Submitted for publication in the Transactions
of the American Fisheries Society

Original: American Fish.
cc: Fish Division
Education - Game
Institute for
Fisheries Research
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March 26, 1953

Report No. 1366

COMPARATIVE MORTALITY BETWEEN FLY-HOOKED AND WORM-HOOKED BROOK TROUT[1]

[1] Contribution from the Institute for Fisheries Research

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Abstract

Investigations on this problem were conducted during 1950, 1951, and 1952 at the Hunt Creek Fisheries Experiment Station, Montmorency County, Michigan, both in screened natural raceways and in the open stream, to determine if earlier observations (Westerman, 1932) on comparative mortalities from the two methods of fishing, made in hatchery ponds, were applicable to natural waters, and to obtain additional information on hooking mortality.

The experiments of 1950 were a failure because of loss of numerous experimental fish to disease, predators, and poaching.

In 1951, four series of experiments, conducted over 1,600 hatchery-reared brook trout (range in total length, 4.8-9.5 inches) held in screened natural raceways, were carried out. Two experiments compared

angling mortality resulting from the use of No. 12 artificial fly with mortality from the use of No. 8 long-shank hooks baited with worms; the other two experiments compared mortalities resulting from hooking with No. 12 flies against hooking mortalities from capture with No. 4 and No. 2 long-shank hooks baited with worms. It was found that the No. 12 artificial fly killed 1.70 percent of the 484 fly-hooked fish, while the No. 2, No. 4, and No. 8 long-shank hooks baited with worms killed 37.5 percent of 550 bait-hooked fish on which complete information was obtained. For all major comparisons the observed differences in mortalities between fly-fishing and worm-fishing are significant at the 99 percent level or above, according to adjusted Chi-square tests. It was demonstrated that the minor percentage of experimental fish lost to predators and/or other causes could not have influenced the final results. Of the long-shank bait hooks, the smaller sizes (No. 4 and No. 8) killed significantly more fish than did the No. 2's.

In 1952, three additional series of hooking experiments, using either one-half hatchery fish and one-half wild fish or all wild fish, yielded data which confirmed results of 1951. Of 82 brook trout hooked with No. 12 fly, 2 (2.44 percent) died; while from 79 brook trout captured by No. 6 and No. 8 long-shank hooks and worms, 33 (41.77 percent) died. The difference again is statistically significant.

In both 1951 and 1952, all mortalities observed were preserved for postmortem examination. Also, after the initial experiment in 1951, points of hooking for worm-caught fish were recorded for comparison with locations of lethal wounds among the preserved mortalities. In both years it was found that worm-caught fish hooked in the throat or gill arches were the most likely to die. The cheek, tongue, roof of the mouth, and eye or orbit occasionally were lethal hooking sites.

No fish hooked in the jaw were found dead. Mortalities assigned to throat hookings died as the result of injuries to internal organs, mainly the heart, arteries and liver. A limited amount of furunculosis, determined to be present by kidney examinations of a random sample of the preserved mortalities in both years, did not appear to have influenced the conclusions.

Combining the 1951 and 1952 results with data obtained earlier, it was concluded that fly hooking with No. 10 and No. 12 flies resulted in a mortality of 2.20 percent, as against a mortality of 26.65 percent for brook trout hooked on No. 2, No. 4, No. 6, and No. 8 baited hooks.

Implications of the experiments as they relate to problems of brook trout management are discussed briefly.

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For several decades fisheries administrators as well as trout fishermen have debated vigorously the merits of legislation limiting the taking of trout with various kinds of lures. The chief argument has been between the fly fishermen and the bait fishermen. The users of flies have long contended that the artificial fly in its various forms is an effective and sporting method for taking adult trout, and is less injurious than baited hooks to fish smaller than the legal minimum size. On the other hand, bait fishermen argue that natural baits are consistently better lures during more varied water conditions and that they take more and larger fish. Also, many of them claim that a properly fished bait hook is no more injurious to immature fish than is the artificial fly.

In the past, attempts to limit the taking of trout to the use of artificial fly have been called "class legislation." However, it seems high time to permanently lay this ghost to rest; the majority of trout stream anglers observed on Hunt Creek and other nearby streams during the past 10 years used some form of fly-rod and its accompanying equipment, regardless of the lure. The thought that restrictions against worms and calling for the use of artificial flies will deprive some barefoot, teen-age youth of his customary rights because of economic considerations involved in the necessary tackle is to a large extent fallacious.

What neither school of thought appears to have considered is the ultimate effect of the fishing method on the fish population over which

the angling is conducted. When all the facts are gathered, the angling method which inflicts considerably less damage to the stock of trout over the long run will be accepted by the intelligent sportsmen.

In 1930 and 1932, two sets of experiments on hooking loss were conducted at the State Fish Hatchery at Harrietta, Michigan, under the direction of F. A. Westerman (1932). These tests involved the hooking of 400 brook trout with No. 10 and No. 12 barbed artificial flies, 400 with barbed hooks (No. 6 and No. 8) with bait, and 500 with barbless hooks with bait. The fish were captured by hooking in one hatchery pool, then transferred to, and held for 30 to 43 days in, separate pools according to the lure used. The losses from hooking were: with artificial flies, 2.75 percent; with barbless hook and bait, 5.60 percent; with barbed hook and bait, 8.75 percent.

It was desired to learn if these results obtained by Westerman in ponded hatchery conditions were applicable to normal trout streams, and to obtain additional information on hooking mortality. Accordingly, the staff of the Hunt Creek Fisheries Experiment Station began exploratory studies in the summer of 1950 to determine comparative losses from hatchery-reared brook trout hooked with No. 12 fly and with various sizes of long-shank hooks baited with worms.

The 1950 experiments were a failure because of considerable loss of experimental fish to disease, predators, and poaching. Analysis of the effect of hooking with either fly or worm was almost impossible. The experience gained did aid in the conduct of the 1951 and 1952 experiments.

In 1951 the experimental technique was as follows: 100 hatchery-reared brook trout were planted in Diversion IIA and fished over with No. 12 barbed flies (either wet or dry). At the same time, 100

hatchery-reared brook trout were released in Diversion IIIA and fished over with different sizes of hooks baited with worms. These diversions are a part of the former natural stream channel, and were screened off with No. 4-mesh hardware cloth screens. Various staff members of the Institute for Fisheries Research attempted to make 100 hookings in each diversion. Hooked fish were marked by fin-clipping--adipose fin for first hooking, right pelvic fin for second, right pectoral fin for third hooking, etc. At the end of about a week, after noting any mortalities which occurred, the diversions were drawn down; all survivors were removed with the AC shocker, measured, and checked for marks. Mortalities occurring during the course of the experiment, both hooked and non-hooked, were preserved for later examination as to cause of death. The experiment was then repeated, using 100 new fish in each diversion; the location of the fly fishing and the bait fishing was reversed so as to eliminate the possible effect of differences of habitat between the two diversions.

This general experimental pattern was used to test No. 8 long-shank bait hooks (two separate runs), No. 4 long-shank bait hooks, and No. 2 long-shank bait hooks, each against No. 12 flies. Long-shank hooks were chosen for experimental use because they allow the greater shank length to grasp when extricating hooks from a fish's mouth.

The dimensions of the bait hooks used were as follows: No. 8 long-shank, 6.5 mm. gape by 30 mm. length; No. 4 long-shank, 9 mm. gape by 33 mm. length; and No. 2 long-shank hook, 11 mm. gape by 40 mm. length; these hooks were mainly of the Aberdeen type. The No. 12 flies had a gape of 5 mm., and the length varied depending on the pattern. Most flies were tied on either the Mustad or Allcock regular shank hooks.

In the course of the 1951 experiments 1,600 hatchery-reared brook trout were utilized, ranging in total length from 4.8 to 9.5 inches. Of the 800 fish available to the fly-fishing portion of the experiment, 512 fish were hooked; while 585 fish were hooked from a similar number of fish angled over with worms. The data concerning the four double runs operated in 1951 are summarized in Table 1. To determine if the various mortality ratios of fly-hooked fish differed significantly from the mortality ratios of bait-hooked fish, adjusted Chi-square tests were applied, following the procedure as outlined in Section 9.6, page 197, of Snedecor (1948). Except for testing the mortalities among the "lost, not hooked, not found" group, the figures used are found by the proper summations. The computed Chi-square values are listed in Table 2.

The 1951 Results

Considering first the total results from all fish hooked in 1951, and on which we had complete observations, Table 1 demonstrates that from 484 (476 + 8) hatchery-reared brook trout hooked with No. 12 flies, 8 fly-hooked fish died; while at the same time from 550 brook trout of similar origin hooked by the use of various long-shank hooks and worms, 206 fish later died. This difference in mortality ratios of hooked fish, between those hooked by fly and those hooked by bait, is highly significant (Chi-square = 198.87, P = 99.9+%). From the above figures it is computed that bait-fishing in this experiment was 22.1 times more lethal than angling with the No. 12 flies (mortality ratio for various long-shank hooks and worms, 37.5 deaths per 100 fish hooked; for No. 12 fly, 1.7 deaths per 100 fish hooked).

Table 1.--Observed hooking losses and survivals among hatchery-reared brook trout and numbers of experimental fish lost, in the 1951 hooking experiments.

Item	Trout present at start	Lost, not found, not hooked	Balance	Number of times fish were hooked (observed living--observed dead)					Hooked (once-twice) but not found
				0	1	2	3	1-3	
No. 12 fly	200	0	198	37-2	120-0	39-0	0-0	159-0	2-0
No. 8 LS (1)	200	3	192	26-1	58-82	8-14	3-0	69-96	4-1
No. 12 fly	200	2	193	78-1	97-2	15-0	0-0	112-2	5-0
No. 8 LS (2)	200	5	189	49-0	77-25	27-9	2-0	106-34	5-1
No. 12 fly	200	4	188	100-4	76-5	3-0	0-0	79-5	8-0
No. 4 LS	200	17	163	55-0	55-45	5-3	0-0	60-48	17-3
No. 12 fly	200	7	180	53-0	108-1	18-0	0-0	126-1	12-1
No. 2 LS	200	10	186	48-1	92-27	17-1	0-0	109-28	3-1
Totals No. 12 fly	800	13	759	268-7	401-8	75-0	0-0	476-8	27-1
Totals LS hook	800	35	730	178-2	282-179	57-27	5-0	344-206	29-6

Table 2.—Chi-square values resulting from comparisons of the living/dead ratios and the hooked-recovered/hooked-unrecovered among the fly versus bait replications of experimental fish (data are taken from Table 1). Underlined values are significant at the 95 percent level or above, and in favor of flies except for the comparison marked *.

Item	Lost, not hooked, not found*	Number of times fish were hooked					Hooked, not found**
		0	1	2	3	1-3	
No. 12 fly vs. No. 8 LS (1)	1.43	0.11	<u>99.99</u>	<u>28.71</u>	...	<u>128.68</u>	0.51
No. 12 fly vs. No. 8 LS (2)	0.82	0.06	<u>19.97</u>	3.00	...	<u>24.41</u>	0.07
No. 12 fly vs. No. 4 LS	9.11	0.88	<u>31.85</u>	0.24	...	<u>33.14</u>	1.73
No. 12 fly vs. No. 2 LS	0.26	0.00+	<u>23.07</u>	0.00	...	<u>24.05</u>	<u>4.07</u> *
Total No. 12 fly vs. Total LS hooks	<u>11.22</u>	0.53	<u>172.43</u>	<u>26.82</u>	...	<u>198.87</u>	0.05

* These values based on the "lost, not hooked, not found" category compared with the average number of unhooked fish present. The latter figure was regarded as the sum of the trout present at the start plus those lost, not hooked, not found plus the observed survivals and mortalities not hooked, this sum divided by 2.

** Chi-square values here computed from ratios of fish hooked and not found to the total fish hooked and found (both living and dead).

At the same time the brook trout not hooked in the experiment which were accounted for at the end of each "run" were as follows: brook trout in the fly water, 268 not hooked and living, 7 not hooked and dying; in bait water, 178 not hooked and living, 2 not hooked and dying. A Chi-square test of the difference between the ratios of living/dead non-hooked fish accounted for yields a value of 0.53 (P = 51%); the difference is non-significant. This evidence suggests that, aside from the mode of hooking, factors causing mortality were approximately equal in the two types of water. Reference to Table 1 shows further that the ratio of hooked fish unaccounted-for to total fish hooked, among fly-hooked fish, was 28/512; among bait hooked fish it was 35/585. The difference between these ratios also is non-significant (Chi-square = 0.05, P = 10%). The similarity in rate of loss of hooked fish (unaccounted-for) between fly water and bait water, occurred in three of the four tests, but not in the other one (No. 12 fly vs. No. 2 long shank hook and worm), as inspection of Tables 1 and 2 will show. In this latter test, where 13 fly-hooked fish were not found as compared to only 4 worm-hooked fish not found, the observed Chi-square value for hooking mortality would not be changed significantly by inclusion of records on hooked fish which were not accounted-for, even if all missing fly-hooked fish were regarded as observed mortalities and all missing bait-hooked fish were assumed to have been recovered alive. It therefore seems certain that the loss of information, because of predation, possible poaching, or inefficient final collection, has not influenced the conclusions to be made from this study.

For some reason, unexplicable at present, more non-hooked fish were lost (unaccounted-for) in the bait waters than in the fly waters

(Table 1). This result is at odds with the conclusion reached after analysis of the "hooked but not found" category. However, nothing is known of the fate of the "lost, not-hooked" fish after they were released, except that they disappeared. Many may have been removed by predators as healthy fish during the experimental work. Visual records and tracks of raccoon, mink, kingfishers, and blue herons provide evidence that predators were present in the vicinity of the diversions during the hooking tests.

It was thought possible to correct the mortality figures for hooked fish by the rates of mortality and loss for non-hooked fish, and arrive at a figure representing true hooking mortality. The resulting calculations yielded corrected mortality rates for fly and worm fishing much lower than those observed and later verified by autopsies. This confusing situation results apparently from the inclusion of the "non-hooked, lost" fish in the correction calculations--the group about which we have no definite knowledge as to possible causes of death and/or disappearance.

Finally, if one assumes the most adverse distribution of the lost fish as regards their effect on the conclusions concerning fly fishing (all lost fish in fly water hooked and observed to die, all lost fish in bait water hooked and observed to live, and these fish added to the observed survivors and mortalities), the ratio of survivors to mortalities for all experiments then would be:

No. 12 fly	476 living, 49 dead
All bait hooks	414 living, 206 dead

A Chi-square test of these ratios still indicates extreme significance in favor of fly fishing (Chi-square = 93.26, P = 99.9+%), even though

the unaccounted-for fish (both hooked and not-hooked) were assigned in a manner most likely to change the observed results.

It has been shown that inclusion of the unaccounted-for loss of experimental fish during the experiments could not change the ultimate conclusions, even when the most extreme assumptions are made on the side of safety. Generally, it is concluded that the lost fish may be disregarded, and that the dead fish among the observed categories may be regarded as mortalities caused by hooking. That almost all deaths among the observed mortalities definitely are attributable to the method of hooking also is substantiated by autopsies (see below).

In theory, the ratios of living/dead among hooked fish in the fly portions of the experiment should be about the same, since fly size was held constant throughout all tests. Chi-square tests of the living/dead ratios of fly-hooked fish from the four runs indicate one significant difference. Larger numbers of fly-hooked fish died during the "run" involving No. 12 fly vs. No. 8 long-shank hook (Table 3). All other comparisons of living/dead ratios were non-significant. This general uniformity in mortality of fly-hooked fish is also shown by Table 4, where the percentages of hooked fish dying are listed. In the four experiments, the rates were 0.0, 1.8, 6.0 and 0.8 percent respectively, for the experiments on No. 8 (1st), No. 8 (2nd), No. 4 and No. 2 bait hooks.

On the other hand, the ratios of living/dead among bait-hooked fish show considerable variation. Percentage mortality figures are 58.2 and 24.3 for two tests with No. 8 long-shank hooks, 44.0 for one test with No. 4, and 20.4 for one test with No. 2 (Table 4). If the data from the two tests on the No. 8 hook are combined, the average is not significantly different from the figure for the No. 4 long-shank hook

Table 3.--Chi-square values for comparison of mortality ratios among four lots of fish caught by No. 12 fly, and similar comparisons of mortality ratios among four lots of fish caught by various sizes of bait hooks (based on data in Table 1). Underlined values are significant at the 95 percent level or above.

Lot number	Lot number		
	No. 2	No. 3	No. 4
By No. 12 fly			
No. 1	0.90	6.92	0.01
No. 2	..	1.42	0.01
No. 3	..	..	3.19
Lot number, bait hook size	**Lot number and bait hook size**		
	No. 2; No. 8	No. 3; No. 4	No. 4; No. 2
By bait hooks			
No. 1; No. 8	34.20	4.41	42.51
No. 2; No. 8	..	10.30	0.39
No. 3; No. 4	..	..	15.17

Table 4.--The percentage of hatchery-reared brook trout dying after hooking 0-3 times by No. 12 fly and various sizes of bait hooks (data taken from Table 1).

Item	Number of times fish were hooked				
	0	1	2	3	1-3
No. 12 fly	5.4	0.0	0.0	...	0.0
No. 8 LS (1)	3.8	58.6	63.6	0.0	58.2
No. 12 fly	1.3	2.0	0.0	...	1.8
No. 8 LS (2)	0.0	24.5	25.0	0.0	24.3
No. 12 fly	3.8	6.2	0.0	...	6.0
No. 4 LS	0.0	45.0	37.5	...	44.0
No. 12 fly	0.0	0.9	0.0	...	0.8
No. 2 LS	2.0	22.7	5.6	...	20.4
Total No. 12 fly	2.6	2.0	0.0	...	1.7
Total LS hooks	1.1	38.8	32.1	0.0	37.5

(Chi-square = 0.05, P = 10%). However, the average figure for the No. 8 is significantly higher than the figure for No. 2 (Chi-square = 19.30, P = 99.9%), and the figure for No. 4 is significantly higher than that for No. 2.

There are several possible reasons for the variation in percentages of hooked fish dying in the subdivisions of the bait portion of the experiment. One explanation might be that the fish tend to take worms more avidly earlier in the season; this might account for the variation in results noted in the two runs with No. 8 long-shank hooks. Another probably factor operating here is the difference in hook gape width at least between No. 8 and No. 2 long-shank hooks (5.5 mm.). Still another possible explanation lies in possible differences in average size of the fish hooked.

To examine the question of the effect of size, Table 5 has been prepared, which gives the size-frequency distribution of the fish available, of the hooked survivors and the hooked mortalities observed for the three subdivisions of the experiments (the tests involving the No. 8 long-shank bait hook are combined). The average sizes of the various categories within each subdivision are given also. It will be noted that there is little difference between the fish available to either fly or bait fishing in each subdivision (0.01 to 0.05 inches), but that the differences in average sizes of the fish available to No. 8, No. 4, and No. 2 hooks ranged between 0.44 and 1.38 inches.

The effect of variation in average size can be eliminated by applying Chi-square tests to the observed results for the 6.0-6.9 and 7.0-7.9 inch groups, which are present in all subdivisions of the experiment.

Table 5.--The length-frequency distribution of experimental fish at start, of the hooked survivors (H.S.), and the hooked mortalities (H.M.), 1951.

Type and size of hook	Item	Length frequency classes in inches						Average total length (inches)	Number of specimens
		4.0-4.9	5.0-5.9	6.0-6.9	7.0-7.9	8.0-8.9	9.0-9.9		
No. 12 fly	At start	1	46	202	134	17	...	6.75	400
	H.S.	...	19	126	113	13	...	6.86	271
	H.M.	...	...	1	1	...	...	6.90	2
No. 8 LS	At start	1	55	200	130	14	...	6.70	400
	H.S.	1	25	89	54	6	...	6.64	175
	H.M.	...	10	57	57	6	...	7.17	130
No. 12 fly	At start	...	73	98	29	...	...	6.25	200
	H.S.	...	25	44	10	...	...	6.26	79
	H.M.	...	1	4	...	...	...	6.44	5
No. 4 LS	At start	...	69	101	30	...	...	6.26	200
	H.S.	...	20	35	5	...	...	6.18	60
	H.M.	...	6	29	13	...	...	6.52	48
No. 12 fly	At start	...	...	22	123	51	4	7.63	200
	H.S.	...	...	13	79	34	...	7.56	126
	H.M.	...	...	...	1	...	...	7.50	1
No. 2 LS	At start	...	2	23	116	55	4	7.64	200
	H.S.	...	...	10	75	22	2	7.60	109
	H.M.	...	...	2	11	14	1	8.01	28

* The results of the two separate tests involving comparison of the No. 12 fly with the No. 8 long-shank hook bait with worm have been combined here.

When the results from bait fishing with hooks of various sizes are examined, it is demonstrable for fish in the 6.0-6.9 inch size group that the size of the hook was not a factor in the ratio of living/dead among the fish hooked. The calculated Chi-square values all were non-significant, ranging from 0.49 (No. 8 vs. No. 4) to 2.34 (No. 4 vs. No. 2). However, when similar tests are applied to the fish of the 7.0-7.9 inch size group, it can be shown that No. 8 and No. 4 hooks caused a significantly higher proportion of deaths among fish hooked than did the No. 2 hook (Chi-square No. 8 vs. No. 2 = 30.21; No. 4 vs. No. 2 = 26.40). There appears to be no significant difference between the No. 8 and No. 4 hooks in their lethality among 7.0-7.9 inch fish (Chi-square = 1.94).

In the only other comparisons possible (No. 8 vs. No. 4 in the 5.0-5.9 inch size group, No. 8 vs. No. 2 in the 8.0-8.9 inch size group), the Chi-square tests resulted in the non-significant values of 0.04 and 0.11, respectively. If now the data are divided between sublegal (up to 6.9 inches) and legal trout (Michigan legal minimum length = 7.0 inches), it can be shown that for the combined data there was little difference between legal and sublegal fish in their mortality after bait hooking (Chi-square = 0.11). Subdividing the information by the three different hook sizes, it was found that No. 8 and No. 4 hooks killed more legal fish than sublegal fish (Chi-square = 5.47, P = 98.2% in both tests), The No. 2 hook did not appear to kill a significantly larger number of either group (Chi-square = 0.001).

When size of fish is not considered, it has been shown that significantly fewer hooked fish were killed when using No. 2 baited hooks than when using No. 4 or No. 8. There appears to be no significant difference in hooking mortality between No. 8 and No. 4 hooks.

Mortality from all bait hooking was shown to be about the same for fish smaller than 6.9 inches as for fish larger than this size, although it can also be shown that No. 4 and No. 8 hooks killed significantly more hooked fish larger than 7 inches than did the No. 2's.

1952 Experiments

After reviewing the results of the 1951 experiments the authors were questioned about the possibility of bias in the results originating from the fact that equal numbers of hookings by fly and worm were not made by the same individuals. Also, since the 1951 work was performed entirely on hatchery-reared fish, there was some question as to whether the results obtained would be applicable to wild brook trout. Accordingly we redesigned the operating technique slightly and experimented over wild brook trout both in screened diversions and in the natural stream at Hunt Creek. The one completed "run" in the enclosed diversions during 1952 was over 200 wild and 200 hatchery fish, and all anglers hooked approximately equal numbers of fish by fly and by worm. Although this work comparing mortalities resulting from hooking with No. 12 fly against No. 8 long-shank and bait was done early in the season (between May 11-24) when the fish normally would take either bait or fly readily, relatively few experimental fish were hooked. Possibly the influencing factors were that half of the fish were of wild stock collected by electro-fishing and/or that also both wild and hatchery fish were of smaller average size than were those used the previous year.

Despite the changes in technique and the relatively small numbers of fish hooked, the trend of the results was the same as in the previous year (Table 6). Disregarding for the moment the origin of the fish, there is very little doubt that the No. 8 hook with worm killed a

Table 6.--Observed hooking losses and survivals among experimental brook trout in various length-frequency classes, 1952 hooking experiments. H.S. = hooked survivors H.M. = hooked mortalities

Location and kind of fish	Type and size of hook	Item	Length frequency classes in inches						Average total length (inches)	Number of specimens
			3.0-3.9	4.0-4.9	5.0-5.9	6.0-6.9	7.0-7.9	8.0-9.9		
Screened diversion, half wild and half hatchery fish	No. 12 fly	At start	...	5	56	103	35	1	6.31	200
		H.S.	...	1	7	19	9	...	6.38	36*
		H.M.	...	0	0	0	0	...	...	0
	No. 8 LS	At start	...	...	45	105	46	4	6.49	200
		H.S.	...	...	2	17	4	...	6.57	23**
		H.M.	...	...	0	5	6	...	6.95	11
Natural stream with live crate, all wild fish	No. 12 fly	H.S.	1	4	14	3	...	...	5.28	22
		H.M.	0	0	1	0	...	...	4.50	1
	No. 8 LS	H.S.	1	7	3	0	...	...	4.85	11
		H.M.	0	6	5	2	...	...	5.06	13
	No. 12 fly	H.S.	...	9	5	5	2	1	5.66	22
		H.M.	...	0	1	0	0	0	5.60	1
	No. 6 LS	H.S.	...	4	6	1	1	...	5.39	12
		H.M.	...	3	3	3	0	...	5.54	9

*In addition to the listed totals, 2 other fly-hooked fish were not found.
**In addition to the listed totals, 4 other bait-hooked fish were not found.

significantly greater number of brook trout than did the No. 12 fly (Chi-square = 11.50, P = 99.9+%). Again the No. 8 long-shank hook killed a higher percentage of fish in the 7.0-7.9 inch size class than in the 6.0-6.9 inch size class.

A second experiment, using only wild fish, was started in the screened diversions, but extreme difficulty was encountered in persuading them to take the lures frequently enough to obtain a reasonable number of hookings. We then followed the suggestion of Dr. Edwin L. Cooper of hooking equal numbers of wild fish from the natural stream with flies and various sizes of bait hooks and confining them in a live crate overnight. Fly-caught fish were given one mark (fin-clip), worm-caught fish a different one. All fish were measured, checked for marks, and mortalities recorded and preserved on the morning following fishing. The live-crate series of experiments was performed using No. 8 long-shank and No. 6 long-shank hooks (Table 6), comparing each with results from fishing No. 12 flies. This procedure simplified record tabulation and eliminated considerable handling of the experimental fish. Although it was not possible to observe mortalities from hooking which might occur later than 24 hours, this objection applied equally to fly-hooked or bait-hooked fish.

Although the number of hookings recorded was smaller than in the 1951 work in the screened diversions, the results from the live-crate experiments were very similar to the earlier work. Significantly larger numbers of fish died after hooking with the long-shank hooks and worms than with the fly. The No. 8 hook killed 13 of 24 fish captured, while only one of 23 fish caught on the No. 12 fly died (Chi-square = 11.65, P = 99.9+%). In the test of the No. 6 hook, 9 of 21 wild brook trout caught with the No. 6 long-shank hook and worm were killed, but only one

of 23 fish taken by No. 12 fly was mortally wounded by hooking (Chi-square = 7.22, P = 99.3%).

Post Mortem Examination of Mortalities from the Experiments

Pathological examinations were made on all but one or two badly decomposed mortalities found. On discovery, dead fish were measured, labelled and preserved in 10% formalin. Random samples were taken from among observed mortalities to determine the presence or absence of furunculosis by sectioning and staining portions of kidney tissue. The mortalities from hooking were listed as dead because of injuries to various organs where evidence indicated hooking was the most likely cause of death. After the initial run with No. 8 long-shank hooks, records were kept as to the site of hooking among worm-caught fish for later comparison with the records of the location of lethal wounds. Enlarged photographs of experimental fish showing lethal and non-lethal wounds are to be found in Figures 1 and 2.

No record was kept during the first 1951 test of the No. 8 long shank vs. No. 12 fly as to hooking sites. Examination of mortalities in this test revealed the following: For mortalities among fish of the fly portion of the experiment, 2 non-hooked fish, cause of death was not determined with certainty. For 96 bait-hooked mortalities, damage to heart caused 53 deaths; body cavity and arterial damage, 18; liver, 11; gills, 6; stomach, 1; undetermined, 7. For one non-hooked mortality from bait water, cause was undetermined. Portions of kidney from 11 specimens were sectioned and studied for the presence of furunculosis. All were negative.

Table 7 gives the records for bait-hooked fish comparing the hooking sites and the location of lethal wounds (except for the previously-mentioned initial run involving No. 8 long-shank hooks). The classification

Figure 1.--Lethal hooking of a legal-sized trout with No. 8 long-shanked hook baited with worm. Note point of hook penetrated lobe of heart which has been slightly cut away to show hook point. May, 1951.

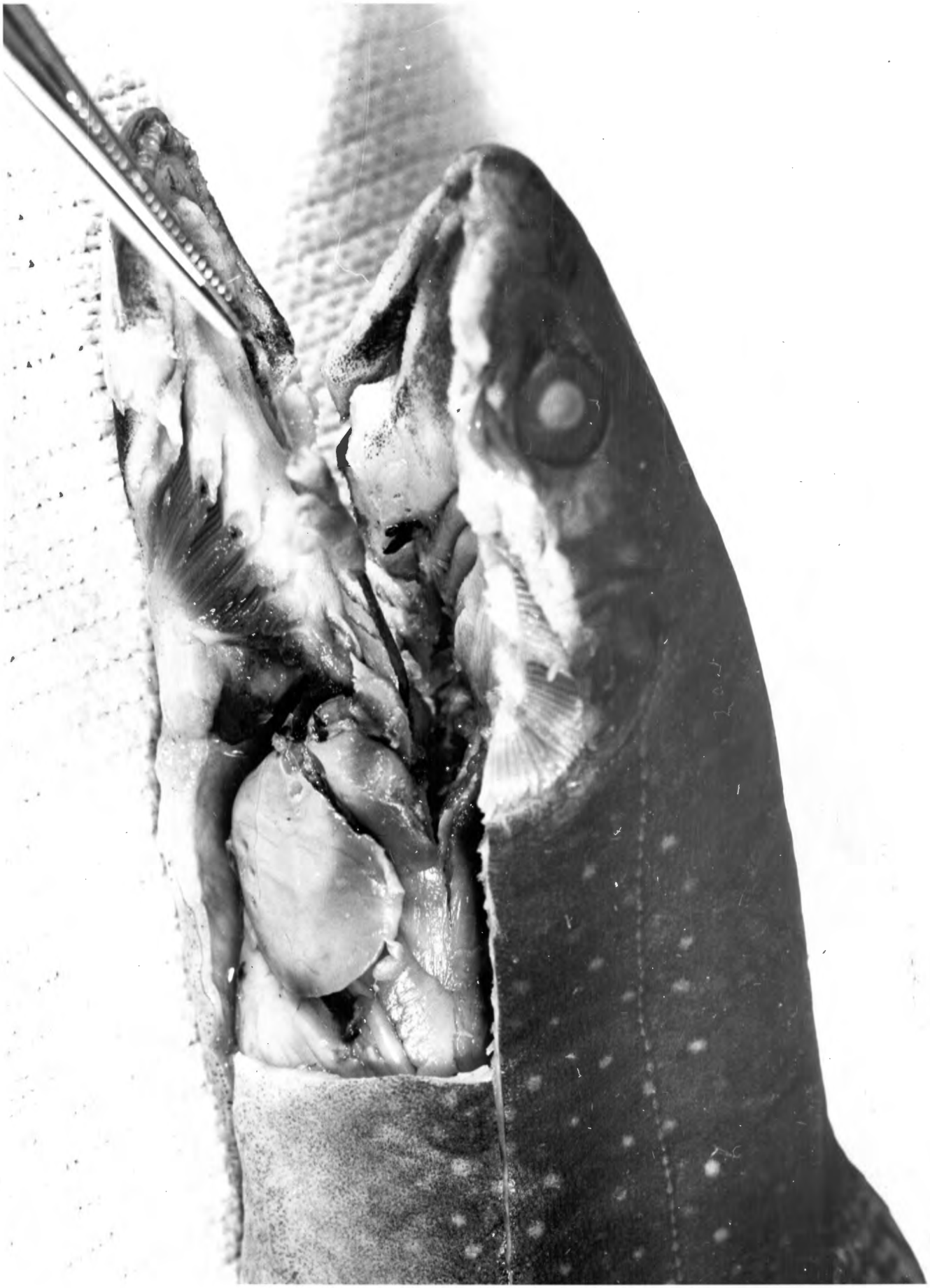

Figure 2.--Non-lethal hooking of a sublegal brook trout with No. 8 long-shanked hook baited with worm. Hook lodged in orbit before leader parted. Fish alive at end of experimental run. May, 1951.

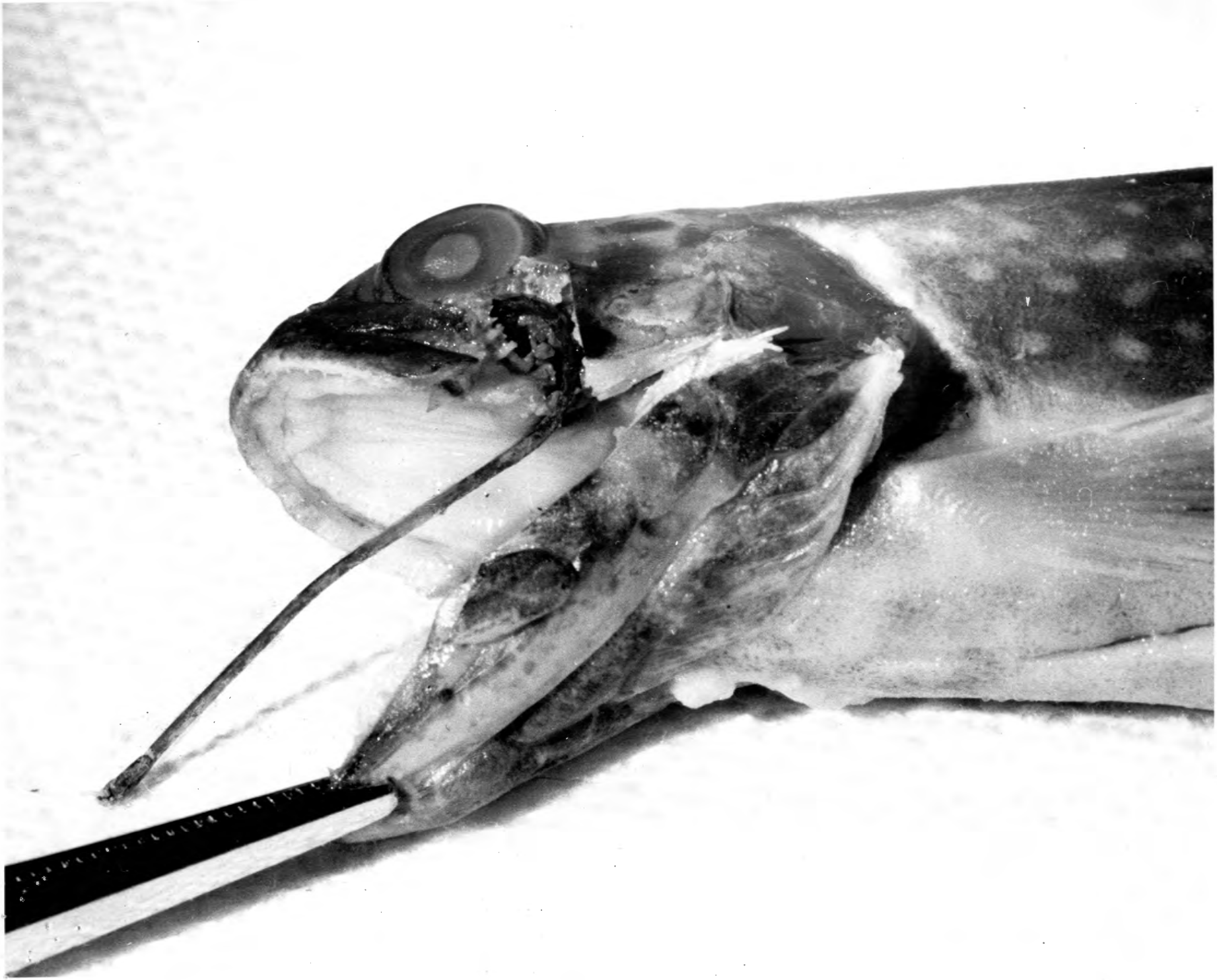

Table 7.—Records of sites of hooking* compared with numbers of fish dying from wounds at various sites, 1951 experiments, bait-hooked brook trout.

Size of bait hook	Item	Site of hooking and site of lethal wound								Total
		Jaws	Gills	Throat	Cheek and tongue	Mouth roof	Eye or orbit	Foul	?	
No. 2 LS	Hooking site	58	39	12	20	14	11	5	2	161
	Lethal site	0	8	12	1	0	1	1	5	28
No. 4 LS	Hooking site	28	21	39	7	9	15	..	16	135
	Lethal site	0	3	30	0	1	3	..	11	48
No. 8 LS (2)	Hooking site	47	8	53	5	20	5	..	..	138
	Lethal site	0	6	27	0	0	0	..	1	34
All hooks	Hooking site	133	68	104	32	43	31	5	18	434
	Lethal site	0	17	69	1	1	4	1	17	110

*In 1951, numerous experimental fish were hooked two times. One fish may appear in the hooking site records more than once. Thus the comparison between hooking site and lethal site is not on a fish-for-fish basis.

of hooking sites is somewhat broad. Obviously when a trout is listed as hooked in the throat, the point of the hook actually may have pierced the leart, liver, kidney, stomach, or main artery. Any such injuries causing death were assigned to throat hookings. Foul hookings were listed as such when a fish was hooked on the exterior surface of the head or body. The "?" classification was necessary because with No. 4 LS and No. 2 LS hooks many fish wriggled off on the bank before the hooking site could be determined. Probably most of such fish were lightly hooked in the jaws.

In 1951, points of hooking fell into the eight groupings of jaws, gills and gill arches, throat, cheek and tongue, roof of mouth, eye or orbit, foul hook (body or head exterior), and "?". Hookings in any of the three tests were never found in fewer than six of the groups. From the data in Table 7, it can be shown that the two most lethal points of hooking were the gills (and gill arches) and the throat. From 104 throat hookings, 69 dead fish were noted; from 68 gill or gill arch hookings, 17 observed mortalities were found. Relatively few fish died from hooking wounds in the cheek and tongue, roof of mouth, eye, or foul hooking. No deaths were observed among jaw-hooked, bait-caught fish.

Among the eight fly-hooked fish found dead, injury to gill arches caused the death of two fish; one each was killed by wounds in the orbit and roof of the mouth, and the cause of death was not determinable for four specimens.

Although the hatchery-reared brook trout secured for the experiments from the Oden Hatchery were demonstrated to be free of furunculosis in the first test by culture and kidney section examination, the disease was apparently present to a slight degree in later experiments. In

the fly portions, kidney sections of 4 mortalities revealed one infected fish, and in the bait water of 17 dead fish, two were found with furunculosis-infected kidneys. The presence of furunculosis in a minor degree does not appear to have influenced the experimental results in 1951.

In 1952 there were no duplicate or triplicate hookings made. Therefor the comparison between hooking sites and lethal wounds is on a basis of number of fish hooked to number of fish dying. In the live crate experiments, although the fish were hooked only once, the previous hooking history is unknown because they had been subject to public angling. The results of the 1952 autopsies are listed in Table 8, which also compares the lethal wounds with observed points of hooking.

The autopsy data of 1952 substantiate the earlier observations, for, of all fish inspected among bait-hooked mortalities, the great majority of deaths were the result of throat or gill and/or gill arch wounds.

Some furunculosis was present among the experimental fish in 1952. One non-hooked hatchery fish from the fly water in the diversion experiment was found to have the disease among seven mortalities chosen at random from the 1952 mortalities preserved.

Some Implications of the Findings

The data presented here have a practical consideration in establishment of tackle and minimum size restrictions. For instance, where it is desirable to have the maximum number of brook trout available with the least mortality to small brook trout hooked and released, restrictions eliminating worm fishing will reduce one cause of mortality. Also, where an increase in minimum legal length is contemplated, the possibility

Table 8.--Records of numbers of fish hooked once at various sites compared with numbers of fish dying from wounds at various sites, 1952 experiments.

Type and size of hook	Item	Site of hooking and site of lethal wound								Total
		Jaws	Gills	Throat	Cheek and tongue	Mouth roof	Eye or orbit	Foul	?	
No. 12 fly	Fish hooked	29	..	..	4	..	..	..	5	38*
	Lethal site	0	..	..	0	..	..	..	0	0
No. 8 LS	Fish hooked	7	4	17	5	1	3	..	1	38**
	Lethal site	0	1	9	0	0	0	..	1	11
No. 12 fly	Fish hooked	16	..	..	5	2	..	..	..	23
	Lethal site	0	..	..	1	0	..	..	..	1
No. 8 LS	Fish hooked	6	4	10	3	0	1	..	..	24
	Lethal site	0	1	8	1	1	0	..	2	13
No. 12 fly	Fish hooked	18	1	..	2	1	..	1	..	23
	Lethal site	0	0	..	0	0	..	0	1	1
No. 8 LS	Fish hooked	3	3	8	5	2	..	..	0	21
	Lethal site	0	2	3	0	0	..	..	4	9
Totals No. 12 fly	Fish hooked	63	1	..	11	3	..	1	5	84
	Lethal site	0	0	..	1	..	..	0	1	2
Totals Nos. 8 and 6 LS	Fish hooked	16	11	35	13	3	4	..	1	83
	Lethal site	0	4	20	1	1	0	..	7	33

* 2 fly-hooked fish not found.
** 4 bait-hooked fish not found.

of increasing hooking loss must be considered, because an additional number of fish in the size range between the old and the new minimum legal lengths now become subject to hooking mortality. Elimination of worm fishing would reduce these additional potential losses.

Although specific information of a controlled nature is not immediately available concerning the ultimate effect of hooking mortality on brook trout populations, some inferences may be drawn from population and creel census data found in the files of the Hunt Creek Fisheries Experiment Station. In Section C, for the years 1946, 1947, and 1948, the September population of brook trout measuring less than 7 inches in length is known from studies made by electric shocker (AC). Also, during the same fishing seasons, anglers were questioned as to the numbers of hooked fish returned which were less than legal length. If the hooking mortality noted in the various hooking experiments for fly and bait hooks are applied to the recorded numbers of worm-caught and fly-caught fish, it becomes possible to estimate how many more fish might have remained alive as part of the post-season population.

The mortality rate for fly-hooked fish is calculated to be 2.20 percent and the mortality rate for worm-hooked fish (includes all hook sizes) is calculated as 26.65 percent. These figures are weighted[1]

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[1] The sum of the observed percentages of mortality multiplied by the number of experimental fish involved divided by the total fish in all experiments.

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averages from data recorded in F. A. Westerman's earlier work plus the 1951 and 1952 Hunt Creek Experiments comparing barbed flies and barbed bait hooks of all sizes from No. 2 to No. 8, and include observed results on 966 fly hookings and 1,029 bait hookings.

The estimated effect of hooking sublegal brook trout with both fly and bait in Section C in 1946, 1947 and 1948, based on the mortality rates outlined above, is presented in Table 9. During the three years in question, worm fishermen are estimated to have killed 9.54, 16.14, and 8.53 percent respectively of the estimated potential mid-September sublegal brook trout populations in 1946, 1947, and 1948. Fly fishermen are estimated to have killed 0.04 and 0.08 percent in 1946 and 1948, none in 1947.

These estimates are believed to be conservative. In Section C during these years the minimum legal length was 6.0 inches. Had 7.0 inches been the minimum size limit, an additional 188 (1946), 125 (1947), and 102 (1948) fish would have been included among the sublegal trout hooked and released, as the numbers indicated were in the 6.0-6.9 inch category. Since most were caught by worm, an additional 27 to 50 mortalities might be inferred under the situation postulated. Also, the population estimates include fish of all sizes from 1.5 to 6.9 inches, whereas the hooking experiment data concerned fish mainly larger than 4 inches. Were it possible to estimate with accuracy the Section C brook trout populations in the size range of 4.0 to 6.9 inches, the numbers vulnerable to hooking would be lower, and the resulting hooking mortality on the population would be proportionately higher. Furthermore, if a high proportion of the worm fishermen used the smaller sizes of bait hooks, the mortality rate on fish hooked and returned could well have been higher.

The foregoing observations suggest that it is possible to reduce one cause of mortality in brook trout streams by eliminating the use of worms as bait. In the face of ever-increasing angling pressure on brook trout waters, all possible steps such as this should be taken to

Table 9.--The estimated effect of worm fishing and fly fishing on the September population of brook trout less than 7 inches long, Section C, Hunt Creek, in three different years.

Year	Brook trout less than 7 inches hooked and released		Estimated numbers* killed by hooking		Population estimate, brook trout less than 7 inches	Percentage loss by hooking	
	Worm anglers	Fly anglers	Worm anglers	Fly anglers		Worm anglers	Fly anglers
1946	890	33	237	1	2,246	9.54	0.04
1947	825	14	220	0	1,143	16.14	0.00
1948	462	38	123	1	1,319	8.53	0.08

* Mortality from worm fishing 26.65 percent.
Mortality from fly fishing 2.20 percent.

keep the supply of fish, either wild or newly planted, at the maximum number. By this suggestion it is not meant that all brook trout waters should be closed to worm fishing, but rather only those stream areas where it is possible to take fish through most of the season with artificial flies. The headwater portions and small tributaries which are usually brushy and not fishable with a fly could be left open to worm fishing, also the lower courses of the larger rivers tributary to the Great Lakes frequented by migratory rainbows. A good knowledge of local fishing conditions and angler use of the area in question would be demanded in establishing the boundaries of waters restricted to fly fishing.

In conclusion, we should point out that the results described here apply specifically to brook trout, and specifically to comparisons between the No. 12 fly and the several sizes of bait hooks used. It is suspected that the mortality rates for rainbow trout and brown trout, hooked with either worm of fly, might differ because of variation in size and shape of the mouth in these species. The mortality rates described for worm fishing very probably cannot be applied to minnow fishing for brook trout because of the difference in manner of taking the two baits. To properly determine the mortality rate for minnow fishing, another series of experiments similar to these should be operated. It is tentatively planned to test the comparative mortality rates for fly and worm fishing on brown and rainbow trout during the coming trout season.

Acknowledgments

We are grateful to Hatchery Supervisors L. B. Hoodmaker and Barney Engel for providing numerous experimental fish used in 1950,

1951 and 1952. Mr. Engel also constructed a live crate for experimental work in the natural stream for us in 1952 which was very useful.

Dr. Don Hayne, Zoology Department, Michigan State College, reviewed the 1951 data, and suggested certain changes in the experimental procedures for 1952.

We appreciate the suggestions made by Dr. Gerald P. Cooper, Institute for Fisheries Research, as to methods of tabulation and presentation of the results.

The following individuals assisted the authors in the experimental fishing, and we are grateful for their efforts: Dr. A. S. Hazzard, Dr. Dwight A Webster, Dr. E. L. Cooper, K. E. Proshek, H. Gowing, A. M. Schiffman, H. B. Hard and O. L. Brailey.

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