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IRRIGATION DRAWDOWN AND KOKANEE SALMON
EGG TO FRY SURVIVAL IN BANKS LAKE

by

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CONTENTS

	<u>Page</u>
1.0 ABSTRACT	ix
2.0 ACKNOWLEDGMENTS	x
3.0 INTRODUCTION	1
4.0 DESCRIPTION OF STUDY AREA	3
5.0 MATERIALS AND METHODS	7
5.1 Hydraulic Egg Sampler	7
5.2 Fry Trap	12
5.3 Fry Trap Deployment	14
5.4 Monitoring Environmental Parameters	16
6.0 RESULTS AND DISCUSSION	18
6.1 Environmental Parameters	18
6.1.1 Air Temperature	18
6.1.2 Dissolved Oxygen and Water Temperature	18
6.1.3 Sedimentation	22
6.2 Egg Sampling	22
6.2.1 Efficiency of Hydraulic Egg Sampler	22
6.2.2 Abundance of Kokanee and Lake Whitefish Eggs and Alevins	27
6.2.3 Development of Kokanee Eggs	29

6.3	Fry Sampling	31
6.3.1	Kokanee Fry Emergence	31
6.3.2	Kokanee Fry Emergence from the Million Dollar Mile Area	35
6.3.3	Survival of Kokanee Eggs and Alevins	38
6.3.4	Lake Whitefish Fry Emergence	38
6.3.5	Kokanee Fry Quality	41
6.4	Kokanee Spawning, Incubation, Emergence, and Drawdown	48
7.0	SUMMARY AND CONCLUSIONS	56
8.0	REFERENCES CITED	62
9.0	APPENDIX TABLES	64

LIST OF TABLES

Table No.		Page
1	Dissolved oxygen and water temperature during fry emergence at the prime spawning area, 1978, 1979	20
2	Sedimentation rates at the artificial gravel beds and prime spawning area	23
3	Efficiency tests of the hydraulic egg sampler in removing lake whitefish eggs based on comparison of standard single sampling vs. vigorous multiple sampling of the spawning substrate	25
4	Comparison of hydraulic sampling vs. manual excavation in removing kokanee and lake whitefish eggs from two known kokanee spawning redds	26
5	Kokanee and lake whitefish eggs and alevins sampled from the transects on the prime spawning area	28
6	Estimated emergence of kokanee fry from the prime spawning area in 1979 by depth by stratum and week	33
7	Kokanee fry emergence and survival rates at the prime spawning area in 1977, 1978 and 1979	39
8	Estimated emergence of lake whitefish fry from the prime spawning area in 1979 by depth by week	42

APPENDIX TABLES

Table No.		<u>Page</u>
1	Catch of emergent kokanee fry from the prime spawning area, 1979	65
2	Catch of emergent kokanee fry from Million Dollar Mile area of Banks Lake	67
3	Catch of emergent lake whitefish fry from the prime spawning area, 1979	68
4	Length and weight of emergent kokanee fry from prime spawning area, 1979	71

LIST OF FIGURES

Figure No.		Page
1	Banks Lake indicating the areas where suitable shoreline spawning substrate occurred and where live kokanee spawners were observed during 1978	4
2	Banks Lake surface elevations, rates of irrigation water input and withdrawal, 1973 to 1979 (USBR)	5
3	Detail of venturi pump and collection net used by SCUBA divers to capture eggs and alevins dislodged from the gravel by a water jet	8
4	Underwater sampling of kokanee eggs and alevins by SCUBA and hydraulic sampler	10
5	Kokanee fry emergent trap with detachable cod-end	13
6	Prime kokanee spawning area of Banks Lake showing area of concentrated spawning in 1978, lowest drawdown level during spring, 1979, and locations of traps used to capture emerging kokanee and lake whitefish fry	15
7	Comparison of mean monthly air temperatures from October to May for 22 years of record from 1958 to 1979	19
8	Dissolved oxygen and temperature from 3 m subsurface at the prime spawning area, 1979	21
9	Mean weekly catch of kokanee and lake whitefish fry from the prime spawning area during 1977, 1978 and 1979	32
10	Depth of emergence of kokanee and lake whitefish fry from the prime spawning area of Banks Lake, 1979	36
11	Distribution of kokanee fry emerging into traps on the prime spawning area by week, depth, and transect	37
12	Distribution of lake whitefish fry emerging into traps on the prime spawning area by week, depth, and transect	40
13	Comparison between condition and emergence timing of kokanee fry from the prime spawning area of Banks Lake, 1979	44
14	Comparison between condition and emergence depth of kokanee fry from the prime spawning area of Banks Lake, 1979	45
15	Comparison between condition and transect of emergence of kokanee fry from the prime spawning area of Banks Lake, 1979	46

Figure No.		Page
16	Rule curves for Banks Lake drawdown to allow fry emergence from a small kokanee spawning population	49
17	Rule curves for Banks Lake drawdown to allow fry emergence from a large kokanee spawning population	52

1.0 ABSTRACT

The effect of lake level drawdown on the 1979 kokanee fry emergence in Banks Lake was determined by monitoring the catch of 90 emergence traps placed on six transects ranging in depth from 0.6 to 13.6 m (2 to 45 ft) on the prime spawning area. An additional 12 traps monitored the emergence from a lesser spawning area at Million Dollar Mile. The lake drawdown reached 4.2 m (13.9 ft) below full pool before emergence began and thus killed the eggs and alevins in 90% of the primary spawning gravel, which occurs between 1.5 and 4.6 m (4.9 and 15 ft). The principal emergence occurred from secondary spawning gravel from 4.6 to 6.7 m (15 to 22 ft) below full pool. The deeper area was extensively spawned in 1978, because of increased competition for spawning sites which forced the use of less desirable gravel at greater depth. The estimated emergence of kokanee fry from the prime spawning site was 26,162 ($Z\alpha = \pm 11,152$) based on a trap efficiency of 100%. The estimated kokanee fry emergence indicated below optimum survival, which may result in a poor kokanee fishery in 1982. An estimated 1,706,967 lake whitefish fry emerged from the prime spawning area during April and were not affected by drawdown.

The relationships between the depth range of the kokanee spawning area, time of spawning, egg incubation, and fry emergence and the spring reservoir drawdown for 1977, 1978, and 1979 were analyzed graphically. Drawdown limits which allow fry emergence to occur were developed for small spawner populations restricted to the primary depths and a large population including the secondary spawning area. The rule curves are used to determine a water management strategy for kokanee fry survival as well as to estimate the loss when the curves are exceeded.

KEY WORDS: kokanee salmon, lake whitefish, irrigation, reservoir, beach spawning, eggs-alevins, incubation, fry emergence, drawdown, fry survival, rule curves, fishery management, water management.

2.0 ACKNOWLEDGMENTS

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3.0 INTRODUCTION

A comprehensive study of the operational effects of irrigation and pumped storage on the ecology of Banks Lake was conducted from 1973 to 1977 (Stober et al. 1977). A portion of this research included surveying the relative number and location of the spawning adult kokanee in the reservoir each year since 1975. The size of the spawning population remaining in the reservoir was increased in 1977 and 1978 by the development of a net barrier (Stober et al. 1979) to prevent the loss of spawners into the irrigation canal which supplies water to the Columbia Basin Irrigation Project. Evaluation of the screening efficiency of the net barrier on adult kokanee has shown that it is an effective means of increasing the size of the spawning population and the fish available to the sport fishery, thus providing an economical solution to one of the two major impacts of irrigation on the kokanee population in the reservoir.

The adult kokanee select talus shoreline areas around the reservoir for spawning. The depths of the most intensively utilized areas range from 1.5 to 4.6 m (4.9 to 15 ft) below full pool elevation. Drafting of irrigation water during the spring has been found to dewater these spawning areas causing losses of eggs and alevins. Major impacts due to drawdown occurred in 1973 and 1974 which resulted in two very small adult year classes in 1976 and 1977. Studies of the emergence and survival of kokanee fry in the shoreline spawning areas were begun in 1976 to determine the actual effects of drawdown on fry survival. In order to conduct these studies a fry trap was developed in 1976 which would catch fry emerging from the gravel and also withstand the harsh environmental conditions imposed by wave action, rock slides, and wave deposition of large quantities of gravel.

Spawning occurs during October and November with peak spawning around November 1, and the incubation period extends throughout the winter and early spring.

Fry emergence data were obtained for the years 1977 and 1978 which represented the progeny of small spawner year classes of 1,851 and 11,039 in 1976 and 1977, respectively. Due to these small spawner populations estimated from spawner survey counts (Stober et al. 1979), the information obtained on the fry did not include emergence data from a large spawning population needed for a more complete evaluation of the drawdown effects on fry survival. The spawner population in 1978 was estimated by mark and recapture (Stober et al. 1979) to be more than three times larger (35,381) than either of the preceding years and as a result moderate spawning was observed to occur at depths greater than 4.6 m (15 ft) below full pool elevation. This was due both to the large number of spawners and the limited amount of prime spawning gravel in the reservoir. The barrier net, by retaining larger populations, may increase the spawning below the usual operational drawdown level, allowing greater flexibility in the spring reservoir drawdown.

The principal objective of this study was to determine the depth and timing of emergence of kokanee fry from the primary and secondary spawning areas in Banks Lake during the spring of 1979 to evaluate the effect of drawdown on fry survival resulting from a large spawning population. Fry emergence in the secondary spawning area below the average annual drawdown of 4.6 m was of particular interest. Additional objectives were to compare length-weight condition factors of fry by time and depth; to test an egg sampling device to quantify the abundance of eggs and alevins in the gravel prior to emergence; and to determine the depth and timing of lake whitefish fry emerging from the prime spawning area. These data were compared with the 1977 and 1978 fry emergence and rule curves were graphically developed to indicate the drawdown regime required for fry survival.

4.0 DESCRIPTION OF THE STUDY AREA

Banks Lake was established in 1951 by flooding 10,926.5 ha (27,200 ac) along a 46.5-km (28.9-mi) section of the upper Grand Coulee between two earth-filled dams (Wolcott 1964) (Fig. 1). The North Dam constitutes the northern boundary of the lake. Dry Falls Dam (also known as South Dam) bounds the southern end of the lake. The pumping plant located at the left forebay of Grand Coulee Dam pumps water from Franklin D. Roosevelt Reservoir up 111.2 m (365 ft) into a 2.5-km (1.6-mi) long feeder canal which supplies water to Banks Lake adjacent to the North Dam. The pumping plant contains six pumps, each rated at 45.3 m³/sec (1,600 cfs) and two pump generators, each rated at 49.6 m³/sec (1,750 cfs) in the pumping mode. Water for irrigation is withdrawn from Banks Lake through the irrigation canal headworks at Dry Falls Dam to supply the agricultural requirements on about 202,000 ha (500,000 ac) of farmland in the Columbia Basin. The present maximum rate of irrigation withdrawal is 223.6 m³/sec (7,900 cfs).

The present study was focused on sampling eggs and emergent fry on the prime spawning area along the extreme southwest shoreline of the reservoir (Fig. 1). Additional sampling was conducted at the bases of six talus slopes along Million Dollar Mile. Both sampling areas were characterized by talus slopes which extended from well above full pool elevation to at least 13.7 m (45 ft) below full pool elevation. Another concentrated spawning area in the entrance to Coulee City Harbor was not quantitatively sampled because the spawning area below 4.6 m (15 ft) was minimal. Two sites were sampled on the west shore between areas 5-04 and 6-01 where alluvial fans extended into the reservoir.

Variations in the operational rates of water supply and withdrawal to Banks Lake result in water level fluctuations in the reservoir. Rates of irrigation water input and withdrawal and changes in water level elevation from January 1973 to June 15, 1979, are presented in Fig. 2. Maximum surface elevation is 478.5 m (1,570 ft) and maximum drawdown will reduce

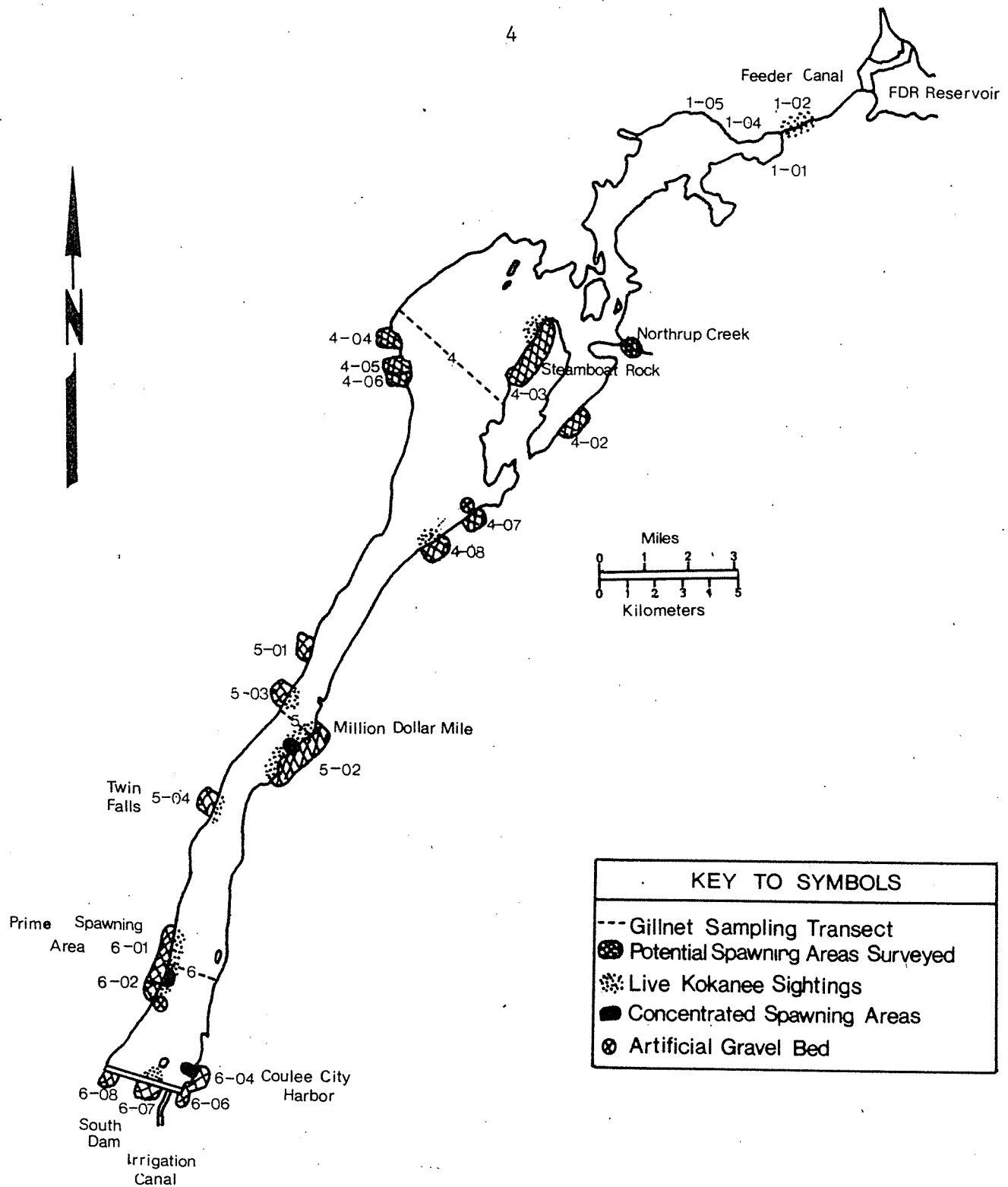


Fig. 1. Banks Lake indicating the areas where suitable shoreline spawning substrate occurred and where live kokanee spawners were observed during 1978. The prime kokanee spawning area is located in the southwest sector of the lake. (Stober et al. 1979).

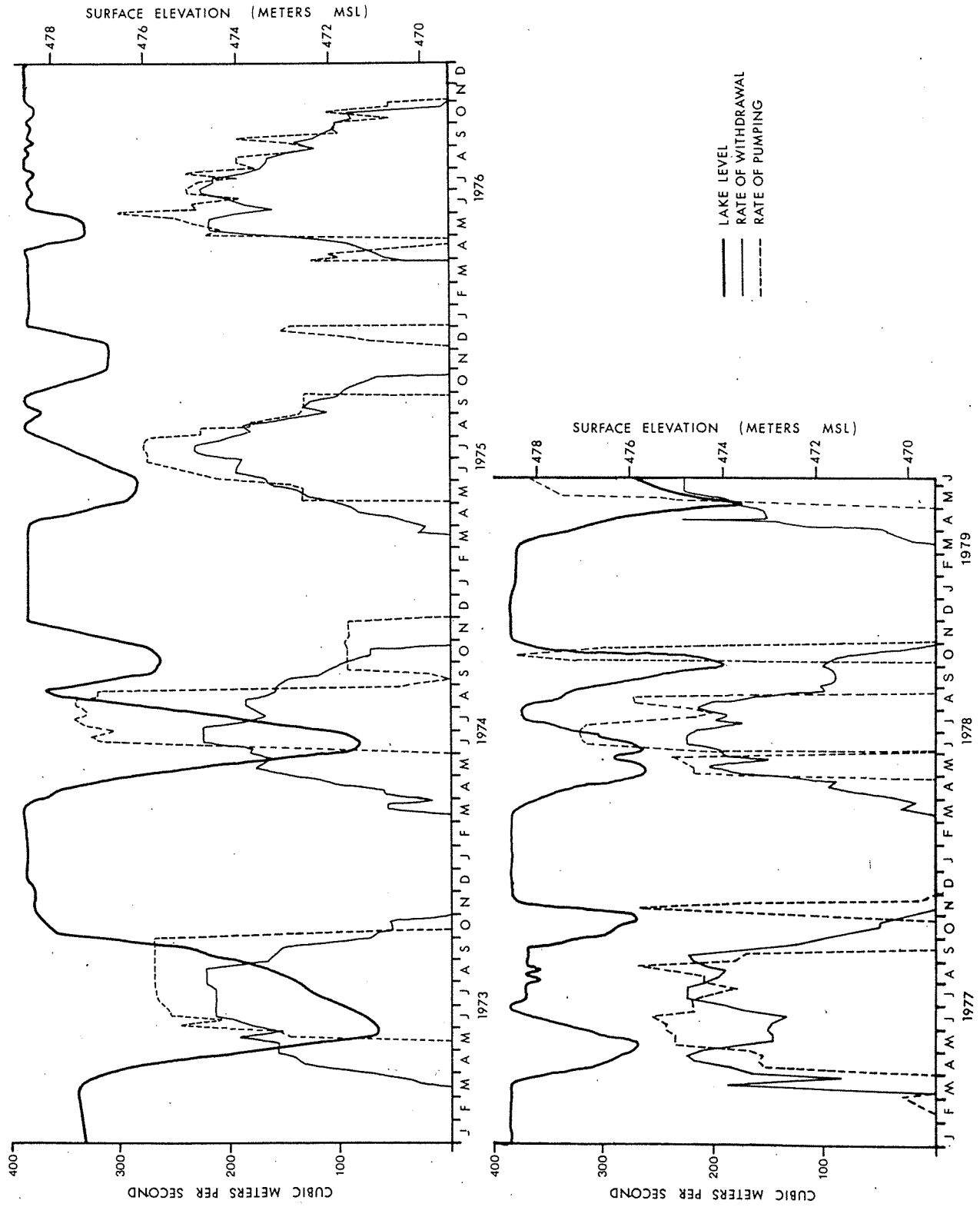


Fig. 2. Banks Lake surface elevations, rates of irrigation water input and withdrawal, 1973 to 1979 (USBR).

the surface elevation to 469.4 m (1,540 ft). The annual drawdown does not normally exceed 4.6 m (15 ft) but during the past few years drawdown reached 7.6 m (24.9 ft) and 7.2 m (23.6 ft) during the spring of 1973 and summer of 1974 (Fig. 2). Extreme decline in the water level has not occurred since 1974.

5.0 MATERIALS AND METHODS

5.1 Hydraulic Egg Sampler

A method for extracting kokanee eggs from lakeshore spawning gravel was needed in order to estimate the density of egg deposition and survival prior to emergence. The short time period available for development of a sampling device limited the effort to a single design which could be operated by SCUBA divers in a wide range of substrate sizes and result in uniform quantitative samples.

The apparatus included a probe to inject water into a small area of the substrate to cause expansion of the gravel, forcing the eggs and alevins to the gravel surface. A water-powered venturi suction device was used to capture the eggs loosened by the probe. The venturi pump principle, which is used widely in various forms of underwater excavation and archeology, employs a small jet of high velocity water within a larger tube to create a suction. The nozzle of the probe and the intake of the venturi pump were operated beneath an inverted circular pan (3420 cm² area; 33 cm radius by 10 cm high), which was held firmly on the substrate to insure a uniform sample area.

Two water pumps were used to provide independent water supplies for the injection probe and the venturi device. The injection probe system consisted of a 4 hp centrifugal water pump (568 l.min⁻¹; 150 g.min⁻¹), 27.4 m (90 ft) of 5 cm O.D. fire hose and a 4.4 cm O.D. galvanized steel pipe 1.2 m (4 ft) long. The probe tip was cut at a 45° angle to facilitate penetration of the substrate.

The venturi device was supplied by a water pump of similar capacity (568 l.min⁻¹; 150 g.min⁻¹), 13.7 m of 5 cm O.D. fire hose and 13.7 m of 2.5 cm O.D. fire hose connected with a reducing coupling. A PVC valve was placed on the line approximately 1 m from the sampler to allow the diver control of the rate of flow and amount of suction (Fig. 3). The venturi

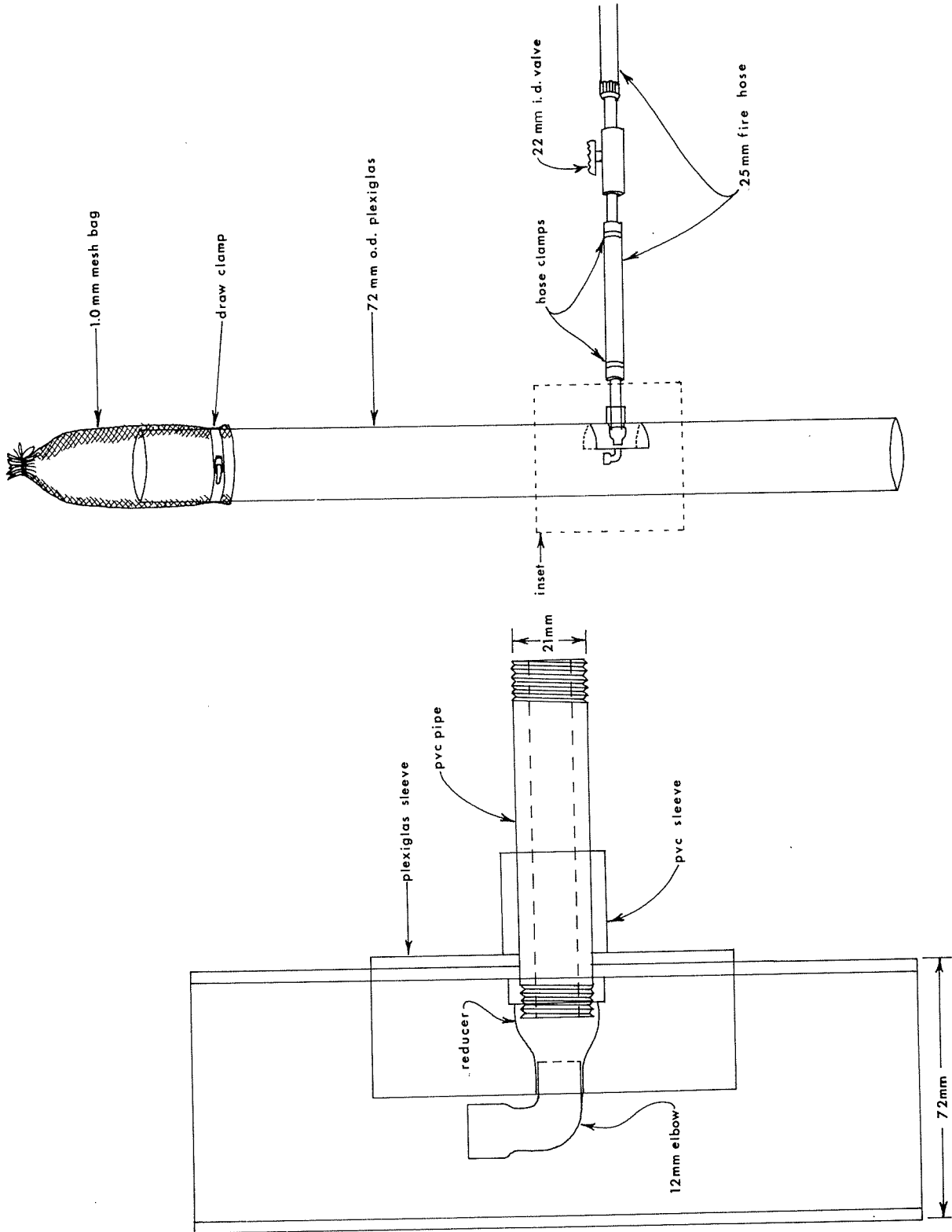


Fig. 3. Detail of venturi pump and collection net used by SCUBA divers to capture eggs and alevins dislodged from the gravel by a water jet.

tube was a 1.4 m length of 72 mm O.D. Plexiglas tube. Water was injected midway in the length of the venturi tube through a 13 mm diameter elbow attached to a 19 mm to 13 mm diameter reducer. This was placed inside the venturi tube with the elbow pointing toward the discharge end. The elbow was fastened in place with a 19 mm PVC nipple and collar, and the 25 mm O.D. fire hose was clamped to the PVC nipple.

The inverted circular metal pan standardized the sampling area and concentrated the action of the water jet and suction device. One hole was cut in the top center for the injection probe and a second hole was cut along the side for the suction tube. Flexible rubber boots attached to the pan around the holes sealed the probe and venturi tube and prevented egg loss.

Eggs and alevins were collected in a mesh bag attached with a quick-disconnect clamp over the discharge end of the venturi tube. The collection bags were made of 1.0 mm mesh fiberglass screen. Strips of screen were cut and glued to form tubes approximately 80 mm in diameter. A drawstring on the distal end facilitated access to the contents.

The egg sampler was operated underwater by two SCUBA divers (Fig. 4). One diver placed the sampling pan on the sample site and held it firmly in place and operated the venturi device while the other diver inserted the injection probe through the pan and forced the probe 15-30 cm (6-9 in) into the substrate. The valve was opened on the venturi device and the gravel was flushed for 5 min. The probe was then withdrawn and the collection bag containing the sample was removed and exchanged. Divers sampled from 12 to 14 points per transect per dive. Either one or two persons at the surface processed the contents of the collection bags and tended the water pumps.

Three methods were utilized to test the efficiency of the hydraulic egg sampler. A known number of preserved eggs was planted in the gravel and the percentage recovered was determined with the hydraulic sampler. A

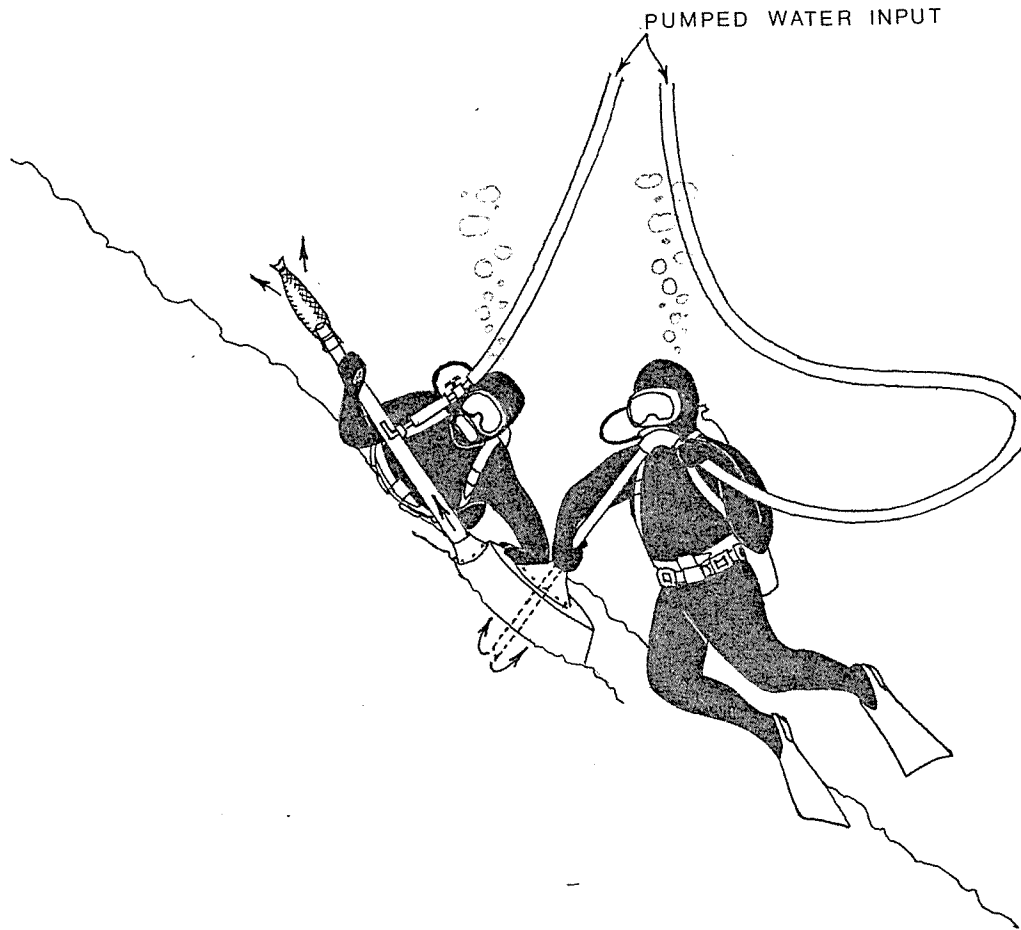


Fig. 4. Underwater sampling of kokanee eggs and alevins by SCUBA and hydraulic sampler.

sampling station was selected where the presence of eggs was anticipated. A sample was taken using the standard hydraulic sampling procedure, then the site was rigorously and repeatedly excavated to a greater depth to determine if eggs had been missed during the initial sampling. Finally, a known redd was sampled and re-sampled followed by manual excavation using a gardening claw, and any additional eggs were removed with the venturi device.

Eggs and alevins were preserved in Stockard's solution in individual containers. Samples were analyzed at a later date when the eggs were separated into live and dead categories and the developmental stages determined following the method outlined by Pelluet (1944). The purpose of staging the eggs was to establish the approximate time of mortality and the ratio of live to dead eggs which might be related to environmental conditions; however, detailed staging was not possible due to advanced decomposition and only un-eyed and eyed stages were determined.

Egg samples were collected in the primary spawning area with the hydraulic sampler prior to the emergence of kokanee fry. Egg samples were taken beside each fry trap on the same contour interval within 3 m (10 ft) of each of six traplines (Section 5.3) at depths ranging from 0.9 to 13.7 m (3 to 45 ft). Tests of hydraulic sampler efficiency were made concurrently with the routine sampling.

In addition to the subsurface sampling, manual excavations of dewatered gravel were made to determine the occurrence of eggs that had been dewatered. On two of the six slopes sampled at Million Dollar Mile, excavations were made below the water surface to determine if spawning had occurred, and if so, at what depths. Eggs found subsurface were collected with the venturi device.

5.2 Fry Trap

The trap was conical for maximum resistance to rockfall, gravel slides, and wave action. The cone was constructed of 20-gauge galvanized sheet metal (Fig. 5). The bottom edge of the cone was turned out to form a 5-mm lip for rigidity. The cone measured 56.4 cm diameter by 48.8 cm high and sampled $1/4 \text{ m}^2$ of substrate. The slope of the cone was 60° , for efficient leading of fry into the cod-end (Collins 1975), and good stability. An opening at the top measured 12 cm diameter. A removable cod-end, which fitted over the opening, incorporated several features enabling SCUBA divers to replace the cod-end easily without dislodging the cone. The cod-end was quickly and tightly attached and detached by means of two draw-pull catches. A fyke was built into the cod-end which prevented the catch from escaping while the cod-end was being replaced and transported underwater. The catch was removed easily at the surface by unscrewing a cap and pouring out the 2 liters of contained water.

The cod-ends were assembled from available heavy-gauge plastic products; a 2-liter polypropylene bottle from which the bottom was removed, and a polyurethane funnel with a slope which closely matched the slope of the cone. The stem of the funnel was cut to an opening of 16 mm and inserted into the cutaway bottom of the bottle to form a fyke. The bottle and funnel were joined by pop rivets.

The top of the cone was screened to prevent sculpins from entering the cod-end. Stainless steel wire mesh screens with 5-mm openings were welded inside the cones at the top.

Each trap was equipped with a stainless steel trolling snap installed on the bottom lip of the cone enabling the trap to be secured to a wire cable attached to a steel post emplaced at the full pool elevation. This attachment prevented shifting of the traps positioned on the loose talus material.

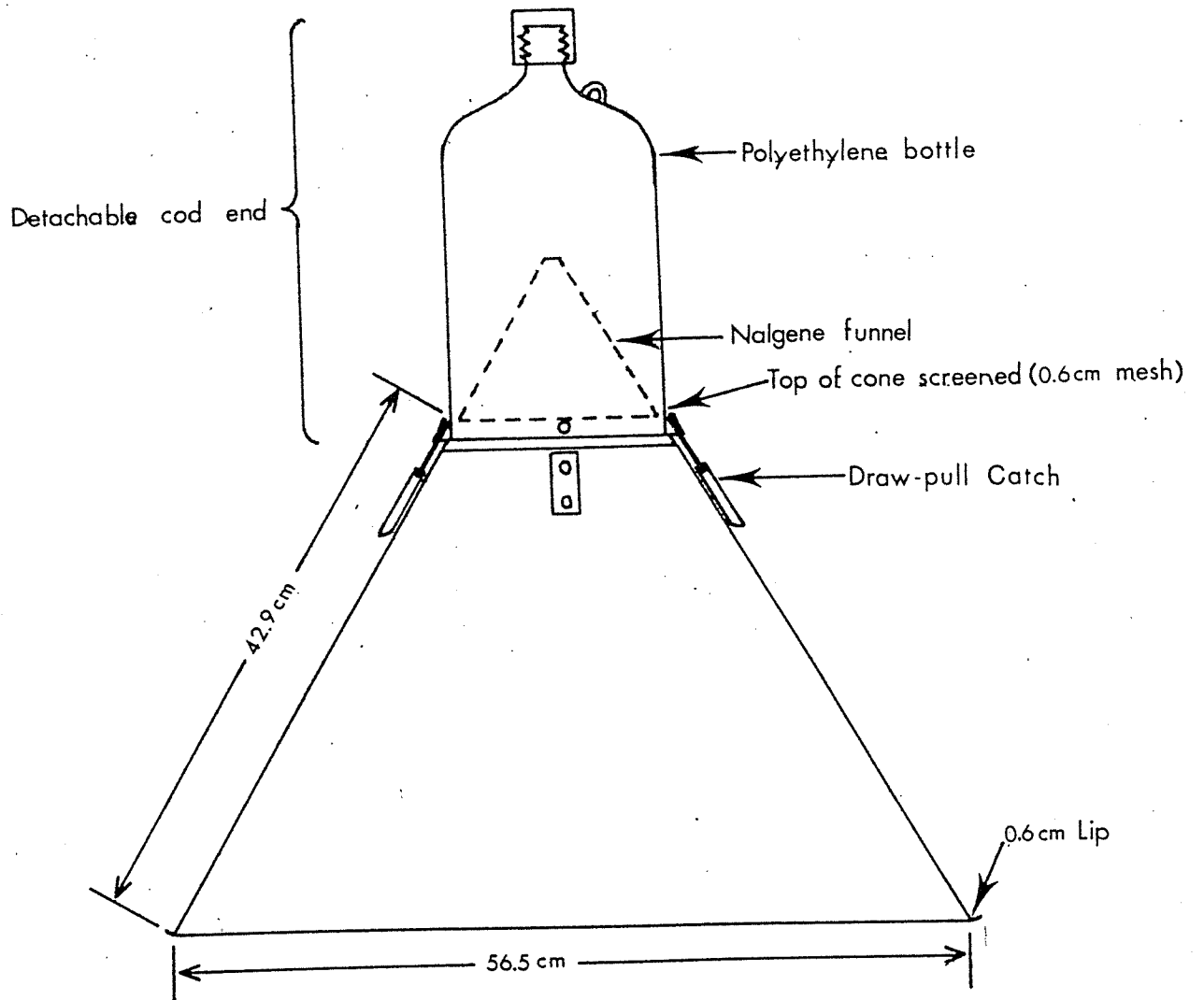


Fig. 5. Kokanee fry emergent trap with detachable cod end.

5.3 Fry Trap Deployment

The prime spawning area was sampled along 6 transects (trap lines A through F) extending perpendicularly from the shoreline (1,570 ft elevation) down the talus slope to a depth of 13.3 m (45 ft). Initially, 15 traps were attached to each trap line at depth intervals of approximately 0.6 m (2 ft) from surface to 6.5 m (20 ft) and at depth intervals of approximately 1.5 m (5 ft) between 6.5 m and 13.6 m (45 ft). All traps and cod-ends were marked by transect and depth location. The distribution of traps is shown in Fig. 6. As the traps dewatered due to drawdown of the lake surface, some were moved to deeper locations on the traplines and others were moved to known spawning redds independent of the trapline. The known redds were located by the positions of painted rocks which had been placed during spawning.

During 1977 and 1978, fewer traps were deployed because small adult populations were observed only in the primary spawning area. Traps were deployed over known redds or randomly distributed in the spawning area because transect sampling would have been largely unproductive.

The traps were monitored at 7-day intervals. As a diver removed a cod-end the fyke opening was plugged with a rubber stopper and the cod-end was strung on a cord. Use of the plugs prevented any possible escape of fry during underwater transport. After all cod ends had been collected from a trapline, they were taken to the surface, lifted into an attending boat and placed neck-down in a rack built for the purpose. A set of replacement cod-ends was re-installed immediately on the traps by a second diver.

Captured fry were removed from the cod-ends by unscrewing the caps and straining the contained water through an aquarium net. The catches were preserved separately in labeled jars containing Stockard's solution.

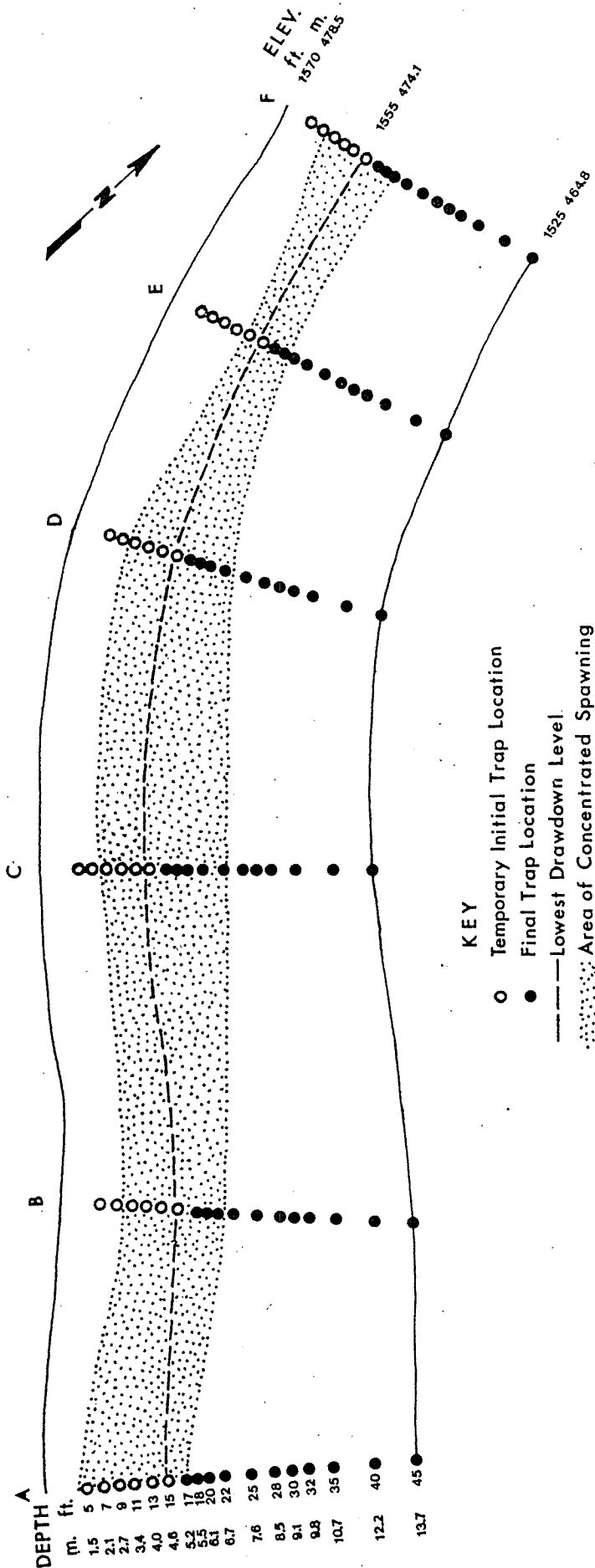


Fig. 6. Prime kokanee spawning area of Banks Lake showing area of concentrated spawning in 1978, lowest draw-down level during spring 1979, and locations of traps used to capture emerging kokanee and lake whitefish fry.

After a set of cod-ends from one trap line had been emptied they were re-lettered for the next trap line, strung on a cord in installation order, and passed to a diver.

The sampling crew consisted usually of two divers and two tenders. The 6 transects with 90 traps were serviced weekly; half on each of two days. In situ time required to service the traps totaled three hours.

Three trap lines with four traps each were utilized to sample the Million Dollar Mile area of Banks Lake. These traps were installed May 3 on two separate talus slopes at 1, 2, 3, and 4 m subsurface. These depths equated to elevations 474.7, 473.7, 472.7, and 471.7 (1554.1, 1550.8, 1548.1, and 1544.8 ft). The cod-ends were checked at 7-day intervals.

5.4 Monitoring Environmental Parameters

Dissolved oxygen and water temperature measurements were taken weekly from the primary spawning site during the period March 30 through June 8, 1979. Measurements were made at 0 and 3 m depths using a YSI meter (Model 54) lowered from a stationary float located between transects C and D.

Silt settling out of the water column was collected in wide-mouth jars measuring 8 mm in diameter. In 1977, arrays containing three jars each were placed and leveled at the north and south artificial gravel bed sites (Fig. 1) and on the primary natural spawning area according to the following depth and time periods: 7.9 m (26 ft) from November 4 to November 24, 6.7 m (22 ft) from November 3 to November 30, and 4.0 m (13 ft) from November 3 to November 30, respectively. Sediment jars were replaced at these sites on May 20, 1978 and exchanged on November 30, 1978. On April 15, 1979 the jars on the north and south sites were retrieved while the jars on the primary site were exchanged and moved to a depth of 6.1 m (20 ft). The silt volume from each jar was measured after

settlement was complete in a graduated cylinder and daily siltation rates calculated.

6.0 RESULTS AND DISCUSSION

6.1 Environmental Parameters

6.1.1 Air Temperature

Unusually cold air temperatures prevailed during the winter of 1978-1979, which caused concern about possible harmful effects to incubating kokanee eggs. The cold temperatures caused a complete ice cover of Banks Lake from mid-December through March to a maximum thickness of 1 m at the south end. The duration and thickness of ice cover were about double the usual occurrence.

Air temperature data from the U.S. Bureau of Reclamation weather station at Dry Falls Dam were compared for 22 years (1958-1979) to determine the relative severity of the 1978-1979 winter weather. Mean monthly air temperatures for October through May during 1958 to 1979 were compared (Fig. 7). The mean temperatures for November, December, and January averaged 1.7 to 2.8°C (3 to 4°F) colder than any previous year compared. The air temperatures during October 1978, March, April, and May 1979 were near normal.

6.1.2 Dissolved Oxygen and Water Temperature

The dissolved oxygen concentrations and water temperatures were measured weekly immediately below the water surface and at the 3-m depth from March 30 to June 8, 1979 (Table 1, Fig. 8). The dissolved oxygen concentrations ranged from a high of 12.8 ppm on March 30 to a low of 9.5 ppm on June 8. These concentrations were at or just below the saturation level for concurrent water temperatures which ranged from 4.0 to 14.7°C.

The temperature and dissolved oxygen concentrations were normal during the period observed. No monitoring was conducted during the period of ice cover, a time when intra-gravel dissolved oxygen may have been

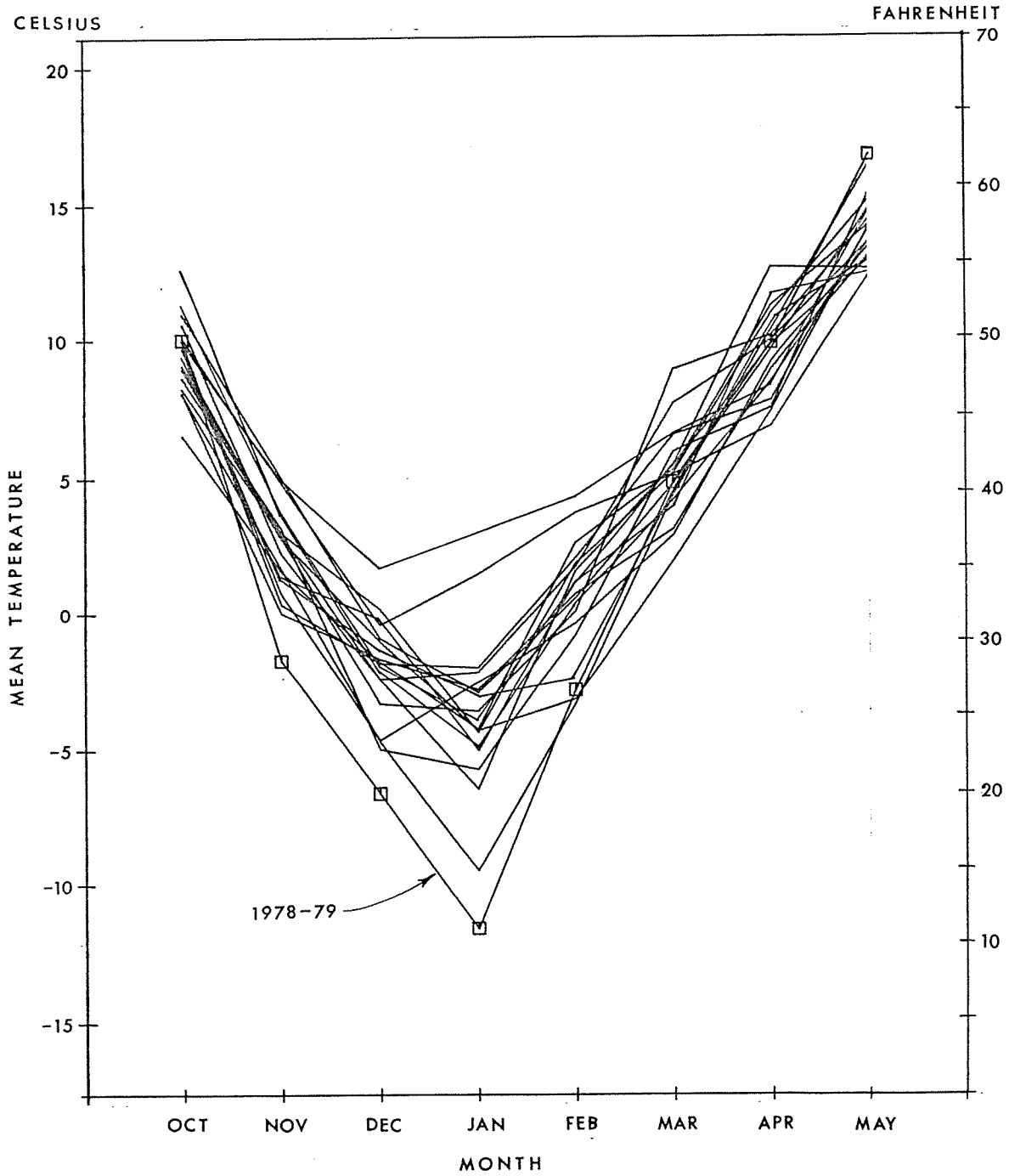


Fig. 7. Comparison of mean monthly air temperatures from October to May for 22 years of record from 1958 to 1979.

Table 1. Dissolved oxygen and water temperature during fry emergence at the prime spawning area, 1978, 1979.

Date	1978			1979		
	Depth m	Temp. °C	D.O. ppm	Depth m	Temp. °C	D.O. ppm
3/30	5	3.6		0	4.0	12.8
				3	4.9	12.8
4/6	5	5.4		0	5.3	12.6
				3	5.1	12.5
4/13	5	5.0	15.0	0	5.1	12.6
				3	5.1	12.6
4/20	5	5.7	9.3	0	7.9	12.0
				3	7.0	12.0
4/27	5	7.8		0	9.5	11.8
				3	9.2	11.0
5/4	5	8.8		0	8.0	11.2
				3	8.0	10.8
5/11	5	9.1		0	10.2	10.8
				3	9.8	10.6
5/18	5	10.0		0	12.3	10.2
				3	12.3	10.2
5/25	5	10.9		0	14.5	9.6
				3	13.5	9.5
6/1	5	10.9	7.9	0	14.7	10.4
				3	13.0	10.8
6/8				0	14.3	9.5
				3	14.1	9.6

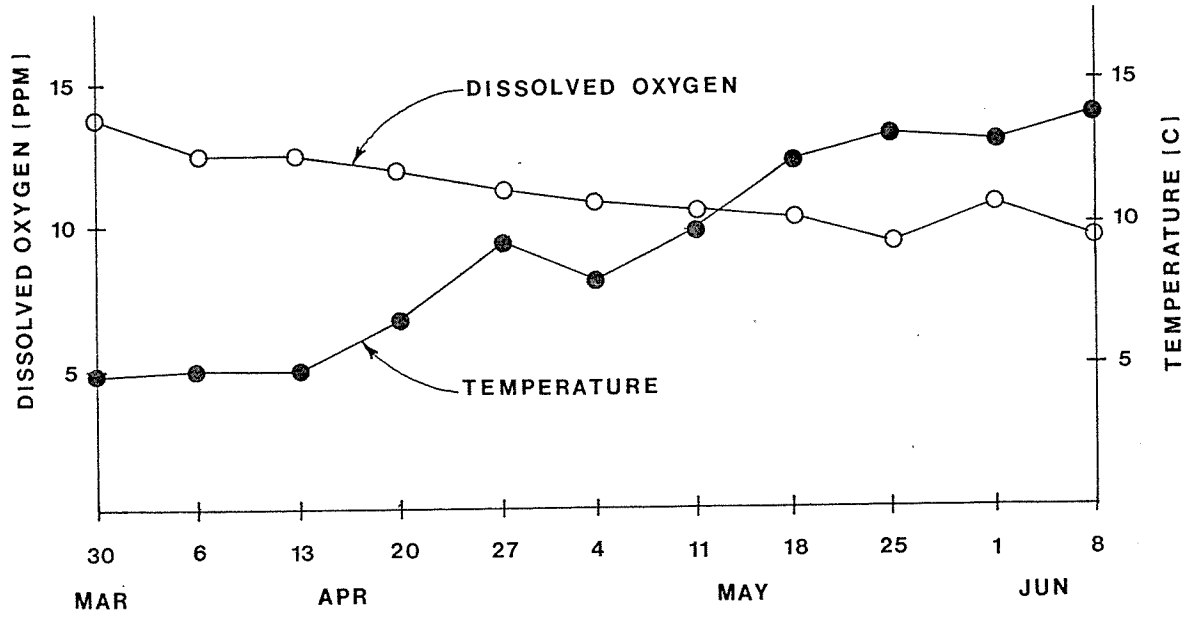


Fig. 8. Dissolved oxygen and temperature from 3 m subsurface at the prime spawning area, 1979.

insufficient at some sites for developing kokanee embryos. A recording thermograph was left on the prime spawning area during the winter period; however, the thickness of the ice prevented recovery and the instrument was lost.

6.1.3 Sedimentation

The sedimentation rates were monitored on two artificial gravel beds (Fig. 1) and the prime spawning area to determine the amount of sediment accumulation which may affect egg to fry survival. The sedimentation rates were lowest during the winter months due to ice cover which usually lasts from mid-December through February (Table 2). During winter 1979, the effect of ice cover on sedimentation was particularly noticeable at the north gravel site where a sediment rate of .081 cm/day was measured during October and November and 0.000 cm/day was measured during the period of ice cover, December through March. The sedimentation rate appeared to be lowest on the prime spawning area when compared to the north and south artificial gravel beds. Sedimentation of fine material apparently did not hinder fry survival during 1978-1979.

6.2 Egg Sampling

6.2.1 Efficiency of Hydraulic Egg Sampler

The efficiency of the hydraulic egg sampler in removing eggs from the substrate was tested initially by burying 200 preserved sockeye salmon eggs 15 cm (6 in) deep in the gravel and then excavating them by the standard method. A single test recovered 96% of the eggs but was not considered representative of the kokanee egg sampling because the sockeye eggs were buried in relatively small, uniform gravel which expanded easily.

The efficiency of sampling kokanee eggs was also tested by multiple hydraulic sampling of randomly selected points following initial sampling

Table 2. Sedimentation rates at the artificial gravel beds and prime spawning area.

Bed	Period	Mean rate mm/day	Std. Dev.
South	11/3-11/30/77	0.057	0.003
	3/30-5/25/78	0.053	0.004
	5/25-9/27/78	0.056	0.003
	9/27-11/29/78	0.075	0.005
	11/29-4/5/79	0.015	0.002
North	11/4-11/24/77	0.071	0.005
	3/30-5/24/78	0.033	0.004
	5/24-10/2/78	0.074	0.004
	10/2-11/29/78	0.081	0.009
	11/29-4/5/79	0.000	0.000
Primary	11/3-11/30/77	0.016	0.011
	3/30-5/25/78	0.023	0.004
	5/25-9/27/78	0.037	0.005
	11/29-4/5/79	Carried away by a slide	
	4/5-	" " " "	" "

by one standard method. The repetitive sampling was done more vigorously and longer than the standard single sampling procedure in an attempt to remove all eggs from the substrate. The results of these tests were inconclusive, due to the low recovery of kokanee eggs from the coarse substrate.

The incidental catch of lake whitefish eggs and alevins in these tests did provide an estimate of the sampling efficiency for this species of 48.3% (Table 3). This estimate was considerably higher than that expected for kokanee because lake whitefish eggs occurred nearer the substrate surface and were therefore much more easily dislodged.

A third test of the hydraulic sampler efficiency was made by manually excavating the substrate following standard sampling and vigorous re-sampling of two known kokanee spawning redds. The manual excavation was made by a diver using a garden claw. Eggs dislodged were collected by a second diver using the venturi tube of the hydraulic sampler. The number of kokanee and lake whitefish eggs and alevins recovered by standard single sampling, vigorous multiple sampling and manual excavation are compared in Table 4. Eggs and alevins were removed more effectively manually than by the hydraulic sampler. Manual excavation, even though preceded by at least two hydraulic samplings, yielded 82 and 47% of the kokanee eggs recovered from the two redds compared to 36 and 27% of the lake whitefish eggs. The principal disadvantage with manual excavation was the greater time required and the difficulty with maintaining a standard sample area.

The efficiency of the hydraulic sampler was probably reduced by several factors. The sampler probe was patterned after types used in stream beds where gravel is generally of a rounded river-run type which expands more easily than the angular fractured basalt at Banks Lake. Eggs may be trapped more readily in the interstices of angular rock than of rounded rock and partially decomposed eggs may be more difficult to dislodge by water jet. This seems to have been indicated by the

Table 3. Efficiency tests of the hydraulic egg sampler in removing lake whitefish eggs based on comparison of standard single sampling vs. vigorous multiple sampling of the spawning substrate.

Transect	Depth	No. Lake Whitefish Eggs		Percent Efficiency A/(A+B)(100)
		Single Standard Sampling (A)	Vigorous Multiple Sampling (B)	
A	17	0	1	---
	28	0	28	---
B	30	92	115	44
C	17	190	227	46
	35	89	61	59
D	15	5	18	22
	30	17	27	39
E	13	36	34	51
	20	22	4	85
F	17	19	23	45
	45	27	34	44
			MEAN	48.3

Table 4. Comparison of hydraulic sampling vs. manual excavation in removing kokanee and lake whitefish eggs from two known kokanee spawning redds.

Redd	Species	Standard Single Sampling	Vigorous Multiple Sampling	Manual Excavation	Efficiency of Standard Sampling (Percent)
		(A)	(B)	(C)	(A/A+B+C)(100)
1	Kokanee	2	4	29	6
	Lake white- fish	227	121	203	41
2	Kokanee	40	41	74	26
	Lake white- fish	94	121	82	32

relatively high efficiency achieved in the initial test in which 96% of preserved sockeye eggs were recovered by the hydraulic sampler.

6.2.2 Abundance of Kokanee and Lake Whitefish Eggs and Alevins

A total of 67 sample sites covering a combined area of 32 m² was excavated in the prime spawning area by the hydraulic sampler from April 11-25, 1979. In all, 306 kokanee eggs and 1 alevin were recovered (Table 5). All kokanee eggs were dead and the alevin was alive. Manual excavations of dewatered gravel in the prime spawning area yielded numerous dead eggs between 2.3 and 3.4 m (7.5 and 11 ft) below full pool. Kokanee eggs ranging in number from 12 to 150 eggs each were found in individual pockets. The pockets were spaced approximately 1 m (3 ft) apart. No eggs were found in two minor spawning areas on the west shore north of the prime spawning area.

Manual excavation of six talus slopes along the Million Dollar Mile area yielded a total of 1,000 to 1,500 dead eggs. Eggs were found in five of the six slopes at approximately the same density and water depths as in the prime spawning area. Subsurface manual excavations on two of the six slopes yielded eggs from the water surface at 4.6 m (15 ft) to 8.5 m (28 ft) below full pool.

Egg survival rates for kokanee spawning in lakes have not been found in the literature. Since this is the first attempt at sampling pre-emergent egg/alevin densities in Banks Lake, no comparative values exist. The low survival of sampled eggs may have been due to unusually cold weather during the 1978-1979 incubation period, but in view of the fact that fry emerged into the adjacent traps, it appears more likely that the hydraulic samples were selective for eggs near the surface of the substrate and these eggs suffered a high rate of mortality due to exposure. Kokanee eggs deposited near the substrate surface probably incurred a higher mortality due to superimposition of redds, exposure to light, and jarring or abrasion from gravel slides.

Table 5. Kokanee and lake whitefish eggs and alevins sampled from the transects on the prime spawning area.

Transect	Samples	Kokanee		Lake Whitefish	
		Eggs	Alevins	Eggs	Alevins
A	12	265	1	76	6
B	12	3	0	435	1
C	12	24	0	162	18
D	10	14	0	216	8
E	11	0	0	506	11
F	10	0	0	554	6
Totals	67	306	1	1949	50

Egg densities derived from the hydraulic samples were much lower than the estimates of potential egg deposition derived from spawner counts. The efficiency of the hydraulic sampler was so low and inconsistent that meaningful comparisons were not possible. The density of surviving eggs and alevins based on these samples was essentially zero; however, fry trap samples indicated that some emergence did occur. Kokanee egg survival was probably greatest from redds dug, 15-25 cm (6-10 in) into the substrate and beyond the sampling capability of the hydraulic sampler.

Lake whitefish eggs and larvae were found in large numbers at most transects of the primary spawning site. The largest numbers occurred at transects E and F where the substrate was coarsest (Table 5). Since sampling occurred during the emergence period, only a portion of the population was sampled.

6.2.3 Development of Kokanee Eggs

Kokanee eggs were separated only into eyed and un-eyed categories because of their advanced state of decomposition which precluded identification of structure. Of the 263 eggs staged, 24% were un-eyed, 18% were eyed, and 58% were unidentifiable (broken eggs). Staging did not provide sufficient data to allow estimation of the time or cause of egg mortality. Due to the influence of temperature on the rate of egg development (development rate decreases with temperature) eggs deposited early in the spawning season may develop in a few weeks to a stage that may take eggs spawned later in the season several months to reach. This was found in tests of kokanee egg development in 1977 (Stober et al. 1977) in which eggs planted on October 27th eyed around mid-November (~24 days), while eggs planted November 11 eyed around mid-December (~30 days), and those planted November 27 eyed around mid-March (~103 days). Successively later egg plants required much longer development time due to declining lake temperatures and resultant slower temperature unit accumulation.

Water temperature data for 1979 are available only for the period October 15 through November 17 because the thermograph was lost after ice cover formed in mid-December. The date by which early-spawned eggs reached the eyed stage was determined by computing accumulated temperature units.¹ Information from the 1976 fry study (Stober et al. 1977) indicated that kokanee eggs reach the eyed stage at approximately 475 temperature units. Using this criterion, eggs spawned on or before October 15, 1978 reached the eyed stage around November 10th, whereas eggs spawned in late November did not reach the eyed stage until late March or early April. This extrapolation was based on previous studies at Banks Lake which showed that water temperatures averaged 4°C during the period of ice cover.

Future sampling to determine egg density, distribution, and total deposition should be done immediately after spawning is completed and before ice formation, preferably during the first two weeks of December. Sampling to determine mortality rates, date, and cause of mortality should involve periodic sampling during the entire incubation period; however, winter observations were not possible under conditions of this contract.

The hydraulic egg sampler may be a potentially useful device for lakeshore use, but needs improvement in removing available eggs from the wide range of substrate sizes found in Banks Lake. The best sampling method used in this study was manual excavation with suction recovery of dislodged eggs.

¹Temperature unit (T.U.) = 1°F above 32°F for a period of 24 hr.

6.3 Fry Sampling

6.3.1 Kokanee Fry Emergence

Emergent fry traps were placed on the prime spawning area on March 28, 1979. They remained in place and were checked weekly throughout the emergence period until June 13. The emergence of kokanee fry occurred during a period which began about May 1, reached a peak by May 10, and ended during the first week in June. The emergence timing and magnitude during the years 1977, 1978, and 1979 are compared in Fig. 9.

The beginning and ending of emergence in 1979 were one week later than in 1978 and the beginning was approximately four weeks later than in 1977. The lateness of emergence is attributed to delayed development due to unusually cold winter weather which prevailed from November through March. In spite of the late beginning of emergence in 1979, the date of peak emergence coincided with the peak observed in 1978.

The total emergence of kokanee fry from the primary spawning area was estimated from calculations of weekly emergence by depth strata (Appendix Table 1). The weekly catch of emergent fry by the six traps on each of 12 depth strata was extrapolated from the area sampled to the area of the slope within the strata. The total estimate was obtained by summing the weekly estimates (Table 6). The calculations are summarized in the following formula:

$$\text{Estimated weekly emergence } \hat{E}_w = \sum_{i=1}^{12} \frac{C_i A_i}{6a}$$

where C_i = fry catch in the i th depth stratum

A_i = area of the i th depth stratum (the depth range of a stratum extends halfway to adjacent higher and lower strata)

a = area sampled by one trap

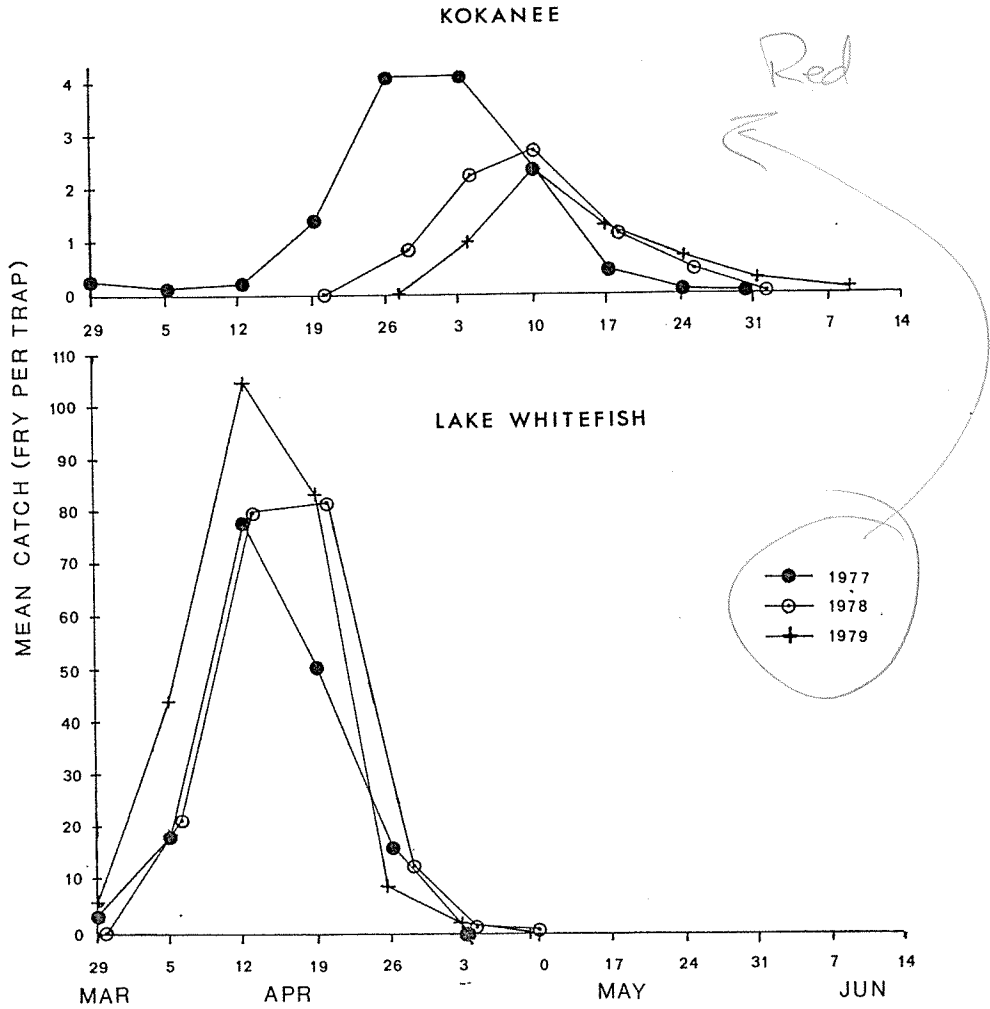


Fig. 9. Mean weekly catch of kokanee and lake whitefish fry from the prime spawning area during 1977, 1978 and 1979.

Table 6. Estimated emergence of kokanee fry from the prime spawning area in 1979 by depth by stratum and week.

Sample Period	DEPTH STRATA														Σ	95% confidence interval	
	0-4.2 m 0-14 ft	4.6 15	5.2 17	5.5 18	6.1 20	6.7 22	7.6 25	8.5 28	9.1 30	9.8 32	10.7 35	12.2 40	13.7 45	Σ			
4/19-4/26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4/27-5/3	0	842	57	57	601	461	0	73	0	0	0	0	0	0	0	0	2,181
5/4-5/10	0	0	1707	1764	2405	2213	881	365	543	452	713	695	0	0	0	0	11,738
5/11-5/17	0	1149	911	797	827	1106	330	219	271	181	713	347	340	0	0	0	7,191
5/18-5/24	0	536	285	512	75	645	73	0	362	181	570	347	170	0	0	0	3,756
5/25-5/31	0	77	0	0	0	92	110	73	90	90	0	347	340	0	0	0	1,219
6/1-6/7	0	77	0	0	0	0	0	0	0	0	0	0	0	0	0	0	77
6/8-6/12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Σ	0	2681	2960	3130	3908	4517	1394	730	1266	994	1996	1736	850	26,162	11,152	0	0
Area (m ²) ¹	955.1	114.9	85.4	85.4	112.8	138.3	165.1	109.6	135.6	135.6	213.8	260.6	255.3	2,767.5	0	0	0
Estimated fry/m ²	0	23.3	34.7	36.7	34.6	32.7	8.4	6.7	9.3	7.3	9.3	6.7	3.3	12.4	0	0	0

¹The depth ranges of strata were measured on the slope to midpoints between adjacent higher and lower strata.

$$\text{Total estimated emergence } \hat{E}_t = \sum_{j=1}^6 E_{wj}$$

where E_{wj} = estimated weekly emergence in the j th week.

The estimate of total fry emergence was 26,162 with 95% confidence limits of $\pm 11,152$ based on a trap efficiency of 100%. Since the efficiency of the trap was unknown, but was probably less than 100%, a second estimate of 37,427 was calculated based on an efficiency value from the literature of 69.9% (Collins 1975). This efficiency value was obtained from laboratory tests of a trap of different design but of similar side slope.

Confidence intervals about the total estimated emergence were calculated at the 95% level from the variances of emergence by 12 depth strata each week (Table 6). The data were pooled across transects because the emergence was least variable across the width of primary spawning area. The calculations were based on the following formulae:

Variance of 6 trap catches in the i th stratum $\rightarrow s_i^2 =$

$$\text{Var}_{C_{ij}} = \frac{1}{6-1} \left[\sum_{i=1}^6 C_{ij}^2 - \frac{\left(\sum_{i=1}^6 C_{ij} \right)^2}{6} \right]$$

where C_{ij} = catch in i th stratum of j th transect.

Variance of emergence from one sampling period $\rightarrow \text{Var } \hat{E} =$

$$\sum_{i=1}^{12} \text{Var } \hat{E}_i = \frac{1}{6a^2} \sum_{i=1}^{12} A_i^2 s_i^2$$

The spring drawdown in 1979 probably destroyed about half of the total kokanee fry production from the area in which concentrated spawning occurred (Figs. 6 and 10). However, at least 90% of the fry in the primary spawning area were lost. Because fry emergence was unusually late, drawdown had reached 4 m (13 ft) below full pool before emergence began. One week later, during peak emergence, the water level reached 4.2 m (13.9 ft) below full pool. The drawdown may also have impacted the alevins to a depth about 0.6 m below the drawdown level due to wave action, as evidenced by the substantially smaller catches of the traps at depth stratum 4.6 (15 ft) compared with catches from deeper strata.

The distribution of fry emergence based on trap catches from the prime spawning area is shown in a series of three-dimensional graphs in Fig. 11. Each of the graphs represents a week during which emergence occurred. The number of fry caught are represented by depth strata and transect. Emergence was greatest at transects B and D, intermediate at transects A and C, and lowest at transects E and F. Emergence was highest at depth strata 5.2 m (17 ft) through 6.7 m (22 ft), intermediate at 4.6 m (15 ft) and relatively low from 7.6 m (25 ft) to 13.7 m (45 ft).

6.3.2 Kokanee Fry Emergence From the Million Dollar Mile

Traps which were removed from the prime spawning area after they had dewatered were installed April 27 on two talus slopes along the Million Dollar Mile area. The traps were placed on three trap lines (M, N, and O) at depths of 5.2 m (17 ft), 6.1 m (20 ft), 7.0 m (23 ft) and 7.9 m (26 ft). The traplines M and N were placed approximately 10 m apart on one talus slope and the trapline O was placed 300 m south on a second talus slope.

The catches from traplines M and N totalled 22 and 38 kokanee fry, respectively, while only 1 kokanee fry was caught from trapline O (Appendix Table 2). The density, timing, and depth distribution of the catch were similar to that observed from the primary spawning area.

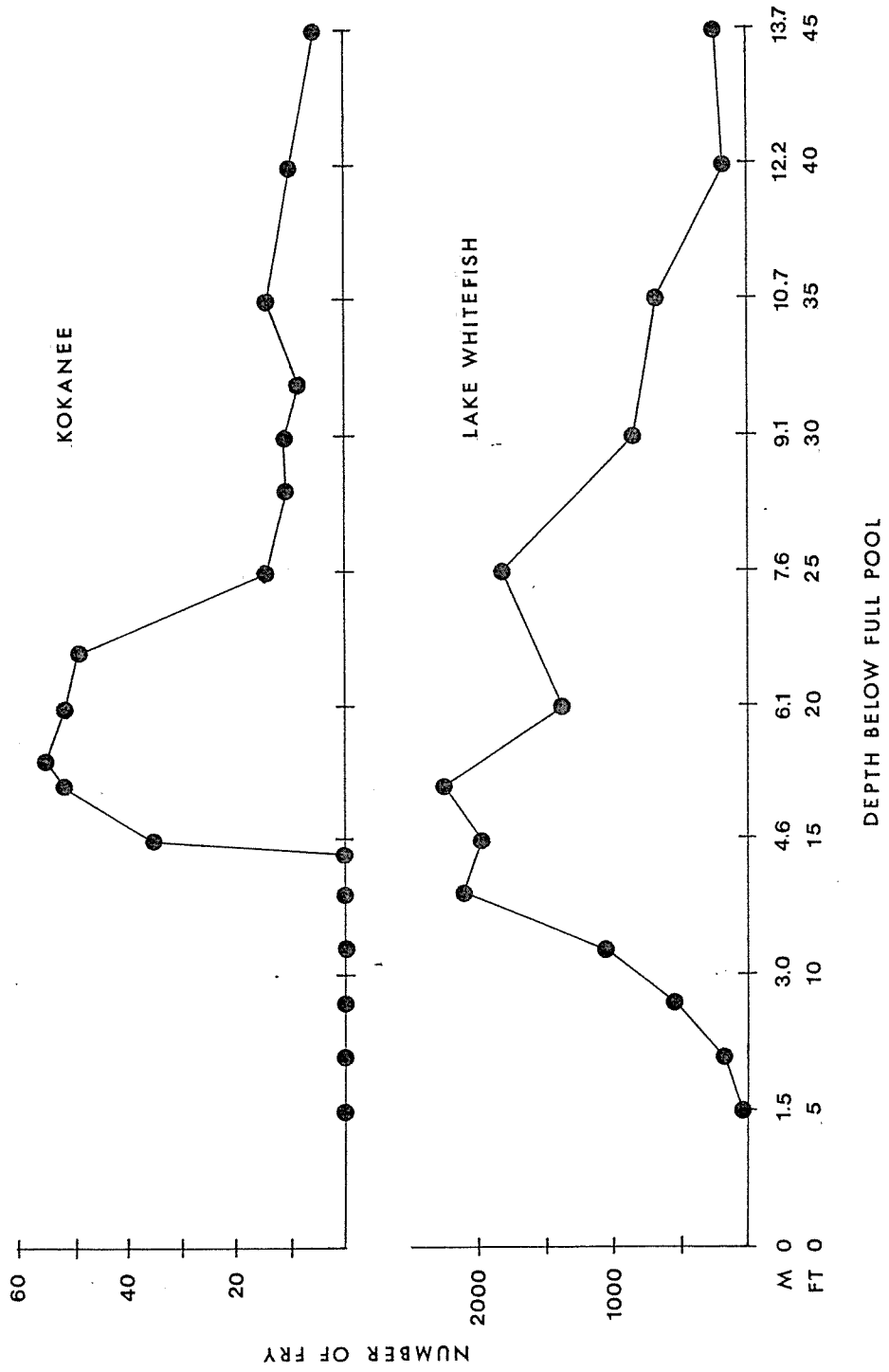


Fig. 10. Depth of emergence of kokanee and lake whitefish fry from the prime spawning area of Banks Lake, 1979.

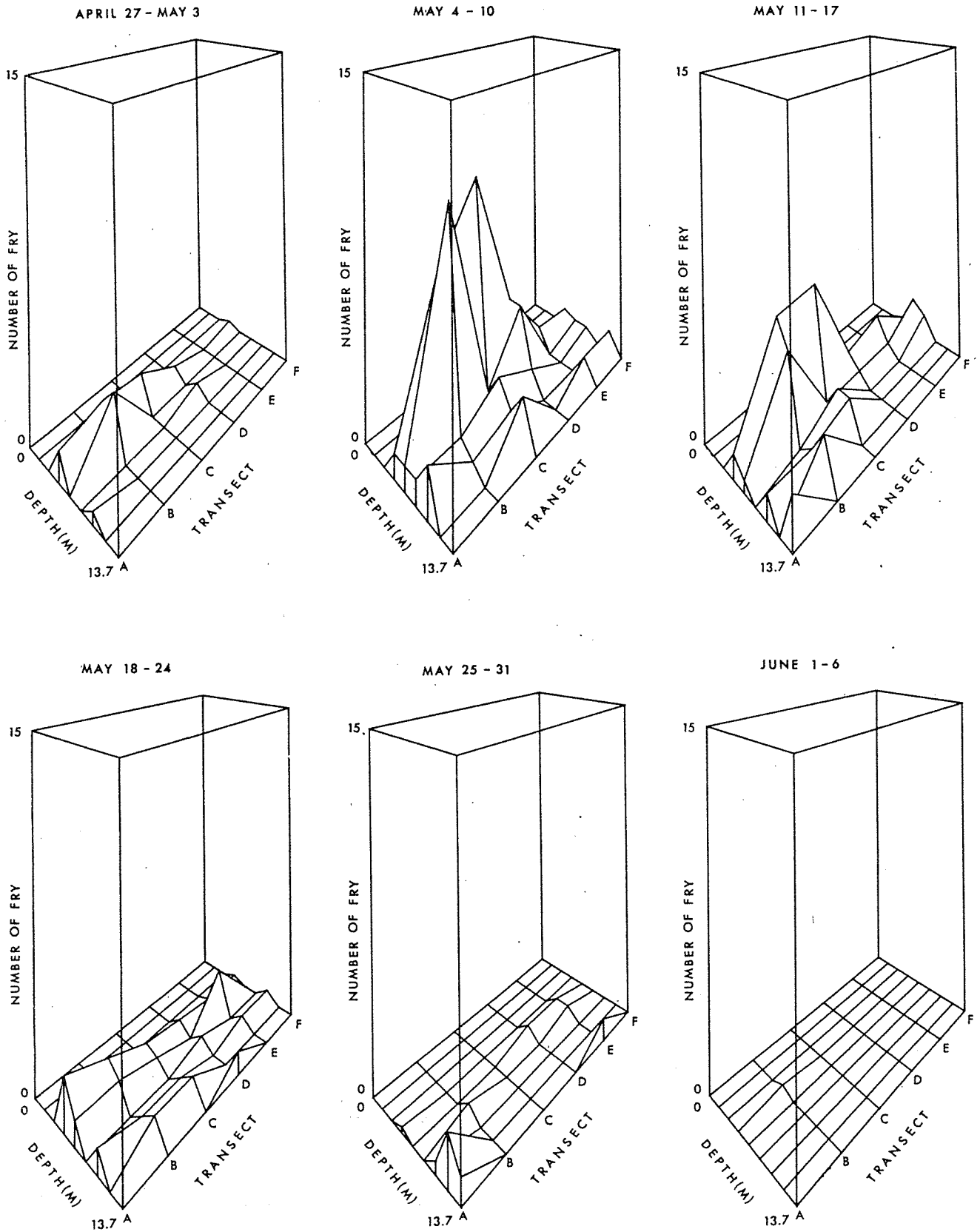


Fig. 11. Distribution of kokanee fry emerging into traps on the prime spawning area by week, depth, and transect. Divisions on the depth scale = 1.7 m.

6.3.3 Survival of Kokanee Eggs and Alevins

The survival to emergence of kokanee eggs and alevins was estimated based on the potential egg deposition of spawners and on the estimated emergence of fry. However, two unquantified factors prevented calculation of a single survival estimate. The redd life, or turn-over rate of spawners, is not known for Banks Lake kokanee and therefore estimates from the literature were used. Because the two available turn-over rates are divergent, two estimates of potential egg deposition were calculated. The estimates of total egg deposition for 1978 based on turn-over rates of 15.4 and 5.7 days were 1,760,780 and 4,757,735 (Table 7) (Stober et al. 1979). The second unquantified factor concerns the catch efficiency of the emergence trap. A single literature value of 69.9% (Collins 1975) is compared with a theoretical value of 100%. Thus four survival rates are presented ranging from 0.55 to 2.13%. Regardless of which value is used, the survival rate of the 1979 year class was low. This rate was approximately one-fourth the rate observed in 1978, and approximately one-ninth the rate observed in 1977. This variation is attributed primarily to the desiccation of eggs and alevins by drawdown during the spring of 1979.

The consequence of such poor survival in 1979 was partially offset, however, by the greater amount of spawning and increased production which took place below the 4.6 m (15 ft) depth strata. The production below 4.6 m was estimated at 26,162 and 37,427 for trap efficiencies of 100% and 69.9%, respectively. Thus, the 1979 production was 63% of the 1978 production of 41,677 and 59,624 fry (based on the same trap efficiencies). The increased spawning below 4.6 m is attributed to retention by a barrier net of a larger population of spawners.

6.3.4 Emergence of Lake Whitefish Fry

The emergence timing and distribution of lake whitefish fry from the prime spawning area is depicted in Figs. 9, 10, and 12. Emergence began

Table 7. Kokanee fry emergence and survival rates at the prime spawning area in 1977, 1978 and 1979.

Emergence Year	Bed	Traps (No.)	Trap Area (m ²)	Total Area (m ²)	Total Catch (No.)	Estimated Emergence		Total Egg Deposition (No.)	Survival (% of Deposition)				
						Trap Efficiency	Total Egg Deposition (No.)		100%	69.9% ²			
1977	Prime	15	3.75	165	238	10,516	15,044	63,239	171,019	16.69	6.15	23.88	8.80
1978	Prime			1579		41,677	59,624	516,906	1,396,196	8.34	2.98	11.92	4.26
	Primary	10	2.5	568	98	22,266	31,854						
	Secondary ⁵	10	2.5	1011	48	19,411	27,770						
1979	Prime			2768	0	0	0	1,760,780	4,757,735	1.49	0.55	2.13	0.79
	Primary	16	4.0	955	0	0	0						
	Secondary ⁵	84	21.0	1813	315	26,162	37,427						

¹100% trap efficiency

²69.9% trap efficiency from Collins (1974)

³Turnover time in days from Pfeifer (1978)

⁴Turnover time in days from Lewis (1972)

⁵4.6 m and below

during the week ending March 29, reached a peak by April 12 and ended by May 3. Despite colder water temperatures and prolonged ice cover the emergence was not delayed, in fact, appeared to be slightly earlier than was observed in 1977 and 1978.

The survival of lake whitefish fry was largely unaffected by the spring drawdown because emergence preceded drawdown. The estimated total emergence was 1,706,967 (Table 8). Emergence occurred principally between depth strata of 2.7 m (9 ft) and 8.5 m (28 ft) and from the coarser substrate at transects E and F (Appendix Table 3).

6.3.5 Kokanee Fry Quality

The fitness of fry at emergence greatly determines their ability to survive. Koski (1975) working with chum salmon concluded that fry fitness consisted of three basic components: (1) size and robustness, (2) stage of development, and (3) timing of emergence of the fry. He also asserted that each of these components is a consequence of the adaptability of the fry and of the severity of environmental conditions such as temperature, dissolved oxygen, and substrate composition.

Size and robustness can affect success in several ways. Prior to emergence, selection can be toward smaller larvae having greater mobility within substrates high in sand content (from Koski 1975; Bjornn 1969; Phillips 1973). However, following emergence, larger fry exhibit decreased susceptibility to predation, better swimming performance, and increased resistance to starvation before first feeding than do smaller fry (Koski 1975). Although fry size is determined primarily by egg size and parental characteristics, it is heavily influenced by environmental conditions during development and any environmental stress can cause consumption of energy reserves necessary for growth.

The relative robustness of fry emerging from different transects and depths of the prime spawning area and during different sample periods was

Table 8. Estimated emergence of lake whitefish fry from the prime spawning area in 1979 by depth by week.

Sample Period	DEPTH STRATA																	Σ
	1.5 m 5 ft	2.1	2.7	3.4	4.0	4.6	5.2	5.5	6.1	6.7	7.6	8.5	9.1	9.8	10.7	12.2	13.7	
3/20-4/5	4,765	5,044	9,794	5,670	7,458	2,834	1,025	1,110*	451	471*	771	636*	542	540*	855	173	170	42,309
4/6-4/12	3,335	13,112	44,570	26,856	51,912	28,495	20,724	23,383*	10,979	7,085*	7,705	6,182*	4,972	6,734*	13,540	2,085	5,276	276,945
4/13-4/20	*	101	58,261	72,810	116,779	91,537	59,154	45,490	37,149	80,214	73,524	21,043	27,481	24,861*	35,206	6,776	15,829	766,215
4/21-4/27	*	*	*	12,632	29,832	45,654	44,180	27,783	49,632	50,710	105,334	53,704	31,730	25,764	44,327	21,717	15,148	558,147
4/28-5/3	*	*	*	*	*	2,068	2,277	1,879	4,211	7,284	10,897	5,773	4,701	4,339	2,423	1,042	3,234	50,128
5/4-5/10	*	*	*	*	*	*	171	683	0	8,667	220	950	271	452	1,140	521	0	13,075
5/11-5/17	*	*	*	*	*	*	0	0	75	0	0	73	0	0	0	0	0	148
Σ	8,100	18,257	112,625	117,968	205,981	170,588	127,531	100,328	102,497	154,431	198,451	88,361	69,697	62,690	97,491	32,314	39,657	1,706,967
Area (m ²)	357.4	151.3	149.9	149.2	147.2	114.9	85.4	85.4	112.8	138.3	165.1	109.6	135.6	135.6	213.8	260.6	255.3	
Estimated fry/m ²	22.7	120.7	751.3	790.7	1399.3	1484.7	1493.3	1174.8	908.7	1116.6	1202.0	806.2	514.0	462.3	456.0	124.0	155.3	

*Traps dewatered or no trap in place; data interpolated from catches of adjacent traps.

calculated (Appendix Table 4). Fulton's condition factor (Ricker 1975), equal to weight (g) \div length (cm)³ was calculated for individual fry. An important assumption in this context is that larger fry (high condition factor) have a higher probability of survival than less robust fry.

The condition of the fry may have been influenced by time of emergence and depth of emergence, but the tests were inconclusive because of the small numbers of fry available for analysis. The most significant difference in condition factor was associated with time of emergence (Fig. 13) with the highest condition index (0.761) coinciding with the week of peak emergence on May 10. This difference was significant at the .05 level by the Student-Newman-Keuls multiple range test. The lowest condition factor occurred during the last week of emergence; however, the number of fry captured was small.

The fry with the highest condition factors emerged from depth strata between 7.6 and 9.8 m (25 to 32 ft) below full pool (Fig. 14). The lowest condition factors were observed in fry emerging at the shallowest and deepest strata: 4.6 m (15 ft) and 13.7 m (45 ft), respectively; however, this relationship was not statistically significant.

Except for the two depth extremes, condition and density of emergence appeared inversely related, with condition highest where emergence density was lowest; however, this possible relationship cannot be verified statistically.

A comparison of fry condition versus transect showed no significant differences (Fig. 15). The high and low condition values occurred from adjacent transects E and F (0.668 and 0.761, respectively).

The small number of fry trapped in the wave zone at 4.6 m (15 ft) suggests that drawdown may have caused mortality and stressed the surviving fry to a depth of about 0.6 m (2 ft) below the maximum drawdown level.

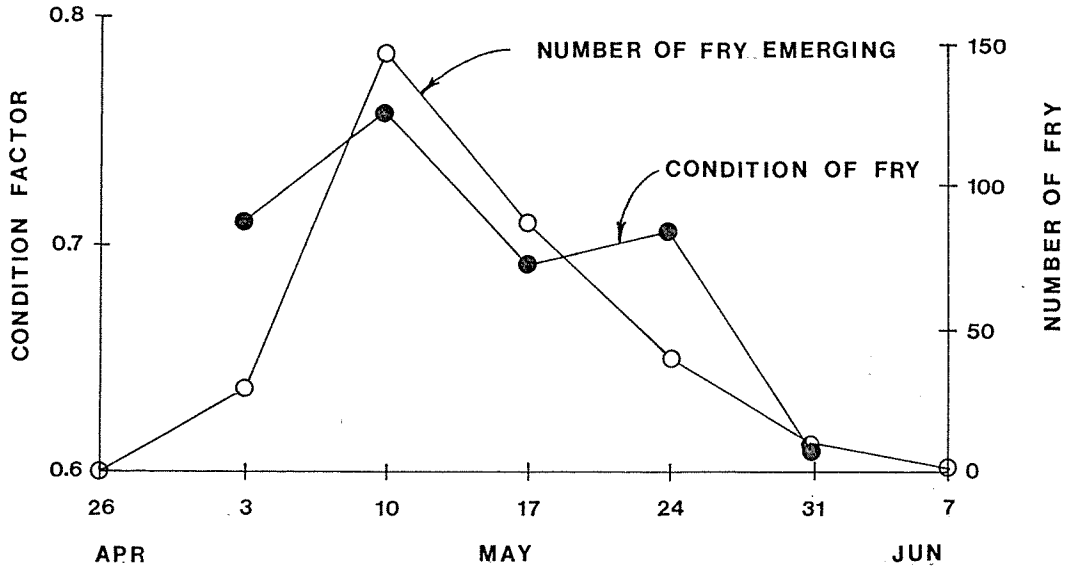


Fig. 13. Comparison between condition and emergence timing of kokanee fry from the prime spawning area of Banks Lake, 1979.

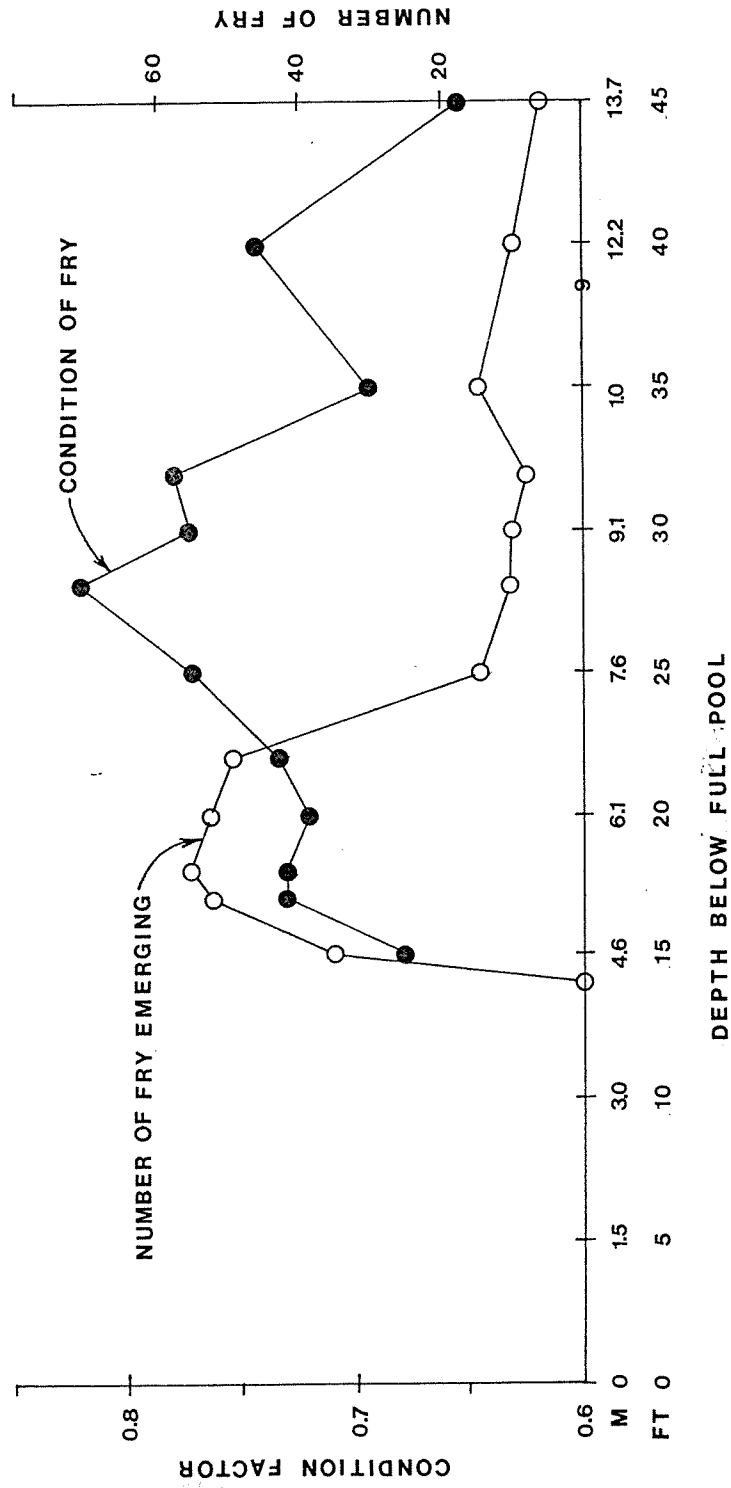


Fig. 14. Comparison between condition and emergence depth of kokanee fry from the prime spawning area of Banks Lake, 1979.

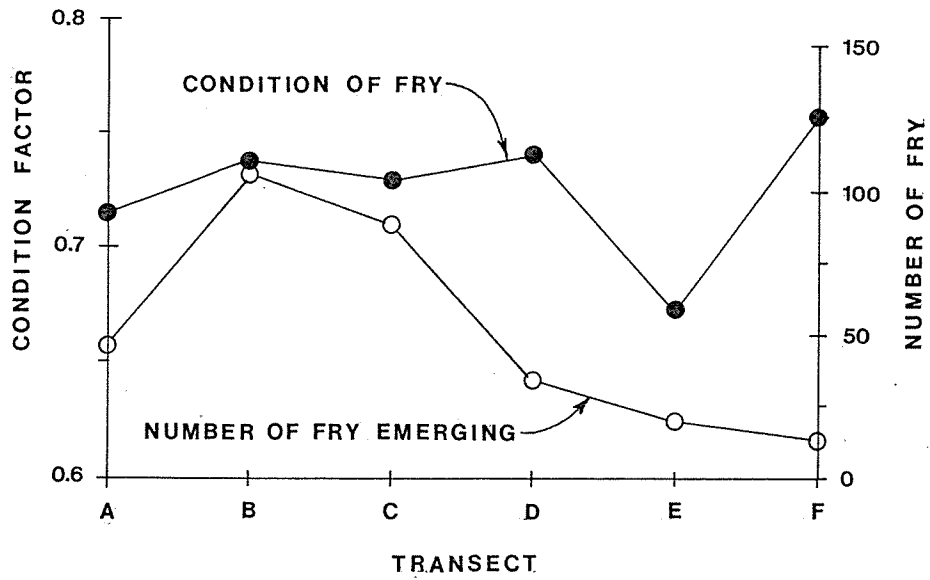


Fig. 15. Comparison between condition and transect of emergence of kokanee fry from the prime spawning area of Banks Lake, 1979.

The shape of the curve in Fig. 14 suggests that large numbers of fry did not move from the drawdown area to deeper strata. The curve shows a relatively large and uniform emergence from traps at 5.2, 5.5, 6.1, and 6.7 m (17, 18, 20, and 22 ft). If large numbers of fry had followed the waterline down from dewatered strata, the emergence should have been substantially greater from immediately below the wave zone.

6.4 Kokanee Spawning, Incubation, Emergence, and Drawdown

The spring drawdown due to irrigation withdrawal is the most critical operational factor limiting kokanee fry survival. An analysis of water surface elevations during the period from 1971-1978 (Stober et al. 1979) showed that drawdown during the remainder of the year had less effect on survival. The general operating procedure has been to maintain the reservoir at or near full pool elevation during the fall, winter, and early spring seasons.

The relationships between the depth interval of the kokanee spawning area, the time of spawning, egg incubation, and fry emergence and the spring reservoir drawdown are illustrated in Fig. 16. These relationships show the observed conditions with small kokanee spawning populations of 1,851 in 1976 and 11,039 in 1977 which only spawned in the primary area at depths from 1.5 to 4.6 m (4.9 to 15 ft) below full pool. A large spawning population of 35,381 utilized greater depths in 1978 which ranged from 1.5 to 6.7 m (4.9 to 22 ft). Both early and late spawners were observed to utilize the entire depth interval throughout the spawning season. Little spawning was observed above 1.5 m (4.9 ft) during any year.

The timing and rate of the spring reservoir drawdown is of critical importance in relation to the survival to emergence of kokanee fry. Fry emergence was observed from late March until early June. Maximum emergence occurred on April 28, 1977 and May 8, 1978. The emergence for 1979 has been included in Fig. 16 for comparative purposes and was found to peak on May 10. Normalized emergence curves have been plotted with peaks on May 1, 10, and 12 for 1977, 1978, and 1979, respectively. Two-day safety margins were added to allow for error in estimating the emergence peaks. The 1979 fry emergence curve was the latest so far observed and was skewed to the right. This resulted from the extremely low air temperatures during the 1978-1979 fall-winter period which were the coldest in the last 22 years recorded. The delay in emergence represents an extreme, useful for similarly severe fall-winter periods.

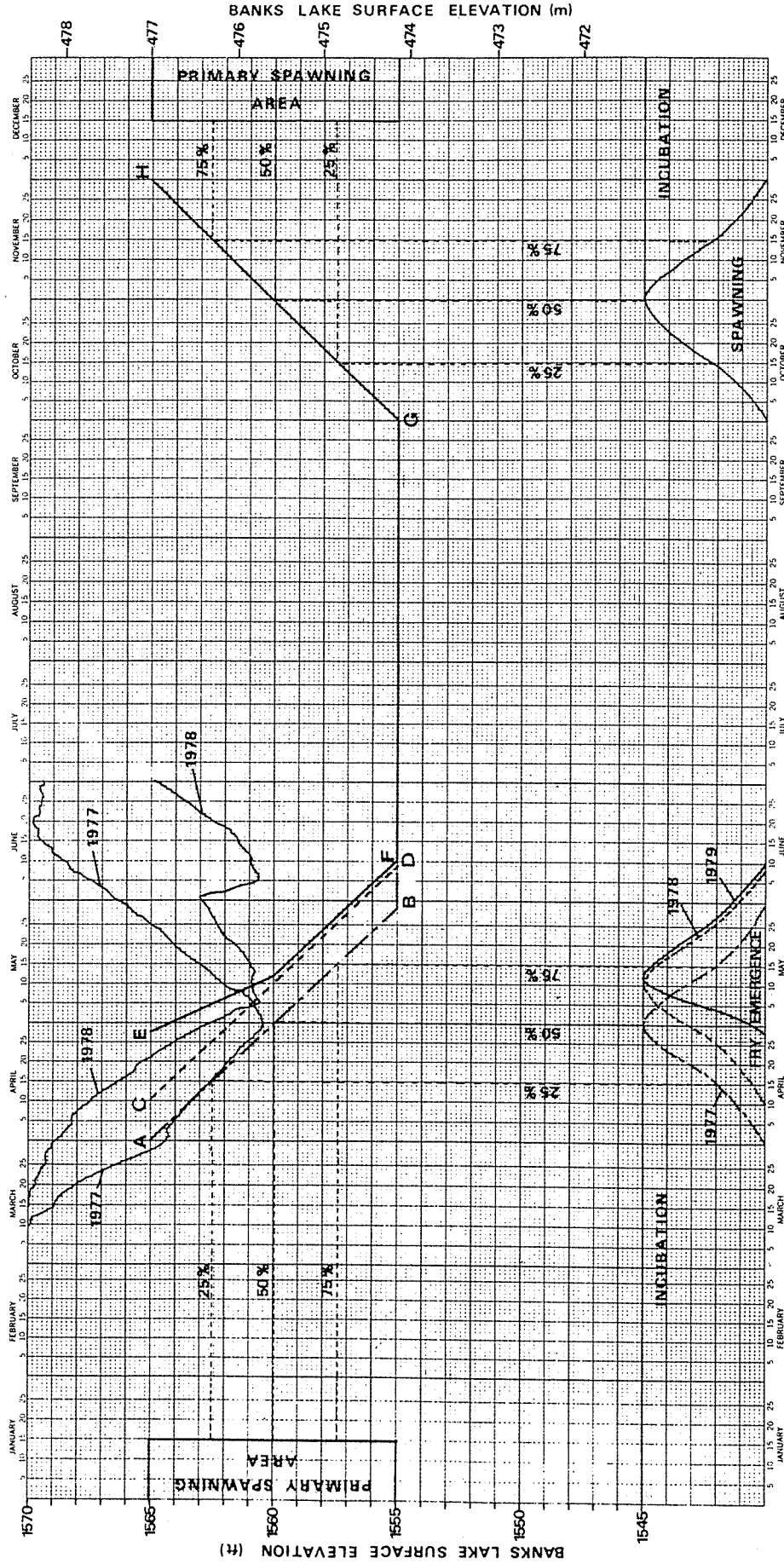


Fig. 16. Rule curves for Banks Lake drawdown to allow fry emergence from a small kokanee spawning population. Rule curves AB, CD, and EF are based on 1977, 1978 and 1979 fry emergence timing, B, D, F & G indicates minimum summer drawdown and GH are the water level requirements for spawner access to the prime spawning area. Drawdown curves for spring 1977 and 1978 are shown.

Drawdown limits (rule curves) have been developed to estimate the effects of drawdown on kokanee fry survival as well as to indicate the rate and timing of drawdown which would allow fry sufficient development time to emerge. The rule curves were developed by aligning the 25, 50, and 75% levels of the spawning area with the corresponding time intervals from the fry emergence curves. The procedure is illustrated in Fig. 16 for the 1977 emergence. Additional points were located in a similar manner and connected to define a rule curve for each year of fry emergence.

Three rule curves are shown for a small spawning population restricted to the prime spawning area and relate to early (AB), late (CD), and extremely late (EF), fry emergence based on the past three years of data. The rate of drawdown prescribed by these limits cannot exceed 5.18 cm/day (0.17 ft/day) for AB and CD, and if followed through a specific fry emergence period would reduce potential survival by 25%. The emergence sampling in 1979 indicated that alevins did not move down through the spawning ground to avoid desiccation; however, this question should be investigated further. These limits, therefore, represent a compromise between limited fry mortality and operational flexibility of the reservoir. The rule curve (EF) resulting from the 1979 emergence timing is shown to indicate an extremely late year in which drawdown below 477 m (1,565 ft) would have to be delayed until April 28 in order to limit fry loss to 25%. The slope of the first half of this curve was 11.0 cm/day (0.36 ft/day) to elevation 475.5 m (1,560 ft) due to the delay in emergence. The remainder of the rule curve EF paralleled CD shifted two days later.

A large population of 35,381 kokanee was estimated to have spawned in 1978. Spawner counts in the fall of 1978 showed intensive activity on the primary spawning area while fry emergence observed the following spring was relatively high to a depth of 6.7 m (22 ft) below full pool elevation. Some spawning and fry emergence was observed below 6.7 m (22 ft); however, numbers were much lower. Based on these observations, the spawning area

from 1.5 to 4.6 m (4.9 to 15 ft) was designated primary and from 4.6 to 6.7 m (15 to 22 ft) was secondary. The secondary area was spawned in 1978 due to crowding of a large spawning population. The large number of spawners resulted from operation of the barrier net which reduced the loss of spawners into the irrigation canal.

The survival of fry could not be measured above a depth of 4.2 m (13.9 ft) due to the drawdown in 1979. It is assumed that a substantial production of fry would have occurred from the primary area. The substrate size in the secondary area was less desirable (Stober et al. 1979) and probably produced less kokanee fry; however, a vertical comparison could not be made. Rule curves were developed to illustrate the relationship of drawdown for a large population by combining both spawning areas from 1.5 to 6.7 m (4.9 to 22 ft). Equal percentages of spawning area and emergence time were aligned in Fig. 17 as previously described for Fig. 16. The emergence curves for 1977, 1978, and 1979 remained the same; however, the larger spawning area produced a new series of rule curves which indicate an increased rate of reservoir drawdown.

Rule curves A'B' and C'D' (Fig. 17) were based on 1977 and 1978 emergence curves, respectively, and presented slopes of 8.5 cm/day (0.28 ft/day). Rule curve A'B' indicates a drawdown regime for a large spawning population during a year when early emergence occurs, while C'D' is ten days later and indicates a drawdown regime for late emergence. Rule curve E'F' indicates the actual drawdown regime which would have been required to limit fry loss to 25% in 1979. Due to the extremely late fry emergence in 1979 which resulted in a distribution skewed to the right, drawdown would have had to be delayed to April 28 at elevation 477 m (1,565 ft). The slope of this rule curve down to elevation 474.4 m (1,556.5 ft) was 18.6 cm/day (0.61 ft/day). The remainder of E'F' paralleled C'D' to elevation 471.8 m (1,548 ft) and shifted two days later.

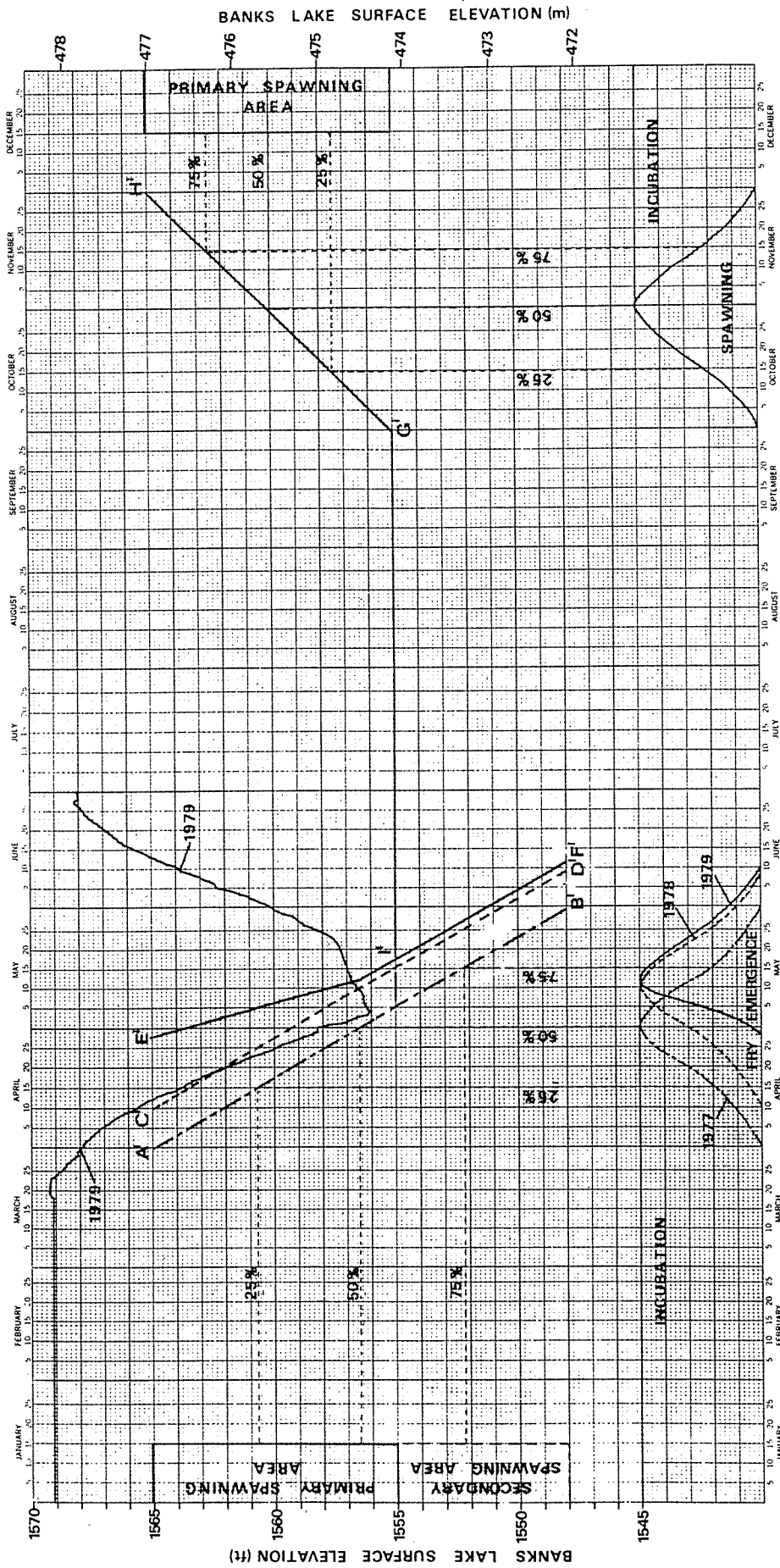


Fig. 17. Rule curves for Banks Lake drawdown to allow fry emergence from a large kokanee spawning population (>30,000). Rule curves A'B', C'D' and E'F' are based on 1977, 1978, and 1979 fry emergence timing; I'G' indicates minimum summer drawdown and G'H' are the water level requirements for spawner access to the prime spawning area. The drawdown curve for spring 1979 is shown.

Extremely early or deep drawdown should be avoided under any circumstance due to the detrimental effects on fry survival; however, Fig. 17 illustrates a substantial increase in potential operational flexibility if large spawning populations are known to have spawned at depth in the lake. However, the rule curves in Fig. 17 heavily impact the primary spawning area by shifting the timing of drawdown 13 days earlier at elevation 475.5 m (1,560 ft) and 24 days earlier at 474 m (1,555 ft) at the lower limit of the primary spawning area. Heavy reliance is thus placed on the survival of eggs and fry from the deep secondary spawning area at the sacrifice of the primary area. An advantage of large spawning populations is the greater spawning at depths which may be relied upon to avert a total fry loss during years of inadvertent early or extreme drawdown, e.g., due to construction. Routine utilization of the rule curves in Fig. 17 would not allow optimum production of kokanee to be achieved in the lake.

The rule curves can be used to make rough estimates of the fry mortality due to drawdown occurring during each of the last three years. Based on the timing and rate of drawdown, about 25% of the fry were lost in 1977 while less than about 5% were lost in 1978 (Fig. 16). The loss of fry due to drawdown in 1979 was at least 50% based on the combined primary and secondary spawning areas (Fig. 17); however, at least 90% of the eggs and alevins was lost from the primary spawning area. Since there were critically small numbers of eggs deposited in 1977 and 1978, it would have been advisable to avoid additional loss due to drawdown in both years. The survival from the secondary spawning area in 1979 averted a potentially disastrous loss of fry. The estimated fry emergence in 1979 following 35,381 spawners was only 63% of that occurring in 1978 from one-third as many spawners. The loss of fry from the primary spawning area due to drawdown eliminated any increase in the population which could have been achieved from the large 1978 spawning. The small production of fry in 1979 is not expected to be adequate to support a good sport fishery in 1982. However, artificial stocking to supplement this yearclass is not recommended because such action would confound evaluation of the popu-

lation size in the year of maturity. The size of the 1982 population should be monitored because the vertical spread in the distribution of spawners may also have given rise to a greater horizontal distribution which may yet result in a large adult population.

Spawning kokanee in the fall are less impacted by manipulation of the lake level and potential effects have been discussed for the water elevations from 1971-1978 (Stober et al. 1979). The rule curves GH (Fig. 16) and G'H' (Fig. 17) for spawning were constructed in a similar way to those for emergence except that each was based on the depth of the primary spawning area where the best spawning substrate occurs and on the time of spawning. As long as the water level exceeds these curves the primary area will be accessible to spawning kokanee. Once a given elevation is spawned, the water level cannot be reduced during the incubation period until emergence has occurred without resulting in mortality due to desiccation of the eggs and alevins. The level of drawdown from May through September (rule curve B, D, F, G, Fig. 16, and rule curve J', I', G', Fig. 17) should be limited to 4.6 m (15 ft) in order to minimize the predator-prey and competitive interactions of the surviving fish populations in the reservoir.

In the future, we recommend that management of Banks Lake water surface elevations be carried out to achieve as much natural kokanee production as possible by utilization of the rule curves presented in Fig. 16. These rule curves do not represent a major departure from the usual operational drawdown of the reservoir. If no further research or monitoring is done it is recommended that the most conservative rule curve be applied each year (i.e., CD; Fig. 16) except following extremely cold winters; then EF (Fig. 16) should be applied. However, if annual water management for irrigation and future power production is to be optimized along with natural kokanee production, then monitoring of two parameters would be useful: 1) daily Banks Lake water temperature at Dry Falls Dam during the incubation period from October to June each year in order to determine the number of degree-days, and 2) the size of the spawning

population of kokanee each fall. With both kinds of data a model could be developed to predict in March of each year the appropriate rule curve for survival of each yearclass of kokanee fry. This would allow early water withdrawal during warm years and some potential flexibility in the rate of withdrawal following years of large spawning populations. However, if only temperature could be obtained, a prediction of the expected time of emergence could be made which would yield an appropriately timed rule curve similar to those in Fig. 16. Only very limited application should be made of the rule curves in Fig. 17 because these curves severely reduce survival from the primary area. If drafting were expected to exceed a rule curve, then the proper lake level could be maintained by pumping sufficient quantities of water during the early spring from F.D.R. Reservoir. This practice would eliminate the need to supplement the kokanee population artificially. A cost-benefit analysis of such a multiple use management plan should be made. Fry survival should be monitored during the first several years to insure that the fish management goals are met.

7.0 SUMMARY AND CONCLUSIONS

The purpose of this study was to determine the depth and timing of kokanee fry emergence from the primary and secondary spawning areas in Banks Lake during 1979. The effect of reservoir drawdown on the survival of fry (1979) from a large spawning population was compared to the fry survival (1977 and 1978) resulting from small spawning populations.

The air temperature data from the Dry Falls weather station were compared for the months of October through May from 1958 to 1979 to determine the relative severity of the 1978-1979 weather during the kokanee incubation period. The monthly temperatures for November, December, and January averaged 1.7 to 2.8°C (3 to 4°F) colder than any previous year compared. The air temperatures during October 1978 and March, April, and May 1979, were normal. The unusually cold temperatures caused a complete ice cover of Banks Lake from mid-December through March to a maximum thickness of 1 m at the south end of the reservoir. The duration and thickness of the ice cover were about double the usual occurrence. However, because observations were not made during the winter, it was not determined whether this ice cover caused any additional mortality of kokanee embryos.

Dissolved oxygen concentrations and water temperatures were measured weekly at surface and 3 m depths from March 30 to June 8, 1979. The dissolved oxygen concentration was at or very near the saturation level, and water temperatures increased in normal progression during the period.

The sedimentation rate during the winter of 1978-1979 was much less than was observed during two previous years. The low rate is attributed to the prolonged period of ice cover which prevented wave action. Sedimentation did not appear to be a limiting factor in the prime spawning area.

An attempt was made to determine the pre-emergent abundance of kokanee eggs and larvae by the development and use of an egg pump. However, the short time period available for development of the device allowed only one design which proved to be incapable of sampling the large gravel to a necessary depth. The egg samples obtained were probably heavily biased toward eggs near the gravel surface which had undergone very high mortality.

The emergence of kokanee fry was monitored by an array of 90 traps placed in six transects with 15 traps each at depths ranging from 0.6 to 13.6 m (2 to 45 ft) below full pool elevation. Emergence began about May 1, peaked by May 10, and ended by June 7. Because fry development was very late, lake drawdown reached 4.2 m (13.9 ft) below full pool by the beginning of emergence. Surviving eggs and alevins in the upper 90% of the prime spawning area were killed by desiccation. The density, timing, and depth distribution of kokanee fry emergence based on the catch of 12 traps placed on spawning slopes at the Million Dollar Mile area was similar to that observed at the primary spawning area and indicated that the effects of the drawdown were equally severe.

The distribution of fry emergence by depth indicated that fry did not move from the drawdown area to deeper strata. The traps at 5.2, 5.5, 6.1, and 6.7 m (17, 18, 20, and 22 ft) caught large and approximately equal numbers of fry. If fry had followed the waterline down from dewatered strata, the emergence would have been expected to increase at traps immediately below the wavezone. This conclusion is based on circumstantial information and should be tested by further sampling.

The largest fry emergence occurred from depth strata between 4.6 and 6.7 m (15 and 22 ft). Emergence occurred from all depth strata sampled to 13.7 m (45 ft), but the emergence below 6.7 m (22 ft) was relatively minor. The drawdown apparently caused mortality of fry to an additional depth of 0.6 m (2 ft) below the drawdown level as evidenced by the low emergence and poor condition of fry in that stratum.

The estimated emergence of kokanee fry from the prime spawning site was 26,162 ($Z\alpha = \pm 11,152$) based on a trap efficiency of 100%, or 37,427 based on an efficiency of 69.9%.

The estimate of percent survival of kokanee eggs and alevins from deposition to emergence ranged from 0.55 to 2.13 depending on choice of factors used in determining redd-life of spawners and efficiency of the fry traps. Regardless of which rate is used, the survival was very low; approximately one-fourth and one-ninth the rates observed in 1978 and 1977, respectively.

The production of kokanee fry in 1979 was 63% of the production in 1978. The poor survival in 1979 was partially offset by increased egg deposition below 4.6 m (15 ft). Increased egg deposition below 4.6 m is believed to have resulted from increased competition for spawning sites by a large population of spawners, which forced the use of less desirable gravel at greater depth.

The emergence of lake whitefish fry was monitored incidental to the emergence of kokanee fry. Emergence began during the week ending March 29, reached a peak by April 12, and ended by May 3. The emergence timing of lake whitefish was normal and apparently was unaffected by the colder temperatures during incubation. The emergence timing of lake whitefish fry largely preceded the lake drawdown. The total estimated emergence of 1,706,967 occurred primarily between depth strata 2.9 m (9 ft) and 8.5 m (28 ft) and was greatest from the coarsest substrate.

The fitness (condition) of kokanee fry emerging from the primary spawning area was determined from length and weight measurements. Condition appeared to have been influenced by emergence timing and depth; however, the sample size was inadequate for statistical testing. The fry of best condition emerged during the week of peak emergence and fry of poorest condition emerged during the last week of emergence. The fry of best condition emerged from moderately deep strata between 7.6 and 9.8 m

(25 and 32 ft) below full pool. The fry of poorest condition emerged from the shallowest and deepest strata; 4.6 and 13.7 m (15 and 45 ft), respectively. The condition and density of emergence, except for the deepest and shallowest strata, also appeared inversely related, with condition best where emergence was lowest. It is possible that the unusually prolonged period of ice cover from mid-December 1978 through March 1979 caused some oxygen deficiency for developing embryos which would have had greatest effect in areas of highest egg density.

The relationships between the depth range of kokanee spawning area, time of spawning, egg incubation and fry emergence, and the spring reservoir drawdown for 1977, 1978, and 1979 were analyzed. Drawdown limits (rule curves) which allow fry emergence to occur were graphically developed from these data, using the primary and secondary spawning areas located, respectively, 1.5 to 4.6 m (4.9 to 15 ft), and 4.6 to 6.7 m (15 to 22 ft) below full pool and the normalized fry emergence and spawning curves for each year. Separate rule curves based on small spawner populations restricted to the primary area and a large population including the secondary area were developed. The rule curves represented early, late, and extremely late emergence observed during 1977, 1978, and 1979, respectively. The slope of the rule curves for small populations restricted to the primary area was 5.18 cm/day (0.17 ft/day) with the early curve, beginning at elevation 477 m (1,565 ft) on April 1, and ending at 474 m (1,555 ft) on May 28. The late curve was shifted 10 days later over the same interval. The extremely late curve began on April 28 with a slope of 11.0 cm/day (0.36 ft/day) to elevation 475.5 m (1,560 ft) and ended on June 10 at elevation 474 m (1,555 ft). The extremely late curve resulted from the late fry emergence in 1979 due to the coldest fall-winter on record.

Rule curves based on the area (primary and secondary) utilized by a larger population of spawners resulted in slopes of 8.5 cm/day (0.28 ft/day) with the early curve beginning at elevation 477 m (1,565 ft) on April 1 and ending at 471.8 m (1,548 ft) on May 28. The late curve was

shifted 10 days later over the same interval. The extremely late curve began on April 28 with a slope of 18.6 cm/day (0.61 ft/day) to elevation 474.4 m (1,556.5 ft) and ended on June 10 at elevation 471.8 m (1,548 ft). The large population, by spawning at greater depths, provided some additional drawdown flexibility but these rule curves heavily impact survival in the primary area by shifting the timing 13 days earlier at elevation 475.5 m (1,560 ft) and 24 days earlier at 474 m (1,555 ft) at the lower limit of the primary area. Major reliance is thus placed on survival from the secondary area which did not yield adequate production in 1979. Rule curves based on the larger spawning area should probably not be utilized for routine operation.

The rule curves were utilized to make rough estimates based on the timing and rate of drawdown of the percentage of fry lost each year. About 25% and less than 5% were lost in 1977 and 1978, respectively. The loss of fry in 1979 was about 50% overall with at least 90% of the survival from the primary area eliminated due to the extremely late emergence and drawdown which occurred. Survival from the deeper secondary area helped to avert a near-disastrous loss of the 1979 fry yearclass. Rule curves for fall spawning and summer minimum reservoir level were also included; however, neither were as critical to kokanee survival as the spring drawdown.

It is recommended that the rule curves developed be applied in the future water management of the reservoir in order to allow the optimum natural kokanee production to occur. These rule curves do not represent a major departure from the usual operational drawdown of the reservoir. If no further research or monitoring is conducted the most appropriate conservative rule should be applied. However, if an optimized water management plan were developed to include fish survival, monitoring data on the October to June Banks Lake water temperature regime and spawner population index could be used in a predictive model to determine the appropriate drawdown regime for kokanee fry survival by March each year. If the appropriate rule curve were to be exceeded, the lake level could be

maintained by pumping of sufficient quantities of water during early spring from F.D.R. Reservoir. The cost benefit ratios for such a comprehensive management plan should be determined. If such a multipurpose plan were adopted fry survival should be monitored during the first several years to insure that the fish management goals are met.

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APPENDIX TABLES

Appendix Table 1. Catch of emergent kokanee fry from the prime spawning area, 1979

Transect	Depth (ft)	April		May			June		Σ
		27 - 3	4-10	11-17	18-24	25-31	1-7		
A	15	5	—*	1		1		7	
	17		1	2	3			6	
	18		2	1	6			9	
	20		1					1	
	22				1			1	
	25		2	1	1			4	
	28		1					1	
	30		1					1	
	32	1				1	1	3	
	35		4	2	1			7	
	40						2	2	
	45			2			1	3	
								<u>45</u>	
B	15		—*	5	2		1	8	
	17		3	3	2			8	
	18	1	5	7	2			15	
	20	6	20	5				31	
	22	5	17	6	1			29	
	25		3	2	1			6	
	28		2			1		3	
	30			1				1	
	32		1	1				2	
	35			1	1			2	
	40			2	1			3	
	45							<u>108</u>	
	C	15	4	—*	8	3			15
17		1	19	7				27	
18			15	3				18	
20		1	6	3				10	
22			1	1	1			3	
25			1					1	
28			1	2				3	
30			3	1				4	
32			1	1	1			3	
35			1	2				3	
40			2		1			3	
45								<u>90</u>	

*Trap pulled out

Appendix Table 2. Catch of emergent kokanee fry from Million Dollar Mile area of Banks Lake.

Transect	Depth (ft)	4/27-5/3	5/4-5/10	5/11-5/17	5/18-5/24	5/24-5/31
M-1	17		9	1		
M-2	20		10			
M-3	23		2			
M-4	26					
N-1	17			6	1	1
N-2	20		14	4	1	
N-3	23		5	2	1	
N-4	26		1	1		1
O-1	17			1		
O-2	20					
O-3	23					
O-4	26					

Appendix Table 3. Catch of emergent lake whitefish fry from the prime spawning area, 1979.

Transect	Depth (ft)	March			April			May	
		21-28	29 - 4	5-11	12-18	19-26	27 - 3	4-10	11-17
A	5								
	7			1					
	9			1					
	11				2				
	13			9	36	15			
	15			28	122		1		
	17		1	29	110	60	2		
	18				89	60	1		
	20			4	67	40	2		
	22				189		3		
	25		5	9	151	194	25		
	28				73	238	5	3	
	30		3	19	70	42	3		
	32					20	4		
	35		2	38	54	3	7		
	40			5	23	30			
45		1	22	58	24	3			
B	5		1						
	7			2					
	9		1	18					
	11			12	21				
	13			46	77	38			
	15			14	49	60			
	17		3	167	266	105	7		
	18				150	139	19	1	
	20		2	84		125	23		
	22				269	126	22		
	25		2	19	146	163	15		
	28				59	67	3	5	1
	30			17	91	39	6		
	32					68	7	2	
	35			22	88	123	3		
	40				2	16			
45			5	23	48	12			
C	5		1						
	7		6	12					
	9		8	55					
	11		8	69	274				
	13		5	98	124	65			
	15		14	72	142	367	19		
	17		8	76	291	166	11		
	18				87	118	6	1	

Appendix Table 3 - Continued

Transect	Depth (ft)	March		April			May	
		21-28	29 - 4	5-11	12-18	19-26	27 - 3	4-10
F	5		13					
	7		3	1				
	9		42	116				
	11		21	69	156			
	13		15	132	360	100		
	15		10	64	178	104		
	17		3	29	50	92		
	18				80	46	3	2
	20			5	69	79	6	
	22				66	160	3	24
	25				62	85	16	
	28				19	34	7	
	30		1		2	8	2	
	32					9	1	
	35				4	1	3	
	40		1	1	4	17		2
	45					2		

Appendix Table 4. Length and weight of emergent kokanee fry from prime spawning area, 1979¹

Date	Transect Depth	Fry Length	Fry Weight	Date	Transect Depth	Fry Length	Fry Weight	
4/30	C-13	23	.08	5/10	B-18	26	.14	
		24	.09			25	.13	
		--	.10			25	.12	
5/3	A-15	23	.08			27	.15	
		25	.11			27	.16	
		24	.11	B-20	24	.11		
		23	.07		24	.10		
		22	.08		26	.12		
		A-32	26		.12	26	.12	
	B-18	24	.11		25	.12		
	B-20	24	.11		24	.09		
			24	.11	25	.13		
			25	.12	27	.14		
			25	.13	25	.13		
			25	.10	26	.14		
			22	.07	26	.14		
		B-22	24	.09	25	.11		
			24	.09	26	.14		
			25	.11	23	.09		
			25	.10	25	.12		
			24	.08	25	.10		
		C-15	24	.11			25	.11
			24	.09			23	.09
			25	.11			24	.10
			25	.11			25	.13
			25	.11	B-22	26	.14	
		C-17	26	.12		24	.11	
		C-20	25	.11		25	.11	
		D-20	24	.11	26	.12		
		D-28	26	.15	26	.14		
	F-15	22	.07	24	.09			
	X-11	22	.07	24	.11			
5/10	A-17	24	.11			25	.11	
	A-18	24	.08			25	.11	
		25	.15			25	.12	
	A-20	24	.11			25	.11	
	A-25	26	.14			26	.13	
	A-28	25	.11			25	.11	
	A-35	25	.11			24	.12	
		26	.15			24	.12	
		25	.12			24	.10	
		25	.11			25	.13	
		25	.11	B-25	25	.13		
	B-17	24	.10		24	.13		
		24	.11		25	.14		
			23	.08			24	.13
					B-28	24	.13	

¹Includes only those fry which were in good condition at time of preservation.

Appendix Table 4 - Continued

Date	Transect Depth	Fry Length	Fry Weight	Date	Transect Depth	Fry Length	Fry Weight	
5/10	B-28	25	.14	5/11	D-22	24	.11	
		24	.11		D-25	26	.13	
	C-18	25	.13				26	.13
		26	.12			D-30	25	.12
		23	.09			D-17	24	.10
		25	.13			E-18	24	.10
		24	.10				22	.08
		25	.12			E-20	22	.07
		24	.08			E-40	24	.08
		24	.08			F-18	24	.11
		23	.09				24	.11
		24	.08			F-20	24	.09
		25	.10			F-22	24	.10
		24	.10			F-28	24	.11
		23	.08			F-40	23	.09
		24	.11		5/17	A-15	22	.07
		C-20	24			.11	A-17	22
	25		.14				24	.11
	23		.09				24	.11
		24	.12				24	.09
	C-25	25	.14				23	.09
	C-28	24	.13			A-18	25	.12
	C-30	25	.14			A-25	24	.09
		23	.10			A-35	25	.07
	C-32	25	.13				25	.09
	C-35	23	.09			A-45	24	.09
	C-40	24	.12				23	.08
23		.10		22		.07		
5/11	B-25	25	.10			23	.06	
		23	.08			22	.07	
	B-30	25	.11		23	.08		
		24	.09		B-18	24	.09	
	C-17	23	.08			23	.08	
		23	.09			24	.08	
		24	.09			23	.09	
	D-17	23	.10		B-20	23	.08	
		25	.11			24	.09	
		24	.10			23	.09	
		25	.13			24	.09	
		25	.12		B-22	24	.11	
	D-18	23	.09			22	.09	
		24	.10			22	.08	
		25	.10			23	.10	
		24	.10			22	.08	
		23	.10			23	.08	
	D-20	24	.10		B-25	25	.12	
		22	.08	5/18	D-15	26	.13	
		24	.09		D-17	24	.12	
	22	.07			23	.08		
	D-22	24	.11			24	.10	
		24	.10		D-18	23	.08	
		25	.12			25	.12	
		24	.09			25	.10	

Appendix Table 4 - Continued

Date	Transect Depth	Fry Length	Fry Weight	Date	Transect Depth	Fry Length	Fry Weight
5/18	D-20	25	.10		C-35	25	.12
		25	.10			24	.10
5/24	A-17	24	.09	5/25	C-40	23	.09
		25	.10			25	.10
		24	.09			24	.10
		24	.11			26	.13
		24	.11			26	.13
		25	.13			26	.13
		25	.14			35	.10
		25	.11			27	.17
		22	.08			24	.10
		23	.10			25	.10
		23	.09			24	.08
		21	.07			24	.09
		23	.09			24	.08
		23	.07				
23	.09						
23	.09						
23	.09						
22	.08						
24	.09						
26	.13						
25	.11						
24	.07						
24	.10						
23	.09						
24	.10						
25	.12						
26	.12						
24	.08						
23	.08						
25	.12						
24	.09						
26	.12						
25	.09						
25	.11						
25	.09						
25	.11						
24	.10						
24	.10						
24	.09						
24	.10						
24	.10						
23	.08						
24	.11						
23	.10						
25	.12						