SOCKEYE EGG-TO-FRY MORTALITY IN THE FULTON RIVER SPAWNING CHANNELS

Technical Report 1972 - 10

by

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July, 1972

ABSTRACT

Possible causes of low egg-to-fry survival of sockeye salmon (Oncorhynchus nerka) in the Babine Lake artificial spawning channels were studied from November, 1971, to March, 1972. Concurrent studies were conducted on the Fulton River and Pinkut Creek spawning areas.

Intragravel and surface water levels of dissolved oxygen and free carbon dioxide were conducive to satisfactory embryonic growth, development and survival in the spawning channels, but not in all sections of Fulton River and Pinkut Creek. Significant mortalities occurred in areas of the two rivers characterized by high silt loads and low dissolved oxygen concentrations. Other ionic constituents of river and channel water were present in normal amounts in all spawning areas except in Channel No. 2 where abnormal nitrate concentrations prevailed. Nitrate levels were not high enough to affect egg-to-fry survival. Evidence suggested intragravel water delivery rates were adequate for embryonic survival. Intragravel water temperatures throughout the incubation period were within the limits required for embryonic survival. Gravel deterioration resulting from sedimentation and organic buildup in Channel No. 1 and from organic buildup in Channel No. 2 did not contribute significantly to embryonic mortality. Observed variations in bottom fauna types and numbers were characteristic of respective stream habitats.

Significant mortality in the Fulton River spawning channels occurred during the period from deposition to the late pre-eyed stage and indications were that mortality occurred shortly after deposition. Areas experiencing initial crowding from excessively high spawning densities, and wave spawning, underwent high mortality in comparison to areas having low densities suggesting that mortality was density-dependent. High-low mortality trends within a channel were attributed to heavy and light spawning. Percentage of unspawned females was directly related to spawning density in both Fulton spawning channels and it appeared that overcrowding was more prevalent in Channel No. 2 than Channel No. 1.

It was concluded that the major mortality factor in the Fulton River spawning channels was superimposition of redds causing mortality from mechanical disturbance. Over-crowding and superimposition resulted from excessively high initial spawning densities, and wave spawning.

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INTRODUCTION

To survive, a fertilized salmonid egg must be protected against mechanical disturbance; must receive adequate water having a high content of dissolved oxygen, a low content of toxic substances, and a suitable temperature; and must be protected against attack from pathogens, parasites and predators (McNeil, 1968). Obviously all of these requirements are never fully satisfied for all fertilized eggs in natural streams but expectations are that artificial spawning channels should provide near optimal conditions for eggs to develop and survive without experiencing significant mortalities.

In general egg-to-fry survival in the Babine Lake spawning channels has been low - 20 to 30%. During the 1971 spawning season to the subsequent fry migration a study was conducted on the Fulton River spawning channels (Fig. 1) to determine the cause(s) of high egg-to-fry mortality in these facilities. Factors examined were: water quality with emphasis on dissolved oxygen and free carbon dioxide levels of intragravel water; water temperature; organic and inorganic sedimentation and bottom fauna populations; spawning densities; egg deposition and embryonic mortality of eggs. Concurrent studies were done on Fulton River, and Pinkut Creek and Channel (Fig. 2) but only a few of the above factors were examined.

This study is reported in two sections, the first dealing with the effects of the spawning bed environment on egg-to-fry survival and the second with the effects of spawning densities on survival.

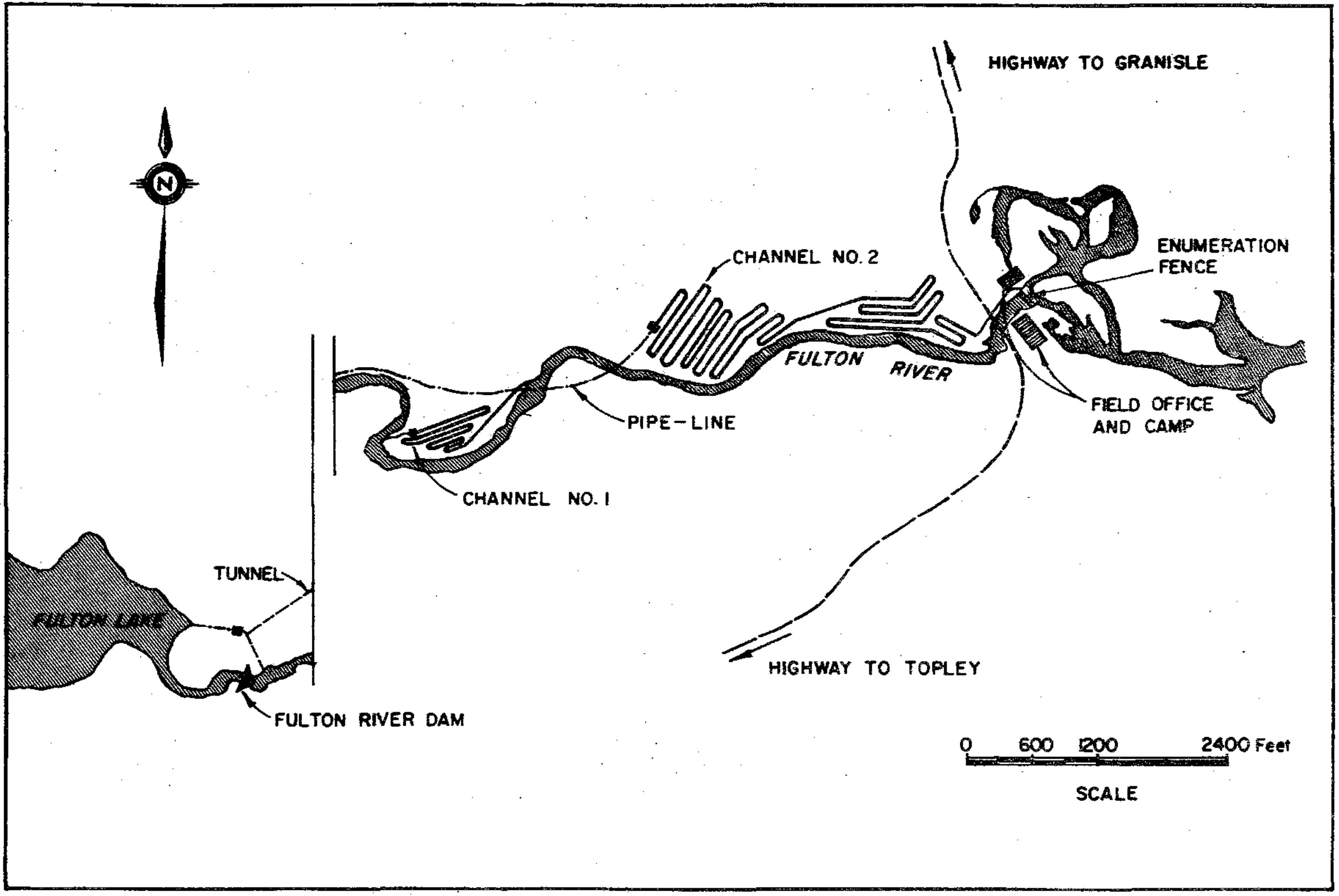


Figure 1. Map of Fulton River and adjacent spawning channels.

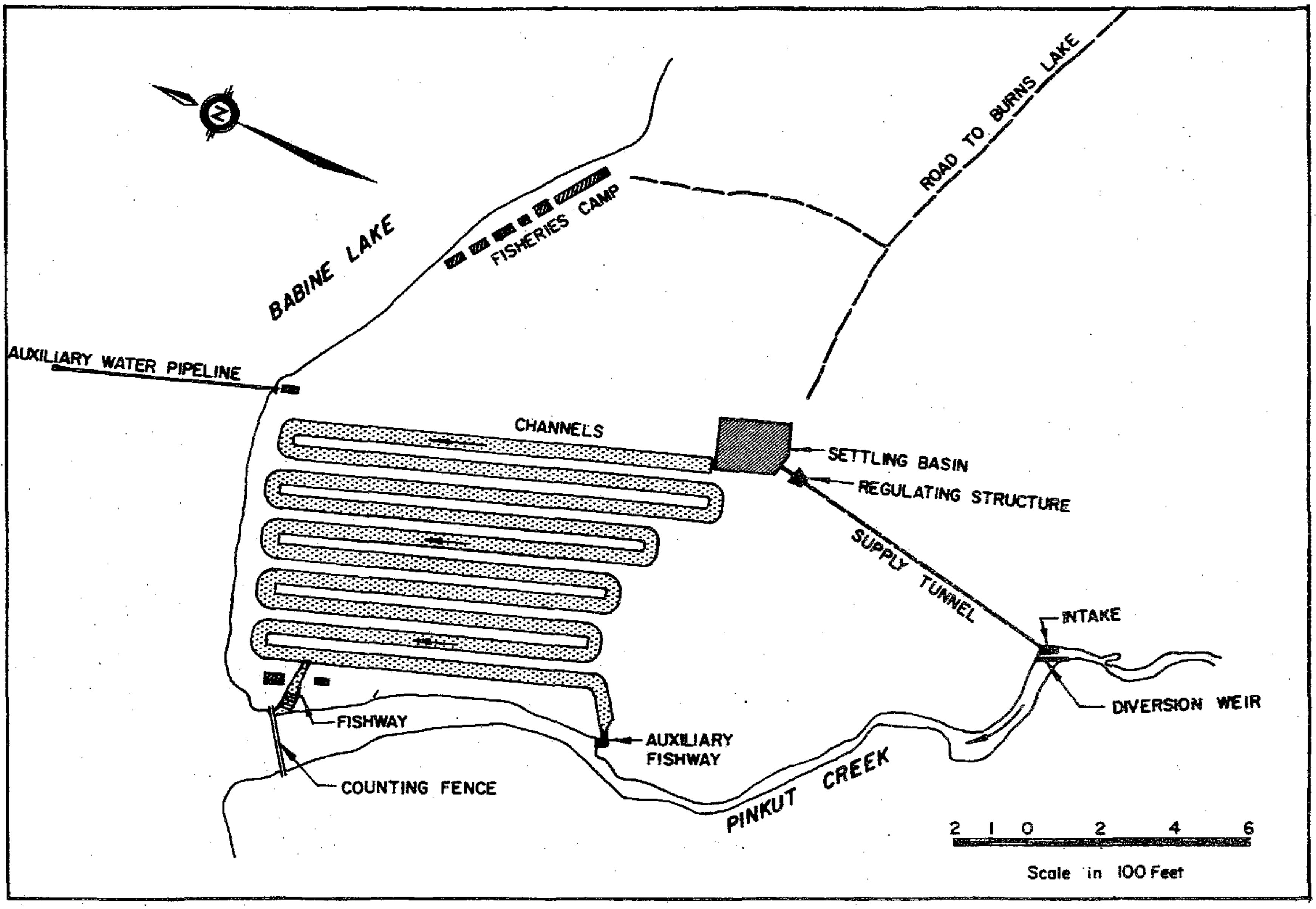


Figure 2. Map of Pinkut Creek and the adjacent spawning channel.

SECTION I SPAWNING BED ENVIRONMENT AND ITS EFFECT ON EGG-TO-FRY SURVIVAL

INTRODUCTION

The prerequisite for the survival of salmonid spawn is an adequate flow of oxygen-bearing water through gravel containing the eggs. Good delivery rates prevent accumulation of toxic metabolic wastes (i.e. carbon dioxide, ammonia) from inhibiting development and survival. The occurrence of toxic ions even in small concentrations may prove fatal to incubating eggs, and alevins. According to Merrell (1962) and others, water temperature might be a contributing factor in poor egg-to-fry survival. Claire and Phillips (1968) concluded that some genera of stonefly nymphs when present in large numbers in spawning areas could be a serious predator on salmonid eggs and alevins. Cordone and Kelly (1961) and others, indicate that sedimentation can impair water quality to the extent that it affects salmon egg and alevin development and survival. Although other environmental factors could affect survival the above mentioned factors appeared to be the ones most likely to cause high egg-to-fry losses in the Babine spawning channels, and for this reason they were examined, either directly or indirectly, in the course of the study.

SAMPLING SITES

Three sampling terms: "sampling area", "sampling location" and "sampling site" were used in the text to describe where a specific sample was taken and to distinguish samples within and between locations. A sampling area refers to a general area or facility, i.e. Spawning Channel No. 1, Fulton River, etc.; a sampling location refers to a local area within a facility, i.e. Leg 1; a sampling site is a specific sampling point within a location, i.e. sample 1, 2, 3, etc.

The main sampling areas were: Spawning Channel No. 1, Spawning Channel No. 2, Fulton River, Pinkut Spawning Channel and Pinkut Creek. Measurements of all environmental variables were done at arbitrarily chosen locations within a sample area. Dissolved oxygen and free carbon dioxide levels were sampled in Legs 1, 4 and 7, and Legs 1, 13 and 21 in Channels No. 1 and 2 respectively. Three locations, upper (opposite Leg 1, Channel No. 1), middle (opposite Leg 1, Channel No. 2) and lower (opposite Leg 13 and 21, Channel No. 2) were sampled in Fulton River. Bottom fauna and sedimentation were examined in Legs 1, 4 and 7 in Channel No. 1, Legs 1, 3, 5, 13 and 17 in Channel No. 2, and four locations in Fulton River three of which were mentioned above. The fourth location was opposite Leg 13 of Channel No. 2. Water quality samples at Fulton River were taken from: Fulton Lake Reservoir; Fulton River at the base of the dam and at the enumeration fence; Legs 1 and 7 of Channel No. 1; and Legs 1, 13 and 21 of Channel No. 2.

Intragravel water temperatures were monitored in Legs 1 and 7 in Channel No. 1, and Legs 1, 13 and 21 of Channel No. 2.

At the Pinkut spawning area, only dissolved oxygen and other water quality measurements were taken. Dissolved oxygen was sampled in Legs 1, 3 and 5 of the channel and the upper, middle and lower portion of the section of Pinkut Creek extending from the channel outlet to the enumeration fence. Water quality samples were taken from: Pinkut Creek at the diversion site, lower canyon and the enumeration fence; the auxiliary water supply; the settling pond and Leg 9 of the Pinkut Channel.

METHODS AND RESULTS

Dissolved Oxygen Levels of Intragravel Water

Water samples were obtained from standpipes which were open cylinders having 20 holes, 0.48 cm (3/16") in diameter spaced in the lower 10 cm (4") of pipe. Standpipes, about 100 cm (3 1/2') in length and made of commercial grade black steel pipe, had an inside diameter of 2.54 cm (1"). For sampling, standpipes were driven into the gravel with a driving bar (Fig. 3) to a depth approximating 30 cm. Theoretically, intragravel water flowing through the pipes originated from the region 20 to 30 cm below the gravel surface. A minimum of 24 hours elapsed from the time pipes were placed in the gravel to actual water sampling.

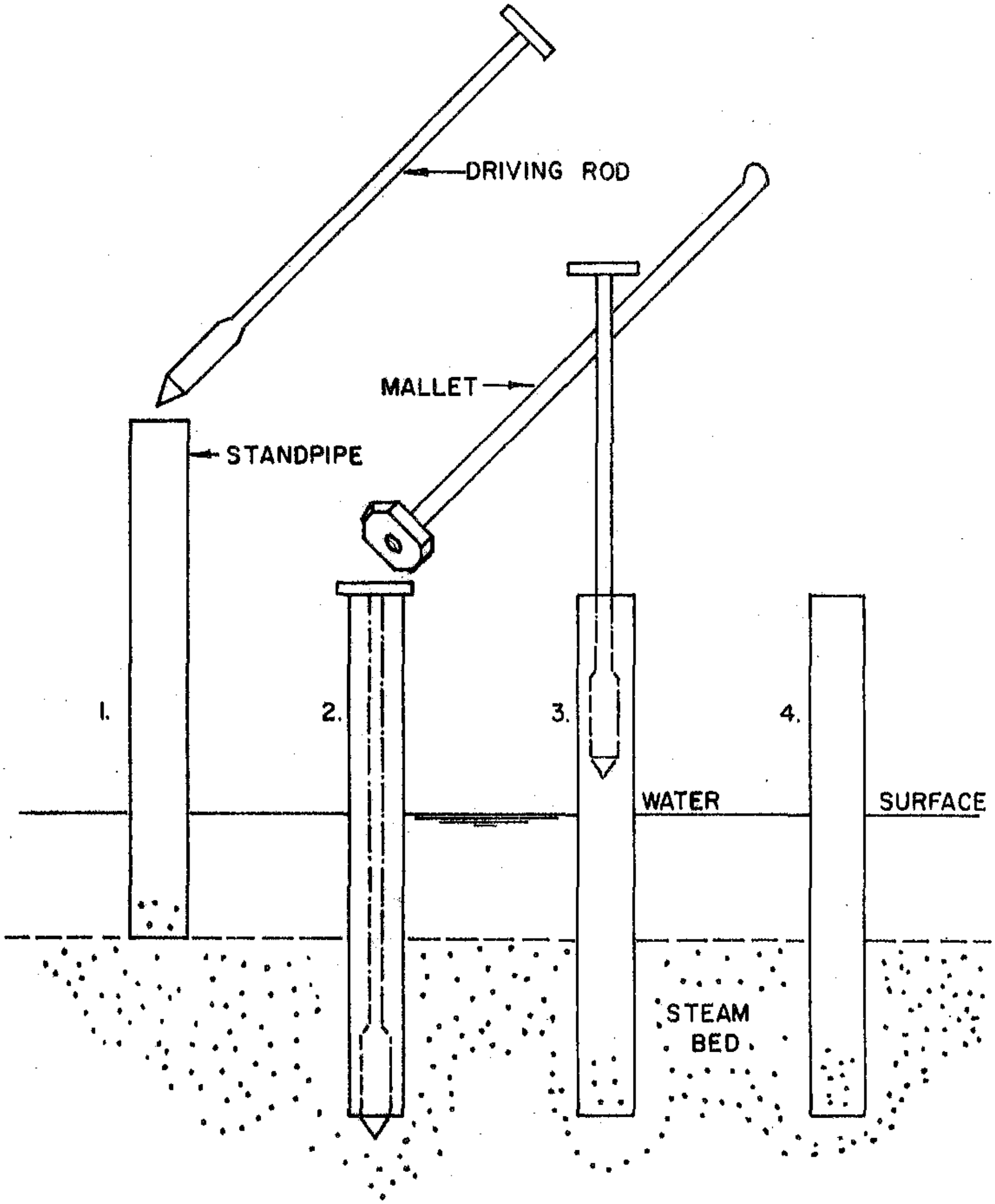
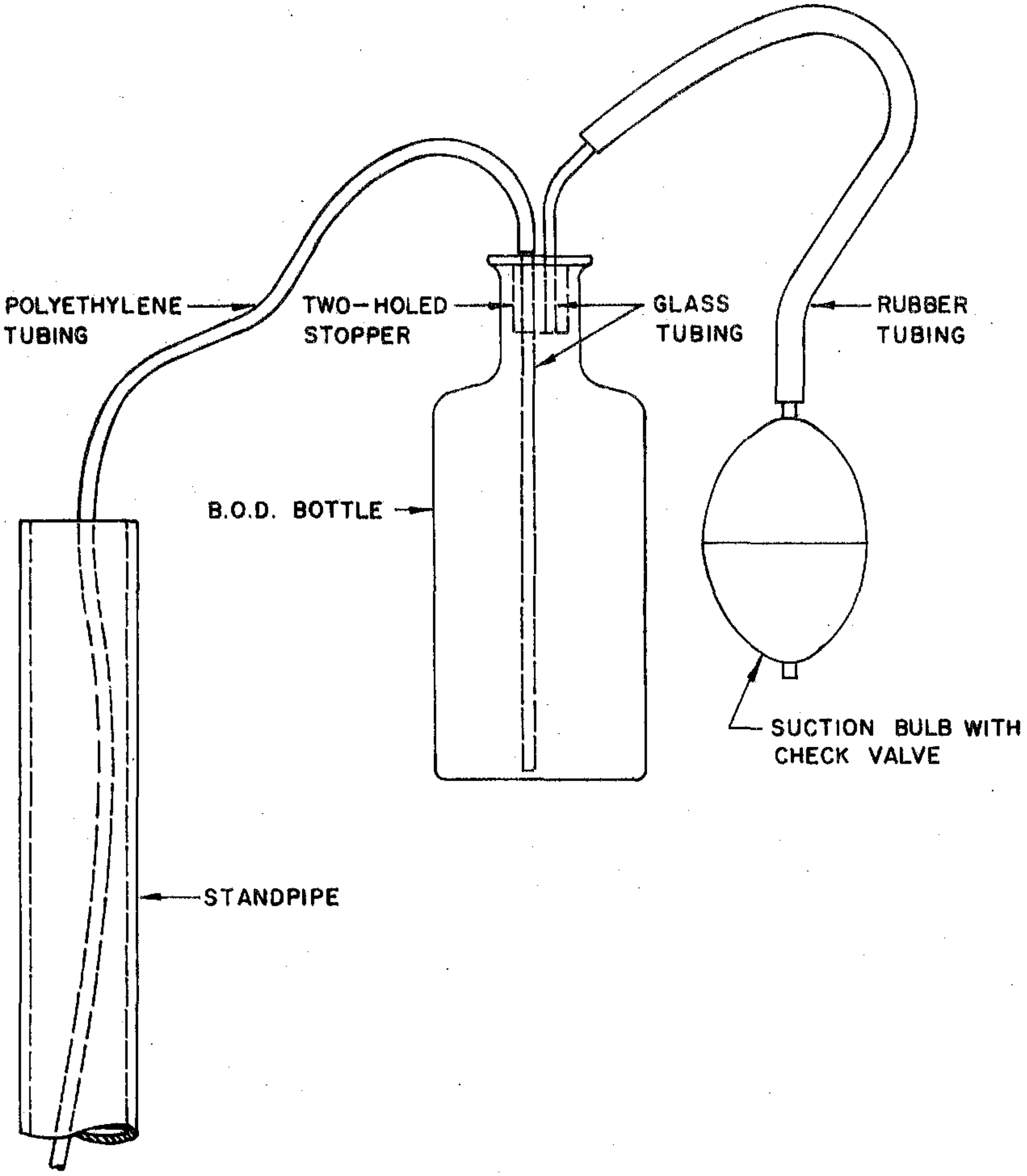


Figure 3. Method of placing standpipe in streambed for collection of water samples for chemical analyses.

Water samples were drawn from the standpipes with an apparatus (Fig. 4) consisting of polyethylene tubing, a two-hole No. 3 rubber stopper, a suction bulb and a 300 ml B.O.D. bottle. Before capping the sample, chemicals to fix the sample were introduced with automatic pipetters. The azide modification of the Winkler method was used for analyses. All samples (200 ml) were analyzed within 24 hours of sampling. In each location there were eight sample sites and the arrangement of standpipes was different between the rivers and channels. In the channels standpipes were positioned two abreast and at four consecutive 90 m intervals down a leg. Each pair of pipes were located 2 m from the "toe" of a berm or divider wall, and the pipes were located opposite each other in a leg. Standpipes in Fulton River and Pinkut Creek were distributed uniformly, at 5 m intervals over each sampling location.

To determine spatial differences, and day to day temporal changes in dissolved oxygen within and between locations, each standpipe was sampled once on each of two days over each four day sampling period. At Fulton, samples were taken in August, October, December (1971), and January and March (1972). Freezing air temperatures in January prevented using the water sampling apparatus. Consequently January samples were from surface waters. For the same reason, samples at Pinkut were taken only in August and October.

Hour to hour and minute to minute temporal changes were examined only in August. In each location three samples were taken from three sites every four hours over a 16 hour



WATER SAMPLING APPARATUS

Figure 4. Sampling apparatus used to obtain intragravel water samples.

sampling period while minute to minute samples were taken over a three minute period at another site. Each sample in the three minute sequence was drawn over a 30 second time period to qualitatively determine whether intragravel water velocities were sufficient to supply adequate oxygen to developing embryos.

The results indicate that dissolved oxygen content of intragravel water underwent seasonal and daily change in the various spawning areas. Changes were also observed from hour to hour and minute to minute. Spatial differences existed from area to area, location to location and site to site.

In terms of absolute values, seasonal changes in dissolved oxygen (Fig. 5) were significant (1% level) in all spawning areas, but in terms of percent saturation changes were not significant. Throughout the study, saturation levels of channel water ranged between 75 and 85%. In Channel No. 1 and No. 2 lowest mean oxygen levels observed were 8.0 and 8.5 ppm respectively; these occurred in August when water temperatures were high, 13°C (55°F). Levels in all Fulton spawning areas were asymptotic at about 12.0 ppm in January when water temperatures were at their lowest, 0°C (32°F). Saturation levels in the upper and middle locations of Fulton River were between 55 and 60% throughout the study but in the lower sampling location levels ranged between 5 and 15% in August and October. During the same period oxygen levels in the lower sampling location approximated 2.0 ppm while other locations

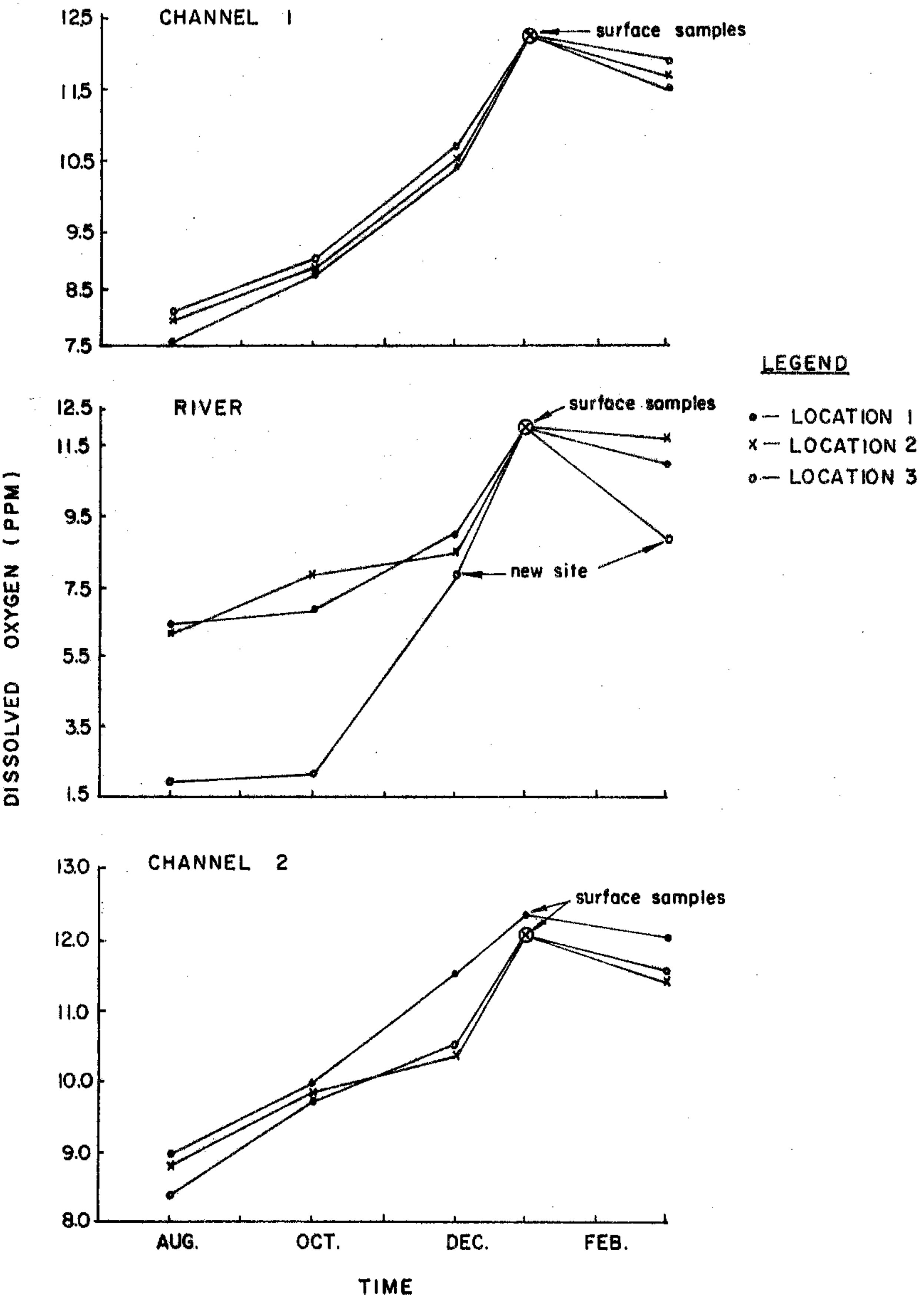


Figure 5. Mean dissolved oxygen concentrations in Channel No. 1, Fulton River and Channel No. 2 from August, 1971 to March, 1972.

averaged 6.5 ppm. Saturation levels in Pinkut Creek during August ranged between 25 and 30%.

Observations indicated that low oxygen levels were prevalent only in sampling locations characterized by high silt loads and low stream flows. Since the oxygen requirement of incubating eggs ranges from about 1 to 7 ppm depending on the stage of development, expectations are that significant embryonic mortality occurred in the areas of Fulton River and Pinkut Creek having high silt loads and low dissolved oxygen levels. Accordingly, high levels in the channels suggests that little mortality occurred in these areas from a lack of oxygen.

Day to day changes (Table I) at a point were not appreciable; oxygen levels generally never varied more than 1 ppm when measured two days apart. Since levels showed little variation over this time span, it was concluded that similar results would have been obtained had the samples been drawn one day apart. On several occasions no difference in oxygen levels was observed at specific sites, while the greatest difference was 4.2 ppm which occurred in Leg 13, Channel No. 2 during the August sampling period. The discrepancy was probably due to improper technique in drawing and (or) analyzing the sample.

Dissolved oxygen levels at five consecutive four hour intervals varied but with no distinct pattern (Table II). Variation with time was generally never greater than 1 ppm indicating that the biological oxygen demand did not create serious oxygen deficiencies with time.

TABLE I. Seasonal and daily change in dissolved oxygen content (ppm) of intragravel water at 8 points sampled concurrently in each sampling location.

Area and Location	Date	Days After Placing Standpipes	Standpipe Numbers								$\bar{X}$
			I	II	III	IV	V	VI	VII	VIII	
Channel 1	Aug 26	1	8.2	8.1	7.7	8.3	8.3	8.1	7.9	8.3	8.09
Leg 1	28	3	8.6	8.1	7.4	8.3	8.2	8.2	7.4	7.7	
	Oct 18	1	9.1	7.9	7.8	8.6	11.2	8.1	9.4	8.8	8.74
	20	3	8.5	7.6	8.1	8.6	9.8	8.4	9.1	8.8	
	Nov 29	1	10.6	10.2	10.1	10.6	11.1	11.2	11.2	10.6	10.46
	Dec 1	3	9.8	9.4	9.8	10.1	10.7	10.8	10.7	10.5	
	Mar 4	1	11.3	11.3	12.1	11.9	11.7	11.8	11.3	11.9	11.69
	6	3	11.5	11.6	11.9	11.8	11.7	11.6	11.5	11.5	
Channel 1	Aug 26	1	7.8	7.7	7.6	7.8	8.0	8.1	8.0	8.2	7.91
Leg 4	28	3	8.0	7.7	8.2	8.0	7.4	8.2	8.0	7.9	
	Oct 18	1	9.0	8.7	8.5	8.6	8.6	8.9	9.1	8.3	8.99
	20	3	8.9	8.0	8.8	8.3	8.4	8.8	8.7	7.8	
	Nov 29	1	11.0	11.0	10.3	10.9	10.6	10.9	10.0	11.1	10.49
	Dec 1	3	10.6	10.4	9.8	10.2	10.5	9.9	9.9	10.8	
	Mar 4	1	11.5	11.3	11.7	11.7	11.5	11.6	11.9	11.3	11.99
	6	3	11.5	11.5	11.6	11.6	11.5	11.8	11.7	11.1	
Channel 1	Aug 26	1	8.3	8.2	8.3	8.5	8.4	8.5	8.5	8.2	8.22
Leg 7	28	3	7.9	8.1	8.4	8.4	7.9	8.2	8.0	7.7	
	Oct 18	1	8.3	9.1	10.0	9.2	9.3	8.6	9.1	9.0	8.96
	20	3	8.2	8.4	10.3	8.9	9.0	8.6	9.0	8.4	
	Nov 29	1	10.9	11.4	11.2	10.8	10.8	10.7	10.9	10.6	10.77
	Dec 1	3	10.8	10.9	10.9	10.5	10.8	10.3	10.5	10.3	
	Mar 4	1	11.4	11.8	12.0	10.9	12.0	10.9	11.7	11.6	11.64
	6	3	11.6	12.0	12.1	11.6	12.0	11.1	11.6	12.0	
Channel 2	Aug 26	1	8.9	9.1	9.1	9.0	9.0	9.1	8.9	9.0	8.89
Leg 1	28	3	8.1	9.1	9.0	8.6	9.1	8.6	8.9	8.8	
	Oct 18	1	10.2	10.1	10.1	9.9	9.8	10.1	10.3	10.2	9.98
	20	3	10.2	10.0	10.1	9.1	9.5	10.0	10.0	10.0	
	Nov 29	1	11.3	11.6	11.8	12.0	11.7	11.9	10.5	11.0	11.51
	Dec 1	3	11.4	11.6	12.1	11.9	11.8	12.2	10.9	10.4	
	Mar 4	1	11.3	11.9	12.1	12.1	11.9	12.5	11.6	11.8	11.96
	6	3	11.6	12.1	12.4	12.5	12.0	12.4	11.6	11.5	

TABLE I. (continued)

Area and Location	Date	Days After Placing Standpipes	Standpipe Numbers								$\bar{Y}$
			I	II	III	IV	V	VI	VII	VIII	
Channel 2 Leg 13	Aug 26	1	8.7	8.6	8.9	8.9	8.4	4.8	9.1	9.1	8.81
	28	3	12.1	8.9	8.9	8.8	8.8	9.0	9.0	9.0	
	Oct 18	1	10.3	10.1	9.1	10.0	9.8	10.1	10.3	9.7	9.86
	20	3	10.1	10.0	9.2	10.0	10.0	10.0	9.7	9.4	
	Nov 29	1	11.2	11.4	11.5	10.9	11.7	11.7	11.2	11.4	11.09
	Dec 1	3	10.8	10.7	10.7	9.6	11.5	11.0	10.8	11.3	
	Mar 4	1	11.7	11.5	11.1	9.6	11.4	11.7	12.1	12.0	11.39
	6	3	11.9	11.8	11.2	9.5	11.3	11.8	11.8	11.8	
Channel 2 Leg 21	Aug 26	1	8.9	9.1	8.9	8.8	9.0	8.7	2.3	8.6	7.98
	28	3	8.8	8.8	8.7	9.2	8.8	8.7	2.1	8.5	
	Oct 18	1	9.7	10.0	10.0	9.6	10.0	9.8	10.1	10.1	9.78
	20	3	9.3	9.5	9.8	9.2	9.8	9.6	10.0	10.0	
	Nov 29	1	11.7	11.6	11.6	3.8	11.4	11.3	11.0	11.7	10.54
	Dec 1	3	11.6	10.9	11.4	4.8	11.5	11.2	11.6	11.6	
	Mar 4	1	11.6	10.7	11.8	5.9	11.4	10.7	10.5	11.7	10.67
	6	3	11.8	10.7	12.0	7.2	11.1	10.5	10.8	12.3	
Fulton River opposite Channel 1	Aug 26	1	3.8	7.9	8.5	8.8	7.4	4.5	6.9	1.9	6.33
	28	3	3.3	7.0	8.3	9.2	6.1	5.0	5.8	5.9	
	Oct 18	1	7.4	7.6	9.2	5.5	5.2	6.8	8.3	5.5	6.88
	20	3	6.5	8.9	9.1	7.3	4.4	7.4	7.6	3.4	
	Nov 29	1	11.8	11.7	3.5	4.5	6.8	5.1	6.9	8.4	7.46
	Dec 1	3	10.8	11.1	4.2	6.0	7.4	4.7	7.3	9.2	
	Mar 4	1	11.9	12.0	12.2	11.6	10.0	10.0	10.5	11.4	10.88
	6	3	11.3	11.2	11.1	11.7	9.1	9.2	9.8	11.1	
Fulton River opposite Channel 2 entrance	Aug 26	1	4.2	7.7	8.3	7.4	7.8	8.1	8.5	5.4	6.84
	28	3	3.9	7.5	4.1	7.9	7.9	8.1	8.6	4.5	
	Oct 18	1	8.7	9.3	8.4	7.3	5.0	9.4	8.8	8.5	7.80
	20	3	8.2	8.1	7.3	6.4	4.5	8.7	8.7	7.5	
	Nov 29	1	5.6	11.2	8.7	11.4	2.1	6.7	10.3	10.8	8.00
	Dec 1	3	4.1	11.0	7.3	11.1	1.2	6.2	9.7	10.6	
	Mar 4	1	10.3	10.1	10.0	10.1	11.1	11.3	11.6	11.1	10.93
	6	3	11.1	10.8	10.5	10.0	11.9	11.8	11.3	11.9	

TABLE I. (continued)

Area and Location	Date	Days After Placing Standpipes	Standpipe Numbers								$\bar{X}$
			I	II	III	IV	V	VI	VII	VIII	
Fulton River opposite Leg	Aug 26	1	3.9	0.5	0.5	0.1	4.5	0.4	*	*	1.84
	28	3	4.9	0.2	0.5	0.5	6.0	0.1	*	*	
13, Channel 2	Oct 18	1	2.0	0.6	3.7	3.1	0.8	0.1	0.4	7.3	2.10
	20	3	2.4	1.0	3.4	1.7	2.7	0.1	0.1	4.2	
1 to 4 opp. Leg 13	Nov 29	1	10.8	7.6	8.9	8.5	10.5	9.1	2.8	5.3	7.73
	Dec 1	3	10.3	8.6	8.2	7.2	7.3	10.1	3.3	5.2	
5 to 8 immed. below ennum. fence	Mar 4	1	11.3	9.6	11.3	9.7	8.4	8.1	3.1	3.6	8.48
	6	3	12.0	10.0	11.8	9.3	9.1	8.9	5.3	4.1	
Pinkut Channel	Aug 16	1	8.0	8.0	6.0	8.0	8.0	7.0	8.2	7.8	7.67
Leg 1	17	2	8.2	7.2	7.1	8.2	7.6	7.1	8.3	8.0	
	Oct 22	1	10.5	10.5	11.0	11.5	11.4	11.3	10.5	10.8	11.03
	23	2	11.5	10.6	11.4	11.4	11.5	11.2	10.4	11.0	
Pinkut Channel	Oct 22	1	4.2	11.2	11.2	10.5	10.5	6.8	11.5	11.4	9.43
Leg 3	23	2	2.3	10.7	11.3	10.7	10.6	5.0	11.6	11.4	
Pinkut Channel	Oct 22	1	10.9	10.6	11.2	11.2	11.1	11.1	12.7	11.3	11.14
Leg 5	23	2	10.1	10.6	11.4	10.7	11.4	11.3	11.3	11.3	
Pinkut Creek	Aug 16	1	3.2	0.1	5.7	4.5	5.5	5.7	6.4	5.3	4.86
Upper	17	2	3.7	0.3	4.8	7.3	5.6	6.8	6.5	6.4	
	Oct 22	1	5.7	8.9	7.9	10.2	8.2	4.4	6.5	8.0	7.69
	23	2	6.3	8.6	7.4	10.8	9.1	6.6	5.1	9.4	
Pinkut Creek	Aug 16	1	3.6	4.5	0.5	4.9	2.6	0.2	4.4	2.6	2.81
Middle	17	2	2.7	5.1	0.1	4.5	2.0	0.2	4.3	2.7	
	Oct 22	1	6.5	8.9	1.0	9.2	6.4	10.2	8.4	9.5	7.59
	23	2	6.3	9.5	1.8	8.8	5.5	10.4	9.6	9.5	
Pinkut Creek	Aug 16**	1	0.5	6.3	0.5	0.4	0.4	4.6	0.1	7.0	2.20
Lower	17**	2	0.5	3.3	0.3	0.4	0.7	4.3	0.1	5.8	
	Oct 22	1	10.3	8.9	11.1	9.9	9.1	9.8	9.3	10.7	9.95
	23	2	10.5	7.8	11.0	10.7	9.2	9.9	10.2	10.8	

* Backup of river water to the area from enumeration fence barricade.

** Backup of lake water into lower section of Pinkut Creek.

TABLE II. Hourly change in dissolved oxygen content (ppm) of intragravel water.

Area	Location	Site	Time				
			0600	1000	1400	1800	2200
Fulton Channel 1	Leg 1	1	8.6	8.2	7.9	7.9	8.0
		2	8.6	7.7	8.1	7.9	7.6
		3	8.2	8.1	8.1	7.7	8.0
	Leg 4	1	7.9	7.9	8.1	7.6	7.8
		2	7.8	7.6	7.9	7.7	7.7
		3	8.9	8.2	7.5	8.0	7.8
	Leg 7	1	7.9	7.8	8.1	7.7	7.6
		2	7.9	8.2	8.2	8.0	7.6
		3	7.7	7.8	7.9	7.5	7.1
Fulton Channel 2	Leg 1	1	8.2	8.7	8.1	8.4	8.5
		2	8.8	9.0	8.8	8.9	8.9
		3	8.9	9.1	8.7	8.8	9.0
	Leg 13	1	8.8	9.1	8.7	8.7	9.1
		2	8.8	9.0	8.9	8.6	9.0
		3	8.8	8.9	8.7	8.5	9.0
	Leg 21	1	8.9	8.4	8.7	9.0	8.3
		2	8.9	9.0	8.7	8.9	8.7
		3	8.5	8.9	8.2	8.9	8.7
Fulton River	Opposite Channel 1	1	4.0	4.3	4.3	4.9	4.7
		2	7.5	8.0	7.8	8.0	7.8
		3	8.2	8.6	8.3	8.3	8.0
	Opposite Channel 2	1	7.6	7.5	7.0	7.0	7.0
		2	8.3	8.9	8.1	8.3	7.4
		3	7.4	7.4	7.6	7.6	7.5
	Inlet Tower Pool	1	3.9	5.4	3.2	4.6	4.5
		2	1.4	1.8	1.4	1.3	0.7
		3	0.6	0.8	0.4	0.9	0.9
Pinkut Channel	Leg 1	1	8.0	8.2	8.0	7.6	8.1
		2	8.0	7.1	7.2	7.1	5.9
		3	6.0	7.4	6.8	6.6	6.8
Pinkut Creek	Upper	1	3.2	4.2	3.7	3.5	4.3
		2	5.7	6.5	5.8	5.5	4.4
		3	4.5	7.1	6.8	6.4	5.7
	Middle	1	3.6	2.7	2.4	2.5	3.0
		2	0.1	0.5	0.1	0.1	0.1
		3	4.0	4.5	3.7	4.0	4.4
	Lower	1	0.5	0.5	0.5	0.5	0.7
		2	6.3	6.5	3.3	3.4	5.4
		3	2.9	2.9	6.7	2.8	2.7

Minute to minute oxygen levels (Table III) tended to increase with time. Initial samples were high but the second and third samples were higher suggesting that intragravel water velocities are high enough to supply the necessary oxygen required by developing eggs, and to remove metabolic wastes which could affect embryonic growth and development.

Spatial differences in dissolved oxygen within and between sampling locations were more extreme in the rivers than channels. During August and October, and probably in later months, oxygen levels were as low as 0.1 ppm in heavily silted areas of the rivers.

Overall the results indicate that dissolved oxygen content and delivery rate of intragravel water in the respective channels is adequate to support growth, development, and survival of eggs and alevins. Accordingly, embryonic mortality observed during the present study period and probably in the past could not have resulted from an inadequate dissolved oxygen supply.

Free Carbon Dioxide Levels of Intragravel Water

Water samples were obtained from the same standpipes and in the same manner as for dissolved oxygen. Samples were collected in 500 ml bottles, transported to the laboratory and analyzed within minutes of taking the sample. A total of nine samples were taken from each of ten locations in two sampling periods, December, 1971, March, 1972. Prior to analysis, all

TABLE III. Minute to minute change in dissolved oxygen content (ppm) of intragravel water.

Area	Location	Site	Time		
			1 Min	2 Min	3 Min
Fulton Channel No. 1	Leg 1	7	7.9	8.1	8.3
	Leg 4	6	8.1	9.1	8.3
	Leg 7	6	8.4	8.4	8.4
Fulton Channel No. 2	Leg 1	6	8.7	8.8	8.9
	Leg 13	7	9.1	9.1	9.1
	Leg 21	8	8.8	8.7	8.8
Fulton River	Opposite Channel 1	7	6.9	7.2	7.3
	Opposite Channel 2	8	8.1	8.3	8.4
	Tower Pool	5	4.5	6.5	7.4
Pinkut Channel	Leg 1	8	8.0	8.0	8.0
Pinkut Creek	Upper	8	6.6	7.6	7.7
	Middle	7	7.3	7.8	7.6
	Lower	8	7.9	7.7	7.6

samples were stored at 35°F to minimize changes in their gaseous content from a rise in temperature.

The nomographic method (from "Standard Methods, for the Examination of Water and Wastewater", 13th edition) was used for analysis. Total dissolved solids were obtained from specific conductance (mhos/cm) conversions and pH measurements were taken with an electrometric pH meter calibrated to a standard pH-7.01 buffer solution. Alkalinity was determined by titration with a standard solution of sulphuric acid.

The results (Fig. 6, Table IV) show that free carbon dioxide levels of intragravel water underwent daily and seasonal changes. Spatial differences also existed within and among sampling locations of a spawning area but were of small magnitude. The maximum day to day change was 4 ppm but in most instances changes were in the order of about 1 ppm. Seasonal changes were significant (1% level) in both channels and the river (10% level). Seasonal difference in mean carbon dioxide levels was 1.0 ppm in Channel No. 1 with early December concentrations being about 6.4 ppm and early March 5.4 ppm. Mean seasonal difference in Channel No. 2 was 1.1 ppm with December concentration of about 6.5 ppm and March 5.4 ppm. December concentration in Fulton River was about 2 ppm greater than March levels with the former being about 6.9 ppm and latter 4.9 ppm. The higher December concentrations compared to March are characteristic of lake-fed rivers. Both carbon dioxide and dissolved oxygen levels in the water are dependent on biochemical reactions occurring in Fulton Lake. Whenever a

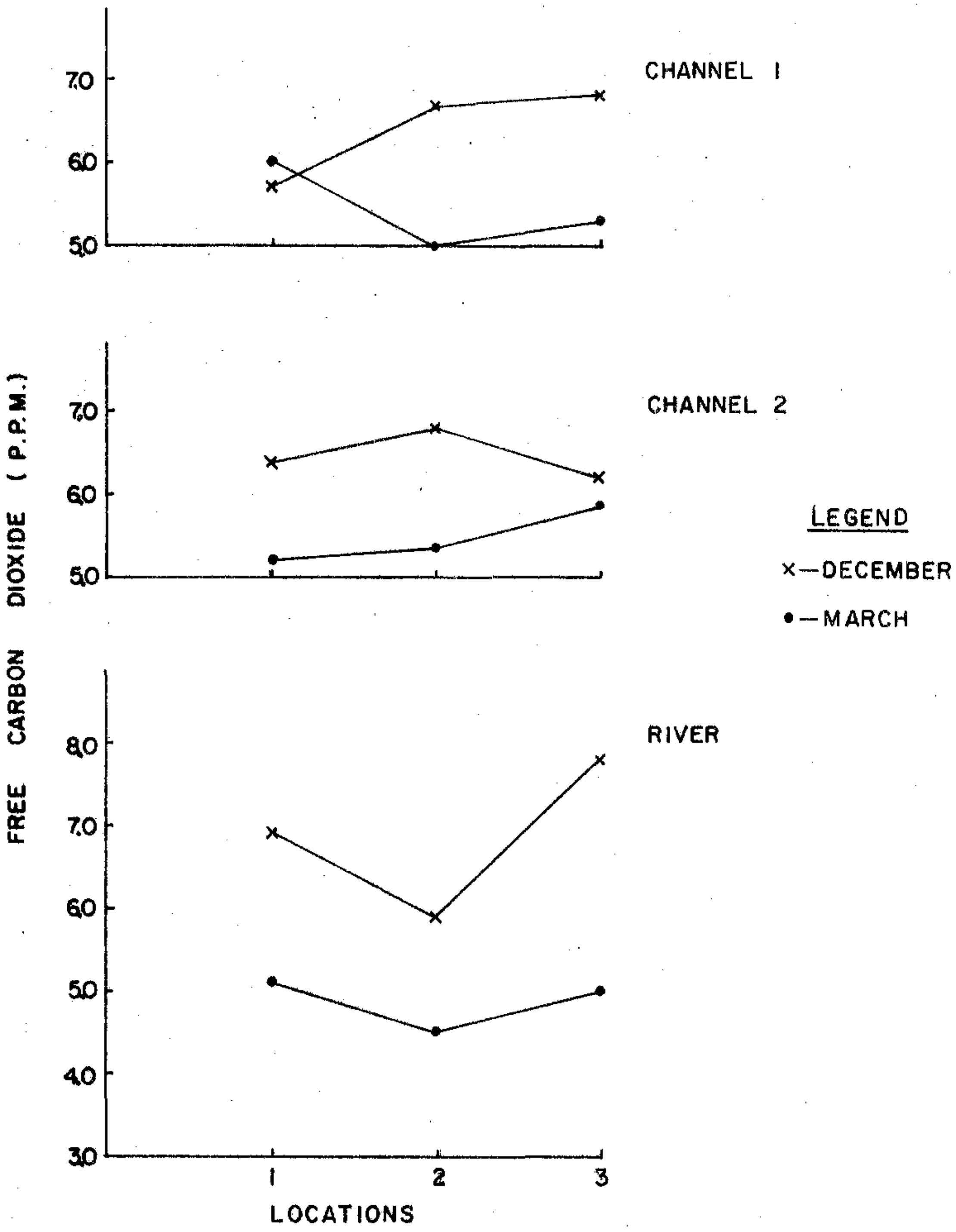


Figure 6. Mean free carbon dioxide concentrations in Channel No. 1, Fulton River and Channel No. 2 during December, 1971 and March, 1972.

TABLE IV. Seasonal changes in free carbon dioxide concentrations (ppm) in Fulton spawning areas.

Free CO_2 Concentrations (ppm)							
Location	Sample Site	December Series			March Series		
		Day 1	Day 2	Day 3	Day 1	Day 2	Day 3
Upper River	1	6.0	10.0	6.5	5.2	4.5	5.0
	2	6.5	6.5	6.0	5.2	5.0	5.5
	3	7.0	5.5	8.0	5.0	4.5	6.0
Middle River	1	6.5	4.5	6.5	4.5	-	5.5
	2	7.0	4.5	6.0	4.5	-	4.5
	3	6.5	6.5	5.5	4.5	-	3.5
Lower River	1	6.0	6.0	7.5	4.0	5.5	6.0
	2	6.5	6.5	8.5	4.0	5.0	5.5
	3	10.0	10.0	9.0	4.0	5.5	5.5
Channel 1 Leg 1	1	6.0	6.0	5.5	5.0	6.5	6.5
	2	5.5	5.5	6.0	5.0	6.5	6.0
	3	5.5	5.5	6.0	5.2	7.0	6.0
Channel 1 Leg 4	1	7.5	9.0	7.0	4.0	4.5	6.0
	2	6.5	5.5	6.0	4.5	5.5	5.5
	3	6.5	5.5	6.5	4.5	5.0	5.5
Channel 1 Leg 7	1	7.0	7.0	6.0	4.5	5.0	6.0
	2	6.5	7.0	6.0	4.5	5.0	6.5
	3	6.5	7.0	6.0	4.5	5.0	6.0
Channel 2 Leg 1	1	6.5	6.5	5.5	4.0	6.0	6.0
	2	7.0	7.0	6.0	4.0	5.5	5.5
	3	7.0	6.0	6.0	4.0	6.0	6.0
Channel 2 Leg 13	1	7.0	6.5	5.5	4.5	5.5	6.0
	2	7.5	6.5	6.0	4.0	6.0	6.0
	3	6.0	6.5	8.0	4.0	6.5	5.5
Channel 2 Leg 21	1	6.5	6.0	6.5	-	6.0	5.5
	2	6.0	6.0	6.0	-	5.5	6.0
	3	6.0	6.0	6.5	-	6.0	6.0

chemical gradient of biogenic origin occurs in the lake, distributions of carbon dioxide and dissolved oxygen in the water are inversely related; as dissolved oxygen levels increase, carbon dioxide levels decrease.

Free carbon dioxide levels of intragravel water at specific sites are dependent on seepage rates to the sites which in turn depend on gravel porosity. Spatial differences (1 to 4 ppm) in carbon dioxide in the various spawning areas can be attributed to the variation in gravel porosity.

Apparently free carbon dioxide levels of intragravel channel water are not high enough to cause significant mortality of incubating eggs. Levels approaching 25 ppm can be lethal to pre-eyed eggs of rainbow trout (Salmo gairdneri) without depleted oxygen. With insufficient oxygen, the lethal level is much reduced (Surber, 1935). At these levels sockeye eggs would be similarly affected but since oxygen concentrations in the channels were adequate throughout the sampling period while carbon dioxide levels were low, it is highly improbable that carbon dioxide levels caused significant embryonic mortality. Additionally the porous nature of a redd following deposition opposes the likelihood of free carbon dioxide reaching lethal levels shortly after deposition (the time when significant embryonic mortality occurred - discussed later). However, in areas of the two rivers characterized by high silt loads and low dissolved oxygen levels, significant embryonic mortality can probably be attributed to high free carbon dioxide levels.

Overall, the results suggest that free carbon dioxide levels of intragravel water did not cause significant embryonic mortality losses in the channels during this study period and probably in the past.

Intragravel Water Temperature

Intragravel water temperatures in Channel No. 1 (Legs 1 and 7) and No. 2 (Legs 1, 13 and 21) were monitored throughout the study period with Taylor Fulscope temperature recorders. Probes were buried about 30 cm below the gravel surface. Capillary tubes were buried in the gravel as much as possible to prevent interference from ambient air temperatures.

The results (Fig. 7) indicate that water temperatures were conducive to normal growth and development of eggs and alevins. Temperatures declined steadily from about 13°C (55°F) in August to about 1°C (34°F) in December where with few exceptions they remained through most of the winter. Maximum daily variation was 0.5°C (2°F) while overall temperature decline from deposition to November 15 (late pre-eyed to early-eyed incubation stage) was about 8°C (15°F). Since the temperature decline was gradual, mortality from direct exposure to wide temperature fluctuations is unlikely. Consequently, embryonic mortality during the early incubation stage must be attributed to other factors.

As expected intragravel water temperatures during late September and early October were colder at the channel

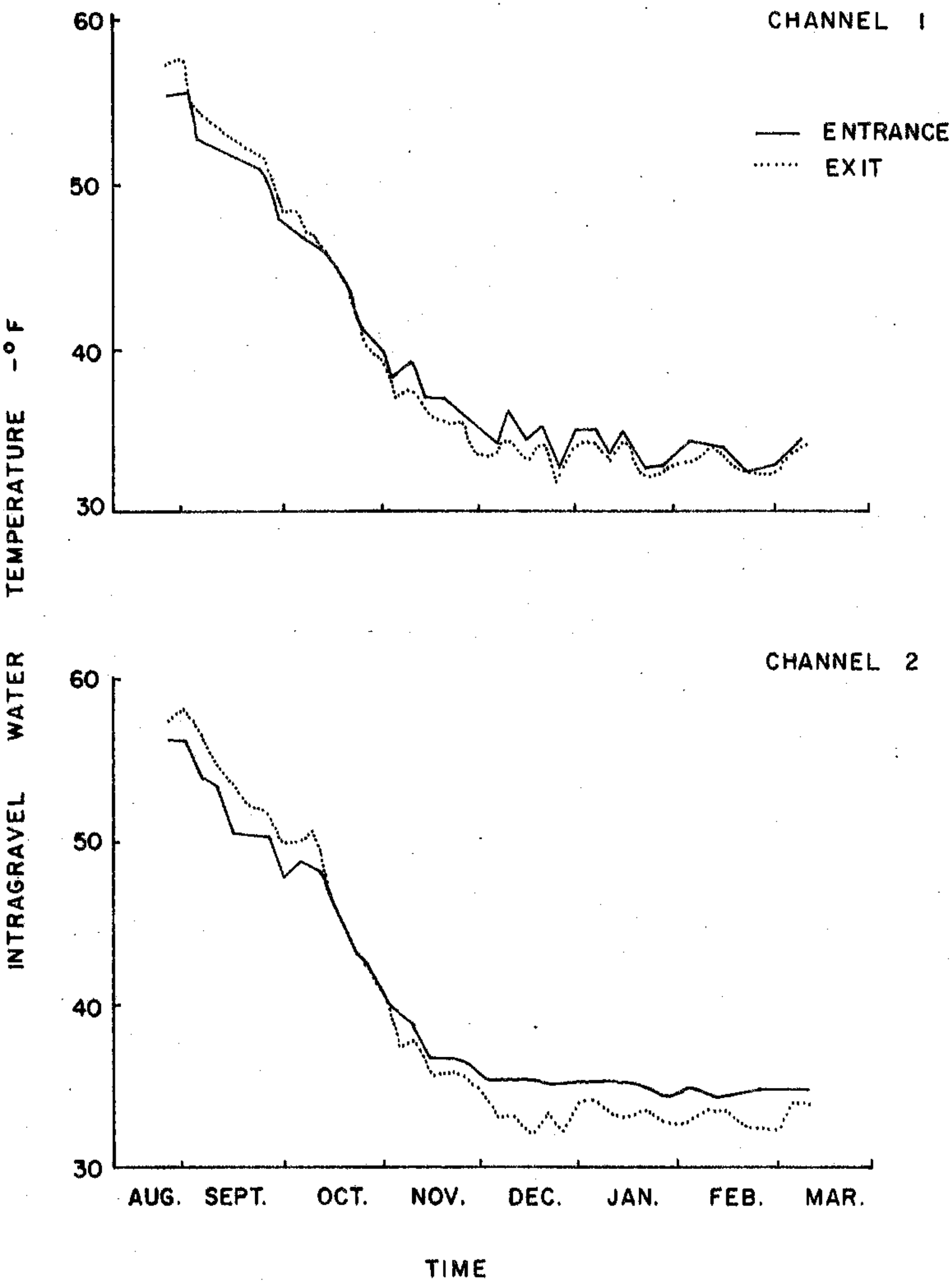


Figure 7. Seasonal intragravel water temperatures in Channels No. 1 and No. 2.

entrances than at the outlets; the opposite occurred during winter months. This reversal is closely associated with Fulton Lake fall turn-over (holomictic circulation). Extremely cold air temperatures occurring from time to time in January and February resulted in icing conditions in the lower section of Channel No. 2 (Legs 18 - 21). The result was heavy anchor-ice buildup and gravel scouring in Legs 19 to 21; particularly in Leg 19. Hydraulic sampling in early March indicated that gravel scouring caused significant, if not total mortality, in and adjacent to Leg 19. Considering potential fry production from the entire channel, losses in Leg 19 were probably not significant.

Water Quality

A basic water quality study, using a model DR-EL Hach Kit equipped for colorimetric tests was conducted at both Fulton and Pinkut spawning areas in November, 1971, and at Fulton in February, 1972. The different variables measured were alkalinity, carbon dioxide, chloride, chlorine, chromate, copper, calcium hardness, total hardness, hydrogen sulphide, iron, manganese, nitrate, dissolved oxygen, pH, phosphate, silica, sulphate and turbidity. Surface and intragravel water samples were taken in November, 1971, while February samples were from surface water. In November surface samples at Fulton were taken from Fulton Reservoir and the base of Fulton River Dam, and at Pinkut from the diversion site, auxiliary water supply and the settling pond. All samples were collected in 500 ml bottles. Intragravel samples were drawn with the same apparatus used for dissolved oxygen and carbon dioxide.

The results (Tables V and VI) of the study although primarily intended to be a basis for future comparison, have biological implications to the spawning channels. Since almost all elements appeared to be present in normal amounts, only those appearing to have direct biological significance to the channel ecosystem will be discussed.

Analysis for nitrate (NO_3^-) showed Channel No. 2 water contained the highest levels. Channel No. 1 water was second highest with Fulton River and Fulton Lake Reservoir containing the lowest amounts. Channel No. 2 contained mean levels of 22.0 ppm at the entrance and 14.7 ppm at the outlet in November, and 24.5 ppm at both locations in February. Channel No. 1 water showed similar differences. Fulton Lake water contained the lowest readings of all sites sampled, 11.7 ppm in November, and 19.8 ppm in February. The apparent slight difference in nitrate levels between Fulton Lake and Channel No. 2 could be attributed to nitrogen supersaturation of the channel water supply. Although very stable with respect to dissociation into single atoms, the N_2 molecule is unstable with respect to oxidation by O_2 in the presence of water to nitrate ion, NO_3^- (Sienko and Plane, 1961). If a plunging effect is occurring at the pipeline terminal structure and the energy dissipater is not functioning properly, supersaturation

TABLE V. Results of basic water quality study conducted in Fulton spawning areas. (All values expressed in ppm except turbidity which is in JTU's. For two or more samples, results are mean values.)

Variable Measured	Date	Fulton Reservoir	Base Fulton Dam	Channel 1 Entrance	Channel 1 Outlet	Channel 2 Entrance	Channel 2 Outlet	Fulton River Fence	Number of Samples Per Site
Alkalinity	Nov 4/71	38.3	40.0	42.3	40.0	40.3	42.3	45.3	3
	Feb 4/72	50.0	45.0	46.0	45.5	40.5	45.3	46.5	3
Calcium Hardness	Nov 4/71	20.7	26.0	27.3	23.7	26.7	28.3	30.3	3
	Feb 5/72	30.0	25.5	29.0	28.0	26.0	25.0	30.0	3
Total Hardness	Nov 4/71	36.7	33.3	37.0	37.3	36.3	35.0	40.0	3
	Feb 5/72	40.0	38.0	39.5	39.5	37.5	37.0	40.0	2
Carbon Dioxide	Nov 4/71	4.0	4.0	6.7	3.3	5.2	3.7	11.3	3
	Feb 3/72	4.0	4.0	3.0	4.2	7.4	4.0	4.0	2
Chlorine	Nov 4/71	0	0	0	0	0	0	0	3
	Feb 4/72	0	0	0	0	0	0	0	1
Chloride	Nov 6/71	2.5	2.5	2.5	2.5	2.5	2.5	2.5	3
	Feb 4/72	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2
Chromium	Nov 8/71	0	0	0	0	0	0	0	1
	Feb 4/72	0	0	0	0	0	0	0	1
Copper	Nov 6/71	0.02	0.02	0.02	0.02	0.02	0.02	0.02	1
	Feb 4/72	0.02	0.02	0.02	0.02	0.02	0.02	0.02	1
Iron	Nov 6/71	0	0.03	0.02	0.02	0	0	0.35	1
	Feb 5/72	0.01	0.01	0.02	0.02	0.02	0.02	0.01	1
Hydrogen Sulphide	Nov 5/71	0	0	0	0	0	0	0	2
Manganese	Nov 7/71	0	0	0	0	0	0	0	1
	Feb 5/72	0	0	0	0	0	0	0	1
Nitrite	Nov 5/71	0	0	0	0	0	0	0	1
	Feb 5/72	0	0	0	0	0	0	0	1
Nitrate	Nov 5/71	11.7	14.7	17.6	11.7	22.0	14.7	11.7	3
	Feb 5/72	19.8	18.0	22.0	22.0	24.2	25.5	22.0	1
Oxygen	Nov 6/71	7.6	10.6	10.2	9.8	10.4	11.4	2.6	1
	Feb 3/72	11.0	14.0	13.0	13.0	12.0	12.0	13.0	1
pH	Nov 5/71	7.5	7.5	7.5	7.5	7.5	7.5	7.5	3
	Feb 5/72	7.5	7.5	7.5	7.5	7.5	7.5	7.5	2
Phosphate (ortho)	Nov 6/71	0.02	0.02	0.02	0.02	0.02	0.02	0.02	1
	Feb 8/72	0.02	0.02	0.02	0.02	0.02	0.02	0.02	1
Sulphate	Nov 6/71	2.0	2.7	4.0	3.0	3.0	3.0	3.0	2
	Feb 8/72	2.0	3.0	3.5	4.0	3.0	3.0	3.0	1
Silica	Nov 7/71	5.0	5.0	5.0	5.0	5.0	5.0	5.0	1
	Feb 8/72	3.9	5.3	5.1	5.4	5.4	5.3	5.5	1
Fluoride	Feb 5/72	0.20	0.15	0.13	0.13	0.14	0.12	0.12	1
Turbidity	Oct 4-19/71	-	-	4JTU	-	4JTU	-	4JTU	Variable

TABLE VI. Results of basic water quality study conducted in Pinkut spawning areas. (All values expressed in ppm except turbidity which is in JTU's. For two or more samples, results are mean values.)

Variable Measured	Date	Settling Pond	Channel Leg 9	Creek Diversion Site	Creek Above Diversion	Creek at Counting Fence	Auxiliary Water	Samples Per Site
Alkalinity	Nov 19/71	48.0	50.0	50.0	50.0	50.0	47.7	3
Calcium Hardness	Nov 19	25.0	28.3	26.3	28.3	28.3	24.0	3
Total Hardness	Nov 19	43.0	39.3	38.7	39.7	40.0	36.3	3
Carbon Dioxide	Nov 19	2.3	3.3	3.6	2.7	1.7	3.7	3
Chlorine	Nov 23	0	0	0	0	0	0	1
Chloride	Nov 22	1.5	1.3	1.7	1.5	1.7	2.0	3
Chromium	Nov 22	0	0	0	0	0	0	1
Copper	Nov 19	0.03	0.04	0.05	0.02	0.05	0.04	1
Iron	Nov 19	0.04	0.03	0.02	0.01	0.02	0.01	1
Hydrogen Sulphide	Nov 22	0	0	0	0	0	0	1
Manganese	Nov 22	0	0	0	0	0	0	1
Nitrite	Nov 22	0	0	0	0	0	0	1
Nitrate	Nov 22	3.5	4.6	5.0	5.3	3.9	6.2	3
Oxygen	Nov 19	11.2	10.4	11.2	10.4	10.0	10.2	1
pH	Nov 19	7.5	7.6	7.6	7.6	7.5	7.5	3
Phosphate (ortho)	Nov 22	0.02	0.08	0.02	0.01	0.01	0.02	1
Sulphate	Nov 22	2.0	2.0	3.0	2.0	1.5	2.5	1
Turbidity	Nov 23	0.5	1.0	1.0	0.5	1.5	0	2
Silica	Nov 23	9.3	8.9	9.5	9.2	9.3	6.1	1

could be resulting from the mixture of air and water under high pressure. However, the higher Channel No. 2 levels could be a result of normal sample variation. The frequent presence of <u>Ulothrix</u>, a green algae, in the upper reaches of Channel No. 2 could be partially attributed to high nitrate levels. Water temperature appears to be a limiting factor since algae only appears when temperatures are above 0.5°C (33°F). The absence of algae in Channel No. 1 even though nitrate levels are high may be explained by examining physical, chemical and biological differences (temperature, nutrient load, incident radiation, benthic and terrestrial fauna, substrate, etc.) between the two channels. For example, light reflection into the water is greater in Channel No. 2 than No. 1. Shotcrete sides of Channel No. 2 are light coloured and uniform in slope and have a greater ability to reflect light than the granite-rock berms and black divider walls of Channel No. 1. Observations have shown that algae in Channel No. 2 first appears on the sides of shotcrete berms receiving the greatest amount of sunlight. Another example would be the lack of benthic grazers in Channel No. 2 which if present might control or curtail algae growth.

Obviously, many factors limit algae growth and to determine why algae flourishes in Channel No. 2 and not in Channel No. 1 would require intensive field testing with emphasis on the above mentioned variables. Since algae growth has in the past caused mortality of emerging fry, examination of its cause warrants immediate consideration. Additionally,

data?

bacterial decomposition of algae creates "channel deterioration" which could have an indirect effect on quality and production of sockeye from the channels.

Bottom Fauna, and Organic and Inorganic Sedimentation

Fulton River and adjacent spawning channels were randomly sampled at each of several locations and analyzed for bottom fauna, and organic and inorganic sedimentation in February, 1972.

Samples were collected using an apparatus (Fig. 8) similar to a Surber square-foot bottom sampler. The sampler consisted of two wooden frames attached together; one frame carries the net (No. 10 silk) that is stretched downstream by the flow of water for trapping bottom-dwelling forms, and sediment, while the other marks the boundary of the area (approx. 0.33 m^2) from which the collection is to be made. In use, the net was placed in the stream with the opening upstream. The frame marking the bottom area to be sampled was worked carefully into the bottom. When held in position in the current, the area inside the square-foot frame was churned, to a depth approximately 30 cm (12"), with a hand shovel and the material rising into the flow was trapped in the net located immediately downstream. The technique possibly introduced some bias because of the loss of silt in suspension during collection and when the sample was lifted from the stream. Samples collected in locations characterized by slow water

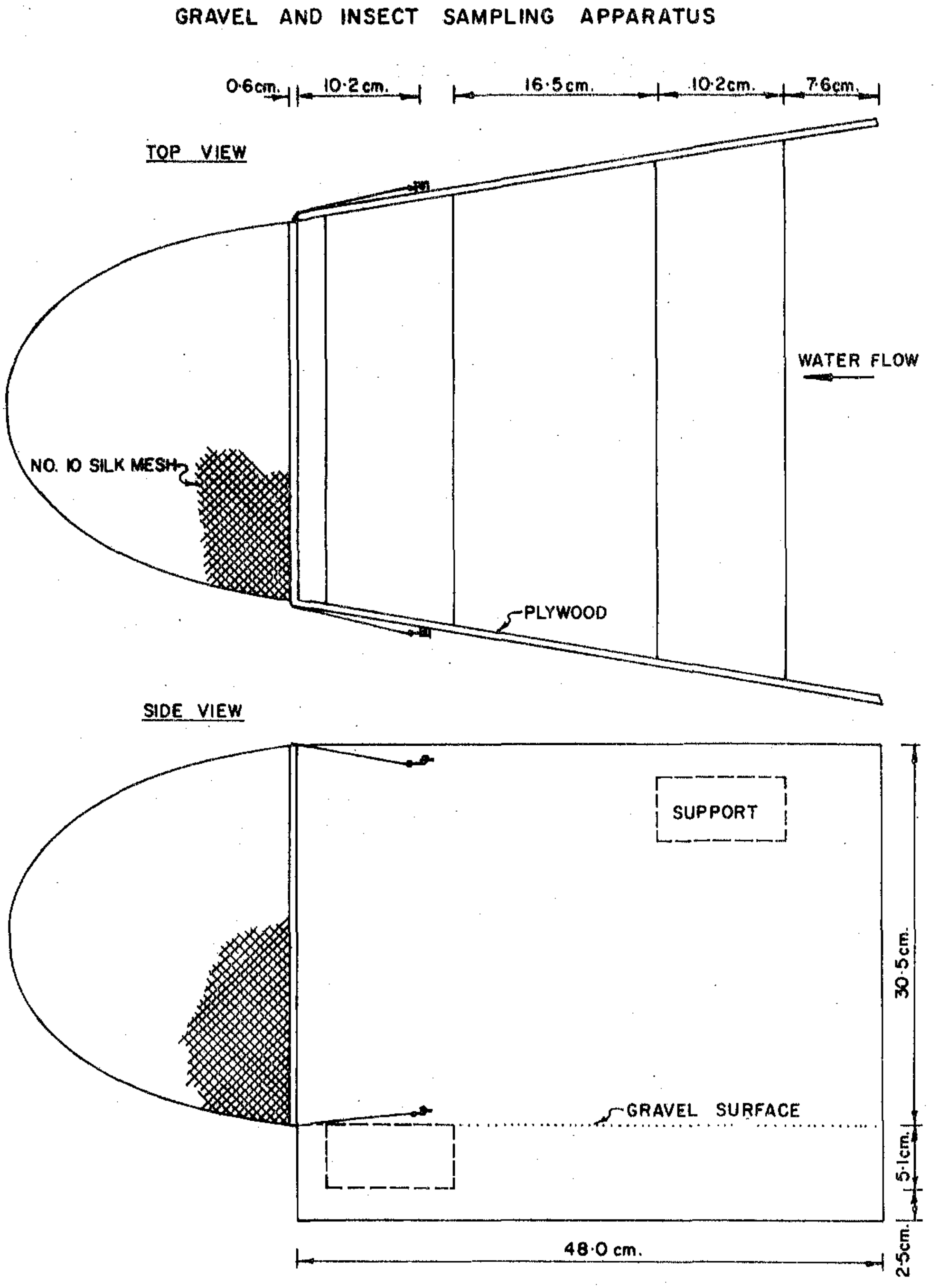


Figure 8. Sampling apparatus used to obtain bottom fauna and sediment samples.

velocities no doubt contained a greater quantity of fine solids than samples collected in high velocity locations. Consequently, the results obtained only have qualitative significance to channel deterioration. All samples were oven dried at 65°C. Prior to drying one sample from each location was analyzed for fauna, but all fauna was returned to the original sample before drying. When dry, samples were screened with a mechanical shaker, separated into organic and inorganic sediment, and weighed. All sediment passing through an Endecott sieve with a 0.149 mm pore opening was arbitrarily classified as organic. Material passing through a sieve with a 1.190 mm pore opening but retained by a 0.149 mm sieve was arbitrarily classified as inorganic. The classification introduces bias into the results because material smaller than 0.149 mm is both organic and inorganic. Again the results only have qualitative significance to channel deterioration.

Results of this study show differences in sedimentation, and bottom fauna within and among the various spawning areas. In Channel No. 1 the amount of inorganic sediment (Fig. 9) was significantly different among three sample locations; mean dry weight was 0.25, 0.18 and 0.05 gm per square foot in Legs 1, 4, and 7 respectively. These differences can be attributed to the influence of Fulton River on Channel No. 1 and the latter's uniform stream gradient. Leg 1 being nearer to the intake would receive proportionately greater amounts of fine sediment than lower locations. A similar trend occurred in Fulton River however due to the

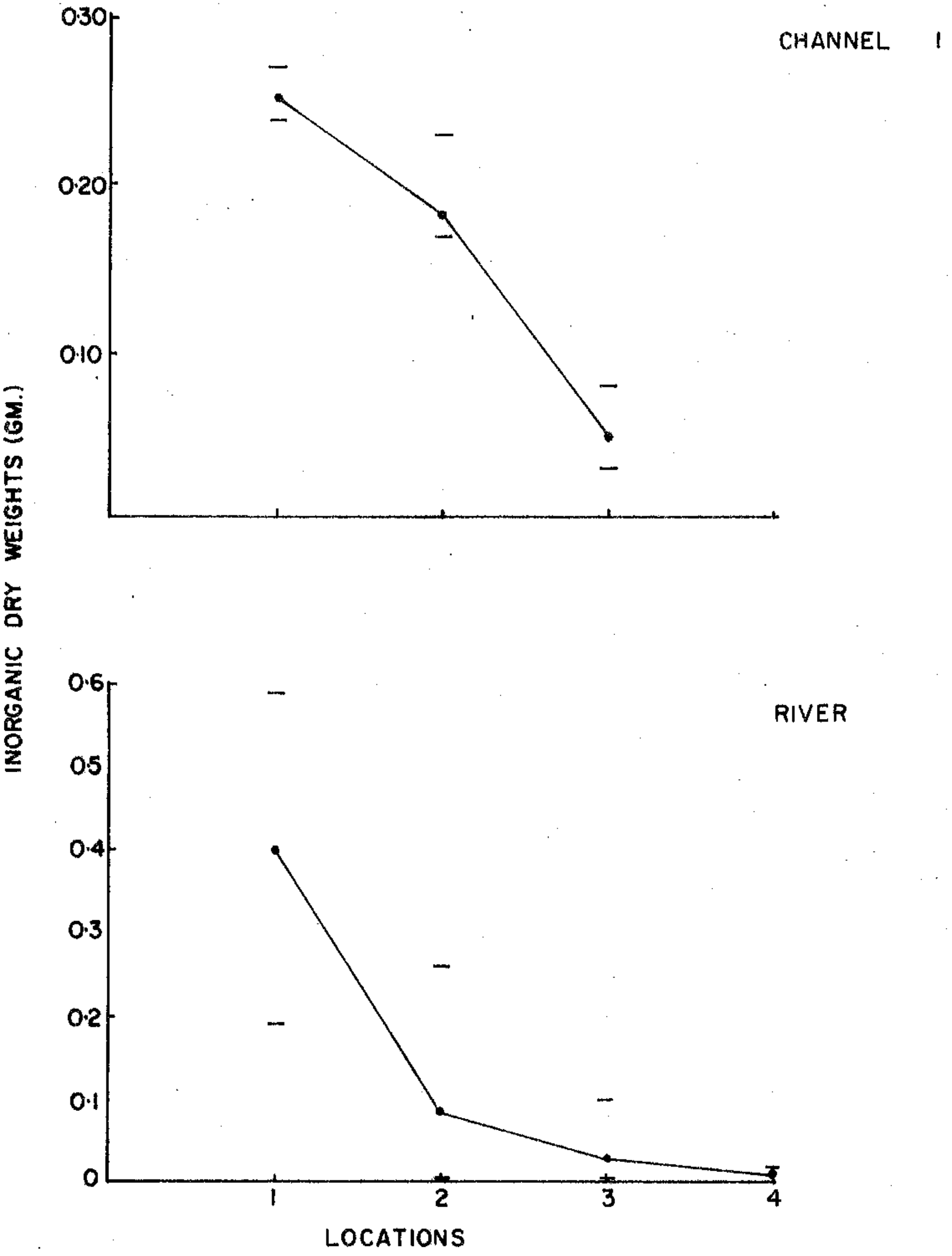


Figure 9. Inorganic sedimentation in Channel No. 1 and Fulton River in February, 1972.

variable nature of water currents and velocity from place to place it is incorrect to assume that sedimentation will decrease down the course of the river. In Fulton River, spatial differences in sedimentation would be partially dependent on water velocity. Samples from the upper sampling location (opposite Leg 7, Channel No. 1), which is characterized by very slow-flowing water, had a mean inorganic sediment weight of 0.40 gm per square foot of stream bed sampled. Three consecutive locations down the river, each characterized by fast-flowing water, had mean weights of 0.08, 0.04 and 0.01 gm per square foot respectively. In comparison to Channel No. 1, samples from Channel No. 2 contained virtually no inorganic sediment. The absence of sediment can be attributed to the difference in water supply between the two channels; river water flowing into Channel No. 1 contains significant amounts of suspended sediment.

10-80 mg/ft^2

Organic buildup (Fig. 10) varied within and among spawning areas. Samples from both channels showed a gradual decline with distance down each channel while no differences existed among the various river locations. Organic matter in Channel No. 2 probably consists entirely of decomposing algae, sockeye eggs and insects. Since little algae frequents Channel No. 1, organics would be composed mainly of detritus from Fulton River and decomposing eggs and insects. Organics in Fulton River would consist mainly of decomposing terrestrial outfall, eggs and insects.

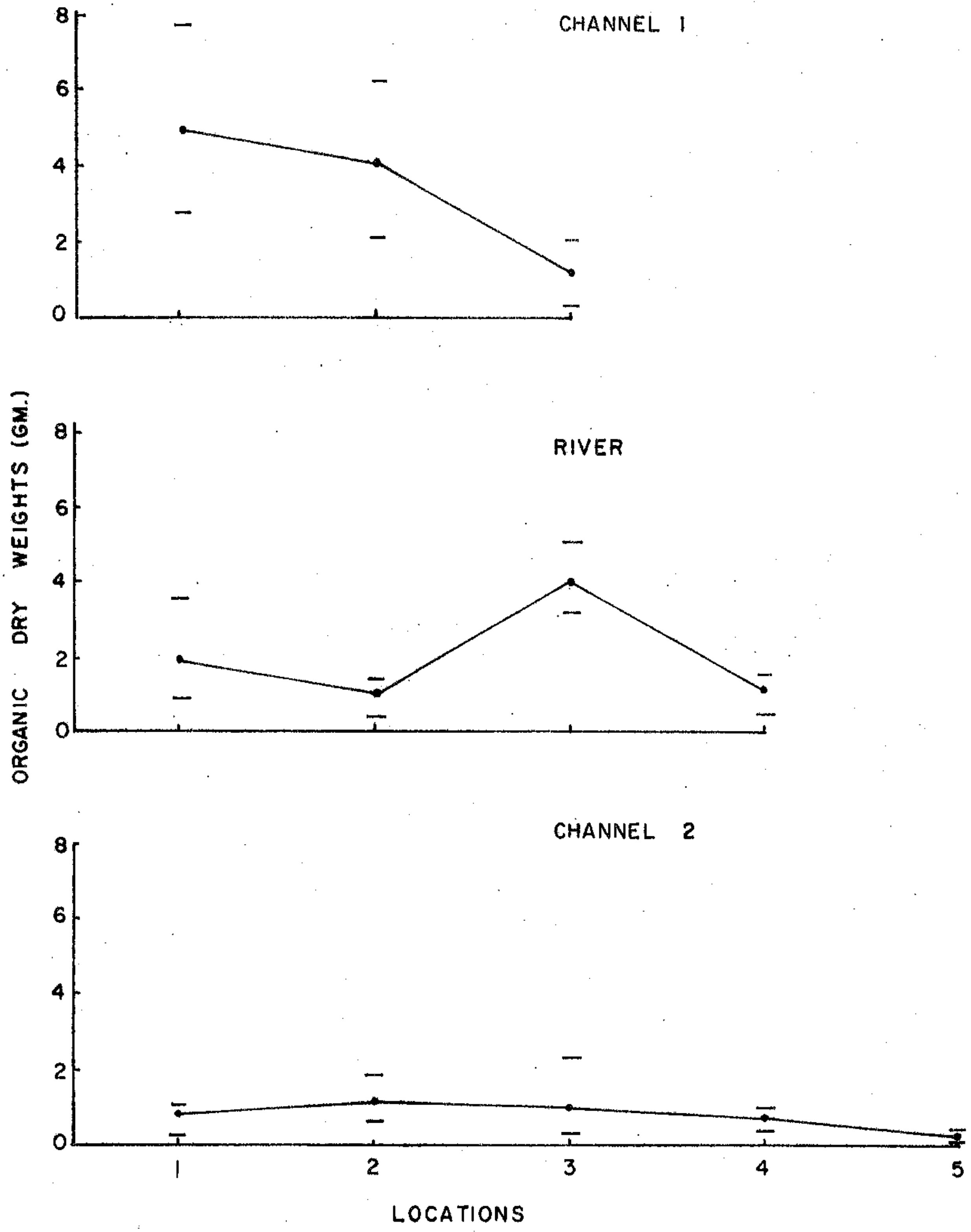


Figure 10. Organic sedimentation in Channel No. 1, Fulton River and Channel No. 2 in February, 1972.

Sedimentation leading to reduced gravel permeability and subsequent embryonic mortality from insufficient oxygen or excessive metabolic buildup did not appear to occur in the Fulton spawning channels. For example, dissolved oxygen and free carbon dioxide levels were not abnormal suggesting that spawning beds were suitably permeable. Additionally, disturbance of bed materials from redd digging activities of spawners enhances conditions for eggs and alevins by removing silt and organic detritus (McNeil and Ahnell, 1964). Since major mortality occurred shortly after deposition (as discussed later), significant embryonic mortality from sedimentation at that time is highly unlikely. The results do indicate where spawning beds are deteriorating and the causes. Expectations are that fry quality and egg-to-fry survival will be affected in the future if sedimentation continues unchecked.

Bottom fauna types and densities (Fig. 11) varied considerably within and between spawning areas. The dominant form in both channels and in some locations in Fulton River was the midge larvae, Chironomus sp. This form feeds on organic matter on the bottom of bodies of water and are found in rivers, lakes, ditches and stagnant ponds. The obvious food supply of midge larvae in Channel No. 2 is decomposing algae and old sockeye eggs. Stonefly (Pleocoptera) nymphs were present in varying numbers in both the river and Channel No. 1. The similarity in fauna inhabiting Channel No. 1 and Fulton River is not unexpected since channel water comes directly from the river. A comparison between degree of inorganic and organic

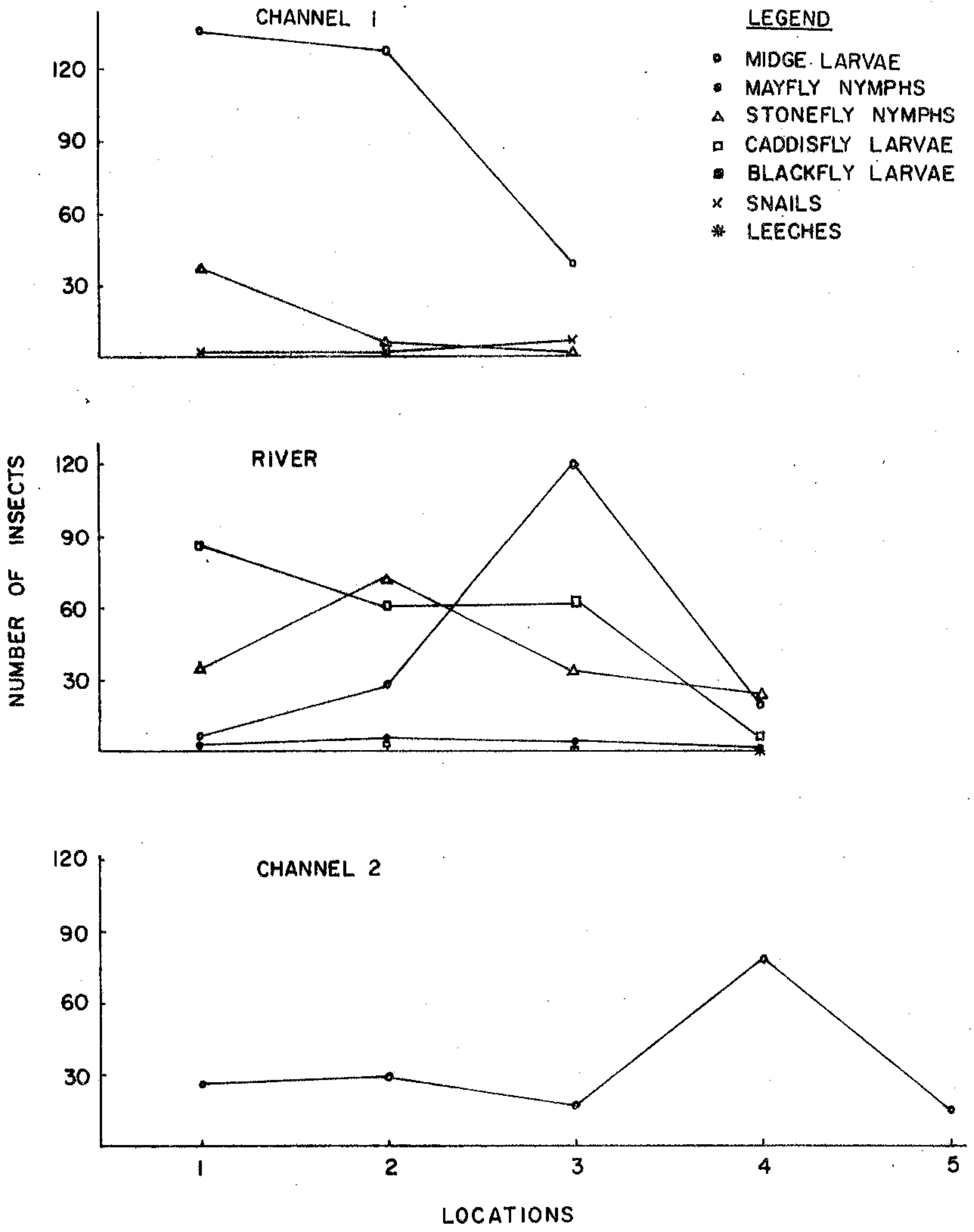


Figure 11. Bottom fauna types and densities in Channel No. 1, Fulton River and Channel No. 2 in February, 1972.

sedimentation and midge larvae density in Channel No. 1 suggests they are directly related. For example, sedimentation and midge densities show a gradual decline down the length of the channel. Obviously midge densities in Channel No. 1 are dependent on the degree of sedimentation or food availability in the sediment. The presence of stonefly nymphs in a spawning bed has an implication to developing sockeye eggs and larvae. Apparently certain stonefly nymphs (Alloperla sp., Acroneuria pacifica) can be serious predators (Claire and Phillips, 1968) but evidence presented later suggest little if any mortality can be attributed to stonefly predation in the Fulton spawning areas. Experimental studies by MacDonald (1966) indicated that stonefly consume dead eggs. Egg disappearance after mortality could be attributed to scavenging stonefly nymphs, in which case accurate assessment of embryonic mortality of eggs could be difficult.

Overall, it is felt that sedimentation and bottom fauna populations inflicted little if any embryonic mortality of sockeye eggs in the Fulton spawning channels. High sediment buildup could impair dissolved oxygen levels and supply to developing embryos however, evidence discussed earlier suggests otherwise. Areas in Fulton River having low dissolved oxygen levels and high sediment loads undoubtedly experienced high embryonic mortality.

DISCUSSION

The foregoing results indicate the spawning bed environment in the Fulton River spawning channels is suitable for efficient embryonic growth, development and survival of sockeye salmon. The various physical, chemical and biological parameters examined were variable from place to place and from time to time but within the limits of tolerance. For example, dissolved oxygen levels were above 7 ppm throughout incubation and free carbon dioxide levels approximated 6 ppm. Indirect evidence suggested that dissolved oxygen delivery rates were sufficient to meet normal requirements of embryonic life. Intragravel water temperatures never exceeded 15°C (58°F) during spawning, and during incubation temperatures slowly declined to about 1°C (34°F), the level it remained at throughout most of the winter incubation period. Periodic sampling to determine water chemistry showed no abnormal toxic ion concentrations but nitrate nitrogen levels in Channel No. 2 appeared abnormally high. A possible cause of high nitrate levels could be attributed to the structural design of the water supply system. Periodic growth of the green algae, Ulothrix in Channel No. 2 was partially attributed to high nitrate levels in the channel water. In comparison to Channel No. 1, Channel No. 2 was experiencing little sediment buildup, however there was no indication that buildup in Channel No. 1 was resulting in significant embryonic mortality. Bottom fauna types and densities in the channels appeared to be dependent on the respective channel environments. Midge larvae, and stonefly and mayfly nymphs inhabited Channel No. 1 while only midge larvae were found in Channel No. 2. Since Channel No. 1 is influenced by Fulton River and Channel No. 2 by Fulton Lake, one could not expect otherwise.

Fulton River is characterized by a spawning bed environment having highly variable physical, chemical and biological parameters. Additionally, aside from flow control, Fulton River can be considered a natural stream, that is, one having spawning areas of inferior quality. Accordingly high embryonic and larvae mortality in these areas is not unexpected since they are characterized by low dissolved oxygen and high free carbon dioxide levels both of which significantly reduce embryonic survival.

Measurement of the various environmental parameters were gross but the results indicated that, at present, the spawning bed environment in the Fulton River channels is conducive to high egg-to-fry survival and high fry production. Although Hach Kit analyses of water quality showed high nitrate levels in Channel No. 2, a more sophisticated method should be used to determine whether nitrate levels are abnormally high before attempting to remedy a problem that may be non-existant. Attempts to eliminate algae growth in Channel No. 2 should focus on environmental differences existing between the Fulton channels. The effect of light reflection off shotcrete berms on algae growth may be examined by comparing growth in experimental areas covered with black polyethylene with growth in control areas. Factors such as structural design, water quality, water temperature and absence of invertebrate grazers could be examined experimentally under a replicated factorial. Finally, if algae growth and sedimentation continue unchecked in the respective spawning areas, one can expect the spawning bed environment to inflict significant embryonic mortalities and reduce fry quality in future years.

SECTION II SPAWNING AND ITS EFFECTS ON EGG-TO-FRY SURVIVAL

INTRODUCTION

Although the environment ultimately determines if a fertilized egg will develop and survive to produce fry, survival may be influenced to a large extent by the behaviour of the parents. Of special significance are spawning distributions and crowding on spawning beds. Provided the physical and physiochemical conditions prevailing in the gravel are conducive to normal development and growth of incubating embryos within the eggs, a fertilized salmon egg must be protected against mechanical disturbance in order to survive. After deposition and during water hardening salmon eggs are particularly sensitive to jarring. Thereafter for a period of several hours, eggs may be moved without experiencing injury or loss. When cell division commences, sensitivity to movement again increases until eye pigmentation begins (Foerster, 1968). From studies by Smirnov (1960) on coho, pink and chum eggs Foerster suggests that digging up of already filled redds by later-arriving spawners can lead to 75% mortality immediately after deposition and while eggs are hardening, to around 20% about 15 days after deposition (during cell division and active development). It would appear that sockeye eggs would be affected similarly.

This section of the report deals with spawning densities, egg retentions and unspawned female frequency, in relation to egg-to-fry survival in the various spawning areas. It will be shown that the main cause of low egg-to-fry survival in the Fulton spawning channels has been mechanical disturbance of incubating eggs caused by superimposition which in turn results from over-crowding or over-utilization of spawning beds.

METHODS AND RESULTS

Spawning Densities and Egg Deposition by 1971

A dead recovery program was conducted to obtain accurate counts of adult densities and unspawned female densities as well as estimates of egg retention, fecundity and actual egg deposition, in individual locations of each Fulton spawning channel. The individual sampling locations were: Legs 1-7 inclusive in Channel No. 1 and Legs 1-21 inclusive in Channel No. 2. A total of 300 and 400 females were sampled from Channel No. 1 and No. 2 respectively during the spawning season for length, egg retention and fecundity, and the data were used to determine deposition. Actual deposition within a location was determined by subtracting the sum of egg retention plus the product of the unspawned number and the mean regression fecundity, from the ~~total~~ potential deposition within that location. Actual deposition for an entire spawning channel was determined by summing actual deposition figures for all locations within the channel.

A less intensive dead recovery program was conducted at the Pinkut spawning channel. Sampling for unspawned females was not conducted. Actual deposition was determined in the same manner as described for the Fulton spawning channels. Unspawned female densities were interpolated from the percentage of unspawned that occurred at Fulton. Individual spawning locations were Legs 1-5.

Spawning densities (expressed as sq. yds. per female, or per fish), percentage of unspawned females, and egg deposition for various areas and locations are given (Tables VII and VIII). Area allotment per female varied between 0.82 and 1.60 sq. yds. in Channel No. 1 and between 0.58 to 5.66 sq. yds. in Channel No. 2. In the Pinkut Channel area varied from 1.68 to 4.59 sq. yds. per female. On a per fish basis area allotment is much lower.

The unspawned female density in both Fulton channels varied among locations and indications are that the density was directly related to spawning densities. The negative regression of the percentage of unspawned females against area allotment per female was not significant for Channel No. 1 but significant (~~5%~~ 10% level) for Channel No. 2 (Fig. 12). In Channel No. 1 the highest percentage (0.59%) occurred in Leg 4 and the lowest (0.18%) in Legs 5 and 6. The highest percentage (2.93%) in Channel No. 2 occurred in Leg 21 while the lowest (0.23%)

TABLE VII. Spawning area per female and per fish, percentage of unspawned females and percentage egg-to-fry survival (based on ratio of live to total eggs recovered). always results in a survival overestimate due to uncounted egg disappearance (loss)

Spawning Area	Location	Area Per Female (sq. yds.)	Area Per Female & Male (inc. jacks)	% Unspawned Females	Mean % November Survival	Mean % March Survival
					12	26
Channel 1	Leg 1	1.18	0.58	0.04	86.7	60.9
	Leg 2	1.03	0.54	0.40	76.8	56.5
	Leg 3	0.90	0.45	0.51	-	-
	Leg 4	0.82	0.38	0.59	75.7	81.1
	Legs 5&6	1.60	0.66	0.18	79.5	63.7
	Leg 7	1.32	0.58	0.30	71.7	75.3
Channel 2	Legs 1&2	1.60	0.65	0.34	47.0	30.8
	Legs 3&4	1.66	0.92	0.82	50.2	42.4
	Legs 5&6	1.21	0.69	0.85	65.8	50.7
	Legs 7&8	1.51	0.83	1.20	66.6	55.8
	Legs 9-12	1.21	0.59	0.74	59.9	50.5
	Leg 13	1.24	0.62	0.66	57.1	52.8
	Legs 14&15	1.75	0.73	0.42	69.4	53.5
	Legs 16&17	3.40	1.41	0.47	92.2	66.9
	Legs 18-20	5.66	2.42	0.23	85.5	66.1
	Leg 21	0.58	0.25	2.93	64.6	52.1
Pinkut Channel	Leg 1	1.73	0.67	-	84.2	-
	Legs 2&3	1.68	0.64	-	92.8	-
	Legs 4&5	4.59	1.19	-	95.2	-

TABLE VIII. Potential deposition, egg retention, unspawned female egg loss and actual deposition.

Spawning Area	Potential Deposition	Egg Retention[1]	Eggs Not Deposited[2]	Actual Deposition
Fulton Channel 1	41,262,859	877,418	140,768	40,244,673
Fulton Channel 2	193,901,222	1,333,011	1,862,343	190,705,868
Fulton River	252,946,737	7,425,568	2,147,740	243,345,821
Pinkut Channel	32,708,863	187,361	277,425	32,244,077
Pinkut Creek	12,338,802	145,569	104,391	12,088,842

[1] Average retention per female X female density.

[2] Number of fish unspawned X average fecundity.

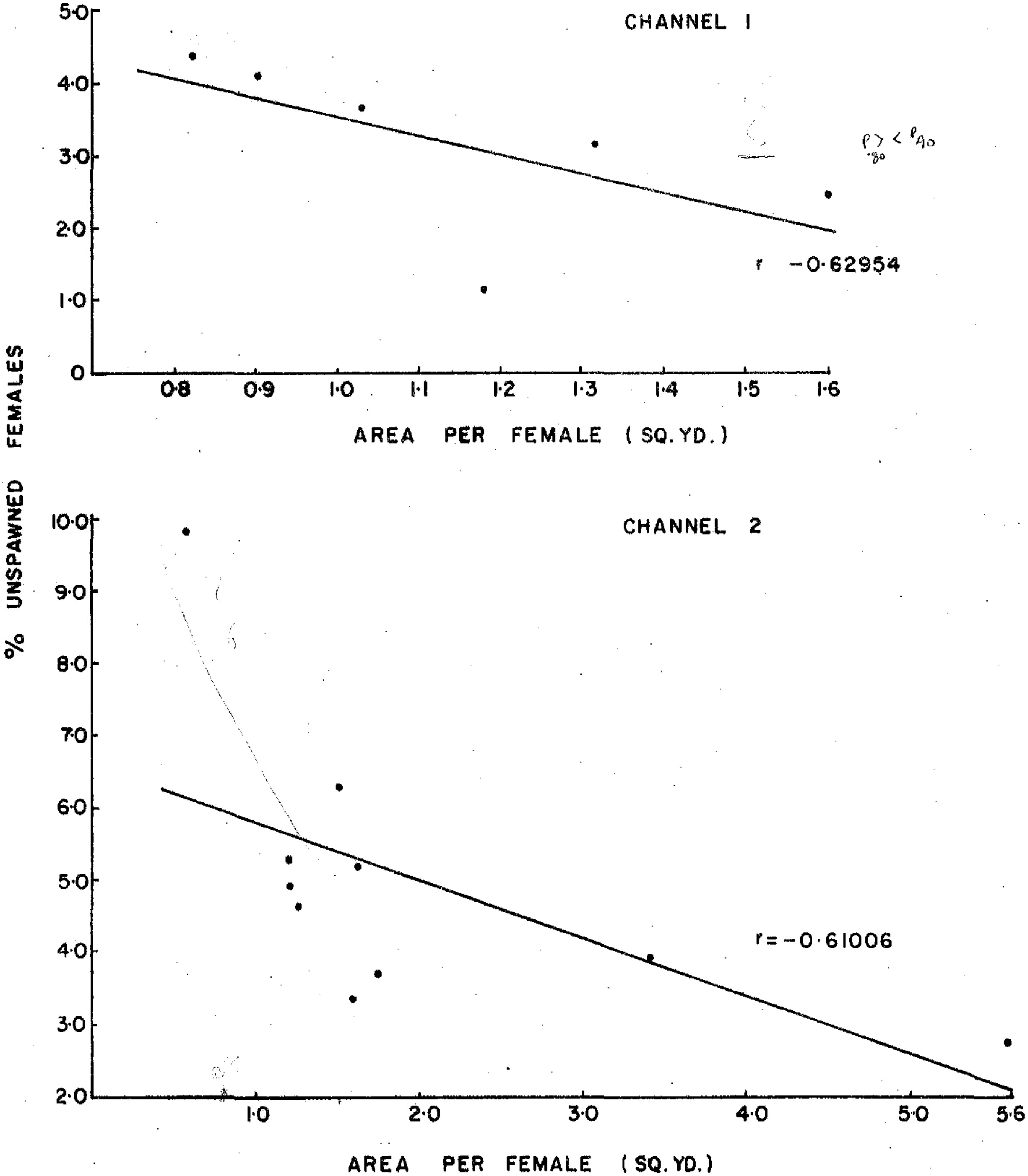


Figure 12. Relationship between percentage of unspawned females and spawning area per female.

occurred in Legs 18-20. In each channel the highest spawning density resulted in the highest percentage of unspawned females.

Indications are that the Babine spawning channels have been over-utilized. Studies by Krokhin and Krogius (from Foerster, 1968) on the Kurile Lake (Kamchatka) spawning grounds suggest the amount of bottom utilized by a female for redd construction approximates 2.5 m^2 (3 sq. yds.). Baranenkova, in a similar study, concluded that in spring areas of Nachikinsky Lake which are considered to be excellent for spawning, the area required for one female was about 3 m^2 (3.5 sq. yds.). Spawning distribution studies by A. Tautz (pers. comm.) in Leg 1 of Channel No. 2 during the 1971 spawning season indicate that a female requires about 2.5 m^2 (3 sq. yds.) to spawn. The spawning area allotted per female in the Babine spawning channels is currently 1.1 m^2 (1.25 sq. yds.) which is well below that suggested above. Furthermore, at these high female densities little area is available to an equally high density of males which in addition to utilizing a portion of the spawning area must create territorial interaction. Additionally with high male and female densities it is difficult to conceive of a pair of spawners utilizing 1.25 sq. yds. of bed without interfering with or disturbing neighbouring redds and (or) spawning pairs.

Source of this value?

The managing capacity of a spawning channel is based on the premise that all fish spawn at the same time. Therefore, successive

if excessive waves of spawners come onto and utilize the spawning areas, the spawning territory available to each female or each pair of fish during its spawning period would be ? correspondingly greater. Indications are that this logic does not apply to areas heavily over-utilized such as the Babine spawning channels. For example, five successive waves of spawners utilized the Fulton spawning channels during the 1971 season (Fig. 13 and 14), with the high density waves occurring within a relatively short period of time. On September 20, 1971 20,000+ spawners were present in Channel No. 1 and 100,000+ in Channel No. 2. At an even distribution, 1.1 m^2 (1.32 sq. yds.) was available for each female in Channel No. 1 and 1.29 m^2 (1.55 sq. yds.) in Channel No. 2. Area per female in both areas are well below the requirements described earlier. Obviously not all fish were spawning at once, but it is quite probable that a large majority were. For example, considering that early spawners do not spawn until two or three weeks after arrival, it is conceivable that both early and late individuals spawned during the same period. Examination of the slopes of the dead recovery curves (Fig. 15) and accepting the idea that females generally occupy their redds for about seven days supports the possibility of high density spawning during a short period of time. Compounding the high density spawning is the effect of superimposition resulting from later successive spawning waves. In his study A. Tautz (pers. comm.) observed as many as three successive waves during the spawning season which resulted in certain redds being superimposed upon two and

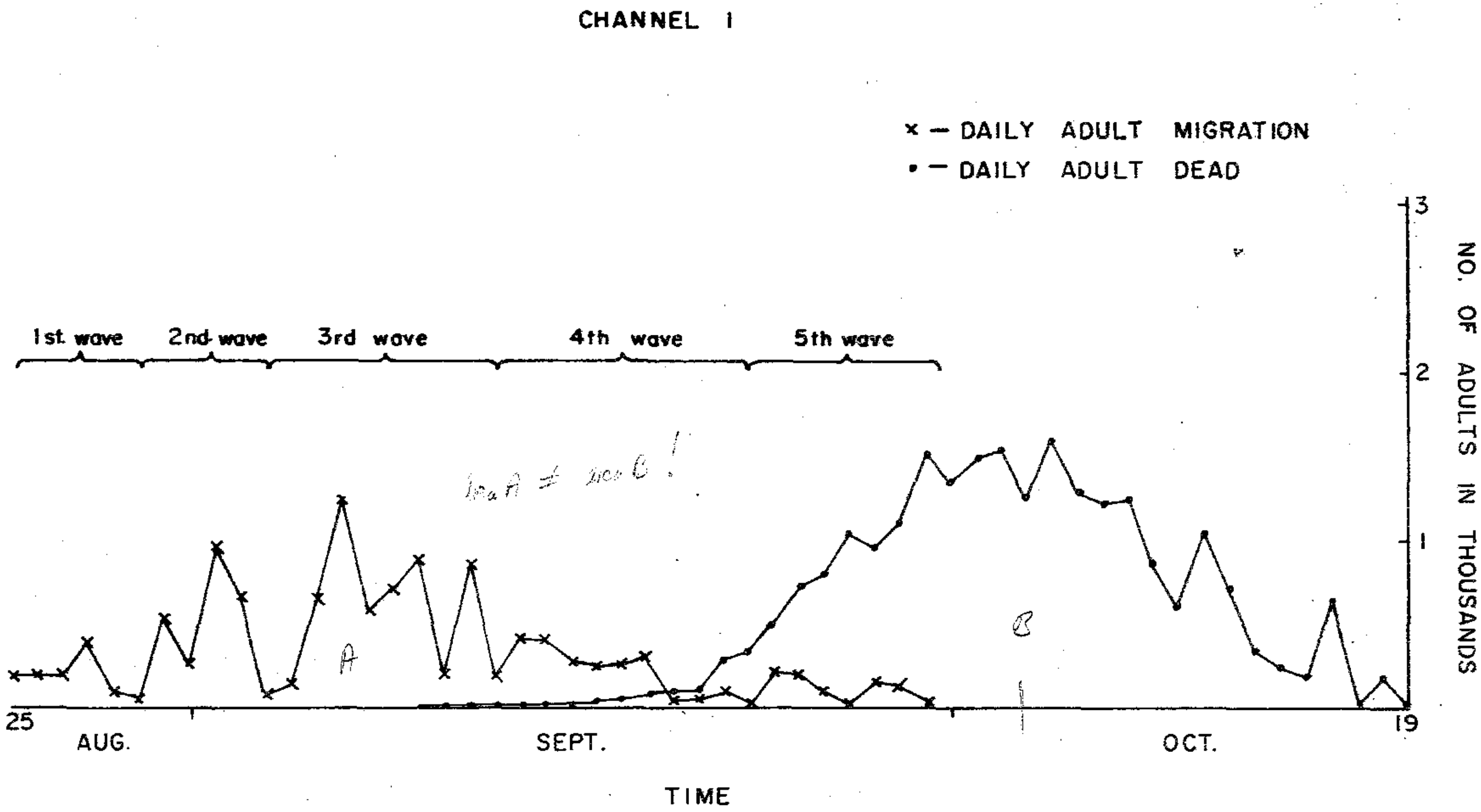


Figure 13. Daily adult migration and dead recovery for Channel No. 1 (1971).

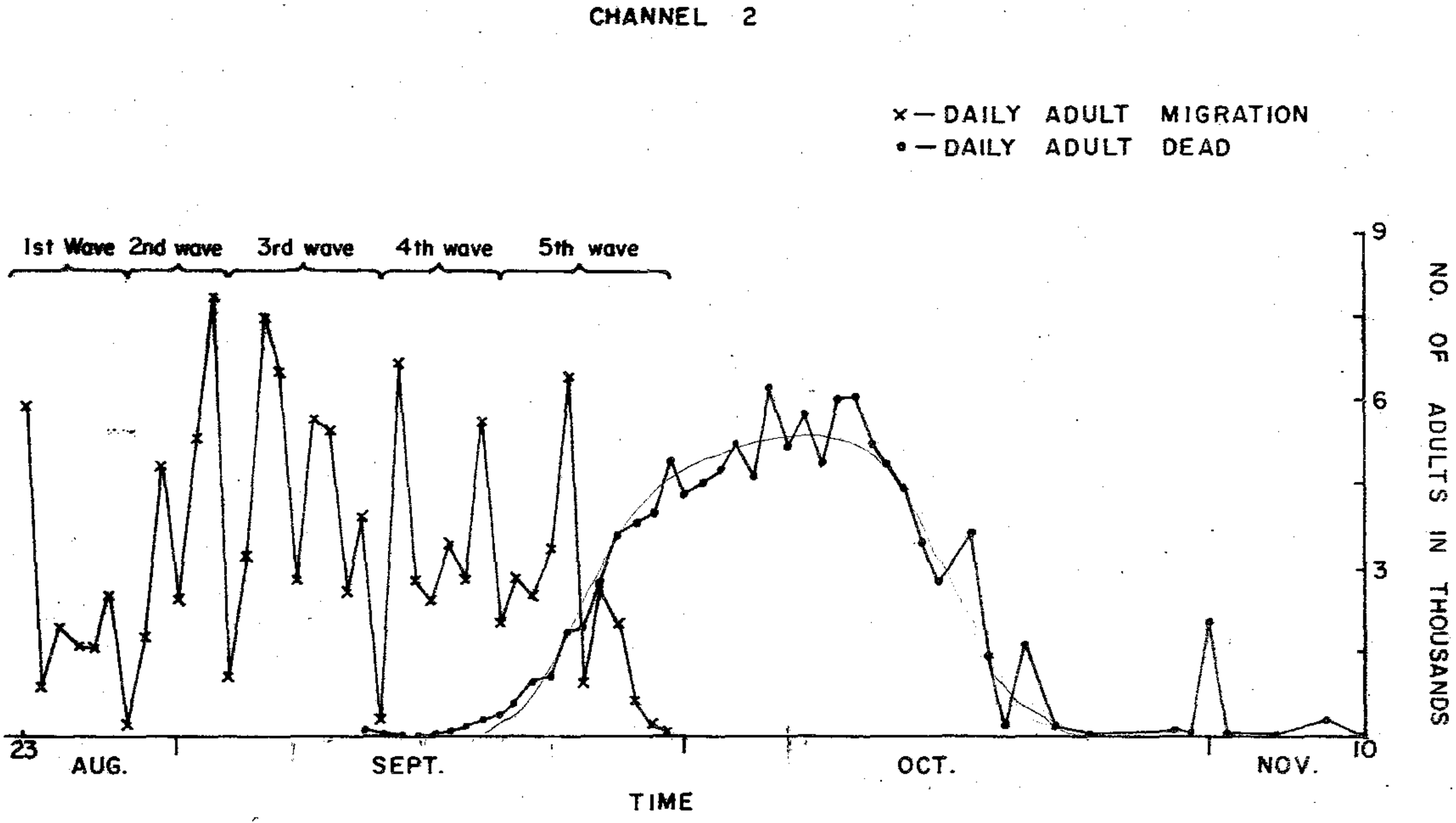


Figure 14. Daily adult migration and dead recovery for Channel No. 2 (1971).

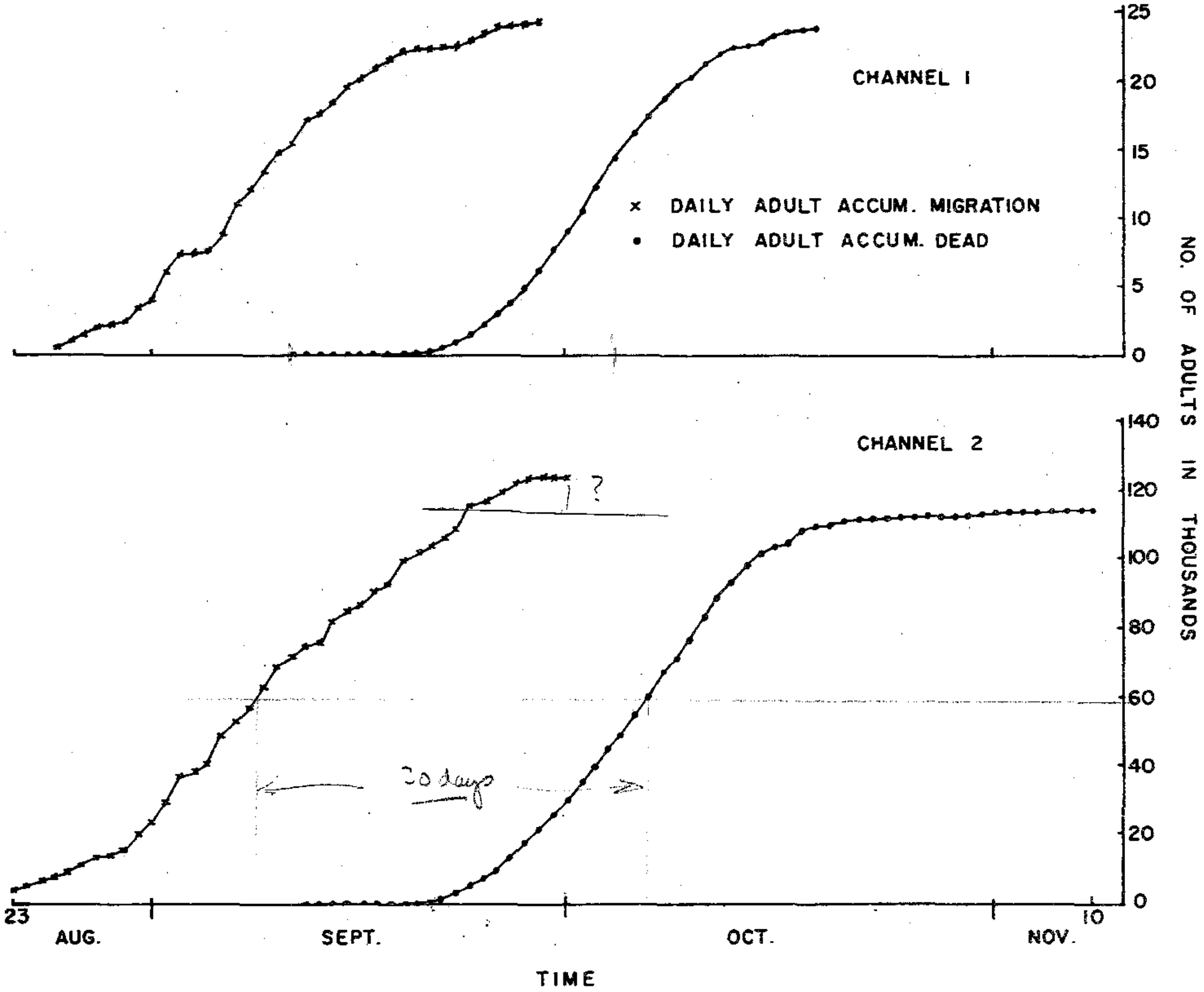


Figure 15. Accumulative adult migration and dead recovery for Channels No. 1 and No. 2 (1971).

sometimes three times. Since superimposition occurred in Leg 1, Channel No. 2 which had a theoretical area allotment of 1.60 sq. yds. per female, it is not difficult to realize the extent of over spawning in other locations which had even less area available per spawner.

Studies by Mathisen (MS 1955) and Semko (from Foerster, 1968) suggest that a density dependent relationship exists between the total number of sockeye on a spawning ground and completeness of egg expression. Additionally the occurrence of unspawned females is a measure of competition for spawning area. These relationships were apparent at the Fulton spawning channels during the 1971 spawning season. For example, a significant negative correlation (r = -0.61006*) between d.f.? unspawned females and area per female (Fig. 12) occurred in Channel No. 2. Although statistically insignificant (r = 0.62954), the same trend occurred in Channel No. 1. Comparison of overall egg retention for both channels shows an inverse relationship between retention and area available per female. Average retention in Channel No. 1 was 71 eggs (approximately 2%) at a mean area per female of 1.1 m^2 (1.14 sq. yds.) while it was 23 eggs (approximately 0.70%) in Channel No. 2 which had a mean area per female of 1.65 m^2 (1.98 sq. yds.). This suggests that competition for space was greater in Channel No. 1 than in No. 2, however comparing the percentage of unspawned females in Channel No. 1 (0.33%) with Channel No. 2 (?) suggests the opposite. Although there is no evidence indicating which data is more indicative of over-crowding, it is felt that the occurrence of unspawned females is the more reliable of the two. Accordingly, it is suggested that overall competition for space was greater in Channel No. 2 than in Channel No. 1.

Since the area requirements in the literature are well above those employed at the Fulton Channels, the suggestion is that over-crowding has occurred and the degree has been dependent on spawning densities. Expectations are that egg-to-fry survival decreases with crowding which in turn results from excessively high spawning densities. This relationship has occurred at Fulton and will be discussed below.

Embryonic Mortality of Eggs

Embryonic and alevin mortality in the Fulton spawning areas was examined by hydraulic sampling, from November 9-13, 1971, and from February 18-25, 1972. Pinkut Creek and Channel were sampled on November 15, 1971. The results were intended to determine (1) total mortality from all causes, (2) periods of significant changes in mortality, and (3) mortality trends within a spawning area.

The various locations sampled in the Fulton Channels were: Legs 1, 2, 4, 5 and 7 in Channel No. 1, Legs 1, 3, 5, 7, 9-13, 15, 17 and 18-21 in Channel No. 2. Pinkut Channel was sampled in Legs 1, 3 and 5. Sampling of Fulton River and Pinkut Creek was done in the immediate vicinity of the dissolved oxygen sampling locations. Seven samples were taken in all locations except in Legs 9-12 and 18-21 in Channel No. 2 in which 10 samples were taken per location.

Sample sites in the two rivers were selected at random. Channel sample sites were arbitrarily chosen to be at 30 m (100 ft.) intervals down a leg (location) except in Legs 4 and 5 of Channel No. 1 where they were at 15 m (50 ft.) intervals. A randomized design (Table of Random Numbers from Li, 1966) based on a given number of steps from a berm or divider wall was used in selecting individual sample sites at each interval down a leg. Sample sites in February were offset about 14 m (50 ft.) upstream from November sites in all legs except 4 and 5 of Channel No. 1; these were offset about 7 m (25 ft.) upstream. The experimental site in Leg 1 of Channel No. 2 used by A. Tautz in his spawning distribution study was sampled at random in February; five samples were taken.

All November samples were cleared in Stockard's Solution and then analyzed in the laboratory while February samples were analyzed on site immediately after being taken. The clearing solution facilitated determining embryonic development at mortality, and whether dead eggs were fertilized. Criteria to differentiate between live and dead eggs was as follows. Eggs live at time of recovery were those having a visible embryo after treatment with the clearing solution. Eggs dead at time of recovery were white-spotted, clear or opaque. Eggs completely cleared and showing no embryonic development were classified as unfertilized.

Confidence limits, used to estimate total mortality from all causes were calculated from the double inequality

$$1 - \frac{\bar{a}}{E'} < m_t < 1 - \frac{\underline{a}}{E'}$$

The values of $\bar{a}$ and $\underline{a}$ are the upper and lower confidence limits of the estimated number of live eggs and larvae per square foot of spawning bed and E' is the expected number per square foot. Values of $\bar{a}$ and $\underline{a}$ were calculated with the "t"-distribution and the standard error of the mean obtained from arithmetic counts of live eggs and larvae (from McNeil, 1964).

The upper, lower and mean confidence limit estimates of egg-to-fry survival from deposition to November and deposition to late February are shown in Table IX. Approximate mean estimates of expected fry production from the Fulton spawning areas were Channel No. 1 - $\overset{20}{16}$ million, Channel No. 2 - $\overset{80}{70}$ million, Fulton River - $\overset{31}{41}$ million; estimates for Pinkut Creek and Pinkut Channel were $\overset{2.2}{2}$ million and $\overset{16.7}{20}$ million respectively. The observed differences for the Fulton areas between the first and second sampling series are attributed to natural mortality and experimental error. Of significance is the greater mortality occurring from deposition to the time of November sampling. Examination of dead eggs cleared in Stockard's Solution showed that fertilization had taken place. Since slight embryonic development was visible, mortality obviously occurred shortly after deposition during the pre-eyed embryonic stage.

Although estimates of total mortality based on ratios of live eggs to total number collected are sometimes biased by the disappearance of eggs from the spawning bed, they do give

TABLE IX. Estimated egg-to-fry survival in Babine spawning areas.

Spawning Area	Date	90% Confidence Limit Estimates of Egg-To-Fry Survival		
		Lower	Upper	Mean
Fulton Channel 1	November 1971	33.7 ✓	70.2	51.9 ±35%
	March 1972	24.8 ✓	52.6	39.6
Fulton Channel 2 (old section)	November 1971	40.4	62.3	51.4
	March 1972	21.8	37.8	29.8
Fulton Channel 2 (new section)	November 1971	43.5 ✓	85.6	64.6
	March 1972	22.4	74.7	48.6
Fulton River	November 1971	19.2 ✓	41.0	30.1
	March 1972	9.5	24.4	17.0
Pinkut Channel	November 1971	37.8 ✓	85.4	61.6
Pinkut Creek	November 1971	17.5 ✓	50.9	34.2

important evidence of mortality caused by factors not associated with direct removal of eggs from spawning beds. Mortality estimated from ratios (Table VII) indicate major mortality occurred during the period from deposition to November. Comparing mean mortality estimates, based on confidence limits (Table IX), for the incubation periods -- deposition to November and deposition to late February -- shows highest mortality in the Fulton spawning channels occurring during the first period. In Channel No. 1 it was twice as high while in the old section of Channel No. 2 it was 2 ~~four times~~ as high. Gravel scouring from freezing weather conditions resulting in heavy mortality in Legs 17, 18 and 19 of Channel No. 2 is probably the reason for near equal mortality during the two periods in the new section of Channel No. 2. Fulton River mortalities high throughout both incubation periods, are normal in that many physical and chemical factors operate in the river throughout the incubation period to cause mortality.

Spawning locations with low spawning densities experienced higher egg-to-fry survival than high density locations. This relationship is shown in Figure 16. The positive correlation of percent survival to area per female was significant (Nov. r = +0.72076*, March r = +0.59871*) for Channel No. 2. Channel No. 1 results were not significant; a positive relationship occurred in November (r = +0.12763) but in March it was negative (r = -0.32379). The negative trend

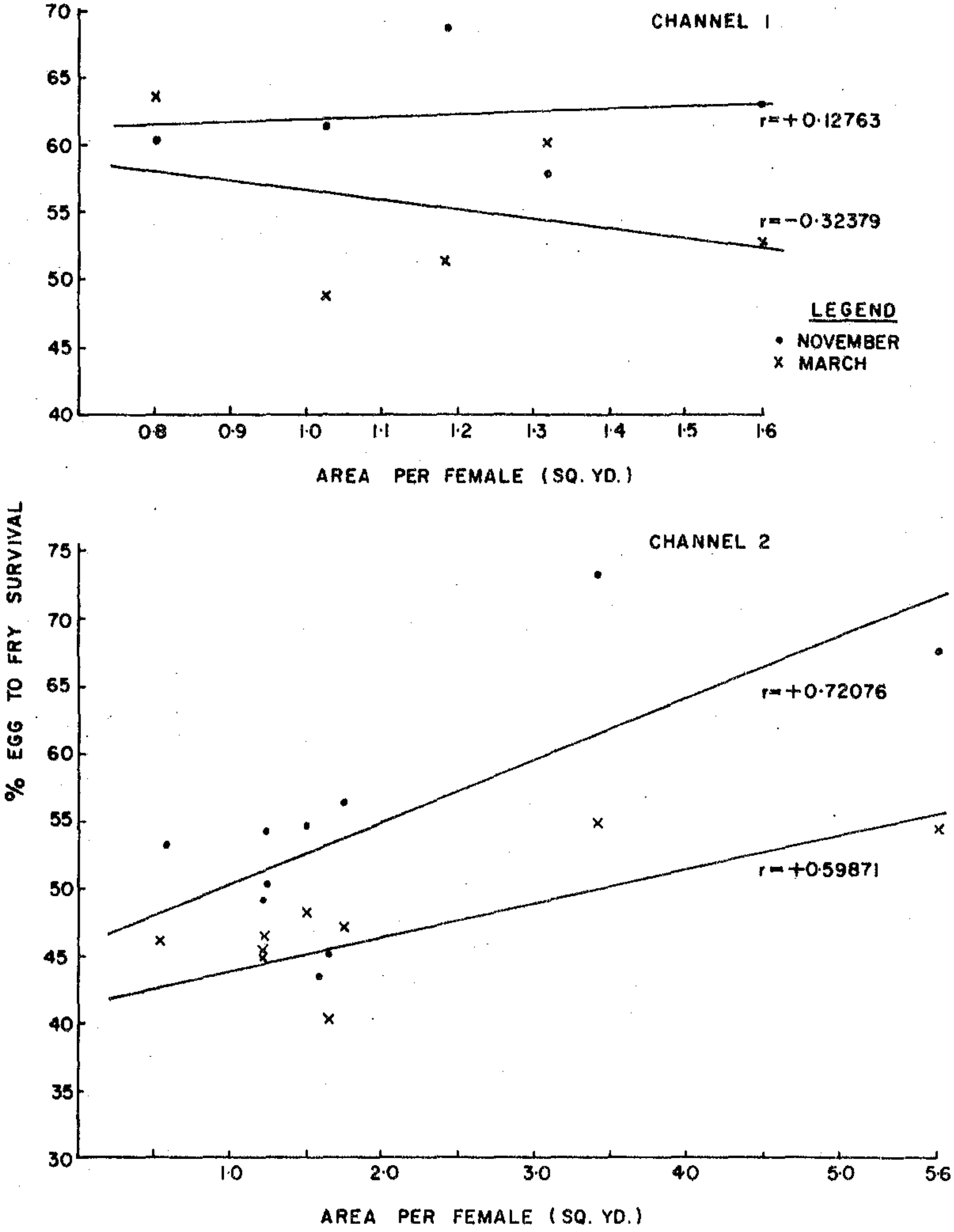
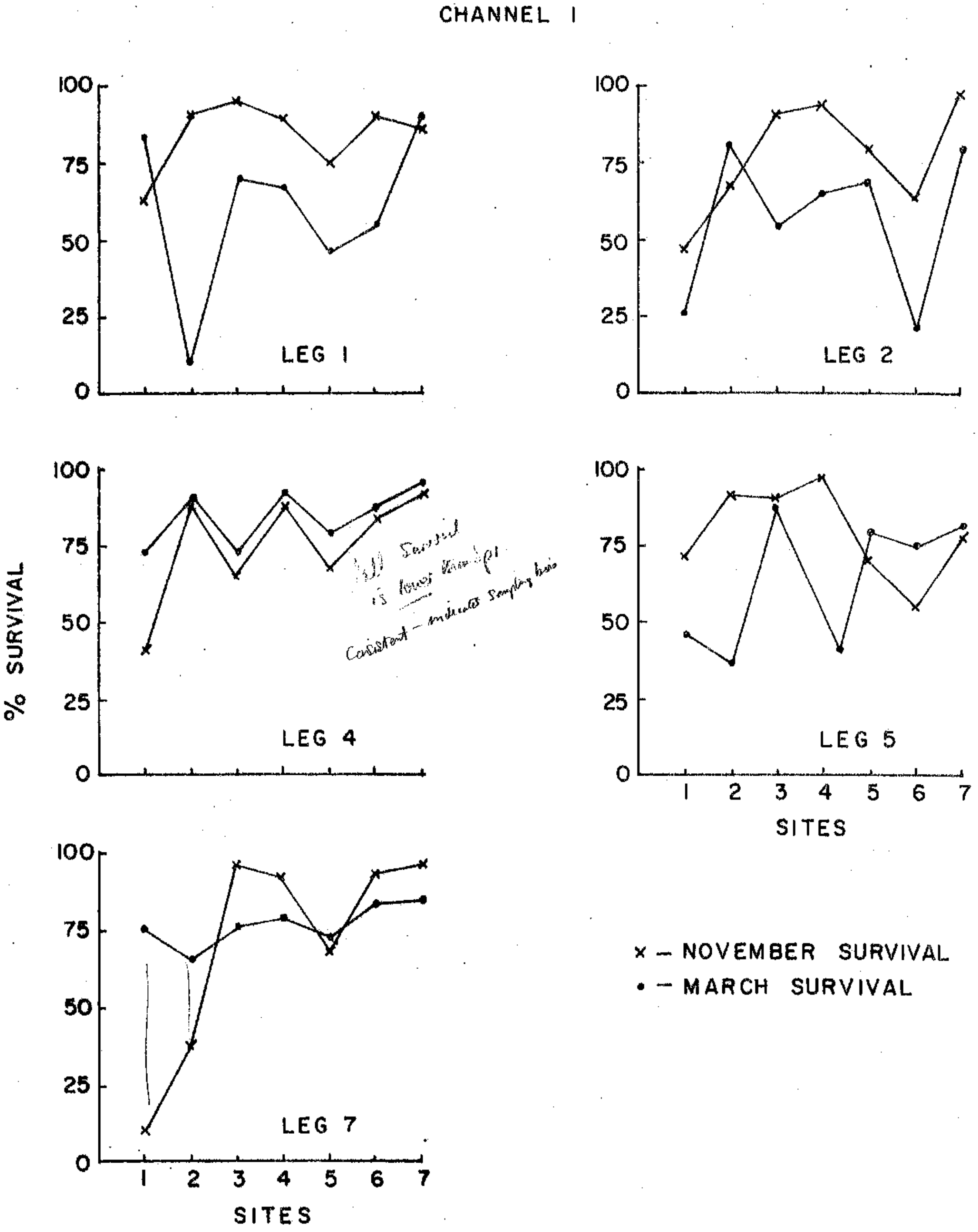


Figure 16. Relationship between percentage egg-to-fry survival and spawning area per female.

was due to the abnormally high survival obtained for the female area allotment which was 0.80 sq. yds. However, since a positive trend occurred in three out of four cases, it is felt that mortality in the channels is dependent on spawning densities.

Both Fulton spawning channels displayed unique fluctuating mortality trends (Fig. 17, 18 and 19) in that most locations sampled were characterized by alternating low-high-low-high mortalities both in November, 1971 and February, 1972. Sites undergoing heavy spawning and experiencing high egg mortality support the theory that embryonic mortality was dependent on spawning densities. Good examples of these high spawning density high mortality areas were the first sites sampled in each channel loop. Expectations are that mortality in these areas has resulted from mechanical injury incurred shortly after deposition when developing embryos are very susceptible to death from disturbance. Movement of both eggs and gravel by redd superimposition resulted from over-crowding and wave spawning. Observed superimposition of redds from wave spawning in the experimental area located in Leg 1 of Channel No. 2 is in agreement with this reasoning. Additional evidence is the low survival occurring in this area -- 22.8, 60.2, 4.3, 30.4 and 4.8% (based on percentage live to total eggs collected).

The apparent high survival occurring in Leg 21 of Channel No. 2 contradicts the theory of over-crowding causing mortality from superimposition. A possible explanation is that



Nov Survival is lower than [illegible] Consistent – indicates Sampling bias

Figure 17. Egg-to-fry survival in Channel No. 1 for the incubation periods: October 15 (mean date of deposition) to November 9; and October 15 to February 18.

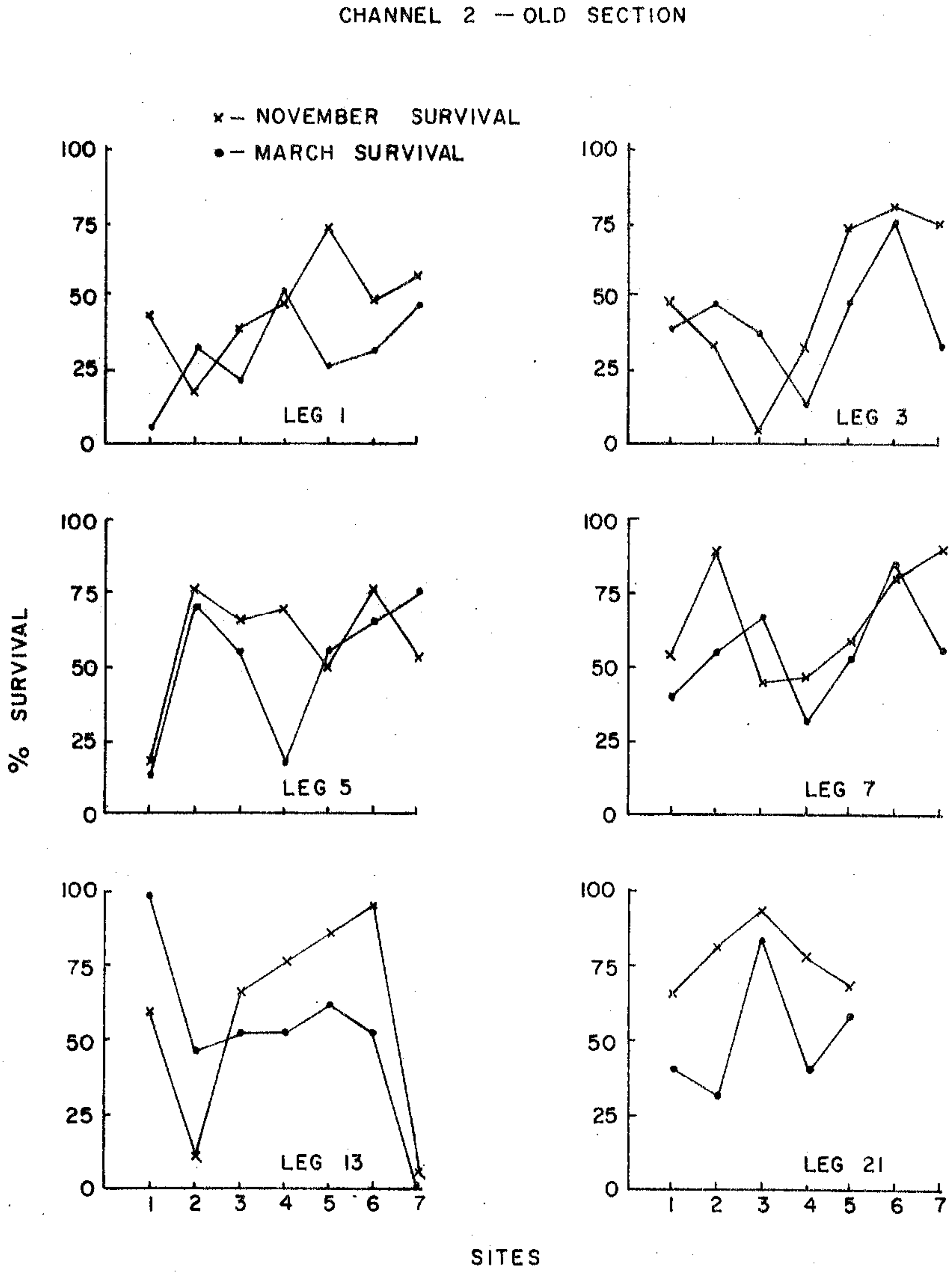


Figure 18. Egg-to-fry survival in old section of Channel No. 2 for the incubation periods: October 15 (mean date of deposition) to November 12; and October 15 to February 23.

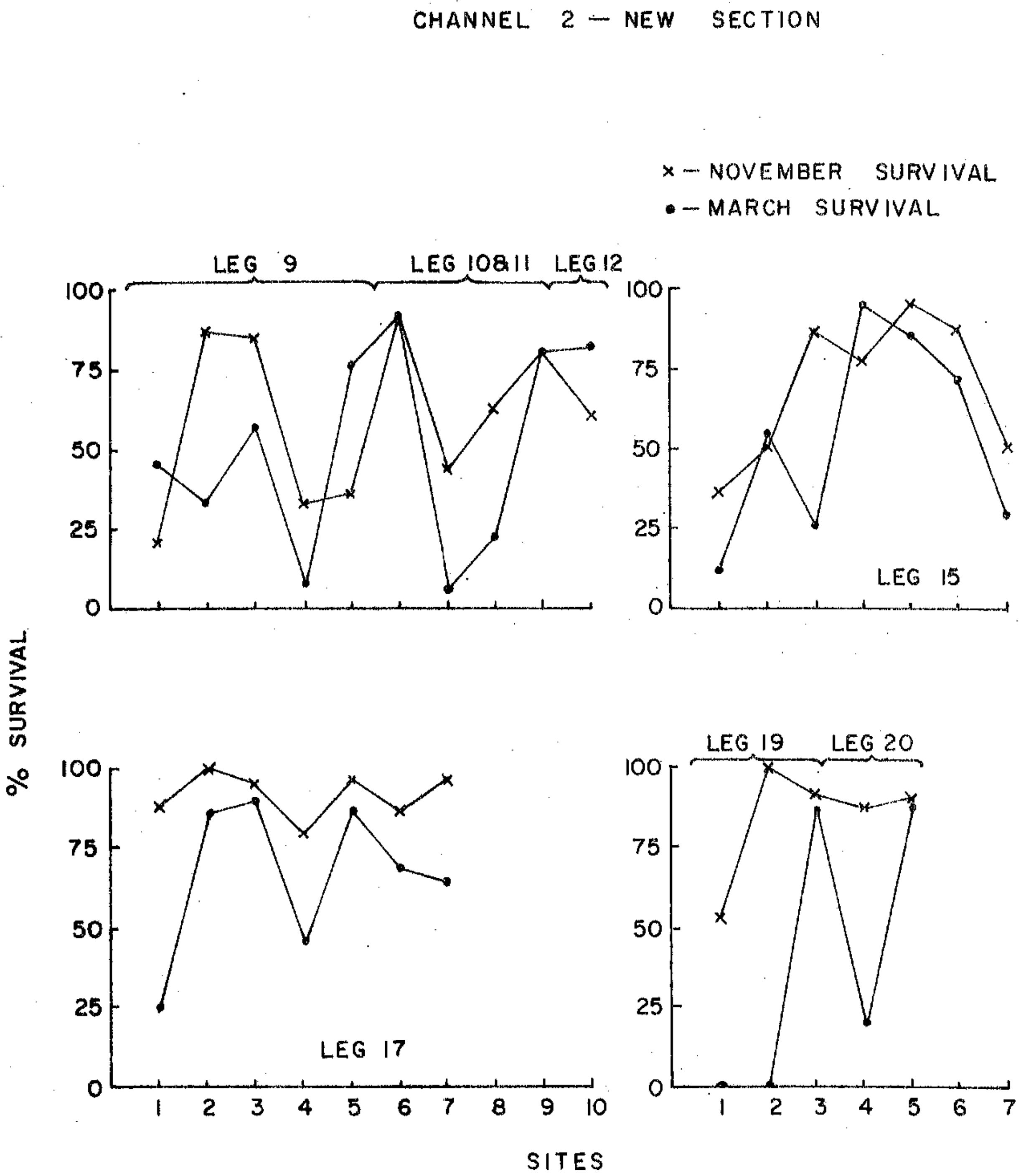


Figure 19. Egg-to-fry survival in new section of Channel No. 2 for the incubation periods: October 15 (mean date of deposition) to November 13; and October 15 to February 24.

many of the early deposited eggs were removed by redd superimposition and carried downstream into the forebay area at the channel outlet or into the pool located immediately above the outlet. If a significant proportion of eggs observed in the forebay area originated from redds in Leg 21, sampling results would be incorrect. (The analytical method employed relies on the assumption that deposited eggs do not leave the gravel.) The possibility of Leg 21 experiencing high egg-to-fry survival when the area allotment per female was 0.58 sq. yds. is remote, especially considering that males must occupy space. Additionally, it is difficult to conceive of a female sockeye utilizing only 0.58 sq. yds. to construct a redd without affecting adjacent redds. It is felt that Leg 21 experienced mortality at least equal to and probably greater than that occurring in less crowded areas. Finally, large mortality differences occurring in Legs 19 and 20 between November and March are probably due to scouring and freezing that occurred there in January and February.

DISCUSSION

Studies on survival of pink salmon (Oncorhynchus gorbuscha) and chum salmon (Oncorhynchus keta) eggs and alevins in three southeastern Alaska streams by McNeil (1968) showed the most serious mortality factor during spawning to be superimposition of redds. Smirnov (from Foerster, 1968) showed that pink and chum salmon eggs in the sensitive state, experienced varying degrees of mortality when subjected to agitation in a mechanical vibrator. It was suggested that mortality would range from 75% immediately after deposition and during hardening to around 20% while cell division and development are taking place. Foerster (1968) concluded that sockeye eggs experiencing superimposition would be similarly affected. There is certainly adequate field and circumstantial evidence supporting the effects of superimposition on embryonic survival of salmon eggs. The results of the present study suggest the major mortality factor in the Fulton spawning channels has been superimposition which in turn resulted from over-utilization of the spawning grounds. For example, the spawning capacity of 1.25 sq. yds. per female currently applied to the Babine spawning channels is far below that suggested as optimum by the literature. Significant positive correlations between egg-to-fry survival and the theoretical area allotment per female indicated mortality in the channels was directly proportional to spawning densities. Observations of superimposition in an experimental area experiencing high embryonic mortality supports the theory of over-crowding leading to superimposition of redds. Additionally, areas experiencing heavy spawning were found to experience high embryonic mortality. This was particularly evident from the unique mortality trends occurring within each spawning channel. Indications were that mortality occurred shortly after deposition which suggests mortality probably occurred during the spawning season. Finally combining all of the above evidence and realizing that the physical, chemical and biological conditions of the spawning beds were favourable throughout the incubation period, indicates that low egg-to-fry survival in the channels has resulted from over-utilization of the spawning beds.

GENERAL DISCUSSION

The foregoing has suggested reasons for high egg-to-fry mortality in the Fulton River spawning channels in recent years. Indications are that physical, chemical and biological factors did not cause significant mortalities but some were suggested as possible mortality factors in Fulton River. Low egg-to-fry survival was attributed to superimposition of redds causing death of embryos from mechanical disturbance. Evidence accumulated indicated that superimposition of redds resulted from initial over-crowding and wave spawning. The resultant effect was that eggs from early spawning females experienced heavy mortality from superimposition of redds by late spawners. Expectations are that eggs from early-spawning females will experience lower mortality from superimposition of redds if spawners were less numerous. However, it still remains to be determined experimentally and under conditions that wish to be imposed, whether an increase in survival at the expense of reduced spawning densities will outweigh the possible maximum fry production resulting from present spawning densities.

Overall the results of this study on the Fulton River spawning channels indicate that:

(1) the designed managing spawning capacity is excessively high resulting in over-utilization of the spawning beds;

(2) in some areas, a high male to female sex ratio is contributing to over-crowding;

(3) wave spawning has resulted in superimposition of redds in areas of high density spawning;

(4) spawner entry over the entire spawning season appears to enhance over-crowding and superimposition;

(5) the Channel No. 2 water supply contains abnormally high concentrations of nitrate nitrogen; and ?

(6) gravel deterioration is resulting from inorganic and organic sedimentation in Channel No. 1, and from organic sedimentation in Channel No. 2 -- organic sedimentation is caused by bacterial decomposition of dead algae and sockeye eggs.

To alleviate the above mentioned factors in hope of obtaining fry of good quality, high egg-to-fry survival and maximum fry production, the following recommendations warrant consideration:

(1) redefine the designed managing capacity of the spawning channels;

(2) determine and implement an optimum male to female spawner sex ratio;

(3) critically assess the concept of wave spawning in terms of the benefits it gives to fry production;

(4) limit spawner entry to the peak migration period;

(5) determine and eliminate the cause(s) of algae growth; and

(6) develop a method of channel cleaning and implement accordingly.

In conclusion, it is felt that if the above recommendations are considered and pursued in the appropriate manner, expectations are that egg-to-fry survival will increase significantly and that resultant fry production in the future will equal or exceed that of the past.

ACKNOWLEDGEMENTS

The author would like to express his gratitude to Mr. R. A. Leamont, Mr. S. Everitt and Mr. D. Lawseth for their assistance in collecting the field data. Thanks are due to Mr. R. K. Kearns, Mr. R. N. Palmer, Dr. F. K. Sandercock and Mr. F. E. A. Wood for reviewing the manuscript.

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