SPRINGS AND GROUND-WATER AS FACTORS AFFECTING SURVIVAL OF CHUM SALMON SPAWN IN A SUB-ARCTIC STREAM

A

THESIS

Presented to the Faculty of the
University of Alaska in Partial Fulfillment
of the Requirements
for the Degree of
MASTER OF SCIENCE

By
Dennis Raymond Kogl, B.S.
College, Alaska

July, 1965

SPRINGS AND GROUND-WATER AS FACTORS AFFECTING SURVIVAL OF CHUM SALMON SPAWN IN A SUB-ARCTIC STREAM

APPROVED:

Chairman

Department Head

APPROVED: ______________________ DATE: 28 July 1965
Dean of the College of Biological Sciences
and Renewable Resources

____
Vice President for Research and
Advanced Study

ABSTRACT

The distribution of spawning chum salmon in relation to springs and ground-water seepage, and the survival of chum salmon eggs in those areas, was studied on the Chena River in 1963-65. Chinook and chum salmon censuses indicated low population levels although spawning density of chum salmon appeared high. Chum salmon predominantly spawned in locations supplied with ground-water seepage, while chinook salmon avoided areas of strong ground-water outflow. Chum salmon appeared to be limited in their distribution on the spawning grounds by the distribution and quantity of spawning substrate in seepage areas.

Intragravel water was sampled by means of plastic standpipes which were kept serviceable in winter by the addition of kerosene. Water was analyzed for dissolved oxygen, pH, alkalinity, hardness, and iron content.

Fertilized chum salmon eggs, contained in plastic-mesh bags, and placed in gravel beds affected by ground-water, had an average survival at hatching of 84.2%. Apparently high survival occurred despite dissolved oxygen levels of 2 mg/1 or lower. A linear correlation between oxygen concentration and dry weight of newly hatched alevins was demonstrated.

Egg losses in bags, possibly due to decomposition or scavenging, amounted to about 5%.

Results of water quality analyses and chum salmon egg survival in seepage areas were consistent with findings of Russian investigators studying chum salmon of similar spawning ecology.

ACKNOWLEDGMENTS

The salmon spawning study on the Chena River was financed jointly by the National Science Foundation, under grant #GB1068, and the U.S. Fish and Wildlife Service. In addition, field assistance and the use of equipment was extended by the U.S. Fish and Wildlife Service.

I wish to express gratitude to Drs. James E. Morrow, Jr., Clyde F. Herreid, II, and David R. Klein who critically read my thesis. Special appreciation is extended to Dr. James E. Morrow, Jr., who provided assistance with field work under any circumstances.

My appreciation is also extended to several fellow students who helped with field work, frequently in the face of inclement weather.

TABLE OF CONTENTS

	PAGE
INTRODUCTION	1
THE STUDY AREA	3
METHODS AND MATERIALS	7
Salmon Census	7
Standpipes	7
Water Quality	8
Egg Survival	11
RESULTS	15
Censuses and Distribution of Salmon	15
Water Quality	16
Ice Cover	24
Survival and Growth of Embryos	26
DISCUSSION	34
Census and Distribution of Salmon	34
Water Quality	35
Survival	37
CONCLUSION	46
LITERATURE CITED	48
APPENDIX	51

LIST OF TABLES

TABLE NO. PAGE

1. Survival of eggs in bags and other observations 29

2. Analysis of variance comparing survival in bags with location in the study area 39

APPENDIX

1. Results of fish censuses (1963) 52

2. Results of fish censuses (1964) 53

3. Intragravel and surface water temperature (C) in the study area and in the main river 54

4. Intragravel and surface water dissolved oxygen (mg/l) in the study area and in the main river . . . 56

5. Intragravel and surface water analyses in the study area and in the main river 58

LIST OF FIGURES

FIGURE NO.		PAGE
1.	Schematic drawing of the Chena River indicating the principal study area	4
2.	Schematic drawing of the Chena River indicating the study area and access route	5
3.	Standpipes and the water-sampling tent in the study area	9
4.	Locations of intragravel water sampling and egg survival sites in the study area	13
5.	Dissolved oxygen concentration and temperature in seepage effluents	18
6.	Dissolved oxygen concentration and temperature of surface water in the study area	19
7.	Dissolved oxygen concentration and temperature of intragravel water at point A	21
8.	Dissolved oxygen concentration and temperature of intragravel water at point 9	22
9.	Dissolved oxygen concentration and temperature of intragravel water at point 1	23
10.	Dissolved oxygen concentration and temperature of intragravel water at point 1N	25
11.	Maximum and minimum air temperatures recorded at Eielson Air Force Base	27
12.	Size comparison of embryos from points 1 and 2, and an opened chum salmon redd with ground-water . . .	30

FIGURE NO. PAGE

13. The relation of the average dry weight of newly hatched alevins in bags with the average dissolved oxygen concentration under which they were reared 32

INTRODUCTION

Certain salmonoid fishes, such as brook trout (*Salvelinus fontinalis*), sockeye salmon (*Oncorhynchus nerka*), and chum salmon (*O. keta*), regularly or preferentially spawn in springs or upwelling ground-water. Brook trout have been observed spawning directly downstream from springs or in gravel supplied with ground-water (White, 1930; Hazzard, 1932; Webster, 1962). Gravel that appears suitable to the casual observer may be completely ignored in preference to sites supplied with ground-water. Frequently brook trout will use an unlikely-looking sand-silt substrate possessing upwelling ground-water in preference to gravel beds not supplied with ground-water (Webster, 1962). Sockeye salmon seem less specific in their spawning requirements than brook trout. However, in the Wood River Lakes system, Alaska, where sockeye salmon spawn on lake beaches, in streams, or springs, survival is generally highest in certain springs (Burgner and Church, 1960). Two ecotypes of chum salmon, the summer and autumn races, occur in the Amur River, Siberia. The summer race has a fairly wide distribution but spawns predominantly in the lower reaches of the river in main channels not supplied with ground-water. The autumn race, on the other hand, is composed of larger fish, having greater fat reserves, which ascend the Amur to its tributaries and spawn in quiet creeks supplied with ground-water (Birman, 1953). Due to its habit of spawning in non-freezing springs, the autumn race has a more stable population size. Population expansion of the autumn race appears limited by the distribution of springs and the quantity of spawning area in them while the summer chum has no such limitations and, given a large escapement and a mild winter, can produce staggering numbers of offspring (Birman, 1957). In severe winters, the redds of summer chum salmon are strongly affected by freezing and the progeny perish en masse.

According to Lovetskaya (1948), returning adults of Amur River autumn chum salmon have virtually the same length, weight, and age composition of returning adults as do chum salmon of the Yukon River, Alaska. By contrast, chum salmon in other river systems of North America bear a strong morphobiological resemblance to summer chum salmon of the Amur.

Some chum salmon spawning occurs in springs in the Yukon drainage. That several Yukon tributaries which produce chum salmon have extensive gravel beds, which are unutilized for spawning, tends to indicate that a similar ecological spawning requirement may exist for Interior Alaskan chum salmon as for autumn chum salmon of the Amur River. Although potential gravel beds are present in these streams, perhaps freezing mortality would make them "unavailable" for spawning.

The present study was designed to determine the effect of ground-water on the distribution and abundance of spawning salmon in the Chena River. In addition, survival of chum salmon from egg to alevin and the conditions of incubation in spring seepage areas was investigated. Both natural redds and artifical methods of incubation were studied. Techniques for obtaining water samples from intragravel water sources for water quality analyses in winter were developed. An attempt was made to compare survival of chum salmon eggs and alevins in spring water seepages with water quality. Tentative findings on survival in redds and in containers buried in spawning beds are reported in this paper.

THE STUDY AREA

The Chena River is approximately 150 miles long with a watershed area of about 1,980 square miles and an average annual discharge of 1,344 cubic feet per second (Figure 1). It is a non-glacial stream, with thickly forested banks and an abundance of ground-water sources. Water temperature frequently reaches 16 C in July. Surface freezing usually occurs in November while the spring flood takes place in the latter part of May.

Fish species in the Chena are chinook salmon (*Oncorhynchus tschawytscha*), chum salmon (*O. keta*), northern pike (*Esox lucius*), grayling (*Thymallus arcticus*), brook lamprey (*Entosphenus sp.*), burbot (*Lota lota*), northern sucker (*Catostomus catostomus*), slimy sculpin (*Cottus cognatus*), and several species of coregonids.

The specific spring area investigated is 64 river miles upstream from the confluence of the Chena and Tanana Rivers (Figure 2). Springs are located in a left bank channel approximately one and one-quarter miles long. This auxiliary channel of the main river, or slough, derives its water source primarily from springs during low river flows in summer and entirely from ground-water sources in winter. Abundant spring outfalls occur along the base of a bank rising three meters above water level. Individual seepages contribute about 0.3 gallons per minute each to surface water in winter. Minimum slough discharge in winter is approximately three cubic feet per second. Water depth in winter ranged from 30 to 90 cm over the particular gravel bed investigated. Surface water velocity was 0.2 meters per second during salmon spawning in August 1964, falling to zero mps in winter.

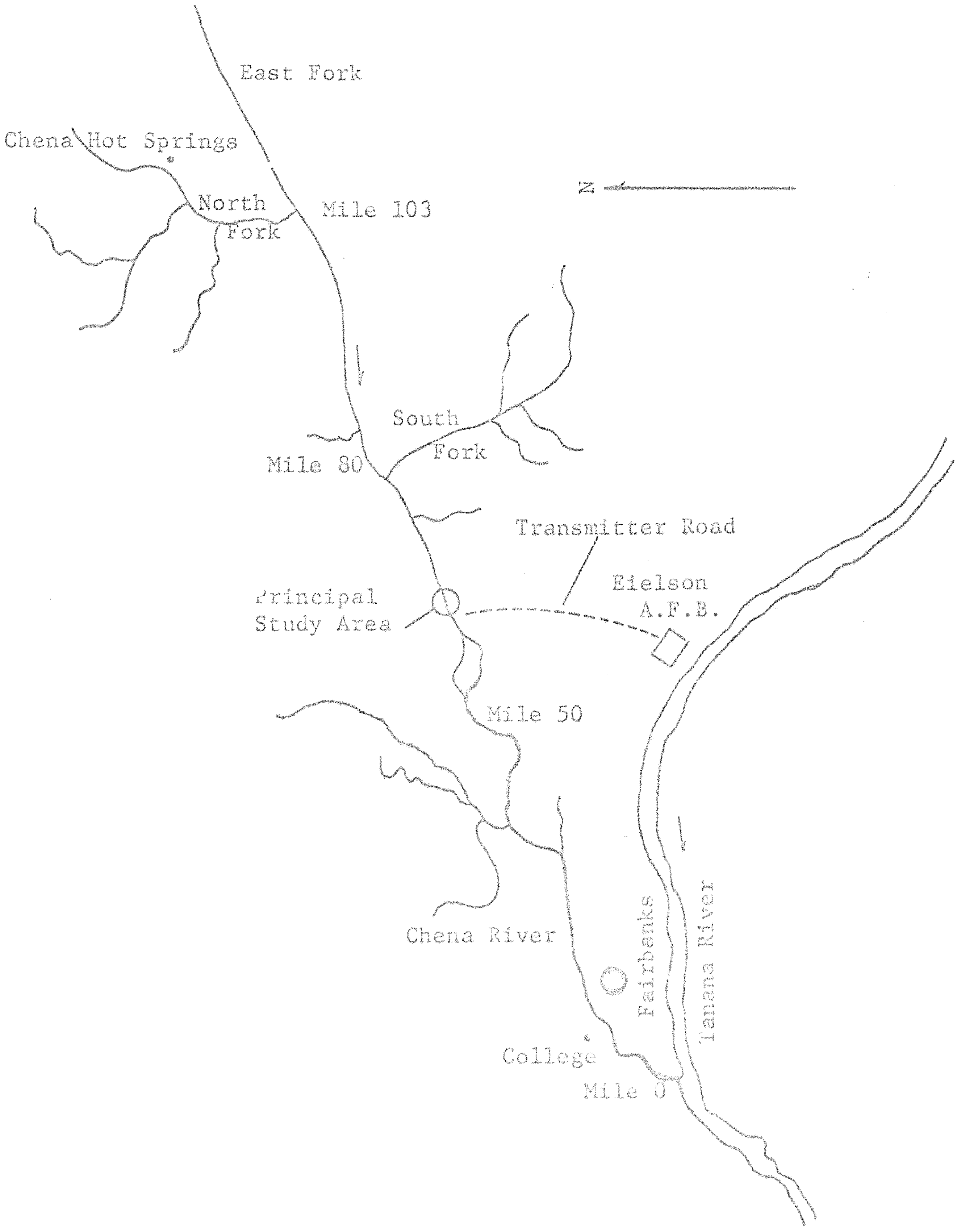


Figure 1. Schematic drawing of the Chena River indicating the principal study area.

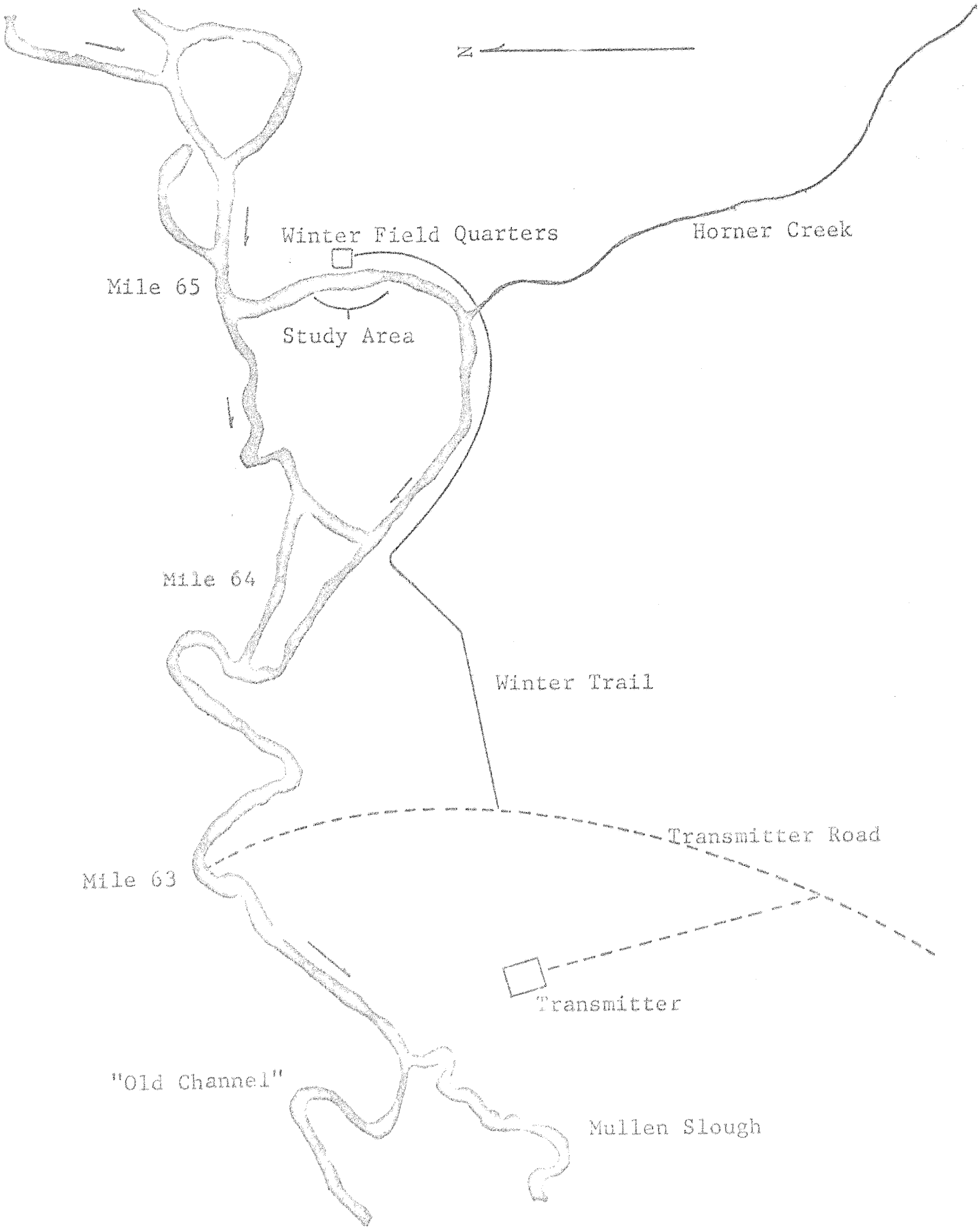


Figure 2. Schematic drawing of the Chena River indicating the study area and access routes.

The spring area described was selected on the basis of (1) past use by spawning chum salmon, (2) the presence of springs, and (3) its accessibility in winter. In summer the study area could be reached on foot, or by boat by embarking from a maintained road passing through Eielson Air Force Base and terminating at the river in the vicinity of river Mile 63. In winter, the site was reached on foot, or by snow vehicle.

METHODS AND MATERIALS

Salmon Census

Salmon censuses were made during both summers of the study. Adult salmon on redds were counted from a boat proceeding upstream. Limits of the spawning area were defined by noting the incidence of live fish and carcass concentrations. The general length of river sampled was between Mile 58 and Mile 100. Subtotals of fish counted were recorded for five-mile segments. The upper reaches of the Chena, above Mile 100, were usually unnavigable due to low water.

To avoid counting the same carcasses twice, all carcasses were collected. These were tabulated, marked, and removed from the water. A curve of the river where spawners were known to concentrate was "run" to count live fish and then a second pass was made to gather carcasses. All sloughs and tributaries were treated in a similar manner.

Major spawning concentrations were observed concurrently with counts. Redds were marked at the shore with colored tape. Exploratory excavations were occasionally made to verify suspected redds.

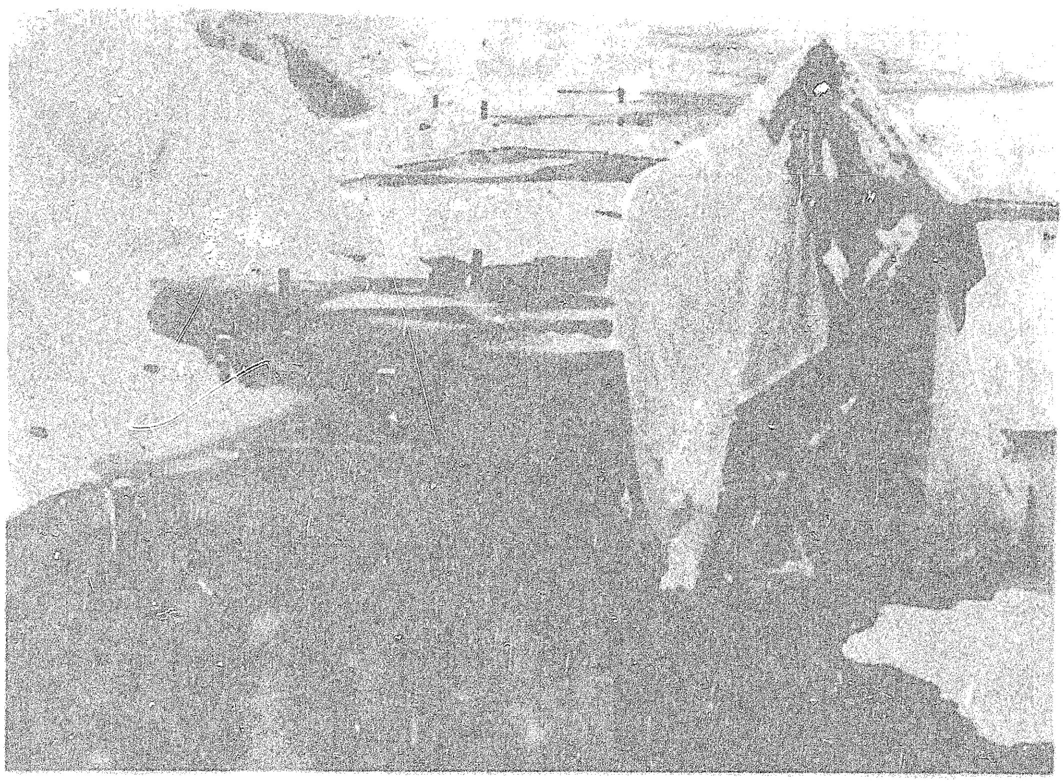
Standpipes

Physical and chemical characteristics of chum salmon redds were determined by obtaining intragravel water from standpipes placed on them. Standpipes were constructed of "ABS-80" plastic pipe. This material, which is 4.2 cm in inside diameter, was cut to a length that would allow a few centimeters to project above water when the pipe was in sampling position. Four evenly spaced circumferential rows comprised of 24 four-millimeter holes were drilled in each pipe commencing 1.9 cm from one end. A white line around the circumference of each pipe, 25 cm from the end bearing holes, served as a depth indicator. Pipes were set in the streambed to the level of the line. This was accomplished by digging a hole 25 cm deep to receive them. The stratum of water sampled was that lying between 17.4 and 25.0 cm in the streambed. Turbid water was removed from pipes immediately after placement. A quantity of kerosene (sp gr 0.8) was added to prevent freezing by depressing the water level. Addition of a cap completed standpipe installation (Figure 3).

Fairly reproducible results can be obtained when using standpipes for intragravel water sampling so long as certain precautions are taken. Twenty-four hours should elapse before sampling freshly installed pipes and samples should be small (McNeil, 1962). The first precaution insures that the streambed has stabilized and the second insures that water does not flow into the pipe rapidly, increasing the possibility that water originating from a different gravel stratum is sampled. By obtaining two large water samples in sequence, McNeil showed that dissolved oxygen was lower in the second sample in the case where the point sampled had a fairly low level of dissolved oxygen, and higher at points where the oxygen level was high. He attributed the former to poorly oxygenated ground-water serving as the source of intragravel water, and the latter to highly oxygenated stream surface water being the source.

Water Quality

Water samples were drawn from standpipes in 8-dram shell vials via 4-mm rubber tubing. A glass "U" tube at the terminus of the suction line raised the point of intake about 5 cm above the bottom of the standpipe well.



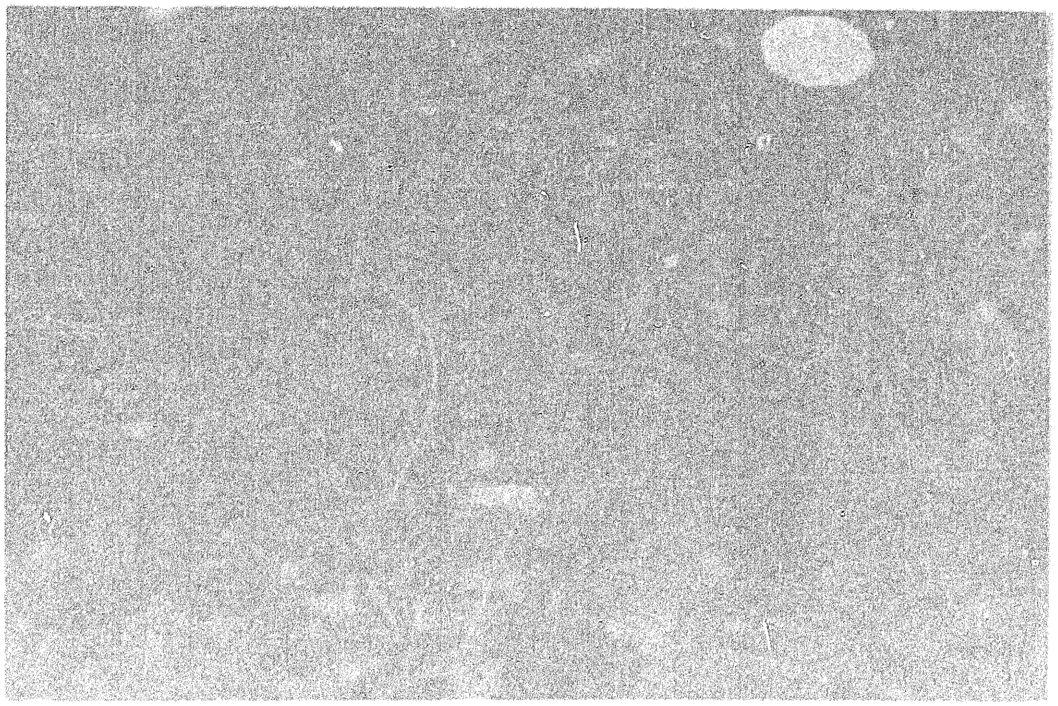


Figure 3. The upper photo shows the water sampling tent and standpipes in the study area. The lower photo shows a standpipe-egg-group set. Nylon cords and identification tags are visible above the gravel.

Samples were analyzed for dissolved oxygen, carbon dioxide, pH, iron, alkalinity, and total hardness. Dissolved oxygen was "fixed" in shell vials according to the method adopted by McNeil (1962). Twenty-five-ml portions of solution were titrated against 0.0125 N sodium thiosulphate. A stock solution of sodium thiosulphate was standardized against 0.025 N potassium dichromate. Standardization and dilution of thiosulphate was done prior to a series of water analyses. Oxygen determinations were fairly precise when careful technique was used. Tests conducted under laboratory conditions gave a range of 0.4 mg/l in terms of a mean value. A student's t test ($t_{.05}$) indicated no significant difference between means of samples containing small amounts of kerosene in comparison with those without kerosene. Three duplicate water samples taken from the Chena River in winter agreed to 0.1 mg/l.

Fifty-ml samples of water were titrated against 0.0114 N sodium hydroxide to determine carbon dioxide concentration. Thirty-ml samples were taken to perform other analyses which were done with Hach chemical kits. Results were based on color changes or comparison with color standards.

Temperature was taken with a model 43 Yellow Springs Tele-Thermometer. A #401 submersible probe with vinyl tip was employed. Standpipe temperatures were determined by lowering the probe to the bottom of the well. Tele-Thermometer readings agreed closely with those taken using a hand held Celsius thermometer. Surface water temperature was determined by taking one reading each time at the same place in the study area.

Sampling was carried out in a heated tent when outside air temperature was below 0 C. A tent frame constructed of willow poles was covered with sections of a parachute canopy (Figure 3). A small Coleman stove suspended from the apex of the poles provided a heat source. Extraction of water samples at temperatures below minus 30 C (-22 F) was not efficient due to suction line freezing within the tent.

Chemical analyses and cursory egg and alevin examinations were made at the study area in a small cabin.

Egg Survival

On 30 September 1964, approximately 8,000 chum salmon eggs were taken and fertilized at the Delta-Clearwater River for survival experiments on the Chena River. Facilities and equipment of the Alaska Department of Fish and Game were made available to the investigator at its Delta-Clearwater field station. Chum salmon were caught in a spring-fed slough tributary to the Delta-Clearwater but connected with the Tanana River. Eggs were fertilized as the fish were caught. Unfertilized eggs were also taken. Eggs were held overnight while in transit to the Chena River planting site. Water temperature at the Delta-Clearwater was the same as in the study area. On 1 October 1964, 28 hours after fertilization, eggs were planted in the study area. Eggs were counted into 100-egg samples and placed in plastic-mesh bags along with about one pint of stream gravel. Plastic bags, under the trade name "Saran", measured 19.2 x 33.9 cm with eight meshes per centimeter. After addition of eggs and gravel, bags were tied shut with nylon cord, to which was attached an identifying tag, and buried in the streambed. Ten groups of bags were planted using a non-systematic distribution scheme. A random scheme was not used because of excessive depth and unsuitable bottom composition in some places. Two bags of unfertilized eggs were handled in the same manner as fertilized eggs to compare their rate of decomposition with unfertilized or dead eggs in fertilized samples. Water depth from surface to gravel over egg bags ranged from 9 cm to 46 cm.

The remaining fertilized eggs were incubated by one of two methods. One hundred eggs were placed in each of ten plastic-screen containers of dimensions 8 x 8 x 1 cm tied on racks in a covered wooden box resting on the streambed. The other portion of eggs (about 3,000) was buried free in a pit to simulate a salmon redd.

One standpipe was placed at the downstream edge of each egg-bag group, at the artificial redd, and on four natural redds in the study area. Four standpipes were set in the main river at the head of a riffle 0.3 mile upstream from the study area. Each point sampled by standpipe, or standpipe-egg group combination, was given a code designation. Egg groups were numbered from one to ten, and pipes on redds were designated by number with the suffix "N". The artificial redd was designated "A". Figure 4 depicts the arrangement of egg-bag groups and salmon redds in relation to ground-water sources.

One egg-bag from each group was removed at three intervals during the incubation period. Bags were removed on the same day. Specimens were preserved for subsequent evaluation.

Magnification was required to determine survival at the blastodisc stage, whereas at later stages it could be determined by gross examination. Eggs containing embryos displaying slightly less growth than the majority of embryos in the sample were considered alive if no signs of disintegration were seen. If the difference was great, a subjective

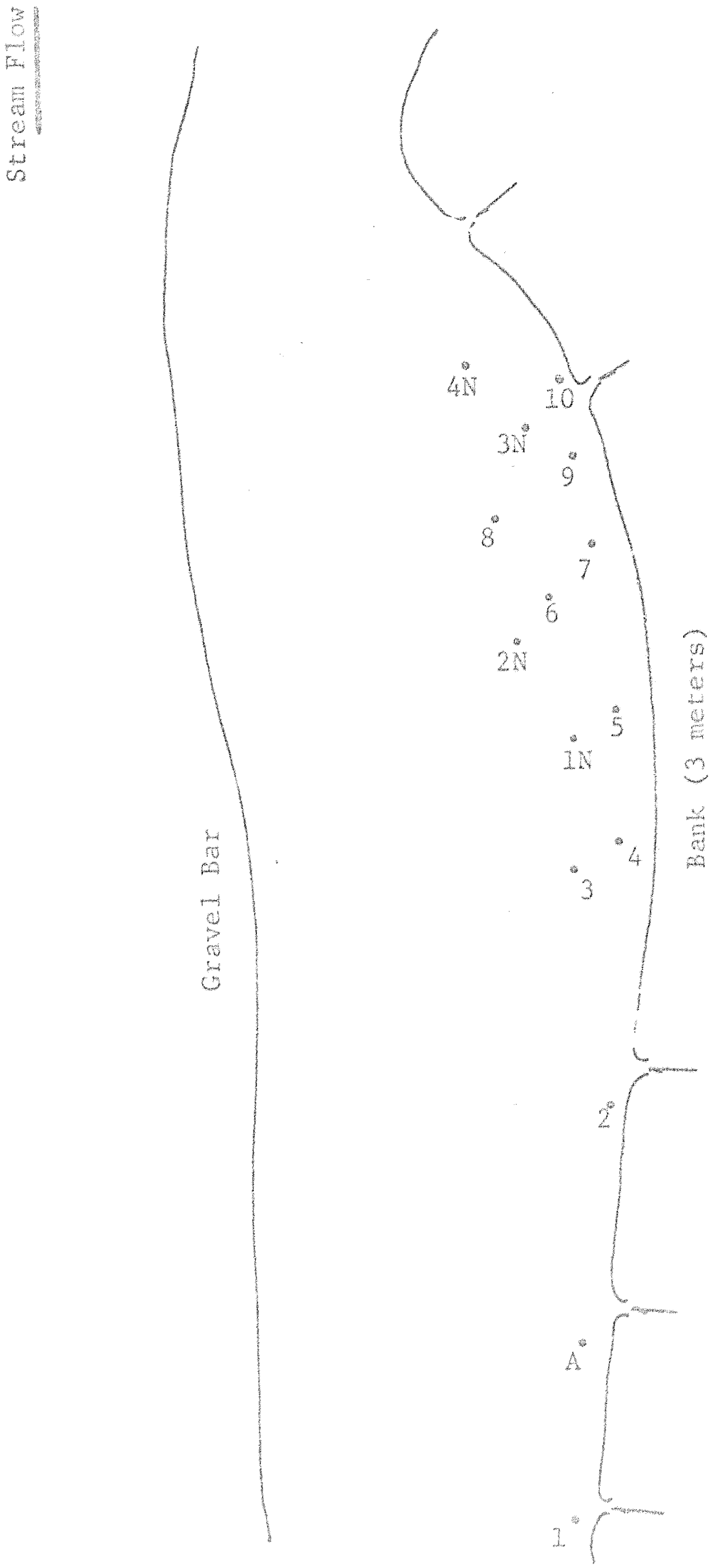


Figure 4. Locations of intragravel water sampling and egg survival sites in the study area. The arrows indicate visible ground-water effluents. Surface water flow is from top to bottom.

decision was made as to whether or not the embryo had been alive in the bag. Other observations made included recording the incidence of clear, opaque, ruptured, and mouldy eggs per sample. Aquatic insects occurring in bags and redds were collected and identified.

Ten eggs were taken from each sample at the second egg-bag removal and fixed in Bouin's Solution. Embryos were freed from yolk and stained in borax carmine. Alevins from bags, at the last removal, were dried and weighed for attained growth comparison between samples.

RESULTS

Censuses and Distribution of Salmon

The minimum total salmon run to the Chena River based on counts made by boat, was 898 chum and 147 chinook salmon in summer and fall, 1963. In 1964 the totals were 401 chum and 46 chinook salmon. The river carried a heavy silt load throughout much of the 1964 spawning season. In addition to siltation resulting from summer freshets, construction of the Chena Hot Springs Road, running parallel to the river on the north side of the valley, resulted in highly turbid water over the most important spawning beds in the Chena drainage. The road bed was laid over several side channels which produced turbid discharges into the main river. The main river channel was diverted south away from the road site in several locations. Salmon counts were impeded and often rendered impossible by the siltation which resulted from these activities. In two cases, cessation of flow or slough blockage, probably resulted in destruction of salmon eggs in spawning beds. Approximately one mile of the main river channel was diverted south away from the mouth of Colorado Creek. Before the change was effected, 11 chinook salmon were seen on redds just above Colorado Creek. Surface flow over those redds was eliminated after the diversion was completed.

In 1963 chum salmon concentrated in three areas supplied with groundwater outflow: (1) the lower end of the old channel at Mile 58, (2) a side channel at Mile 64, and (3) Hodgins Slough. More than 100 fish were counted in each area, with the largest number, 291 fish, occurring in the side channel at Mile 64. In 1964, however, the distribution of spawning chum salmon in springs was somewhat different. Hodgins Slough was blocked by road construction and no chum salmon spawned there. A natural channel change of the river occurred at Mile 76 during the 1964 spring flood. Approximately 28 chum salmon spawned there before the change while over 100 fish were observed in the area in August 1964. Water velocity and depth changed from 0.6 mps (meters per second) to about 0 mps, and from 1.0 m to about 0.3 m, respectively. Slightly less than 50% as many chum salmon were counted in the side channel at Mile 64 in 1964 as in 1963. The 1964 run to the old channel at Mile 58 was 66% smaller than in 1963.

Chinook salmon were more evenly distributed on spawning riffles than were chum salmon in both years. Chinooks built redds at water depths of 1.2 to 1.8 m and water velocities of about 0.5 to 0.8 mps. In contrast, chum salmon spawned at depths ranging from 0.05 to 1.2 m and water velocities of 0.0 to 0.6 mps. Results of fish censuses by five-mile river segments appear in Tables 1 and 2 (Appendix).

Water Quality

All seepage water analyzed during the summer and winter had (1) a pH of 6.5, (2) a temperature lower than the main river in summer and higher in winter, (3) an iron content of about 0.1-0.3 mg/l, and (4) a lower dissolved oxygen level than in surface waters of the main river. Two general types of ground-water seepages were detected in the study area: those with low temperature and high dissolved oxygen and those with high temperature and low dissolved oxygen (relative to channel surface water in winter). A seepage near point 1 had a temperature of 2-3 C and an oxygen level of about 2-3 mg/l as compared with a seepage near point 2 whose temperature was less than 1 C and whose oxygen level was about 4 mg/l (Figure 5). One exception was encountered in a spring area at Mile 66 where both dissolved oxygen and temperature were low. Seven chum salmon had spawned in this spring in 1963 but no fish or redds were seen there in 1964.

Temperature in the main Chena dropped to 0 C in December 1964 while surface water in the study area was about 2 C and declining slowly. At the end of the egg incubation experiment, study area surface water was fairly steady at 1 C. Intragravel water temperature was generally 1 or 2 C higher than the study area surface water. Only one of the points sampled was consistently lower in temperature.

Dissolved oxygen sampling in connection with egg survival experiments was begun on 30 October 1964. Study area surface dissolved oxygen concentration was initially 5.7 mg/l. Oxygen concentration apparently fell fairly rapidly to 3.8 mg/l by mid-November, then rose to 4.9 mg/l by mid-December, and then declined less precipitously to about 2.0 mg/l in March 1965 (Figure 6). Intragravel water dissolved oxygen was usually lower than that of the surface, but in those cases where temperature was lower, dissolved oxygen was higher.

Point A consistently had the lowest levels of dissolved oxygen and the highest temperature readings. Dissolved oxygen concentration at that point, which was 3 mg/l lower than in surface water at the initial sampling, experienced a number of fluctuations that were not observed at other points. While surface water oxygen concentration was falling from 5 mg/l to 3 mg/l, intragravel water at point A dipped below 1 mg/l although no similar trend occurred in surface water. At the onset of

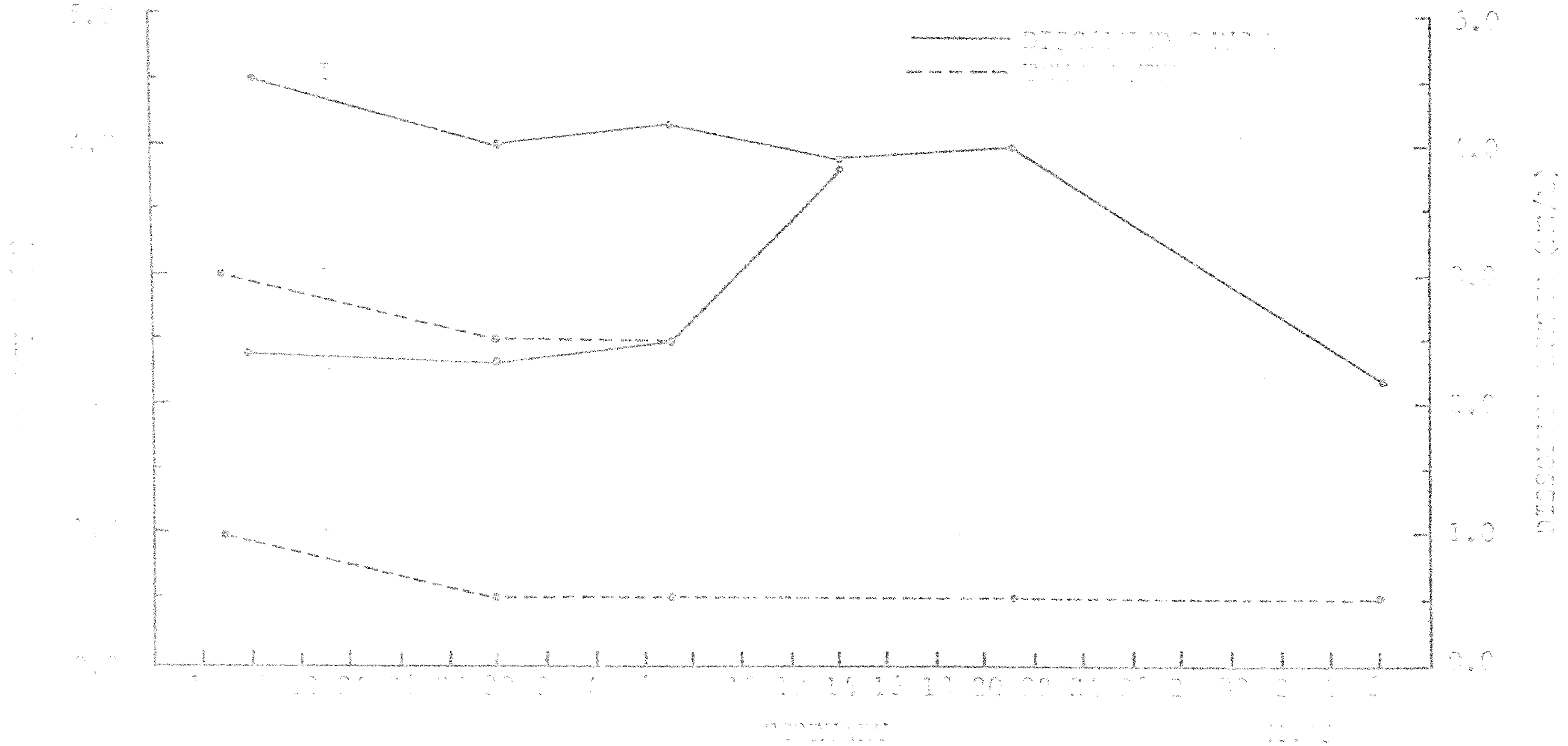
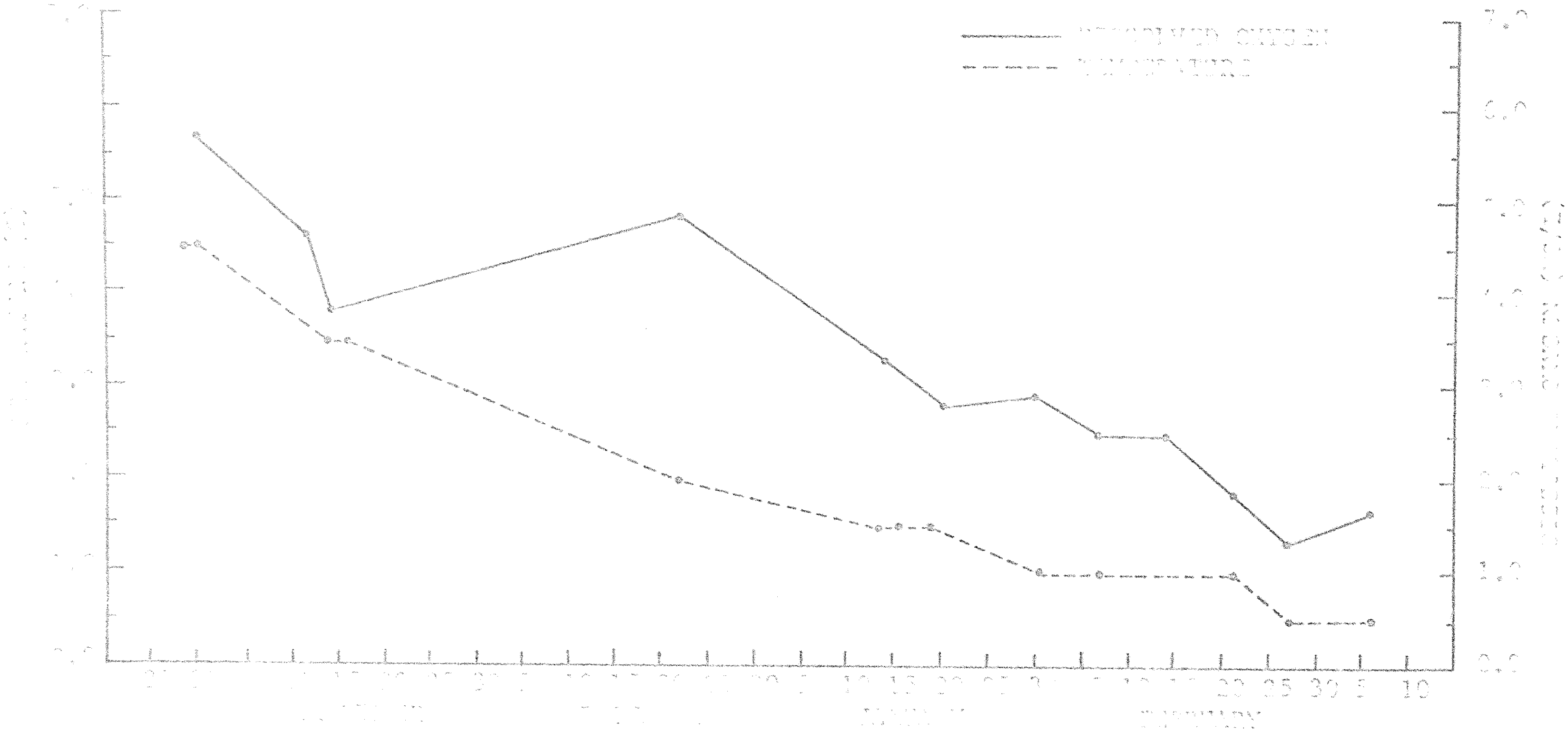


Figure 5. Dissolved oxygen and temperature in seepage water effluents, I= at [illegible]
[illegible] point 2, II= at effluent near point 3.


7.0
6.0
1.0
0.0
25 30 5 10

sampling, temperature at point A was slightly lower than surface water temperature, but did not fall as sharply, or as far, as surface temperature (Figure 7). The difference in water quality observed through comparison of dissolved oxygen concentration and temperature levels at point A and at the surface indicate that point A was strongly affected by ground-water. In a similar manner, by comparison of point 9 with the surface, the same conclusion is reached as for A. In contrast to conditions at point A, point 9 was higher in dissolved oxygen concentration than the surface water. Dissolved oxygen at point 9, with a few minor fluctuations, declined gradually from 6 mg/l to about 3 mg/l by March 1965. Dissolved oxygen concentration at point 9, and a few other points, could not be determined at the time the last egg-bags were removed due to ice formation in those standpipes. Intragravel water at point 9 was slightly lower in temperature than surface water at the beginning of sampling, and remained lower throughout the experiment with eggs in bags (Figure 8). At point 1 the effect of ground-water seepage became more apparent in January and February 1965. The dissolved oxygen concentration at point 1 was initially about 2 mg/l lower than at the surface, but it seemed to change in phase with surface oxygen concentration. During the terminal part of egg incubation, dissolved oxygen concentration at point 1 and in surface water no longer corresponded with one another. Temperature at point 1 was generally higher than at the surface. Fluctuation in temperature corresponded to fluctuation in dissolved oxygen at point 1 in late January and February 1965 (Figure 9). Water quality determined in a salmon redd (point 1N) was typical of most points sampled. Dissolved oxygen in the redd followed closely the level

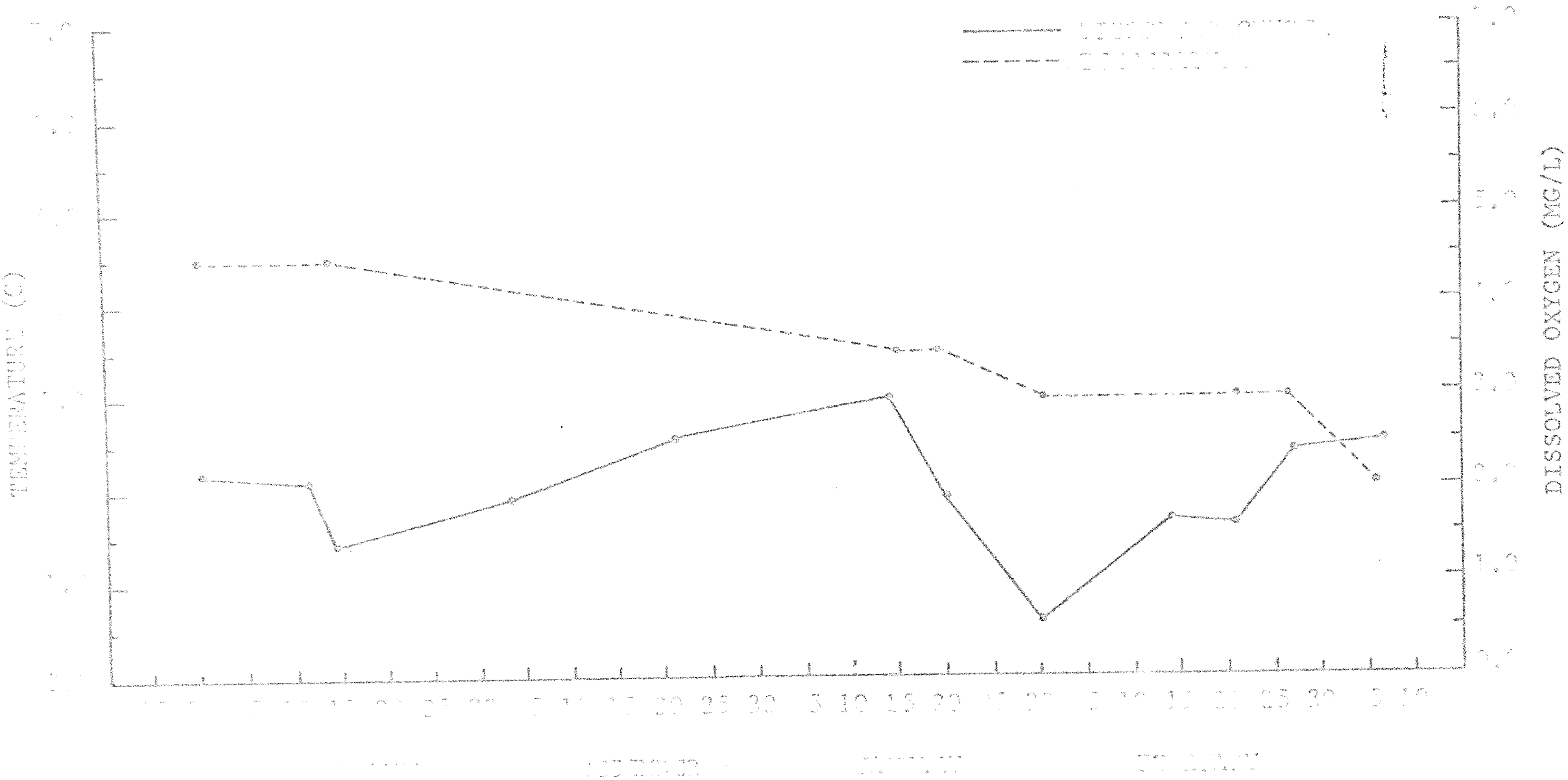
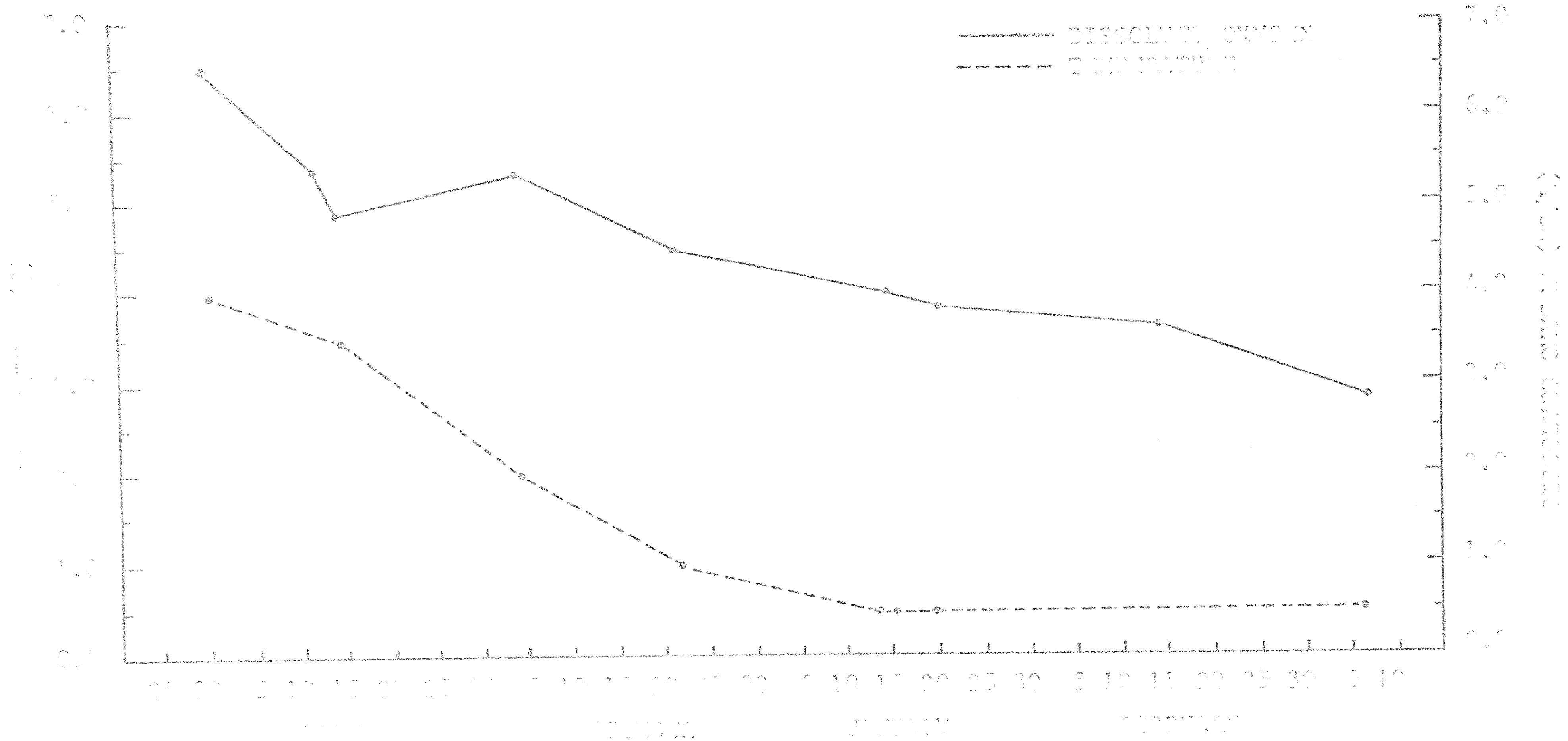


Figure [illegible]. Dissolved oxygen concentration and temperature of intragravel water at point A.



[illegible] concentration and temperature of [illegible] gravel water at point 9.

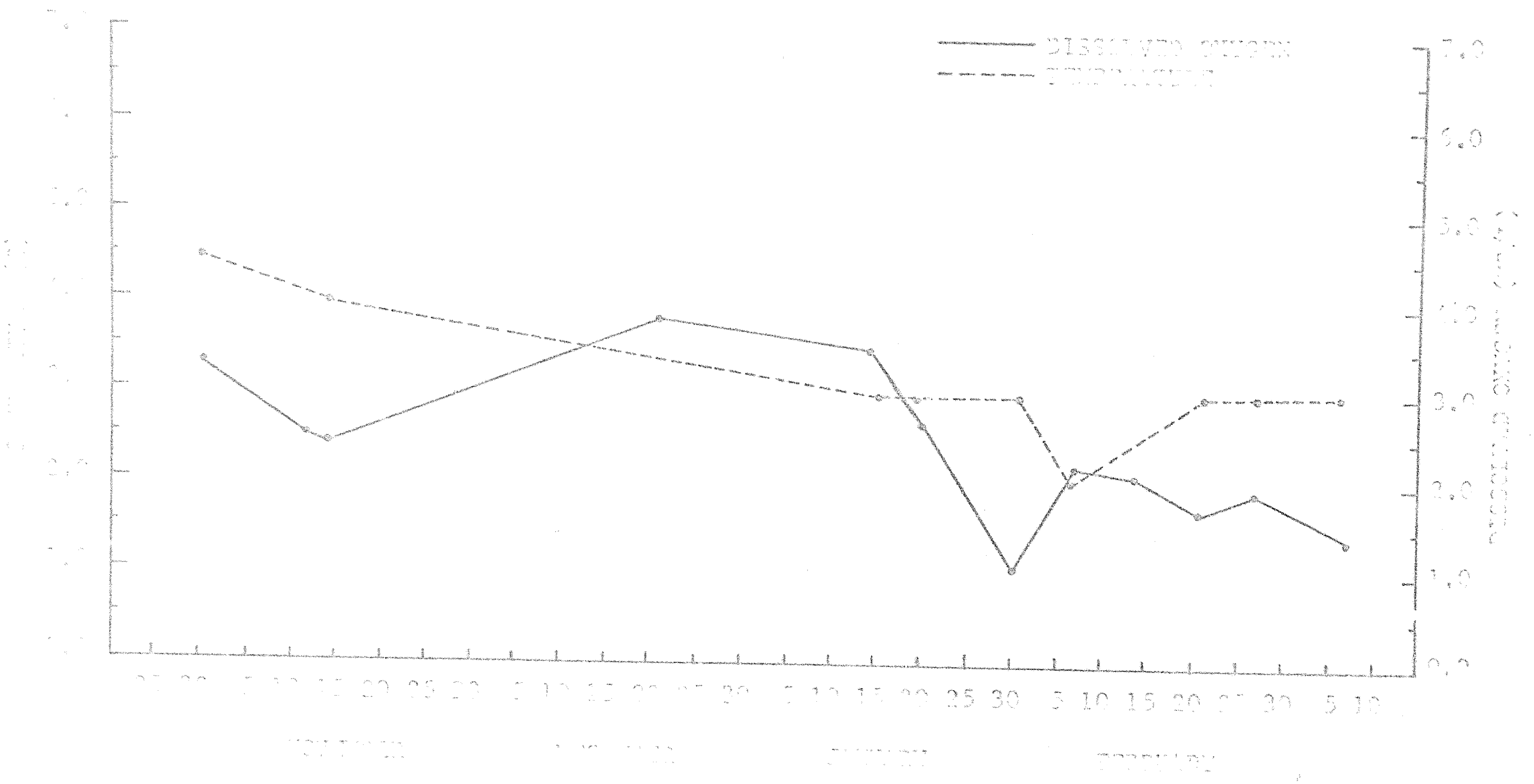


Figure 6. Dissolved oxygen concentration and temperature of intragravel water at point 1.

in the surface water. There was generally about 1 mg/l less of dissolved oxygen in the redd than in surface water, while the temperature was about 1 C warmer than the surface (Figure 10).

Average dissolved oxygen concentration (about 3.8 mg/l) for all points of intragravel water sampled at the estimated time of egg hatching in salmon redds, which occurred about 1 December 1964, was higher than at the last removal of egg-bags (about 2.2 mg/l) on 31 January 1965. Temperature and dissolved oxygen determinations made in fall and winter 1964-65 appear in Tables 3 and 4 (Appendix).

Intragravel water hardness (in terms of $CaCO_3$) increased in the study area from approximately 86 mg/l, during the incubation of eggs in bags, to about 103 mg/l one month after hatching began. Alkalinity was initially 69 mg/l and increased to 86 mg/l during the same period. Iron levels ranged from 0.1 mg/l to 0.3 mg/l but were usually 0.1 mg/l. Intragravel water in the study area remained at pH 6.5. On 18 January 1965, pH in redds appeared to be slightly higher than at most experimental egg sites, but did not reach 7.0. Results of water analyses appear in Table 5 (Appendix).

After 20 January 1965, several standpipes were frozen both in the main river and study area. Although ice obstruction could be removed temporarily, pipes were usually frozen on the following day.

Ice Cover

An ice layer was first observed at the edge of a gravel bar in the study area on 24 October 1964, although surface temperature at mid-channel was 4.5 C. Ice cover advanced or receded depending on air temperature. Surface water from the main river ceased entering the channel by 10 November, although main river overflow allowed temporary re-entry.


DISSOLVED OXYGEN (MG/L)

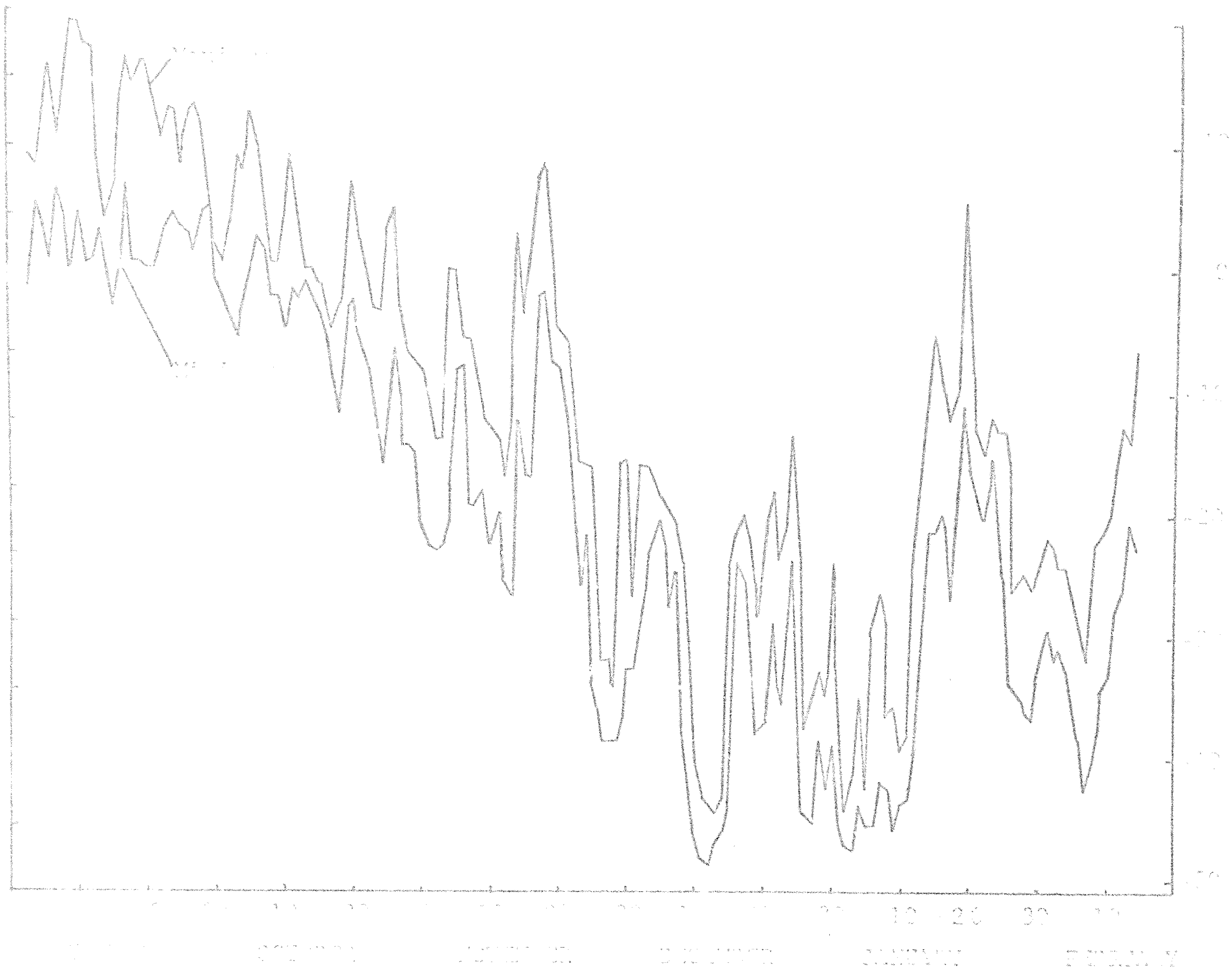
Ice cover was complete on the study area, except for places of groundwater upwelling, at the end of December. Ice thickness in a few places unaffected by upwelling was 10-15 cm by that time.

Warm weather (-18 to +2 C) in mid-January 1965, allowed parts of the channel to reopen and remain free of ice for some days after cold weather had returned. By the end of January, the surface was refrozen. Ice thickness was highly variable not only at different locations but at different times at the same location. Thickest ice observed in the study area was 25 cm at point 5 when the last subset of egg-bags was removed.

The coldest period of the winter occurred in December 1964 and early January 1965. December low temperatures set new records and distinguished the month as one of the coldest on record. Despite severe freezing conditions, no freezing of salmon redds was encountered. It is possible that redds might have been affected had the low temperatures been more persistent, or had they occurred later in the new year after surface water in the study area had reached its winter low temperature. Maximum and minimum air temperatures recorded near the study area appear in Figure 11. Main river riffles remained open or were covered with a very thin layer of ice throughout winter. Thickest main river ice measured 45 cm on 17 January 1965. There was considerable evidence of ice slump and overflow as the water level fell. By February the river had fallen approximately 1 m from its October level. Water level in the study area had dropped about 5 cm during the same period.

Survival and Growth of Embryos

The first subset of [illegible] egg-bags was removed on 17 November 1[illegible],


10
20
30

after 49 days of incubation. Average survival was 95.2% with a range of 89-99%. Survival in the second subset removed at 109 days averaged 88.6% with a range of 80-97%. Average survival in the last subset, removed 31 January 1965 at 123 days, was 84.2% with a range of 52-97%. Thirty-two percent of the total eggs in bags were hatched with a sample range of 0-89% at the last removal. Embryo survival and other observations made during specimen sorting appear in Table 1.

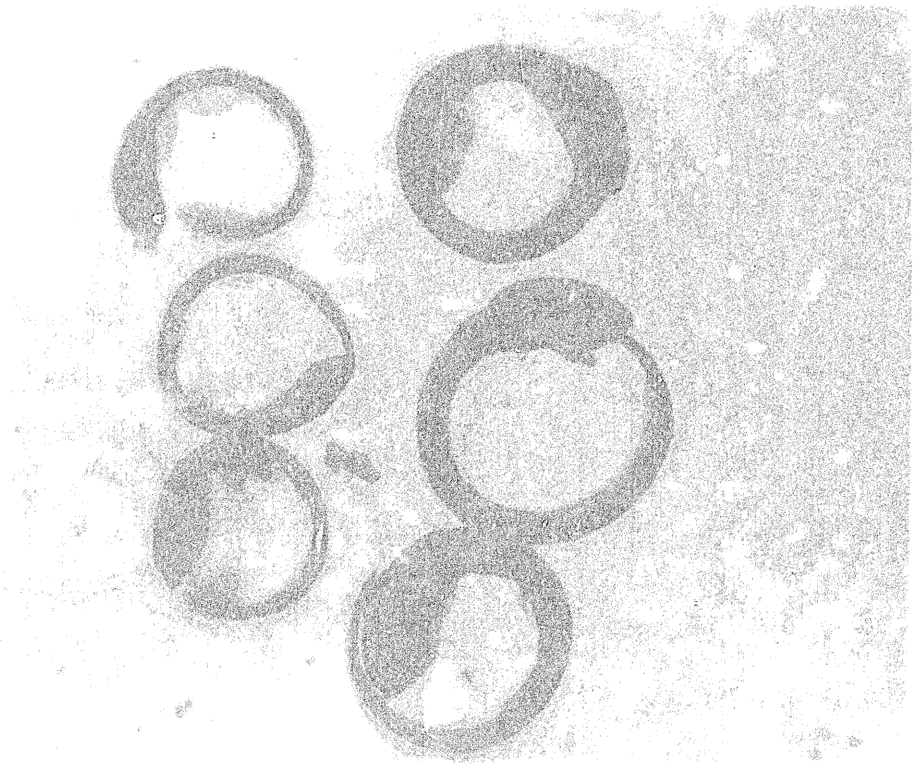
Survival of eggs in the artificial redd (point A) was 66% on 26 October 1964, 46.3% on 17 November 1964, and 0% on both 30 December 1964 and 28 February 1965. Survival in the surface water box, from which samples were removed at bimonthly intervals, ranged from 54-100%.

Embryos exhumed from redds in the latter part of October 1964, had eye pigment (eyed) and were about one month from hatching. The importance of determining survival prior to hatching was not appreciated at the time and only a few redds were explored. Ninety-four percent survival of eggs was found in 1N on 25 October 1964. On 31 December, when alevins and a few egg fragments were found, survival was 70.9% in 1N. In 4N survival was 61.3% with 49 live alevins, 17 decomposed alevins, and 14 ruptured eggs. On 27 February 1965, 100 live alevins but no egg fragments were found in the same redd. Extensive digging in 2N on the same day produced nine alevins and 11 egg fragments. An alevin sample from 3N was misplaced before it had been evaluated. A redd excavated at Mile 76, on 24 January 1965, was found to contain 51 alevins and two egg fragments. When the redd was opened, ground-water was seen to flow up through the sand in the bottom of the pit (Figure 12). Alevins were robust in appearance and averaged [illegible] mm in total length.

TABLE 1. Survival of eggs in bags and other observations

Sample	Total Specimens			Eggs												Alevins						Percent Hatched			Percent Survival		
				Clear			Arrested			Opaque			Ruptured			Live			Dead								
#	1*	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
1	100	100	95	2	3	-	5	6	1	2	3	2	0	1	1	0	0	87	0	0	2	0	0	89	91	80	89
2	100	92	95	1	0	-	0	0	3	6	-	1	0	6	2	0	2	73	0	0	1	0	2	74	93	86	85
3	100	99	91	6	2	8	8	8	5	2	?	4	1	8	18	0	0	29	0	0	4	0	0	33	89	83	52
4	100	99	94	1	3	0	14	17	4	2	1	1	0	13	2	0	0	41	0	0	2	0	0	43	97	82	85
5	100	99	90	3	-	0	0	7	8	-	-	1	0	5	3	0	0	1	0	0	0	0	0	1	96	92	83
6	9[illegible]	100	97	0	1	5	0	4	2	1	-	2	0	3	2	0	2	6	0	0	0	0	2	6	97	92	86
7	100	98	96	0	1	2	0	1	1	2	0	1	0	0	0	0	0	8	0	0	0	0	0	8	96	94	92
8	100	101	97	2	2	0	5	2	2	1	-	0	0	6	0	0	0	50	0	0	4	0	0	54	96	87	90
9	100	10[illegible]	100	1	2	0	2	2	0	0	0	1	0	1	1	0	0	0	0	0	0	0	0	0	99	97	97
10	101	96	90	1	1	0	5	4	0	0	0	5	0	[illegible]	0	0	0	9	0	0	2	0	0	11	98	93	83

* This row indicates the removal group. 1= 17 November 1964; 2= 16 January 1965; 3= 31 January 1965



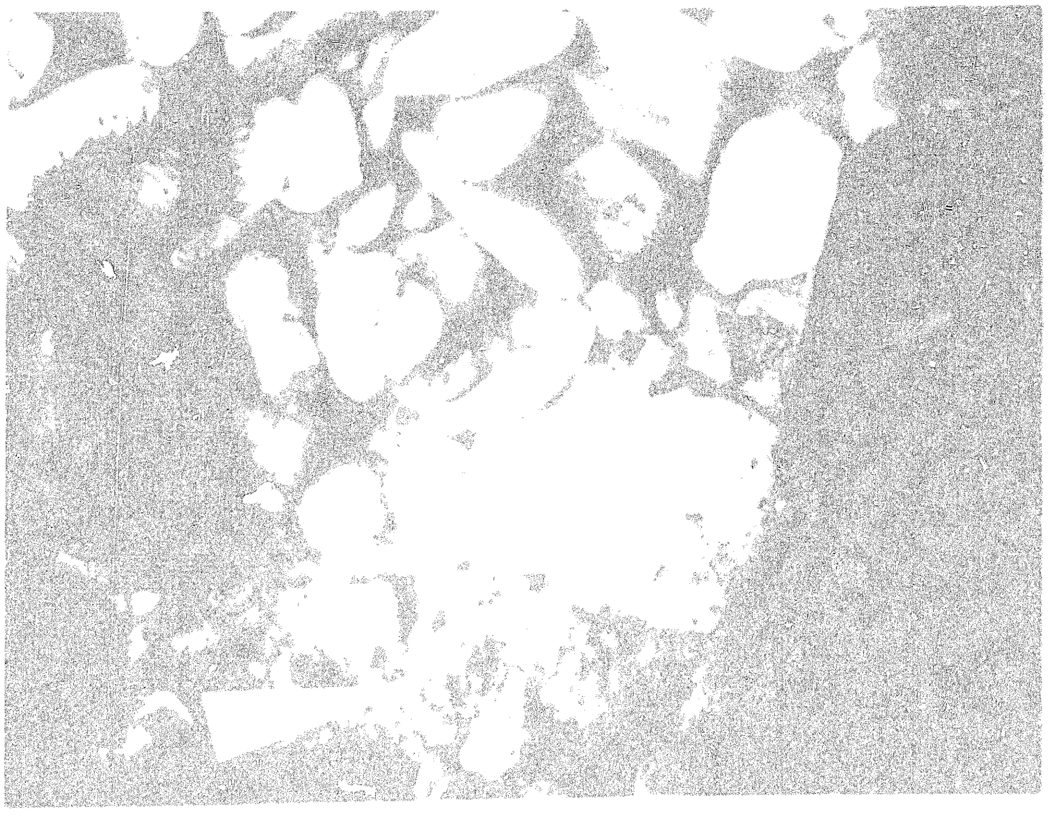
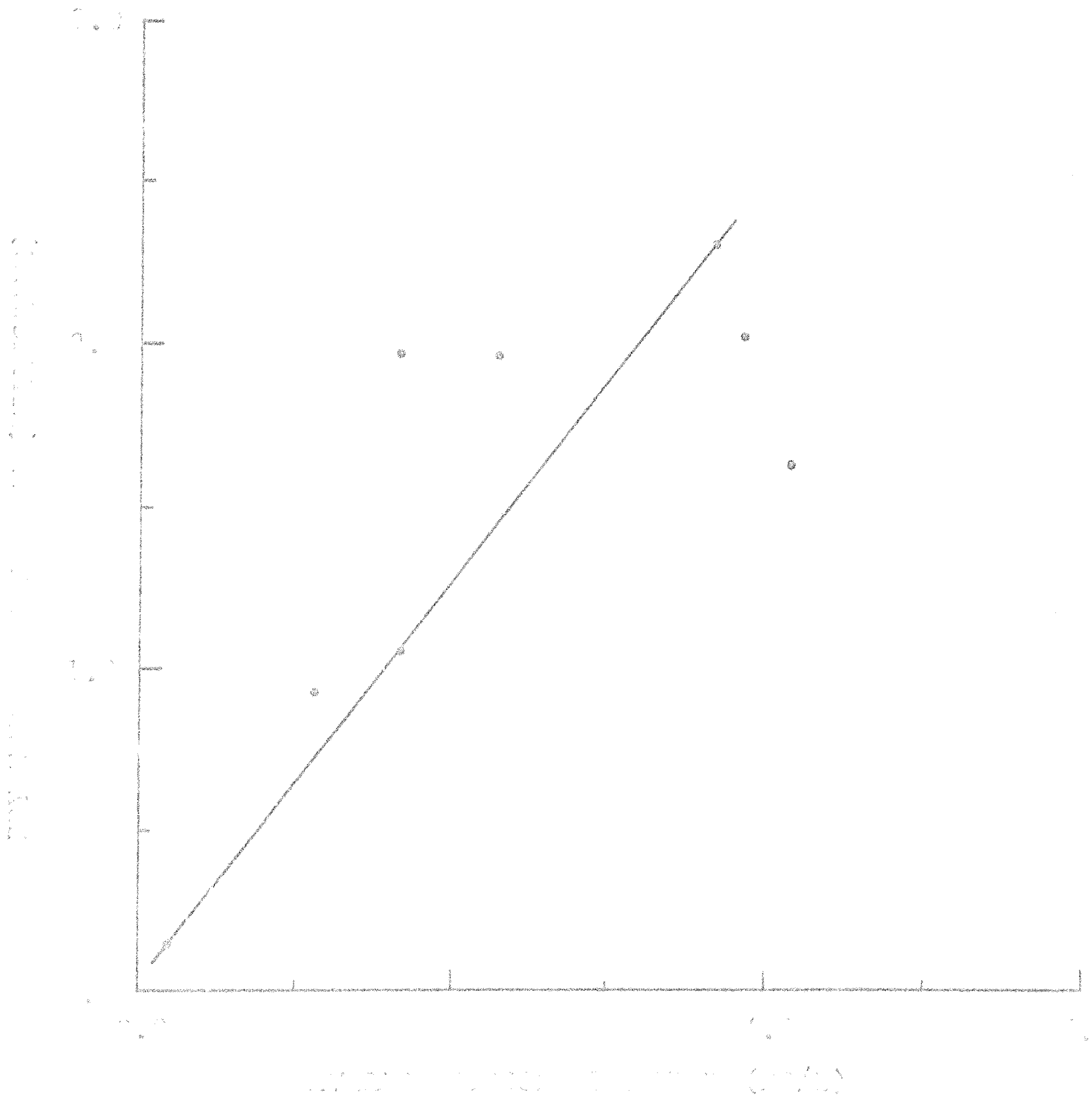


Figure 12. The upper photo shows the size comparison of embryos from point 1, on the left, and from point 2, on the right (embryos about 4X). The lower photo is of an opened chum salmon redd having upwelling ground water.

Fourteen chinook salmon alevins at advanced yolk-sac stage were taken from a redd at Mile 65 on 28 February 1965. The pit of this redd had been dug shortly before 27 July 1964, but just when eggs were deposited is unknown.

Each egg-bag group had at least one bag containing some embryos classified as arrested or displaying less attained growth than the majority of embryos in that bag. The total amount of arrestment at the first removal was 3.9% with 5.1% at the second, and 2.6% at the last removal. Differences in overall attained growth between egg samples were apparent at the second egg-bag removal. Embryos from sites 1 and 2 represent extremes in growth while embryos from other samples were intermediate in size (Figure 12). At the last removal (124 days of incubation), alevins from point 2 were the largest (2.3 mg) and those from point 6 were the smallest (0.2 mg). Alevins hatching from eggs incubated at higher average dissolved oxygen concentrations were larger in size (dry weight) than those incubated at lower levels of dissolved oxygen. Dry weight of alevins from bags in relation to dissolved oxygen concentration are compared in Figure 13.

Embryos from point A were substantially smaller and less developed than embryos from other locations. Ten embryos from point A averaged 5.6 mm in total length while ten embryos from point 7 averaged 9.1 mm on 17 November 1964. Embryos from point 7 had well defined optic cups, lens placodes, pectoral fin buds, and a vitelline vein while those at point A were undifferentiated. Development in the surface box was slightly more advanced than at point A but was definitely retarded in comparison with embryos in bag samples. No hatching had occurred in the surface



box as late as 65 days after 32% of the embryos in bags had hatched.

Although eggs were incubated in closed containers, and each bag was thoroughly checked to be sure that all eggs and fragments had been removed, some eggs were missing in the second and third subsets. The average number of eggs recovered per subset was 100 in the first (99-101), 98.4 in the second (92-101), and 94.3 in the third (90-100). Many eggs occurred as fragments in the last subset. Egg group 9 experienced no loss while egg samples from 2 at the second and third removals, collectively, lost 7.5%. Unfertilized eggs at 124 days sustained a 5% loss. Unfertilized eggs were 90% clear at 48 days and 9.5% clear at 124 days. Many clear specimens at 48 days had structures grossly similar to the blastodiscs of fertile eggs at 17 days.

Decomposing egg-masses from the 1963 brood year were found in several locations in summer and winter 1964-65. On 7 August 1964, not only were eggs of the 1963 and 1964 brood years found in close apposition with one another in the study area, but also viable alevins of the 1963 brood year were present. These alevins appeared rather emaciated however. Masses of dead eggs, although not quantified, were found frequently. Notable amounts were found at redds 1N, 2A, and 4N.

DISCUSSION

Censuses and Distribution of Salmon

The Chena River does not support a large population of salmon by Alaskan standards. Production is small although extensive apparently potential spawning beds are available. This situation may not be surprising when redd site selectivity of the species, particularly chum salmon, is considered. Salmon surveys during 1963 and 1964 indicated that chum salmon chose well defined locations for spawning. Specific places were used to the neglect of others that seemed equally suitable. A common characteristic of chum salmon spawning grounds on the Chena River was the presence of surface springs or sub-surface seepages. One apparent exception was noted in summer 1963 when spawning took place concurrent with a freshet. A few redds were discovered above water level after the river subsided. In one instance spawning had occurred at the foot of a run-off rivulet that had subsequently dried up, and gravel over the eggs was partially emergent. Another redd was found totally exposed on a gravel bar. Survival was negligible in exposed redds. A very similar situation is observed among summer chum salmon of the Amur River. Russian fisheries workers have begun fencing certain shallow areas in tributaries to prevent summer chum from spawning in places that will be exposed to freezing and drying when river levels approach winter minimums (Nikolskii, 1956).

Surface current seemed to be less important than presence of groundwater in determining the choice of redd sites. Chum salmon spawned at greater depths in the main river than when spawning in spring-fed side [illegible] Although chum salmon [illegible] curves of the Chena showed slight shifts in relative abundance, spawning apparently occurred in the same general places, and in some cases the same specific locations, in 1964 as in 1963. High spawning density in 1963 and the apparent inflexibility of spawning site choice suggest that the "available" spawning area in relation to the total potential spawning area may have been filled in 1963. If ground-water seepage is a requirement for chum salmon spawning, as it appears to be, then much of the area that is not used may possibly lack such influence. Although this is submitted as conjecture because it is based on qualitative estimation, it is in accord with observations made by Russian investigators on fish of similar ecological characteristics. Distribution and abundance of Chena River chum salmon may well rest on location and surface area of spawning substrate influenced by ground-water seepage. Fish which spawn in the main river channel must deposit eggs at water depths greater than 1 m if eggs and alevins are to escape drying and freezing during winter. Survival of eggs and alevins probably becomes most precarious in years when freezing occurs while the river remains at its low summer level.

Water Quality

Silt pollution from road construction probably had a deleterious effect on salmon egg and alevin survival. The effect of polution of this sort would probably be more severe on the spawn of chinook salmon, which apparently has a higher dissolved oxygen requirement, than of chum salmon. Gangmark and Broad (1955) have shown that high mortality of chinook salmon eggs in Mill Creek, California, is associated with silt deposition over spawning beds during the incubation period. Silt pollution in the Chena was persistent and possible at any level of stream flow.

Springs associated with chum salmon spawning grounds on the Chena River were of the type described by Miller (1965), where ground-water finds its way to the surface by passing through pervious material. Ground-water outflow usually takes the form of "boils" in sand. Upwelling ground-water was sometimes detected by the absence of silt over the gravel. In some cases it was strong enough to cause turbulence at the surface. Gravel in the vicinity of points 9, 10, and 3N in the study area was clean after a light silt layer had formed over other parts of the spawning bed.

Springs apparently have little influence on surface water quality in the main river during moderate and high summer flows. During winter, after water level has fallen, springs eventually become the sole source of water flow.

Channel surface water in the study area seemed to represent an aggregate of various kinds of spring water influenced by surface freezing in winter and some amount of aeration at open spots in the ice cover. Water quality representing various locations of ground-water seepage on the Chena River was similar to water quality at the spawning grounds of autumn chum salmon in the Amur River system, Siberia. Spring-fed tributaries of the Amur are characteristically low in dissolved oxygen, dissolved solids, volume of flow, and level of pH (6.5), but high in carbon dioxide content, and maintain a fairly stable temperature regime (Levanidov, 1954).

Results of intragravel water analysis for dissolved oxygen, as depicted in Figures 6 through 9, indicate that oxygen levels declined after a fairly stable ice cover had formed on the surface water in the study area. Large differences in dissolved oxygen concentration at points as little as two meters apart attested to the variability of the intragravel environment.

A general rise in dissolved oxygen concentration in both intragravel water and surface water in the study area, observed on 21 December 1964, may be associated with a warming trend in air temperature (Figure 11). Warmer air temperature had the effect of allowing surface ice to melt, and perhaps this condition facilitated interchange of atmospheric oxygen with surface water. Of the points that were influenced by ground-water, point 9 was one location that was apparently unaffected by the condition that caused the general rise in dissolved oxygen level. It is probably unlikely that the increased level of oxygen was due to an increase in the oxygen concentration in ground-water.

Survival

Results of egg and alevin sampling in winter 1963-64, which are not reported in this paper, made clear the need for a method of containing a known number of eggs for survival data. The choice of containers was made on the basis of personal communication with Harold A. Gangmark (United States Fish and Wildlife Service). Gangmark and Broad (1955) found that survival of chinook salmon eggs in bags was comparable to survival in natural redds in Mill Creek, California. They observed the entire gamut of survival in bags (0-100%). A fairly wide range of survival in bags on the Chena River tends to suggest that bags exerted little if any influence on chum salmon egg survival.

Survival of eggs in ten bags at 49 days of incubation averaged 95.2%

indicating that handling loss and infertility of eggs were low at time of planting. On the basis of high survival in both the second sample taken from the surface box (100%) and from point 9 at 49 days (99%), it may be assumed that survival at planting was greater than 95%. Disler (1953) claims 97% of chum salmon eggs taken at Teplovskii Hatchery (Bira River, Siberia) are successfully fertilized. Observed survival of eggs and alevins, amounting to 84.2%, is fairly high in comparison with Pacific salmon survival to emergence of larvae in general. Natural survival rarely exceeds 25% and frequently is less than 10% (Royce, 1959; McNeil, 1962). This comparison is made with the assumption that the mortality rate of alevins is small. Levanidov (1954) reports survival to exceed 90% in certain autumn chum salmon redds in the River Khor, Siberia. He also contends that the coefficient of survival of embryos and alevins in areas supplied with ground-water is significantly greater than in areas without it.

Although there appeared to be a relationship between egg survival and bag location (comparing points 9 and 3) in the study area, treatment of survival data by analysis of variance did not support a contention that there was a difference in environmental quality (Table 2). High survival appeared to be related to high dissolved oxygen at point 9. By the same token low survival and low dissolved oxygen appeared correlated at point A. Although dissolved oxygen fell below 2.0 mg/l at points 1 and 6 and approached 2.0 mg/l at points 3, 7, and 8 toward the end of incubation, no excessive mortality occurred between the second and third removals at those points. Levanidov (1954) found 3.3% of dead eggs in a redd containing autumn chum salmon eggs at advanced eyed stage at an

TABLE 2. Analysis of variance comparing survival in bags with location in the study area.

Source of Variation	Sum of Squares	d.f.	Mean Square	F	$F_{.95}$
Total	2,331	29			
Location	991	9	110.1	1.64	2.39
Within Samples	1,340	20	67		

oxygen concentration of 2.0 mg/l. He further claims that eggs close to hatching can survive at an oxygen concentration of 0.5 mg/l, while alevins are capable of enduring oxygen levels as low as 0.28 mg/l. In the current study the correlation coefficient between dissolved oxygen and survival in bags was insignificant (r= 0.36). Therefore, no linear relation was indicated between the two. Silver *et al.* (1963) subjected incubating chinook salmon and steelhead trout (*Salmo gairdneri gairdneri*) eggs to concentrations of dissolved oxygen of 11.5 to 1.6 mg/l at different velocities and found that no appreciable mortality occurred at the lower levels of oxygen except at 1.6 mg/l where complete mortality resulted. Coble (1961) found the percentage survival of steelhead trout eggs incubated in stream beds to be directly associated with dissolved oxygen concentration. Wickett (1954) found that chum salmon eggs in gravel beds experienced high mortality at pre-eyed stages under low oxygen saturation conditions. These apparently conflicting results may be due to the difficulty of tracing and defining variables affecting eggs in streambeds or perhaps to differences in incubation brought about by the experimental condition in the hatchery. Silver's laboratory study suggests a lower lethal dissolved oxygen threshold for steelhead trout embryos, while Coble's work, under field conditions, indicates a linear association between survival and oxygen concentration. In view of Levanidov's work, and in terms of fairly high survival in the Chena study area in the face of low dissolved oxygen concentration, there is reason to expect survival of chum salmon eggs which are deposited in springs to conform to a lower dissolved oxygen threshold and not to a linear association with oxygen.

A significant correlation coefficient was demonstrated for dissolved oxygen concentration and dry weight of alevins in bags (r=0.78 at the 5% level of significance). Alderdice et al. (1958) have determined that the respiration rate of chum salmon eggs is unaffected by oxygen levels as low as 1 mg/l in the early stages of development but that this level rises to 7 mg/l near the end of incubation. Shumway et al. (1964), working with coho salmon and steelhead trout embryos, discovered that alevin weight varied directly with dissolved oxygen concentration and water velocity. Dissolved oxygen had much the stronger effect. When eggs were reared at constant temperature and velocity, resultant alevins were twice as large at an average dissolved oxygen concentration of 4.9 mg/l than at 2.8 mg/l. They also found that eggs hatched sooner at higher oxygen levels. In the present study, a decrease in oxygen consumption in response to low oxygen concentration in the environment probably accounts for the observed variation in size of alevins between samples. Deviation of samples from the line depicting the relationship between oxygen and alevin weight (Figure 12), or experimental error may be due to a number of factors. Differences in water velocity past chorionic surfaces is the most likely possibility. To say that dissolved oxygen is high does not preclude the possibility that the delivery rate of oxygen to the chorion is low. Also, even at high dissolved oxygen, waste products might accumulate and interfere with respiration. Spatially separate sources of water, and in some cases differing qualities of water, affected gravel beds in the study area. Slight shifts in location of upwelling groundwater occurred during the experimental incubation period. These observations, coupled with a lack of surface flow in the channel, suggest that the environment of developing salmon embryos is highly variable. There is good reason to suspect that the rate of intragravel water seepage is different from point to point. Differential rates of flow could account for a large part of alevin weight variation with respect to oxygen concentration. In terms of survival, however, the only necessary environmental condition may be a sufficient flow of water, bearing at least some oxygen, past embryos and alevins (Levanidov, 1954).

Another potential source of variation lies in the distance between eggs and points of water quality sampling (standpipe wells). Although embryos in a bag from point 9 appeared advanced and on the verge of hatching on 16 January 1965, 15 days later there appeared to have been no further development in another bag from that point. This probably indicates that a few centimeters in distance between bags might make a difference in environmental quality. Embryos at point 1 appeared arrested on 16 January 1965, yet the last bag removed contained 89% of hatched embryos of substantial size. The three egg-samples at point 1, unlike other egg-groups, were placed in individual excavations for burial. The last bag removed, which was about 40 cm from the second bag removed, was directly in the path of a ground-water outfall about 45 cm away (Figure 4). Eggs were bathed directly in ground-water as temperature and dissolved oxygen concentration at point 1 suggests (Table 4-Appendix). A similar condition might have been observed at 2. In that case the seepage was 1.1 m from the standpipe but water quality at that point did not confirm presence of the seepage (Table 4-Appendix).

Embryos not only displayed considerable variability in the number hatched at 124 days, but also the percent hatched did not correspond well with calculated elapsed temperature-days. Defining the incubation period in terms of temperature-days is done by calculating the product of the number of days of incubation and the average Celsius temperature. Some of the egg samples at the last removal, although apparently having more accrued temperature-days, had a smaller percentage of hatched embryos. The duration of the incubation period in days apparently conformed well with a norm established by Disler (1953), based on autumn chum salmon eggs incubated in a hatchery. He found hatching to occur between 122-128 days after fertilization (408-420 degree-days). According to Kol'gaev (1962), autumn chum salmon hatch 7-9 days sooner under hatchery conditions than under natural conditions. He considered premature hatching detrimental to hatchery fry because it occurs at the expense of development and viability. His general conclusion, based on the finding that premature hatching can be evoked by adverse stimuli, was that hatchery methods can be improved by completing late phases of incubation in containers of natural substrate with adequate water circulation. Kol'gaev found that survival in incubation apparatuses containing eggs in a coarse sand matrix was directly related to volume of flow through the sand. He claimed a positive correlation existed between particle size and duration of incubation.

Carbon dioxide determinations made in the field were apparently unreliable. Analyses were discontinued when it was found that duplication of results was not possible. Results that were obtained tended to indicate fairly high levels of dissolved carbon dioxide (20-30 mg/l) but little confidence was placed in indistinct titration end points. Levanidov (1954) reports the occurrence of 25-30 mg/l of carbon dioxide slightly inhibits developmental rate. Alderdice and Wickett (1958) found no decrease in oxygen uptake by chum salmon eggs at carbon dioxide concentrations below 125 mg/l when eggs were incubated at 2.5 mg/l of dissolved oxygen for nine days.

Sampling survival in redds proved somewhat difficult. The major problem was the lack of current in the spring-fed sloughs containing chum salmon redds. Without current embryos could not be readily carried free of the gravel into a collecting net. Due to inefficiency of the technique employed catch per unit effort was low. Predation on chum salmon eggs and alevins by chinook salmon fingerlings proved to be a problem during egg digging.

Hatching in chum salmon redds in the study area took place in early December 1964. The best estimates of survival were those obtained near the hatching time and from the first sample of a redd. A survival of 94% of eyed eggs, determined at 1N, probably represents the best estimate obtained. Survival at 1N after correction for total egg loss would represent eggs that had been successfully deposited and not those retained in the female or swept away. According to Levanidov (1954), the eggs not deposited in redds amount to about 25% of the total, of which 0.5 to 1.5% are retained in the female and the rest are swept out of the redd or perhaps consumed by predators.

Statistically, egg loss was linearly unrelated to temperature and dissolved oxygen (non-significant correlation coefficients). Eggs probably disappear from redds due to decomposition, predation, and scavenging (McNeil et al., 1964). Aquatic insects were generally found in bags at 108 and 123 days. Specimens of Trichoptera, Plecoptera, Diptera, and Ephemerida could evidently pass through bag meshes. During separation of eggs and alevins from gravel, a plecopteran was observed feeding on the yolk sac of a living alevin. Whether egg loss might occur in this manner in redds is unknown. Although slimy sculpins were found in redds, none were seen in bags. Those capable of passing the meshes of the bags would not be able to consume whole eggs in the event that this type of predation occurred. Cottids found in redds were small (3-4 cm) and apparently not abundant.

McNeil et al. (1964) have shown that dead pink salmon alevins disappear from spawning beds within two months of fry emergence, while dead eggs may linger as long as 18 months and be identifiable after the succeeding generation of eggs has been deposited. These authors contend that the quantity of dead eggs carried over is related to the density of spawners in the second year. Intensive spawning has a cleansing effect on gravel beds by loosening organic debris including dead eggs.

Perhaps the most significant effect of decomposing eggs in redds lies in the quantity of dissolved oxygen demanded. The amount of oxygen required in aerobic bacterial decomposition is dependent on water temperature. Kaganovskii (1949) claims a higher rate of egg loss due to accelerated decomposition in redds of salmon located in springs in comparison with those located in river fairways where winter temperatures fall to 0 C. McNeil et al. (1964) suggest, on the basis of pink salmon studies, that decomposing eggs from a large escapement of salmon may impair water quality in spawning gravel for more than one year. The occurrence of decomposing chum salmon eggs of the 1963 brood year, recovered as late as February 1965 (18 months after deposition), indicates the possibility of a similar effect on chum salmon spawning beds in the study area. Disler (1953) has found that unfertilized eggs of autumn chum salmon can survive the duration of the incubation period in the absence of mechanical shock and at low temperature. He considers the phenomenon a survival adaptation which lessens redd fouling due to egg decomposition.

The cause of complete mortality at A was not established. Groundwater affected point A as the high water temperature there indicates. Relatively low dissolved oxygen supports this contention. It is unknown whether the method of placing eggs in the gravel was instrumental in precipitating mortality or whether the effect was due to low dissolved oxygen. Also in question is the possibility that respiring and decomposing eggs might have affected dissolved oxygen in their turn.

Arrested development in the surface box may have been the result of exposure to light during sample removals. That light is deleterious to salmon eggs has been demonstrated by Eisler (1957).

CONCLUSION

The Chena River does not support a large salmon population. Chum salmon that spawn in the Chena choose well defined spawning sites that are directly or indirectly affected by spring seepages. Although levels of dissolved oxygen in gravel beds influenced by ground-water are low, survival of spawn to the hatching stage does not seem to be adversely affected. No evidence of redd freezing was observed in the study area although air temperatures in December 1964, and January 1965, reached record lows.

Spring water in sloughs had a lower pH, dissolved oxygen, and iron concentration than in the main river during summer and fall. In late winter, however, the pH level in the main river fell to the same level as water in springs. Sloughs having seepages were notable in their surface level stability and high temperature relative to the main river. Thickness of ice at seepage areas was variable due to local effects of upwelling ground-water but was relatively thinner than ice in the main river in places where water velocities at the two locations were comparable. Ground-water varied in quality. Ground-water of the poorest quality detected, from the standpoint of dissolved oxygen concentration, nevertheless supported chum salmon egg incubation.

Chum salmon egg survival in bags was not found to be associated with dissolved oxygen concentration. Weight of alevins in bags, however, was linearly correlated with oxygen. Although this relationship was not studied in redds, it can be assumed that redds having higher levels of oxygen will produce larger alevins.

Some chum salmon redds were located directly over upwelling ground-water. Ground-water influence at most redds was indistinct as determined by water sampling in standpipes. Ground-water did influence surface water temperature and consequently ice cover over redds.

Dead eggs were still recognizable 18 months after their brood had been deposited. Decomposing egg masses could possibly impair water quality in chum salmon redds.

According to Levanidov (1954), the spawning of autumn chum salmon under the influence of springs is not only a survival adaptation, but has become a spawning requirement in the course of evolution. The absence of a direct effect of ground-water on redds in the study area may indicate that it is not necessary per se. If this is true then perhaps the primary importance of ground-water is its relatively warm temperature in preventing freezing of redds. The results of the investigation of salmon survival in springs on the Chena River are consistent with the hypothesis that the major influence of springs on the redds of autumn chum salmon in Siberia is the prevention of freezing.

LITERATURE CITED

Alderdice, D. F., W. P. Wickett and J. R. Brett. 1958. Some effects of temporary exposure to low dissolved oxygen levels on Pacific salmon eggs. Jour. Fish. Res. Bd. Canada, 15(2): 229-249.

Alderdice, D. F. and W. P. Wickett. 1958. A note on the response of developing chum salmon eggs to free carbon dioxide in solution. Jour. Fish. Res. Bd. Canada, 15(5): 797-799.

Birman, I. B. 1953. Dinamika chislennosti i sovremennoe sostoyanie zapasov kety i gorbushi basseina Amura (Dynamics of abundance and present condition of stock of chum and pink salmon of the Amur Basin). Akademiya Nauk SSSR, Ikhtiologicheskaya Komissiya, Trudy Soveshchanii. Pp. 22-37.

Birman, I. B. 1957. Prisposobitelnye osobennosti nerestovoi migratsii amurskoi kety (Adaptative characteristics of the spawning migration of Amur chum salmon). Izvestiia Tikhookeanskovo N.-I. Instituta Rybnovo . ziaistva i Okeanografii. 37: 109-127.

Burgner, R. L., and W. A. Church. 1960. Observations on mortality of red salmon eggs in the Wood River Lakes, fall 1959. Fish. Res. Inst., Univ. Washington Coll. Fish. Circ. 113. 5 p.

Coble, Daniel W. 1961. Influence of water exchange and dissolved oxygen in redds on survival of steelhead trout embryos. Trans. Amer. Fish. Soc. 90: 469-474.

Disler, N. N. 1953. Razvitie osennei kety reki Amura. (Development of autumn chum salmon in the Amur River). Trudy Soveshchaniya po Voprosam Lososevogo Khozyaistva Dal'nego Vostoka. 9: 129-143.

Eisler, Ronald. 1957. Some effects of artificial light on salmon eggs and larvae. Trans. Amer. Fish. Soc. 87: 151-162.

Gangmark, Harold A. and Robert D. Broad. 1955. Experimental hatching of king salmon in Mill Creek, a tributary of the Sacramento River. California Fish and Game, 41(3): 233-242.

Hazzard, A. S. 1932. Some phases of the life history of the eastern brook trout Salvelinus fontinalis Mitchell. Trans. Amer. Fish. Soc. 62: 344-350.

Kaganovskii, A. G. 1949. Nekotorye voprosy biologii i dinamiki chislennosti gorbushii (Some problems of the biology and population dynamics of pink salmon). Izvestiya Tikhookeanskogo N.-I. Institute Rybnogo Khozyaistva i Okeanografii. 31: 3-57.

Kol'gaev, A. M. 1962. Prodolzhitel'nost' inkubatsionnogo perioda razvitiya ikry osennei kety pri inkubatzii ee na ramkakh i y grunte (Duration of development of eggs of autumn chum salmon by incubation on frames and on the bottom). Izvestiya Tikhookeanskogo Nauchno-issledovatel'skogo Instituta Morskogo Rybnogo Khozyaistva i Okeanografii "TINRO". 48: 207-209.

Kol'gaev, A. M. and A. P. Ivanova. 1962. Opyty inkubatsii ikry amurskoi osennei kety v grunte (Experiments with incubation of eggs of the Amur autumn chum salmon in the ground). Izvestiya Tikhookeanskogo Nauchno-issledovatel'skogo Instituta Morskogo Rybnogo Khozyaistva i Okeanografii "TINRO". 48: 209-210.

Levanidov, V. Ya. 1954. Puti usileniya vosproizvodstva kety Amura (Ways of increasing the reproduction of Amur chum salmon). Akademiya Nauk SSR, Ikhtiologicheskaya Komissiya, Trudy Soveshchanii. 4: 120-128.

Lovetskaya, E. A. 1948. Materialy po biologii amurskoi kety (Data on the biology of the Amur chum salmon). Izvestiya Tikhookeanskogo Nauchno-issledovatel'skogo Instituta Rybnogo Knozyaistva i Okeanografii. 27: 115-137.

McNeil, William J. 1962. Variations in the dissolved oxygen content of intragravel water in four spawning streams of southeastern Alaska. U. S. Fish and Wildl. Ser., Special Scientific Rpt. Fish. 402. 15 p.

McNeil, William J., Ralph A. Wells, and David C. Brickell. 1964. Disappearance of dead pink salmon eggs and larvae from Sashin Creek, Baranof Island, Alaska. U. S. Fish and Wildl. Ser., Special Scientific Rpt. Fish. 485. 13 p.

Miller, Roland B. 1965. How to care for a spring. The Conservationist-State of New York Cons. Dept. 19(4): 48-49.

Nikolskii, G. V. 1956. Rybovodno meliorativnye stantsii po vosproizvodstvu dal'nevostochnykh lososei (Stations for improving natural propagation of far east salmon). Rybnoe Khozyaistvo. 32(2): 55-59.

Royce, William F. 1959. On the possibilities of improving salmon spawning areas. Trans. N. Amer. Wildl. Conf. 24: 356-366.

Shumway, Dean L., Charles E. Warren, and Peter Doudoroff. 1964. Influence of oxygen concentration and water movement on the growth of steelhead trout and coho salmon embryos. Trans. Amer. Fish. Soc. 93: 342-356.

Silver, Stuart J., Charles E. Warren, and Peter Doudoroff. 1963. Dissolved oxygen requirements of developing steelhead trout and chinook salmon embryos at different water velocities. Trans. Amer. Fish. Soc. 92: 327-343.

Webster, Dwight A. 1962. Artificial spawning facilities for brook trout *Salvelinus fontinalis*. Trans. Amer. Fish. Soc. 91: 168-174.

White, H. C. 1930. Some observations on the eastern brook trout (*S. fontinalis*) of Prince Edward Island. Trans. Amer. Fish. Soc. 60: 101-105.

Wickett, W. Percy. 1954. The oxygen supply to salmon eggs in spawning beds. Jour. Fish. Res. Bd. Canada, 11(6): 933-953.

APPENDIX

TABLE 1. Chena River salmon censuses (1963)

River Mile	25-26 July				20-21 August				26-29 August*				31 August-5 September			
	Chinook		Chum		Chinook		Chum		Chinook		Chum		Chinook		Chum	
	Live	Dead	Live	Dead	Live	Dead	Live	Dead	Live	Dead	Live	Dead	Live	Dead	Live	Dead
55-60	-	-	-	-	-	-	-	-	0	0	47	0	0	0	12	73
60-65	-	-	-	-	-	-	-	-	0	0	102	5	0	7	100	191
65-70	70	0	0	0	-	-	-	-	0	0	22	0	0	13	11	71
70-75					-	-	-	-	0	1	23	0	0	16	12	73
75-80	29	0	4	0	-	-	-	-	0	0	28	0	0	6	65	235
80-85	29	0	1	0	-	-	-	-	0	0	40	0	0	6	3	36
85-90	9	0	0	0	-	-	-	-	0	1	4	0	0	0	0	0
90-95	-	-	-	-	0	2	12	2	-	-	-	-	-	-	-	-
95-100	-	-	-	-	0	7	4	0	-	-	-	-	-	-	-	-
100-105	-	-	-	-	0	1	0	0	-	-	-	-	-	-	-	-
Total	137	0	5	0	0	10	16	2	0	2	266	5	0	50	203	695

* Carcasses were not collected on this survey.

TABLE 2. Chena River salmon censuses (1964)

River Mile	12 August*				21-24 August				29-31 August			
	Chinook		Chum		Chinook		Chum		Chinook		Chum	
	Live	Dead	Live	Dead	Live	Dead	Live	Dead	Live	Dead	Live	Dead
55-60	-	-	-	-	0	1	19	11	-	-	-	-
60-65	-	-	-	-	0	0	82	0	-	-	-	-
65-70	2	0	0	0	0	2	37	2	0	4	85	16
70-75	0	0	0	0	0	5	7	3	0	2	0	2
75-80	0	0	0	0	0	5	87	35	0	5	71	25
80-85	9	0	0	0	0	2	52	13	0	10	59	60
85-90	30	0	0	0	-	-	-	-	0	0	9	4
90-95	-	-	-	-	-	-	-	-	0	0	6	3
95-100	-	-	-	-	-	-	-	-	0	1	0	0
Total	41	0	0	0	0	15	284	64	0	22	230	110

* Excessive turbidity from road construction hampered this survey.

TABLE 5. Intragravel and surface water temperatures (C) in the study area and in the main river (1964-65)

Date	S.s.	R.s.	4N	10	3N	9	8	7	6	2N	5	1N	4	3	2	A	1	10*	**
			Study area standpipes																
Oct. 30	4.5		4.0	4.0	4.0	4.0	4.5	4.0	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5		
Nov. 14	3.5		4.0	4.0	4.0	3.5	4.5	4.0	4.5	4.5	4.0	4.5	4.5	4.5	4.5	4.5	4.0		
Nov. 16	3.5																		
Nov. 17		0.5																	
Dec. 4						2.0			4.5	4.0									
Dec. 22	2.0		2.5	2.0	1.5	1.0	3.5	3.0	4.0	3.5	2.0	3.0			2.5			1.5	
Dec. 27		0.0																	0.0
Jan. 2																		1.0	
Jan. 13	1.5					0.5	2.5												
Jan. 15	1.5		1.5	1.0	1.0	0.5	2.0	1.5	2.5	2.5	1.5	2.5	2.0	2.5	2.0	3.5	3.0	1.0	
Jan. 17		0.0																	0.0

TABLE 3. Continued

			Study area standpipes																
Date	S.s.	R.s.	4N	10	3N	9	8	7	6	2N	5	1N	4	3	2	A	1	1*	2*
Jan. 19	1.5		1.5	1.0	1.0	0.5	2.5	1.5	2.5	2.5	1.5	2.0	1.5	2.0	2.0	3.5	3.0	3.0	1.0
Jan. 31	1.0		fr.	fr.	0.5	fr.	1.5	fr.	fr.	2.0	fr.	2.0	fr.	2.0	fr.	3.0	3.0	2.5	0.5
Feb. 7	1.0		fr.	1.0	1.0	fr.	2.0	1.5	1.0	fr.	fr.	fr.	fr.	2.0	fr.	fr.	2.0	2.5	0.5
Feb. 21	1.0		1.0	0.0	0.5	fr.	1.0	1.0	1.0	1.5	fr.	fr.	fr.	1.0	fr.	3.0	3.0		0.5
Feb. 27	0.5		1.0		0.5					1.0						3.0	3.0		
Mar. 6	0.5			0.5		0.5	1.0	0.5	1.0		fr.	1.0	fr.	1.0	1.0	2.0	3.0		0.5
Mar. 7		0.5																	

S.s. Study area surface water

R.s. River surface water

* Temperature in seepage effluent

** An average for two standpipes in the main river

fr. Standpipe frozen

TABLE 4. Dissolved oxygen concentration (mg/l) of intragravel and surface water in the study area and in the main river (1964-65)

			Study area standpipes																
Date	S.s.	R.s.	4N	10	3N	9	8	7	6	2N	5	1N	4	3	2	A	1	10*	**
Oct. 30	5.7		4.8	5.7	5.9	6.5	3.7	4.1	3.4	3.6	5.3	4.4	4.7	3.2	5.3	2.2	3.3		
Nov. 12	4.7		4.2	4.7	5.3	5.4	2.7	3.0	2.4	2.6	4.5	3.8	3.9	2.7	4.2	2.1	2.5		
Nov. 14	3.8		3.8	4.1	5.0	4.9	2.6	2.8	2.2	2.5	4.2	3.3	3.8	2.5	3.9	1.4	2.4	4.9	
Dec. 3						5.3										1.9		5.5	
Dec. 21			3.8	4.4	5.3	4.5	3.5	4.4	2.5	2.6	3.9	4.1	4.8	2.8	7.5	2.6	3.8		
Dec. 22	4.8					4.9									4.7			4.9	
Jan. 14	3.3		2.6	3.1	4.2	4.0	2.4	3.2	1.5	2.3	3.4	2.8	5.1	2.1	3.3	3.0	3.5	3.9	
Jan. 17		7.3																	7.1

TABLE 4. Continued

Date	S.s.	R.s.	Study area standpipes																
			4N	10	3N	9	8	7	6	2N	5	1N	4	3	2	A	1	1*	2*
Jan. 20	2.8		2.2	2.6	3.9	3.8	-	3.1	1.6	2.3	3.0	2.4	3.5	2.5	2.8	1.9	2.7	2.4	4.5
Jan. 30	2.9		fr.	2.5	3.1	fr.	2.1	fr.	fr.	2.7	fr.	2.1	fr.	2.1	fr.	0.6	1.1	2.3	4.0
Feb. 7	2.5		fr.	2.2	2.8	fr.	1.6	0.6	1.5	fr.	fr.	fr.	fr.	2.5	fr.	fr.	2.2	2.5	4.2
Feb. 14	2.5		1.4	fr.	2.9	fr.	1.7	1.1	1.1	3.0	fr.	fr.	fr.	1.4	fr.	1.7	2.1	3.8	3.9
Feb. 21	1.8		1.4	1.9	2.9	fr.	1.5	1.4	1.7	2.8	fr.	fr.	fr.	1.8	fr.	1.6	1.7		4.0
Feb. 27	1.3				3.6					2.9						2.4	1.9		
Mar. 6	1.7			1.7			1.4	1.0	1.1		fr.	1.1	fr.	1.1					
Mar. 7		7.5				2.8									1.8	2.5	1.4		

S.s. Study area surface water

R.s. River surface water

* Taken in seepage effluent near the designated standpipe

** An average for two standpipes in the river

fr. Standpipe frozen

TABLE 5. Intragravel and surface water analyses in the study area and in the main river (1964-65)

Location	date	pH	alkalinity (mg/l)	hardness (mg/l)	iron (mg/l)
4N	11/12	6.5	68.5	85.6	0.1
	1/18	>6.5	68.5	85.6	0.1-0.3
10	10/30	6.5	68.5	85.6	0.1
	1/18	6.5	68.5	102.7	0.1
	3/7	6.5	85.6	102.7	0.1
3N	11/12	6.5	68.5	85.6	0.3
	1/18	>7.0	-	-	0.1-0.3
9	10/30	6.5	68.5	85.6	0.1
	1/18	6.5	85.6	102.7	0.1-0.3
	3/7	6.5	85.6	102.7	0.1
8	10/30	6.5	68.5	85.6	0.1
	1/18	6.5	68.5	85.6	0.1-0.3
	3/7	6.5	85.6	102.7	0.1
7	10/30	6.5	68.5	85.6	0.1
	1/18	6.5	68.5	85.6	0.1-0.3
	3/7	6.5	85.6	102.7	0.1
6	10/30	6.5	68.5	68.5	0.1
	1/18	6.5	68.5	85.6	0.1-0.3
	3/7	6.5	85.6	102.7	0.1
2N	11/12	6.5	68.5	85.6	0.1
	1/18	>6.5	68.5	102.7	0.1
5	10/30	6.5	[illegible]	85.6	0.1
	1/18	6.5	68.5	85.6	0.1-0.3
1N	11/12	6.5	68.5	85.6	0.1
	1/18	<7.0	-	-	0.1-0.3
	3/7	6.5	85.6	102.7	>0.3
4	10/30	6.5	68.5	85.6	0.1
	1/18	6.5	68.5	85.6	0.1-0.3
3	10/30	6.5	68.5	68.5	0.1-0.[illegible]
	1/18	6.5	68.5	85.6	0.1-0.3
	3/7	6.5	85.6	102.7	<0.3

TABLE 5. Continued

Location	date	pH	alkalinity (mg/l)	hardness (mg/l)	iron (mg/l)
2	10/30	6.5	68.5	85.6	0.1
	1/18	>6.5	-	-	0.1-0.3
	3/7	6.5	85.6	85.6	0.1
A	10/30	6.5	68.5	85.6	0.1
	1/18	6.5	68.5	85.6	0.1-0.3
	3/7	6.5	85.6	102.7	0.1
1	10/30	6.5	68.5	85.6	0.1
	1/18	6.5	68.5	85.6	0.1-0.3
	3/7	<6.5	85.6	102.7	0.3
Channel surface	3/7	6.5	85.6	85.6	0.1
Main river					
1	1/18	7.0	85.6	102.7	1.5
3	1/18	7.0	>68.5	102.7	4.0-7.5
Surface water	1/18	7.0	85.6	102.7	0.3
	3/7	6.5	85.6	85.6	0.1