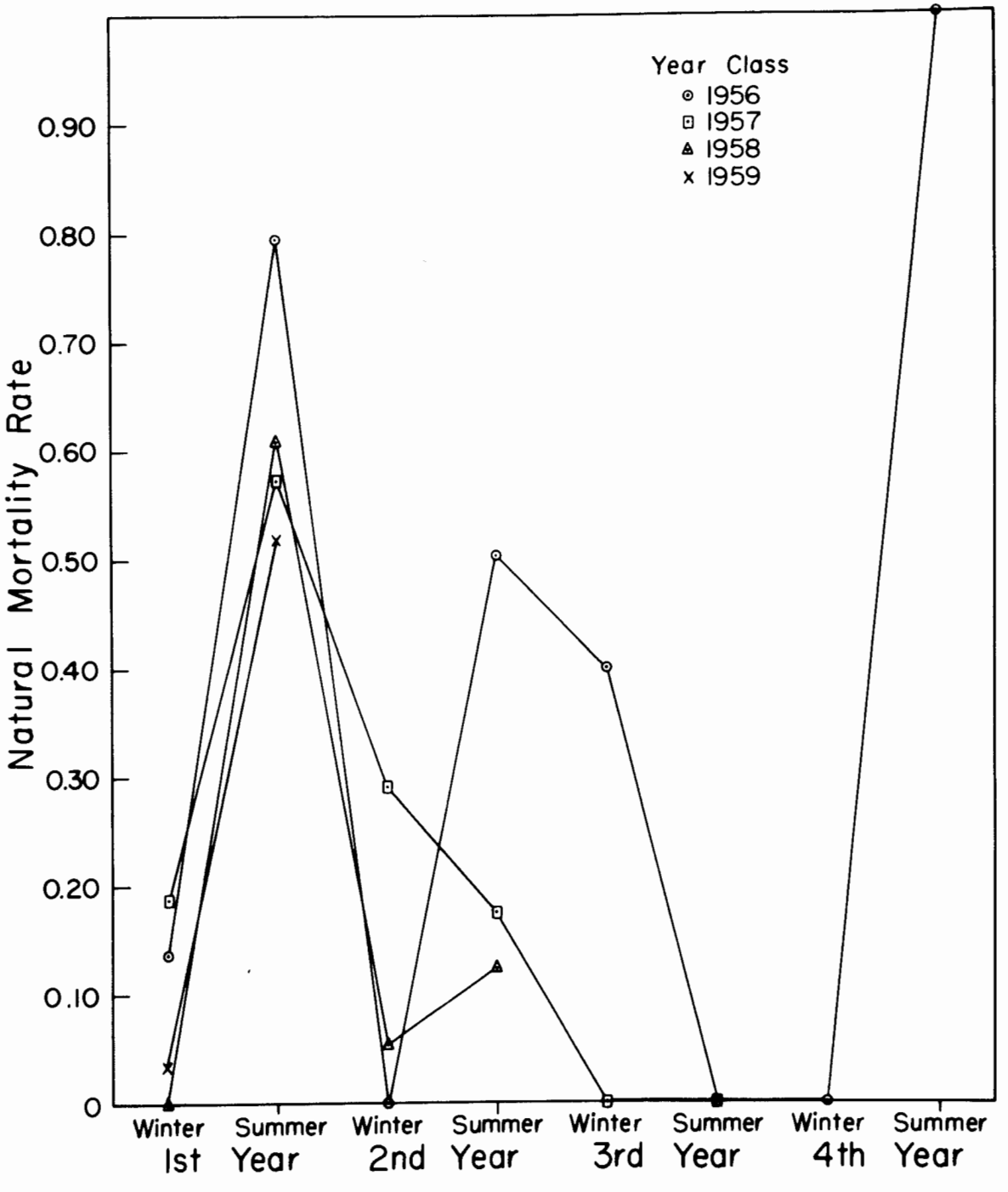
Year Class
1956
1957
1958
1959
Natural Mortality Rate
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0
Winter
Summer
Winter
Summer
Winter
Summer
Winter
Summer
1st Year
2nd Year
3rd Year
4th Year

Figure 2

Figure 3.--Natural mortality rate, n, for each year class of brook trout during each summer in Ford and Hemlock lakes, 1957-60.

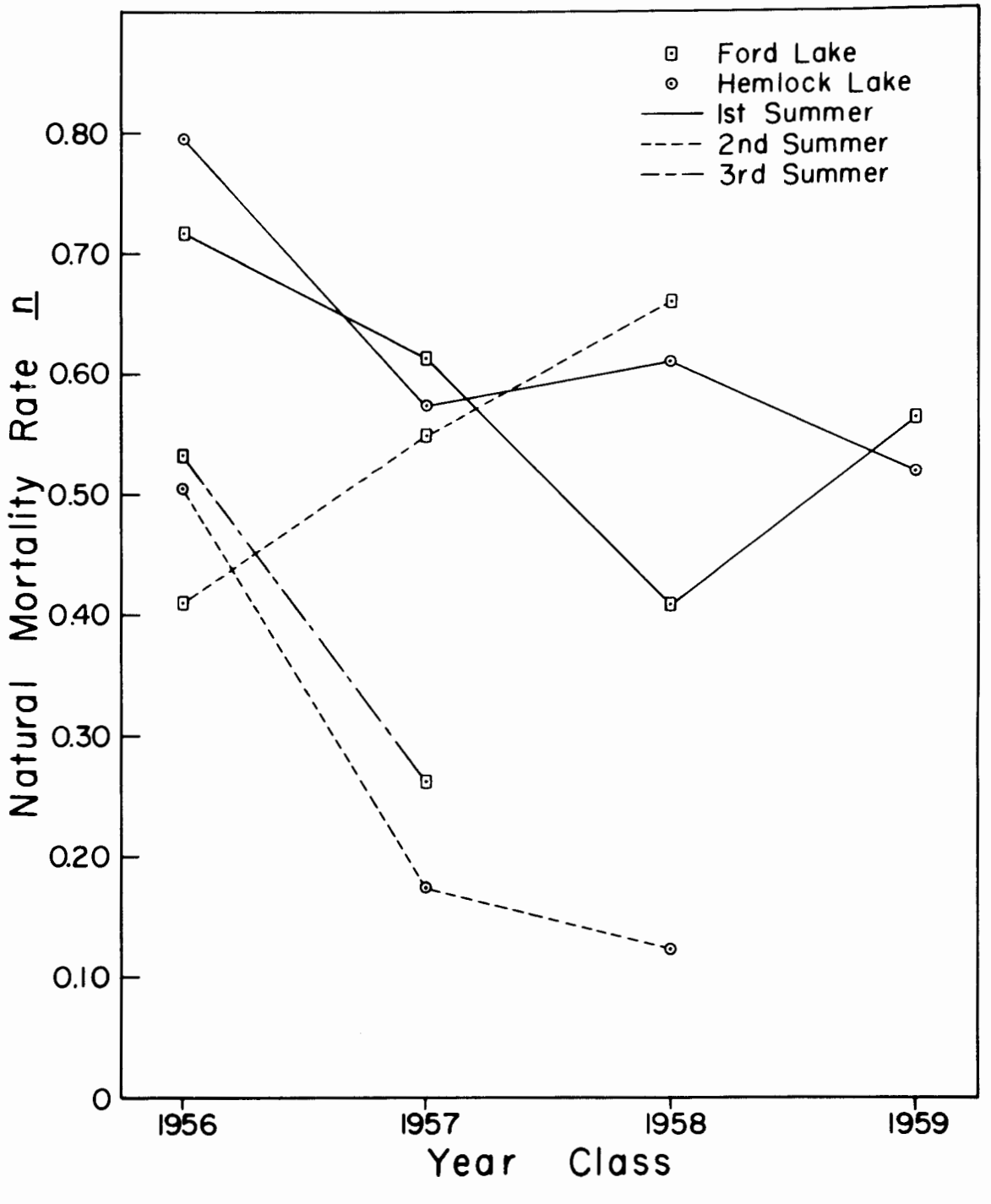
Ford Lake
Hemlock Lake
1st Summer
2nd Summer
3rd Summer
Natural Mortality Rate n
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0
1956
1957
1958
1959
Year Class

Figure 3

Figure 4.--Total number of brook trout estimated to be present in April, 1957-60, in Ford and Hemlock lakes.

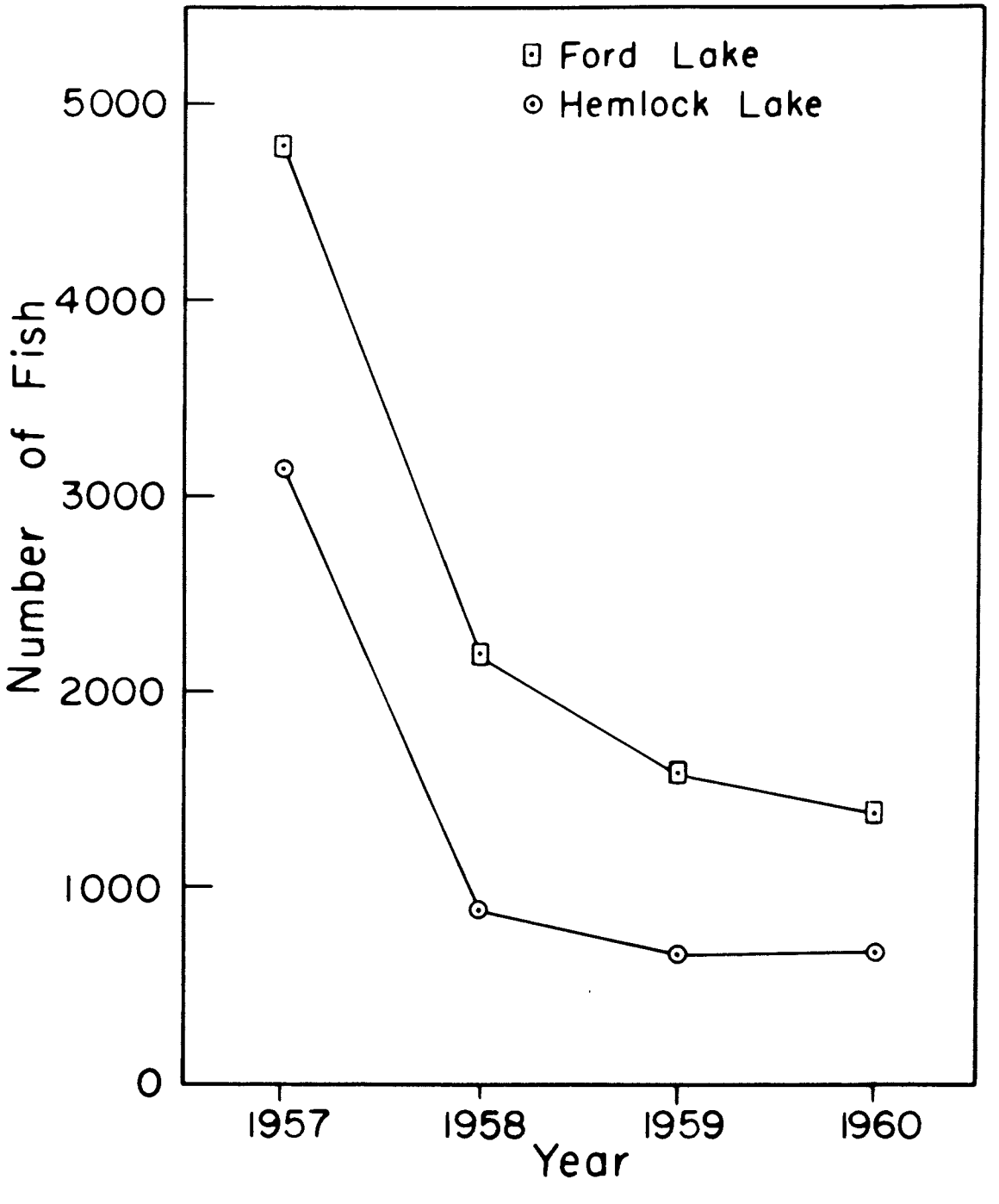
Ford Lake
Hemlock Lake
5000
4000
3000
2000
1000
0
Number of Fish
1957
1958
1959
1960
Year

Figure 4

With a decrease in the number of fish in each lake there has been a tendency for an increase in the fishing mortality rate (Figure 5). The exceptions were the first summers for the 1958 and 1959 year classes in Hemlock Lake. The explanation for this may lie either with fishing pressure (hours) which decreased in 1959 and 1960 (Table 11) or in growth which also decreased during these years[2] or a combination of these two factors.

While there has been a decrease in fishing pressure on Hemlock Lake, there has been an increase in pressure on Ford Lake (Table 11).

Discussion

Eipper (1960) found a pattern of mortality, similar to what I found, for "spring fingerlings" (about two inches long) of brook, brown and rainbow trout planted in the spring in farm ponds in New York.

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[2] In Hemlock Lake, growth increment for the first summer in the lake for each year class has decreased from 3.44 inches for 1958, to 2.71 inches for 1959, to 2.53 inches in 1960. Probably this is associated with the increase in numbers of bluntnose minnows in the lake during the same years, but there is no quantitative information available on degree of increase in the minnow population. Larkin and Smith (1954) documented a decrease in growth of the Kamloops trout with an increase in abundance of the redside shiner.

Figure 5.--Fishing mortality rate, m, for each year class of brook trout during each summer in Ford and Hemlock lakes, 1957-60.

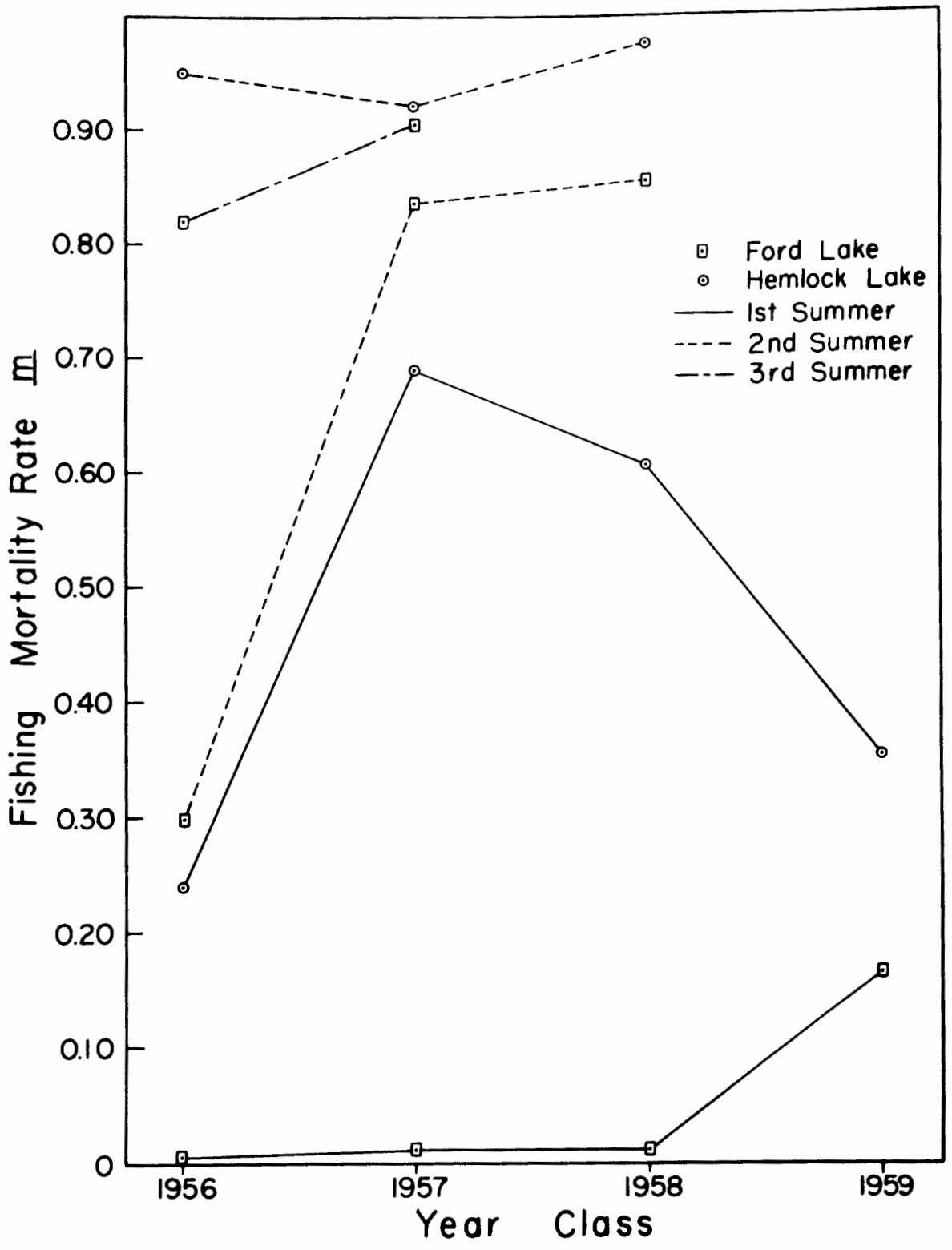
Fishing Mortality Rate m
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0
1956
1957
1958
1959
Year Class
Ford Lake
Hemlock Lake
1st Summer
2nd Summer
3rd Summer

Figure 5

During the first summer, mortality averaged about 70 percent. In the two succeeding summers, average mortality was about 50 percent. Over-winter mortality in each year of life was commonly between 20 percent and 40 percent. These "spring fingerlings" were apparently planted at the rate of 2,000 per acre.

In an unfished farm pond planted at the rate of 600 "fall fingerlings" (brook or rainbow trout, 3 to 7 inches long) per acre, the mortality over winter was of the same magnitude as that over summer. Similar results were obtained when fewer trout were stocked. Eipper states "This trout mortality from natural causes is a gradual process and takes place more or less continuously, even though the dead fish are very seldom seen."

In planting "spring fingerlings" Eipper got a mortality pattern similar to that in Ford and Hemlock lakes, but in planting "fall fingerlings," which would be comparable to the size of the brook trout planted in Ford and Hemlock lakes, rate of mortality was about the same during winter and summer and apparently there was no decrease in mortality with a decrease in planting rate (or density of the population).

Alexander and Shetter (1961) planted 300 brook trout and 300 rainbow trout, in October, in East Fish Lake, Michigan. The trout ranged in total length from 8.5 to 9.5 inches. Natural mortality for the rainbow trout was practically nil, while two-thirds of the brook trout died before the fishing season opened the following April. Most of the loss occurred between November 9 and January 2.

The causes of the natural mortality in Ford and Hemlock lakes remain unknown. Neither Eipper (1960) nor Alexander and Shetter (1961) present any evidence for the causes of death in their studies. Speculations range from predation to a physiological change associated with spawning. With some information now accumulating on the rate and season of natural mortality, the next step is to determine the causes.

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Table 1.--Methods of capture and estimates of population size for each year class of brook trout in Ford and Hemlock lakes, April and October, 1958

Lake	Date of population estimate	Method of capture for		Year class	Estimate (number of brook trout)	95 percent confidence limits
		Marking	Recovery			
Ford	April, 1958	Nets	Shocking 1N,[1] fishing[2]	1956	1,110	930-1,506
		Nets	Shocking 1N, fishing	1957	1,023	691-1,535
Hemlock	April, 1958	Shocking 1N, nets	Creel census[3]	1956	428	367- 530
		Shocking 1N, nets	Fishing	1957	488	391- 719
Ford	October, 1958	Fishing	Shocking 2N, nets	1956	459	381- 513
		Fishing	Shocking 2N, nets	1957	386	340- 446
Hemlock	October, 1958	Fishing	Shocking 2N, nets	1956	10	8- 22
		Fishing	Shocking 2N, nets	1957	65	60- 72

[1] Direct-current shocker used at night with underwater lights; 1N indicates number of nights at the lake.

[2] Station personnel fishing with flies.

[3] Anglers' catch examined for ratio of marked to total number of fish caught.

Table 2.--Methods of capture and estimates of population size for each year class of brook trout in Ford and Hemlock lakes, April and October, 1959

Lake	Date of population estimate	Method of capture for		Year class	Estimate (number of brook trout)	95 percent confidence limits
		Marking	Recovery			
Ford	April, 1959	Shocking 2N[1]	Creel census,[2] shocking 2N	1956	463	369-787
		Shocking 2N	Creel census, shocking 2N	1957	399	307-554
		Shocking 2N	Shocking 2N	1958	720	596-920
Hemlock	April, 1959	Shocking 2N	Creel census, shocking 1N	1956	6	...
		Shocking 2N	Creel census, shocking 1N	1957	46	38- 85
		Shocking 2N	Shocking 1N	1958	604	515-746
Ford	October, 1959	Fishing[3]	Shocking 2N	1956	39	35- 55
		Fishing	Shocking 2N	1957	29	23- 51
		Fishing	Shocking 2N	1958	418	356-535
Hemlock	October, 1959	Fishing	Shocking 2N	1958	93	80-112

[1] Direct-current shocker used at night with underwater lights; 2N indicates number of nights at the lake.

[2] Anglers' catch examined for ratio of marked to total number of fish caught.

[3] Station personnel fishing with flies.

Table 3.--Methods of capture and estimates of population size for each year class of brook trout in Ford and Hemlock lakes, April and October, 1960

Lake	Date of population estimate	Method of capture for		Year class	Estimate (number of brook trout)	95 percent confidence limits
		Marking	Recovery			
Ford	April, 1960	Shocking 2N[1]	Creel census[2]	1956	39	21- 117
		Shocking 2N	Creel census	1957	28	18- 140
		Shocking 2N	Creel census	1958	425	316- 612
		Shocking 1N	Shocking 1N	1959	891	648-1,296
Hemlock	April, 1960	Shocking 2N	Creel census	1958	88	70- 130
		Shocking 1N	Shocking 1N	1959	579	468- 743
Ford	October, 1960	Fishing[3]	Shocking 2N	1958	31	...
		Fishing	Shocking 2N	1959	325	268- 404
Hemlock	October, 1960	Fishing	Shocking 2N	1959	180	146- 231

[1] Direct-current shocker used at night with underwater lights; 2N indicates number of nights at the lake.

[2] Anglers' catch examined for ratio of marked to total number of fish caught.

[3] Station personnel fishing with flies.

Table 4.--Number planted, anglers' catch and estimates of population size for each year class of brook trout in Ford Lake, 1956-60

Year	Month	Procedure	Year class			
			1956	1957	1958	1959
1956	October	Plant	5,850	...	...	...
1957	April	Estimate	4,410[1]	...	...	...
	April-September	Catch	14	...	...	...
	October	Estimate	1,244[2]	...	...	...
	November	Plant	...	1,170	...	...
1958	April	Estimate	1,110	1,023	...	...
	April-September	Catch	261	7	...	...
	October	Estimate	459	386	...	...
	November	Plant	...	...	1,170	...
1959	April	Estimate	463	399	720	...
	April-September	Catch	292	252	6	...
	October	Estimate	59	29	418	...
	November	Plant	...	...	...	1,170
1960	April	Estimate	39	28	425	891
	April-September	Catch	36	23	257	101
	October	Estimate	1[3]	2[3]	21	325

[1] Estimate from Waters, 1960.

[2] Estimate from Waters, 1960, manuscript. Fish to be marked were caught by angling and recaptures were taken with wire traps. See Waters, 1960 for discussion of procedure.

[3] Minimum estimate; number of fish handled.

Table 5.--Number planted, anglers' catch and estimates of population size for each year class of brook trout in Hemlock Lake, 1956-60

Year	Month	Procedure	Year class			
			1956	1957	1958	1959
1956	October	Plant	3,000	...	...	...
1957	April	Estimate	2,591[1]	...	...	...
	April-September	Catch	322	...	...	...
	October	Estimate	380[2]	...	...	...
	November	Plant	...	600	...	...
1958	April	Estimate	428	488	...	...
	April-September	Catch	319	244	...	...
	October	Estimate	10	65	...	...
	November	Plant	...	...	600	...
1959	April	Estimate	6	46	604	...
	April-September	Catch	5	40	254	...
	October	Estimate	1[3]	3[3]	93	...
	November	Plant	...	...	...	600
1960	April	Estimate	1[3]	...	88	579
	April-September	Catch	0	3	83	149
	October	Estimate	...	...	2[3]	180

[1] Estimate from Waters, 1960.

[2] Estimate from Waters, 1960 manuscript. Fish to be marked were caught by angling and recaptures were taken with wire traps. See Waters, 1960 for discussion of procedure.

[3] Minimum estimate; number of fish handled.

Table 6.--Instantaneous mortality rates (total, i; fishing, p; natural, q) for each year class of brook trout in Ford Lake, 1956-60

Year and season	Year class											
	1956			1957			1958			1959		
	i	p	q	i	p	q	i	p	q	i	p	q
1956-57 Winter	0.28	...	...	...	...	...	...	...	...	...	...	...
1957 Summer	1.27	0.01	1.26	...	...	...	...	...	...	...	...	...
1957-58 Winter	0.11	...	...	0.13	...	...	...	...	...	...	...	...
1958 Summer	0.88	0.35	0.53	0.96	0.01	0.95	...	...	...	...	...	...
1958-59 Winter	0.00	...	...	0.00	...	...	0.49	...	...	...	...	...
1959 Summer	2.47	1.71	0.76	2.61	1.81	0.80	0.53	0.01	0.52	...	...	...
1959-60 Winter	0.00	...	...	0.03	...	...	0.00	...	...	0.27	...	...
1960 Summer	3.69	3.49	0.20	2.64	2.34	0.30	3.00	1.92	1.08	1.01	0.18	0.83

Table 7.--Instantaneous mortality rates (total, i; fishing, p; natural, q) for each year class of brook trout in Hemlock Lake, 1956-60

Year and season	Year class											
	1956			1957			1958			1959		
	i	p	q	i	p	q	i	p	q	i	p	q
1956-57 Winter	0.15	...	...	...	...	...	...	...	...	...	...	...
1957 Summer	1.86	0.27	1.59	...	...	...	...	...	...	...	...	...
1957-58 Winter	0.00	...	...	0.21	....	...	...	...	...	...	...	...
1958 Summer	3.69	2.99	0.70	2.02	1.16	0.86	...	...	...	...	...	...
1958-59 Winter	0.51	...	...	0.35	...	...	0.00	...	...	...	...	...
1959 Summer	1.79	1.79	0.00	2.73	2.54	0.19	1.87	0.93	0.94	...	...	...
1959-60 Winter	0.00	...	...	0.00	...	...	0.06	...	...	0.04	...	...
1960 Summer	∞	0.00	∞	∞	∞	0.00	3.77	3.64	0.13	1.17	0.44	0.73

Table 8.--Conditional mortality rates (total, a; fishing, m; natural, n) for each year class of brook trout in Ford Lake, 1956-60

Year and season	Year class											
	1956			1957			1958			1959		
	a	m	n	a	m	n	a	m	n	a	m	n
1956-57 Winter	0.246	...	...	...	...	...	...	...	...	...	...	...
1957 Summer	0.718	0.005	0.717	...	...	...	...	...	...	...	...	...
1957-58 Winter	0.108	...	...	0.126	...	...	...	...	...	...	...	...
1958 Summer	0.585	0.298	0.409	0.617	0.011	0.613	...	...	...	...	....	...
1958-59 Winter	0.000	...	...	0.000	...	...	0.385	...	...	...	...	...
1959 Summer	0.915	0.818	0.532	0.926	0.836	0.549	0.414	0.011	0.408	...	...	...
1959-60 Winter	0.000	...	...	0.034	...	...	0.000	...	...	0.238	...	...
1960 Summer	0.974	0.970	0.178	0.929	0.904	0.262	0.950	0.853	0.659	0.635	0.164	0.563

Table 9.--Conditional mortality rates (total, a; fishing, m; natural, n) for each year class of brook trout in Hemlock Lake, 1956-60

Year and season	Year class											
	1956			1957			1958			1959		
	a	m	n	a	m	n	a	m	n	a	m	n
1956-57 Winter	0.136	...	...	...	...	...	...	...	...	...	...	...
1957 Summer	0.844	0.239	0.795	...	...	...	...	...	...	...	...	...
1957-58 Winter	0.000	...	...	0.187	...	...	...	...	...	...	...	...
1958 Summer	0.975	0.950	0.504	0.867	0.688	0.574	...	...	...	...	...	...
1958-59 Winter	0.400	...	...	0.290	...	...	0.000	...	...	...	...	...
1959 Summer	0.833	0.833	0.000	0.935	0.921	0.174	0.846	0.605	0.610	...	...	...
1959-60 Winter	0.000	...	...	0.000	...	...	0.054	...	...	0.035	...	...
1960 Summer	1.000	0.000	1.000	1.000	1.000	0.000	0.977	0.974	0.124	0.689	0.353	0.519

Table 10.--Total number of brook trout estimated to be present in April, 1957-60, in Ford and Hemlock lakes

Year	Number of fish	
	Ford Lake	Hemlock Lake
1957	4,769	3,144
1958	2,167	898
1959	1,576	656
1960	1,380	668

Table 11.--Annual fishing pressure (hours) on Ford and Hemlock lakes, 1957-60

Year	Ford Lake	Hemlock Lake
1957	417.5	992.5
1958	360.0	995.0
1959	510.5	745.5
1960	503.0	670.5