FULTON RIVER FRY QUALITY AND ECOLOGY PROGRAM

Report of 1968 Studies

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I. INTRODUCTION

A. Purpose of Fry Quality Study

The Resource Development Branch of the Department of Fisheries of Canada embarked, in 1965, on a major program of artificial spawning channel construction at Babine Lake, British Columbia. The purpose of the program was to increase the number of sockeye salmon fry (*Oncorhynchus nerka*) entering the lake, which is considered by the Fisheries Research Board of Canada to be capable of supporting many more sockeye fry than can be produced in its natural tributary streams.

The first spawning channel at Babine Lake was completed in October, 1965, at Fulton River, tributary to the main basin of the lake (Fig. 1). Adult sockeye salmon (28,000) spawned in the channel in the fall of 1966 and produced 25.5 million fry, representing an egg-to-fry survival of 69%.

The development program will be most successful if these channel fry are able to survive as well as the river fry when placed in the natural environment, i.e. if the fry produced artificially are of the same "quality" as fry produced in the natural stream.

The present study was designed to measure and compare the quality of the fry produced in the artificial channel and in the natural river. A number of "quality indices" were selected for study. These were: (1) length; (2) weight; (3) development stage; (4) percent solids; (5) percent lipids; (6) percent nitrogen; (7) swimming performance; (8) vulnerability to

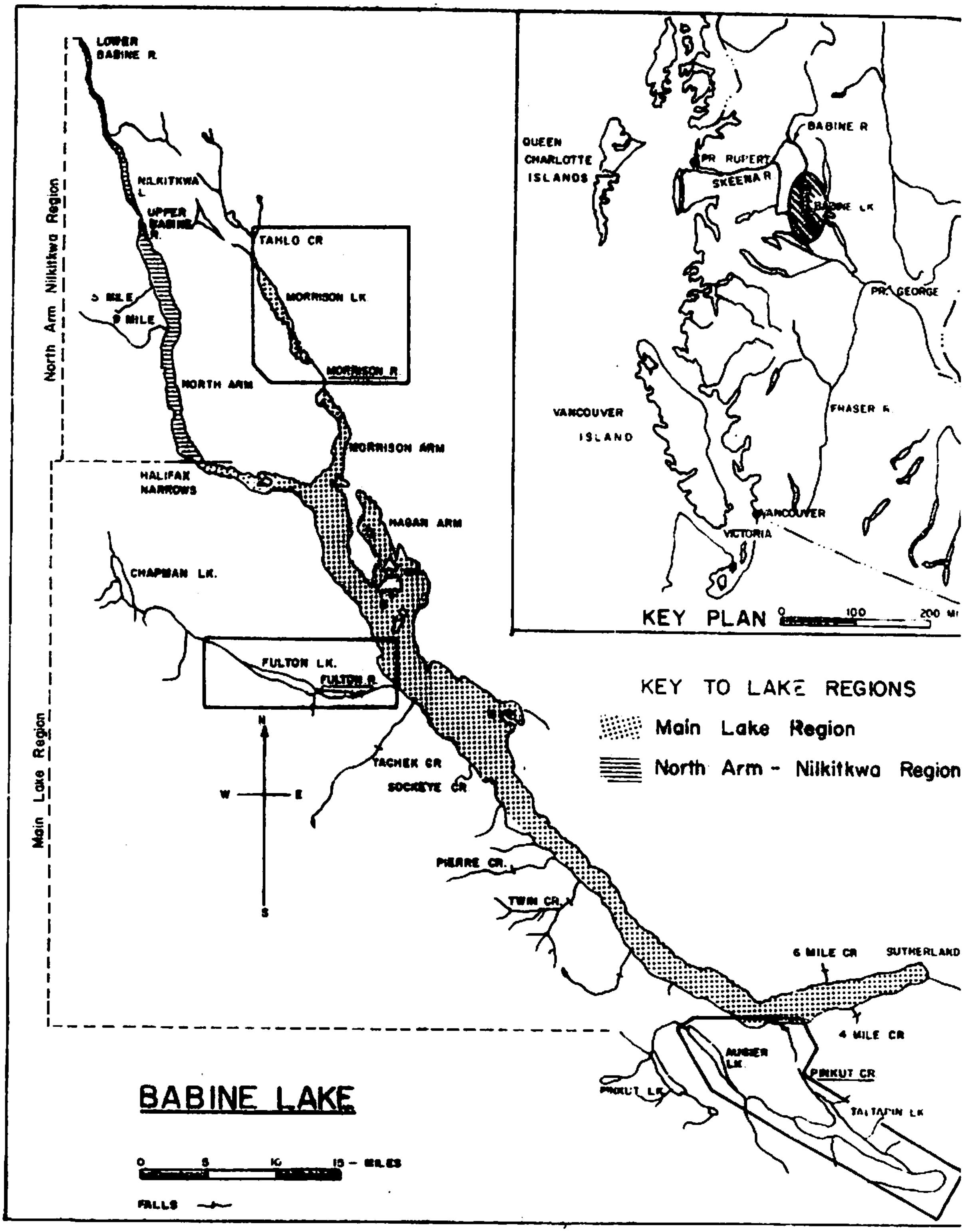


Figure 1. Babine Lake, British Columbia.

predation; (9) starvation resistance; and (10) temperature tolerance.

B. Literature Review - Salmonid Quality Studies

Studies comparing artificially and naturally produced salmonids fall into three categories. Some authors have compared the quality of the two groups at the time of their release into the natural environment, while others have compared the survival of the two groups subsequent to their release. A third approach has been to compare wild and domestic strains reared under identical conditions. The results of these three approaches will be considered in turn.

1. Comparative quality at the time of release

Robertson (1919) compared Pacific salmon fry from hatcheries and from natural spawning areas. He found the natural fry to be 25% longer and 50% heavier, and their eye-diameter to be 100 to 200% larger. They also showed better avoidance responses to trout and ducks. "The wild natural fry hugged the shore singly or in very small schools, and when pursued made for a hiding place with frenzied erratic dashes. Hatchery fry when liberated swam aimlessly about .....". Robertson concluded that the "smooth sides and bottoms of hatchery troughs offer no inducement to the fry to seek hiding places, and their instinct in this respect is soon dulled." In a further report Robertson (1937) stated that "there is something inherently good in the underground contact of egg and gravel and the detention of the fry in darkness", and that "the physical superiority of fry incubated in contact with this substance...is so pronounce as to be discernible at a distance of twenty feet."

Vibert (1956, 1958) compared the vulnerability to hi and low temperatures, the resistance to current, and the resistance to predation of fry of Atlantic salmon (Salmo salar L.), brown trout (S. trutta), rainbow trout (S. irideus) and brook trout (Salvelinus fontinalis) hatched under gravel and in hatchery incubators. The results of a tests on all species were in agreement: the fry hatched i gravel were superior to those hatched in the incubators.

The chemical composition of hatchery coho fry was compared to that of a wild population of coho, of the same age and from the same parent stock, in Minter Creek, Washington by Wood et al. (1960). The results were:

	% of Dry Wt.	
Analysis	Wild Fish (3 mos.)	Hatchery Fish Sampled at 3 Mos.
Protein	80.1	65.4
Lipid	9.6	26.1
Ash	12.8	12.3

The high lipid levels of the hatchery-fish were said to be related to the "moderately high fat diets generally fed to salmonids on the Pacific Coast." Salo and Bayliff (1958) found that Minter Creek hatchery coho survive less well than do wild fry.

Bams (1967) measured the "quality" of four groups of sockeye fry (*Oncorhynchus nerka*) incubated under different conditions. The results of two tests, swimming performance and vulnerability to predation, agreed closely. Ranked in decreasing order of performance the groups rated as follows: naturally propagated fish, fish incubated in gravel from time of hatching, fish incubated in gravel only for the last few weeks as pre-migrants, and fish that spent their entire incubation period without gravel in hatchery baskets. The key factor responsible for the differences in performance was the size of the fish. The swimming performance test was found to be more sensitive to differences than was the predation test.

Fenderson, Everhart and Muth (1968) compared the agonistic and feeding behaviour of 10 to 12 month old Atlantic salmon (*Salmo salar*). Hatchery salmon were found to be more aggressive and to have lower feeding rates than wild salmon. The authors suggested that high levels of aggressiveness may contribute to mortalities of hatchery reared salmon planted in streams because of loss of feeding time, excessive use of energy, and increased exposure to predators.

2. <u>Comparative survival after release</u>

Schuck (1948) presents data from a study at Crystal Creek, New York that stream survival of hatchery brown trout was significantly less than that of wild trout. He considered it to be a general rule that hatchery trout have a lower survival ability than wild trout, and listed the following possible causes in the hatchery environment: (1) high percentage of fats and carbohydrates in the diet; (2) overfeeding leading to detrimentally high growth rate; (3) relative lack of exercise; (4) conditions where foraging for food is unnecessary; (5) freedom from predators; (6) stability of water temperatures; and (7) relative absence of natural live food.

R. B. Miller, working at the University of Alberta, studied the survival of hatchery and wild trout in Gorge Creek, Alberta. He found (1953) that hatchery-reared trout survived less well than stream-reared fish when liberated into a natural stream, and concluded that the low survivability of hatchery fish was due to the absence of natural selection at early stages in the life histroy. In another paper Miller (1958) noted that deaths recorded in some studies may not be attributable to hatchery-background but largely to some aspect of competition with resident trout. Thus, unless the two groups to be compared are liberated into the same unoccupied stream (as in the 1953 study), confounding factors enter the picture and make any comparison difficult.

It has been suggested by Wales (1954) that the relatively high mortality of hatchery trout after planting may be the result of lack of selection at the pre-planting stages. He stated: "our hatchery practices are, in certain respects, so very good that survival after planting is bound to be low. There may be nothing we can do about this. Even though the hatchery care pampers the weak individuals, Nature will quickly weed them out; the end result will be similar to the mortality rate in naturally spawned fish." Deleterious factors in the hatchery environment may also result in lower survival after liberation.

Adelman and Bingham (1955) compared the over-winter survival of hatchery-raised and native trout in screened-off areas of Hunt Creek and Slagle Creek, Michigan. The results from the two studies were contradictory, native trout surviving better in Hunt Creek but less well in Slagle Creek. The authors concluded that there was "little or no difference between hatchery-reared brook trout and native brook trout in their ability to survive the winter months", and criticized previous studies for failing to screen off the study area to eliminate any differential movement of hatchery and wild trout. Screening-off the study area, however, does not allow for behaviour differences between the two groups and is not entirely natural, since emigration could reduce competition. The results, therefore, are no more conclusive than those of previous studies.

The records of the coho salmon hatchery at Minter Creek, Washington were examined by Salo and Bayliff (1958). They concluded that "comparative returns of artificial and natural propagation, for relatively small numbers of spawners, are in favor of artificial propagation provided long-term (6 to 12 month) rearing is practiced", but that "there seems to be no advantage in the artificial spawning of adults for the purpose of planting zero-silvers [fry] into Minter Creek if natural spawners are available". In other words, unless the artificial fish are reared for a considerable period before release, their low stream survival in the first 12 months will offset their high egg-to-fry survival.

Eipper (1963) found that characteristics of hatchery water supply can influence the natural mortality rate of brown trout (*Salmo trutta*) after stocking. "Normal" trout were reared at the Cortland, New York, hatchery in water averaging 54°F. Growth "retarded" trout were raised at the same hatchery in 47° water. The mortality of "retarded" trout was higher than that of "normal" trout even two years after their release in Fall Creek, N.Y. The fat of the "normal" fish was harder, i.e. had a lower iodine number, at the time of stocking and their temperature tolerance may therefore have been higher. It has been shown that high temperature acclimation in the goldfish (*Carassius auratus*) is accompanied by a decrease in iodine number of the body fat (Hoar and Cottle, 1952).

3. Comparison of wild and domestic strains reared under identical conditions

Greene (1952) compared the survival after stocking, and the condition when caught, of wild and hatchery strains ("grown under hatchery conditions without mixture with outside strains since 1902") of brook trout (*Salvelinus fontinalis*) reared under identical conditions and released into Stillwater Pond, N.Y. The wild stock had a higher survival rate but a lower condition factor at the time of catch than did the hatchery trout.

A similar study on wild and domestic (selectively bred for 90 years) brook trout reared under identical conditions in the Cornell University hatchery has been conducted by Vincent (1960). He reported:

> "After 1 year under these conditions the domestic fish were 5.2 inches in length and the wild, 3.6 inches. Throughout the rearing the domestic stock were tamer and exhibited less fright than wild-stock fish. Laboratory tests showed that wild stock could stand a greater concentration of accumulated metabolites, that they could endure higher water temperature, and that domestic stock had a surface response whereby they moved to the surface of a rearing trough or a tall aquarium. Domestic fish also lacked the desire to conceal themselves. Stamina tests conducted by swimming 1,522 fish individually until exhausted in a small trough showed that the wild stock had greater stamina throughout the size range tested. Survival trials in a small stream and a pond indicated that wild fish experienced less mortality and had a growth rate similar to or better than domestic fish in both habitats."

The stamina of brook trout from wild and domestic parents has also been compared by Green (1964). The stocks were subjected to similar rearing conditions. The wild stock fish were able to swim longer against a current of constant velocity, although they were smaller than the domestic fish. This may be due to the hatchery trout having a lower proportion of muscle to other tissue and a higher percentage of fat (cf. Phillips et al., 1956, and Vincent, 1960).

4. Conclusions

The bulk of the literature supports the general hypothesis that wild fry are superior to artificial fry, in terms both of quality at the time of release and of survival after release. Three general explanations have been advanced:

(1) Poor quality of the artificial environment - e.g. lack of gravel, presence of light, poor quality food, etc.;
(2) Overly high quality of the artificial environment, resulting in high initial survival but a lowering of average "fitness" due to lack of natural selection;
(3) Hereditary characteristics of artificially produced fish due to generations of selective breeding, intentional or unintentional.

Clearly, if any differences are found between channel and natural sockeye fry at Fulton River, they will be due to one of the first two causes. The second, lack of natural selection, is the most probable since the spawning channel was designed to provide an ideal incubation environment and appears to be ideal in every factor measured to date (Dill, M.S., 1968). It is thus possible that, even if the channel fry are shown to be of poor "quality", no steps could be taken to remedy the situation. If this is the case, however, the egg-to-adult percent survival should be the same as for the natural fish. If on the other hand the egg-to-adult survival proves to be lower than for natural fry then the cause would have to lie in an inadequate incubation environment.

C. 1967 Fulton River Fry Quality Studies

Some preliminary fry quality studies were carried out at Fulton River in the spring of 1967 by Mr. R. K. Kearns, Department of Fisheries project biologist. The methods and results have been briefly reported (Dill, 1968). The river sockeye fry, at the time of emergence, were significantly heavier (160 mg. compared to 147 mg.), insignificantly longer (29.4 mm. compared to 29.3 mm.), and less well developed. The other tests, though inconclusive, suggested that: (1) river fry were better swimmers than channel fry; (2) river fry were able to resist starvation for a longer period; and (3) there were no differences between the populations with regard to vulnerability to predation or biochemical composition. The limitations of these experimental results will be discussed with respect to choice of experimental design in a later section (II. A.1).

D. Purpose of Auxiliary Tests and Ecological Survey

1. Auxiliary tests

The general purpose of these tests was to provide information useful in the design of future fry quality tests.

One series of tests was carried out to determine the reliability of the sampling methods, i.e. whether or not sampling was random and representative of the two populations studied. Another series of tests was carried out to determine the reliability of the method chosen to quantify stage of development, and another series to determine if a yolk dry weight:fish dry weight ratio would be an adequate measure of this quality index. Other tests were conducted to determine the contribution of differences of migration timing of the two populations to any quality differences observed. Another test series examined the effect of one variable, holding period, on the reliability of swimming performance measurement.

2. Ecological survey

The ecological survey was initiated in an attempt to determine the relevance of the results of the standard fry quality tests to the natural situation. Predator vulnerability was chosen for study. An attempt was made to determine the population sizes, movements, food habits, and digestive rates of the various predator species in the Fulton River. Drift insect abundance was studied in an attempt to determine whether there was a differential "buffering" effect of alternate food types on the rate of predation upon the two fry populations, which migrate at different times.

A series of auxiliary predation studies was conducted in the laboratory by Mr. M. Falk, a BSc. Honours candidate at the University of Victoria. These tests were designed to determine the natural food preferences of various predators and their degree of selection for the length or development stage of the fry.

It was hoped that the results of this survey would be useful in interpreting the meaning of the measured quality indices, and in designing a more natural test situation for future studies.

II. STANDARD FRY QUALITY TESTS

A. Experimental Design

1. General approach to quality testing

Bams (1967), in the only comparable study reported in the literature, advocates the measurement of "relative" rather than "absolute performance", since it is difficult to make sure that all tests are made under truly comparable conditions. According to Bams, "unless tests that are separated in time and space are rigidly controlled and performed under truly comparable conditions, direct comparison of absolute performance data is, at best, of doubtful value".

"Relative" tests are performed by placing samples of the two groups to be compared into a single test situation and comparing their responses to it. It is advocated since "under varying conditions, valid comparisons can be made", if it is assumed "that a limited degree of variation in test conditions which would affect absolute performance does not affect relative performance". The validity of this assumption is questionable since, if two fish vary in such things as swimming speed and predator avoidance, they may also have different responses to the uncontrolled variables in the test environment -- such as water temperature, or dissolved oxygen concentration.

Even if the above assumption is made, the relative method of quality testing cannot be employed at Fulton River, as was done by Kearns in 1967, because the migration timing of the two fry populations differs (e.g. Fig. 2) and because their physical characteristics are a function of time and change at different rates (e.g. Fig. 3). On any given day during the period of migration, a relative method of quality testing would compare two entirely different groups of fry. Thus, the results would be applicable only to conditions on the day the test was made and extrapolation to compare the total fry populations would be a statistical impossibility, regardless of the number of tests conducted.

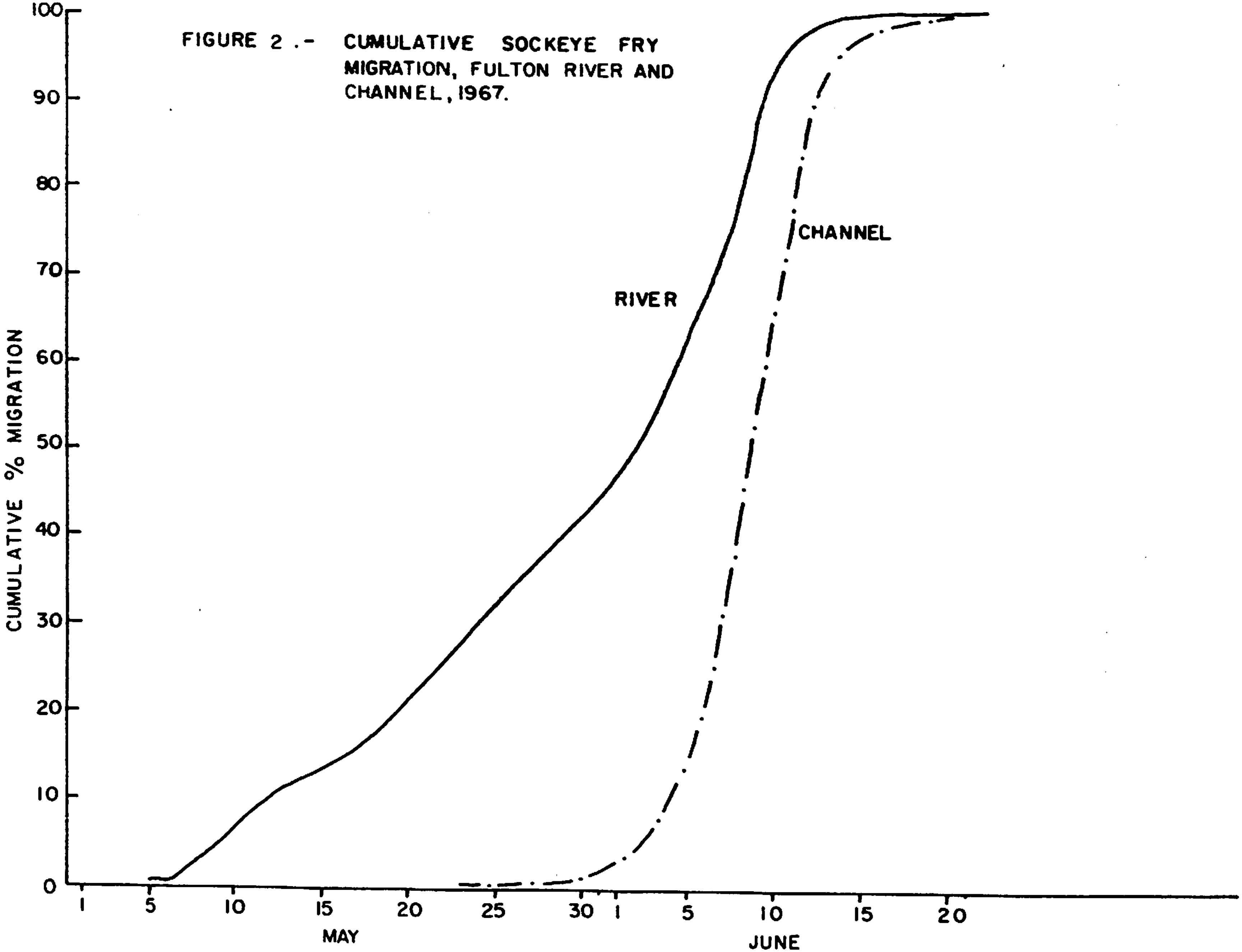


FIGURE 2 .- CUMULATIVE SOCKEYE FRY MIGRATION, FULTON RIVER AND CHANNEL, 1967.

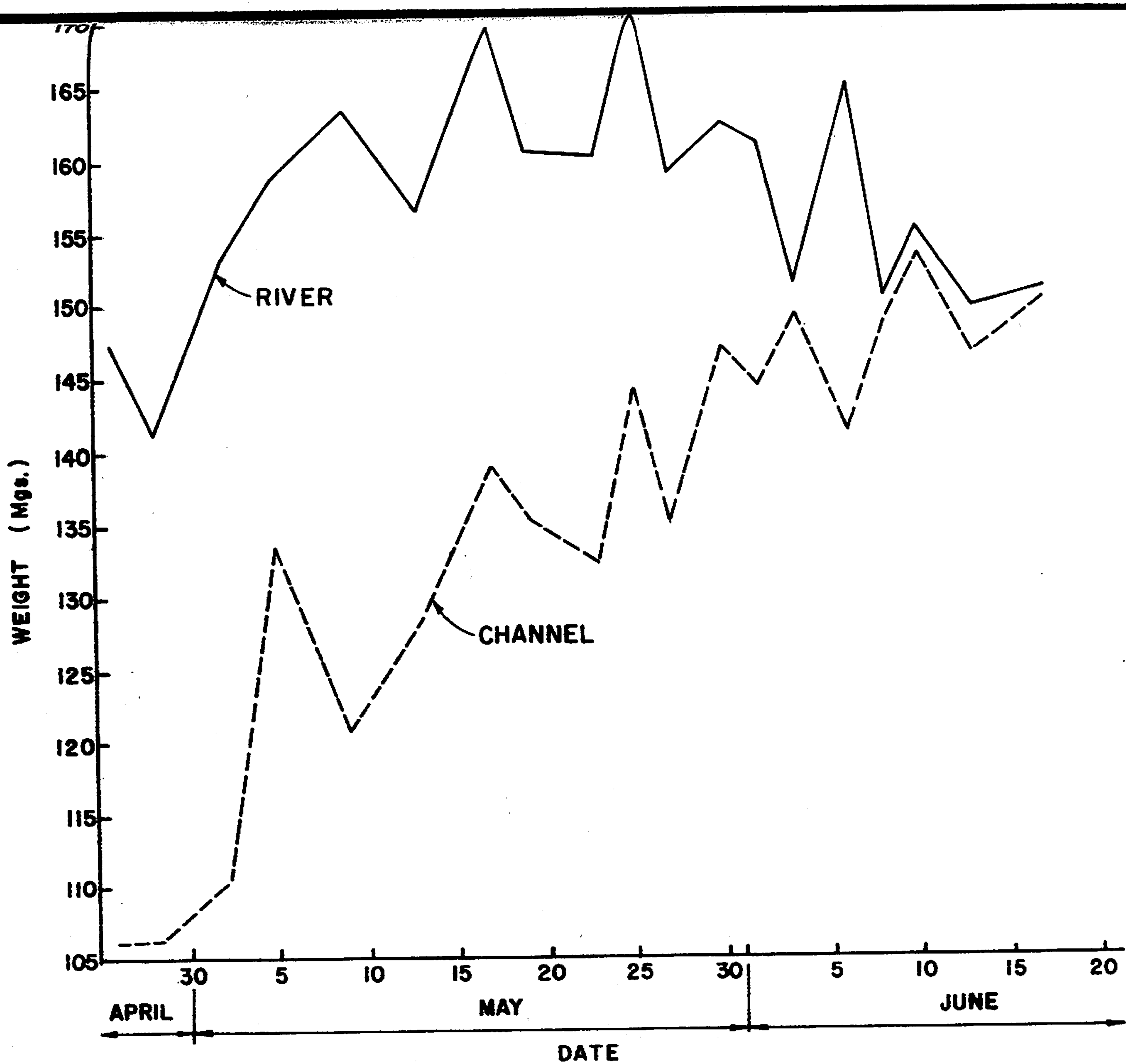


Figure 3 Mean daily weights (mg.) of Fulton River and Channel sockeye fry 1967.

"Quality", therefore, must be measured on an absolute basis at Fulton River, despite the practical problems resulting from acceptance of this methodology. This was done in the present study and every attempt was made to control environmental factors in the test situation. The response of each group of fry to the test variable was measured independently of that of the other group, but under identical test conditions.

2. Experimental design and statistical analysis

A stratified sampling design was employed in the present study. The migration period of each fry population was divided into intervals, or strata, and a random sample drawn from each one.

In most of the tests the responses of each fish to the test variable (temperature, lack of food, current), or the characteristics of each fish (weight, length, development stage) were ascertained. In other tests (biochemical, predation) sub-samples were drawn from the original sample to provide replication. Controls were provided for the starvation and temperature tests to determine whether the response noted among the experimental fish was due solely to the test variable under consideration.

In every case, the mean and the variance of each quality index was determined for each strata. The data were then analyzed on a computer using the following formulae (Steel and Torrie, 1960):

Population mean $= \Sigma W_i \bar{x}_i$

where $\bar{x}_i$ = mean value of index in interval i

$W_i = N_i/N$

N_i = population size in interval i

N = total population size

$$\text{Population variance} = \Sigma W_i^2 \frac{S_i^2}{n_i}$$

S_i^2 = variance of index in interval i

n_i = number of samples on which S_i^2 based

The populations were then compared with Student's t-test:

$$t = \frac{\bar{x}_A - \bar{x}_B}{\sqrt{S_c^2 \left(\frac{1}{n_A} + \frac{1}{n_B}\right)}}$$

where $n_A = \Sigma n_i$ in first population

$n_B = \Sigma n_i$ in second population

$$S_c^2 = \frac{(n_A - 1)(S_A^2) + (n_B - 1)(S_B^2)}{(n_A - 1) + (n_B - 1)}$$

$$df = n_A + n_B - 2$$

3. Sampling methods

The general topography of the Fulton River area is shown in Figure 4. River fry were sampled from the upper fan traps at the upstream end of the channel (Fig. 5), where river fry are prevented from entering the channel and contaminating the channel population. The channel fry were sampled at the lower fan traps before they entered the river. Sampling was conducted at the peaks of the nightly

Figure. 4.— Diagram of Fulton River, showing fry sampling locations and other areas described in the text.

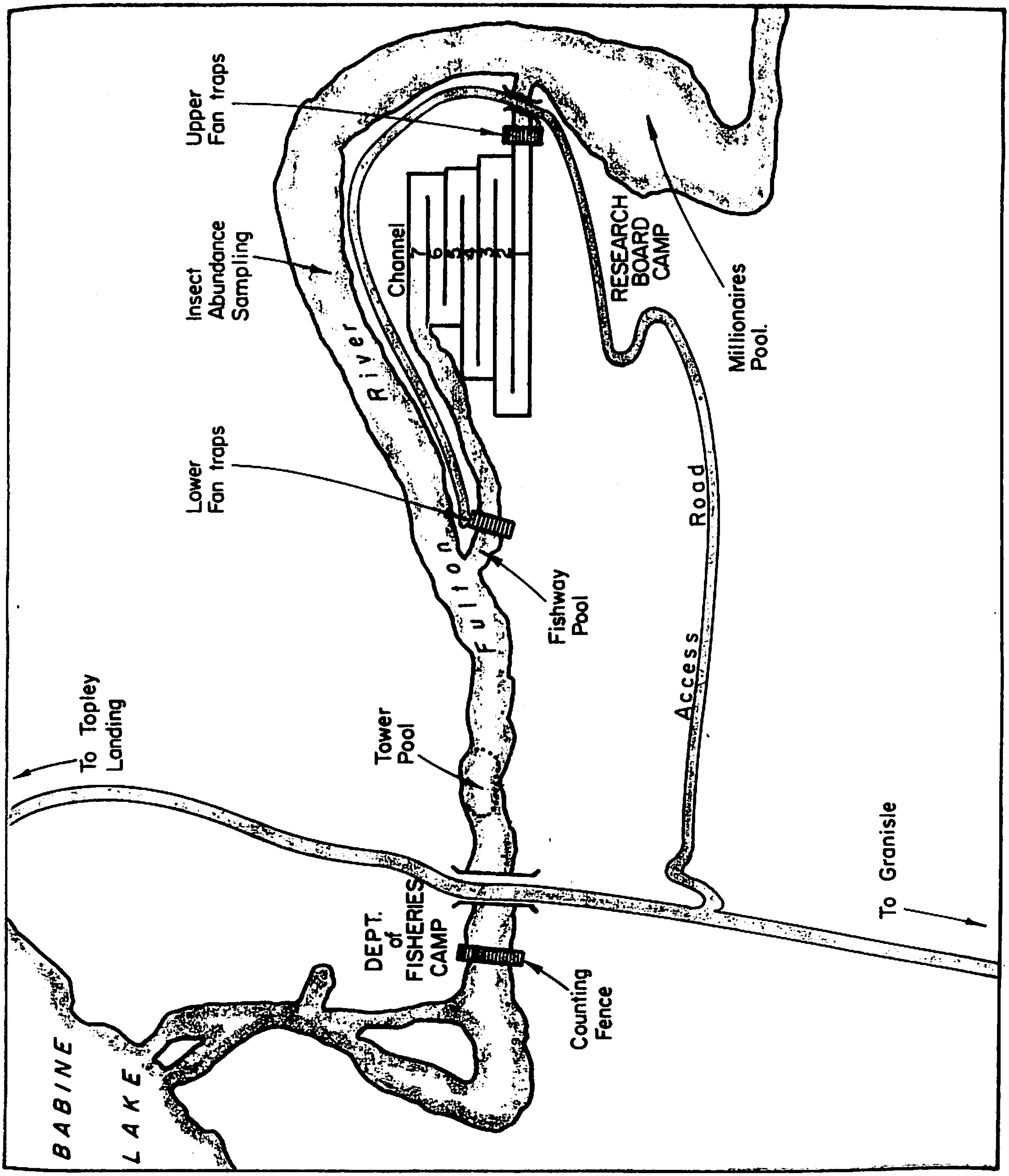
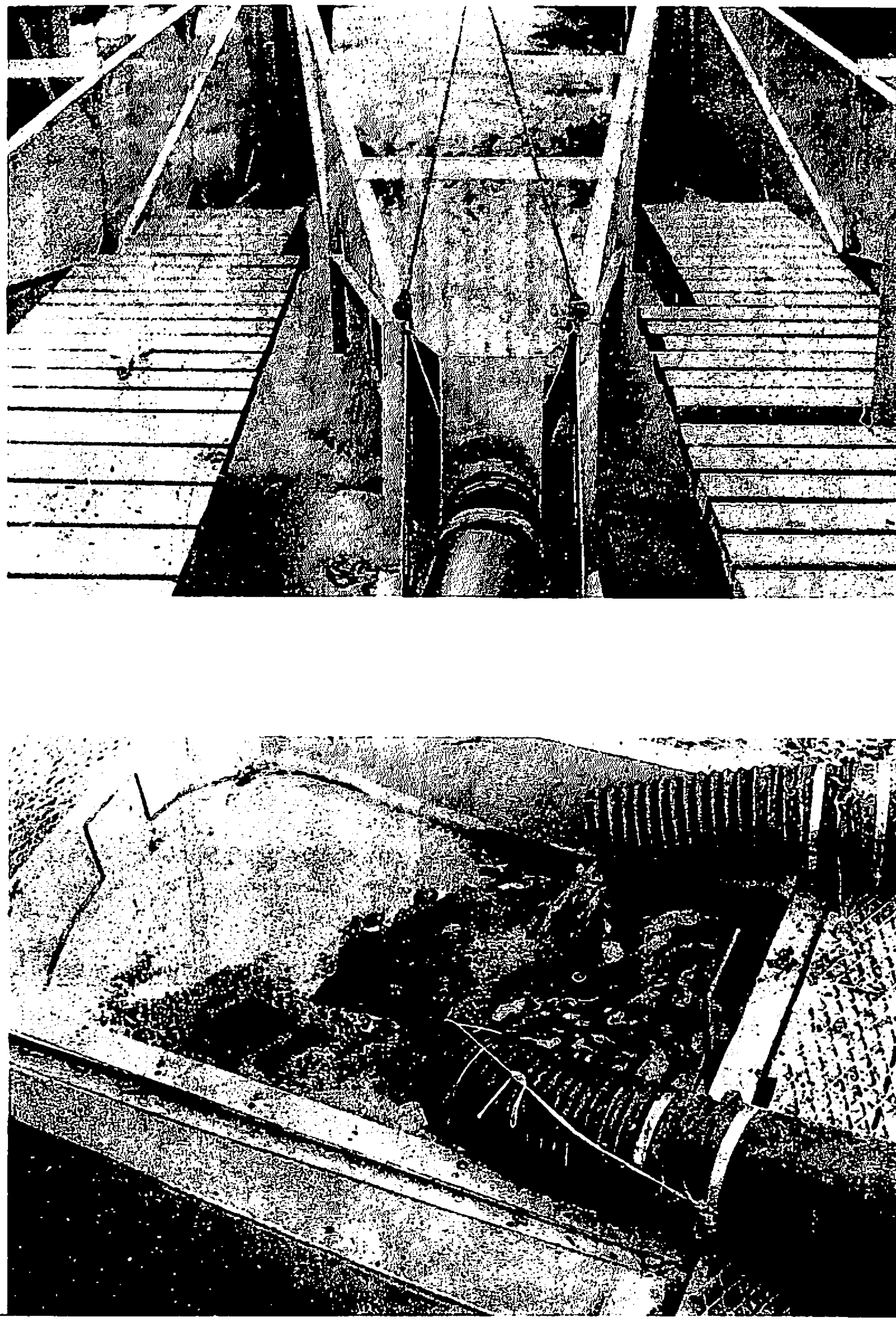


Figure 5. The fan traps. The fry are swept down the inclined plane V-trap (A) and carried through plastic pipe to the live boxes (B).

A

B



migration, 12 P.M. at the lower fan traps and 1 A.M. at the upper fan traps. The samples were netted randomly from the live boxes but at the upper fan traps the fry often had to be separated from leaf litter and other debris. The fry were then held in aerated plastic buckets in the laboratory until morning, when the testing was conducted.

B. Length, Weight, and Development Stage

1. Methods

Each day, fifty fry from each population were anaesthetized with 2-phenoxyethanol, blotted dry, weighed to the nearest milligram on a Mettler electric balance, measured (nose-to-fork) to the nearest millimeter and classified into one of five development stages on the basis of the amount of yolk visible externally (Fig. 6). This staging scheme was first used by M. Giles (pers. comm., 1966).

2. Results

The river fry were significantly heavier than the channel fry but significantly shorter (Table I, and Figures 7 and 8). They emerged at a less advanced development stage. The method of classifying development stage based on the amount of yolk visible proved too subjective to be amenable to statistical analysis (as demonstrated in Section III.A), and the only meaningful results, a comparison of the percent stage IV and V fry, are shown in Figure 9.

Figure 6 - Scheme for classifying sockeye fry into development stages, based on the amount of yolk visible externally.

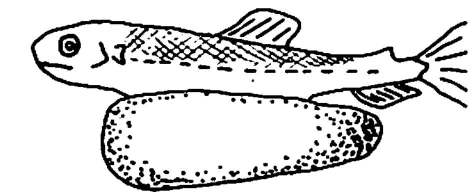
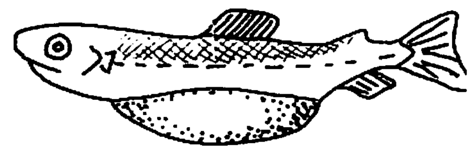
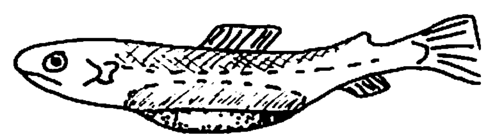
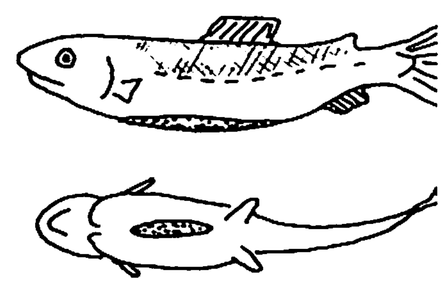
STAGE	DESCRIPTION	ILLUSTRATION
1.	Little or no absorption of posterior lobe of yolk sac.	
2.	Posterior lobe absorbed	
3.	Yolk sac less than half visible in lateral view. Top portion of yolk sac silver	
4.	Skin pigmented on sides and lateral part of ventral surface. Yolk visible in scar.	
5.	Yolk sac scar is healed. No yolk visible externally.	

TABLE I. Mean daily weights (mg) and lengths (mm) of Fulton River and Channel sockeye fry, 1968.

DATE	WEIGHT (mg)				LENGTH (mm)			
	RIVER		CHANNEL		RIVER		CHANNEL	
	$\overline{X}$	S^2	$\overline{X}$	S^2	$\overline{X}$	S^2	$\overline{X}$	S^2
May 06-07	138.94	332.06	-	-	28.28	2.08	-	-
07-08	135.14	459.75	-	-	28.60	1.92	-	-
08-09	149.70	351.27	-	-	29.28	1.39	-	-
09-10	139.32	203.12	-	-	29.10	1.15	-	-
10-11	141.60	322.49	134.42	279.31	28.62	1.67	29.02	1.45
11-12	148.52	373.35	138.22	335.24	29.00	1.35	29.14	1.71
12-13	146.72	307.30	141.22	296.54	28.96	2.49	29.10	1.68
13-14	157.40	337.43	140.74	309.05	29.36	1.54	29.50	1.44
14-15	146.52	324.99	139.66	445.78	28.96	2.45	29.12	2.35
15-16	150.40	355.18	136.96	403.18	29.28	1.27	29.56	0.99
16-17	149.24	340.35	143.02	429.57	29.12	1.50	29.98	1.12
17-18	158.04	389.88	140.06	538.83	29.72	1.27	29.70	2.50
18-19	149.70	376.54	134.04	276.08	29.36	1.38	29.24	1.66
19-20	144.54	408.05	150.92	351.91	29.42	2.09	30.28	1.27
20-21	152.44	531.35	143.18	338.23	29.52	2.38	29.94	1.20
21-22	147.96	320.77	143.86	370.36	29.64	1.54	29.96	1.39
22-23	138.26	228.72	137.48	285.72	28.92	1.26	29.58	0.90
23-24	138.28	457.72	140.06	363.77	28.92	1.26	29.42	1.19
24-25	-	-	137.70	234.63	-	-	25.20	1.10
25-26	152.34	535.90	142.60	327.88	28.66	1.82	29.96	1.06
26-27	143.70	234.74	142.22	339.97	28.64	1.05	29.50	1.15
27-28	143.98	400.10	136.98	216.14	28.80	1.59	29.04	1.30
28-29	149.68	514.38	136.88	421.29	29.08	1.67	29.00	1.59
29-30	146.90	345.44	147.14	432.00	29.58	1.06	30.12	1.70
30-31	144.58	419.88	140.10	275.72	29.16	1.77	29.88	1.29
May 31-01	144.14	339.02	137.20	270.16	29.56	1.35	29.52	1.36
June 01-02	144.22	405.36	137.22	248.25	29.58	1.72	29.48	0.91
02-03	136.50	344.37	134.00	233.22	29.12	1.41	29.42	1.02
03-04	145.74	482.11	138.50	370.87	29.76	1.57	30.14	1.10
04-05	142.22	311.48	143.28	479.96	29.40	1.14	29.94	1.65
05-06	141.54	396.66	143.48	340.09	29.48	1.07	30.04	1.43
06-07	141.04	511.88	138.56	329.59	29.28	1.80	30.04	0.94
07-08	149.80	685.68	137.98	401.29	30.14	2.33	30.18	1.46
08-09	134.54	368.70	143.94	345.04	28.92	1.42	30.38	1.02
09-10	134.26	249.38	146.22	437.15	29.44	1.35	30.08	1.59
10-11	138.30	454.62	145.32	385.08	30.20	1.06	30.32	0.75
11-12	136.82	617.37	141.70	476.87	29.48	1.89	29.82	1.86
12-13	136.68	463.48	141.04	430.97	29.56	1.56	29.96	1.59
13-14	133.12	322.51	141.56	574.99	29.28	1.47	30.22	2.26
MEAN	146.90	.3968	140.05	.3056	29.33	.0018	29.76	.0012

	WEIGHT	LENGTH
t	347.60	415.03
df	3648	3648
Signif @	.001	.001

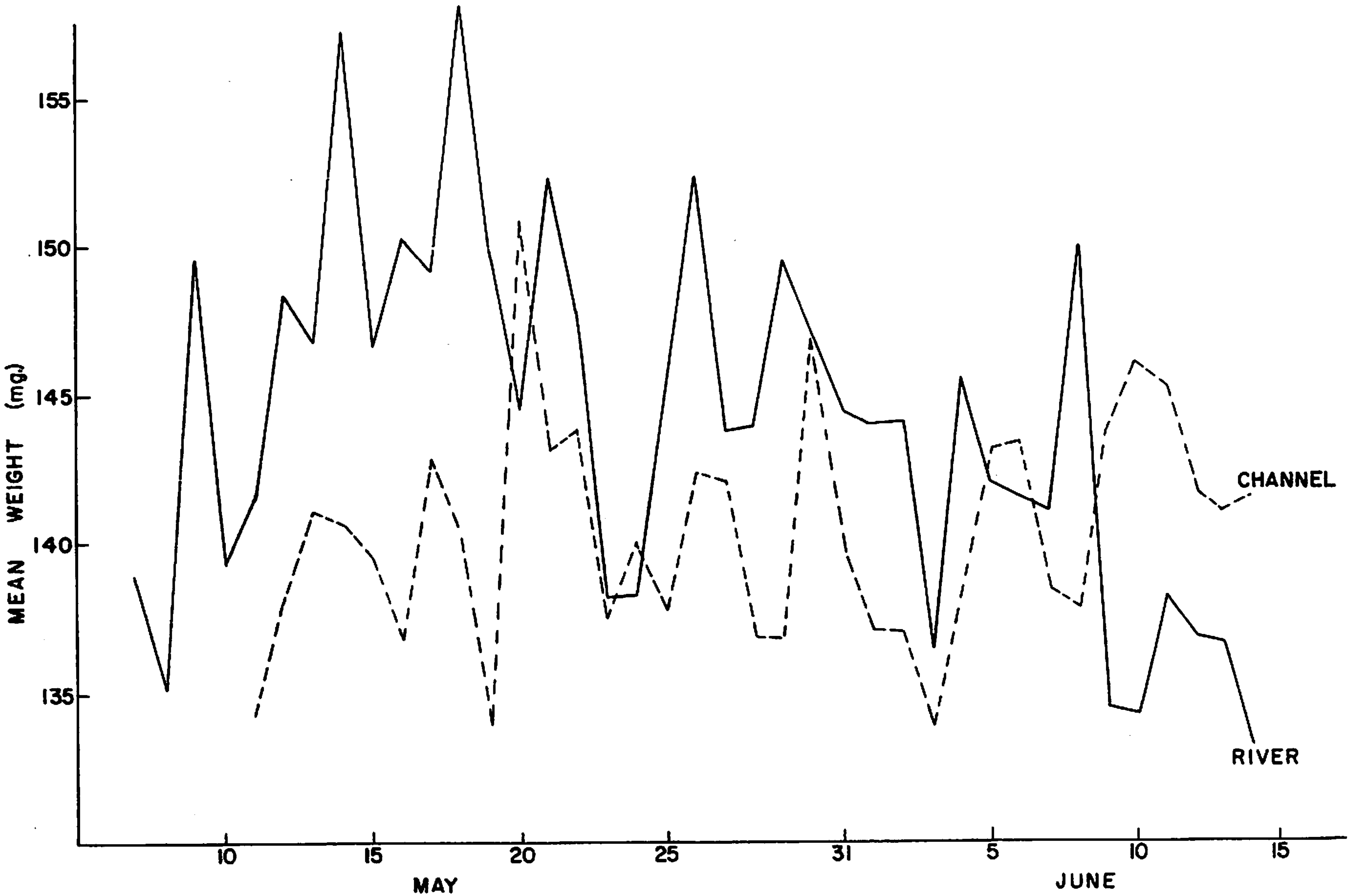


Figure 7.– Mean weights (mg.) of Fulton River and Channel sockeye fry, 1968.

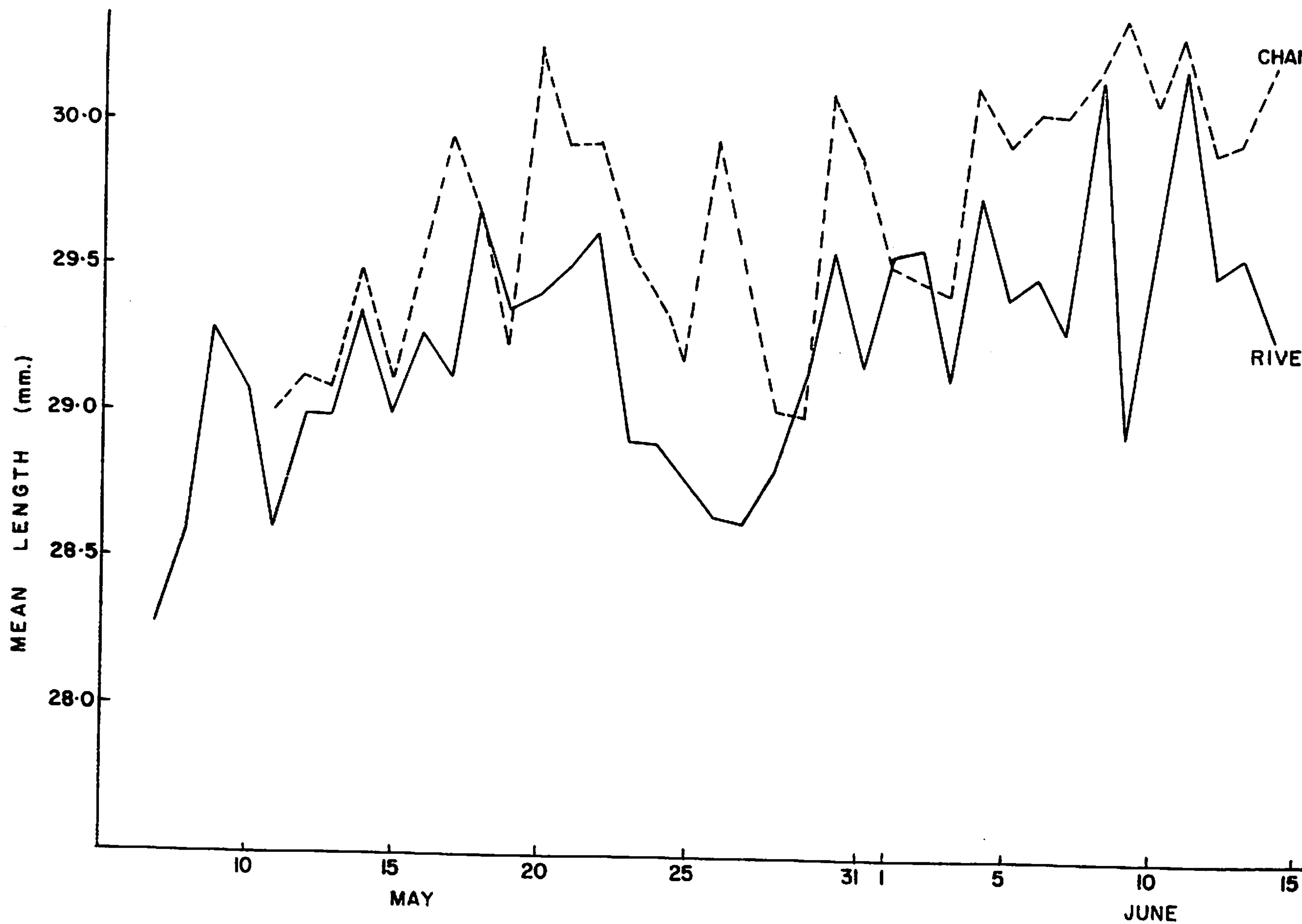


Figure 8. — Mean lengths (mm.) of Fulton River and Channel sockeye fry, 1968.

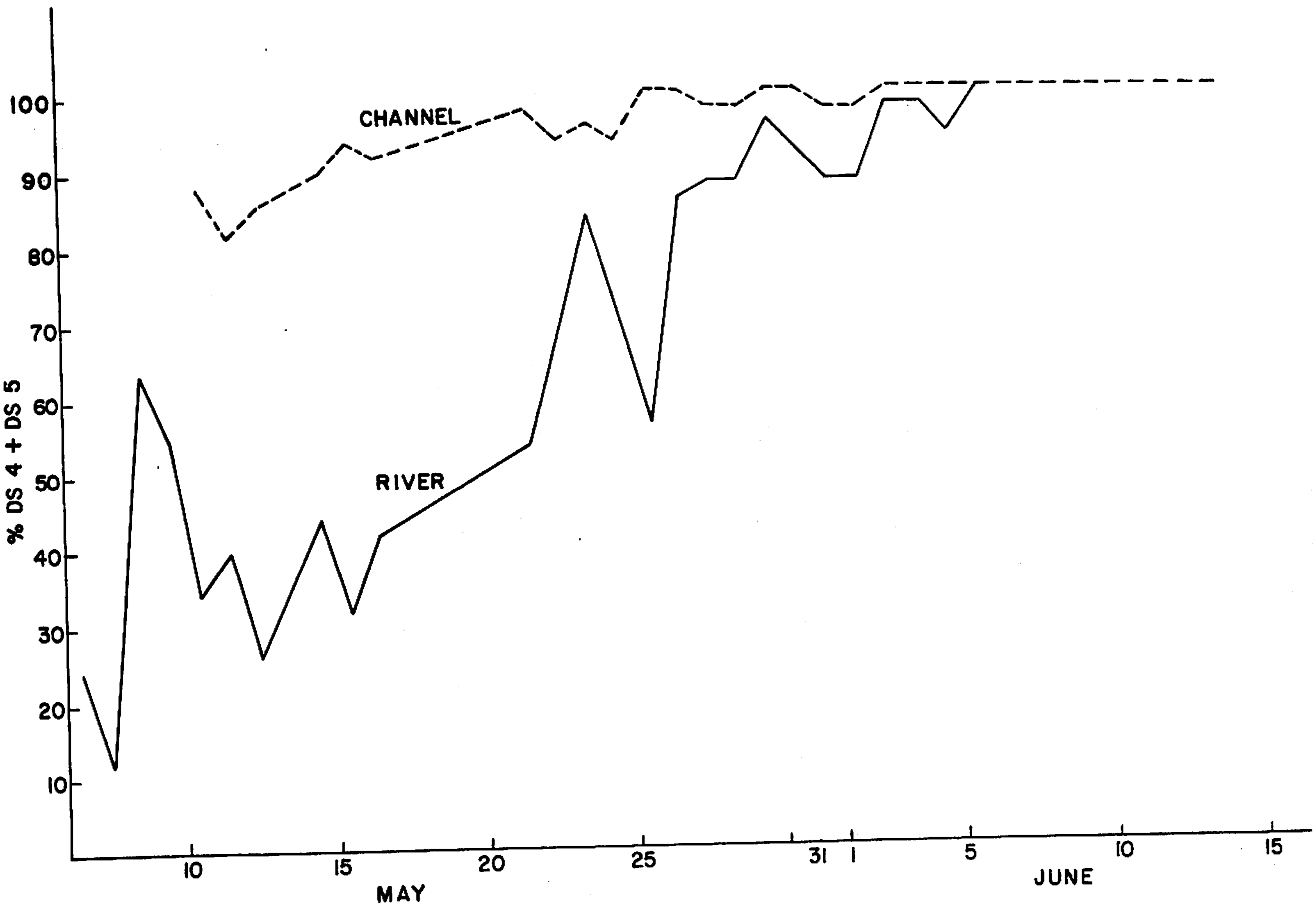


Figure 9.- A comparison of the stage of development at emergence of Fulton River and Channel sockeye fry, 1968

3. Discussion

The river fry initially emerged from the gravel with a greater amount of yolk than the channel fry and consequently were heavier. With time, and the absorption of yolk, the weights of the two groups approximated each other more and more. This is due to the fact that only part of the yolk is converted into tissue (Hayes and Pelluet, 1945). The extra weight of the river fry, being largely or solely of yolk, may therefore not confer any advantage upon them as would be expected on the basis of weight alone (e.g. in a swimming endurance or temperature tolerance test).

The weight differences were not as great as those recorded in the 1967 study.

The channel fry were significantly longer than the river fry statistically, but their slight advantage may not be biologically significant.

C. Biochemical Studies - Solids, Lipids, Nitrogen

1. Methods

At each sampling date, five samples of fifty fish each were sent in air-tight plastic bags to Coast Eldridge consulting chemists, Vancouver, for analysis. Three groups of samples of river fry were taken in each five day period (stratum) and three groups of channel fry samples each four day period. One group of five samples from each set was analyzed for percent solids by wet weight; one for percent lipids; and one for percent nitrogen.

Total solids was determined by drying the samples to constant weight at 100°C; total lipids by the method of Folch, Lees, and Stanley (1957), and total nitrogen by the micro-Kjeldahl procedure.

2. Results

The river fry were found to have a higher percentage of solids, lipids, and nitrogen (Tables II, III and IV). As may be noted in the tables, the sampling intervals are not consistent. This resulted from the loss of some samples by the analyst, or the improper use of a set of samples (e.g. analyzing for solids a sampled intended for nitrogen analysis). The values of the quality indices as a function of time are shown in Figure 10. Differences between the percent solids and lipids of the two fry populations were most pronounced during the early part of the season but decreased toward the end of the migration period. Differences in percent nitrogen showed an opposite trend.

3. Discussion

Since salmonid yolk is comprised primarily of fat and protein (Smith, 1957) the superiority of the river fry in percent lipid and nitrogen is most likely due solely to their emerging at an earlier stage of development and consequently to their having more yolk. Toward the end of the migration period, when the river and channel fry were of similar developmental stage (Fig. 9), the differences became less apparent.

TABLE II. Mean percent solids of Fulton River and Channel sockeye fry, 1968.

RIVER			CHANNEL		
DATE	$\bar{X}$	S^2	DATE	$\bar{X}$	S^2
May 08-09	20.58	.240	-	-	-
09-10	21.05	.240	May 11-12	18.32	.504
10-11	22.98	.240	12-13	19.37	.504
13-14	21.38	.240	13-14	17.08	.504
14-15	22.08	.240	23-24	17.26	.205
23-24	17.26	.245	27-28	16.23	.599
28-29	17.76	.230	31-01	15.98	.775
June 07-08	15.89	.160	June 08-09	16.55	.271
12-13	14.77	.570	12-13	13.71	.194
TOTAL	19.36	.010	TOTAL	16.33	.029

t = 99.83
df = 81
Signif @ .001

TABLE III. Mean percent lipids of Fulton River and Channel sockeye fry, 1968.

RIVER				CHANNEL			
DATE		$\bar{X}$	S^2	DATE		$\bar{X}$	S^2
May	10-11	2.61	.263	May	12-13	1.81	.102
	15-16	2.96	.341		13-14	1.77	.102
	27-28	3.99	.114		17-18	3.01	.062
	30-31	3.21	.563		21-22	2.95	.306
June	04-05	2.47	.020		25-26	2.45	.100
	09-10	2.90	.039		29-30	2.46	.031
				June	02-03	2.71	.144
					06-07	2.60	.070
					10-11	2.72	.056
TOTAL		3.06	.019	TOTAL		2.61	.004

t = 19.38
df = 71
Signif @ .001

TABLE IV. Mean percent nitrogen of Fulton River and Channel sockeye fry, 1968.

RIVER				CHANNEL			
DATE		$\overline{X}$	S^2	DATE		$\overline{X}$	S^2
May	09-10	2.42	.006	May	16-17	2.12	.013
	14-15	2.47	.006		20-21	2.17	.019
	19-20	2.21	.004		24-25	2.13	.011
	29-30	2.09	.006		28-29	2.26	.041
June	03-04	1.99	.014	June	01-02	2.02	.012
	08-09	2.15	.011		05-06	1.82	.006
					09-10	1.85	.039
					13-14	1.65	.004
TOTAL		2.28	.001	TOTAL		2.02	.001

t = 49.79
df = 68
Signif @ .001

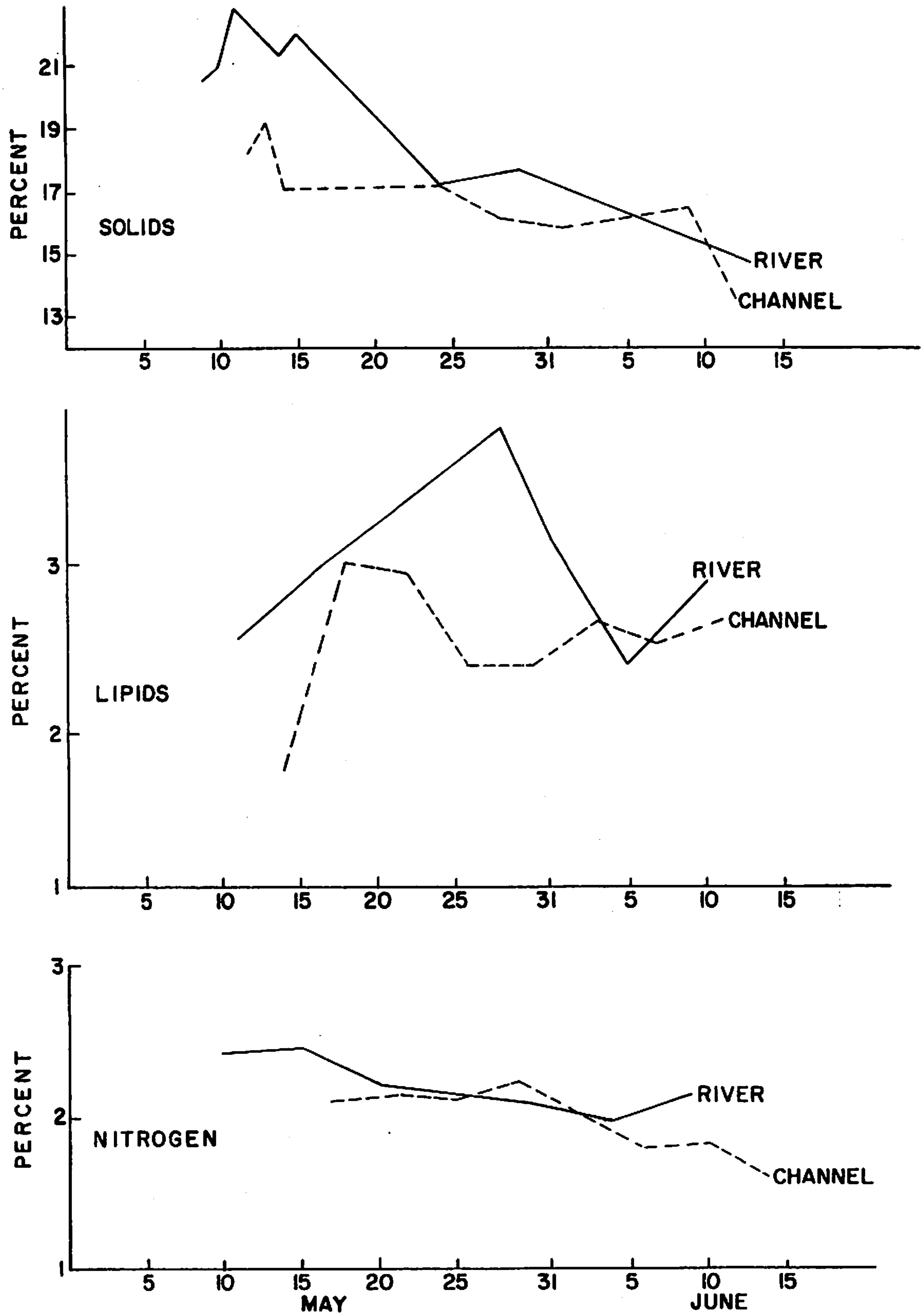


Figure 10.- The mean values of the biochemical quality indices of Fulton River and Channel sockeye fry, 1968.

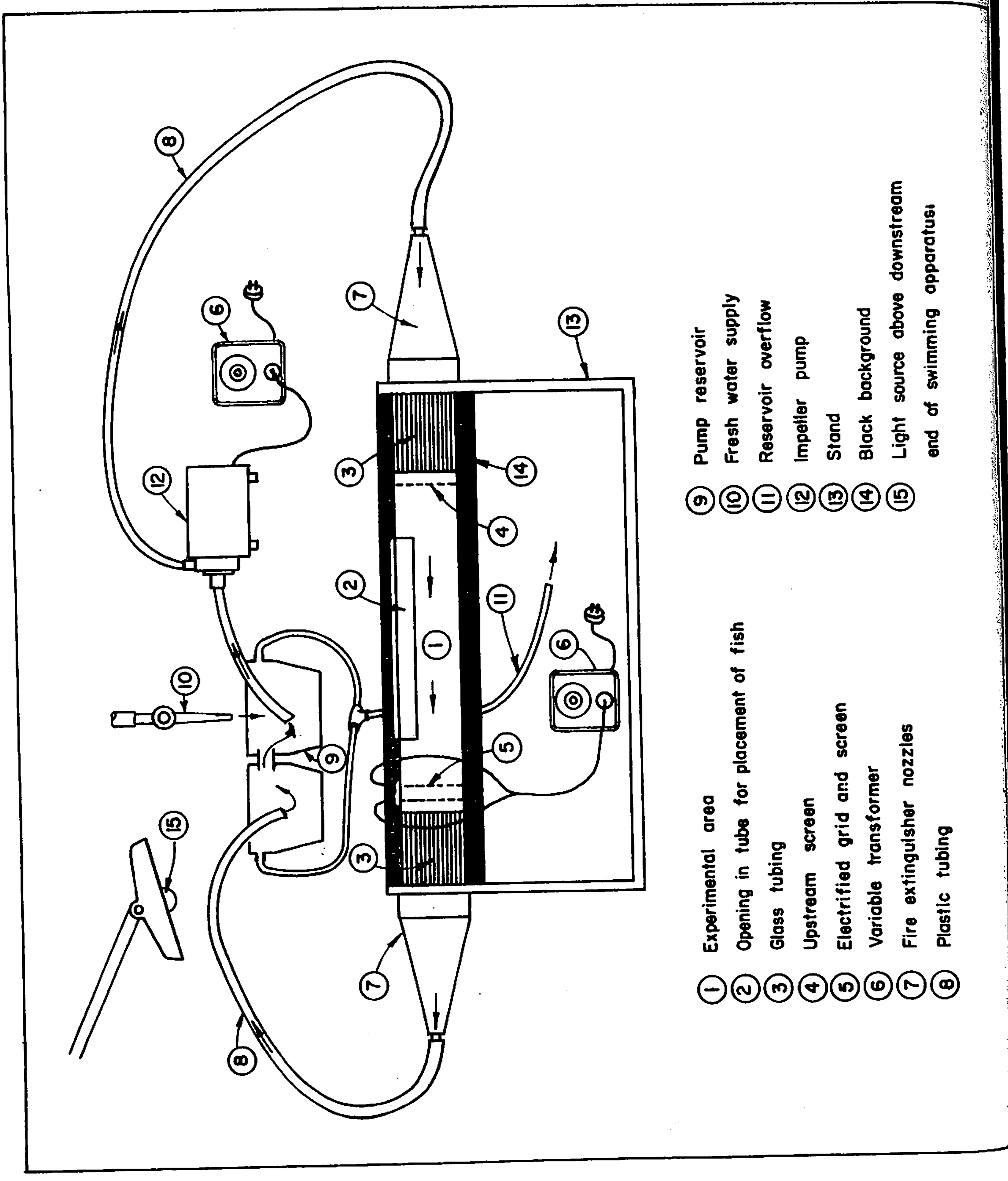
The effects of biochemical composition on subsequent survival of salmonids has received but scant attention in the literature. Wood et al. (1960) reported that hatchery-reared coho had more fat but less protein than wild coho. After release of the hatchery fish, however, the percentage protein increased and the percentage fat decreased to a level nearly identical to that of the wild specimens. Burrows (1968) reports that an increase in fat deposition in chinook fingerlings "from four percent to 8 percent resulted in a 100 percent increase in adult survival". Since the magnitude of the differences noted in the present study are small, and since they appear to be solely a function of development stage, it appears unlikely that they would result in different survival potentials for the two fry populations.

D. Swimming Performance

1. Methods

The apparatus for measuring swimming performance (Fig. 11) consisted of a plexiglass tunnel 2 inches (5.1 cm) inside diameter and 2 feet (61 cm) long. Glass tubing packed longitudinally into both ends of the tunnel helped make the flow laminar and reduced the experimental area to 13.25 inches (33.6 cm). The current was provided by a small electric impeller pump, and the rate of flow controlled by a variable transformer connected to it. The flow was largely recirculated but some fresh water was continuously added in the pump reservoir. A screen at the upstream end prevented

Figure. II.– Diagram of apparatus used to measure the swimming performance of Fulton River and Channel sockeye fry, 1968.



the fry from leaving the apparatus via the tubing and a pair of electrified grids at the downstream end kept the fish swimming in the experimental area until exhausted. A fluorescent light above the downstream end of the apparatus provided a further negative stimulus to drifting downstream.

The fish to be tested (10) were placed in the apparatus during the night and left in it for a 12 hour acclimatization period. During this period the light over the downstream end was turned on, the variable transformer set at 50 volts (approx. .08 ft/sec or 2.44 cm/sec) and 5 volts applied to the downstream grid. A small screen was placed at the downstream end to prevent the fish from vacating the apparatus, and a black cardboard cover placed over the tunnel, with the exception of the lighted area.

At the start of each test the small screen was carefully removed from the downstream end of the chamber with tweezers, the lid replaced and the grid voltage set at 20. A set schedule of velocity increases was then rigidly followed (Table V) and the drop out times of each fish recorded to the nearest second. The velocities in Table V were determined by timing the rate of particle passage through the experimental area.

2. Results

The mean swimming times were determined in two ways: (1) for all ten fish (Table VI); and (2) for only the middle six fish, discarding the first and last 20 percent as

TABLE V. Schedule of velocity increases applied to sockeye fry in the swimming endurance tests, 1968.

TIME FROM TEST START		VARIABLE TRANSFORMER READING (Volts)	APPROXIMATE VELOCITY	
MIN.	SEC.		FT/SEC	CM/SEC
	0	50	.08	2.44
	10	60	.14	4.27
	20	70	.18	5.49
	30	80	.22	6.71
	40	90	.38	11.58
5	0	100	.43	13.11
10	0	110	.45	13.72
20	0	120	.47	14.33
25	0	130	.50	15.24
30	0	140	.59	17.98

TABLE VI. Calculated mean swimming performance (min.) of Fulton River and Channel sockeye fry, 1968, using 100 percent of the fry in the apparatus.

RIVER			CHANNEL		
DATE	$\overline{X}$	S^2	DATE	$\overline{X}$	S^2
May 12-13	15.12	13,539.78	May 11-12	38.07	5,628.84
14-15	26.52	25,884.77	13-14	24.90	1,623.44
16-17	6.89	117.87	15-16	36.86	1,109.71
25-26	177.08	62,210.48	19-20	78.73	23,058.62
29-30	137.22	9,716.91	22-23	361.57	100,316.30
June 03-04	23.41	706.27	28-29	61.70	2,503.57
08-09	26.01	1,215.35	June 02-03	280.48	95,360.05
			07-08	125.21	29,224.54
			10-11	154.19	35,626.12
TOTAL	54.30	375.81	TOTAL	183.42	1,208.41

t = 27.8468
df = 157
Signif @ .001

abnormal (Table VII). A variation of this latter method has been previously used by Thomas et al. (1964). The two methods used are in agreement and show that the channel fry were significantly better swimmers than those from the river. The results are shown graphically in Figure 12.

3. Discussion

It is tempting to hypothesive that the relatively poor performance of the river fry population was due to their relatively high percentage of yolk material, resulting in a hydrodynamic disadvantage due to increased resistance to the current (Bams, 1967). If this is so, however, it would be expected that the river fry would become progressively better performers toward the end of the migration period. Clearly, this was not the case since their performance fell off sharply after May 30. The performance of the channel fry also deteriorated near the end of the migration period.

Many authors have shown that swimming speed increases with the length of the fish tested (Table VIII). The length advantage of the channel fish, however, appears too slight to have had such a marked effect on performance.

The effect of previous experience on subsequently measured swimming performance depends on the length of the rest period between the two. Brett et al. (1958), Thomas et al. (1964), Hammond and Hickman (1966) and MacLeod (1967) found that previous experience of the fish, such as in a rearing pond with currents, increases their subsequent

TABLE VII. Calculated mean swimming performance (min.) of Fulton River and Channel sockeye fry, 1968, using only the middle 60 percent of the fry in the apparatus.

RIVER			CHANNEL		
DATE	$\bar{X}$	S^2	DATE	$\bar{X}$	S^2
May 12-13	2.25	3.94	May 11-12	12.17	72.44
14-15	10.68	37.70	13-14	18.92	907.45
16-17	3.18	4.90	15-16	33.06	562.76
25-26	107.35	31,027.74	19-20	28.43	2,523.93
29-30	139.36	3,519.59	22-23	280.65	7,943.74
June 03-04	13.61	117.27	28-29	66.68	2,213.60
08-09	12.05	38.98	June 02-03	222.58	64,039.38
			07-08	64.64	2,098.72
			10-11	118.76	23,988.84
TOTAL	33.02	226.91	TOTAL	140.66	1,098.01

t = 19.52
df = 94
Signif @ .001

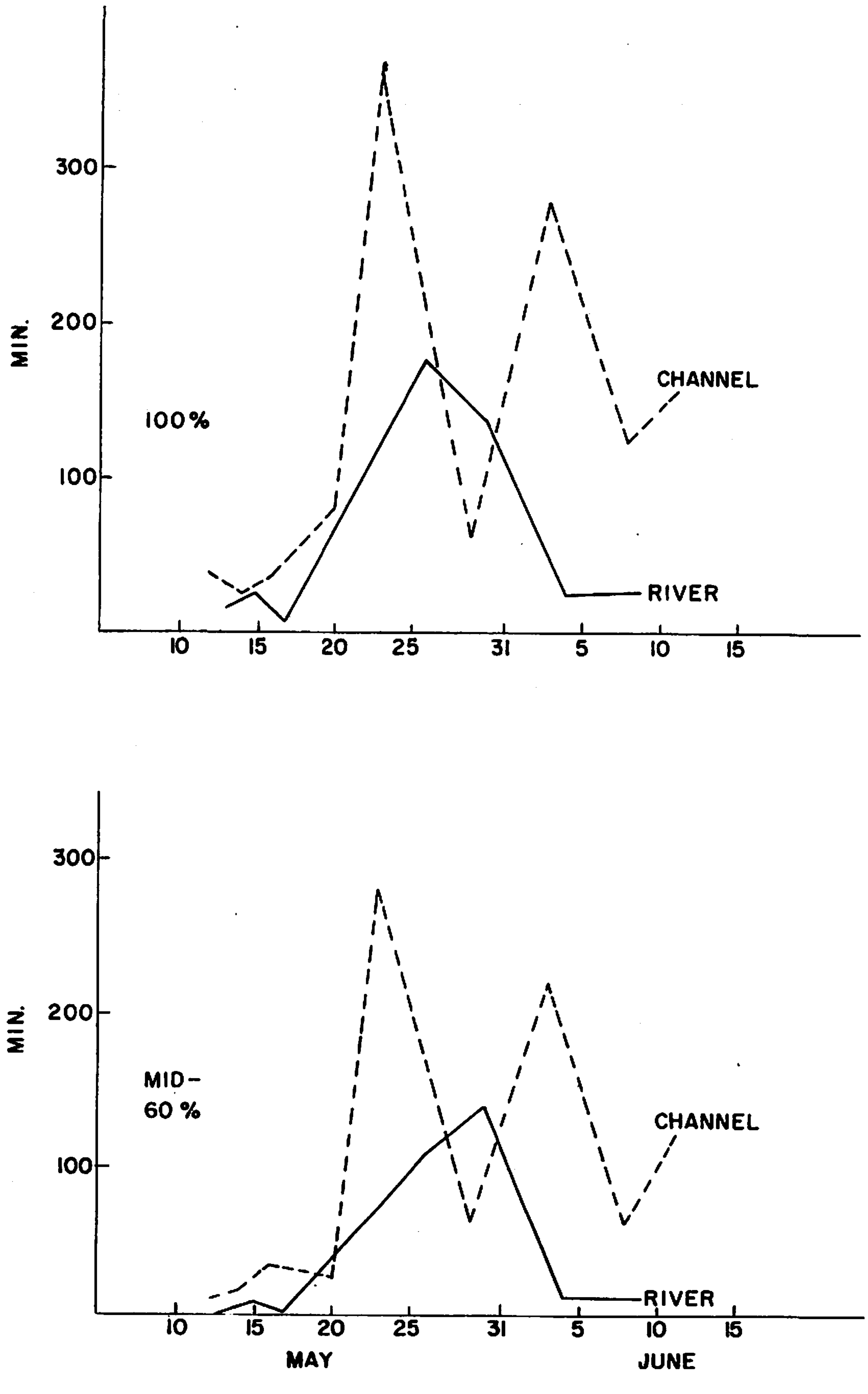


Figure 12.– Swimming performance of Fulton River and Channel sockeye fry, 1968

TABLE VIII. Studies which have demonstrated that the swimming speed of various species of salmonids increases linearly with their length.

AUTHOR	SPECIES
Kerr (1953)	*O. tschawytscha*
Bainbridge (1958)	*Salmo irideus*
Vincent (1960)	*Salvelinus fontinalis*
Groves (1960)	*O. nerka*
Thomas *et al.* (1964)	*O. tschawytscha*
Green (1964)	*Salvelinus fontinalis*
Brett (1965)	*O. nerka*
Bams (1967)	*O. nerka*

performance. This may be due to learning. Bainbridge (1962), however, found that pre-conditioning had no effect on maximum swimming speed. Thomas et al. (1964) found a reduction in re-test performance up to 3 days after a swimming test in young chinook salmon, presumably due to an increase in lactic acid levels (Black, 1957).

The river fish, having been exposed to high currents prior to capture, may therefore have been at a physiological disadvantage. Water velocity in the river was considerably higher than in the spawning channel on the same day (Fig. 13). The relatively poor performance of the river fry may therefore have been an experimental artifact.

Several other test variables may affect performance. These include: high water temperatures, which decrease swimming performance (Brett et al., 1958; Brett, 1959, 1964, 1967; Thomas et al., 1964; Davis et al., 1963); low dissolved oxygen concentrations, which also decrease swimming performance (Davis et al., 1963; Katz et al., 1959; Dahlberg et al.,1968); high carbon dioxide concentrations, which decrease swimming performance (Dahlberg et al., 1968); and increasing numbers of fish in the test, which tend to decrease swimming performance (Thomas et al., 1964).

As noted above, the performance of both the river and the channel fry deteriorated near the end of the migration period. This may have been the result of increasing water temperatures, as these could not be controlled in the laboratory. All other factors were constant from test to

Figure 13. A comparison of conditions in the Fulton River (A) and Spawning Channel (B), during the 1968 fry migration.

A

B

test. The mean daily river water temperatures, and presumably also those of the laboratory supply, from May 1 to June 15, 1968 are shown in Figure 14. The temperature varied from 38 to 52°F during the testing period, May 10 to June 10, 1968, and may have affected the results. However, its effect on both populations was approximately the same.

It must be kept in mind that performance measured in the present study actually involves a number of separate measures, including sustained swimming speed (endurance), burst speed, and learning (to select low velocity areas in the tunnel). Most swimming studies, such as those of Brett, have been concerned with sustained speed and their applicability to the interpretation of the present results is not certain. Brett (1964), for example, found the effect of temperature on sustained speed to be greater than on burst speed and the extent to which temperature variations affected the present results cannot be determined from Brett's figures. One thing is certain however: that temperature must be kept under stricter control in future studies, especially since Keenleyside and Hoar (1954) have shown that high temperatures may cause a reversal of rheotaxis in *Oncorhynchus nerka* and *O. kisutch*, from actively positive to actively negative.

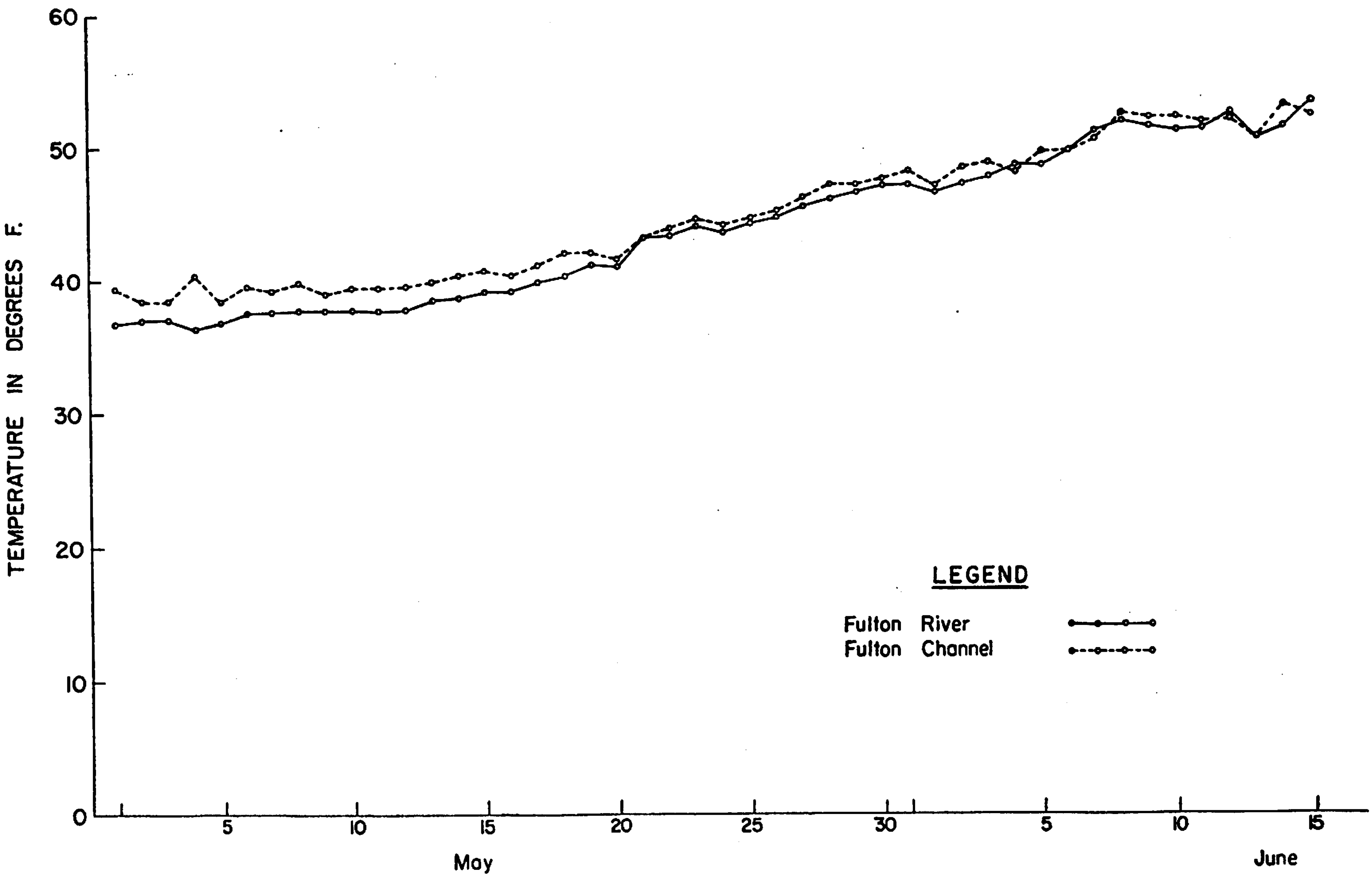


Figure 14. Daily mean water temperatures 1968

E. Predation Vulnerability

1. Methods

The tests were conducted in six aquaria measuring 91.4 x 45.7 x 45.7 cm (190 l. or 50 U.S. gal.). Two aquaria were inside the lab and four outside and all were surrounded with black polyethylene curtains to reduce extraneous stimuli to a minimum. The water in each aquarium was aerated and filtered throughout the test period. The bottom of each aquarium was covered with gravel, ranging from 2 to 15 cm and averaging 5.5 cm in greatest dimension, which provided refuge for the fry.

Rainbow trout (*Salmo gairdnerii*) were used as the predators in all tests. After being caught and transferred to holding tanks in the laboratory, the trout were starved for 48 hours before being presented with fry. Only those trout which demonstrated their ability and disposition to capture and consume fry were used in the tests. This conditioning period usually took 10 to 12 days.

The predators were selected to be as similar in length and weight as possible (Table IX). Two were selected and placed one each in two of the aquaria for a 48 hour conditioning period without food. One hundred fry (from the same source) were then added to each aquarium (i.e. two replicates) and the test commenced. All tests were terminated after six days, regardless of the number of fry consumed. The gravel and fry were then removed from the test aquaria and the percent fry mortality calculated.

TABLE IX. Conditions under which the vulnerability to predation tests were conducted, 1968.

FRY	DATE		PREDATOR			MEAN TEMP.(°C)
	START	END	CAUGHT	LN	WT	
RIVER	May 25	May 31	May 12	20.4	145.3	43
			May 16	26.3	183.9	
	May 28	June 3	May 16	23.3	136.2	46
			May 16	23.3	113.4	
	June 3	June 9	May 16	22.2	110.1	45
			May 16	26.3	183.9	
	June 9	June 15	May 20	27.3	151.7	52
			May 12	25.3	155.8	
CHANNEL	May 25	May 31	May 15	23.4	145.1	43
			May 16	22.2	110.1	
	June 1	June 7	May 12	26.2	162.5	47
			May 12	24.3	149.1	
	June 5	June 11	May 16	23.3	136.2	43
			May 16	23.3	113.4	
	June 11	June 17	May 16	22.2	110.1	50
			May 16	26.3	183.9	
	June 13	June 19	May 16	23.3	124.8	48
			May 23	27.3	161.4	

Tests were usually run at two day intervals, using river and channel fry alternately. Predators in good condition were used in more than one test. Some predators developed fungus infections as a result of handling and were used in only one test.

2. Results

No difference in vulnerability to predation was evident between channel and river fry (Table X). It should be noted that, because of the length of time it took to initially condition the predators, the first tests were not run until May 25, at which time 85 percent of the river fry and 29 percent of the channel fry had already migrated. The large variance encountered on this date would tend to mask any differences between the two populations. Further, most of the yolk-sac fry had migrated prior to the first test and therefore would not be adequately represented in the analysis.

3. Discussion

Although no differences in vulnerability to predation could be demonstrated, it is possible that this was due to sampling difficulties. A review of the literature reveals that differences in vulnerability to predation may be the result of two types of differences in the prey populations: (a) intrinsic differences, both behavioural and structural; and (b) differences in prior experience. Differences in fry "quality" might be the expression of either or both of these. Only the literature on fish predation will be reviewed here.

TABLE X. Differences between the vulnerability to predation of Fulton River and Channel sockeye fry, 1968.

RIVER			CHANNEL		
DATE	MORTALITY		DATE	MORTALITY	
	$\overline{X}$	S^2		$\overline{X}$	S^2
May 25	20.0	800.0	May 25	19.0	450.0
28	36.5	40.5	June 1	12.5	84.5
June 3	27.5	180.5	5	16.0	32.0
9	48.0	98.0	11	54.5	112.5
			13	52.5	0.5
TOTAL	22.7	286.4	TOTAL	20.8	25.2

t = .339
df = 16
Signif @ No

(a) Intrinsic differences between populations

These intrinsic differences may be hereditary or may be environmentally induced. Both may affect the mortality rate of the population due to predation.

Sumner (1934, 1935a, and 1935b) studied the vulnerability to predation of mosquito fish (*Gambusia patruelis*) preyed upon by Galapagos penguins and night herons, and by blue-green sunfish (*Apomotis cyanellus*). Those fish which had been acclimated to the colour of the aquaria in which the test was conducted, or which could rapidly change their colour to match this, were found to be less susceptible to predation. His data was statistically examined by Dice (1949) who came to the same conclusions.

Bams (1967) states that vulnerability to predation depends, at least partially, on "burst swimming" capacity, and demonstrated experimentally that vulnerability to predation is related to the size of the prey, larger sockeye fry being less vulnerable to predation by rainbow trout (*Salmo gairdnerii*). Bams found the condition (K-factor) of the fish to be superimposed on this basic relationship and important since it could "nullify the original advantage the better performing groups have over the lower". Optimum performance occurred at the time of almost complete yolk absorption.

Bams also points out, however, that in a less limiting environment (e.g. one providing cover) "differences in vulnerability between groups may occur as a result of factors entirely unrelated to swimming performance, e.g. behavioural differences that affect the discovery rate". These behavioural differences may be due to differences in the incubation environments or to differences in post-emergence (or pre-emergence?) experience with predators.

The "resistance to predation" (relative testing method) of Salmo and Salvelinus spp. reared in gravel and in classical incubation apparatus was compared by Vibert (1958) who found the gravel-reared fry to be less susceptible.

Veselov (1964) has stated that the survival in a predation situation depends partially on the fry's "unconditioned self-preservation and defense reflexes" (cover, escape) and that "it is of interest to compare defense reflexes of fry-of-the-year grown under natural and artificial conditions--this permits to reveal (sic) the shortcomings of artificial breeding". To my knowledge studies of this type have not yet been reported in the Russian literature.

No effect of incubation environment (presence or absence of gravel and/or presence or absence of light) on vulnerability to predation of chinook salmon (Oncorhynchus tshawytscha) when preyed upon by rainbow trout was found by Thompson (1966).

Several authors have been concerned with the part "physical fitness" plays in vulnerability to predation. Herting and Witt (1967) found that "the impairment of the physical condition of prey fishes, which was caused by seining, columnaris disease, parasitism or starvation, resulted in a significant increase in the vulnerability of bluegill (Lepomis cyanellus) and largemouth bass (Micropterus salmoides) to predation by bowfin (Amia calva). The increase in their vulnerability is attributed to their weakened condition, which resulted in slow swimming movements. This sluggish behaviour may have increased their vulnerability to predation by stimulating the bowfin to attack, because it was observed that bowfin showed a preference for slow-moving or stationary prey."

Vulnerability of fish to bird predation also appears to be related to physical condition. Cormorants have been reported to prey more heavily on roaches (Leuciscus rutilus) parasitized by cestodes (Ligula intestinalis) than on healthy fish (Van Dobben, 1952).

Mossman (1955) altered the fitness of various prey species by means of fin- and spine-clipping and observed the effect of this on vulnerability to predation. He defined fitness to be "the level of adaptation of an organism or group of organisms to its environment". The removal of the main propulsive fins (caudal, dorsal, anal) effectively increased the vulnerability of bluntnose minnows (*Hyborhynchus notatus*) to predation by largemouth bass (*Micropterus salmoides*) and had a progressively less-marked effect on green sunfish (*Lepomis cyanellus*), brook stickleback (*Eucalia inconstans*) and bullheads (*Ameiurus* spp.). Conversely the removal of spines greatly increased the vulnerability of bullheads but had little effect on sunfish. The different responses are presumably related to the defensive tactics of the fish, i.e. fleeing or remaining stationary. Mossman also states that "no clear cut change in selection was found to be correlated with the presence or absence of cover" even though he predicts, on theoretical grounds, "that an increase in 'prey protective cover' should usually cause a decrease in the selectivity of predation if other conditions remain the same". I wish to point out, however, that this could only be expected if the two groups being compared have different cover responses or if cover is 100 percent effective, i.e. no predation possible.

Hoar (1958) presents evidence that differences in cover response affect vulnerability to predation. Hiding is shown to be an innate response of salmonid fry, complete at hatching, but showing inter-specific differences. The sockeye fry (*Oncorhynchus nerka*) shows the greatest cover response and is less vulnerable to predation by crows (*Corvus* spp.) than the pink salmon (*O. gorbuscha*) who's escape movements are not oriented to cover.

Mossman's (1955) conclusions that fin-clipping affects vulnerability to predation are supported by some studies reported in the literature and refuted by others. Parker *et al*. (1963) report that rainbow trout demonstrate a definite selectivity for marked pink fry. Ricker (1949) found that the fin-clipping or young large-mouth black bass resulted in a survival only 52 percent as great as that of unmarked specimens. Vibert (1954) found that eels (*Anguilla anguilla*) obtained more marked (dorsal clipped) than unmarked trout (*S. irideus*) in a large pond. The validity of his results are doubtful since they are more inferred than proven and since no replicates were provided.

On the other hand, Shetter (1952) could find no significant predator preference for marked over unmarked lake trout fingerlings, "fin removal did not increase losses of marked fingerling trout to predatory fishes [brown trout and yellow pike-perch] to any greater extent than might be expected on a basis of chance selection".

Since vulnerability to predation is related to swimming ability the effect of fin-clipping on swimming needs to be considered. Harris (1936, 1937, 1938) found that amputation of a dorsal, pectoral or ventral fin affects the fishes' ability to manoeuvre. Radcliffe (1950) found that clipping the dorsal and/or ventral fins of coho salmon (*O. kisutch*) resulted in "no loss of ability to swim at a constant rate".

(b) Experiential differences between populations

The role of experience in vulnerability to predation has been discussed by Welty (1934) who concludes that "the quicker an individual fish acquires the non-instinctive behavioral responses required of him by his environment, the better will be his chance of survival". Veselov (1964) concurs, stating: "ability to develop conditioned reflexes as a result of the training effect of the environment" partly controls the percent survival from predation. He details a method, the retesting of survivors, which can be used to determine the relative importance of unconditioned and conditioned reflexes. (This pre-occupation with "reflexes", characteristic of Russion behavioural studies, is presumably a Pavlovian influence.) Mossman (1955) could draw from his study "no definite conclusions concerning the role of experience in predator-prey interactions". Robertson (1919) and Schuck (1948) hypothesize that the low survival of hatchery reared salmonids may be due to lack of experience with predators prior to release.

Thompson's (1966) study on chinook and coho salmon provides the best evidence for the role of experience in predator avoidance. He found that juvenile coho and chinook could be conditioned to avoid an electrified model of a predator and that trained chinook salmon had better survival than their untrained counterparts when released into a natural environment (Minter Creek, Washington). Two and one-half times as many untrained fish as trained fish were found in predators' stomachs shortly after prey release.

Popov (1953) conditioned roach fry (Rutilus rutilus) to avoid an electrified model of a large fish. After the release of the conditioned fry into ponds inhabited by pike (Esox lucius), the survival rate of the conditioned fish was found to be three times greater than that of the untrained control fish.

Tuge and Ochiai (1956) produced conditioned defense reactions in guppies (Lebistes reticulatus) and medaka (Oryzias latipes) by means of a model and an electric current, while Kanayama et al. (1964) produced a conditioned defense reaction in rainbow trout, again by means of an electrified model. The investigators were able to show that trained fish showed more effective avoidance responses than did untrained ones.

The acquisition of a defensive behaviour mechanism by verkhovka (Leucapsius delineatus) was reported by Girsa (1962). This training aided the verkhovka in defending themselves against the predaceous catfish (Silurus glanis). The survivors of an initial "bout" of predation were less susceptible to further predatory activity.

Several classical conditioning studies (Otis and Cerf, 1963; Wodinsky et al., 1962; Harlow, 1939) have shown that other species of fish (e.g. goldfish, Carassius auratus; Siamese fighting fish, Betta splendens and Beaugregory, Eupomocentrus leucostictus) are capable of developing long-term conditioned avoidance responses to various stimuli. The ability and the actuality will only be the same if the unconditioned stimulus is not fatal, i.e. if the prey survives its initial contact with the predator.

(c) The role of intrinsic and experiential differences in determining vulnerability to predation as measured in the present study

Intrinsic and experiential differences may affect the discovery rate, attack rate, or capture rate of the predators (Bams, 1967). The discovery and attack rates may be altered by the response of the prey to "concealment cover" (Mossman, 1955) or by the degree to which they stand out as an individual in a school or aggregation (Parker et al., 1963) or against the background (Sumner, 1934, 1935 a & b). Characteristics of weakened prey may cause the predator to attack (Herting and Witt, 1967; Bams, 1967). Mossman (1955) hypothesizes that this is a "sign stimulus" for predation. Capture rate may be altered by the response of the prey to "protective cover" (Mossman, 1955) or by its swimming ability.

In total, then, differential predation rates may be attributed to characteristics of the fry that affect their "capture-to-attack ratio" (Bams, 1967). These characteristics may be environmentally or experientially modified, thus resulting in differences in the vulnerability to predation of different fry populations.

In the present study the channel fry were longer and better developed than the river fry and thus might be expected to be less vulnerable to rainbow trout predation. The river fry, however, may have had greater experience with predators prior to the test, since trout were unable to enter the spawning channel after the start of the fry migration, when screens were placed at the upstream and downstream ends. Thus, the advantages born by each group may have cancelled each other out to produce no net difference in vulnerability. The relevance of these predation tests to conditions in the natural environment will be considered in a later section.

F. Starvation Resistance

1. Methods

Each sample of river or channel fry was sub-sampled to provide two groups of 75 fry each. Each sub-sample was placed in an aquarium measuring 50.8 x 25.4 x 30.5 cm (37.9 l. or 10 U.S. gal.). The two aquaria were identical except that one (the experimental) had a filtered water supply while the other (the control) did not. Both aquaria had plywood covers to prevent entrance of food.

The water supply to each experimental tank was filtered through glass wood in a corner filter on the bottom of each tank. Water quality determinations were made periodically (Table XI). Water temperatures were not controlled but were the same as the river temperatures. Up until June 15 these did not exceed 10^{o}C, but had reached as high as 15^{o}C by July 12, 1968, when the last fish died.

Each aquarium was examined at four hour intervals throughout the day and night, and any dead fry removed and weighed to the nearest milligram (blotted). The procedure was continued until the last fish in the experimental aquarium had succumbed.

2. Results

Two results were obtained: the mean time to death for the experimental sub-samples (Table XII and Fig. 15), and their mean weight at time of death (Table XIII and Fig. 16). The river fry survived significantly longer than the channel fry and were significantly heavier at the time of death, since both groups lost almost an identical percentage of their original mean weight.

3. Discussion

Although the river fry and channel fry exhibited differential mortality rates, this can not be attributed entirely to starvation. In some cases, mortality rates in the control aquaria did not differ significantly from those in the experimental (Fig. 17). Further evidence of this is provided by a comparison of the weights of the fry at the

TABLE XI. Water quality in the starvation resistance aquaria, 1968.

DATE	AQUARIA	CRITERION			
		pH	O_2 (ppm)	CO_2 (ppm)	Hardness (gr/gal)
May 25	Experimental	7.0	9	5	2.5
	Control	7.0	11	5	2.5
June 15	Experimental	7.0	9	5	2
	Control	7.0	10	5	2

TABLE XII. Mean number of days to death in the starvation resistance tests on Fulton River and Channel sockeye fry, 1968.

RIVER				CHANNEL			
DATE		DAYS TO DEATH		DATE		DAYS TO DEATH	
		$\bar{X}$	S^2			$\bar{X}$	S^2
May	07	33.01	51.24	May	11	30.39	38.24
	12	37.88	23.23		15	28.19	25.79
	17	37.22	42.32		19	24.45	12.94
	22	26.56	29.68		23	26.95	16.08
	27	29.57	16.72		27	24.42	10.77
June	01	28.37	13.22		31	24.56	14.73
	06	24.86	20.94	June	04	24.66	10.53
	11	20.92	21.67		08	20.88	18.85
					12	19.31	7.47
TOTAL		31.60	.09	TOTAL		23.92	.03

t = 556.0
df = 1244
Signif @ .001

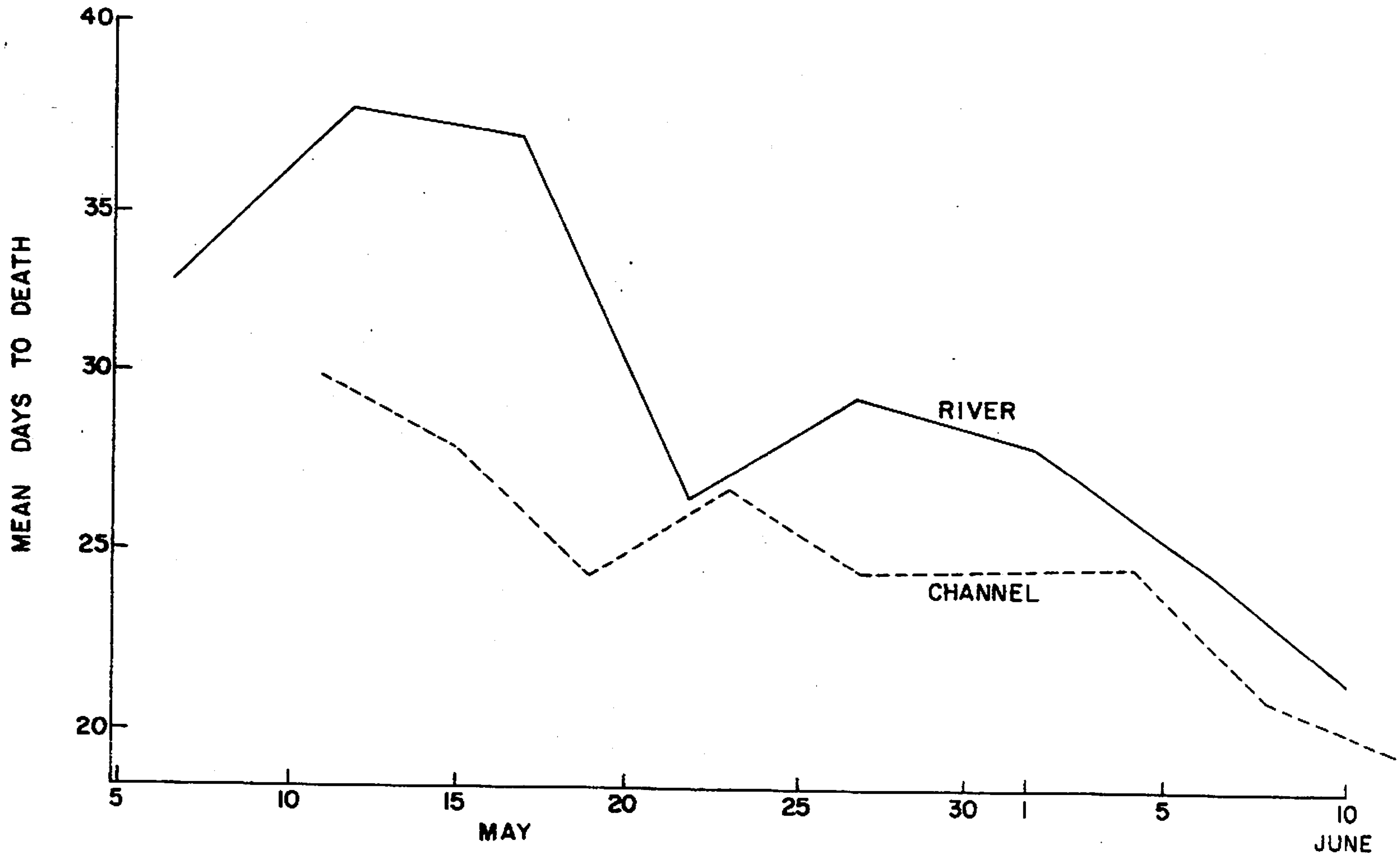


Figure 15.– Mean number of days to death in the starvation resistance tests on Fulton River and Channel sockeye fry, 1968.

TABLE XIII. Mean weight at death (mg) in the starvation resistance tests on Fulton River and Channel sockeye fry, 1968.

RIVER			CHANNEL		
DATE	WEIGHT AT DEATH		DATE	WEIGHT AT DEATH	
	$\bar{X}$	S^2		$\bar{X}$	S^2
May 07	100.11	378.26	May 11	97.13	316.17
12	100.86	237.45	15	96.69	182.33
17	97.86	357.98	19	96.97	376.70
22	94.92	197.36	23	88.80	167.16
27	92.30	211.79	27	93.04	172.10
June 01	91.36	194.21	31	93.70	224.43
06	95.71	239.92	June 04	91.19	208.59
11	94.69	341.66	08	91.69	329.89
			12	97.61	186.65
TOTAL	96.75	.71	TOTAL	92.47	.56

t = 94.78
df = 1243
Signif @ .001

PERCENTAGE WEIGHT LOSS	
RIVER	CHANNEL
$\frac{146.90 - 96.75}{146.90} \times 100$	$\frac{140.06 - 92.47}{140.06} \times 100$
= 34.1%	= 33.9%

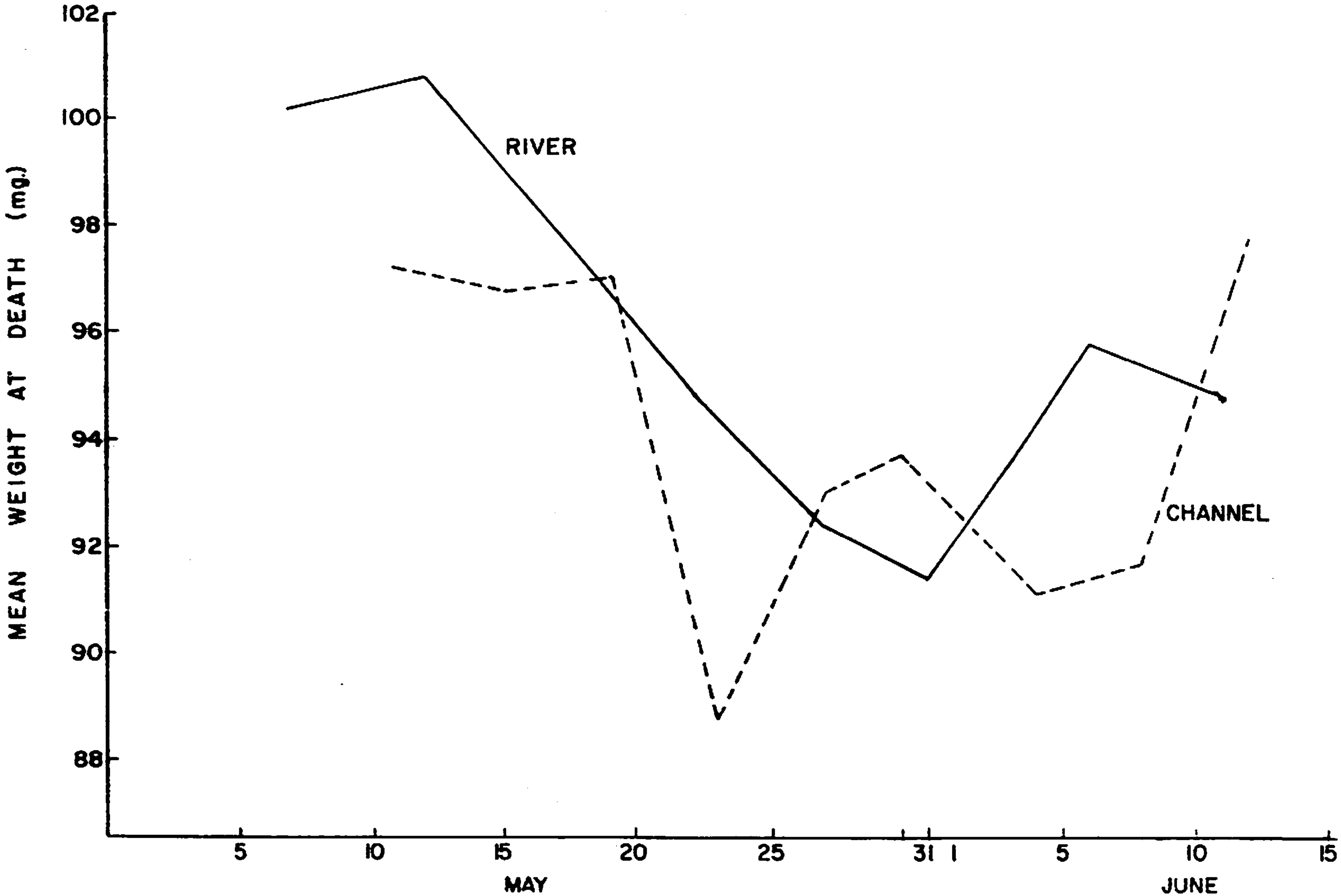


Figure 16.- Mean weight at death (mg.) in the starvation resistance tests on Fulton River and Channel sockeye fry, 1968

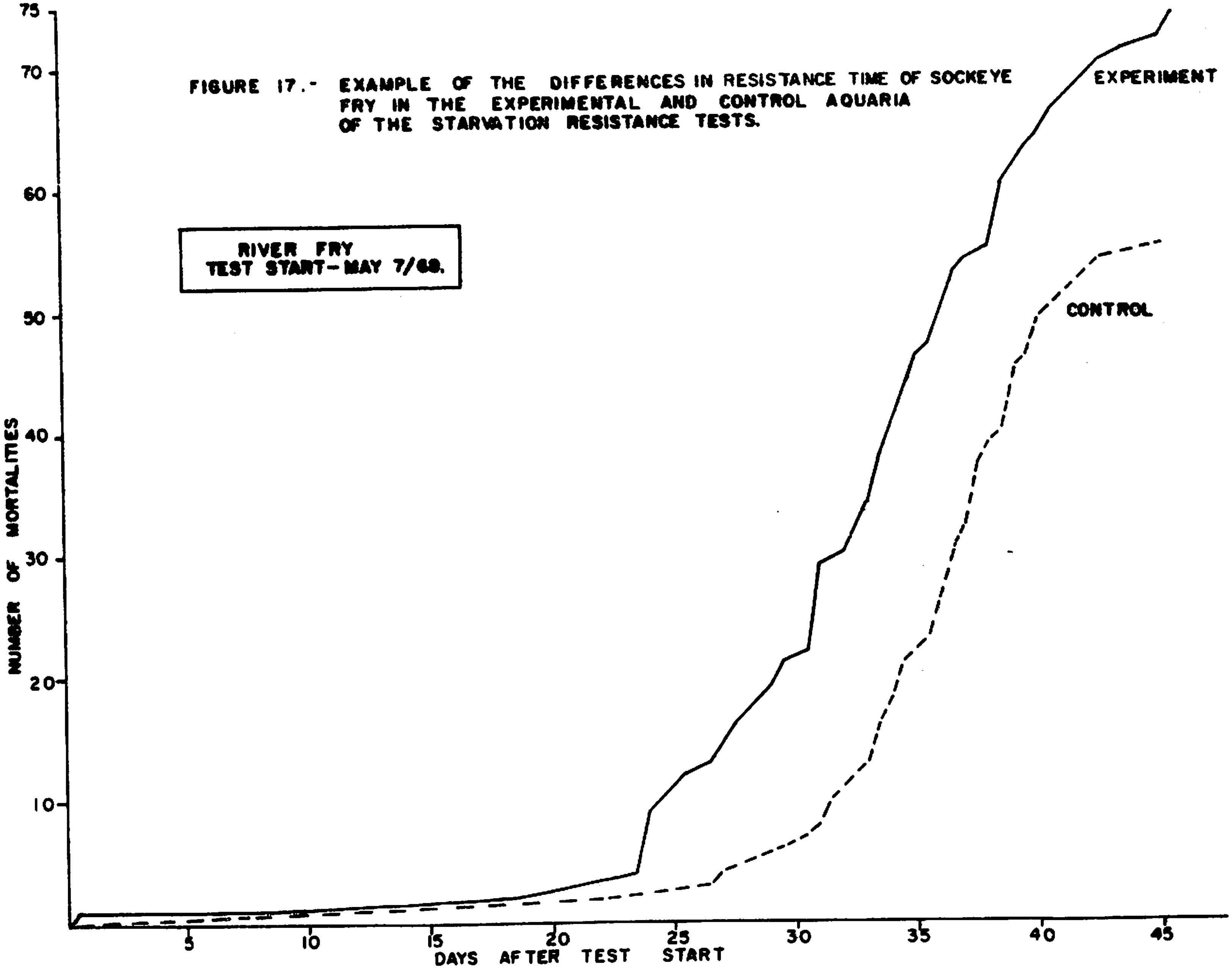


FIGURE 17.- EXAMPLE OF THE DIFFERENCES IN RESISTANCE TIME OF SOCKEYE FRY IN THE EXPERIMENTAL AND CONTROL AQUARIA OF THE STARVATION RESISTANCE TESTS.

time of death (Table XIV). In no case was there any significant difference between the weight of the fry at death in the control and experimental aquaria. Thus the only conclusion that can be made is that the river fry were less susceptible to mortality than the channel fry when held in the laboratory. The relation of starvation to this mortality cannot presently be ascertained. It is possible that much of the mortality was due to a fungus infection on the gills of some of the fry, particularly at the higher water temperatures late in the period of experimentation (early July). Thus, the "quality criterion" actually being measured may be "resistance to fungus infection under conditions of partial starvation at high water temperatures".

In this regard, the interactions of starvation with other environmental factors are of interest.

(a) Effects of starvation upon other factors

Ivlev (1961) has demonstrated that starvation of carp and roach fry decreases their swimming performance; that starved bream have a lower resistance to phenol than their unstarved counterparts; that starvation decreases tolerance to high salinity for bleak and herring, high or low pH for tench and perch, and low oxygen levels for carp and bleak; that starvation results in intensificatio of the rate of destruction of roach fry by disease or fungus infection (see above); and that starvation decreas the ability of roach fry to avoid predators, and of pike,

TABLE XIV. Weights of Fulton River and Channel sockeye fry at the time of death in the experimental and control aquaria of the starvation resistance tests.

SOURCE	DATE		EXPERIMENT		CONTROL		t
			$\overline{X}$	S^2	$\overline{X}$	S^2	
RIVER	May	7	100.11	378.26	94.64	265.13	.2168
		12	100.86	237.45	94.21	247.12	.2997
		17	97.86	357.98	94.04	228.44	.1569
		22	94.92	197.36	100.61	418.10	.2298
		27	92.30	211.79	90.77	224.03	.0766
	June	1	91.36	194.21	94.39	222.65	.1469
		6	95.71	239.92	90.97	216.41	.2224
		11	94.69	341.66	91.85	271.31	.1534
CHANNEL	May	11	97.13	316.17	105.07	635.53	.2593
		15	96.69	182.33	101.04	281.80	.1578
		19	96.97	376.70	100.09	396.40	.1079
		23	88.80	167.16	88.37	170.99	.0172
		27	93.04	172.10	97.35	220.71	.2169
		31	93.70	224.43	88.66	189.10	.2457
	June	4	91.19	208.59	87.49	222.13	.1782
		8	91.69	329.89	89.74	143.36	.0919
		12	97.61	186.65	86.75	213.71	.5400

tench, and bleak to obtain food. In summary, he states that "the phenomenon of starvation is a powerful factor which determines both the character and intensity of different ecological reactions", and that it is a "universal cause upsetting a whole series of physiologica processes".

To further demonstrate this point, the following information is presented. The work of Atkins (1906) indicates, despite the authors own conclusion, that after even a relatively short period of starvation not all the fish (silver salmon, brook trout, lake trout, Atlantic salmon) are capable of utilizing food. This was also demonstrated by Adelman *et al.* (1955). Gibson and Keenleyside (1966) have demonstrated that starved *Salmo salar* change their light response from photonegative to photopositive and that starved *Salvelinus fontinalis* lose some of the strength of their normal photonegative response. Further, Javaid and Anderson (1967) have shown that *Salmo salar*, *Salmo gairdnerii*, and *Salvelinus fontinalis* shift their selected temperatures after starvation, the Atlantic salmon upwards, the others downwards.

(b) *Effect of other factors upon starvation*

Adelman *et al.* (1955) demonstrated that small fish are more susceptible to mortality than large ones. After seven months of starvation 70% of the 3.5 inch (8.9 cm) brook trout had died, compared to 25% of the 5.5 inch (14.0 cm) length group, and 10% of the 7.5 inch (19.1 cm) length group. Reimers (1957) demonstrated that a high initial condition factor favoured survival under conditions of complete starvation, and Ivlev (1961) stated that younger (and therefore smaller) fish had a lower resistance to starvation than their older (and larger) conspecifics.

A number of authors have demonstrated that the resistance of fishes to starvation is improved at low temperatures. These include: Kawajiri (1928) for *Oncorhynchus nerka* and *Salmo irideus*; Lawrence (1941) for *S. gairdnerii*: Phillips *et al.* (1953) and Latta (1969) for *Salvelinus fontinalis*; and Reimers (1957) for *Salmo trutta* and *S. gairdnerii*. This effect is presumably related to changes in metabolic rate with temperature.

Ivlev (1961) has also shown a relationship between the type of feeding normally conducted and degree of resistance to starvation. Predatory fish (sheat fish) were more resistant than benthophages (roach) which were in turn less susceptible than planktophages (bleak).

In conclusion, starvation is inextricably related to all other ecological factors, whether these by physical, chemical, or biological. Even a small difference in starvation resistance between two fry populations may have profound effects on subsequent mortality, since "complete and partial starvation are ecologically synonymous and differ only in intensity" (Ivlev, 1961). Further, food absence in a non-territorial species is an "indiscriminate stress" (Brett, 1958) and applies to every member of the population. There is therefore some cause for concern in light of the present results, even though the mortality recorded was not a direct result of starvation. The results, however, should not be considered conclusive, even though highly suggestive. Further study of this factor appears warranted.

Longevity of salmonids exposed to starvation is extremely high (Table XV). This provides further evidence that mortality in the present study was not solely due to starvation since mean longevities were 31.6 days for river fry and 23.9 days for channel fry. The 1967 Fulton fry quality tests were terminated after 20 days, when most of the fish had expired (R.K. Kearns, pers. comm.). Starvation obviously played little or no part in those results. The 1967 aquaria made no provision for water interchange. Mortality may therefore have been due to metabolite buildup (cf. Vincent, 1960). No controls were provided to assess the results.

G. Temperature Tolerance

1. Methods

Each sample of river or channel fry was sub-sampled into two groups of 50 fry each. Each group was placed in

TABLE XV. Longevity of various salmonids in starvation resistance studies.

SPECIES	SIZE	TEMP. °C	$\overline{X}$ LONGEVITY	SOURCE
Salvelinus fontinalis	3.5"	7.2	≃ 4 mos.*	Adelman *et al.* (1955)
"	5.5"	"	> 7 mos.	"
"	7.5"	"	>> 7 mos.	"
"	23 mm	4.6	67.5 days*	Latta (1968)
"	"	5.8	44.5 days*	"
"	"	7.1	31.0 days*	"
"	"	10.3	27.5 days*	"
O. nerka	fry	2.5	183.7 days	Kawajiri (1928)
"	"	5.0	166.2 "	"
"	"	6.6	139.0 "	"
"	"	8.0	122.1 "	"
"	"	9.2	98.2 "	"
"	"	10.6	95.7 "	"
"	"	11.9	84.5 "	"
"	"	12.7	73.0 "	"
"	"	14.5	54.6 "	"
"	"	16.4	50.1 "	"
S. irideus	fry	5.6	95.4 days	Kawajiri (1928)
"	"	8.3	89.2 "	"
"	"	9.3	75.6 "	"
"	"	12.1	53.3 "	"
"	"	13.2	46.4 "	"
"	"	15.1	46.9 "	"
"	"	16.3	40.0 "	"

*Assuming die-off curve is normally distributed.

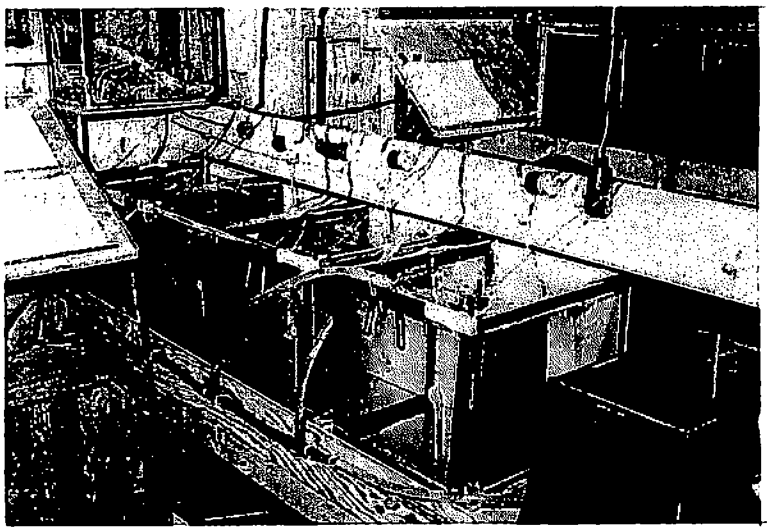
one-half of an aquarium measuring 76.2 x 30.5 x 30.5 cm (75.8 l. or 20 U.S. gal.). The aquaria were divided in two lengthwise by a plastic screen so that two groups of fish (one river and one channel) could be tested at the same time. Thus, on one day, 50 river and 50 channel fry were placed in one aquarium (experimental) and another 50 of each in the second aquarium (control).

Water temperatures in the experimental aquaria (Fig. 18) were raised from ambient over 24 hours and were maintained at 18.5^{o}C by means of aquarium heaters (Evans model) in a small head pond box and in each aquarium. Fairly high precision temperature control could be obtained by adjustments to the rate of water exchange. Consistency was assured through the connection of three heaters to each thermostat (Elephant model). Aeration helped maintain homogeneity within a given aquarium. Water temperatures in the control aquaria fluctuated with that of the main laboratory water supply. Other water quality criteria were approximately the same in both the control and experimental aquaria (Table XVI).

The aquaria were examined at four hour intervals throughout the day and night, and any dead fish removed and weighed to the nearest milligram (blotted). The procedure was continued until the last fish in the experimental aquarium had succumbed.

Figure 18. Apparatus used to study the temperature tolerance of Fulton River and Channel sockeye fry, 1968. A. Experimentals; B. Controls

A



B

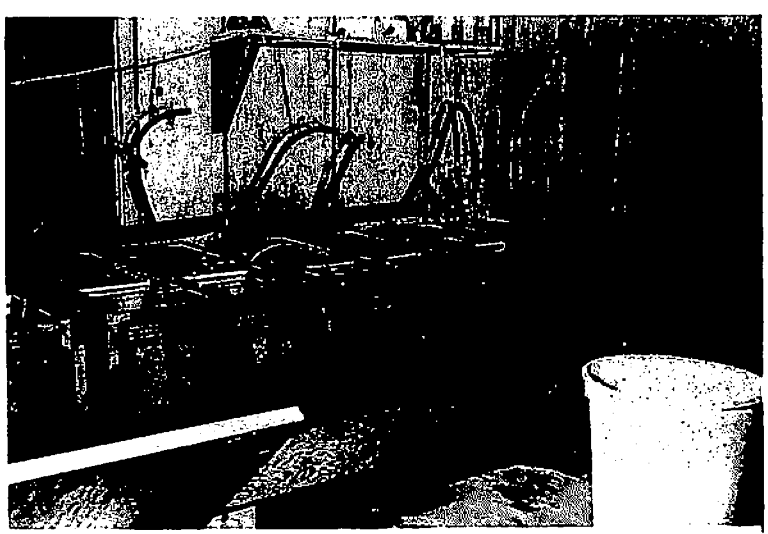


TABLE XVI. Water quality in the temperature tolerance aquaria, 1968.

DATE	AQUARIA	CRITERION			
		pH	O_2 % Sat	CO_2 (ppm)	Hardness (gr/gal)
May 24	Experimental	7	95	5	3
	Control	7	93	5	3
June 15	Experimental	7	85	5	2
	Control	7	88	5	2

2. Results

Two results were obtained: the mean time to death (resistance time) for the experimental sub-sample (Table XVII and Figure 19), and the mean weight of the fry at time of death (Table XVIII and Figure 20). The river fry survived significantly longer than the channel fry and were significantly heavier at the time of death, even though they lost a slightly greater percentage of their initial weight.

3. Discussion

The temperature of 18.5°C used in the present tests is below the upper lethal temperature for all salmonid species studied to date (Table XIX). Mortality, therefore, was not due to a direct effect of high temperatures, since Brett (1952) points out that "temperatures between 8° and 21°C are unlikely to cause death among sockeye no matter what the acclimation, nor what the exposure time". In other words, 8 to 21°C is the zone of tolerance. Outside these limits lies the zone of resistance (Brett, 1956).

Mortality was, however, higher in the experimentals than in the controls (Fig. 21). This would appear to be due to the fact that although temperatures had not reached the incipient upper lethal level, they had reached the loading level (Brett, 1960), above which growth and activity are poor, under the influence of the loading effect of metabolic demand (cf. Donaldson & Foster, 1940). A graph in Brett

TABLE XVII. Mean number of days to death in the temperature tolerance tests on Fulton River and Channel sockeye fry, 1968.

RIVER			CHANNEL		
DATE	DAYS TO DEATH		DATE	DAYS TO DEATH	
	$\overline{X}$	S^2		$\overline{X}$	S^2
May 08	19.97	25.04	May 13	16.60	19.05
13	16.30	31.99	17	14.39	13.87
17	23.13	35.88	20	14.47	18.08
23	16.99	23.06	23	15.03	12.23
28	15.15	66.73	28	15.12	16.53
June 01	17.66	5.83	June 01	13.74	5.29
06	17.76	11.04	06	15.09	7.94
12	12.90	7.30	09	14.94	3.67
			12	11.83	5.42
TOTAL	18.21	.12	TOTAL	14.55	.03

t = 197.13
df = 833
Signif @ .001

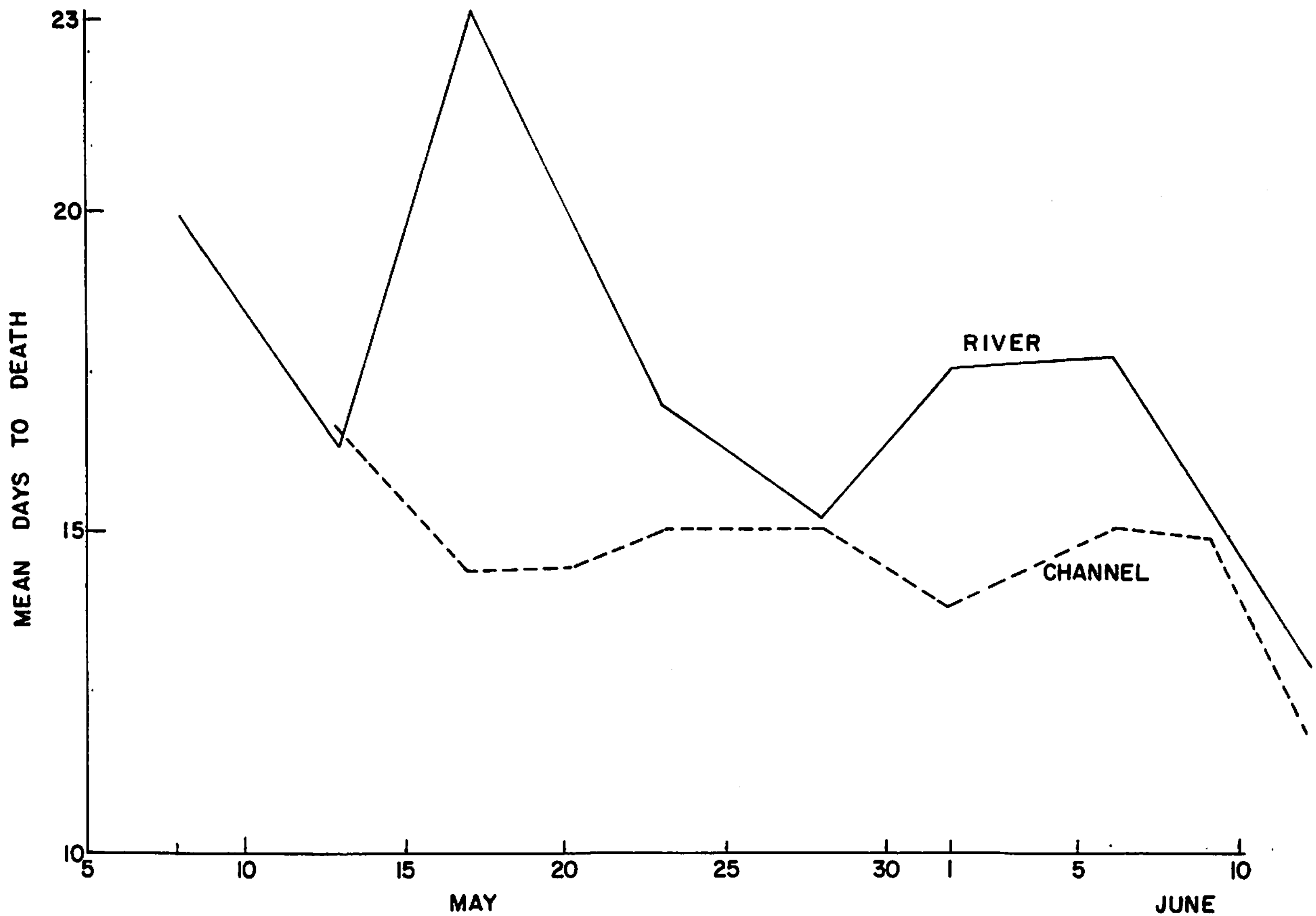


Figure 19. - Mean number of days to death in the temperature tolerance tests on Fulton River and Channel sockeye fry, 1968.

TABLE XVIII. Mean weight at death (mg) in the temperature tolerance tests on Fulton River and Channel sockeye fry, 1968.

RIVER			CHANNEL		
DATE	WEIGHT AT DEATH		DATE	WEIGHT AT DEATH	
	$\bar{X}$	S^2		$\bar{X}$	S^2
May 08	82.28	128.33	May 13	86.25	192.15
13	89.86	511.31	17	84.76	116.54
17	90.81	293.25	20	88.60	428.98
23	85.60	414.55	23	87.62	162.94
28	98.50	823.47	28	91.59	351.08
June 01	85.94	240.30	June 01	84.74	321.15
06	85.24	197.82	06	89.22	408.59
12	89.90	201.11	09	85.88	107.23
			12	94.28	160.12
TOTAL	88.05	1.69	TOTAL	87.85	1.28

t = 2.34
df = 829
Signif @ .02

PERCENTAGE WEIGHT LOSS	
RIVER	CHANNEL
$\frac{146.90 - 88.05}{146.90} \times 100$	$\frac{140.06 - 87.85}{140.06} \times 100$
= 40.4%	= 37.1%

FIGURE 20. - MEAN WEIGHT AT DEATH (MG) IN THE TEMPERATURE TOLERANCE TESTS ON FULTON RIVER AND CHANNEL SOCKEYE FRY, 1968.

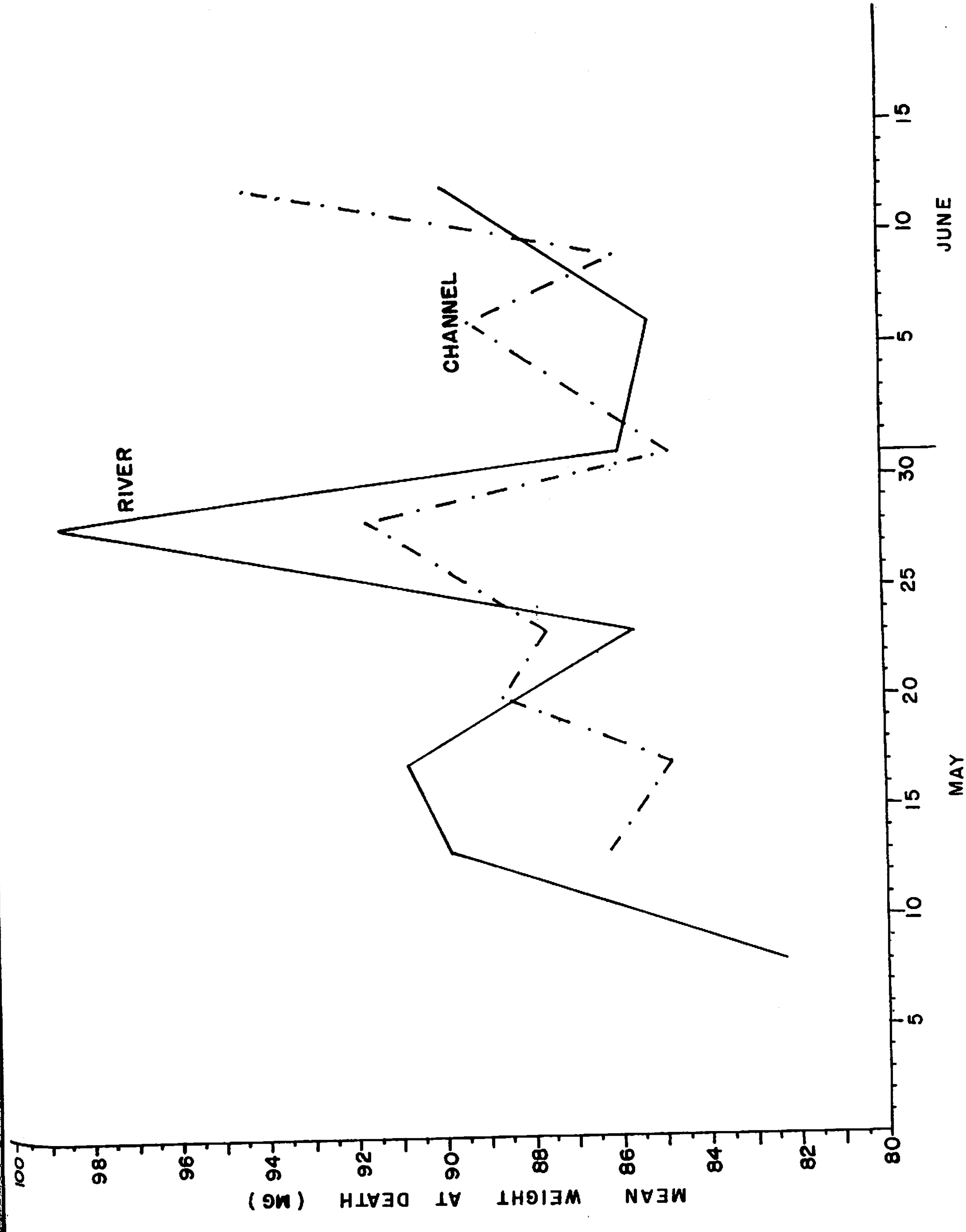


TABLE XIX. Upper lethal temperatures (ULT) for salmonids acclimated at various temperatures.

SPECIES	SIZE	ACCLIM. TEMP. °C	ULT °C	SOURCE
S. salar	Alevin	5-6	22	Bishai (1960)
"	"	10	23	"
"	"	20	23	"
S. trutta	"	5-6	22	"
"	"	10	23	"
"	"	20	23	"
S. trutta f. fario	"	5-6	22.5	"
"	"	10	23	"
"	"	20	23	"
Salvelinus fontinalis	56.9 mm	-	26.1	Brett (1944)
"	approx. 8 gr	3	23.4	Fry et al.(1946)
"		11	24.5	"
"		20	25.3	"
"		24.5	25.3	"
O. nerka	-	11	22	Black (1953)
S. gairdnerii	26.1 g	11	24	"
O. gorbuscha	38 mm	5	21.3	Brett (1952)
"	"	10	22.5	"
"	"	15	23.1	"
"	"	20	23.9	"
O. keta	54 mm	5	21.8	"
"	"	10	22.6	"
"	"	15	23.1	"
"	"	20	23.7	"

(continued)

TABLE XIX. (continued)

SPECIES	SIZE	ACCLIM. TEMP. °C	ULT °C	SOURCE
O. nerka	45 mm	5	22.2	Brett (1952)
"	"	10	23.4	"
"	"	15	24.4	"
"	"	20	24.8	"
O. kisutch	48 mm	5	22.9	"
"	"	10	23.7	"
"	"	15	24.3	"
"	"	20	25.0	"
O. tshawytscha	44 mm	5	21.5	"
"	"	10	24.3	"
"	"	15	25.0	"
"	"	20	25.1	"
S. salar	21 mm 122 mg	7.2	27.64	Spaas (1960)
"	2.25 gr 56.6 mm	"	28.5	"
"	15.04 gr 112.4 mm	"	29.8	"
S. trutta	4.21 gr 66.45 mm	"	26.38	"
"	12.91 gr 100.1 mm	"	29.0	"
S. fario	19.8 mm 85 mg	"	25.46	"
"	4.14 gr 66.6 mm	"	25.91	"
"	21.82 gr 115 mm	"	29.15	"

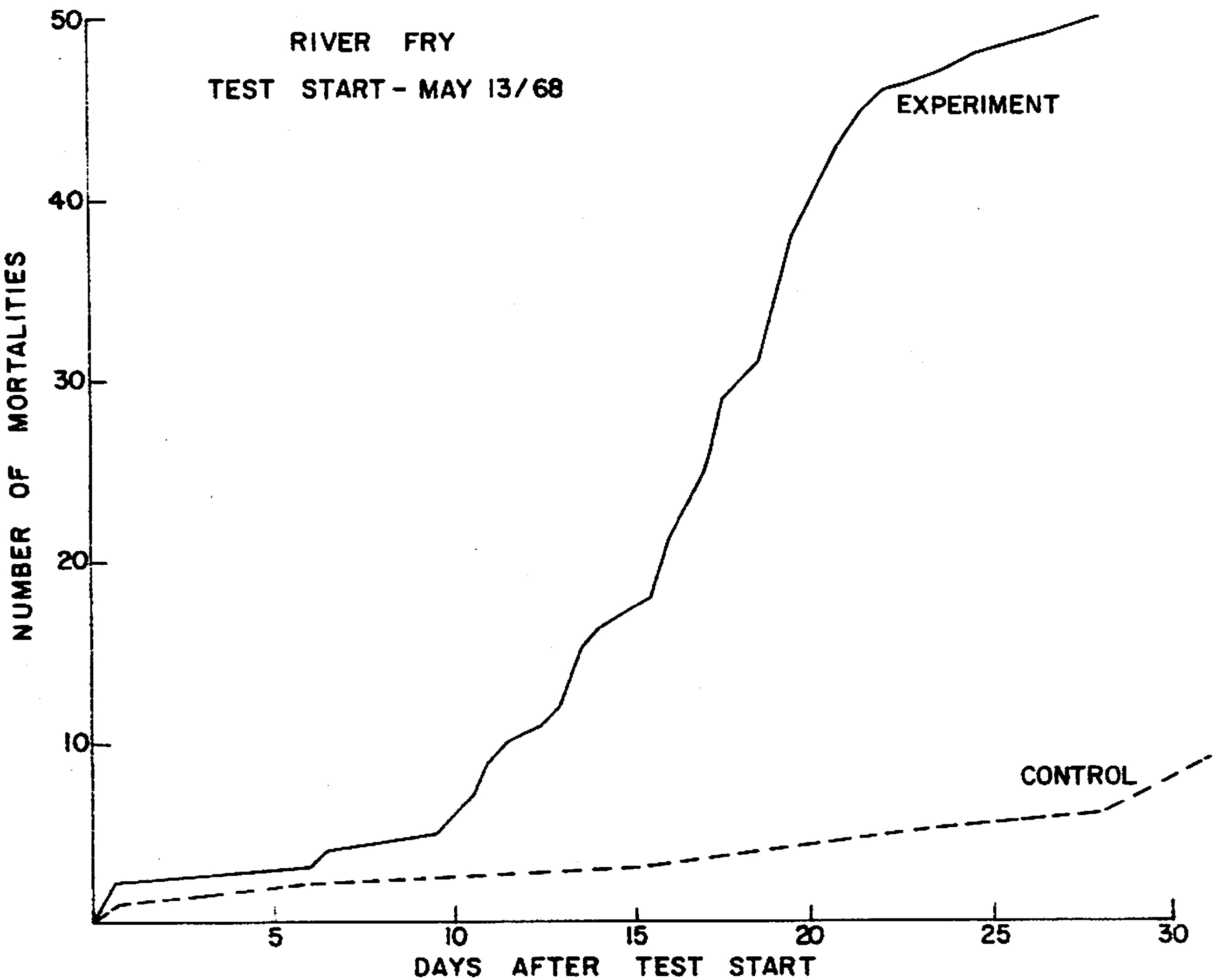


Figure 21.- Example of the differences in resistance time of sockeye fry in the experimental and control aquaria of the temperature tolerance tests.

(1960) indicates that this level for sockeye salmon acclimated at 10°C falls at about 17°C. Thus, the mortality recorded in the present study may be only a secondary effect of high temperature. The sigmoid curve of resistance times is as expected, and permits the application of standard statistical techniques (Brett, 1952).

Differences between the temperature tolerance of two populations of fish may be due to: (1) differences in previous thermal history, or degree of acclimation (acclimatization); or (2) genetic or environmentally produced intrinsic differences. Since differences between the temperatures in the river and the spawning channel were not of sufficient magnitude to produce acclimation differences (Fig. 14) it seems that the results are indeed due to intrinsic differences between the two groups. Vibert (1958) demonstrated that *Salmo salar* fry reared without gravel were more susceptible to high temperatures than those reared under gravel. Vincent (1960) found that wild brook trout (*Salvelinus fontinalis*) suffered only 25% mortality in 26.7° water, while domestic trout suffered 69% mortality under the same conditions.

The differences may be due to the amount or type of fat in the tissues of the two types of fry. Vincent (1960) postulated this to be the cause of the differential mortality of his brook trout and Hoar and Cottle (1952) showed that the degree of saturation (iodine number) of the fat has a marked influence on temperature tolerance. The river fry in the present study had a higher percentage of fat than their channel counterparts, due at least in part to their less advanced stage of development. No assays of iodine number were conducted and this may be a profitable field for future study.

Size *per se* appears to have no effect on temperature tolerance (Brett, 1944, 1952) but development stage may be important (Spaas, 1960). This latter worker considers size and development stage to be different ways of measuring the same thing.

The number of fish tested at one time has not been examined but may be a critical factor. McCauley's (1968) work suggests that "fish undergoing thermal stress may alter the composition of the surrounding water, such that survival times of fish subsequently subjected to lethal temperatures in the same water are measurably increased". This problem, if it exists, would be partially alleviated by the constant interchange of water in the present study but deserves further study.

Finally, it should be pointed out that the test temperature (18.5°C) would seem a realistic one. Between 1957 and 1963 the epilimnion of Babine Lake, near Fulton River, reached as high as 18°C four times in the May through July period (Johnson, 1965). Mid-summer temperatures have never exceeded 20°C and therefore must be considered sub-lethal. These temperatures, however, are sufficient to affect feeding and growth, and therefore cause mortality indirectly.

H. General Discussion of Standard Tests

The results of the standard fry quality tests, summarized in Table XX, suggest that the river fry are superior to the channel fry and thus will have a greater percent fry-to-adult survival. The ultimate test, of course, will be to compare the percentage return with the observed quality of the migrating fry, in order to correlate quality indices with subsequent survival. Burrows (1968) has adopted this approach and has determined that: (1) "an increase in performance rating from 60 to 100 in fall chinook fingerlings as measured by the stamina tunnel resulted in a 60 percent increase in adult survival"; and (2) "an increase in fat deposition in the fingerlings from four percent to eight percent resulted in a 100 percent increase in adult survival".

A second approach, and a shorter term one, is to determine the relevance of the measured quality indices to conditions in the natural environment. This approach has been adopted in the present study. What must be determined is whether or not starvation, predation, high temperatures and strong currents are significant mortality factors in the natural environment, and whether the severity of these factors depends on size, development stage, or biochemical composition. Once

TABLE XX. Summary of the standard fry quality tests performed on Fulton River and Channel sockeye fry, 1968.

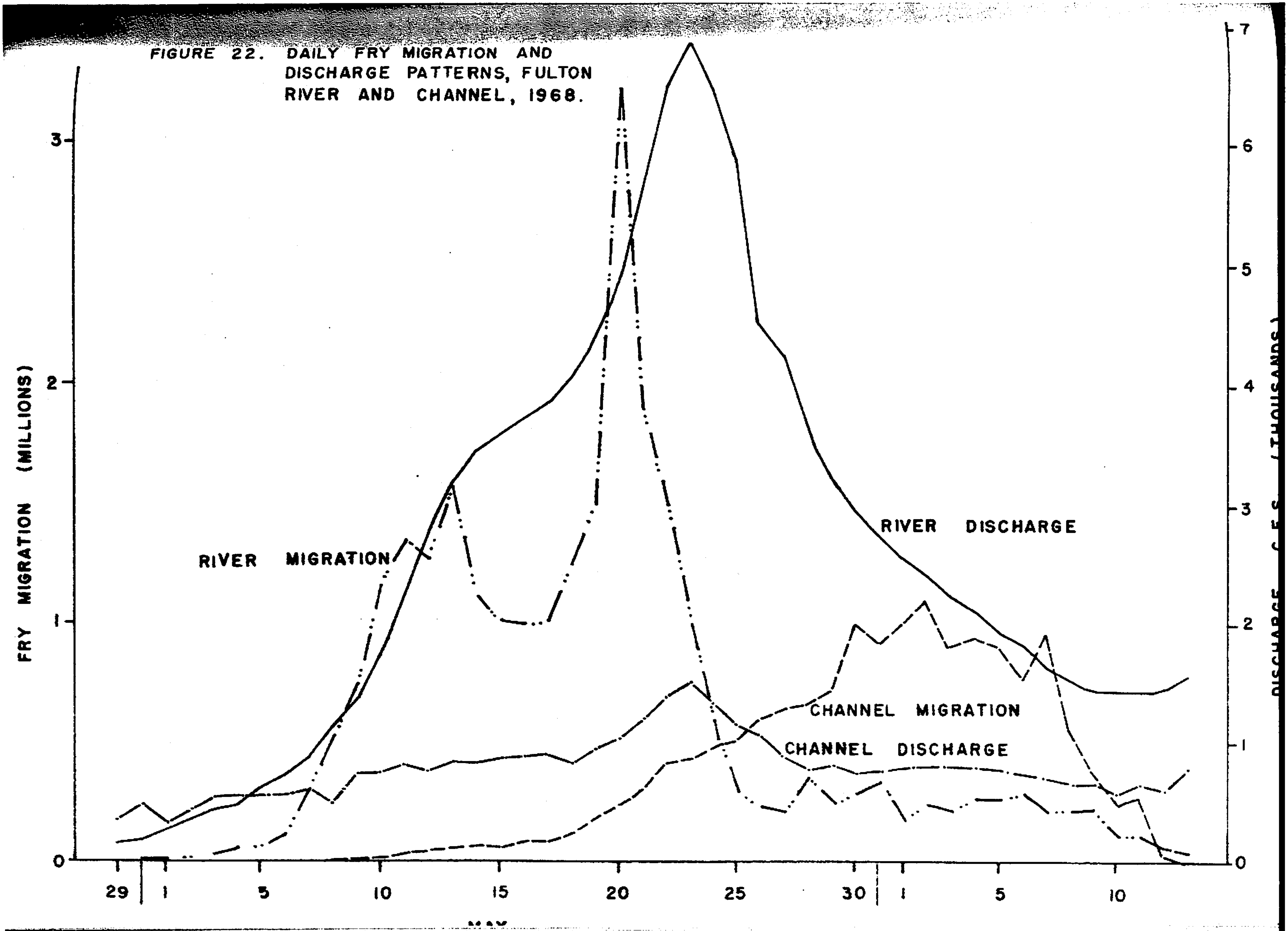
RIVER FRY SUPERIOR	CHANNEL FRY SUPERIOR	NO DIFFERENCE OBSERVED
Percent Lipids	Length	Predation Vulnerability
Percent Nitrogen	Swimming Performance	
Percent Solids		
Weight		
Starvation Resistance		
Temperature Tolerance		

this is known it will be possible to predict survival on the basis of the values of the quality criteria. Presently it is only possible to state that the river fry are superior in terms of the particular tests chosen for this particular study. It is not possible to decide whether the river fry or the channel fry have the net advantage, since it is not possible to state whether it is advantageous to have a high temperature tolerance and a poor swimming ability, or vice-versa.

In the present report, some information will be presented on the ecology of the Fulton River with emphasis on predator-prey interactions (Section IV). In future studies it is suggested that the ecology of Fulton River mouth area also be considered, since it may be there that starvation and high temperatures act as mortality factors.

The adoptance of an absolute method of quality testing was particularly fortunate in 1968. Figure 22 demonstrates that timings of the river and channel fry migrations were vastly different -- the migration peaks being separated by 13 days. The graph also indicates that migration timing was partially, but not entirely, correlated with discharge levels.

FIGURE 22. DAILY FRY MIGRATION AND DISCHARGE PATTERNS, FULTON RIVER AND CHANNEL, 1968.



III. AUXILIARY FRY QUALITY STUDIES

These studies were designed to determine the reliability of some of the standard fry quality tests; to suggest better types of fry quality tests for future studies; to determine the reliability of the sampling procedure; and to test the hypothesis that observed quality differences were due solely to differences in the timing of migration between the two fry populations.

A. Reliability of Development Stage Determination

1. Introduction

The method of development stage classification described in Section II.B.2 is largely subjective, since a high percentage of the fish are usually intermediate between stages and the decision as to their placement is largely one of personal preference. This study was designed to determine the degree of subjectivity of this staging classification.

2. Methods, results, and discussion

A sample of 50 or 100 fry was presented in turn to different members of the laboratory staff who were asked to classify the fish by stage and to calculate the percentage occurrence of each stage in the sample.

The results of 14 such tests (Table XXI) show that individuals varied considerably in their classification. For this reason the data obtained in the daily samples were not considered amenable to standard statistical techniques. After May 23, 1968 one individual (II) did all the development stage classifications, since he was usually closest to the mean value. Figure 9, therefore, represents trends only. It reveals a difference in the degree of development of the two fry populations, but the extent of the difference is only an approximate value.

B. Yolk-Sac Weight Studies

1. Introduction

The two groups of fry obviously differed with respect to development stage, even measured subjectively. They also differed in that the river fry were significantly heavier. The question arises: If the river and channel fry had migrated at the same stage of development would there still have been a weight difference, i.e. is the observed weight difference due solely to differences in migration timing?

2. Methods and results

To answer this question yolk-sacs were carefully dissected from fry (after a 1-2 hr. hardening period in formalin), and both yolk and tissue constituents dried for 24 hours in a 36^{o}C convection oven. Dry weights of fish

TABLE XXI. Comparison of the development stage classifications of different members of the Fulton River fry quality staff, 1968.

FRY SOURCE	DATE	NO.	STAGE	PERCENT BY STAGER				$\bar{X}$	S^2
				I	II	III	IV		
RIVER	May 23	50	3	30	26*	22*	18	24	26.7
			4	60	52*	48	62	55.5	43.7
			5	10	22	30	20*	20.5	67.7
"	May 24	50	3	16	6*	4	2	7	38.7
			4	68	80	84	76*	77	46.7
			5	16*	14	12	22	16	18.7
"	June 2	50	3	12	14	-	-	13	2
			4	66	66	-	-	66	0
			5	22	20	-	-	21	2
"	June 3	50	3	2	4	-	-	3	2
			4	70	80	-	-	75	50
			5	28	16	-	-	22	72
"	June 4	50	3	2	2	-	-	2	0
			4	72	78	-	-	75	18
			5	26	20	-	-	23	18
"	June 6	50	3	0	0	-	-	0	0
			4	50	58	-	-	54	32
			5	50	42	-	-	46	32
"	June 7	50	3	0	0	-	-	0	0
			4	60	60	-	-	60	0
			5	40	40	-	-	40	0

(continued)

TABLE XXI. (continued)

FRY SOURCE	DATE		NO.	STAGE	PERCENT BY STAGER				$\overline{X}$	S^2
					I	II	III	IV		
CHANNEL	May	23	50	3	6	4*	4*	4*	4.5	1
				4	20	18	12	16*	16.5	11.7
				5	74	78*	84	80*	79	17.3
"	May	24	100	3	5	2	4*	2	3.25	2.25
				4	32	36	33*	32	33.25	3.6
				5	63*	62	63*	66	63.5	3
"	June	2	50	3	2	0	-	-	1	2
				4	24	30	-	-	27	18
				5	78	70	-	-	74	32
"	June	3	50	3	0	0	-	-	0	0
				4	18	20	-	-	19	2
				5	82	80	-	-	81	2
"	June	4	50	3	0	0	-	-	0	0
				4	14	14	-	-	14	0
				5	86	86	-	-	86	0
"	June	6	50	3	0	0	-	-	0	0
				4	14	16	-	-	15	2
				5	86	84	-	-	85	2
"	June	7	50	3	0	0	-	-	0	0
				4	12	8	-	-	10	8
				5	88	92	-	-	90	8

*Value closest to $\overline{X}$

and tissue were then obtained to the nearest milligram on an electric balance.

The dry weight of the yolk was next converted to expected dry weight of tissue, using conversion factors taken from Hayes and Pelluet (1945) according to the mean temperature between the sampling date and June 15, 1968, when almost 100% of both populations had reached development stage V. This expected tissue weight gain was then added to the actual dry weight of tissue recorded and an expected total dry weight thereby obtained for each fry sample. The applicability of Hayes and Pelluet's figures to sockeye salmon has been discussed by Dill (1967).

The results (Table XXII) indicate that had the river fry migrated at the same stage of development as the channel fry there would not have been any weight difference between them.

3. Discussion

The statistical comparison between the two groups is, strictly speaking, not valid since all the figures should have been weighted for abundance. This was not possible, however, since variances would be required for each date, i.e. at least two samples would have to have been drawn. Despite this the figures do provide an indication that weight differences were due to timing differences alone.

TABLE XXII. Dry weights of yolk and fish constituents of Fulton River and Channel sockeye fry, 1968, and expected total dry weight at time of complete yolk absorption.

SOURCE	DATE	NO.	DRY WEIGHT		$\bar{X}$ TEMP. °C	CONVERSION FACTOR %	EXPECTED GAIN (mg)	$\bar{X}$ TOTAL (mg)
			YOLK (mg)	FISH (mg)				
RIVER	May 14	50	649	1164	7.2	45	292.1	29.1
RIVER	May 25	50	240	1188	8.9	48	115.2	26.1
RIVER	May 30	34	133	890	10	50	66.5	28.1
CHANNEL	May 25	50	90	1151	8.9	48	43.2	25.8
CHANNEL	May 30	50	67	1426	10	50	33.5	29.2

RIVER $\bar{X}$ = 27.8 CHANNEL $\bar{X}$ = 27.5

S^2 = 2.34 S^2 = 5.78

t = .175

not significant

The method of dissecting yolk from tissue and obtaining dry weights for each suggests a more objective method of determining development stage: by determining yolk to tissue dry weight ratios. A sample of 50 fry could be divided into 5 groups of 10 each and a yolk:tissue ratio determined for each. The development stage of the sample could then be expressed statistically -- with means and variances.

C. Quality Differences Not Related to Timing Differences

1. Introduction

As has been repeatedly pointed out in this report, the river fry migrated downstream in advance of the channel fry. The hypothesis tested in this study is that differences in swimming performance were solely the result of this differential migration timing, due to scouring in the river. To test the hypothesis, samples of channel fry were prematurely removed (scoured) from the spawning channel with a shovel and their swimming performance compared to that of samples of the river fry migrating on the same night. To further test the hypothesis, samples of these scoured channel fry were compared to channel fry migrating the same night. In this latter case, the hypothesis predicts that the scoured fry would be inferior, and be composed of a higher percentage of yolk-sac individuals.

2. Methods

Weights, lengths, and development stages were measured in the manner described under "Standard Tests". When two groups were being compared for development stage, all classifications were made by the same individual.

The swimming performance apparatus (Fig. 23) was modified from a design by Bams (1967), and used previously in the 1967 fry quality studies. Some further modifications were made this year at the downstream end, to prevent back-watering, by lowering one section of the trough. An electric current and a fluorescent light at the downstream end of the experimental area functioned to enforce the positive rheotaxis of the fry. The upper part of the experimental area was shielded from light.

The fry were placed in the troughs, one sample per trough, shortly after capture and acclimatized at low voltage (3.0 v) and low flow (3 tap revolutions). This acclimatization period lasted 12 hours and any fish dropping downstream during this period were forced off the screens with a gentle jet of water.

After 12 hours the test was begun: the voltages were increased to 20 v and the currents increased on the schedule shown in Table XXIII. The taps were opened at the same time, each by one person, to ensure equal treatment to each sample. As each fry dropped out of the apparatus the time and trough number were recorded. A stop-watch was used for this procedure (Fig. 24).

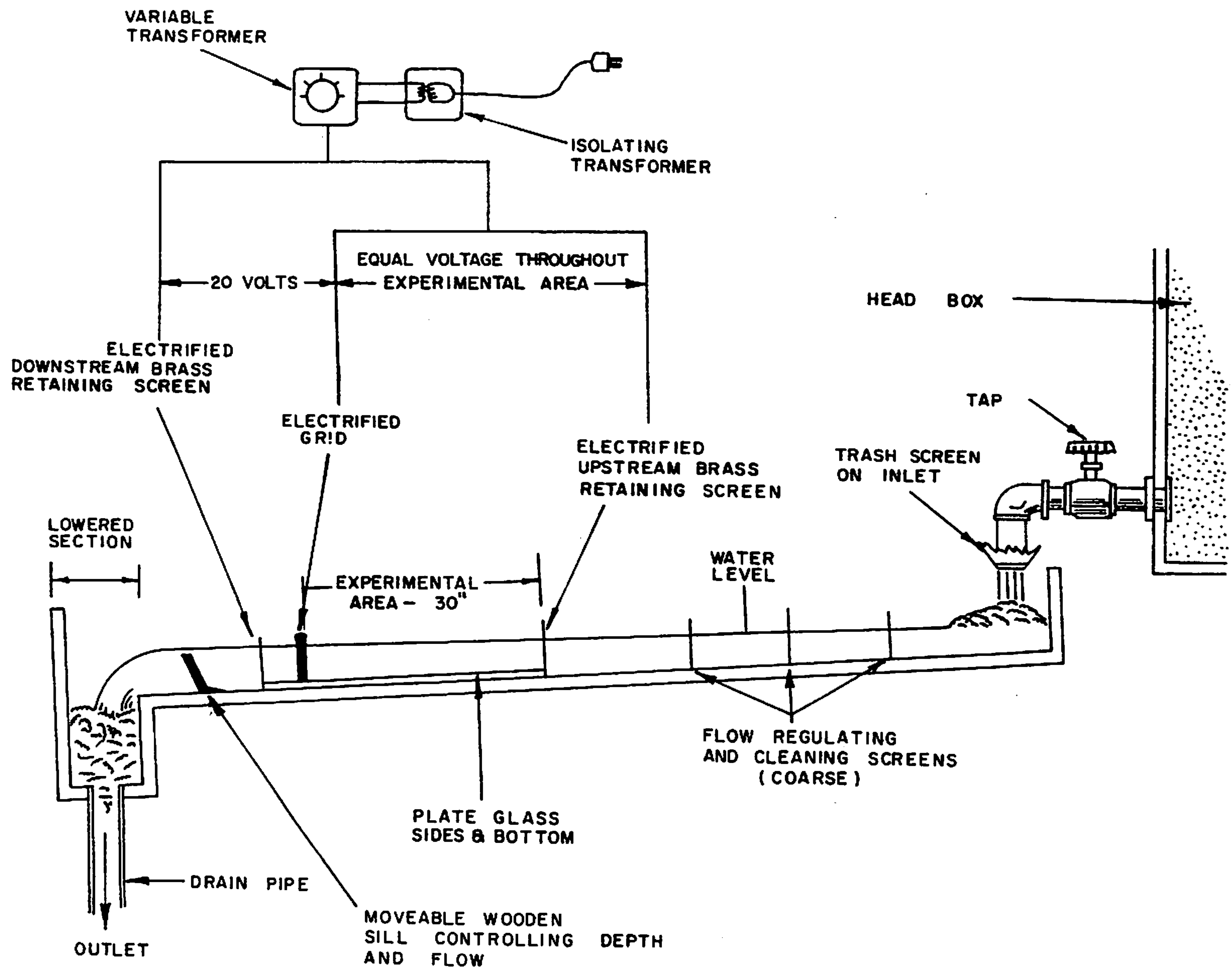


Figure 23. - The relative swimming performance apparatus used in the auxiliary quality tests on Fulton River and Channel sockeye fry, 1968.

TABLE XXIII. Schedule of velocity increases applied to sockeye fry in the auxiliary performance tests, 1968.

TIME FROM TEST START			TAP REVOLUTIONS
HR.	MIN.	SEC.	
		1	3.5
	15	00	4.0
	30	00	4.5
	60	00	5.0
1	30	00	5.5
2	00	00	6.0
2	15	00	6.5
2	30	00	7.0
2	45	00	7.5

Figure 24. Recording the drop-out time (DOT) of sockeye fry in the swimming performance troughs, 1968.

The fish were ranked for statistical analysis in a single series in order of dropout (ODO) and the sum of ranks (R) calculated for each group. The Mann-Whitney U-test (Siegel, 1956) was then applied to determine differences between groups.

$$U = n_1 n_2 + \frac{n_1(n_1 + 1)}{2} - R_1$$

where R_1 = sum of the ranks assigned to group whose sample size is n_1

n_1 = sample size of group 1

n_2 = sample size of group 2

$$Z = \frac{U - \frac{n_1 n_2}{2}}{\sqrt{\frac{(n_1)(n_2)(n_1 + n_2 + 1)}{12}}}$$

The probability of obtaining this calculated Z value was then determined from tables.

3. Results

(a) Channel scour vs. river migrants

The results of two tests of this type (Table XXIV) indicate that fry scoured from the gravel have swimming endurance approximately equal to that of the fry migrating from the river.

(b) Channel scour vs. channel migrants

As predicted, the scoured fry were less well developed than the channel migrants the same night

TABLE XXIV. Comparison between channel and river sockeye fry migrants and fry "scoured" from the spawning channel gravel, 1968.

DATE	TEST	n_1	LOCATION			STATISTIC	P	
			RIVER	SCOUR	CHANNEL			
May 22	Swimming	50	R = 2288.5	R = 2176.5	-	z = 1.840	.0658	2-Tailed
June 10	Swimming	20	R = 364.5	R = 455.5	-	z = .609	.5418	2-Tailed
May 21	Swimming	50	-	R = 2333.0	R = 2717.0	z = .979	.1635	1-Tailed
May 22	Length	50	-	$\bar{X}$ = 147.86	$\bar{X}$ = 143.86	t = .1507	<.5	1-Tailed
	Weight	50	-	$\bar{X}$ = 29.30	$\bar{X}$ = 29.96	t = .3923	<.5	1-Tailed
	% DS5	50	-	30	76	-	-	1-Tailed
June 2	Swimming	50	-	R = 2636.5	R = 2413.5	z = .838	.2005	1-Tailed

(Table XXIV). This difference, however, was not reflected in swimming performance in the two tests of this type conducted.

4. Discussion

The results of the first group of tests confirms the hypothesis that swimming performance is a reflection of development stage alone, and that if the migration timing of the channel fry were the same as that of the river fry their performances would have been similar. The second group of tests, unfortunately, rejects this same hypothesis and suggests that fry scoured from the channel, despite their higher yolk percentage, are not at a disadvantage when their swimming performance is compared to that of channel migrants.

These conclusions, of course, are based on a small amount of data. It is suggested that tests of this sort, because of their possible implications, be carried out to a greater extent in future programs of this type. The small amount of data presented here precludes the drawing of reliable conclusions.

D. Effect of Holding Period on Swimming Performance

1. Introduction

The scheme used for acclimatizing the fry in the standard swimming performance apparatus (Fig. 11) is a complex and rigid one. The question posed: what effect would altering this procedure, either by accident or design, have upon the measured swimming performance of the fry sample?

2. Methods and results

Only one test could be conducted because of demands made on apparatus time by the standard test schedule. For the test a sample of channel fry was captured in the lower fan traps at 2400 hours on June 10, 1968. Two sub-samples of 10 fry each were drawn from this sample. One group was placed in the apparatus after 1.5 hours and acclimated until 1330 hours June 11 (12 hrs.). The second group was held 26.5 hours in an aerated bucket before being acclimated 12 hours (0230 - 1430 hrs. June 12) in the same apparatus. The test procedure was identical to that used in the standard tests.

Mean drop-out times were recorded as: 2 hours, 34 minutes, and 11 seconds after 1.5 hours of holding; and 18 minutes and 14 seconds after 26.5 hours of holding. A Mann-Whitney test on the data (Table XXV) revealed the difference to be significant at the .001 level.

3. Discussion

Since both sub-samples of fry were treated identically with the exception of holding time, and since environmental conditions probably changed little between test days, it seems likely that the differences in drop-out time were due

TABLE XXV. Drop-out times and rank order of sockeye fry held 1.5 and 26.5 hours before quality testing.

FISH NO.	1.5 HOURS				26.5 HOURS			
	HR.	MIN.	SEC.	R	HR.	MIN.	SEC.	R
1	-	02	33	2	-	-	54	1
2	-	03	31	3	-	05	10	5
3	-	04	19	4	-	07	09	8
4	-	07	04	6	-	07	25	9
5	-	07	06	7	-	21	13	10
6	1	00	35	16	-	22	02	11
7	5	09	00	17	-	23	24	12
8	5	24	30	18	-	26	01	13
9	5	25	15	19	-	34	15	14
10	8	18	00	20	-	34	50	15

to the effects of holding in the laboratory. Even though only one test was conducted, the conclusion appears inescapable that measured swimming performance can be greatly influenced by handling procedure. The exact cause of this is not important -- it may have been due to metabolite buildup, constant exercise, etc. -- but the results should be borne in mind in the design of future qualitative studies of this sort. All samples must be treated in identical fashion to avoid jeopardizing the validity of the conclusions.

E. Studies of Sampling Technique

1. Introduction

The statistical techniques applied in the analysis of the standard test data depend for their validity upon the assumption that sampling was random, i.e. that the small sample drawn was an adequate representation of the total fry population moving on that night. The following tests were intended to test this assumption with respect to randomness differences: (1) between samples taken at the same time and location; (2) between samples taken at different times at the same location; and (3) between samples taken at different locations at the same time. Tests of each sort were conducted on both river and channel fry.

2. Methods

Fry samples were drawn from the various live boxes of the upper and lower fan traps and at the fence traps at various times. The mean swimming performance (relative), mean weight, and mean length of these samples were compared to determine the effect of time and location of sampling on measured quality. All techniques were identical to those described earlier in this report. In addition some fry samples were sub-sampled and each of these sub-samples individually examined (with the same tests) to determine the randomness of sampling.

3. Results

(a) Randomness of sampling

The results (Table XXVI) indicate that sampling was usually, but not always, random. Sixty percent of the river tests and 80% of the channel tests failed to reveal any difference between two sub-samples of 50 fish drawn from an initial sample of several hundred.

(b) Time differences

Comparison of samples taken from the upper fan traps at two different times (usually 2400 and 0200 hours) and at the lower fan traps at two different times (various) revealed no trend towards increased quality in either early or late migrants. Sixty-six percent of the

TABLE XXVI. Randomness of sampling Fulton River and Channel sockeye fry populations, 1968.

LOCATION	DATE	TEST	SAMPLE 1		SAMPLE 2		t	SIGNIF. LEVEL
			X̄	S²	X̄	S²		
RIVER	May 4	Swimming (all 50)	93.33 min.	12412.897	159.95 min.	57471.756	0.25	>.5
	May 5	Swimming (all 50)	52.82 min.	13293.308	54.19 min.	10110.914	0.06	>.5
		Swimming (mid 30)	17.10 min.	611.887	33.57 min.	305.174	2.97	.01*
	June 11	Swimming (all 50)	73.82 min.	8821.909	66.20 min.	2583.537	0.51	>.5
		Swimming (mid 30)	43.17 min.	1030.592	64.48 min.	1055.577	2.55	.02*
CHANNEL	May 24	Weight	140.06 mg	363.772	140.82 mg	220.191	0.22	>.5
		Length	29.42 mm	1.187	29.52 mm	0.989	0.48	>.5
	May 26	Swimming (all 50)	370.99 min.	130394.112	396.27 min.	157811.877	0.33	>.5
		Swimming (mid 30)	295.70 min.	33416.792	325.82 min.	52049.069	0.56	>.5
	May 29	Weight	136.82 mg	417.661	135.82 mg	239.847	0.28	>.5
		Length	29.02 mm	1.571	29.10 mm	1.520	0.32	>.5
		Swimming (all 50)	508.84 min.	101376.612	656.98 min.	120691.332	2.22	.05*
		Swimming (mid 30)	543.51 min.	31621.686	683.86 min.	25807.467	3.20	.01*
	May 30	Weight	147.14 mg	432.00	142.78 mg	360.706	1.10	.3
		Length	30.12 mm	1.700	29.98 mm	1.530	0.55	>.5

* = significant difference between samples

tests on both river and channel fry revealed no significant difference (Table XXVII).

In some cases of weight/length determinations river fry were obtained from the same trap at five different times. The maximum and minimum values obtained were the two used in the t-test.

(c) Location differences

Comparison between samples of river fry captured at the same time at the upper fan traps (UFT) and the counting fence (F) revealed no consistent difference (Table XXVIII). In one endurance test (May 5-6) the upper fan trap fish were superior, in the other (May 8-9) the fence trap fish were superior. The one length/weight determination demonstrated no significant difference. Fry obtained from different upper fan trap live-boxes (nos. 1 to 6) were not significantly different with respect to length or weight, even though the maximum and minimum values for the six traps were the ones used in the t-test comparison.

One test on trap-to-trap differences of channel fry captured in the lower fan traps (LFT) revealed no significant difference with respect to length or weight (Table XXVIII). Again, the maximum and minimum values (of the 5 traps) were the ones statistically analyzed.

TABLE XXVII. Quality differences between early and late migrants, Fulton River and Channel sockeye fry, 1968.

LOCATION	DATE	TEST	EARLY SAMPLE HR	EARLY SAMPLE $\bar{X}$	EARLY SAMPLE S^2	LATE SAMPLE HR	LATE SAMPLE $\bar{X}$	LATE SAMPLE S^2	t	SIGNIF. LEVEL
RIVER	May 06-07	Swimming (all 50)	2400	43.54 min.	9676.327	0200	69.12 min.	24642.799	1.74	0.1
		Swimming (mid 30)	2400	1.97 min.	38.548	0200	28.89 min.	572.059	5.96	<.001*
	May 09-10	Weight	2400	139.32 mg	203.120	0200	150.12 mg	286.026	3.45	.001*
		Length	2400	29.10 mm	1.153	0200	28.92 mm	1.953	0.72	.5
		Swimming (all 50)	2400	59.67 min.	2257.080	0200	23.61 min.	696.880	6.69	<.001*
		Swimming (mid 30)	2400	59.30 min.	1282.536	0200	16.47 min.	300.868	5.58	<.001*
	May 11-12	Swimming (all 50)	2400	138.03 min.	24205.387	0200	99.31 min.	8981.790	1.50	.2
		Swimming (mid 30)	2400	57.52 min.	4046.695	0200	50.71 min.	2504.337	0.46	>.5
	May 26-27	Weight	0100	140.88 mg	234.745	0500	151.82 mg	363.947	0.45	>.5
		Length	0100	28.66 mm	1.051	0200	29.60 mm	1.061	0.65	>.5
	June 01-02	Weight	0200	139.14 mg	320.586	0500	145.56 mg	312.088	0.26	>.5
		Length	0200	29.10 mm	0.796	0400	29.94 mm	1.739	0.53	>.5
CHANNEL	May 10-11	Weight	0100	134.42 mg	197.677	0200	136.12 mg	259.087	0.56	>.5
		Length	0100	28.44 mm	1.449	0200	29.26 mm	1.707	3.28	.01*
	May 16-17	Weight	2300	143.04 mg	341.141	0030	143.02 mg	429.571	0.01	>.5
		Length	2300	29.76 mm	1.615	0030	29.98 mm	1.122	0.78	.5
	May 24-25	Weight	2400	137.70 mg	234.622	0200	136.04 mg	308.973	0.50	>.5
		Length	2400	29.20 mm	1.130	0200	29.58 mm	1.310	1.73	.1
	May 29-30	Weight	2400	147.14 mg	432.000	0200	143.22 mg	294.542	1.03	.4
		Length	2400	30.12 mm	1.700	0200	29.90 mm	1.153	1.04	.3
	May 30-31	Swimming (all 50)	2400	328.58 min.	32710.589	0200	440.85 min.	15495.155	3.62	<.001*
		Swimming (mid 30)	2400	378.04 min.	10808.270	0200	443.08 min.	1205.291	4.17	<.001*
	June 01-02	Weight	2400	137.22 mg	248.257	0100	145.78 mg	317.114	2.55	.02*
		Length	2400	29.48 mm	0.908	0100	29.84 mm	2.321	1.41	.2

* = significant difference between samples

TABLE XXVIII. Quality differences between Fulton River or Channel sockeye fry captured at the same time but at different locations, 1968.

SOURCE	DATE	TEST	SAMPLE 1			SAMPLE 2			t	SIGNIF. LEVEL
			LOC	$\bar{X}$	S^2	LOC	$\bar{X}$	S^2		
RIVER	May 05-06	Swimming (all 50)	UFT	66.51 min.	3050.763	F	29.85 min.	2741.511	3.27	.01*
		Swimming (mid 30)	UFT	63.69 min.	1247.491	F	8.32 min.	141.850	8.12	<.001*
	May 08-09	Weight	UFT	149.70 mg	354.78	F	148.88 mg	383.96	0.21	>.5
		Length	UFT	29.28 mm	1.41	F	29.18 mm	1.65	0.40	>.5
		Swimming (all 50)	UFT	16.98 min.	900.297	F	87.16 min.	12817.746	4.24	<.001*
		Swimming (mid 30)	UFT	5.39 min.	190.025	F	31.94 min.	1665.142	3.37	.01*
	June 06-07	Weight	UFT #1	148.34 mg	422.931	UFT #5	137.67 mg	307.674	0.39	>.5
		Length	UFT #1	28.84 mm	1.391	UFT #5	30.00 mm	1.990	0.63	>.5
	June 11-12	Weight	UFT #2	133.43 mg	230.776	UFT #5	143.37 mg	229.502	0.46	>.5
		Length	UFT #2	29.25 mm	3.602	UFT #3	29.37 mm	1.094	0.06	>.5
CHANNEL	June 12-13	Weight	LFT #1	132.11 mg	312.714	LFT #5	145.15 mg	585.398	0.44	
		Length	LFT #1	29.40 mm	2.041	LFT #4	30.30 mm	1.282	0.49	

* = significant difference between samples

4. Discussion

The data presented above indicated that the sampling methods used were reasonably reliable and that the conclusions drawn from the standard quality tests were based on representative samples of the two populations. They indicate that changing the sampling times (from the 0100 hours for river fry and 2400 hours for channel fry, used in the present study) would not alter the results appreciably. They indicate further that sub-sampling 50 fry from a bucket of several hundred is a reasonably unbiased method of obtaining a small sample. Originally, there had been some concern that this type of sub-sampling would select fry of a particular development stage, since yolk-sac fry tended to be nearer the bottom of the bucket. Constant gentle stirring during sampling appears to have alleviated this problem.

The possibility exists that fry caught in the upper fan traps are different from those caught in the fence traps, in swimming performance if not physical features, although the direction of this difference is not consistent. It seems possible that the differences in swimming performance are related to type of capture gear, i.e. to the degree of harm caused to the fry. The extent and direction of the "harm factor" ratio between the two traps may be expected to be discharge level related, i.e. one type of trap may be less harmful at one water velocity but more harmful at another. Unfortunately for this hypothesis, however, the discharge between May 5 and May 9 varied but little. Some time should obviously be devoted to determining the effect of capture method on the fry, and to finding a method suitable for capturing fry without harming them appreciably, a pre-requisite for quality tests of the sort reported here.

IV. FULTON RIVER ECOLOGICAL SURVEY

A. Population Estimates of Possible Predatory Species

1. Introduction

Mountain whitefish (*Prosopium williamsoni*), rainbow trout (*Salmo gairdnerii*), cutthroat trout (*Salmo clarkii clarkii*), burbot (*Lota lota*) and peamouth chub (*Mylocheilus caurinum*) were captured in various sections of the river and spawning channel by means of angling, beach seining and gill-netting. Specimens of each species were tagged in an attempt to determine natural population levels. It was hoped that the information obtained might be applied to the development of a more sophisticated predator avoidance testing method -- by having in the test apparatus predator populations of appropriate densities and species composition.

2. Methods and results

An initial attempt to determine predator populations was made using the underwater census method described by

Northcote and Wilkie (1963). The turbulence of and poor visibility in the river made this an impossible task.

An attempt was therefore made to assess predator populations by the mark-recapture method. A number of the captured specimens were kept for stomach content analysis (see Section IV.C.) while others were marked with numbered plastic Petersen discs (9/16" dia.) and returned to the stream. Summaries of the tagging records are provided in Tables XXIX and XXX.

Recapture was attempted in Tower Pool on June 11 and 13, 1968. Only whitefish were captured each time. The M/C ratios were 1/27 and 1/26 on June 11 and June 13 respectively. These provides population estimates for this single large pool of 1728 and 1664 mountain whitefish respectively. The mean population estimate is 1696 individuals (95% confidence interval: 1289 <1696 <2103).

Recapture was attempted in the spawning channel on June 10 and 11, 1968. Fish captured on June 10 were not returned to the channel. A summary of the recaptures is shown in Table XXXI and indicates that the spawning channel contained 113 whitefish and 84 rainbow trout. No cutthroat trout, chub, or burbot were recovered.

3. Discussion

The estimate obtained of whitefish population levels in Tower Pool is not especially reliable due to: (1) lack of knowledge of emigration or immigration (although only one

TABLE XXIX. Summary of tagging records of possible predatory species in the Fulton River, spring 1968.

SPECIES	DATE	CAPTURE METHOD	LOCATION	NUMBER
Whitefish	May 1	Seine	Tower Pool	27
	"	"	Below Fence	18
	May 5	Seine	Tower Pool	31
	"	"	Below Fence	13
	May 10	Seine	Tower Pool	6
	May 13	Seine	Below Fence	4
	May 17	Gill-Net	Fishway Pool	2
	May 18	Gill-Net	Fishway Pool	19
	May 20	Gill-Net	Fishway Pool	4
	May 21	Gill-Net	Fishway Pool	6
	May 22	Gill-Net	Fishway Pool	14
	May 23	Gill-Net	Fishway Pool	8
	May 27	UFT	UFT	1
	June 3	Seine	Fishway	2
	June 6	Seine	Fishway	2
	Σ	-	-	157
Rainbow	May 18	Gill-Net	Fishway	2
	May 21	Gill-Net	Fishway	1
	May 22	Gill-Net	Fishway	1
	May 23	Gill-Net	Fishway	1
	Σ	-	-	5
Cutthroat	May 18	Gill-Net	Fishway	1
Ling	June 1	Gill-Net	Fishway	1
Chub	June 1	Gill-Net	Fishway	11
	June 2	Gill-Net	Fishway	5
	Σ	-	-	16

TABLE XXX. Summary of tagging records of possible predatory species in the Fulton Spawning Channel, spring 1968.

SPECIES	DATE	CAPTURE METHOD	LOCATION	NUMBER
Whitefish	To May 6	UFT & LFT	UFT & LFT	7
	May 6-9	LFT	LFT	4
	May 9	Seine	Pool 1	1
	"	UFT	UFT	2
	May 14	Seine	Pool 1	7
	May 17	Seine	Pool 3	2
	May 21-28	UFT	UFT	13
	May 28-June 1	UFT	UFT	5
	June 3	Seine	Leg 1	1
	"	"	Leg 3	2
	June 6	Seine	Pool 1	1
	Σ	-	-	45
Rainbow	To May 6	UFT & LFT	UFT & LFT	3
	May 9	UFT	UFT	1
	"	Seine	Leg 1	1
	"	"	Pool 2	2
	May 14	Seine	Pool 1	11
	"	UFT	UFT	4
	May 15	Seine	Pool 1	5
	"	"	Pool 3	2
	May 17	Seine	Pool 3	4
	June 3	Seine	Pool 1	2
	"	"	Pool 3	2
	"	"	Leg 7	2
	Σ	-	-	39
Cutthroat	May 3	Seine	UFT Pool	1
	June 3	Seine	Pool 1	1
	"	"	Leg 7	1
Burbot	May 21-28	UFT	UFT	4
	May 28-June 1	UFT	UFT	6
Chub	May 28-June 1	UFT	UFT	2

TABLE XXXI. Recapture of possible predatory species in the Fulton Spawning Channel, June 10 and 11, 1968.

SPECIES	DATE	M	R	C	EST. POP. SIZE
Whitefish	June 10	31	4	13*	95
	June 11	27	2	3	18
	TOTAL	-	-	-	113
Rainbow	June 10	28	3	9	84

* These fish were not returned to the channel

tagged fish was recaptured outside Tower Pool prior to June 13 and no fish tagged in other areas were seined from it); and (2) the extremely low numbers of recaptures (although the consistency of the M/C ratios on the two recapture attempts is suggestive). Subjective information supports the possible existence of large populations of mountain whitefish in the Fulton River; repeated beach seining and tagging in Tower Pool on a single day would continue to capture many whitefish but few tags; a gill-net in the fishway exit would sink from the shear weight of whitefish after less than 30 minutes.

The population estimates for the spawning channel are far more reliable, since emigration and immigration are rendered impossible by the fan traps at the upstream and downstream ends of the system. The population sizes convert to the following densities: Whitefish - .028/sq.yd. (.033/sq.m.); Rainbow - .021/sq.yd (.025/sq.m.). These densities are not especially high, possibly because the traps were in place before the fry migration could attract predators into the area. The density of whitefish in Tower Pool was calculated to be 1696/4861 sq.yds. = .349/sq.yd. (.418/sq.m.).

B. Movements of Possible Predatory Species

The tagging of various species also served a second purpose in determining their movements both during and after the fry migration period. Summaries of all recovery information is provided in Table XXXII.

Five whitefish tagged in the river were recovered: two tagged in Tower Pool were recovered there one month later; one tagged in Tower Pool was recovered one month later at the fence (413 yds. or 378 m.); and two tagged at the channel exit (fishway) were recovered at the fence 2 and 20 days later (1500 yds. or 1372 m.).

Of the 25 whitefish recoveries made in the spawning channel only 7 were made in the same location as the original release. The rest had moved downstream by at least one leg. Thirteen were captured at the bottom end of the channel (Leg 7 or LFT); all movement was directed downstream.

Recoveries of marked cutthroat trout indicated no movement either in the river or spawning channel. One trout, captured in the spawning channel but released into the river was caught 52 days later in Millionaires' pool by a sport fisherman.

Thirty-one rainbow trout tagged within the channel were recovered before June 15. Seven of these had not moved since they were tagged; five had moved a maximum of two legs; and 14 had moved a greater distance. Only one case of upstream movement was recorded. Five rainbow were captured by sport fishermen after June 15: three in Millionaires' pool; and two in Babine Lake at distances of 4 and 41 miles (6.4 and 66.0 kilometers) from the tagging site after times out of 50 and 91 days respectively. These two types of movements suggest the existence in the area of two ecological races of rainbow trout:

TABLE XXXII. Recoveries of tagged predators during and after the period of fry migration, Fulton River, 1968.

SPECIES	TAG NUMBER	CAPTURE			RELEASE LOCATION	RECAPTURE 1			RECAPTURE 2		
		DATE	GEAR	LOCATION		DATE	LOCATION	RELEASE LOCATION	DATE	LOCATION	RELEASE LOCATION
Whitefish	020	May 1	Seine	Tower Pool	Same	June 13	Tower Pool	Same			
	063	May 5	Seine	Tower Pool	Same	June 10	Fence	Same			
	111	May 10	Seine	Tower Pool	Same	June 11	Tower Pool	Same			
	196	May 22	Gill-Net	Fishway	Same	June 11	Fence	Same			
	219	May 23	Gill-Net	Fishway	Same	May 25	Fence	Same			
	090	May 1-6	UFT & LFT	UFT & LFT	Leg 1	June 3	Leg 7	No			
	092	May 1-6	UFT & LFT	UFT & LFT	Leg 1	May 7	LFT	River			
	093	May 1-6	UFT & LFT	UFT & LFT	Leg 1	May 10	LFT	River			
	094	May 1-6	UFT & LFT	UFT & LFT	Leg 1	June 3	Leg 3	Same	June 10	Pool 3	River
	096	May 1-6	UFT & LFT	UFT & LFT	Leg 1	May 28	UFT	Leg 1			
	101	May 9	LFT	LFT	Leg 1	May 26	LFT	River			
	105	May 9	Seine	Pool 1	Same	May 13	LFT	River			
	128	May 14	Seine	Pool 1	Same	June 10	Pool 1	River			
	129	May 14	Seine	Pool 1	Same	June 11	Leg 1	River			
	130	May 14	Seine	Pool 1	Same	May 25	Pool 2	No			
	132	May 14	Seine	Pool 1	Same	June 10	Leg 1	River			
	135	May 14	Seine	Pool 1	Same	June 10	Pool 3	River			
	225	May 28	UFT	UFT	Leg 1	May 30	LFT	No			
	228	May 28	UFT	UFT	Leg 1	June 10	LFT	No			
	230	May 28	UFT	UFT	Leg 1	June 10	Pool 3	River			
	232	May 28	UFT	UFT	Leg 1	May 30	LFT	No			
	233	May 28	UFT	UFT	Leg 1	June 9	LFT	No			
	237	May 28	UFT	UFT	Leg 1	June 3	Leg 3	Same			
	248	June 1	UFT	UFT	Leg 1	June 10	LFT	No			
	249	June 1	UFT	UFT	Leg 1	June 6	Pool 1	Same			
	251	June 1	UFT	UFT	Leg 1	June 2	LFT	No			
	252	June 1	UFT	UFT	Leg 1	June 6	Pool 1	Same			
	292	June 3	Seine	Leg 1	Same	June 6	Pool 1	Same			
	293	June 3	Seine	Leg 3	Same	[illegible]	[illegible]				

TABLE XXXII. (continued)

SPECIES	TAG NUMBER	CAPTURE			RELEASE LOCATION	RECAPTURE 1			RECAPTURE 2		
		DATE	GEAR	LOCATION		DATE	LOCATION	RELEASE LOCATION	DATE	LOCATION	RELEASE LOCATION
Cutthroat	165	May 18	Gill-Net	Fishway	Same	May 30	Fishway	No			
	045	May 3	Seine	Leg 1	Same	June 3	Pool 1	Same	June 6	Pool 1	Same
	290	June 3	Seine	Pool 1	Same	June 6	Pool 1	Same			
	298	June 3	Seine	Leg 7	River	July 25	Millionaires Pool	No			
Rainbow	099	May 6	UFT	UFT	Leg 1	June 3	Leg 1	Same	June 10	Pool 1	River
	104	May 9	UFT	UFT	Leg 1	May 9	LFT	No			
	106	May 9	Seine	Leg 1	Pool 1	May 17	Pool 3	Same	June 11	LFT	River
	108	May 9	Seine	Pool 2	Same	June 3	Leg 7	River	Aug. 10	Millionaires Pool	No
	110	May 9	Seine	Pool 2	Same	May 29	Pool 6	No			
	121	May 14	Seine	Pool 1	Same	June 10	Pool 3	River			
	122	May 14	Seine	Pool 1	Same	June 20	Pool 2	No			
	124	May 14	Seine	Pool 1	Same	Aug. 23	Millionaires Pool	No			
	125	May 14	Seine	Pool 1	Same	May 27	Pool 6	No			
	137	May 14	Seine	Pool 1	Same	May 17	Pool 3	Same	May 28	Pool 6	No
	138	May 14	Seine	Pool 1	Same	June 12	LFT	River			
	140	May 14	UFT	UFT	Leg 1	May 15	LFT	River			
	141	May 14	UFT	UFT	Leg 1	May 15	LFT	River			
	144	May 15	Seine	Pool 1	Same	June 12	LFT	River	Sept. 11	Pinkut Creek	No
	145	May 15	Seine	Pool 1	Same	May 26	Pool 6	No			
	148	May 15	Seine	Pool 1	Same	June 3	Pool 1	Same	June 6	Pool 1	Same
	149	May 15	Seine	Pool 3	Same	June 7	LFT	River			
	153	May 17	Seine	Pool 3	Same	June 10	LFT	River			
	158	May 17	Seine	Pool 3	Same	May 26	Pool 6	No			
	159	May 17	Seine	Pool 3	Same	June 6	Pool 1	Same			
	289	June 3	Seine	Pool 1	Same	June 6	Pool 1	Same			
	291	June 3	Seine	Pool 1	Same	June 6	Pool 1	Same			
	294	June 3	Seine	Pool 3	Same	June 10	Pool 3	River			
	295	June 3	Seine	Pool 3	Same	July 23	Babine Lake	No			
	299	June 3	Seine	Pool 7	Same	Aug. 9	Millionaires Pool	No			
	199	May 21	Gill-Net	Fishway	Same	Aug. 27	Fulton River	No			

* Legs and pools refer to shallow and deep areas of the Spawning Channel respectively.

one resident in the stream; the other moving in from the main lake during the period of fry migration. This possibility should be more closely examined in future studies. The mean eye-hypural lengths of these two groups of rainbow at the time of tagging were not significantly different at the .05 level (22.9 cm for residents vs. 26.4 cm for migrants).

One rainbow trout tagged in the river was recovered in late August by a sport fisherman. It had not moved out of the tagging area.

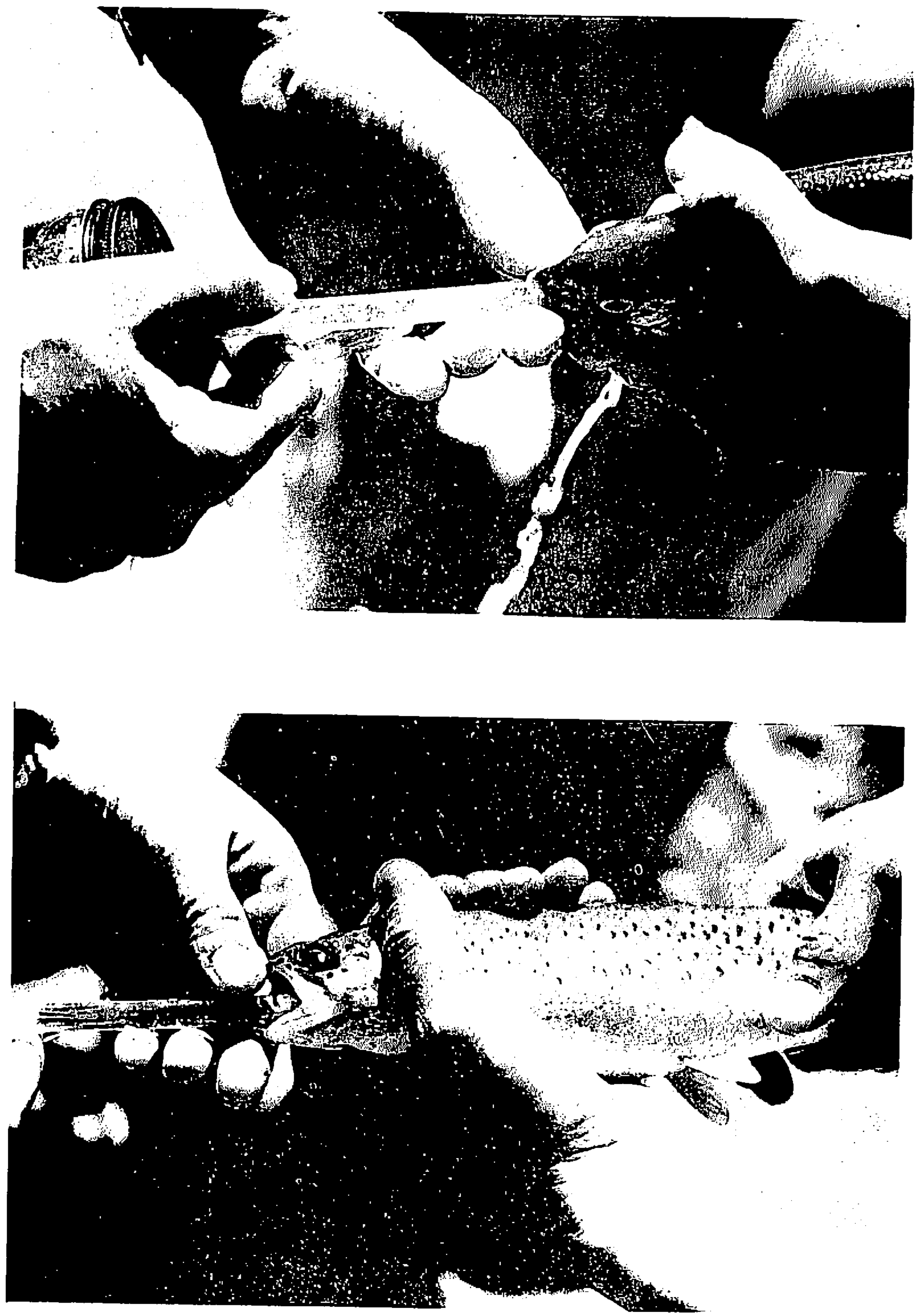
C. Feeding Studies

1. Methods

Stomach samples of the various species of fish were examined, primarily to determine the extent of their feeding on fry. Samples were obtained in two ways: (1) by dissection of moribund specimens; and (2) by removal of the stomach contents with a stomach pump. This pump apparatus (Fig. 25) is based on a design by Seaburg (1957) but modified to the extent that the tubes inserted into the fish's stomach were constructed of clear plastic. The two techniques employed are considered synonymous, since several fish of various species were dissected after pumping and found to have empty stomachs.

The stomach contents were preserved in formalin for a period of at least two weeks. The contents were then examined under a binocular microscope, sorted into food

Figure 25. Use of pump apparatus for removing stomach contents of mountain whitefish (top) and rainbow trout (bottom).



types, weighed to the nearest milligram on an electric balance and, occasionally, counted.

2. Results

(a) Mountain whitefish (Prosopium williamsoni)

A total of 90 whitefish stomach samples was obtained. The results of the analyses, for the main food organisms only, are summarized in Table XXXIII. The average weight of sockeye fry per stomach is included in this table. Tables XXXIV through XXXVII show the average number of sockeye fry per whitefish stomach examined, based on the weights of partially digested fry in three of the stomachs, for whitefish classified according to date, area, length class, and capture time.

Miscellaneous food items in whitefish stomachs included: beetle larvae (Coleoptera), fish eggs and cases, leeches, Megaloptera larvae, Neuroptera larvae, Diptera adults, earthworms, and snails. In addition, sand and small pebbles were commonly found in the stomachs.

(b) Rainbow trout (Salmo gairdnerii)

A total of 50 rainbow trout stomach samples was obtained. The results of the analyses, for the main food organisms only, are summarized in Table XXXVIII.

TABLE XXXIII. Summary of the results of the Mountain Whitefish stomach samples obtained at Fulton River, spring 1968.

	NUMBER EXAMINED	SOCKEYE FRY		PERCENT CONTAINING				
		PERCENT CONTAINING	AVERAGE WT (MG)	STONEFLY LARVAE (PLECOPTERA)	CADDISFLY LARVAE (TRICHOPTERA)	MAYFLY LARVAE (EPHEMEROPTERA)	DIPTERA LARVAE	STONEFLY ADULTS (PLECOPTERA)
DATE								
May 1-10	24	37.5	459	29.2	87.5	75.0	79.2	-
11-20	9	44.4	381	11.1	44.4	88.9	33.3	-
21-31	49	24.5	276	16.3	79.6	44.9	38.8	-
June 1-15	7	28.6	336	14.3	57.1	28.6	42.9	-
AREA								
Tower Pool	21	38.1	521	28.5	80.9	66.6	80.9	-
Fishway	55	29.6	333	14.5	76.4	49.1	41.8	-
Upper Fan Traps	2	-	-	50.0	100.0	100.0	100.0	-
Channel	6	16.7	11	33.3	50.0	100.0	66.7	-
LENGTH (CM)								
15.1 - 20	7	28.6	156	14.3	85.7	14.3	28.6	-
20.1 - 25	46	26.1	291	15.2	80.4	54.3	50.0	-
25.1 - 30	20	30.0	309	10.0	80.0	70.0	70.0	-
>30	5	60.0	58	40.0	80.0	40.0	40.0	-
TIME (HRS)								
0001-0600	-	-	-	-	-	-	-	-
0601-1200	23	17.3	187.4	26.1	87.0	52.2	60.9	-
1201-1800	27	33.3	475.9	29.6	81.5	51.9	74.1	-
1801-2400	16	37.5	274.5	6.3	56.3	56.3	37.5	-

TABLE XXXIV. Feeding of Whitefish by date at Fulton River, B. C. (all areas combined)

DATE	NO. OF STOMACHS	% CONTAINING FRY	AVERAGE NO. PER STOMACH
May 1-10	24	37.5	15.3
11-20	9	44.4	12.7
21-31	49	24.5	9.2
June 1-15	7	28.6	11.2

TABLE XXXV. Feeding of Whitefish by area at Fulton River, B. C.

AREA	NO. OF STOMACHS	% CONTAINING FRY	AVERAGE NO. PER STOMACH
Tower Pool	21	38.1	17.4
Fishway Exit	55	29.6	11.1
Upper Fan Traps	2	-	-
Spawning Channel	6	16.7	.4

TABLE XXXVI. Feeding of Whitefish by length class at Fulton River, B. C. (all areas combined)

LENGTH CLASS (CM)	NO. OF STOMACHS	% CONTAINING FRY	AVERAGE NO. PER STOMACH
<20.1	7	28.6	5.2
20.1 to 25.0	46	26.1	9.7
25.1 to 30.0	20	30.0	10.3
>30.0	5	60.0	1.9

TABLE XXXVII. Feeding of Whitefish by capture time interval at Fulton River, B. C. (all areas combined)

TIME INTERVAL (HRS)	NO. OF STOMACHS	% CONTAINING FRY	AVERAGE NO. PER STOMACH
0001-0600	NO SAMPLES OBTAINED		
0601-1200	23	17.3	6.2
1201-1800	27	33.3	15.9
1801-2400	16	37.5	9.2

TABLE XXXVIII. Summary of the results of the Rainbow Trout stomach samples obtained at Fulton River, spring 1968.

	NUMBER EXAMINED	SOCKEYE FRY		PERCENT CONTAINING				
		PERCENT CONTAINING	AVERAGE WT (MG)	STONEFLY LARVAE (PLECOPTERA)	CADDISFLY LARVAE (TRICHOPTERA)	MAYFLY LARVAE (EPHEMEROPTERA)	DIPTERA LARVAE	STONEFLY ADULTS (PLECOPTERA)
DATE								
May 1-10	4	25.0	209	75.0	-	75.0	75.0	50.0
11-20	11	18.1	211	54.5	18.1	90.9	27.2	36.3
21-31	28	32.1	1259	28.6	46.4	75.0	14.3	28.6
June 1-15	8	37.5	1559	25.0	25.0	37.5	25.0	-
AREA								
Tower Pool	5	20.0	9	40.0	-	-	40.0	-
Fishway	25	36.0	1755	24.0	48.0	80.0	16.0	20.0
Upper Fan Traps	1	100.0	836	100.0	-	100.0	100.0	-
Channel	18	22.2	337	50.0	22.2	77.7	27.7	44.4
LENGTH (CM)								
15.1 - 20	10	20.0	15	30.0	30.0	60.0	20.0	20.0
20.1 - 25	31	35.5	1533	35.5	35.5	80.6	25.8	22.6
>25	4	-	-	25.0	-	25.0	25.0	25.0
TIME (HRS)								
0001-0600	1	100.0	510	-	100.0	-	-	-
0601-1200	7	71.4	7188	14.3	28.5	100.0	14.3	-
1201-1800	15	26.7	169	40.0	60.0	73.3	26.7	26.7
1801-2400	10	20.0	585	20.0	40.0	70.0	20.0	50.0

Miscellaneous food items in rainbow trout stomachs included: Mayfly adults (Ephemeroptera), Neuroptera larvae, fish eggs and cases, adult beetles (Coloptera), water boatmen (Hemiptera), and Diptera pupae.

Weights were not converted to numbers of sockeye fry because not enough data was obtained to enable this to be done with any reliability.

(c) Peamouth chub (*Mylocheilus caurinum*)

Six stomach samples were obtained from peamouth chub captured at the fishway. Four contained no food or undefined food in an advanced state of digestion. One chub, captured June 5, contained 54 mg of stonefly larvae (Plecoptera) and 201 mg of caddisfly larvae (Trichoptera). A second individual, captured June 10, contained 634 mg of sockeye fry.

(d) Prickly sculpin (*Cottus asper*)

Unfortunately, only one stomach sample was obtained for this species. The individual, captured June 6 at the upper fan traps, and measuring 7.8 cm, contained 339 mg of sockeye fry. This abundant predator should be studied more extensively.

(e) Burbot (Lota lota)

Six stomach samples were obtained from freshwater ling or burbot. The results of the analyses of these samples are presented in Table XXXIX. Sockeye fry obviously form a large part of the diet of this species.

D. Digestive Rates of Predatory Species

1. Introduction

Information on the food habits of predators can only be used to determine the extent of predation if the rate of turnover (digestive rate) is known. The present study is an attempt to determine the digestive rates of the prickly sculpin (Cottus asper), mountain whitefish (Prosopium williamsoni) and rainbow trout (Salmo gairdnerii). Part of the data will be used in Section IV.E.

2. Methods and results

(a) Prickly sculpin (Cottus asper)

Seventeen cottids were captured in the upper fan traps over a period of several days and held in live boxes. The fish were force-fed 1-3 sockeye fry with tweezers, starting at 1600 hours June 7, and continuing at 24 hour intervals until 1600 hours June 9, 1968. After this June 9 feeding the cottids were starved for 48 hours. This procedure was an attempt to ensure that all the fish would be in the same physiological state of

TABLE XXXIX. Feeding of Burbot (Lota lota) at Fulton River, spring 1968.

NO.	DATE AND AREA CAUGHT	WEIGHT (MG) OF				
		SOCKEYE FRY	MAYFLY LARVAE (EPHEMEROPTERA)	STONEFLY LARVAE (PLECOPTERA)	CADDISFLY LARVAE (TRICHOPTERA)	OTHER
1	May 25 Fishway	41	2282	30	-	-
2	May 27 Channel	305	1020	-	-	-
3	May 27 Fishway	7260	164	40	115	-
4	June 2 Fishway	382	11	-	-	-
5	June 2 Fishway	621	140	-	-	-
6	June 4 Upper Fan Traps	6759	14	-	-	-

readiness prior to the start of the test. The mean length of the cottids was 11.4 cm.

The test began at 1600 hours June 11 when each cottid was fed 2 sockeye fry. Specimens were then dissected at intervals: 2, 4, 6, 8, 10, 12, 14, 16, 18, 20, 22, 24, 26, 28, 32, and 36 hours after the time of feeding. The stomachs and their contents were preserved in formalin for examination two days after the test. Water temperature during the course of the experiment was 9.0°C. The results are shown in Table XL. The experiment was repeated with another group of 17 cottids and supported the conclusion that the time for complete digestion of sockeye fry by Cottus asper lies between 26 and 28 hours.

(b) Mountain whitefish (*Prosopium williamsoni*)

Seventeen whitefish were seined from the observation pool between June 11 and June 14, and transferred to 50 gallon aquaria in the laboratory. These aquaria were supplied with aerated stream water (10°C).

The fish were held (unfed) until June 18 and were then anaesthetized with 2-phenoxyethanol, weighed, measured, and force-fed 5 sockeye fry each (average ration = 602 mg). The force-feeder used is shown in Figure 26. This preliminary force-feeding was an

TABLE XL. Summary of the data obtained in the study of digestive rate of *Cottus asper*.

TIME	CONDITION OF				
	SKIN	FINS	VISCERA	BODY	GENERAL
2 HRS	- Slight loss of pigmentation	Intact	Intact	Intact	Intact
4 HRS	- Beginning of digestion	- Beginning of digestion	Intact	Intact	Intact
6 HRS	- 3/4 digested - No parr marks	- 1/2 digested - Rays exposed	Intact	Intact	Intact
8 HRS	-	-	- Being digested	- Vertebrae start to show	Intact
10 HRS	-	-	-	- Eyes still visible - Flesh starts to detach	Intact
12 HRS	-	-	-	- Much of the flesh gone	- Recognizable
14 HRS	-	-	-	- Flesh restricted to around vertebral column	- Recognizable
16 HRS	-	-	-	- Head almost gone - Vertebral column intact	- Barely recognizable
18 HRS	-	-	-	- Little change	- Little change
20 HRS	-	-	-	- Vertebral column just recognizable	- Barely recognizable
22 HRS	-	-	-	-	- Jelly-like mass
24 HRS	-	-	-	-	Same
26 HRS	-	-	-	-	Particles
28 HRS (2)	-	-	-	-	-
32 HRS	-	-	-	-	-
36 HRS	-	-	-	-	-

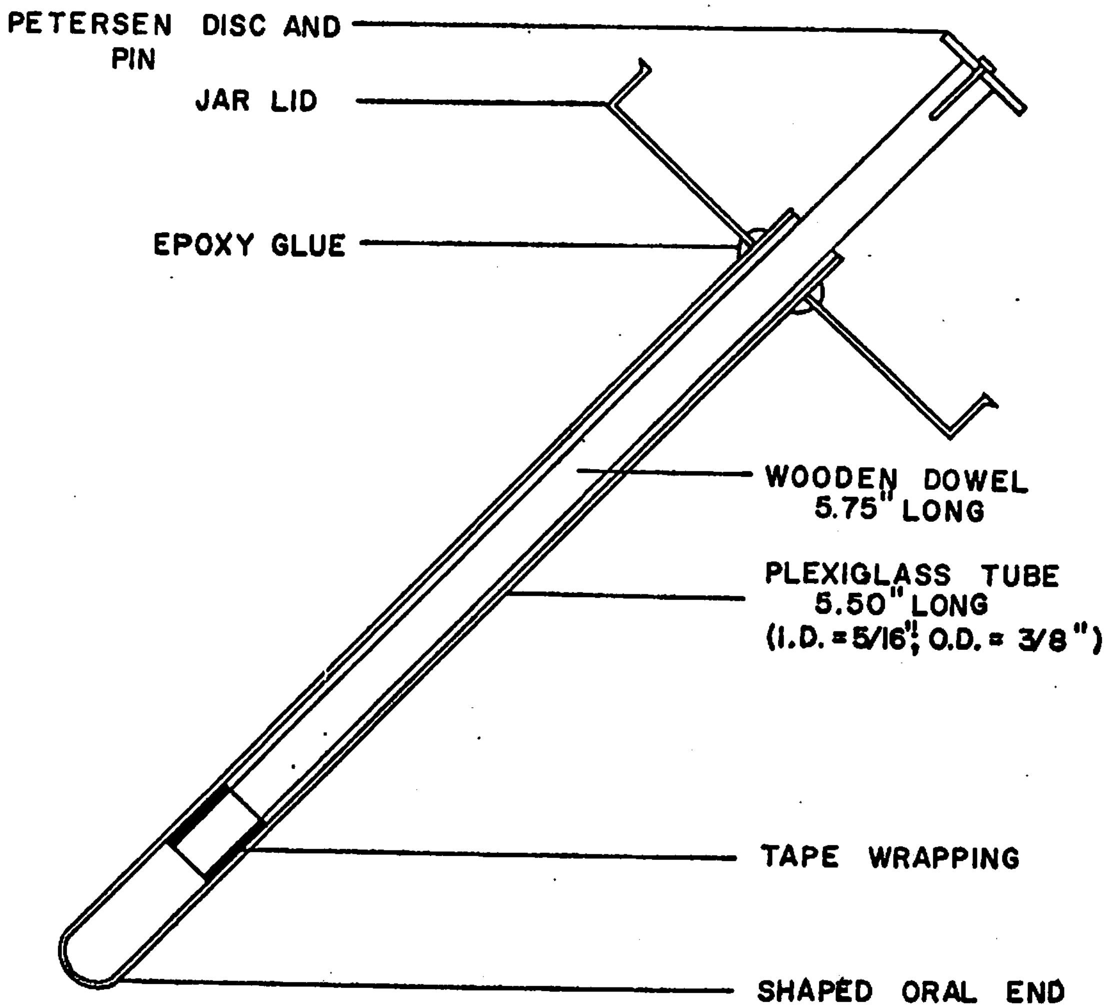


FIGURE 26.- FORCE FEEDER USED IN THE STUDY OF WHITEFISH DIGESTION (CUT-AWAY VIEW).

attempt to ensure that all fish were in the same state of physiological readiness prior to the actual test.

The fish were held 24 hours and one was then dissected. The stomach was empty and the remains of the fry were found in the lower intestine. Each whitefish was then fed another five live fry and dissected at intervals to determine the time required to digest the meal. Percent digestion was expressed as:

$$\% = \frac{\text{wt. of remains at time } t + 1}{\text{wt. of portion fed at time } t} \times 100$$

One hundred percent digestion occurred after 8.5 hours (Fig. 27). There was no apparent relationship between digestive rate and size of whitefish (20.6 to 28.9 cm) or size of portion fed (559 to 651 mg).

(c) Rainbow trout (*Salmo gairdnerii*)

The methods of holding, conditioning and force-feeding the trout were identical to those used in the whitefish study. Water temperature was again 10°C. Two series of tests were conducted. In the first series six trout were force-fed two sockeye fry each and dissected at 3, 6, 9, 12, 12.16, and 12.5 hours after feeding. This test series began at 1830 hours June 19. In the second series three trout were force-fed five fry each and dissected at 6, 9 and 10 hours after feeding. This series began at 0930 hours June 20.

E

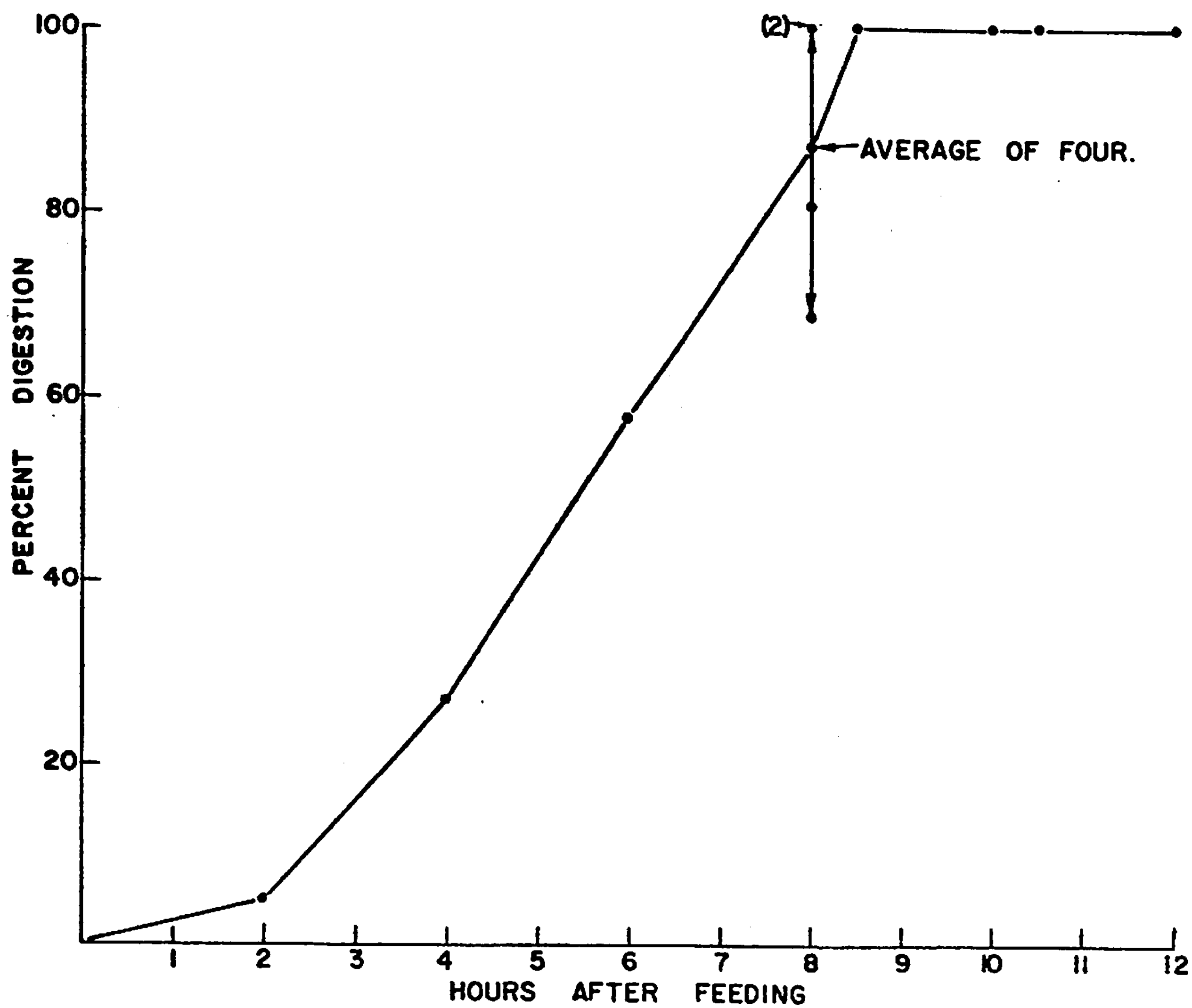


Figure 27. - Percent digestion of sockeye fry by mountain whitefish after force feeding.

The results (Table XLI) suggest that it takes a rainbow trout approximately 10 hours to digest a meal of sockeye fry at 10°C. There was no apparent relationship between digestive rate and size of trout (23.6 to 28.1 cm).

E. Estimated Consumption of Sockeye Fry by Whitefish

1. Introduction

The data on population size, extent of feeding on fry, and digestive rate of mountain whitefish (*Prosopium williamsoni*) may be combined to obtain an estimate of the extent of predation upon sockeye fry. Only the data obtained from the Tower Pool whitefish population is complete enough to be applicable.

2. Methods and results

Daily food consumption was estimated by the following formula (Bajkov, 1935):

$$D = A \frac{24}{n}$$

where D = the daily consumption, A = the average amount of food in the stomach, and n = time required for digestion (hours).

In the Tower Pool A was found to be 17.4 sockeye fry and n to be 8.5 hours. D may then be calculated as 49.1 fry per mountain whitefish per day. If D is multiplied by the number of whitefish (1696) and by the number of days when

TABLE XLI. Summary of the data obtained in the study of digestive rate of <u>Salmo gairdnerii</u>.

SERIES	TIME	CONDITION OF				
		SKIN	FINS	HEAD	BODY	FORM
1	3	-	-	- Largely digested	Intact	Intact
	6	-	-	- Largely digested	- Largely digested	Recognizable
	9	-	-	- Almost gone	- Almost gone	Fragmented
	12	-	-	-	-	-
	12.16	-	-	-	-	-
	12.50	-	-	-	-	-
2	6	-	-	-	- Largely digested	Recognizable
	9	-	-	-	-	Fragmented
	10	-	-	-	-	-

fry were present (May 1 to June 15, or 46 days) it may be estimated that 3,831,000 sockeye fry were consumed by whitefish in Tower Pool alone.

3. Discussion

The above estimate is based on several assumptions. First, it is assumed that feeding upon fry was of equal magnitude throughout the period of interaction. This may not be valid because most of the fish from Tower Pool were captured in May 1-10 period, when predation was most evident. This would tend to lower the estimate.

Second, it is assumed that the rate of digestion of a compound meal, i.e. one containing other food organisms in addition to sockeye fry, would be the same as for fry alone. Studies by Windell (1967) suggest that differences, if any, would be slight, because a number of different food organisms (insects, fish, oligochaetes) showed close agreement in the time required for digestion by bluegill sunfish, and because the rate of digestion for a mixed meal bore a close relationship to the combined average of the individual organisms.

Third, it is assumed that rate of digestion was constant throughout the course of the interaction. This is clearly not the case, since water temperatures varied considerably within the period May 1 to June 15 (Fig. 14). Molnár *et al.* (1967), Molnár and Tölg (1962), Nicholls

(1931), and others have shown that the time required for digestion decreases with increased temperature. Since digestive rate was measured only at 10°C, near the upper limit of the temperature range during the study, it may be concluded that when water temperatures were lower, daily consumption was considerably less. The estimate of 3.83 million sockeye fry consumed must therefore be adjusted downward considerably.

A serious limitation of the Bajkov estimate is that it assumes feeding to be constant throughout the 24-hour period. This is not certain, however, since no stomach samples were obtained other than during daytime hours. However, the whitefish could have fed to satiation three times during daylight hours, such as at 5 a.m., 1:30 p.m., and 10 p.m. However, the estimate should probably again be adjusted downward.

It is also assumed that the population level of the whitefish was constant throughout the period of interaction and that the numbers of fry did not fall below a minimum level needed to supply the whitefish population (i.e. below 1696 x 49.1 = 83,274 fry). This latter is difficult to ascertain since it is not known whether the whitefish were feeding on pre- or post-emergent fry.

It is further assumed that the digestive rate measured in the laboratory is the same as that in the natural environment, i.e. that the transfer and treatment of whitefish did not have a significant effect on digestive rate.

Although it is impossible to provide a reliable estimate of the total predation it would appear to be a significant factor in reducing the freshwater survival of sockeye fry in the Fulton River. It is indisputable that there were large numbers of whitefish present and that they were feeding on sockeye fry. The problem lies in quantification.

The mountain whitefish has never before been considered a serious predator on the young of Pacific salmon, although Ricker (1933) reported that one captured in Cultus Lake contained twelve small sockeye fingerlings. Cartwright (1961) has reported that rainbow trout fry form an incidental part of the diet of mountain whitefish in the Lardeau River, B. C.

The other food items found in mountain whitefish stomachs suggest that the species is a bottom feeder. The amount of sand and small pebbles found in their guts further supports this suggestion. Mountain whitefish have previously been described as bottom feeders by Kemmerer _et al_. (1924), Chapman and Quistorff (1938), McHugh (1940), and Godfrey (1955). It is therefore probable that the fry were obtained from the bottom as well. This hypothesis was supported on one occasion in the laboratory when a whitefish was seen "sucking" sockeye fry from the gravel on the aquarium bottom.

The extent of feeding by whitefish was related to length. Fish between 20 and 30 cm contained, on the average, more fry than did larger or smaller individuals. The average hypural length of all whitefish examined was 23.9 cm, and they were therefore probably three year old fish (Godfrey, 1955).

4. Suggestions for further study

It is suggested that the problem of whitefish predation, because of its possible seriousness, be studied in greater detail in future years. Whitefish population levels, digestive rates and extent of predation could be examined at various times over a 24 hour period and over the season, based on a stratified sampling scheme. Predator behaviour and predator-prey interactions could be examined in the laboratory. In this way it would be possible to obtain a reliable estimate of predation on sockeye fry by mountain whitefish. Similar work could be carried out on other predatory species (such as rainbow trout) so that a total estimate of sockeye mortality due to predation in the Fulton River could be provided.

Another estimate obtained in the present study (and considered preliminary) is provided here for comparison: Loss to whitefish in spawning channel =

$$0.5 \text{ fry/stomach} \times \frac{24 \text{ hrs}}{8.5 \text{ hrs}} \times 113 \text{ whitefish} \times 36 \text{ days} =$$

5736 sockeye

F. Drift Insect Abundance

1. Introduction

Since the migration timing of the two fry populations is so different, since predators are feeding on both fry and drift insects, and since drift insects are reported to have distinct migration patterns of their own (Waters, 1969) it was thought worthwhile to examine the migration timing of the different aquatic insect species in the Fulton River. The hypothesis under examination is that the rates of exploitation of the two fry populations may be different because the predators' alternate food supply (drift insects) is more abundant during the migration of one group than during that of another. In other words, insects may be "buffering" the action of predators on one fry population but not on the other.

2. Methods

A small fyke-net (Fig. 28) was fished in a fixed position in the Fulton River opposite the spawning channel. It fished the top 1 foot of water only. The net was fished for a period of 24 hours on each of the following dates: May 16-17; May 24-25; May 27-28; and June 11-12, 1968. The net was cleaned every eight hours on May 27-28 and June 11-12. These 24 hour samples therefore consist of 3 samples of 8 hours each.

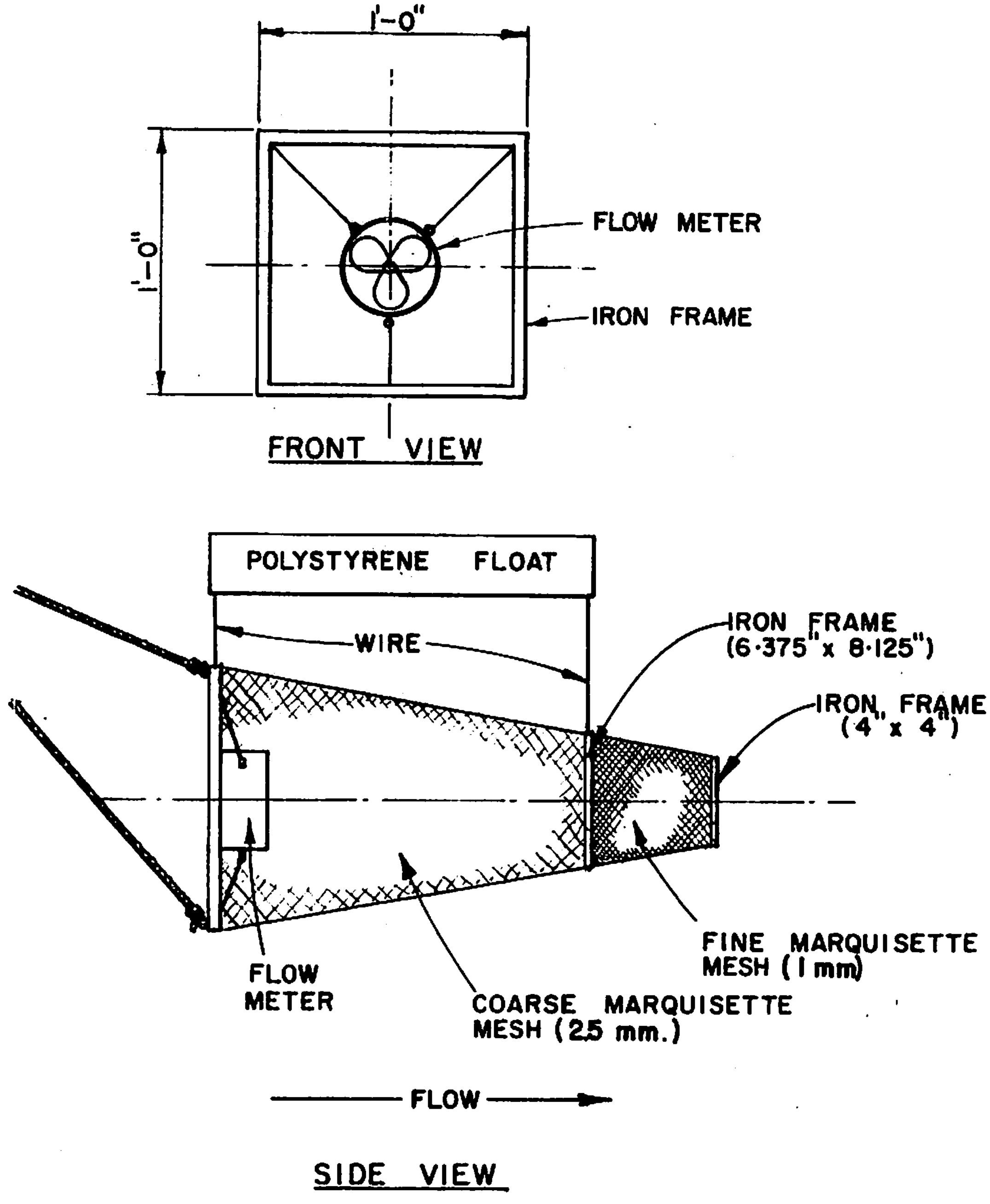


Figure 28.- Sampler used for the capture of drift insects in Fulton River,

The sample was preserved in formalin until examination. At this time the insects were sorted into genera (the keys in Pennak (1953) were used for this procedure). Each genus was then counted, blotted to remove excess water, and weighed to the nearest milligram. The volume was measured as displacement of water in a graduated cylinder.

3. Results

The most common drift insects obtained were: the larvae of the stoneflies Isogenus and Isoperla; the larvae of 2 species of mayflies, Ephemerella; the larvae of the caddisflies Leptocella and Hydropsyche (2 species); and the larvae of the Dipteran Atherix. Only these common types are tabulated and graphed. The following insects were captured occasionally: the larvae of the caddisfly Liminephilus; the larvae of the mayflies Baetis and Rhithrogena; the larvae of Dipteran families Tipulidae (craneflies) and Tabanidae (horseflies); and the adults of the stoneflies Isogenus and Isoperla.

The picture of seasonal migration timing of the drift is similar whether one uses numbers (Table XLII, and Figures 29 and 30), weights (Table XLIII, and Figures 31 and 32), or volumes (Tables XLIV, and Figures 33 and 34). Although there is some variation between individual species, it appears that the total biomass of insect drift fluctuates considerably. The general picture is of a progressive

TABLE XLII. Numbers of insect larvae in the Fulton River drift samples, May and June, 1968.

ORDER	FAMILY	GENUS	DATE							
			MAY 16-17		MAY 24-25		MAY 27-28		JUNE 11-12	
			TIME	#	TIME	#	TIME	#	TIME	#
Plecoptera (Stoneflies)	Perlodidae	Isogenus	Total	5	Total	3	1910	-	0200	-
							0315	-	1007	-
							1115	2	1814	-
							Total	2	Total	-
		Isoperla	Total	16	Total	12	1910	-	0200	7
							0315	9	1007	2
							1115	4	1814	-
							Total	13	Total	9
Ephemeroptera (Mayflies)	Baetidae	Large Ephemerella	Total	32	Total	6	1910	3	0200	4
							0315	8	1007	1
							1115	-	1814	-
							Total	11	Total	5
		Small Ephemerella	Total	8	Total	4	1910	3	0200	14
							0315	7	1007	-
							1115	9	1814	-
							Total	19	Total	14
Trichoptera (Caddisflies)	Leptoceridae	Leptocella	Total	28	Total	14	1910	6	0200	-
							0315	17	1007	-
							1115	13	1814	-
							Total	36	Total	-
	Hydropsychidae	Large Hydropsyche	Total	-	Total	-	1910	9	0200	7
							0315	8	1007	-
							1115	9	1814	-
							Total	26	Total	7
		Small Hydropsyche	Total	11	Total	17	1910	-	0200	-
							0315	-	1007	-
							1115	5	1814	-
							Total	5	Total	-
Diptera (True Flies)	Rhagionidae	Atherix	Total	-	Total	4	1910	-	0200	3
							0315	2	1007	-
							1115	2	1814	-
							Total	4	Total	3

							Total	5	Total	-
Diptera (True Flies)	Rhagionidae	Atherix	Total	-	Total	4	1910	-	0200	3
							0315	2	1007	-
							1115	2	1814	-

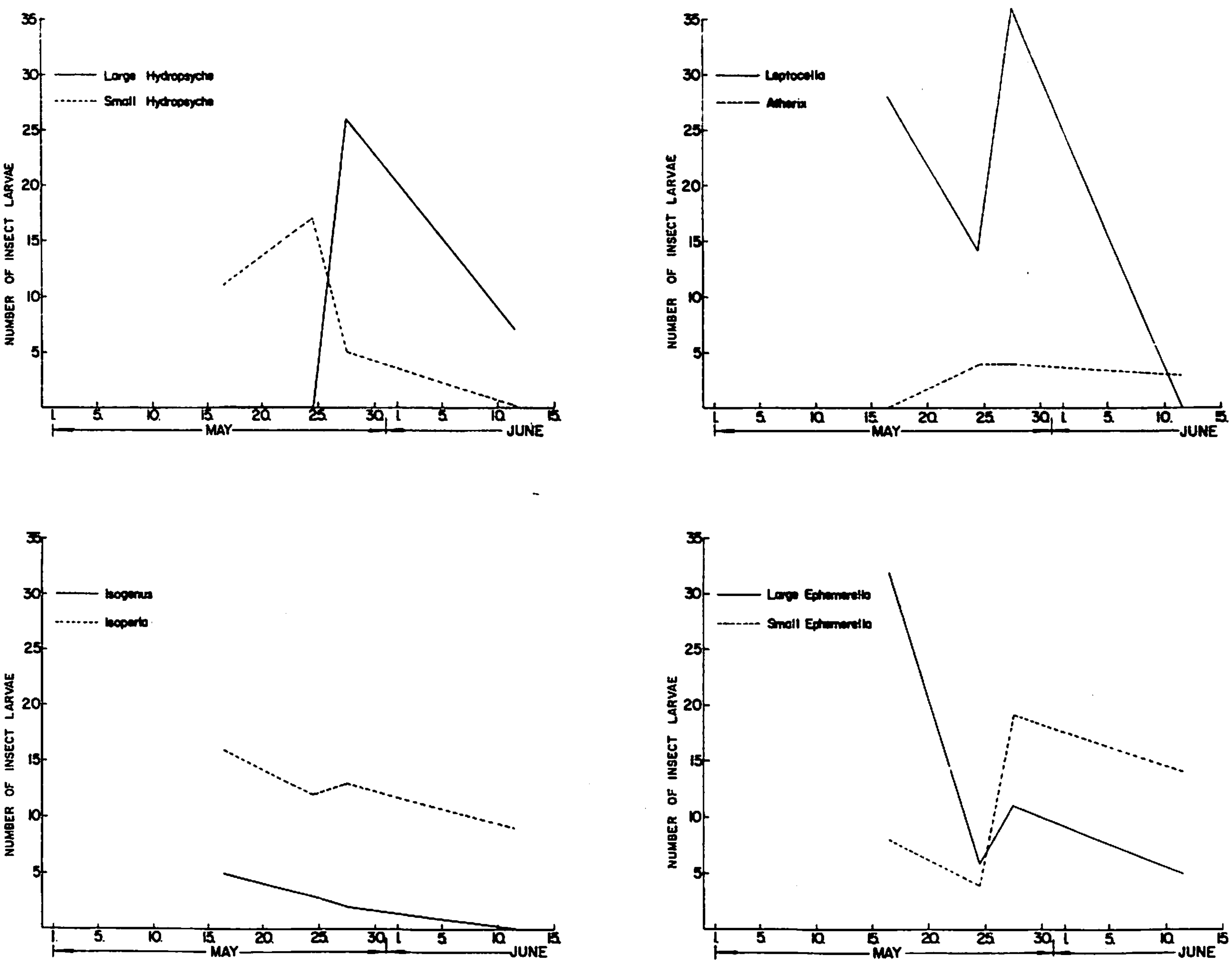


Figure 29.– Number of insect larvae per 24 hr. sample. Fulton River, 1968

TABLE XLIII. Weights of insect larvae (mg) in the Fulton River drift samples, May and June, 1968.

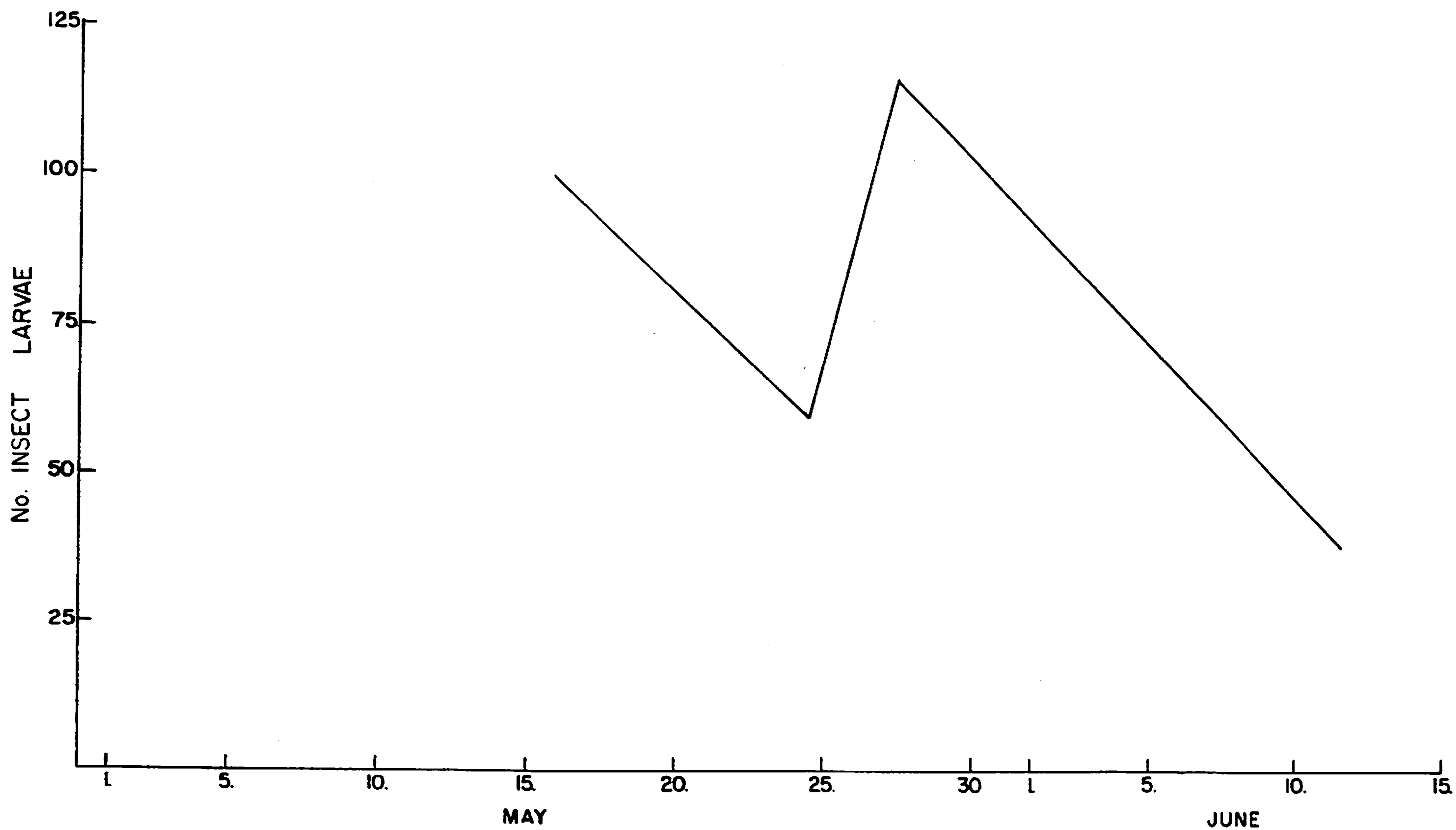


Figure 30.-Total number of insect larvae per 24 hr. sample, Fulton River, 1968.

TABLE XLIII. Weights of insect larvae (mg) in the Fulton River drift samples, May and June, 1968.

ORDER	FAMILY	GENUS	DATE							
			MAY 16-17		MAY 24-25		MAY 27-28		JUNE 11-12	
			TIME	MG	TIME	MG	TIME	MG	TIME	MG
Plecoptera (Stoneflies)	Perlodidae	Isogenus	Total	369	Total	94	1910	-	0200	-
							0315	-	1007	-
							1115	122	1814	-
							Total	122	Total	-
		Isoperla	Total	87	Total	98	1910	-	0200	72
							0315	67	1007	23
							1115	36	1814	-
							Total	103	Total	95
Ephemeroptera (Mayflies)	Baetidae	Large Ephemerella	Total	1581	Total	339	1910	200	0200	334
							0315	420	1007	69
							1115	-	1814	-
							Total	620	Total	403
		Small Ephemerella	Total	67	Total	29	1910	29	0200	128
							0315	44	1007	-
							1115	61	1814	-
							Total	134	Total	128
Trichoptera (Caddisflies)	Leptoceridae	Leptocella	Total	220	Total	68	1910	39	0200	-
							0315	115	1007	-
							1115	84	1814	-
							Total	238	Total	-
	Hydropsychidae	Large Hydropsyche	Total	-	Total	-	1910	135	0200	104
							0315	117	1007	-
							1115	208	1814	-
							Total	460	Total	104
		Small Hydropsyche	Total	118	Total	243	1910	-	0200	-
							0315	-	1007	-
							1115	21	1814	-
							Total	21	Total	-
Diptera (True Flies)	Rhagionidae	Atherix	Total	-	Total	359	1910	-	0200	199
							0315	150	1007	-
							1115	237	1814	-
							Total	387	Total	199

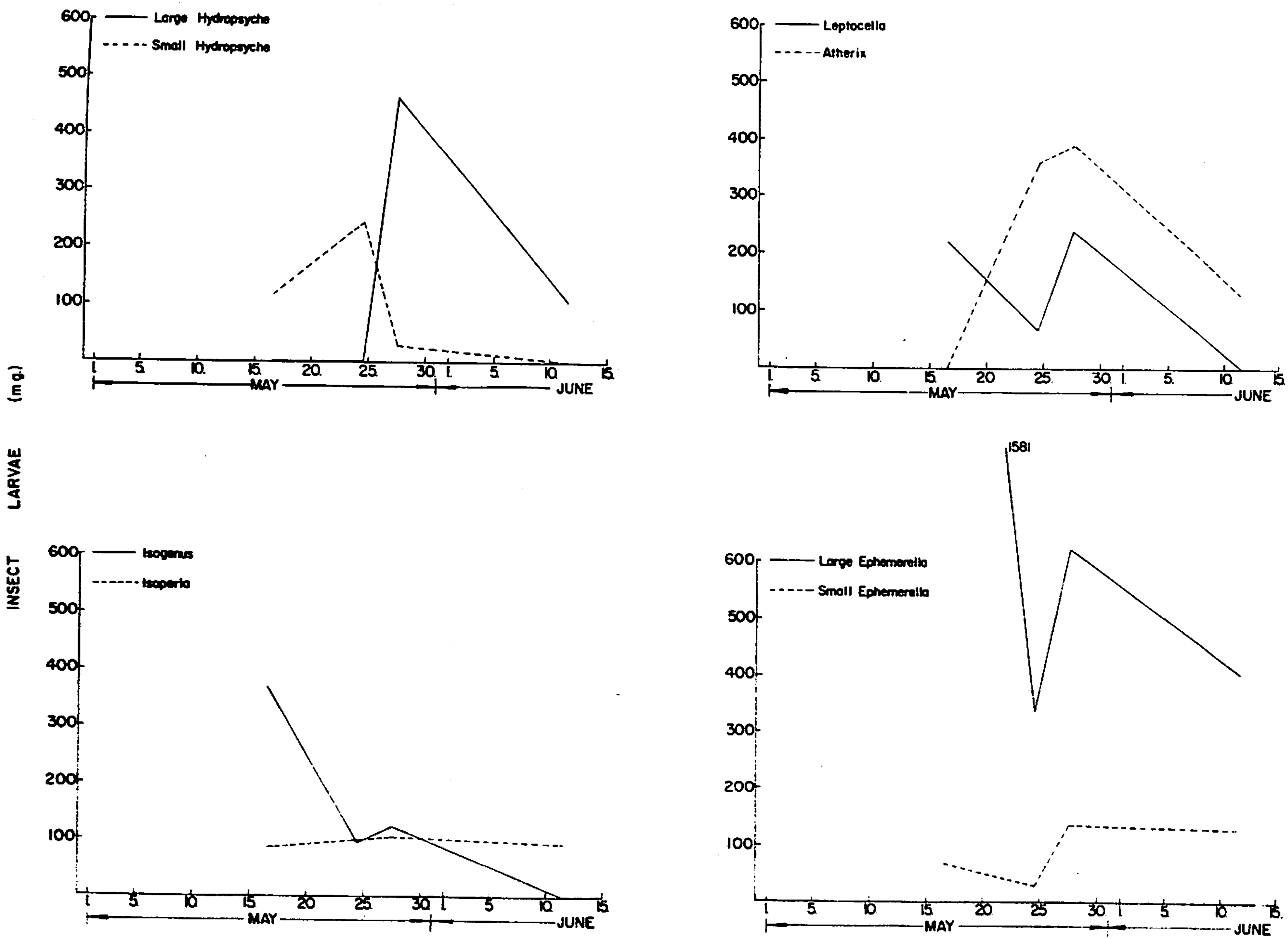


Figure 31 – Biomass (mg.) of insect larvae per 24 hr. sample. Fulton River, 1968.

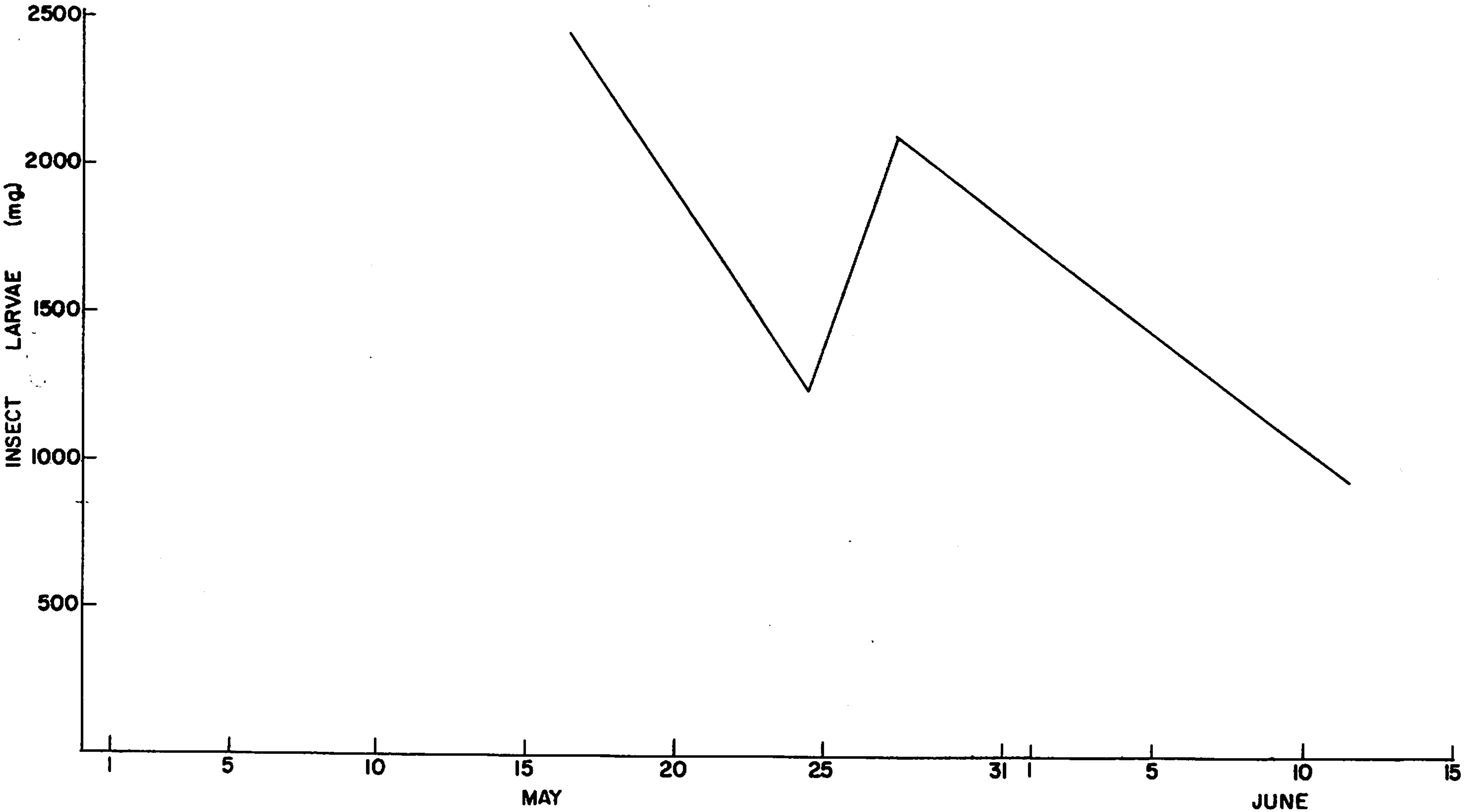


Figure 32.– Total biomass (mg.) of insect larvae per 24 hour sample, Fulton River, 1968.

TABLE XLIV. Volumes of insect larvae (ml) in the Fulton River drift samples, May and June, 1968.

ORDER	FAMILY	GENUS	DATE MAY 16-17 TIME	ML	MAY 24-25 TIME	ML	MAY 27-28 TIME	ML	JUNE 11-12 TIME	ML
Plecoptera (Stoneflies)	Perlodidae	Isogenus	Total	.75	Total	.20	1910	-	0200	-
							0315	-	1007	-
							1115	.40	1814	-
							Total	.40	Total	-
		Isoperla	Total	.25	Total	.20	1910	-	0200	.10
							0315	.10	1007	.05
							1115	.10	1814	-
							Total	.20	Total	.15
Ephemeroptera (Mayflies)	Baetidae	Large Ephemerella	Total	1.70	Total	.50	1910	.20	0200	.30
							0315	.60	1007	.10
							1115	-	1814	-
							Total	.80	Total	.40
		Small Ephemerella	Total	.20	Total	.10	1910	.10	0200	.20
							0315	.10	1007	-
							1115	.10	1814	-
							Total	.30	Total	.20
Trichoptera (Caddisflies)	Leptoceridae	Leptocella	Total	.40	Total	.30	1910	.10	0200	-
							0315	.20	1007	-
							1115	.10	1814	-
							Total	.40	Total	-
	Hydropsychidae	Large Hydropsyche	Total	-	Total	-	1910	.35	0200	.20
							0315	.20	1007	-
							1115	.40	1814	-
							Total	.95	Total	.20
		Small Hydropsyche	Total	.35	Total	.40	1910	-	0200	-
							0315	-	1007	-
							1115	.10	1814	-
							Total	.10	Total	-
Diptera (True Flies)	Rhagionidae	Atherix	Total	-	Total	.50	1910	-	0200	.20
							0315	.20	1007	-
							1115	.40	1814	-
							Total	.60	Total	.20

TABLE XLIV. Volumes of insect larvae (ml) in the Fulton River drift samples, May and June, 1968.

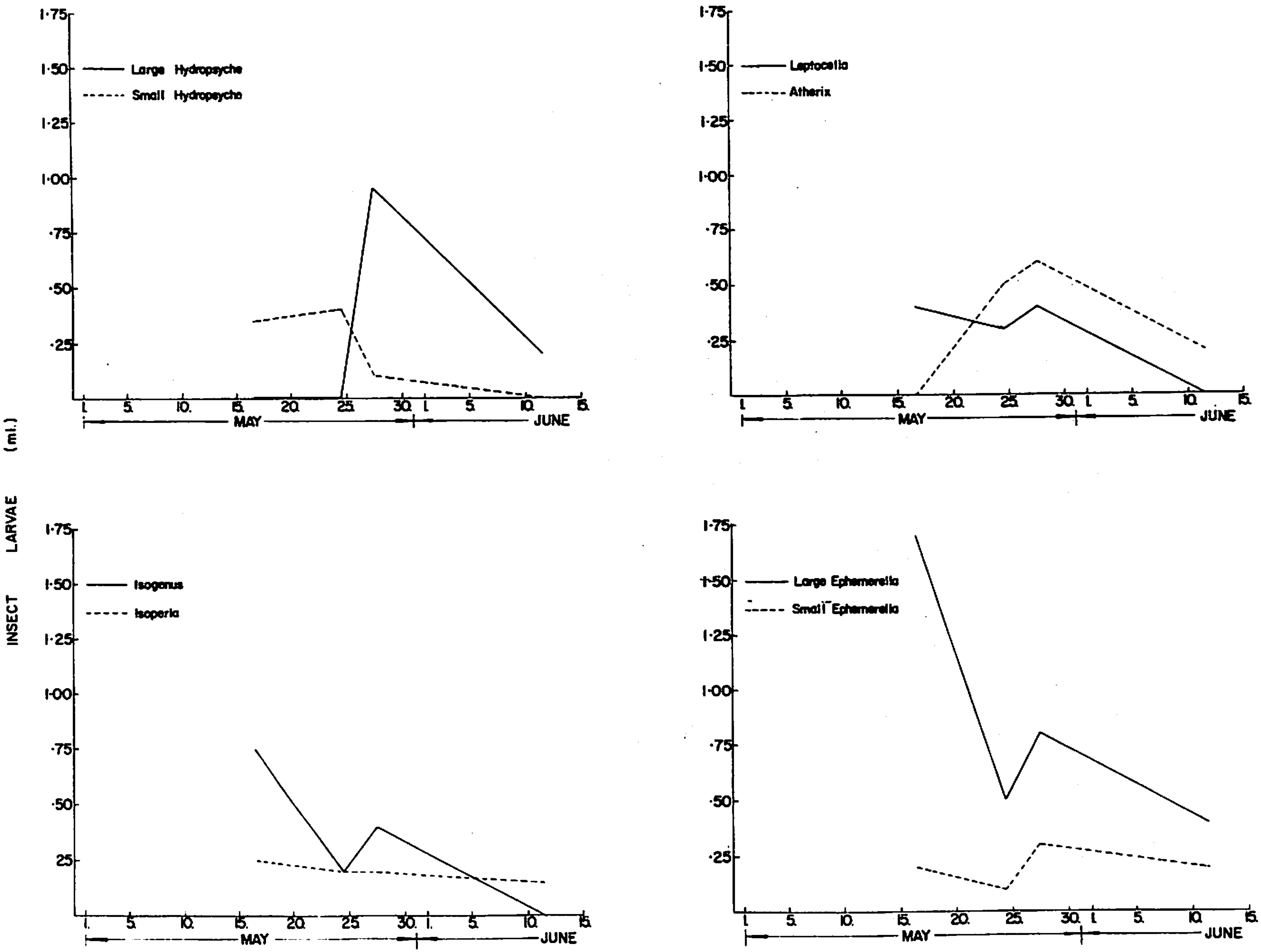


Figure 33.– Biomass (ml) of insect larvae per 24 hr. sample. Fulton River, 1968.

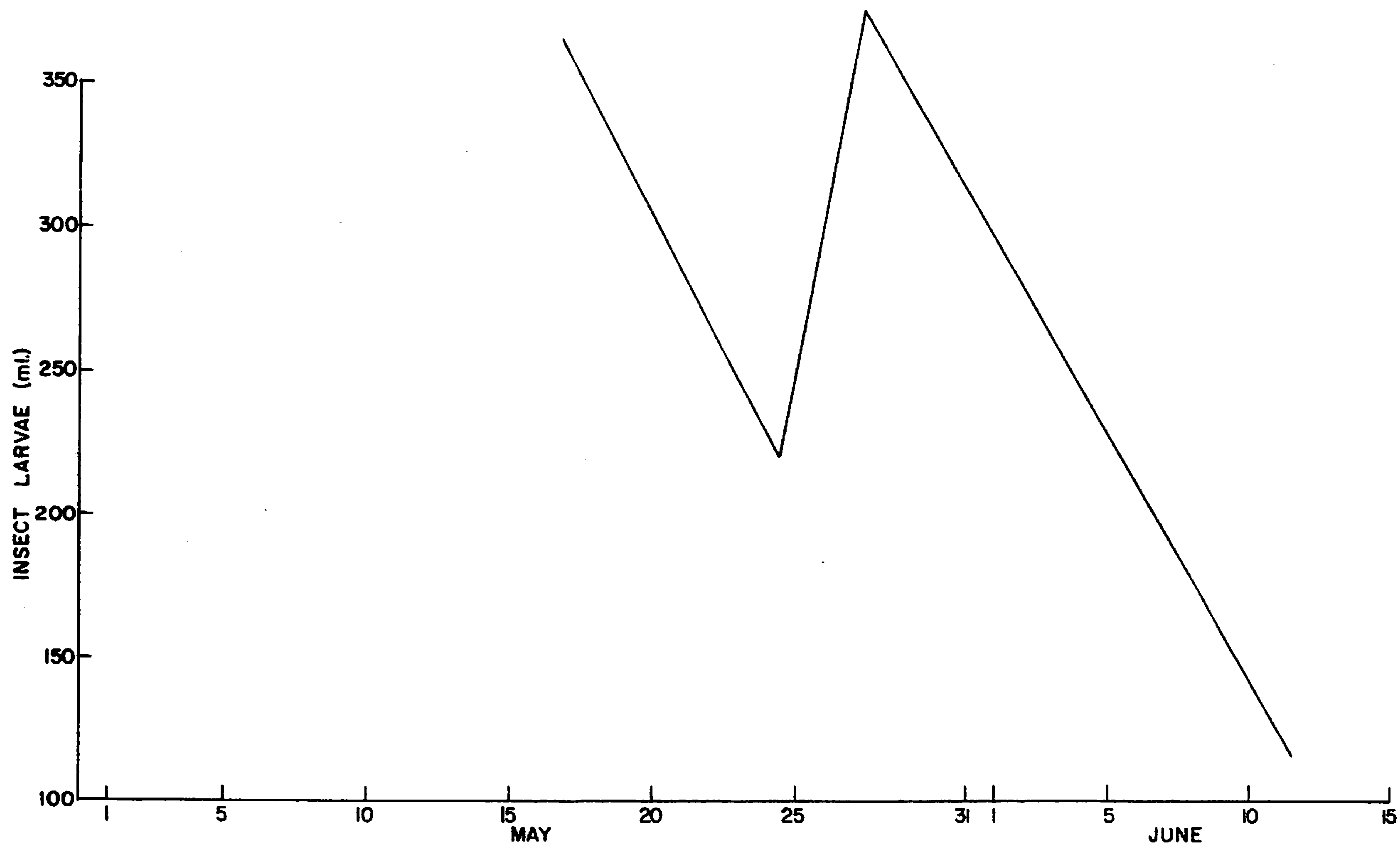


Figure 34.- Total biomass (ml.) of insect larvae per 24 hour sample, Fulton River, 1968.

decline, but with no recognizable change between the dates representing the peaks of the river and channel sockeye fry migrations (May 20 and June 2 respectively).

The graphs of the diel migration timing (Figures 35-40) again reveal individual species differences but the total biomass shows a progressive drop from 0200 to 1800 hours and then the beginning of a further increase. A secondary peak occurs at about 1100 hours. The points in these graphs are calculated as the percentage of the 24 hour biomass captured during each 8 hour period plotted against the midpoint of the period, i.e. a sample from 1200 to 2000 hours would be plotted as occurring at 1600 hours.

4. Discussion

On the basis of such a small number of samples it is impossible to draw any final conclusions. This initial survey has revealed only the composition of the insect drift and its diel timing. The seasonal timing picture cannot yet be resolved.

Since both insects and fry have similar diel (and apparently seasonal) migration patterns, are of roughly the same size, and are both major items of the predators' food supply one might consider this a case of "mimicry among edible prey species". Holling (1965) demonstrated the theoretical possibility of such mimicry "particularly if a flocking behavior evolves simultaneously [since] This development is strongly dependent on prey densities being

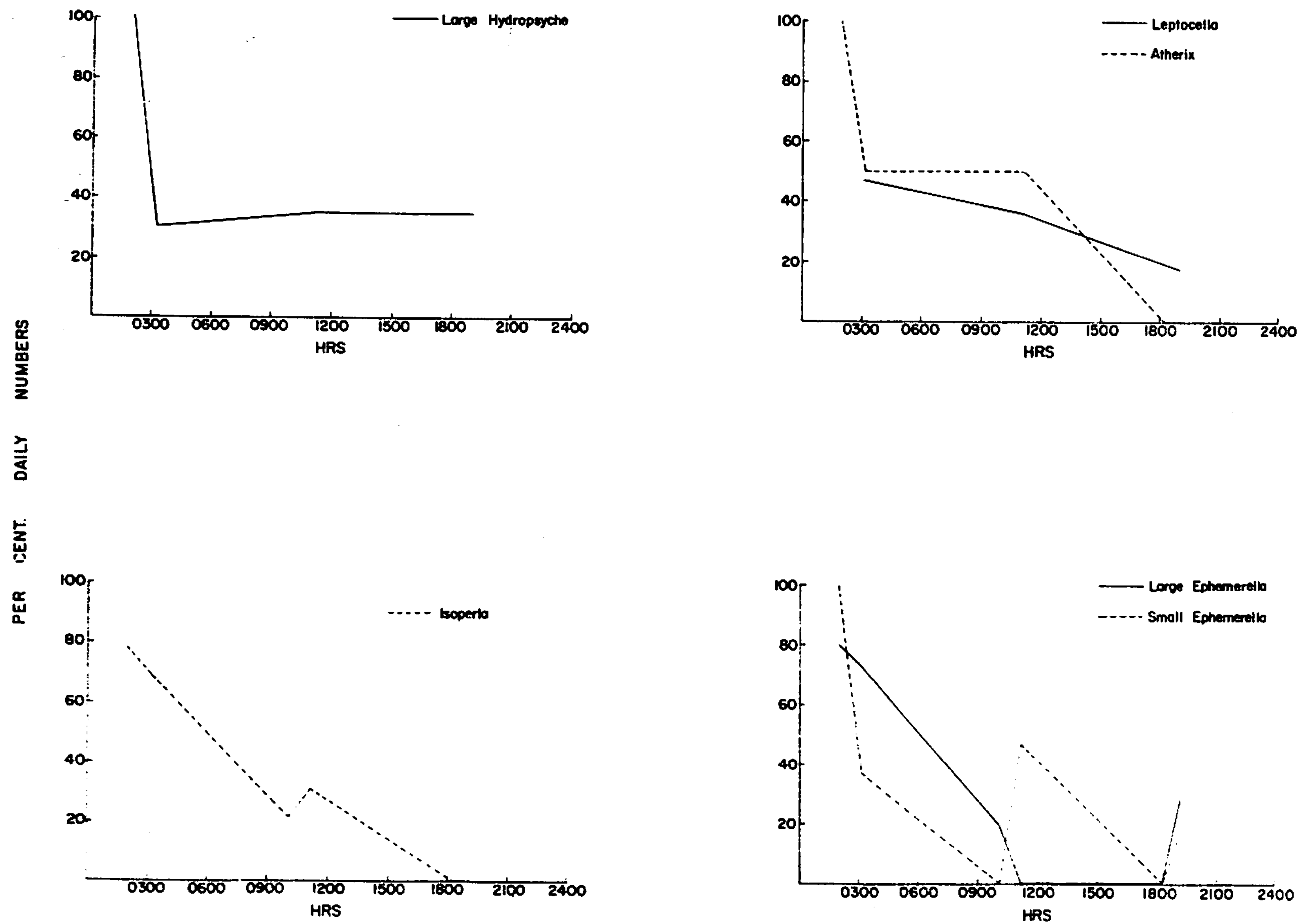


Figure 35.— Per cent daily number of insect larvae at each sampling time. Fulton River, 1968.

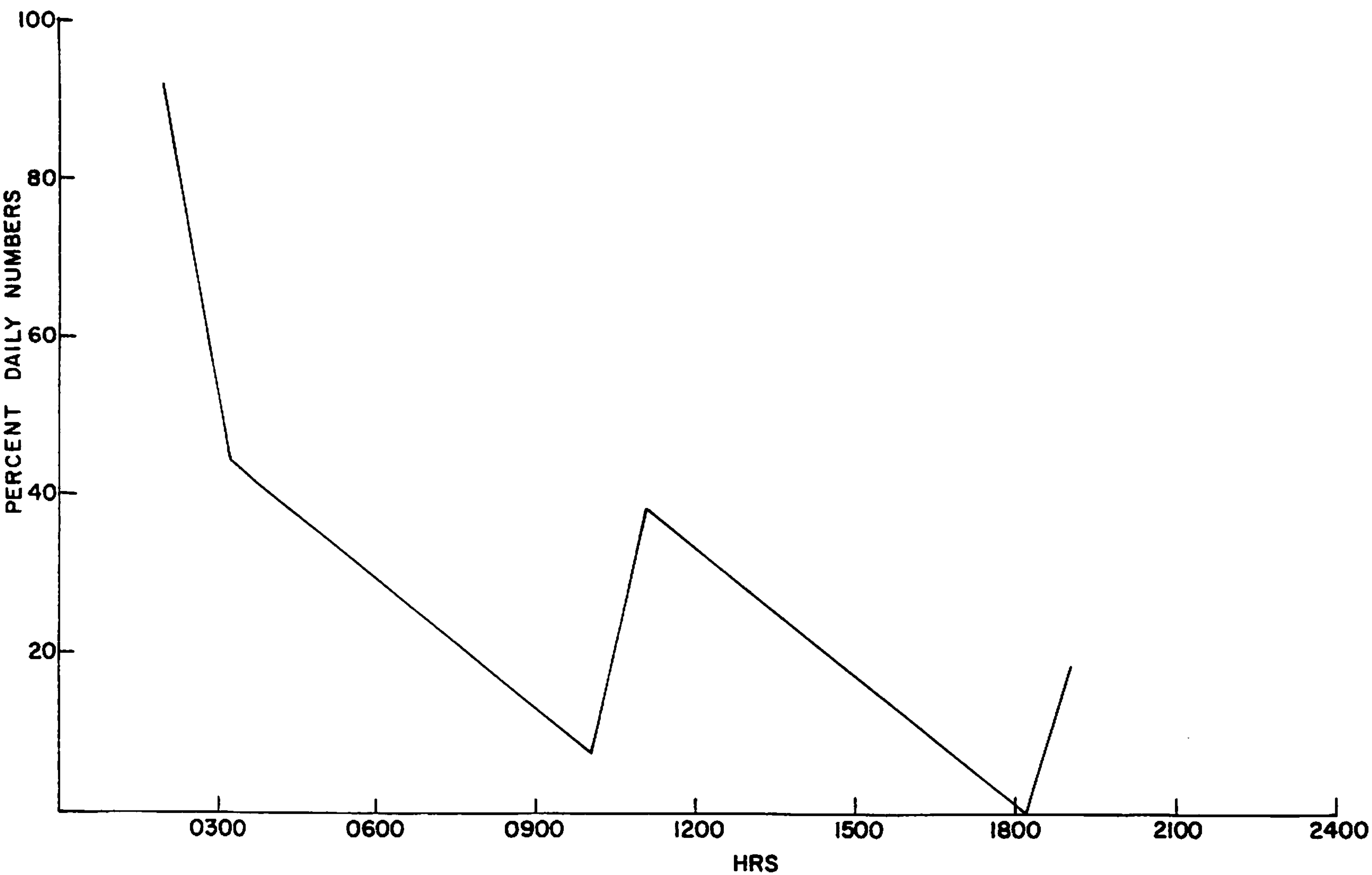


Figure 36.- Percent of daily number of insect larvae (all species combined) at each sampling time, Fulton River, 1968.

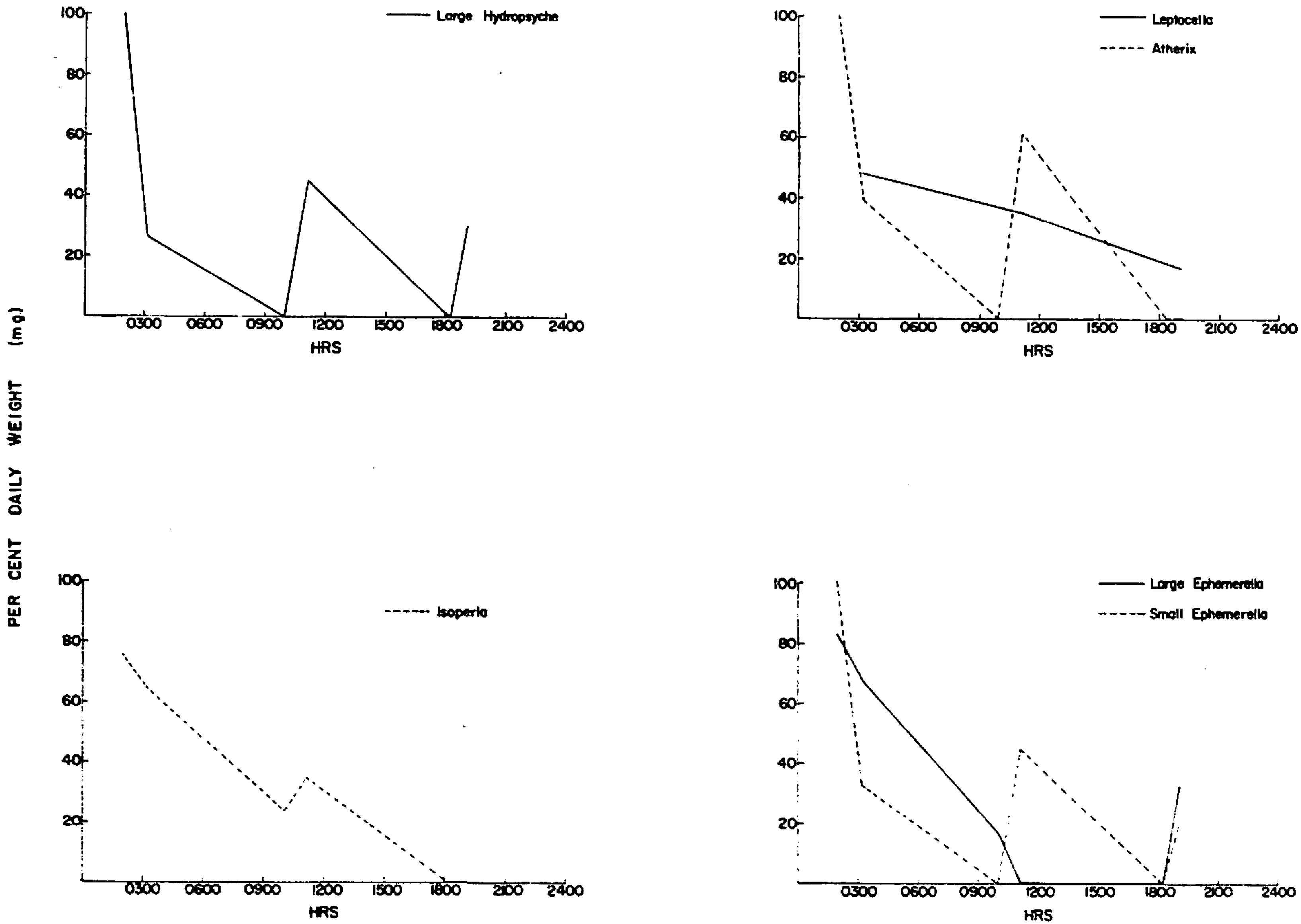


Figure 37 – Daily biomass (mg) of insect larvae at each sampling time. Fulton River, 1968.

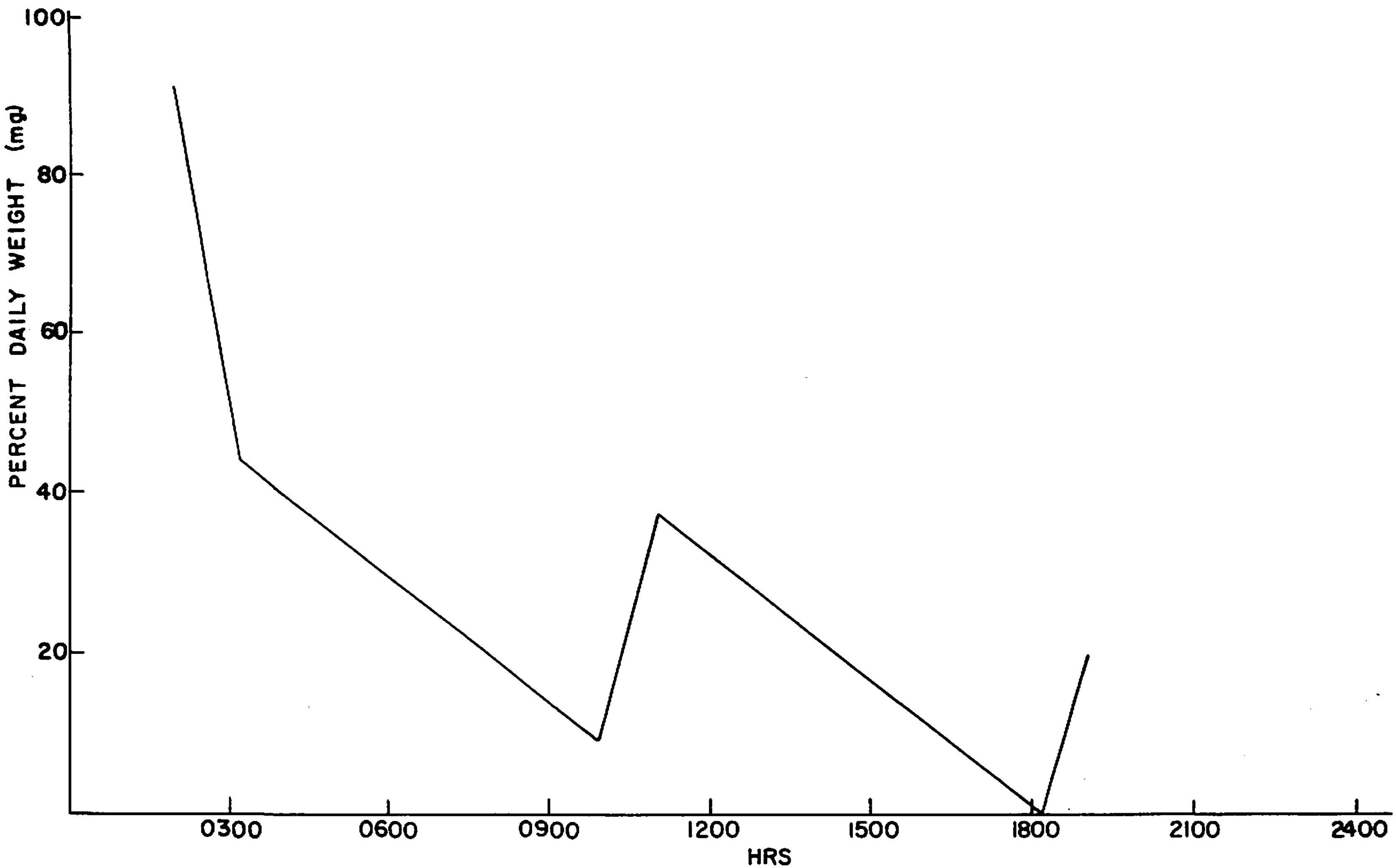


Figure 38.– Percent of daily biomass (mg.) of insect larvae (all species combined) at each sampling time, Fulton River, 1968.

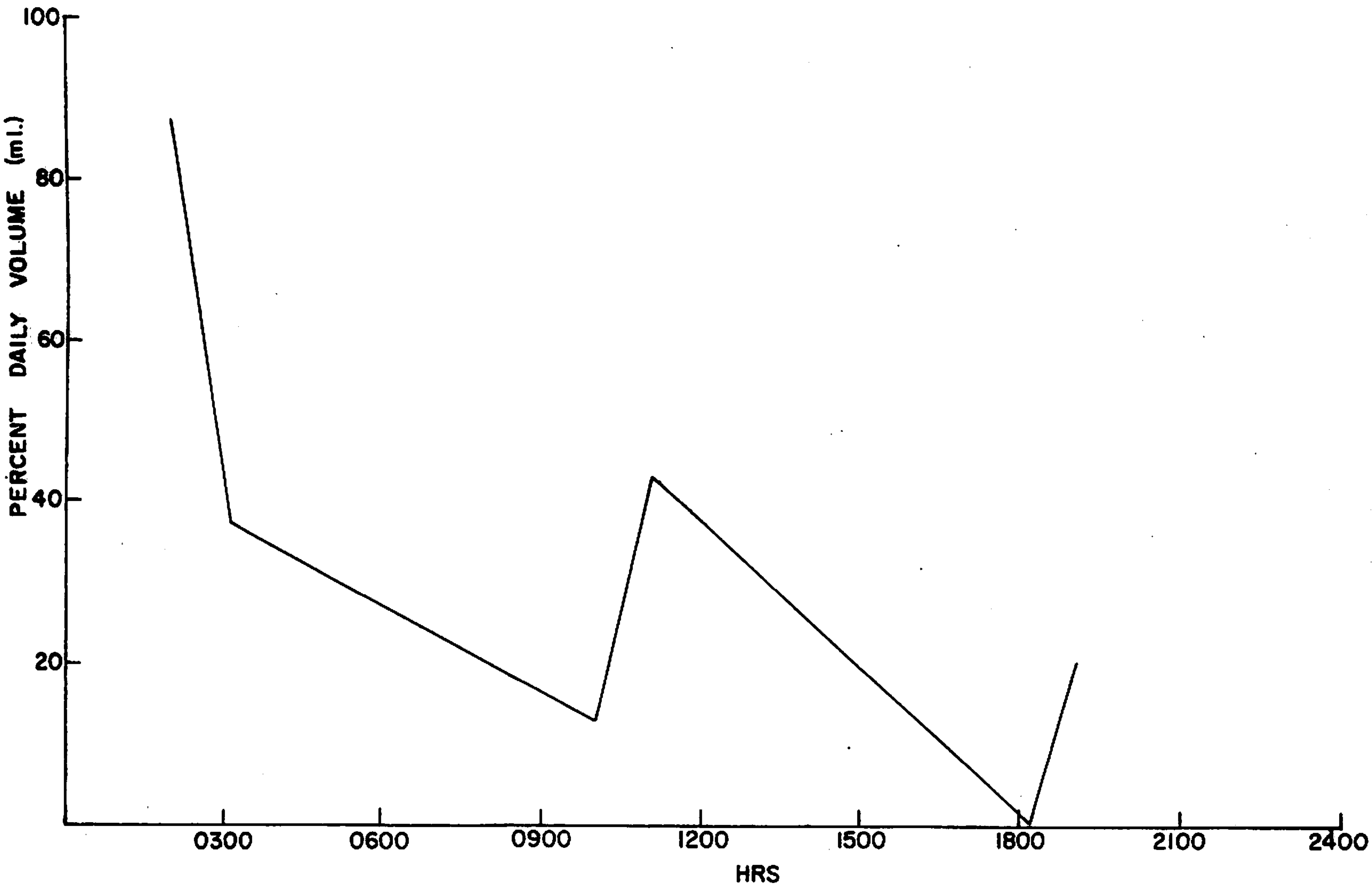


Figure 40.- Percent of daily biomass (ml.) of insect larvae (all species combined) at each sampling time, Fulton River, 1968.

greater than a particular critical density". This type of mimicry has previously been suggested by Van Someren and Jackson (1959) in certain species of African Lepidoptera. The advantage of the process would be that neither species would suffer as high an exploitation by predators as they would if each was moving at a different time, primarily because predators become satiated and the excess prey individuals escape attack (cf. the depensatory mortality of Neave, 1953).

If the abundance of insect drift material is lower at the time of the channel fry migration then these fish may be at a considerably greater disadvantage than their river counterparts. That this is a possibility (in view of the fact that discharge had decreased considerably by the time of the channel fry migration) is suggested by the work of Elliot (1967) who found that a direct linear relationship exists between drift abundance and the amount of water passing the sampling point. Many other workers have recorded the same phenomemon.

If the study is continued next year samples will be taken at more frequent intervals, perhaps every second day, so that a clearer picture of the seasonal migration pattern of the aquatic insects in the Fulton River may emerge.

G. Auxiliary Predation Tests

1. General introduction

The following set of three tests was carried out, under a minimum of direction, by Mr. Mel Falk, who has submitted the results in thesis form for the partial fulfillment of the requirements for the BSc (Honours) degree at the University of Victoria. Only the barest outlines of these studies will therefore be presented in the present report.

2. Insects vs. sockeye fry preference tests

(a) Introduction

Since the drift abundance apparently varied seasonally and since the migration timing of the two fry populations varied considerably, the present tests were designed to determine whether predators prefer fry or an alternate food supply (insects). If predators prefer insect material then predation may be higher on the fry population that migrates when fewer insects are present in the drift, i.e. upon the channel fry.

(b) Methods

A single rainbow trout was presented with a number of sockeye fry, a variety of aquatic insects (dragonfly larvae (Odonata), adult and larvae stoneflies, caddisfly larvae, mayfly larvae, and water boatmen) and, occasionally, some coho fry (Oncorhynchus kisutch) in a bare 20 gallon aquarium with flowing water. After an estimated 50% consumption the predator was removed and the prey species counted out.

Chi square tests were conducted on the data and the significance of differences in predation rates determined. All other rates of predation were compared to that upon mature sockeye fry.

(c) Results and discussion

The raw data and the resultant X^2 values are presented in Table XLV. It appears in every case that insects are more preferable (or at least more available) to the trout than are the sockeye fry. The preference is most significant in the case of mayfly and stonefly larvae.

The same predator was used in the last five tests. It is possible that he fortuitously cultivated a taste for one food type to the exclusion of the others, i.e. that he became conditioned to feed upon insects. For this reason no total X^2 was calculated.

If it is true that trout prefer insects to fry then it is conceivable that the fry population migrating at a time when insects are less abundant (i.e. the channel fry) may be more susceptible to predation. However, this would perhaps be more true if the trout showed no

		TEST NUMBER							
		1	2	3	4	5	6	7	8
TEST START		MAY 8	MAY 8	MAY 8	MAY 31	JUNE 1	JUNE 2	JUNE 4	JUNE 6
Predator	Length (cm)	26.3	29.0	26.2	25.2	25.2	25.2	25.2	25.2
	Weight (gr)	193.8	267.8	203.8	139.7	139.7	139.7	139.7	139.7
Sockeye	Start	20	20	20	10	10	10	10	100
	End	20	20	17	10	10	10	10	82
	%	0	0	15	0	0	0	0	18
Yolk-Sac Sockeye	Start	-	-	-	10	10	10	10	-
	End	-	-	-	4	6	8	9	-
	X^2	-	-	-	1.55	0.56	0.12	0.03	-
Dragonfly Larvae	Start	1	1	10	-	-	-	-	-
	End	1	1	7	-	-	-	-	-
	X^2	0	0	0.12	-	-	-	-	-
Adult Stonefly	Start	10	10	10	10	-	30	30	10
	End	10	10	7	4	-	0	2	2
	X^2	0	0	0.12	1.55	-	18.75*	13.24*	3.71
Stonefly Larvae	Start	10	10	10	-	10	20	20	10
	End	6	1	3	-	0	0	1	0
	X^2	0.68	5.97*	2.08	-	5.69*	13.34*	10.67*	7.86*
Caddisfly Larvae	Start	1	10	1	-	-	-	-	-
	End	1	2	1	-	-	-	-	-
	X^2	0	4.21*	0.21	-	-	-	-	-
Water Boatmen	Start	9	9	9	-	-	-	-	-
	End	0	8	9	-	-	-	-	-
	X^2	7.59*	0.04	0.08	-	-	-	-	-
Mayfly Larvae	Start	-	-	-	10	10	35	35	20
	End	-	-	-	3	0	0	0	1
	X^2	-	-	-	2.39	5.69*	21.35*	21.35*	12.66*
Coho Fry	Start	-	-	-	10	10	10	10	-
	End	-	-	-	4	5	10	10	-
	X^2	-	-	-	1.55	0.98	0	0	-

* = significant

food preference. Further tests, on a variety of predatory species, and at various ratios of alternate food supplies will be required before this question may be accurately resolved.

3. Development stage preference tests

(a) Introduction

Since the river and channel fry migrated at different stages of development (Fig. 9) the present tests were designed to determine if predators preferred well developed (mature) or poorly developed (yolk-sac) fry. If a food preference exists then one fry population may be more vulnerable to predation than the other.

(b) Methods

The tests were conducted on a relative basis, an equal number of yolk-sac fry and mature fry being placed in an aquarium with a single predator. Rainbow trout (*Salmo gairdnerii*), coho yearlings (*Oncorhynchus kisutch*) and sculpins (*Cottus asper*) were used as predators. Coho and sculpin tests were conducted in 5 gal. aquaria while trout tests were conducted in 20 gal. aquaria. Tests were performed with and without a gravel substrate. Each aquarium was provided with aeration, flowing water, and constant light conditions. River fry were used as the prey organisms.

Tests were continued until approximately 50% of the prey had been removed (36-48 hours). The surviving fry were removed, identified and counted. Thirty tests were conducted using various combinations of development stages, predators, and substrates.

(c) Results and discussion

Considering first the DS 2/3 vs DS 5 tests it is obvious that the yolk-sac fry were more vulnerable to all predators in the bare tanks (Table XLVI), but only to sculpins in the gravel substrate tanks (Table XLVII). It appears that in this instance vulnerability is synonymous with availability, since it would appear that the immature fry used the substrate as cover. Even there, however, they were still available to bottom feeders, the cottids.

The results of the semi-mature (DS 4) vs mature (DS 5) fry tests are less meaningful. In bare tanks (Table XLVIII) no difference in vulnerability (availability) is evident. However, DS 4 fry were more vulnerable to coho predation in the gravel bottom tank than were DS 5 (Table IL). This may have been because the DS 4 fry had lost their cover seeking response and were more vulnerable due to poorer swimming ability. Failing behavioural observations on the fry, this must remain only a hypothesis.

TABLE XLVI. Predation on DS 2 and 3 vs DS 5, no gravel. Significance level, p = .05.

PREDATOR	DS 2 + 3		DS 5		X^2
	START	END	START	END	
Rainbow	25	14	25	25	1.77
Rainbow	25	4	25	20	7.56*
Σ	50	18	50	45	7.30*
Coho	25	3	25	14	5.46*
Coho	25	9	25	20	2.70
Coho	25	13	25	17	.34
Σ	75	25	75	51	5.98*
Sculpin	25	0	25	18	19.23*
Sculpin	25	2	25	13	6.39*
Σ	50	2	50	31	20.12*

* = significant

TABLE XLVII. Predation on DS 2 and 3 vs DS 5, gravel. Significance level, p = .05.

PREDATOR	DS 2 + 3		DS 5		X^2
	START	END	START	END	
Rainbow	25	18	25	20	.06
Rainbow	25	21	25	24	.11
Rainbow	25	17	25	13	.34
Rainbow	25	7	25	21	4.68*
Σ	100	63	100	78	.94
Coho	25	14	25	8	.63
Coho	25	17	25	15	1.14
Coho	25	20	25	14	.08
Σ	75	51	75	37	1.41
Sculpin	25	6	25	20	5.13*
Sculpin	25	11	25	18	1.08
Σ	50	17	50	38	5.27*

* = significant

TABLE XLVIII. Predation on DS 4 vs DS 5, no gravel. Significance level, $p = .05$.

PREDATOR	DS 4		DS 5		X^2
	START	END	START	END	
Coho	25	12	25	21	.15
Coho	25	17	25	19	.07
Σ	50	29	50	40	1.04

TABLE IL. Predation on DS 4 vs DS 5, gravel. Significance level, p = .05.

PREDATOR	DS 4		DS 5		X^2
	START	END	START	END	
Coho	25	9	25	8	.04
Coho	25	15	25	18	.17
Coho	25	14	25	23	1.27
Coho	25	15	25	20	.42
Coho	25	6	25	16	3.22
Coho	25	1	25	3	.92
Coho	25	13	25	18	.50
Coho	25	6	25	14	2.32
Σ	200	79	200	120	4 30*
Rainbow	25	11	25	15	.41
Rainbow	25	9	25	10	.04
Rainbow	25	19	25	17	1.80
Σ	75	34	75	42	.56

* = significant

4. Length preference tests

(a) Introduction

The channel fry at the time of migration were significantly longer than the river fry. It was therefore of interest to note whether predators prefer small or large prey. The present test was designed to answer this question.

(b) Methods

Rainbow trout and coho yearlings were used as predators, in 20 and 5 gallon aquaria respectively. These aquaria had aeration, flowing water, artificial light and no gravel. The prey in every case were mature channel fry.

The tests were conducted in a relative manner. The initial and final fork lengths were obtained from the anaesthetized fry (2-phenoxyethanol). The fry compared in each test had a bimodal length frequency distribution, the peaks separated by a two mm. gap. Fourteen tests were conducted.

(c) Results and discussion

The results (Table L) show that both rainbow trout and coho yearlings selected for smaller sockeye fry but that only the rainbow trout X^2 was significant at the .05 level. The grand total length data showed an

TABLE L. Predation on large and small sockeye fry by rainbow trout and coho yearlings.

PREDATOR	SMALL				LARGE				X^2
	START		END		START		END		
	NO.	$\bar{X}_L$(ml)	NO.	$\bar{X}_L$(ml)	NO.	$\bar{X}_L$(ml)	NO.	$\bar{X}_L$(ml)	
Coho	25	28.00	14	28.71	25	31.26	15	31.13	.02
Coho	25	28.86	5	28.50	25	31.02	10	31.30	1.29
Coho	25	28.48	18	28.61	25	31.12	14	31.14	.31
Coho	25	28.74	19	28.66	25	31.22	13	31.15	.69
Σ	100	-	56	-	100	-	52	-	.10
Rainbow	50	27.79	21	27.70	50	30.43	28	31.70	.67
Rainbow	50	28.59	1	29.00	50	31.32	5	31.60	2.52
Rainbow	50	28.61	33	28.70	50	31.15	35	31.20	.04
Rainbow	25	28.80	2	29.00	25	31.40	7	31.80	2.37
Rainbow	25	28.60	13	28.69	25	31.20	17	31.29	.33
Rainbow	25	28.64	12	28.58	25	31.04	14	31.07	.10
Rainbow	25	28.28	7	28.36	25	31.22	10	31.26	.40
Rainbow	25	28.22	13	28.12	25	31.30	16	31.47	.20
Rainbow	25	28.48	8	28.87	25	31.38	17	31.47	2.19
Rainbow	25	28.60	3	29.00	25	31.60	11	31.23	3.63
Σ	325	-	113	-	325	-	160	-	5.71*
Grand Σ	425	28.48	169	28.61	425	31.19	212	31.33	3.36

* = significant

increase for both large and small fry from the beginning to the end of the test, further supporting this conclusion.

From this it would appear that the shorter river fry would be more susceptible than their longer channel counterparts to predation by trout.

5. General discussion

The channel fry would appear to be less likely to be removed by predators because they are both larger and more mature. The river fry, however, may have an advantage because they migrate in the presence of a more abundant alternate food supply. Perhaps no net difference in vulnerability to predation exists, as evidenced by the results of the standard fry quality test.

The results of the standard tests may not be particularly reliable, for several reasons. First of all, the first strata for the river sampling was so large that it may have masked any advantage the channel fry gained by their greater length and maturity. Secondly, the test situation was greatly oversimplified: there were no stretches of rapidly flowing water alternating with pools; no alternate food supply; no interaction between predators; and no combination of predator species each more effective in a particular situation (i.e. rainbow, whitefish, burbot, coho, sculpins, chub, etc.).

A useful test situation might be provided in an artificial stream tank which attempts to imitate conditions in the natural river. This could, if large enough, provide most of the conditions noted above. Since predation is such a complex ecological phenomenon, the measure of vulnerability to predation may be a most meaningful quality index. Priority should therefore be given to its reliable measurement under less artificial conditions than presently used.

V. CONCLUSIONS

1. River fry were significantly heavier than channel fry.
2. Channel fry were significantly longer and migrated at a more advanced stage of development than did the river fry.
3. The difference in stage of development at and timing of migration appears related to discharge conditions in the Fulton River and channel during the spring months. The river fry appear to have been prematurely scoured from the gravel.
4. River fry had significantly greater percent solids, lipids, and nitrogen than did channel fry. This, again, appears correlated with stage of development.

5. Channel fry had a significantly greater swimming endurance than river fry due, perhaps, to their greater hydrodynamic efficiency (less yolk), greater length, and better physiological condition (no lactic acid buildup due to "fighting" high flows in the river).

6. No net difference was observed between the vulnerability to predation of river and channel fry. This may have been an artifact of the test situation.

7. River fry were more resistant to starvation, or at least to holding in the laboratory, than were the channel fry.

8. River fry were more tolerant of high temperatures (18.5°C) than were the channel fry.

9. The development stage classification used to date is too subjective for statistical analysis. A more objective procedure is proposed.

10. Studies of yolk-sac weights indicated that had the river fry migrated at the same stage of development as the channel fry, there would have been no weight difference between them.

11. There is some indication that swimming performance is also an expression of migration timing (stage of development).

12. The swimming performance test is very sensitive to changes in procedure, such as the length of the holding period before testing.

13. The sampling methods used were reasonably reliable and the conclusions drawn from the standard quality tests are based on representative samples of the two fry populations.

14. Tagging studies indicated the presence in the Fulton River of large populations of mountain whitefish and rainbow trout. There may be two ecological races of rainbow trout present -- migratory and resident.

15. Information is presented on the feeding of the various predator species -- most fed on both fry and insect drift. Mountain whitefish appeared to be primarily bottom feeders.

16. Digestive rates were determined for three predatory species. Whitefish required 8.5 hours for 100% digestion; rainbow trout 10 hours; and prickly sculpins (*Cottus asper*) 27 hours.

17. Information is presented on the species composition and timing of the insect drift. It was found to have a distinct diel but vague seasonal timing.

18. Given a choice predators appear to prefer insects to fry, yolk-sac fry to mature fry, and shorter fry to longer fry. This may be largely an expression of availability rather than preference, particularly for the yolk-sac/mature fry comparison.

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