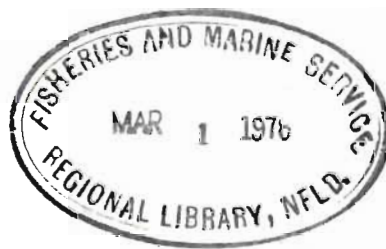


The Meadow Creek Spawning Channel

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La page couverture porte le nom de l'établissement auteur où l'on peut se procurer les rapports sous couverture cartonnée.

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THE MEADOW CREEK SPAWNING CHANNEL

by

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ABSTRACT

Acara, A. H. 1977. The Meadow Creek spawning channel. Fish. Mar. Serv. Tech. Rep. 744: 91 p.

This report describes two years' operation of a salmonid enhancement program in the Duncan-Lardeau River system which flows into the north end of Kootenay Lake, British Columbia.

The object of the Meadow Creek spawning channel was to replace the spawning ground of kokanee lost due to the construction of the Duncan Dam.

This longest spawning channel in the world was the first built for a freshwater fish in British Columbia. Its total length was 3,358 m and the width was 10.4 ± 1.8 m, providing 34,923 m² spawning area with an average grade of 0.25%. Screened gravel was laid to a depth of 23 cm (9 in).

Different spawner and egg densities were compared to develop optimum operation and production criteria for the channel. Satisfactory survivals to the fry stage were obtained at 5.7 kokanee per m² (2.8 female per m²) as 70.8 fry per m². The operation of the channel as well as the rate of survival, egg incubation, emergence timing, size of the fry, discharge and temperature were studied in different sections of the channel during 1967 and 1968 as the basis for evaluation of the channel.

Before construction of the spawning, the mean fry survival from egg deposition in Meadow Creek was 5.87%. Survival increased to 15.75% after the channel became operational. Fry survival in the channel was 25.67% in 1968 and 8.5% in 1969, during the first two years of channel production. Uncontrolled water flows during spawning and fry migration caused these relatively low fry survival rates. The quality of fish appeared similiar to the Lardeau River fry and emergence occurred from mid-April to mid-June in a bimodal pattern. It was concluded, however, that fry production in 1967 and 1968 was greater than the production before loss of the natural spawning ground.

Key words: Spawning, spawning grounds, anadromous species, fish culture, fish ponds, fishery engineering, environmental conditions, inland fisheries, fry.

RÉSUMÉ

Acara, A. H. 1977. The Meadow Creek spawning channel. Fish. Mar. Serv. Tech. Rep. 744: 91 p.

Le présent rapport porte sur deux années d'un programme de mise en valeur des Salmonidés dans les rivières Duncan et Lardeau qui se jettent dans l'extrémité nord du lac Kootenay, en Colombie-Britannique.

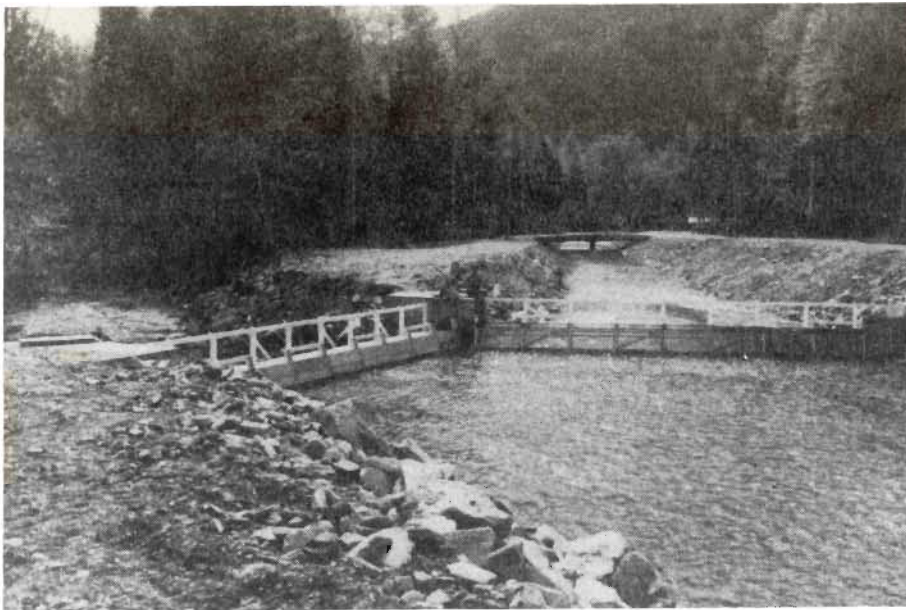
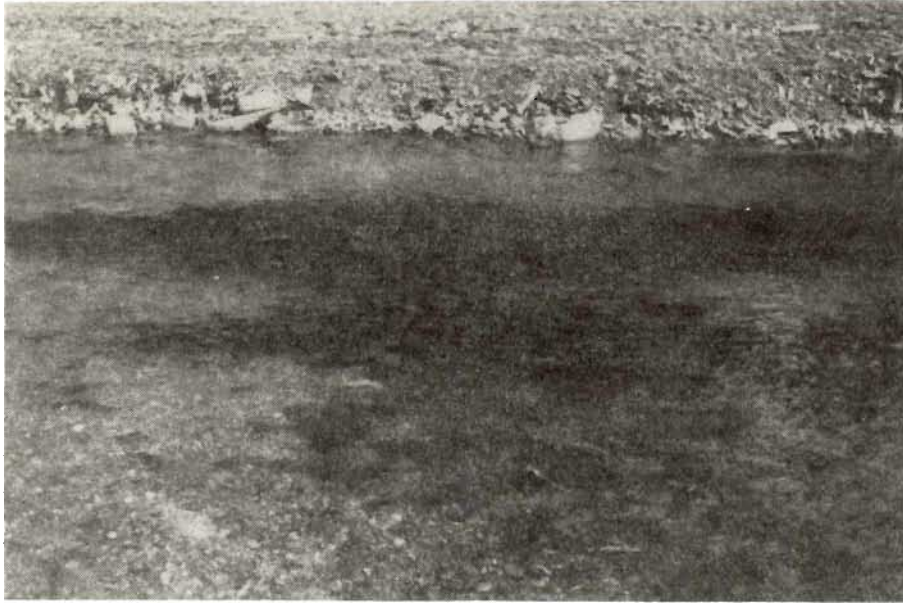
La frayère artificielle du ruisseau Meadow a été créée afin de remplacer la frayère du saumon kokani, détruite lors de la construction du barrage Duncan.

Cette frayère, la plus grande au monde, a été la première à être construite en Colombie-Britannique pour un poisson d'eau douce. D'une longueur totale de 3358 m et d'une largeur de $10,4 \pm 1,8$ m, elle occupe $34\,923\text{ m}^2$ avec une dénivellation moyenne de 0,25 %. On y a déposé une couche de 23 cm (9 po) de gravier tamisé.

On a comparé des géniteurs et des densités d'oeufs afin d'optimiser la production et le fonctionnement. Un taux de survie satisfaisant de 70,8 alevins par m^2 a été obtenu, donnant 5,7 kokani par m^2 (2,8 femelles par m^2). On a étudié le fonctionnement de la frayère, le taux de survie, l'incubation des oeufs, le temps d'éclosion, la taille des alevins, le débit et la température dans diverses sections de la frayère, en 1967 et 1968, afin d'en évaluer le rendement.

Avant la construction de la frayère, la survie moyenne des alevins depuis la ponte dans le ruisseau Meadow était de 5,8 %. Avec la nouvelle frayère, ce taux est passé à 15,75 %. La survie des alevins dans la frayère était évaluée à 25,67 % en 1968, et à 8,5 % en 1969, les deux premières années de fonctionnement. Ces taux relativement faibles ont été causés par l'absence d'une régulation du débit pendant le frai et la migration des alevins. La qualité des poissons était semblable à celle qu'on a observée dans la rivière Lardeau, et l'éclosion s'étendait de la mi-avril à la mi-juin, suivant une configuration bimodale. Toutefois, il a été conclu que la production d'alevins des années 1967-68 avait été plus élevée qu'avant la destruction de la frayère naturelle.

Mots-clés: frai, frayères, espèces anadromes, pisciculture, parcs-réservoirs, techniques de la pêche, conditions ambiantes, pêche en eau douce, alevins.



Kokanee (landlocked sockeye salmon) in the Meadow Creek spawning channel (above),
and upper and diversion fences (below) in 1967.

INTRODUCTION

In early 1966, Duncan Dam on the Duncan River, blocked upstream access of kokanee (landlocked sockeye, Oncorhynchus nerka). Thus a spawning area which in the fall of 1964 was utilized by 2.8 million kokanee (Bull 1965) was destroyed. To offset this loss it was necessary to construct an artificial kokanee spawning channel. Since an artificial spawning channel for kokanee had never been constructed, it was necessary to obtain further information on the reproduction of kokanee in the Duncan-Lardeau system.

Kokanee population estimates, their sex ratio, mean length, weight, fecundity, egg retention and deposition and other meristic characters were studied from 1965-1967.

In the winter of 1965, studies were also conducted on the natural spawning areas in Meadow Creek and the Lardeau River to determine spawning requirements such as spawning gravel, egg incubation, water velocity, temperature, dissolved oxygen in the water and intergravel water. These were conducted each month, November-April in 1965-1966 and 1966-1967. The details of these studies are given in other reports (Acara et al. 1970, and Acara and Fleck 1970). Based on this information, criteria were established for gravel size composition and depth as well as requirements for water depth, velocity and distribution of spawners for the spawning channel. Monthly egg sampling also provided information on the period of incubation and time of fry emergence.

In 1966-1967, information from these studies was extracted, discussed and used for the construction of the channel. During these studies, Meadow Creek was selected as the best site for the spawning channel after considering debris, erosion, flooding and siltation problems as well as costs of construction and maintenance. The engineering survey began in 1966 and continued into early 1967. The construction of the channel started in the fall of 1966 and was completed in the summer of 1967.

During the same years, 1966 and 1967, fry production of Meadow Creek and the Lardeau River was estimated and from these studies the survival rate of kokanee fry from the egg deposition was estimated for the natural spawning grounds. These survival rates together with the survival rates obtained during the first and the second years of channel operation were used to measure the success of the spawning channel.

In addition to reporting on the above data, a brief description of the channel gravel composition, life history and ecology of Meadow Creek kokanee is given in this report. The paper also recommends some alterations and additional facilities to increase the fry production of the spawning channel.

METHODS

ESTIMATING NUMBER OF SPAWNERS

It is common knowledge that an accurate estimate of spawning escapement is of vital importance for the regulation of salmon fisheries. In the past, the abundance of spawners was counted by observers on foot (walking or wading), in boats or on rafts or in aeroplanes (Gilbert 1968), with scuba gear (Orrel and Demory 1962), on towers (Becker 1962) and by weirs. In some instances, counts of redds were also used as an index to abundance of spawners rather than counts of fish themselves (Richards 1958). The other method of estimating total escapement is the application of tags to spawners and subsequent recovery of tagged and untagged fish on the spawning grounds (Schaefer 1951). The most accurate technique is direct counts of individual spawners through a weir in the stream. The technique used to produce data must be comparable from year to year.

In 1965 kokanee spawners in the Duncan-Lardeau River system were estimated by a tagging and recovery program. Fish were tagged at Argenta Bridge on the Duncan River, at the Hatchery Fence on Meadow Creek and at the Marblehead Fence on the Lardeau River (Fig. 1). All fish tagged were sexed to determine the sex ratio for each stream system. Different tag-baffle combinations were used to distinguish between the individual escapements and to provide information regarding the timing and distribution of the upstream migrants (Henderson and Yesaki 1970).

In 1966 and 1967, kokanee spawners were enumerated by direct counts through the fences (weirs) on Lardeau River and Meadow Creek and visual estimates of fish in minor areas below the fences. Four counting stations were installed on the Marblehead Fence and three on Meadow Creek. To determine the period of the day when upstream movement was at a maximum, counts in the Lardeau River were initially made over a full 24-hr period. Fish were counted for 30 minutes of each hour or continuously during the periods of maximum movement.

In 1967, the first year of channel operation, kokanee spawners were enumerated in the spawning channel, above the channel, and in John Creek (Fig. 1). The Lower Fence was kept open until September 25, when very few dead fish were seen in the channel, to obtain natural fish distribution throughout the channel. Surveys were made on foot every 2 or 3 days. During this period, the spawners which accumulated just below the Upper Fence, were counted and allowed to continue their upstream spawning migration above the channel. After September 25, the Lower Fence was closed and direct counting started and continued until November 15, 1967. Dead kokanee were also counted in the channel.

In 1968 kokanee spawners were enumerated in the channel, in John Creek, and above the channel in Meadow Creek. The numbers of spawners were estimated by direct count through the Lower and Upper Fences and by visual count in John Creek.

The accuracy of the techniques was tested. Comparison of the tagging recovery estimates with the counts in Meadow Creek in 1965 showed that the tagging-recovery estimates were within $\pm 3\%$ of the weir count. In 1967, the accuracy of visual counts in the spawning channel was within $\pm 5\%$.

SAMPLING OF SPAWNERS

Samples were taken periodically to obtain length, weight, sex ratio, age, fecundity, egg size and morphometric characters of the spawners in Meadow Creek and Lardeau River in 1965-1967, and in the spawning channel in 1968. Otoliths were used to determine the age of adult kokanee on spawning grounds because of resorption of the margins of scales. On some scales the first and second year annulus had been marred by regeneration of the nucleus.

GRAVEL SAMPLING IN THE CHANNEL

A total of 116 gravel samples was taken in the channel from November 29-December 5, 1967 and analyzed using the method described by McNeil and Ahnell (1962) with the range of gravel size extended to a maximum of 2 in (Acara and Fleck 1970). The sieve sizes used varied from 0-10 or from silt to 2 in (Table 1).

EGG SAMPLING IN THE CHANNEL

The method described by McNeil (1964a, 1964b) was used to obtain egg density, mortality and spawning success in the channel. Spawning success was defined by McNeil (1964a, 1964b) as the ratio of the number of females calculated from the egg sampling to the number of females counted in an area. It was based on the assumptions that each location is available for spawning and each female selects a spawning area at random, i.e. independent of whether or not spawning had previously occurred at the site (McNeil 1967).

In 1967 a total of 58 egg samples was taken by a hydraulic sampler from sections of the channel where the spawning densities and the areas of the sections were known. The density of kokanee that deposited their eggs safely was estimated from the egg samples, known areas of the sections, the mean egg deposition and sex ratio of the spawners in the channel. From these data mortalities during the spawning and egg incubation were estimated in various sections of the channel.

FRY SAMPLING

A vertical sampler was used to obtain the fry output of Meadow Creek and the Lardeau River in 1966 and 1967. The sampling was done only in the spawning channel in 1968 and 1969 to obtain fry production of the channel.

The sampling locations were: Hatchery Fence, Lower Fence, Leg 1, John Creek, Upper and Diversion Fences on Meadow Creek and Marblehead Fence on the Lardeau River (Fig. 1). The details of the method were given by Acara and Smith (1971). Kokanee fry were captured in a series of sampling devices each consisting of an elongated rigid metal frame located with its long axis perpendicular to the stream and supporting a column of nets each with openings 1.0×0.5 ft. All were fitted with nylon marquisette with a mesh size of $3/8$ in to form a bag 2.0 ft deep. Catches made in these nets formed the basis of the daily and seasonal estimates. Nets were fished throughout the vertical water column and individual catches were obtained and recorded in each foot increment from the stream bottom to the surface at 5 locations on Marblehead Fence and Lardeau River, at 3 locations on Upper, Diversion, Leg 1, Lower, Abey's Farm and Hatchery Fence, and at 2 locations on John Creek Fence and Meadow Creek. They were equidistant from the banks and from each other, 50 ft apart on Marblehead Fence and Lardeau River, 12 ft apart on Upper, Diversion, Leg 1 and Lower Fence, 10 ft apart on John Creek, Abey's Farm and Hatchery Fences (Fig. 1, 2). The nets were operated for part of each hour from dusk to dawn, at least every other night. No artificial light was used during fishing periods. Fishing intervals varied with the abundance of the fry. It was 10 min every hr at the beginning and end of the migration, and reduced to 5, 2 and 1 min as the abundance increased (Fig. 2). Catches in every net at each station were expanded to estimates of the number of fry and alevin separately passing hourly in each foot of water in each section of the river (Fig. 2). Thus data were obtained on the horizontal and vertical distribution of the fish.

The total number of fish passing downstream on nights when the nets were operated was estimated by expanding the total catch at all stations in accordance with the fractional part of the stream cross-section, and the fraction of the migration period which was fished. The seasonal total was obtained by adding the estimates obtained on nights when fishing was conducted to those calculated for nights when no fishing was conducted. The latter were estimated by interpolating.

Hourly abundance (C_H) in each ft level at each location was calculated from the equation:

$$C_H = \frac{S}{S_N} \times \frac{60}{T_f} \times C$$

where S is the cross-section area in ft^2 (see Fig. 2a), S_N is the area of the net opening in ft^2 , T_f is fishing time in minutes and C is the catch.¹

¹ Because water levels vary, the portion of the top net which is submerged also varies. However, the expression $\frac{S}{S_N}$ is a constant at any water level the river discharge changes.

For instance, in the spawning channel, taking $S_N = 0.5 \text{ ft}^2$ and $S = 12 \text{ ft}^2$ for the Upper, Diversion, Leg 1, and Lower Fences, the equation becomes :

$$C_H = \frac{12}{0.5} \times \frac{60}{T_f} \times C \quad \text{or } C_H = K.C$$

where K is a constant and its value is 144, 288, 720 and 1,440 for 10, 5, 2 and 1 minutes' fishing each hour respectively.

In the case of John Creek $S = 10 \text{ ft}^2$ and $K = 120, 240, 600$ and 1,200.

However, K must be calculated for each sampling location on a stream each year, because of stream erosion on the banks.

The maximum error depends on the nightly total catch of 0.5 ft^2 net. If the catch was lower than 60 for 10 minutes' fishing, the error was $\pm 11.6\%$. For catches greater than this, the error was $\pm 5.8\%$ (Acara and Smith 1971).

The nightly total fry and alevins originating from the spawning channel was calculated by subtracting the nightly estimates on the Upper Fence and on John Creek from the nightly estimate on the Lower Fence. For the natural spawning areas above the spawning channel, the nightly total fry and alevins was obtained by adding the nightly estimates on Upper and Diversion Fences. The nightly total fry and alevins of the natural spawning areas below the spawning channel were calculated by subtracting the nightly estimates on Lower and Diversion Fences from the nightly estimates on the Hatchery Fence. At each sampling location, the seasonal total was obtained as explained above.

During high water a floating vertical sampler was used on the Lardeau River at Marblehead in 1966 and 1967.

STREAM FLOW AND TEMPERATURE

During the enumeration of the spawners, fry and egg sampling, water depth, velocity, discharge and temperature were measured. The water depth was measured with a standard gauge, velocity with a Pygmy-Gurley current meter, discharge components were calculated by multiplying these velocity readings by the areas of the river sections and the temperature was taken with a bucket thermometer and with recorders.

DESCRIPTION OF THE CHANNEL

DIMENSIONS

The average width of the channel was $10.4 \pm 1.8 \text{ m}$ ($34 \pm 6 \text{ ft}$), the banks were built on a slope of 2:1. The average grade was 0.25%. The total length of the channel, between the Upper, Lower, and John Creek fences was 3,358 m (11,014 ft) which provided about $34,923 \text{ m}^2$ ($41,768 \text{ yd}^2$) spawning areas.² Screened gravel was initially laid to a depth of 9 in.

²The dimensions of the channel were calculated based on the area between the locations where the fry productions were estimated on the upper, lower, and John Creek fences in 1968 and 1969.

GRAVEL COMPOSITION

Spawning gravel must be small enough to retain the eggs and large enough to permit a free flow of oxygenated intergravel water. Therefore, a very uniform gravel was specified for the channel although that actually produced was less uniform (Fig. 3). In the process of placing the gravel in the channel some fine materials were introduced and uniformity was further reduced (Fig. 3). Thus in December 1967, the gravel composition of the upper part of the channel (Leg 1, Table 2) contained an excess of fine materials (below the 85.87% interval shown in Fig. 3). On the other hand, the gravel composition of some sections of the channel contained an excess of coarse materials (above the 85.8% interval shown in Fig. 3). Such locations were in Leg 2, 5, 6, and 7, and Corner 2, 4, 6, and 7 (Tables 3, 4, 5, 6). They represent less than 50% of the samples taken in each leg and corner. Details of the sampling and composition of the gravel are given in another report (Acara and Fleck 1970).

WATER SUPPLY

The water supply for the spawning channel was taken directly from Meadow and John creeks and has a minimum discharge of about 40 ft³/s (1.13 m³/s) in February and March and a maximum discharge of about 700 ft³/s (19.81 m³/s) in May and June (Fig. 7).

WATER TEMPERATURE

During September-November water temperature taken between 1100 and 1300 hr at the Upper, Lower and Hatchery fences indicated that the temperature was higher (1-2 C) at the Lower Fence than at the Upper Fence. It was about 1 C higher at the Hatchery Fence than at the Lower Fence in Meadow Creek due to heat gain of water flowing in shadeless section of the creek (Fig. 4).

During April-July, the water temperature taken between 1900 and 2000 hr at the Upper, Lower and Hatchery fences and John Creek showed that during the downstream migration of fry, temperature was highest at the Hatchery Fence and lowest in John Creek (Fig. 5). The temperature was also lower at the Lower Fence than at the Upper Fence in the channel due to the intervening John Creek discharge (Fig. 1, 5).

OPERATION OF THE CHANNEL

Since there was no fence to prevent entry of spawners to the diversion channel, flow in the spawning channel could not be reduced. Therefore, the entire discharges of Meadow and John creeks run through the spawning channel during the spawning period.

During the fry migration, April to July, the discharge of Meadow Creek entering into the spawning channel was reduced by opening the bottom of the diversion dam. Figure 6 compares discharges and water levels at the Upper and Diversion fences, John Creek and the Lower Fence during April-June in 1968 and 1969. Uniform flow regulation was impossible due to the direct flow of John Creek into the channel. The discharge and water level variation in the channel below John Creek was due largely to the variation of discharge in John Creek. In 1969, at the Upper Fence, for example, the water level was kept almost constant between 0.85 and 1.00 ft (0.26 and 0.31 m) during May and June, but at the Lower Fence water level fluctuated widely between 0.95 and 2.2 ft (0.29 and 0.67 m).

THE NORTH ARM KOKANEE

In Kootenay Lake, three different races of kokanee are distinguished, they are the west, north and south arm stocks which are different in size and morphometric characters. The west arm spawners are the biggest, the south arm spawners are the smallest and spawn at age 3, while the north arm spawners spawn at age 4 (Vernon 1957).

The north arm kokanee spawn in the Duncan-Lardeau River system, mainly in September and October. The downstream migration of fry occurs between April and July (Fig. 7).

In 1967 two daily peaks in the intensity of upstream movement were observed at the fences in Meadow Creek and Lardeau River (Fig. 8). The first peak occurred between 1600 and 1900 hr and the second occurred between 2200 and 0100 hr in Meadow Creek, while the first peak was between 0600 and 0900 hr and the second was between 1300 and 2000 hr in the Lardeau River. During these periods 89.1% of the daily total spawners migrated upstream in Meadow Creek and 86.5% of the daily total migration occurred in the Lardeau River.

For the years 1965-1968, the first fish appeared when the water temperature was 11.1 ± 1.2 C at the Hatchery Fence, 10.7 ± 1.4 C at the Lower Fence on the spawning channel in Meadow Creek and 11.3 ± 2.3 C at Marblehead, Lardeau River (Table 7). The fish arrived at the Hatchery Fence and the Lower Fence of the channel in Meadow Creek on the same day. The first spawners appeared at Marblehead, Lardeau River about a week later than in Meadow Creek, but water temperatures were only very slightly higher than those in Meadow Creek.

ABUNDANCE AND DISTRIBUTION

Kokanee are the most abundant species in Kootenay Lake and the Duncan-Lardeau River system accommodates much larger spawning runs than any other tributary stream. This may be attributed to the low hydraulic slope of the Lardeau and Duncan River system which provides conditions for higher survival than in other streams of the south and west arms of the lake. The escapement to this river system was very consistent with a range of

1.2±0.12 million spawners during 1965-1967 (Table 8). In those three years, the variation was only 10% of the mean. However, in 1964 the escapement was much higher (4.54 million) and in 1968 it was only 0.63 million. (The difference between escapement and spawners was due to eggs taken for artificial propagation in hatcheries.)

In 1964 and 1965, before the Duncan Dam began operations, the spawning escapement into the Duncan River was 62.0% and 42.2%, respectively, of the total in the river system. In Meadow Creek, the spawning escapement was 7.6% of the total in 1964 and 10.8% in 1965. In 1966, when the Duncan River was blocked, the distribution of the spawners changed considerably with 47.5% of the spawners in Meadow Creek and 51.5% in the Lardeau River. In the same year, only 1% of the spawners was accommodated in Duncan River below the dam.

In 1967, during the first year of the spawning channel operation, 32.6% of the total escapement into Meadow Creek spawned in the channel, 31.2% above the channel, 4.0% in John Creek, 31.8% between the channel and the Hatchery Fence and 0.4% below the Hatchery Fence (Table 9).

In 1968, the spawners were estimated in and above the spawning channel and in John Creek only.³ The total spawning escapement into Meadow Creek, the Lardeau River and below the dam was calculated from the spawner distribution in previous years (Table 8, 9).

FACTORS AFFECTING SUCCESS OF REPRODUCTION

The success of reproduction of kokanee primarily depends on the number of females and males, size (length and weight), egg content of each female, age of the spawners, and their relation to the spawning environment.

SEX RATIO OF SPAWNERS

The most desirable is the present equal numbers of female and male fish in the spawning ground. In this case, the highest egg deposition of the spawners occurs in the spawning ground.

The proportion of females in Meadow Creek varied between 50% and 54% in the spawning runs between 1965 and 1968. In the Lardeau River the proportion of females tended to be less than 50% (Table 10).

³In 1968 the spawning escapement was estimated by G. A. Laing, and the visual estimate of the spawners was relatively low in John Creek.

FECUNDITY OF KOKANEE

Fecundity of kokanee is an indication of reproductive potential of the stock. It gives the number of eggs available for deposition by any run of kokanee and depends upon racial characteristics and may change from one stock to another. Therefore, the mean fecundity of the spawners was estimated in 1965-1968 in the Lardeau River and Meadow Creek (Table 10). In general, the length and fecundity indicated a logarithmic relation and the large fish tended to be more variable in their fecundity than small ones.

After the Duncan River was blocked, the mean length and fecundity of kokanee increased in Meadow Creek. This may be an indication of the spawners changing their spawning ground from the Duncan River to Meadow Creek. In 1967, the mean fecundity was the smallest both in the Lardeau River and Meadow Creek (see Table 10).

EGG RETENTION OF KOKANEE

Dead kokanee were examined for eggs retained in the body cavity after spawning and these data were used to estimate the egg deposition in Meadow Creek and Lardeau River during 1965-1968 (Table 10). The calculated percentage of eggs retained in the body cavity was 3.3-11.2% of the mean fecundity. The relatively high egg retention of Meadow Creek spawners in 1967 and 1968 may be due to the spawners changing spawning ground from the Duncan River to Meadow Creek.

EGG DEPOSITION

Female kokanee prepare the redd for egg deposition and then release eggs, at which time the male fertilizes the eggs. The number of eggs released during this spawning act is the egg deposition. The calculated mean egg deposition per female spawner (mean fecundity minus mean egg retention) in the Lardeau River and Meadow Creek is shown in Table 10 for the years 1965-1968. The mean egg deposition was lowest in Meadow Creek and the Lardeau River in 1967, and highest in 1966.

AGE COMPOSITION

Table 11 gives the age composition of samples of kokanee in Meadow Creek and the Lardeau River during 1966 and 1968. The spawners were at age 3, 4, 5, 6, and 7. The predominant age of Meadow Creek spawners was 3 years in 1966 and 4 years in 1967, while in the Lardeau River it was 4 years in 1966 and 5 years in 1967. During these two years the age of the spawners was older in the Lardeau River than in Meadow Creek. In 1968, the samples in Meadow Creek revealed that in the natural spawning ground above the spawning channel the highest percent (29.0%) of the spawners were at age 5 whereas in the channel, 58.0 percent of the spawners were age 4.

DENSITY OF SPAWNERS

In October 1966 in Meadow Creek on a single large grid (46.2 m² or 55 yd²) in a good spawning ground above Abey's Farm (Fig. 1), where egg mortalities were lowest during 1965-1966, observations were made and photographs were taken of tagged spawning kokanee on successive dates. The average density of spawners was 2.59 females per m²; average duration time of females on the spawning area was 7.5 days (Table 12). Successive waves of spawners arrived approximately every 6 days. Then, overall density of the spawners was calculated as 15.6 females per m². These results indicate that a pair of kokanee spawners require 0.39 m² (0.46 yd²) during the spawning act and there was overcrowding in some natural spawning grounds of Meadow Creek.

In 1967 during the first year's operation of the spawning channel, the first fish arrived at the channel on August 14 and most of the run arrived between August 25 and September 25. Very few arrived after October 8 (Fig. 9). Post-spawning mortality started on September 25 and was virtually complete by November 2, indicating that most spawning occurred between September 20 and October 28 with a peak about September 25.

The instantaneous density of spawners was estimated by counting the number of spawners in each leg and corner of the channel and dividing the area expressed as the number of spawners per m². The mean density varied in different locations of the channel (Fig. 10). The most preferred locations were legs of the channel and the highest densities were estimated in Legs 5, 4, 6, 7 and 1. The mean instantaneous density of the spawners increased to 2.4 females per m² on September 25, 1967. Thereafter it decreased as the fish died after spawning (Fig. 9). Estimated density from the cumulative spawners was controlled at an upper limit as 2.83 females per m² (2.73 females per yd²) or 5.67 kokanee per m² (4.74 kokanee per yd²) in the spawning channel. At the beginning of the run, spawners occupied the uppermost part of the channel and tended to occupy the lower parts of the channel at the end of the run (Fig. 10).

SPAWNING SUCCESS

Spawning success was defined by McNeil (1964b) as the ratio between the number of females calculated from the egg sampling and the number of females counted in the same area.

In the spawning channel, an attempt was made to estimate spawning and egg mortality of kokanee on November 24, 1967 just after the completion of the spawning (Fig. 9). The number of spawners depositing their eggs safely was calculated from the total eggs obtained with egg sampling and the known areas of the legs and corners. The number of spawners in each leg and corner was calculated from the spawner estimates on September 25, 1967 when 86.4% of the total spawners were in the spawning channel. The remaining 13.6% of the total was not included in the calculations.⁴ A certain error

⁴The most appropriate was the tagging of spawners at the Lower Fence after September 25, 1967 to estimate the distribution of late spawners which was 13.6% of the total in the spawning channel.

was undoubtedly present for each leg and corner but considering 86.4% of total spawners estimated on September 25, 1967, the estimates were sufficient for the comparisons. However, during the calculation of the overall spawning success of kokanee in the spawning channel, the total number of spawners was used to eliminate this error.

The spawning success of kokanee in each leg and corner is compared in Fig. 11. The highest spawning mortality was found in corner 1 (89.1%). However, the mean spawning mortality was relatively higher in the legs (49.0%) than in the corners (30.6%). The mean overall calculated spawning mortality was 39.7% in the spawning channel.

EGG DEVELOPMENT

During the spawning activities and incubation period, egg losses occurred in the spawning ground. The greatest egg losses usually occur in either the early developmental (eyed) stages when the embryos are quite delicate and highly susceptible to damage, or just prior to hatching when the demand for oxygen for the growing embryos is high (Foerster 1968).

The water temperature primarily controls the rate of egg development in a stream. According to Gray (1928) development of eggs depends on size of the embryo at hatching and is proportional to the total amount of yolk in the fertilized egg and relative to the incubation temperature. Olsen (1968) indicates that intergravel water temperatures are usually cooler than the stream temperature near the bottom. In addition to these, the spawning occurs over a period and it is therefore very difficult to say precisely when hatching and fry emergence take place. However, based on the data collected in Meadow Creek during 1965-1966 and 1966-1967, development of kokanee eggs was related to thermal age.

The egg samples were taken each month from December-March in 1965-1966 and 1966-1967 from natural spawning areas. The development stages of embryos were categorized as fertilized, pre-eyed, eyed and alevin (Fig. 12). Accumulated Fahrenheit degree-days⁵ from October 15 were plotted for 1965-1966 and 1966-1967 (Fig. 13). Inspection of developmental information (Fig. 12) indicated that fertilized eggs required about 600 degree-days to reach the eyed stage, about 1,000 degree-days to hatch and an additional 600 degree-days to emerge from the gravel as free-swimming fry. In Meadow Creek, about 80% of the emergence and downstream migration occurs in the month of May (Acara and Smith 1971).

In the spawning channel during the first winter in 1967-1968, temperature units accumulated more rapidly than in the extremely cold second winter, 1968-1969 (Fig. 14). During both winters, temperature units accumulated more rapidly at Upper Fence than at Hatchery Fence because of cooler water from John Creek (Fig. 5) flowing into the channel. As will be seen in

⁵Fahrenheit degree-day = 5/9 centigrade degree-day.

the following section, fry emergence in the spawning channel was 2 weeks later in 1969 than in 1968.

In the channel, an attempt was made also to estimate egg mortality of kokanee in late November 1967 about 1 month after the completion of spawning. Egg mortality in the early stage should be related to density of spawners if there is overcrowding but would also be dependent on the environmental conditions prevailing in the gravel. Table 13 gives the mean egg mortalities in various areas of the channel. The highest egg mortalities were in corner 3, leg 1, corner 1, corner 4, and leg 2. These high mortalities were not consistently associated with high spawner density (Table 14). High mortalities showed a correlation with gravel compositions which fell outside the 85.87% interval shown in Fig. 3. Leg 1 and corners 1 and 3 had particularly large amounts of silt, fine and coarse gravels (Table 2, 3) and also showed high egg mortalities.

EGG SIZE

The growth in weight and length of embryos of kokanee and their development may be related to the size of eggs in Meadow Creek and the Lardeau River. Therefore, the size of eggs was measured in 1967.

The eggs were averaged at 4.5 mm in diameter and 0.085 g in weight in Meadow Creek while they were 4.8 mm and 0.099 g in the Lardeau River.

The ranges were 3.9-5.0 mm and 0.082-0.122 g in Meadow Creek and 3.1-5.0 mm and 0.1062-0.137 g in the Lardeau River. According to these results in Meadow Creek, the mean egg diameter and weight and their ranges were relatively smaller than in the Lardeau River.

FRY PRODUCTION

Young kokanee, after hatching and completing the alevin stage, leave the gravel to seek food and finally arrive at their nursery area in the lake. The migration of fry is not simple, it is controlled by light, stream velocity and turbidity of the waters.

Measures of salmonid production in streams can be obtained at several life stages, such as the counting of adults, redd sampling or counting, or fry and smolt enumerations. Such estimates are used for predicting the size of the resultant adult population, and a series of several years' data can be used to develop a reproduction curve relating numbers of parents to numbers of progeny. This gives the size of the spawning stock most likely to produce the best return (Ricker 1948, 1958). The greatest accuracy may often be achieved by representative sampling of young as they migrate downstream.

Fry production was estimated in the Lardeau River in 1966 and 1967, and in Meadow Creek in 1966, 1967 and 1968 (Table 15). The greatest numbers were 12,196,000 fry in the Lardeau River in 1967 and 10,072,000 fry in Meadow Creek in 1968. The high value in Meadow Creek was largely due to the production in the spawning channel in its first year of operation. The channel produced 5,360,617 fry during the first year in 1968.

In comparison with the natural spawning streams of the Lardeau River and Meadow Creek, and considering their total areas as about 11,531,520 m² and 107,675 m², the mean fry productions were found to be 0.8 ± 0.3 fry per m² for the Lardeau River and 27.8 - 20.0 fry per m² for Meadow Creek during 1966 and 1967 (Table 15).

Fry production of Meadow Creek increased to 70.8 fry per m² after the spawning channel started to produce fry in 1968. In the channel the production was 154.9 fry per m² in 1968. In the channel the production was 154.9 fry per m² in 1968 and 42.1 fry per m² in 1969 (Table 16). This comparison shows that fry production per unit area was higher in the spawning channel than the natural spawning grounds.

In 1968 daily fry emigration at the Lower and Upper fences showed two abrupt peaks (Fig. 15), the first on May 13 accounted for 8.56%, and the second on May 19 accounted for 6.48% of the total emigration from the channel. Fry production from the channel was relatively small in 1969 and daily variations less abrupt. In 1968, 89.4% of the total emigration occurred between May 1 and May 31 (Fig. 16). In 1969, only 55.3% of the total seasonal migration occurred during May and 89.6% of the total between May 1 and June 12. Emigration was relatively late in 1969 due to lower water temperature during the winter in 1968-1969 than in 1967-1968 (Fig. 14, 16).

SURVIVAL OF FRY

For the years 1965-1966 and 1966-1967, the overall mean fry survival from egg deposition in Meadow Creek was 5.87 - 0.37%, while it was 14.05 - 2.33% in the Lardeau River (Table 15). There was reasonable consistency in the fry survival during two test years, especially in Meadow Creek. This may be attributed in part to the stability of the stream conditions during these two years. After the spawning channel became operational, the overall fry survival in Meadow Creek increased to 15.75% in 1967-1968.

In the spawning channel during the first year 1967-1968, the survival rate was 25.67%, while it was only 8.50% in the second year (Table 16). In 1968-1969 fry survival was also much reduced over that of the previous year in Meadow Creek above the channel and in John Creek. Almost the entire spawning channel was frozen and covered with ice from December-March during the winter of 1968-1969. Thus the lowered survival may have been due in part to low temperatures.

Further observations on the survival of fry during the downstream migration were made between Abey's Farm and Hatchery Fence (Fig. 1) in Meadow Creek during 1966. Downstream migrating fry were estimated at these two locations between May 4 and July 7. The differences between the two estimates are shown in Fig. 17 as the percent gain or loss of nightly total fry at Abey's Farm. The maximum loss between these two locations which is a distance of about 1 mile, was 56% of the nightly total on May 4, and overall mortality was 16.9% of the total fry estimated between May 4 and July 7, 1966. The west bank

of Meadow Creek is lower and during the high-water period (May-July), this area becomes a flooded grassy swamp between Abey's Farm and Hatchery Fence. The temperature of this swampy area was 13.8 C on June 12, 1966 while it was 9.2 C in the main stream. Usually, water temperature was 6-10 C higher in this swampy area than in Meadow Creek during May-July, 1966.

ALEVIN ESTIMATES

Considerable numbers of alevins were found to move downstream with the fry migration and their abundance was estimated in the Lardeau River and Meadow Creek from 1966-1969 (Table 17). In 1966 and 1967, the abundance of alevins as a percentage of total fry production was 4.42% and 10.73% in the Lardeau River, while it was 15.68% and 38.52% in Meadow Creek. Discharge at the end of the 1967 fry migration in June was the highest (Table 18) and probably dislodged and carried out many alevins before they reached the fry stage. Their chance of survival is probably very small especially in severe water flow because their yolk sacs would be highly susceptible to damage. In Meadow Creek estimated alevin mortality between the spawning channel and the Hatchery Fence was 65.0% in 1968 and between Abey's Farm and the Hatchery Fence was 26.0% in 1966 (Table 19).

In the spawning channel, the number of alevins as a percentage of the fry migration was highest in 1968 (51.7%) but was only 5.74% in 1969 (Table 20). However, in Leg 1 of the channel in 1968, alevins as a percentage of the fry were only 7.6% (Table 21). Further, this has produced 49.3% of the total fry in the spawning channel. These results indicate strongly that in 1968 the severe discharge of John Creek into the channel caused the highest abundance of alevin and the loss of 13.3% of total deposited eggs (Table 20).

LENGTH OF FRY

The length of fry caught nightly was measured and recorded for each sampling location on the Lardeau River and Meadow Creek during 1966-1968 (Table 20). The mean length of fry was larger in the Lardeau River than in Meadow Creek. The size of fry was the smallest at the beginning of the run and increased thereafter. In Meadow Creek the mean length of fry increased in 1967 after the Duncan River was blocked in 1966. In 1968, during the first year fry production of the spawning channel, the mean length of fry was the largest (24.9 mm) in Meadow Creek between the years 1966-1968. This may be another indication of spawners changing their spawning ground from the Duncan River to Meadow Creek (Table 22). A gradual increase in the mean length, from 23.9-26.2 mm at Hatchery Fence indicated that fry start to feed during the downstream migration below the spawning channel in Meadow Creek.

Tables 10 and 21 show that the larger spawners of the Lardeau River have larger size eggs and produce a larger size of fry.

MIGRATORY BEHAVIOUR OF FRY

The importance of migratory behaviour on the abundance and production of freshwater fishes was reported by Ricker (1948, 1958) and Allen (1951). Certain physical features of the stream environment such as discharge temperature, etc., may have a profound effect on controlling diel, daily or seasonal timing and intensity of juvenile migration and thereby be of importance in regulating production of young fish from streams (Northcote 1967).

In Meadow Creek, fry exhibited migratory changes during 1968 which were described in general by the pattern of catches at the Hatchery Fence (Fig. 18) (Acara and Smith 1971). A similar illustration was also prepared for the Lower Fence in the spawning channel (Fig. 19).

Although virtually all downstream movement of fry occurred during darkness, changes in hourly abundance occurred through the season (Fig. 18, 19). The migration took place between the hours 1900 and 0700 and two nightly peaks sometimes occurred. The first peak was always larger than the second and occurred between 2100 and 2300 hr.

At the Hatchery Fence in April, between 63.5% and 82.0% of the total migration occurred between 2100 and 0100 hr and in May and June, during this 4-hr interval, the total increased to between 84.5% and 100% (Fig. 18). At the spawning channel Lower Fence in April, between 66.7% and 86.0% of the total migration occurred between 2100 and 2300 hr and in May and June this total increased to between 83.6% and 93.5% (Fig. 19).

Diel patterns were generally consistent for 10-day periods in Meadow Creek (Fig. 20) but were dependent on the abundance of fry. Discrepant distributions may be accounted for by the fact that downstream migration was relatively small and shortened on those nights (Acara and Smith 1971).

In comparison, the diel patterns at the spawning channel Lower Fence and Hatchery Fence in Meadow Creek showed that two nightly peaks sometimes occurred one or two hours earlier at the Lower Fence than at the Hatchery Fence in 1968 (Fig. 18, 19).

Considerable variability was also apparent in the horizontal distribution of fry in the stream channel as indicated by the percent of total catch at the three fishing stations in the fences (Fig. 18, 19). According to Acara and Smith (1971), the greatest fry migration was associated with greatest discharge generally. Vertical distribution of kokanee fry varied also throughout the river profile from surface to bottom and was determined in large part by the volume of water transported at intermediate depths in midstream in Meadow Creek.

DISCUSSION

The object of the kokanee spawning channel in Meadow Creek was to replace the spawning ground lost due to the construction of the Duncan Dam on the Duncan River. It was the purpose of the artificial spawning channel to duplicate gravel size, gradient and water velocities of the best reproduction areas and accommodate the existing run (1.2 ± 0.12 million during 1965-1967, 4.54 million in 1964 and 0.63 million in 1968) on the Duncan-Lardeau River system. Therefore the first year fry production of the spawning channel was compared with the fry production of the Lardeau River and Meadow Creek in 1966 and 1967. Unfortunately in 1966 and 1967, because of the dam construction and sampling difficulties, no kokanee fry production was estimated in the Duncan River. However, considering the similarities of the Lardeau and Duncan rivers, the assumption was made that egg deposition per female and the fry survival from the egg deposition were the same in both rivers. The fry production was calculated for the Lardeau River in 1968 from the number of spawners in 1967 and from the mean fry survival rate obtained in 1966 and 1967 (Table 23).

The fry production with the Duncan Dam and without it are shown in Table 23. The results indicate that in 1967 the fry production of the artificial spawning channel replaced the lost spawning ground for Duncan River stock. If the Duncan Dam had not been constructed on the Duncan River, the Duncan and Lardeau rivers and Meadow Creek would have produced 19,084,339 fry. After the Duncan Dam and the artificial spawning channel were constructed, the total kokanee fry production of the Lardeau River and Meadow Creek was 20,591,782 and 1,507,443 more fry were produced in 1968. Therefore, the results of the first year's operation of the channel are considered encouraging.

Considering the predominant age of Meadow Creek spawners as 4 yr, the Duncan River and Lardeau River spawners as 5 yr, and assuming the Duncan Dam operation would not change the lake environment, thus changing the age composition of kokanee as has been demonstrated for sockeye (Killick and Clemens 1963), the first and second years' fry, which could be progeny of the original Meadow Creek stock, in that case would become spawners in the spawning channel in 1972 and 1973; but in the case of progeny of the Duncan River stock would be spawners in the channel in 1973 and 1974 respectively. It was therefore concluded that any year's fry would have to be considered the progeny of 4- and 5-yr-old spawners of Meadow Creek and the Duncan River stocks, respectively.

The first and second years' spawning channel operations indicate that each female kokanee spawning in the channel would be 1.6 and 4.7 times more productive than in the natural spawning areas below and above the channel in Meadow Creek (Table 15). With the first year's spawners, fry production was equivalent to that obtained from 303,168 and 905,333 kokanee spawners in natural spawning areas above and below the channel in Meadow Creek (Table 9). The artificial spawning channel can be considered a practical and economical method of increasing fry production to Kootenay Lake. Furthermore, the fish produced in the spawning channel may be better able to survive than those from conventional hatcheries.

However, the channel required certain modifications and additional complete flow control during the spawning of kokanee and the downstream migration of fry (John Creek discharges directly into the channel) so that survival could be increased. In 1967, spawning mortality was very high (39.8%) as there was little flow control in the channel during the spawning of kokanee and fry production (Fig. 1, 6). The main purpose of the diversion was to stabilize the spring and winter discharge through the channel. Unfortunately the control of flow with the diversion at the Upper Fence was not possible and variation of the discharge at the Lower Fence was identical to the variation of John Creek discharge during fry enumerations in 1968 and 1969 (Fig. 6). In 1968, the high abundance of alevins in both the spawning channel and John Creek, but relatively low abundance in Leg 1, indicate that the severe discharge of John Creek into the spawning channel brought down many alevins and caused less fry production in the channel (Tables 16, 21). In 1968 fry production could have been 13.31% higher (Table 20) than the estimated value with controlled steady water flow through the spawning channel during the fry migration. The most desirable alterations would be at the upper part of the channel, mixing John and Meadow creeks, and then constructing upper and diversion fences below this confluence. This alteration would also reduce the siltation which originates mainly from John Creek and flows directly into the channel at present. At the lower end, the diversion channel (Fig. 1) needs screens to prevent kokanee and Dolly Varden from entering the diversion channel during the spawning period.

The water velocities were 1.2-1.8 m/s (4-6 ft/s) during the spawning of kokanee in the channel. The observed spawning requirements for kokanee in the natural spawning grounds of Lardeau River and Meadow Creek are shown in Table 24.

The velocities in the natural spawning ground and in the channel indicate that the water velocities were too high during the spawning of kokanee in the channel. According to Foerster (1968) the velocities of flow are 0.1 m/s for sockeye, 0.1-0.3 m/s for chum, and 0.3-0.6 m/s for pink during spawning. These results also indicate that the velocities in the channel were above the spawning requirement for kokanee. High velocities probably carried away eggs during deposition and high discharges after deposition may have been the cause of many eggs lost by bed load movement. The high egg mortalities (38.9-28.1%) in the upper part of the spawning channel (see Table 13) may be attributed to the abundance of finer material in the upper part of the spawning channel (see Fig. 3 and Tables 2-5).

According to Burner (1951) and Andrew and Geen (1960) spawning sockeye salmon avoid firmly cemented gravel, and prefer mud and silt-free areas. Success of spawning and egg incubation depends on gravel size and composition in particular areas of streams. Size and composition can be optimized if discharge is under control.

During 1968, the first year in the spawning channel, the overall mortality rate of fry from egg deposition was analyzed quantitatively and shown as differential mortalities in Table 25. Relatively high egg retention (10.0%) from fecundity might be an indication of the spawning stock's not being absolutely suited to its new environment in the spawning channel. In 1968 the survival rate of fry from egg deposition could have been 78.8% instead of 25.67% if the water flow had been controlled completely during the spawning and fry migrations (Fig. 11, Tables 16 and 20).

During the downstream migration fry were lost in the sloughs along the west bank of Meadow Creek. The west bank of Meadow Creek is relatively low and becomes a flooded grassy area between Abey's Farm and Hatchery Fence (Fig. 1). Water temperature in this swampy area was 6-10 C higher than in the main creek during May-July. Undoubtedly, this relatively high temperature attracts fry and causes mortality in Meadow Creek. During 1966 the fry enumerations at Hatchery Fence and Abey's Farm indicated that abundance was lower at Hatchery Fence (Fig. 17). The difference between nightly estimates varied widely. The loss was 16.9% of the total fry estimated at Abey's Farm between May 4 and July 7, 1966.

Other factors which could reduce the fry production were water temperature, population density and time of arrival of fish in the channel. In 1967 at the Lower Fence, the temperature was 12.1 C on August 15 when the first fish arrived in the channel, 8.7 C at the beginning of spawning activity on September 25 and 5.7 C at the peak of spawning on October 29 (Fig. 4, 9). The downstream migration of fry occurred between 6.4 C and 9.2 C, and between 3.0 C and 9.2 C in Meadow Creek (Fig. 5) in 1968 (Acara and Smith 1971). In 1968 the water temperature was 9.3 C at the Lower Fence on the spawning channel when the first fish arrived (Table 7) and spawning activity started about September 20 when the water temperature was about 7.5 C. The downstream migration of fry occurred between 4.8 C and 10.5 C in 1969. The water temperature appeared to be normal in the channel and was not much higher than in the creek below the channel due to increased exposure to solar radiation (Fig. 4, 5 and Table 7).

The spawning density was different in different legs and corners of the channel in 1967 (Table 12). Legs 5, 4, 6, 7, 1 and corner 5, especially, were above desirable density of 5.2 kokanee per m². However, the overall density of 5.7 kokanee per m² was almost equal to the desirable density in the channel.

It is possible to control the density of spawners in the legs and corners of the channel at a desirable level by constructing simple fences. The arrival of spawners appeared to be normal before and after the opening of the spawning channel in Meadow Creek (Table 7). The arrival of spawners was on August 19 ± 4 to Hatchery Fence, August 18 ± 3 to the spawning channel in Meadow Creek, and August 25 ± 3 to Marblehead on the Lardeau River during 1965-1968. In 1968, the first spawners arrived in the spawning channel 6 days later than in 1967. However, 6 days' difference was still in the range found during the period 1965-1968.

SUMMARY AND RECOMMENDATIONS

This paper studies the artificial kokanee spawning channel in Meadow Creek, British Columbia, during 1967-1969. The spawning channel was built to replace the spawning ground lost due to the Duncan Dam construction by B.C. Hydro and Power Authority on the Duncan River.

The total length of the channel between the Upper, Lower, and John Creek fences was 3,358 m, the width was 10.4 ± 1.8 m, which provided about 34,923 m² Spawning area and average grade was 0.25%. Screened gravel was laid to a depth of 9 in and its composition as finer by weight was 95.74% for 50.8 mm (2 in), 70.80% for 26.9 mm (1.05 in), 35.75% for 13.5 mm (0.525 in), 9.42% for 6.73 mm (0.263 in) and 3.34% for 3.36 mm (0.131 in).

In the spawning channel the total number of spawners was 197,878 (98,939 female) in 1967, and 93,752 (50,626 female) in 1968; and the density of spawners was 5.7 kokanee per m² (2.8 females per m²). At the beginning of the run spawners occupied the uppermost part of the channel and tended to occupy the lower parts of the channel at the end of the run.

The mean fry production was $8.53 \pm 3.68 \times 10^6$ fry (0.8 ± 0.3 fry per m²) for the Lardeau River and $2.99 \pm 2.15 \times 10^6$ fry (27.8 ± 20.0 fry per m²) for Meadow Creek during 1966 and 1967. The fry production increased to 10.07×10^6 (70.8 fry per m²) after the spawning channel started to produce fry in 1968.

For the years 1965-1966 and 1966-1967 the overall mean fry survival from egg deposition in Meadow Creek was $5.87 \pm 0.37\%$, while it was $14.05 \pm 2.33\%$ in the Lardeau River. After the spawning channel became operational, the overall fry survival in Meadow Creek increased to 15.75% in 1967-1968.

In the spawning channel the fry production was 5.36×10^6 fry (154.9 fry per m²) in 1968, and 1.46×10^6 fry (42.1 fry per m²) in 1969. During the first year, 1967-1968, the survival rate was 25.67%, while it was only 8.50% in the second year, 1968-1969. The low production and survival during the second year was due to the severe winter in 1968-1969.

Estimates indicated that if the Duncan Dam had not been constructed, the Duncan and Lardeau rivers and Meadow Creek would have produced 19,084,339 fry. After the Duncan Dam and the artificial spawning channel construction, the total fry production of the Lardeau River and Meadow Creek was 20,591,782. Therefore 1,507,443 more fry were produced to enter Kootenay Lake in 1968.

During the first year, 1967-1968, the differential mortalities from egg deposition were 39.8% for spawning, 21.2% for egg incubation, and 13.3% for alevin. These mortalities were related to John Creek discharging directly into the spawning channel. The survival rate of fry from egg deposition could have been 78.8% instead of 25.67% if the water flow had been controlled completely during the spawning and fry migration in the channel. Desirable water velocities during the spawning of kokanee were 0.2 ± 0.5 m/s or 0.7 ± 1.7 ft/s.

The most desired alteration in the channel to increase fry production and survival would be to direct John Creek into Meadow Creek and then construct upper and diversion fences below this confluence. This alteration would also reduce the siltation which originates mainly from John Creek. The diversion channel needs a fence at the lower end with screens to prevent kokanee and Dolly Varden from entering the diversion channel during the spawning period in fall.

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Table 1. Sieve sizes used in sampling gravel in the spawning channel in 1967.

Sieve number	Inch	Millimeter	Micron
10	2.0000	50.8	
9	1.050	26.9	
8	0.525	13.5	
7	0.263	6.73	
6	0.131	3.36	
5	0.065	1.68	
4	0.0328		841
3	0.0164		420
2	0.0082		210
1	0.0041		105
0	silt		

Table 2. Finer by weight, average percentages and ranges.

No.	Leg 1			Corner 1			Leg 2			Corner 2		
	Average	Range		Average	Range		Average	Range		Average	Range	
10	96.91	94.08	† 5.92	98.54	98.35	† 1.65	93.61	91.39	† 8.61	99.37	99.00	† 1.00
9	75.16	69.37	† 18.09	63.81	63.22	† 16.30	66.08	60.02	† 21.37	80.69	80.22	† 5.37
8	46.86	45.08	† 18.74	33.72	38.12	† 15.40	32.53	25.62	† 21.20	38.12	38.38	† 5.37
7	19.85	23.87	† 16.87	13.61	14.99	† 7.23	10.08	12.45	† 10.82	7.98	7.66	† 4.34
6	9.10	15.51	† 14.24	3.65	4.09	† 2.66	4.44	8.00	† 6.62	2.82	3.07	† 1.47
5	5.34	11.01	† 10.37	1.96	2.55	† 1.98	2.29	4.59	† 3.60	1.50	1.80	† 0.60
4	3.11	7.73	† 7.34	1.34	1.71	† 1.37	1.63	2.75	† 2.05	1.21	1.33	† 0.35
3	1.97	4.99	† 4.67	0.80	0.79	† 0.52	1.25	1.65	† 1.04	1.06	1.18	† 0.34
2	1.32	3.70	† 3.44	0.54	0.65	† 0.43	1.00	1.07	† 0.57	0.89	1.04	† 0.32
1	0.81	1.69	† 1.50	0.39	0.47	† 0.28	0.66	0.59	† 0.25	0.72	0.88	† 0.32
0	0.05	0.06	† 0.02	0.06	0.06	† 0.02	0.06	0.05	† 0.01	0.04	0.03	† 0.03

Table 3. Finer by weight, average percentages and ranges.

No.	Leg 3			Corner 3			Leg 4			Corner 4		
	Average	Range		Average	Range		Average	Range		Average	Range	
10	99.16	98.70 \pm 1.30		97.73	97.22 \pm 2.78		97.61	96.55 \pm 3.45		91.56	90.64 \pm 2.91	
9	78.41	77.37 \pm 6.13		69.69	73.37 \pm 11.40		71.64	71.67 \pm 6.89		65.64	66.50 \pm 3.14	
8	37.46	39.77 \pm 8.37		34.82	37.35 \pm 6.63		35.69	31.63 \pm 12.75		28.33	28.06 \pm 9.60	
7	5.92	7.51 \pm 6.53		10.50	12.18 \pm 7.86		6.64	5.99 \pm 2.51		5.58	5.09 \pm 3.05	
6	2.40	3.33 \pm 2.35		4.20	5.18 \pm 4.65		1.10	1.14 \pm 0.59		1.66	2.15 \pm 1.54	
5	1.59	2.17 \pm 1.39		2.29	2.93 \pm 2.40		0.72	0.98 \pm 0.58		1.22	1.49 \pm 0.98	
4	1.28	1.75 \pm 1.30		1.93	2.50 \pm 2.03		0.64	0.89 \pm 0.54		1.08	1.28 \pm 0.84	
3	1.13	1.53 \pm 1.21		0.98	1.05 \pm 0.59		0.59	0.81 \pm 0.47		1.00	1.16 \pm 0.78	
2	0.99	1.39 \pm 1.15		0.84	0.90 \pm 0.45		0.57	0.80 \pm 0.47		0.90	1.00 \pm 0.63	
1	0.85	1.16 \pm 1.00		0.73	0.76 \pm 0.37		0.47	0.61 \pm 0.37		0.74	0.84 \pm 0.50	
0	0.05	0.04 \pm 0.04		0.05	0.05 \pm 0.02		0.05	0.05 \pm 0.04		0.07	0.07 \pm 0.02	

Table 4. Finer by weight, average percentages and ranges.

	Leg 5			Corner 5			Leg 6			Corner 6		
	Average	Range		Average	Range		Average	Range		Average	Range	
10	91.59	90.27	9.73	93.21	93.28	6.72	95.47	93.92	6.08	96.79	95.70	4.30
9	66.27	61.84	17.15	73.18	77.00	15.25	71.89	69.56	13.02	70.77	70.41	11.69
8	32.92	30.55	21.23	39.86	39.41	6.16	39.14	38.87	14.42	35.87	36.20	5.81
7	7.67	9.67	5.85	13.04	13.91	9.84	9.87	10.40	6.10	8.73	10.10	3.56
6	2.11	2.94	2.27	6.55	6.93	6.11	2.51	2.43	1.66	2.55	3.13	2.29
5	1.38	1.66	1.23	3.23	2.94	2.30	1.13	1.56	1.21	1.55	1.43	0.84
4	1.17	1.64	1.21	1.95	1.59	1.08	0.95	1.45	1.16	1.18	1.15	0.67
3	0.90	0.90	0.55	1.49	1.36	0.91	0.87	1.40	1.14	1.07	1.09	0.69
2	0.84	0.81	0.50	1.29	1.29	0.85	0.80	1.37	1.12	1.01	1.06	0.69
1	0.73	0.76	0.46	1.15	1.20	0.79	0.73	1.30	1.01	0.96	1.02	0.68
0	0.06	0.06	0.03	0.05	0.05	0.01	0.06	0.06	0.02	0.05	0.05	0.03

Table 5. Finer by weight, average percentages and ranges

No.	Leg 7		Corner 7		Leg 8	
	Average	Range	Average	Range	Average	Range
10	96.09	92.95 ⁺ 7.05	94.89	93.87 ⁺ 4.05	93.53	93.28 ⁺ 2.32
9	71.77	68.20 ⁺ 22.08	63.58	58.91 ⁺ 12.57	73.54	71.67 ⁺ 9.77
8	34.82	33.92 ⁺ 16.52	28.08	25.05 ⁺ 14.01	38.17	39.99 ⁺ 14.42
7	7.13	9.43 ⁺ 7.47	4.83	5.80 ⁺ 3.89	9.91	14.47 ⁺ 10.99
6	1.54	1.65 ⁺ 1.02	1.32	1.31 ⁺ 0.50	4.17	8.28 ⁺ 6.50
5	0.93	0.92 ⁺ 0.66	0.83	0.78 ⁺ 0.51	2.71	4.74 ⁺ 4.00
4	0.81	0.84 ⁺ 0.64	0.67	0.59 ⁺ 0.32	2.15	3.29 ⁺ 2.75
3	0.76	0.81 ⁺ 0.62	0.60	0.52 ⁺ 0.27	1.86	2.53 ⁺ 2.02
2	0.72	0.79 ⁺ 0.61	0.54	0.51 ⁺ 0.27	1.70	2.17 ⁺ 1.68
1	0.66	0.72 ⁺ 0.55	0.47	0.49 ⁺ 0.26	1.60	2.05 ⁺ 1.59
0	0.04	0.04 ⁺ 0.04	0.03	0.03 ⁺ 0.03	0.06	0.06 ⁺ 0.03

Table 6. Overall gravel composition of the spawning channel November 29-December 5, 1967.

Sieve No.	Percent finer by weight	
	Average	Range
10	95.74	90.27 ⁺ 9.73
9	70.80	68.47 ⁺ 23.78
8	35.75	34.12 ⁺ 29.70
7	9.42	20.86 ⁺ 19.88
6	3.34	15.14 ⁺ 14.61
5	1.90	10.82 ⁺ 10.56
4	1.40	7.64 ⁺ 7.44
3	1.08	4.93 ⁺ 4.74
2	0.92	3.66 ⁺ 3.48
1	0.77	1.90 ⁺ 1.74
0 silt	0.05	0.05 ⁺ 0.05

Table 7. Date and water temperature (°C) when the first kokanee arrived in Meadow Creek and Lardeau River, 1965-1968.

Year	Date	Meadow Creek Hatchery Fence	Date	Spawning channel	Date	Lardeau River Marblehead Fence
1965	Aug. 22	9.3	-	-	Aug. 27	13.5
1966	Aug. 17	12.2	Aug. 17	*10.7	Aug. 22	12.3
1967	Aug. 15	11.9	Aug. 15	12.1	Aug. 26	12.7
1968	Aug. 21	9.9	Aug. 21	9.3	Aug. 27	9.0
Mean	Aug. 19 ⁺ 4	11.1 ⁺ 1.2	Aug. 18 ⁺ 3	10.7 ⁺ 1.4	Aug. 25 ⁺ 3	11.3 ⁺ 2.3

*Temperature measurement was taken at the Bowles Farm where the spawning channel was constructed in 1967.

Table 8. Abundance and distribution of kokanee in the Lardeau-Duncan River system during 1964-1968.

Year		Meadow Creek	Lardeau River	Duncan River	Total
<u>Kokanee escapement^a</u>					
1964		346,128	1,382,424	2,807,937	4,536,489
	%	7.6	30.4	62.0	
1965		116,095	506,446	455,841	1,078,382
	%	10.8	47.0	42.2	
1966		597,331	646,712	13,100	1,257,143
	%	47.5	51.5	1.0	
1967		606,282	705,351	6,750	1,318,383
	%	46.0	53.5	0.5	
1968		287,583 ^b	334,471 ^b	3,125 ^b	625,180 ^b
	%	46.0	53.0	0.5	
<u>Kokanee spawners^a</u>					
1964		274,128	1,382,424	2,807,937	4,464,489
	%	6.2	30.9	62.9	
1965		98,519	206,446	455,841	1,060,806
	%	9.4	47.7	42.9	
1966		561,021	646,712	13,100	1,220,833
	%	46.0	53.5	0.5	
1967		606,282	705,351	6,750	1,318,383
	%	46.0	53.9	0.1	
1968		287,583 ^b	334,471 ^b	3,125 ^b	625,180 ^b
	%	46.0	53.5	0.5	
<u>Distribution of kokanee (%) before Duncan Dam</u>					
Mean	%	9.2	38.7	52.1	
1964 and 1965					
<u>After the Duncan Dam</u>					
Mean	%	46.0	53.7	0.3	
1966 and 1967					

^aThe difference between kokanee escapement and spawners is due to eggs taken for artificial fish propagation.

^bCalculated from the previous year distribution of spawners and the counting of kokanee escapement in the Meadow Creek spawning channel.

Table 9. Abundance and distribution of kokanee in Meadow Creek.

Year	Above spawning channel	John Creek	Spawning channel	Below spawning channel	Below Hatchery Fence	Total
1967	189,480 31.2%	24,000 4.0%	197,878 32.6%	192,624 31.8%	2,300 0.4%	606,282
1968	47,992	5,000	93,752	91,451 ^a	1,150	287,583 ^a

^aCalculated from the distribution of spawners in 1967.

Table 10. Sex ratio of spawners, mean fork length, mean fecundity, mean egg retention and mean egg deposition per female kokanee in Meadow Creek and the Lardeau River 1965-1968.

Year	Sex ratio (female as the percent of return)	Mean				
		Length (cm)	Fecundity (No. of eggs)	Egg retention		Egg deposition (No. of eggs)
				(No. of eggs)	(% of fecundity)	
<u>Meadow Creek</u>						
1965	50.0	22.2	282	9	3.2	273
1966	50.7	22.4	354	33	9.3	329
1967	50.0	23.5	235	24	10.0	211
1968	54.0	24.5	338	37	11.2	301
<u>Lardeau River</u>						
1965	43.6	23.9	354	25	7.1	329
1966	48.6	23.6	356	25	7.0	331
1967	49.1	24.4	239	17	7.0	222

Table 11. Age composition of spawning kokanee in Meadow Creek and the Lardeau River 1966-68.

Date	Location	No. of fish	Age				
			3	4	5	6	7
Sept. 14-15, 1966	Lardeau River Marblehead	102	41.1	<u>45.1</u>	12.8	1.0	-
Sept. 13-15, 1966	Meadow Creek Hatchery Fence	119	<u>50.4</u>	45.4	1.7	2.5	-
Sept. 27, 1967	Lardeau River Marblehead	55	3.7	29.0	<u>34.5</u>	32.8	-
Sept. 27, 1967	Meadow Creek Hatchery Fence	50	8.0	<u>48.0</u>	30.0	14.0	-
Oct. 17, 1968	Meadow Creek above spawning channel	52	25.0	27.0	<u>29.0</u>	19.0	-
Oct. 17, 1968	Meadow Creek in the spawning channel	50	10.0	<u>58.0</u>	18.0	12.0	2.0

Table 12. Spawning characteristics of kokanee in Meadow Creek during period September 15-October 30, 1966.

Duration of spawning	45 days
Average days for a female to spawn	7.5 days
Successive waves of spawners	6.0 days
Average density of spawners	(2.6 females/m ² or 5.2 kokanee/m ²)
Overall density or utilization	(15.5 females/m ²)

Table 13. Egg mortalities (%) of kokanee in the channel on November 24, 1967. Number of samples shown in parentheses.

Number	Leg mortality (%)	Corner mortality (%)
1	28.1 (9)	25.0 (2)
2	21.9 (4)	9.6 (2)
3	16.0 (5)	38.6 (2)
4	18.1 (5)	24.5 (2)
5	8.7 (5)	13.1 (2)
6	11.0 (6)	5.6 (2)
7	16.6 (6)	4.8 (2)
8	21.2 (4)	
Mean	17.7 (44)	17.4 (14)
	Overall mortality (%)	
Spawning channel	17.6 (58)	

Table 14. Mean density of spawners (kokanee/m²), September 25, 1967.

Number	Leg	Corner
1	6.9	5.0
2	4.2	4.9
3	5.5	4.5
4	8.8	1.3
5	9.2	6.9
6	7.7	3.0
7	6.9	4.9
8	5.1	
Mean	6.8	4.4

Table 15. Potential egg deposition in 1965, 1966 and 1967, fry production and survival as percent production from egg deposition in 1966 and 1968.

Year	Total egg deposition	Fry production	Fry/m ²	Fry survival (%)
<u>Lardeau River</u>				
1965	29,613,440			
1966	104,033,962	4,849,620	0.4	16.38
1967	76,884,594	12,195,427	1.1	11.72
		Mean	0.8 ± 0.3	14.05 ± 2.33
<u>Meadow Creek</u>				
1965	13,447,844			
1966	93,579,986	838,207	7.8	6.23
1967	63,962,751	5,142,371	47.8	5.50
		Mean	27.8 ± 20.0	5.87 ± 0.37
1968		10,072,399	70.8	15.75

Table 16. Potential egg deposition in 1967 and 1968. Fry production and survival as the percent of production from egg deposition in 1968 and 1969.

Year	Total egg deposition	Fry production	Fry/m ²	Fry survival (%)
<u>Spawning channel</u>				
1967	20,876,129			
1968	17,111,588	5,360,617	154.9	25.67
1969		1,455,564	42.1	8.50
<u>Above the channel</u>				
1967	19,900,140			
1968	8,759,608	3,207,114	34.3	16.11
1969		779,136	8.3	8.89
<u>John Creek</u>				
1967	2,532,000			
1968	912,600	401,563	7.7	15.85
1969		8,370	0.2	0.91
<u>Below the channel</u>				
1967	20,321,832			
1968		1,103,105	27.2	5.43

Table 17. Estimated total alevin and its abundance as the percent of total fry production and egg deposition in 1966 and 1968.

Year	Total alevin	Percent of fry	Percent from eggs deposited
<u>Lardeau River</u>			
1966	214,832	4.42	0.73
1967	1,308,932	10.73	1.26
<u>Meadow Creek</u>			
1966	131,458	15.68	0.98
1967	1,981,064	38.52	2.12
1968	1,866,480	18.53	2.91

Table 18. Mean monthly discharge (cfs) of the Lardeau River at Marblehead and Meadow Creek at Hatchery Fence during fry migration in April-July, 1966 and 1967.

Month	1966		1967	
	Meadow Creek	Lardeau River	Meadow Creek	Lardeau River
April	113	1,170	96	714
May	207	3,790	135	2,900
June	247	6,940	265	9,900
July	242	5,390	260	6,890

Table 19. Estimated total number of alevins moving downstream at various locations in Meadow Creek in 1966 and 1968 and estimates of their mortality (%) between these locations.

Year	Location	Alevin	Mortality (%)
<u>Meadow Creek</u>			
1966	Abey's Farm ^a	165,570	26.00
	Hatchery Fence	131,458	
1968	Total: spawning and diversion channels ^a	3,080,412	65.03
	Hatchery Fence	1,866,480	

^aSee Fig. 1.

Table 20. Estimated total alevins and their abundance as a percentage of fry production and total egg deposition in 1968-1969.

Year	Total alevins	Percent of fry	Percent from egg deposition
<u>Spawning channel</u>			
1968	2,771,656	51.70	13.31
1969	106,896	5.74	0.62
<u>Above the channel</u>			
1968	171,144	5.33	0.86
1969	77,194	9.90	0.88
<u>John Creek</u>			
1968	141,140	35.14	5.57
1969	500	5.97	0.05

Table 21. Estimated total fry and alevin and their abundance in Leg 1 of the spawning channel during 1968.

Location	Alevin	Fry	Alevin/fry (%)
<u>Leg 1</u>			
Total	200,932	2,641,530	7.60
Abundance (as the percent of the total in the channel)	7.24	49.27	-

Table 22. Mean length (mm) of kokanee fry 1966-1968.

Date	1966		1967		1968	
	Lardeau River (Marblehead)	Meadow Creek (Hatchery Fence)	Lardeau River (Marblehead)	Meadow Creek (Hatchery Fence)	Meadow Creek	
					(Lower Fence)	(Hatchery Fence)
April 1-10	-	24.2	24.2	-	23.4	23.9
11-20	25.1	24.9	25.2	24.3	24.4	24.3
21-30	25.5	24.5	24.4	23.3	25.0	24.7
May 1-10	25.5	24.5	24.8	24.2	24.9	24.9
11-20	25.5	25.2	25.1	23.9	24.9	24.9
21-30	25.6	23.8	23.9	24.2	24.7	24.9
May 31- June 9	24.2	23.9	-	24.4	24.9	25.5
June 10-19	-	23.7	23.2	24.7	24.5	26.2
20-29	-	22.9	-	24.2		
Mean	25.2	24.1	24.4	24.1	24.6	24.9

Table 23. The success of the artificial spawning channel during the first year of operation in 1967.

	Lardeau River	Meadow Creek	Duncan River	Total
<u>With spawning channel</u>				
Spawners	705,351			
Sex ratio (female as the percent of return)	49.1			
Female spawners	346,327			
Egg deposition per female	222			
Total egg deposition	74,871,054			
Fry survival	14.05			
Fry production	10,519,383 ^a	10,072,399		20,591,782
<u>Without spawning channel</u>				
Spawners % ^b	38.7	9.2	52.1	
Abundance	510,214	121,291	686,878	
Sex ratio (female as the percent of return)	49.1	50.0	49.1	
Female spawners	250,515	60,646	337,257	
Egg deposition per female	222	211	222	
Total egg deposition	55,614,330	12,796,306	74,871,054	
Fry survival % ^c	14.05	5.87	14.05	
Calculated fry production ^d	7,813,813	751,143	10,519,383	19,084,339

^a Calculated from the mean survival rate (14.05%) for the Lardeau River.

^b Based on the data obtained from the spawner distributions in 1964 and 1965.

^c Mean fry survival (%) from egg deposition calculated from the data obtained in 1966 and 1967.

^d Calculated from the mean fry survivals.

Table 24. Environmental conditions during the spawning of kokanee in Meadow Creek and Lardeau River, British Columbia, in 1965 and 1966.

Water	Mean
Depth (cm)	35.1 \pm 26.3
Velocity (m/s)	0.2 \pm 0.5
pH	8.2 \pm 1.0
Temperature ($^{\circ}$ C)	9.0 \pm 7.0
Turbidity (ppm)	9.3 \pm 8.7
Dissolved oxygen (mg/l)	10.2 \pm 5.0
Dissolved oxygen of intergravel water (mg/l)	8.3 \pm 7.0

Table 25. Differential mortalities for kokanee during reproduction in the spawning channel in 1967-1968.

	Mortality (%)
Egg retention	10.0
Spawning	39.7
Egg incubation ^a	21.3
Alevin	13.3
Fry	74.3

^aCalculated from fry, alevin and spawning mortalities.

FIGURES

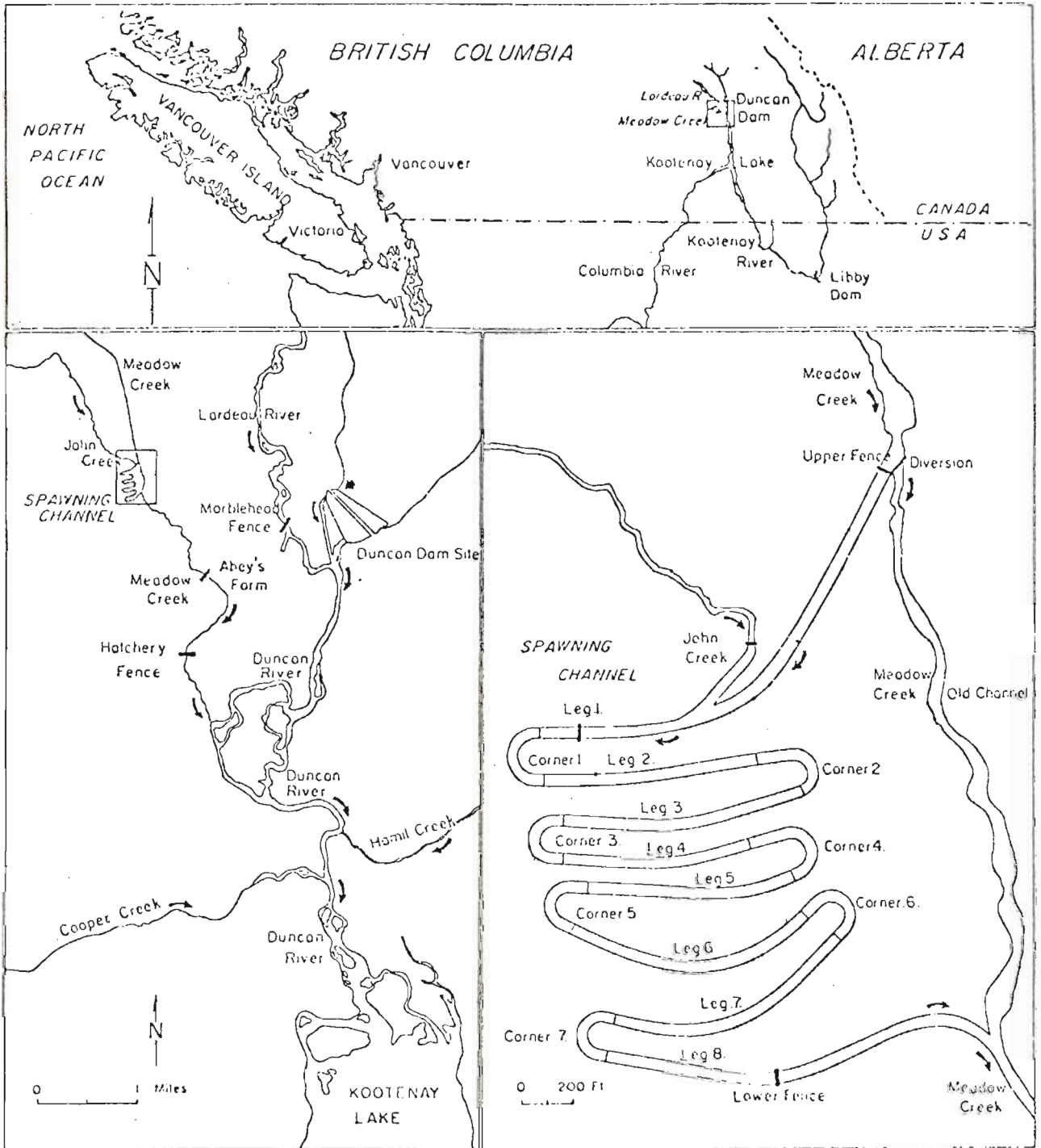


Fig. 1. Map of localities.

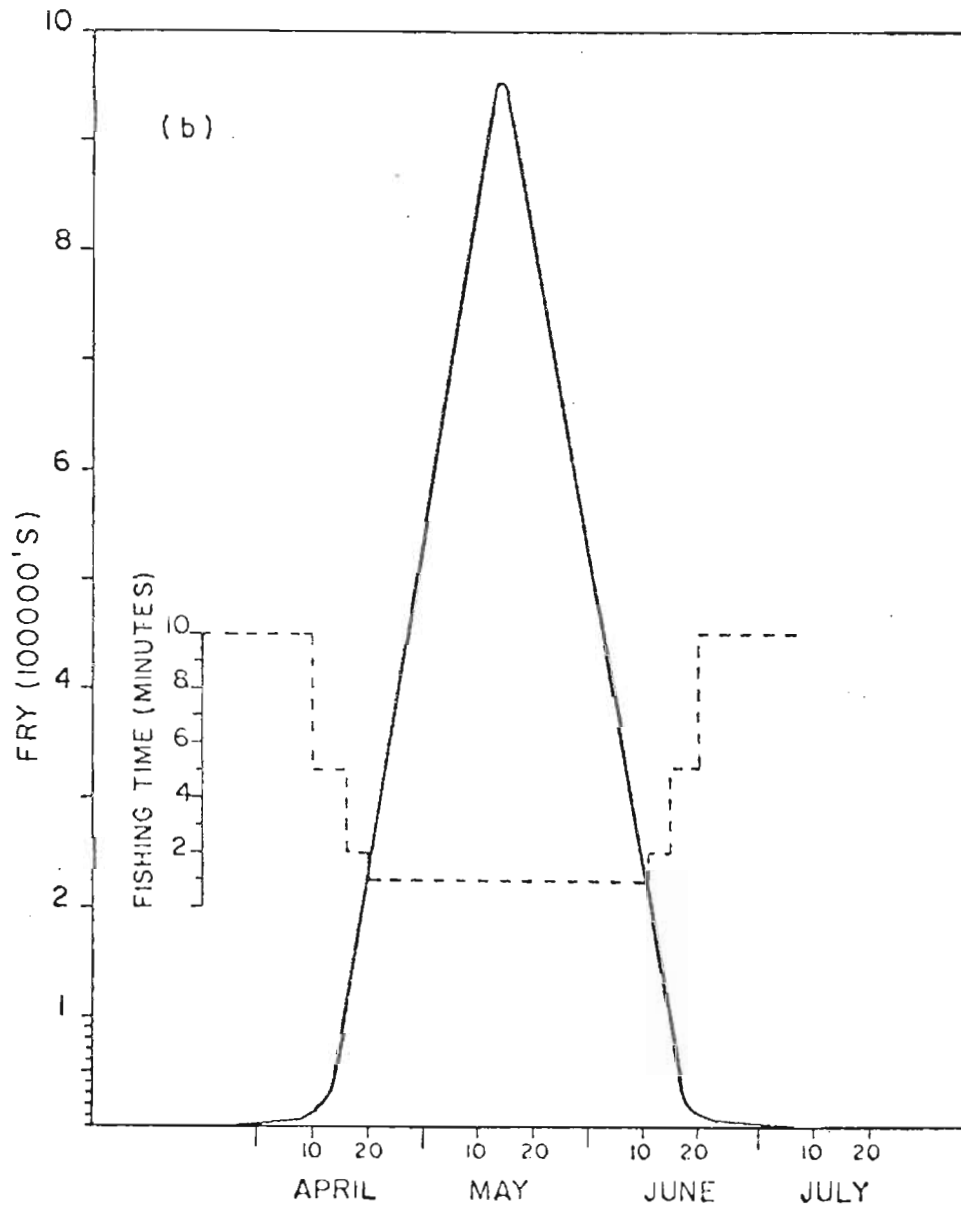
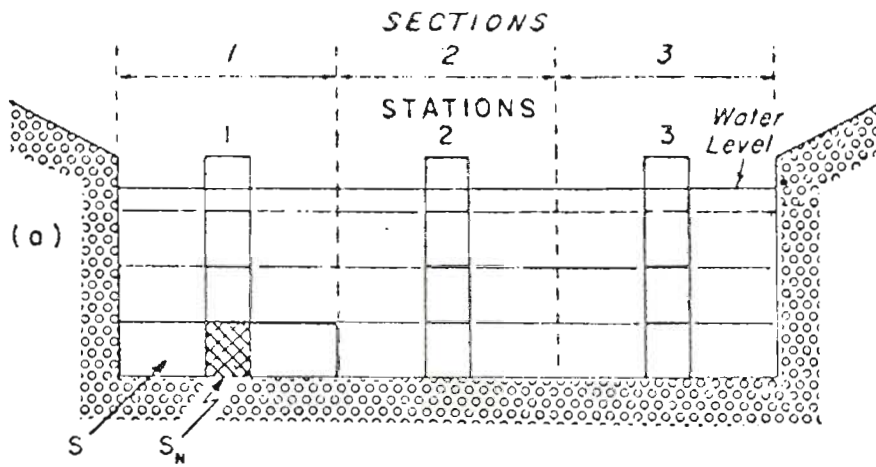


Fig. 2. (a) Location of 3 sampling nets in stream profile. (b) Allocation of fishing times according to fry abundance (Açara and Smith 1971).

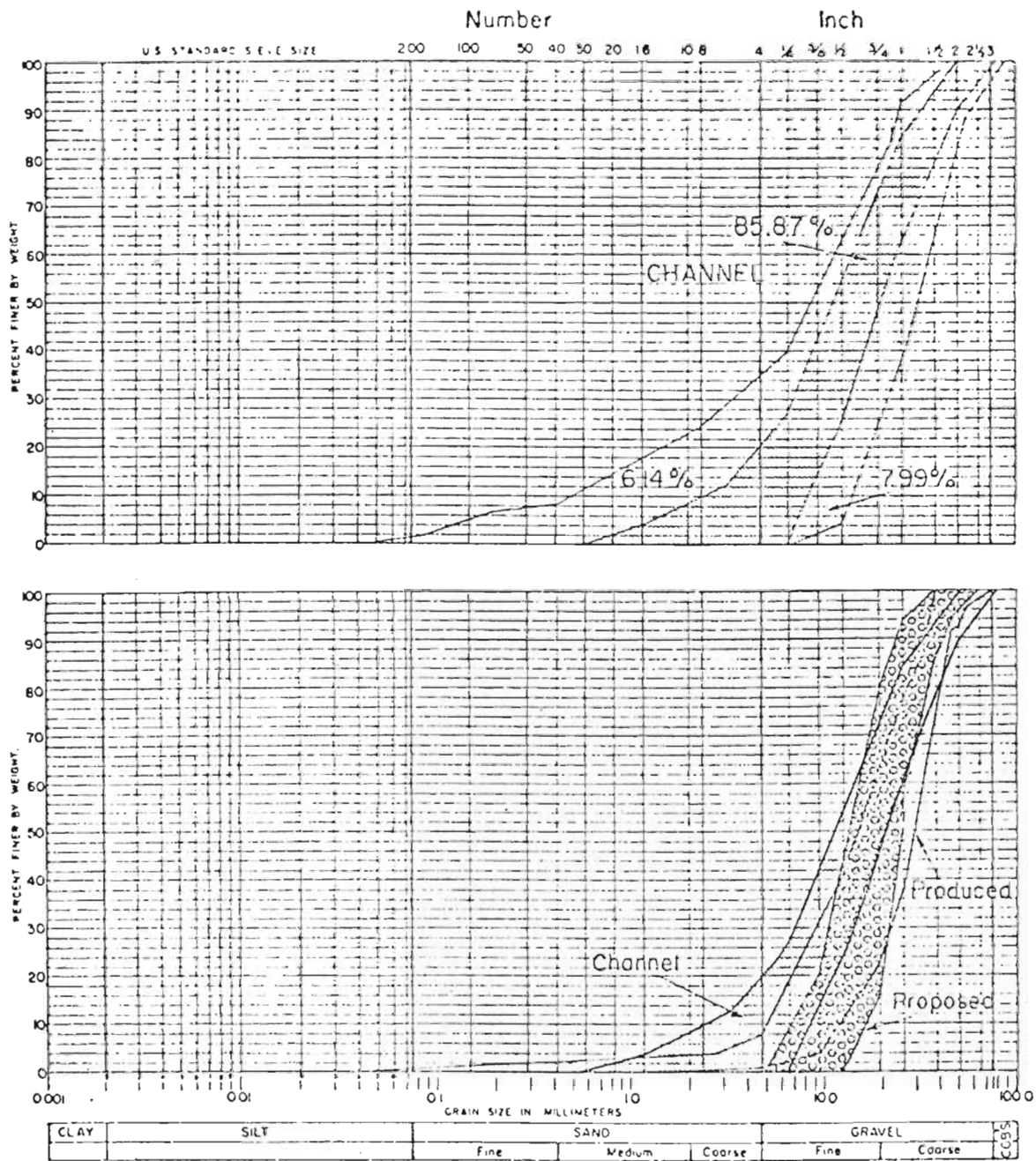


Fig. 3. Gravel composition of the spawning channel in Meadow Creek (above), comparison of proposed and artificially produced gravel with the gravel in the channel (below) (Acara and Fleck 1970).

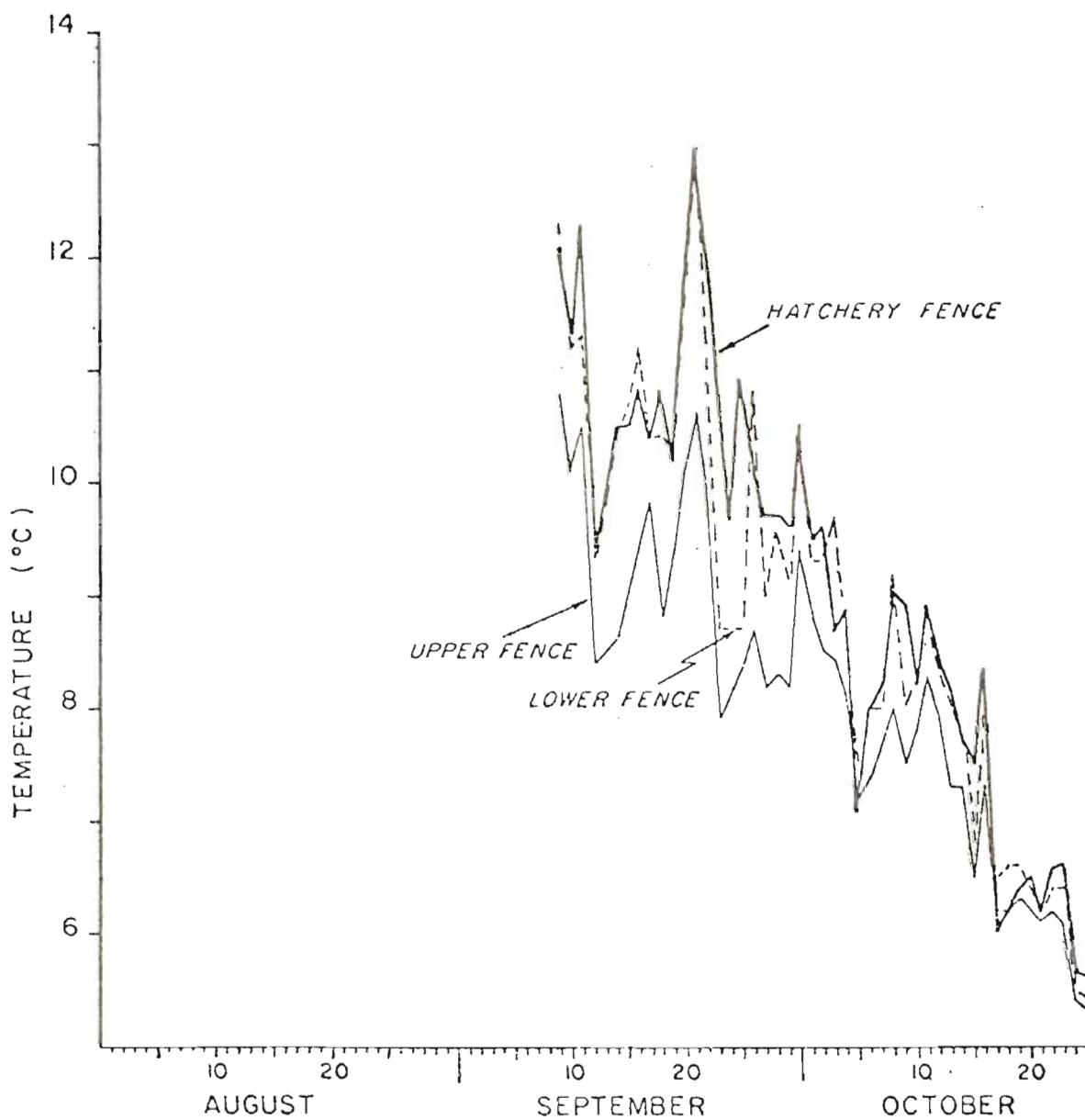


Fig. 4. Water temperatures in Meadow Creek during spawning of kokanee in 1967. Temperature measurements were taken between 1100 and 1400 hr.

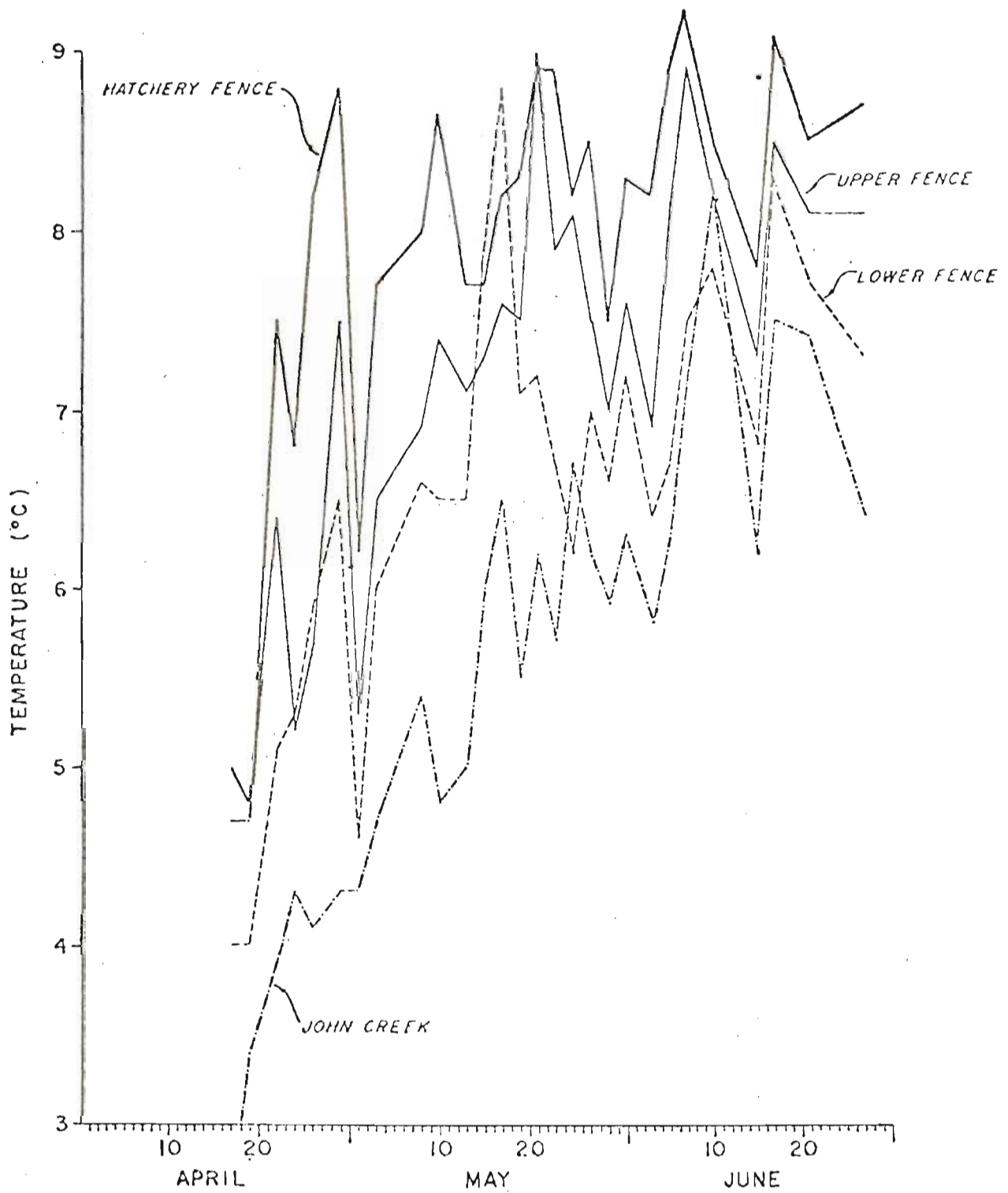


Fig. 5. Water temperatures in Meadow Creek during the downstream migration of fry in 1968. Temperature measurements were taken between 1900 and 2000 hr.

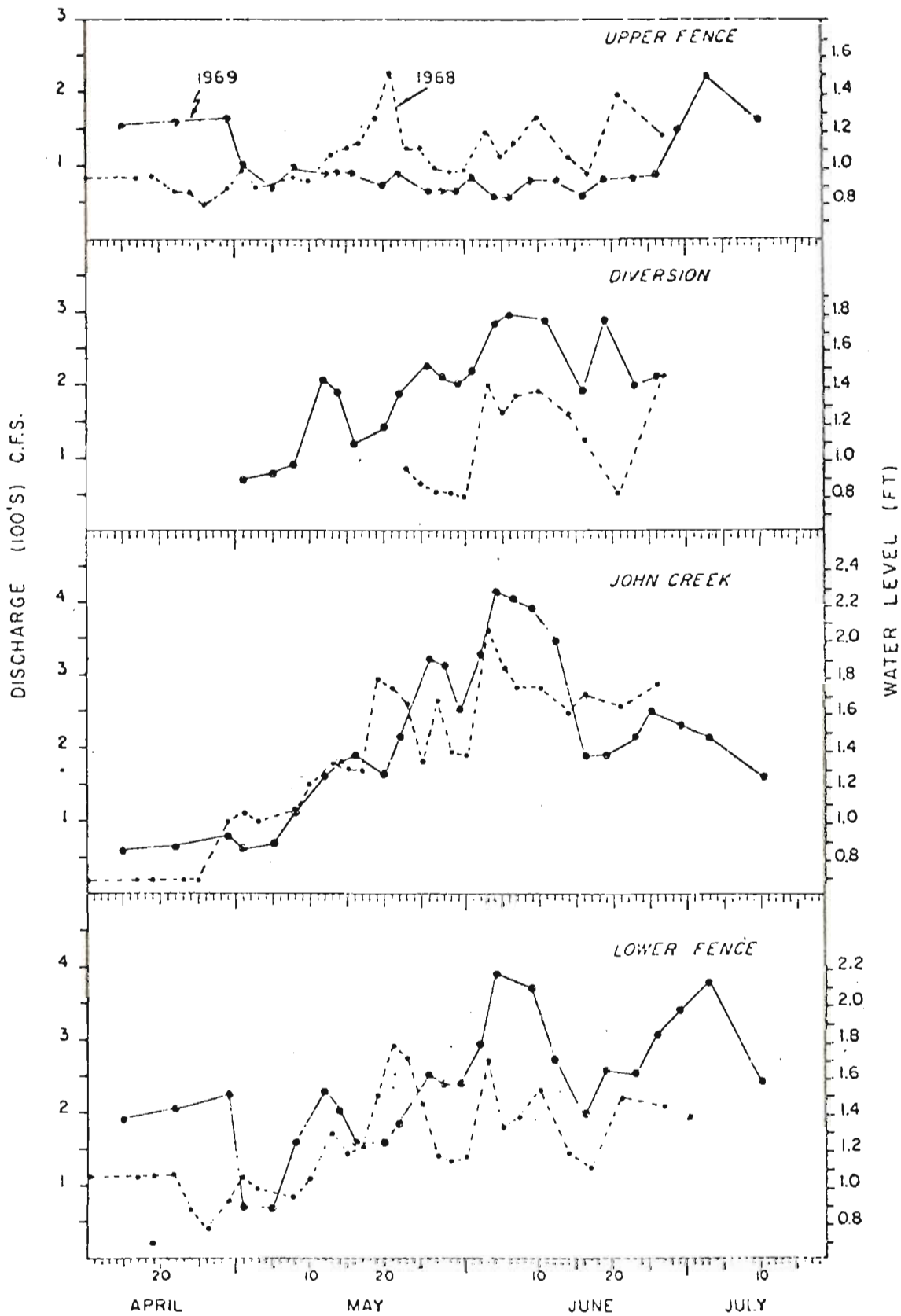


Fig. 6. Discharge (c f s) and water levels (ft) during the operation of spawning channel in 1968 and 1969.

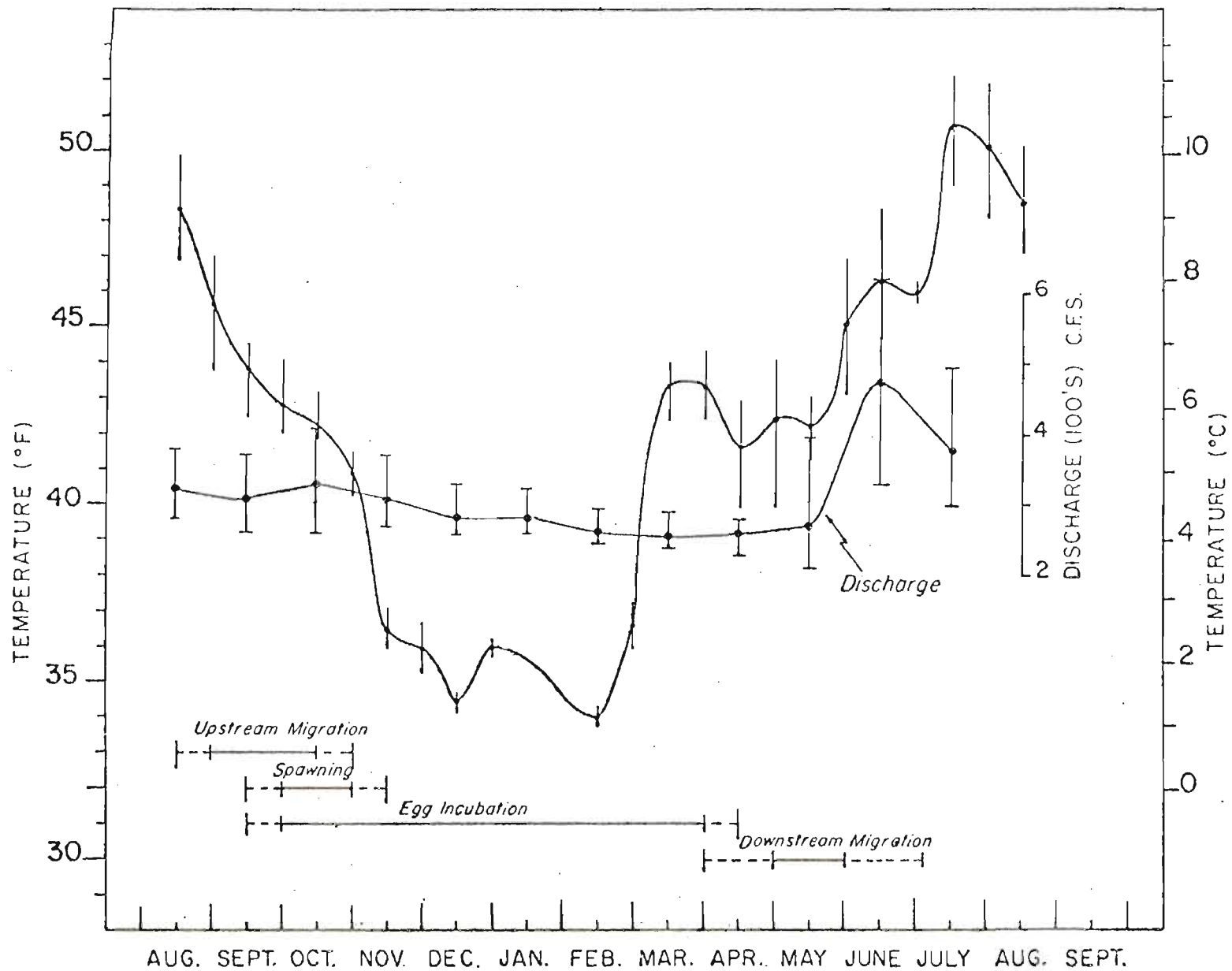


Fig. 7. The life history of kokanee in Meadow Creek with relation to stream discharge (cfs) and temperature (°F and °C) during 1965-1969.

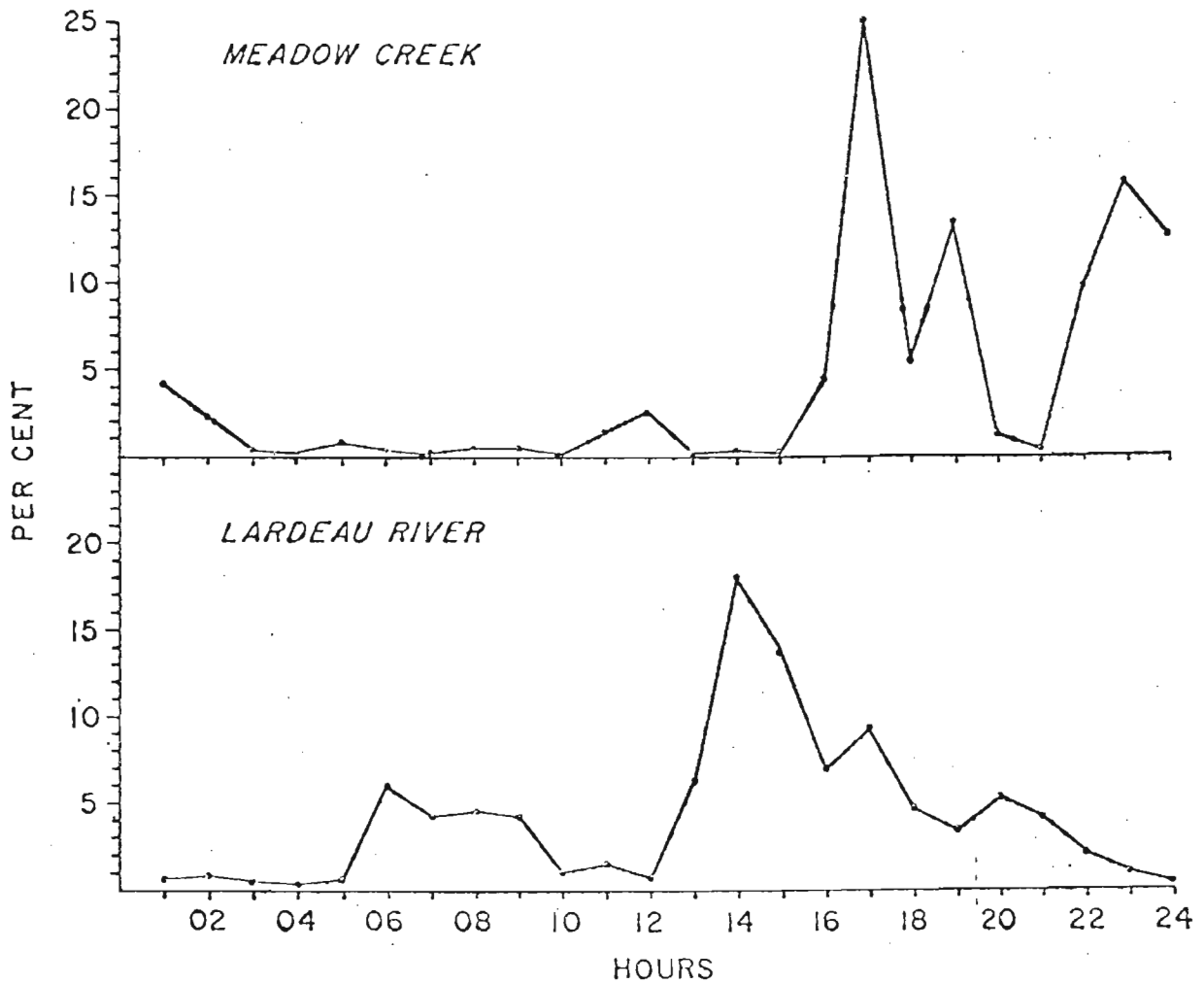


Fig. 8. The abundance of spawners per hour as the percent of 24 hr total count, during 1967 in Meadow Creek and Lardeau River.

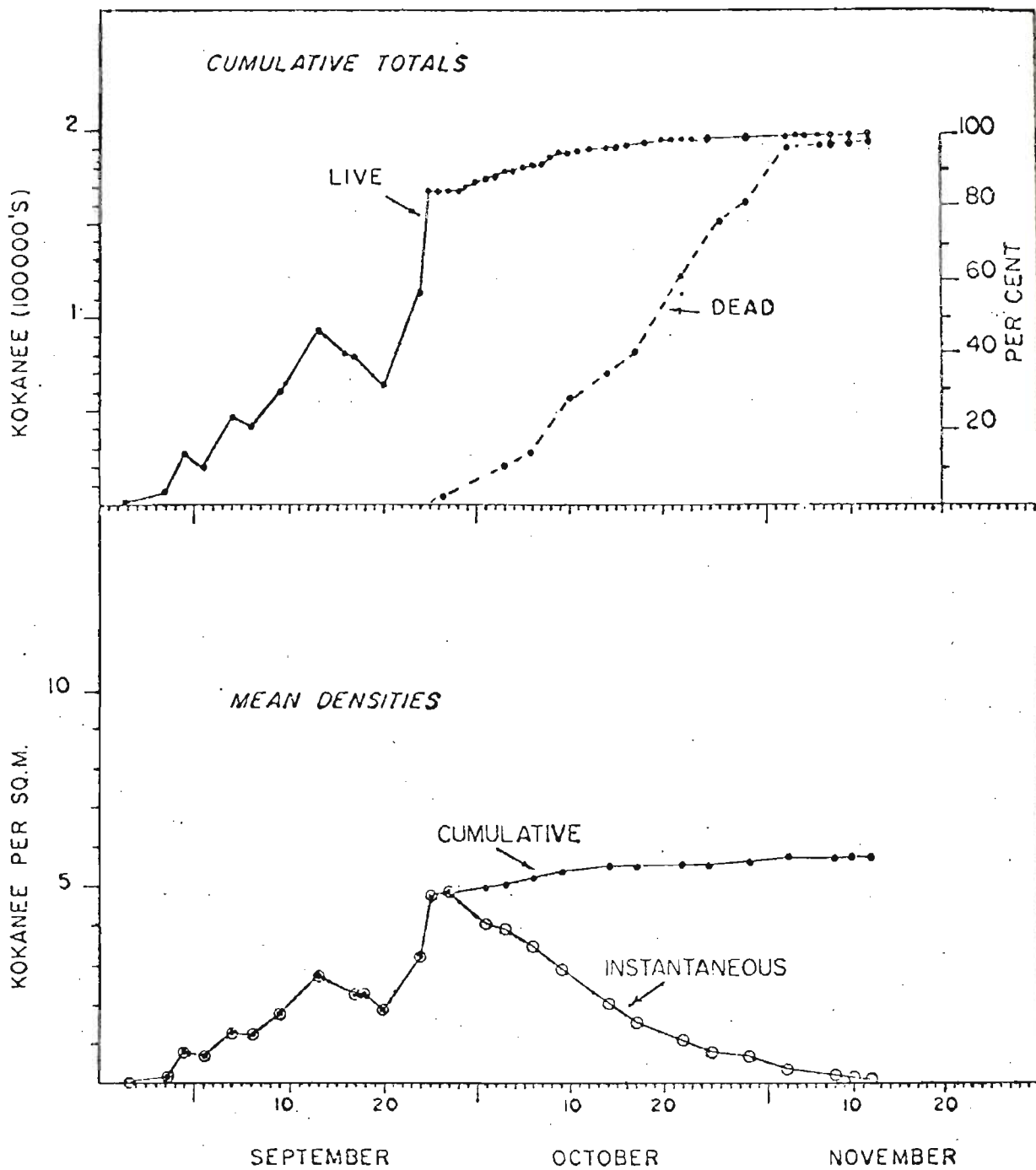


Fig. 9. Cumulative counts of spawners and mean daily densities of spawners in the spawning channel during 1967.

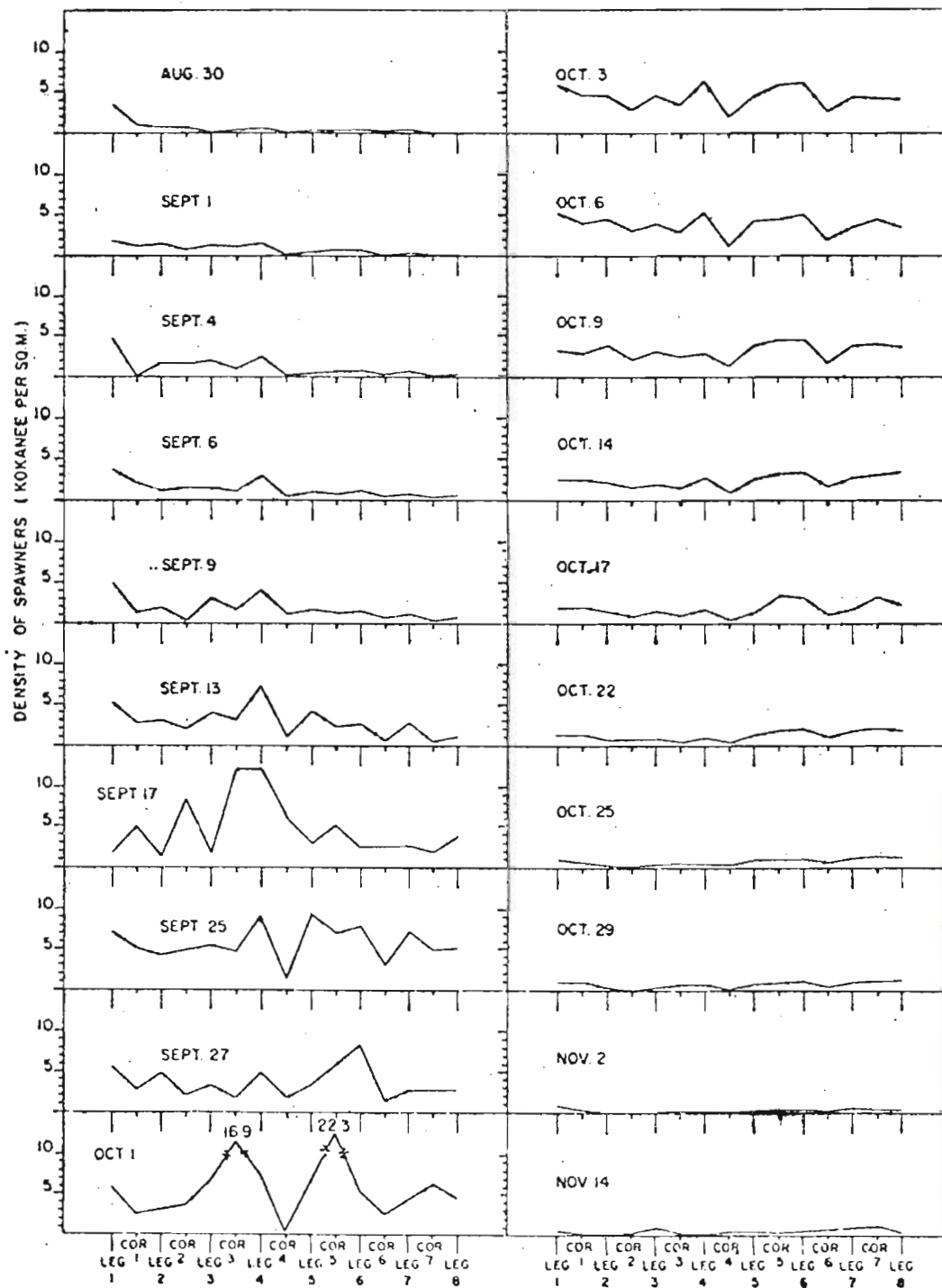
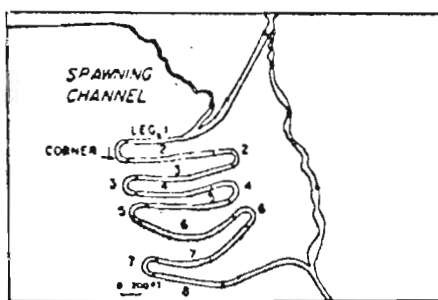


Fig. 10. Mean densities of spawners in the legs and corners of the spawning channel during 1967.

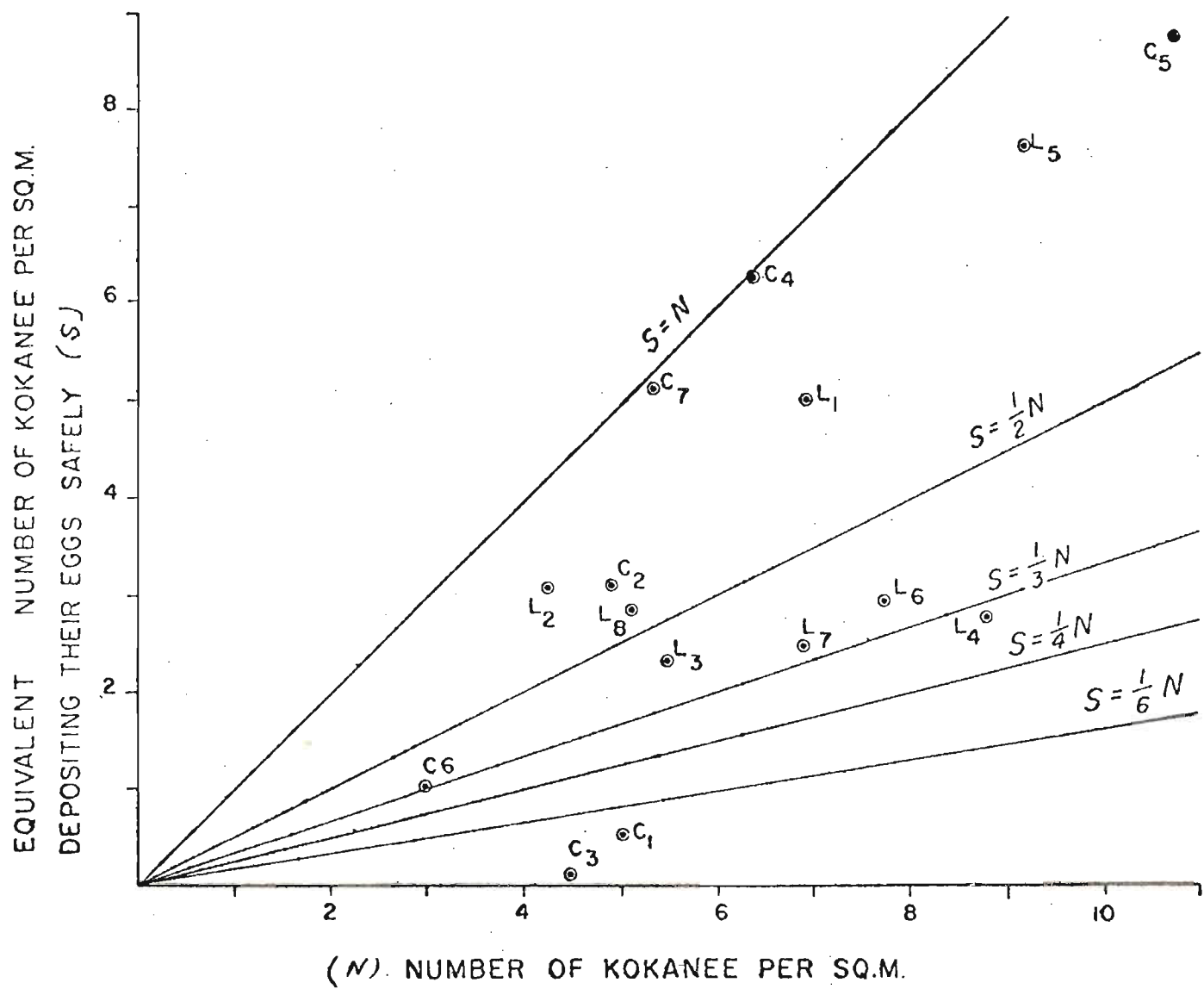


Fig. 11. Spawning success of kokanee in the spawning channel in 1967.

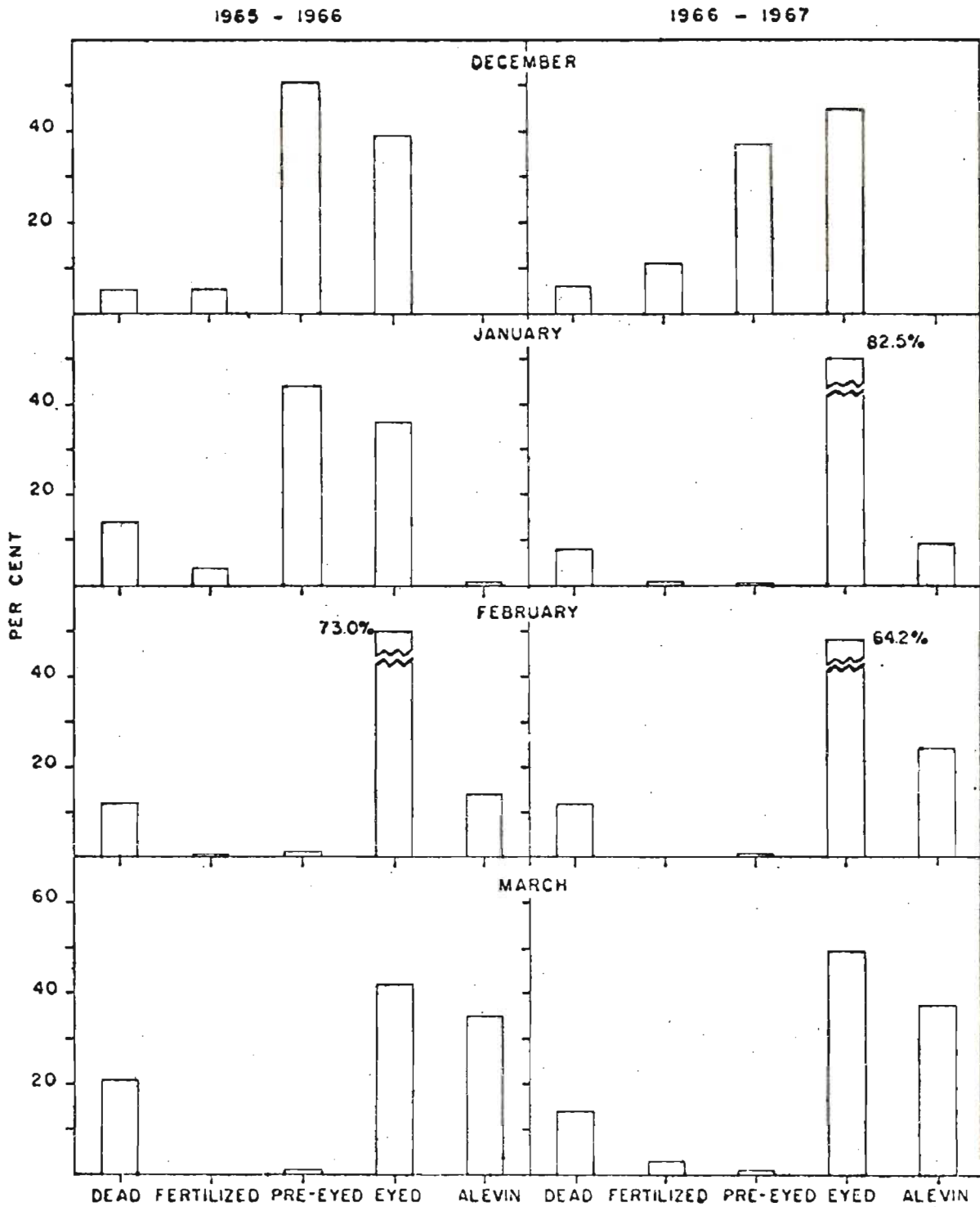


Fig. 12. Development of kokanee eggs in Meadow Creek during 1965-1966 and 1966-1967 (Acara et al. 1970).

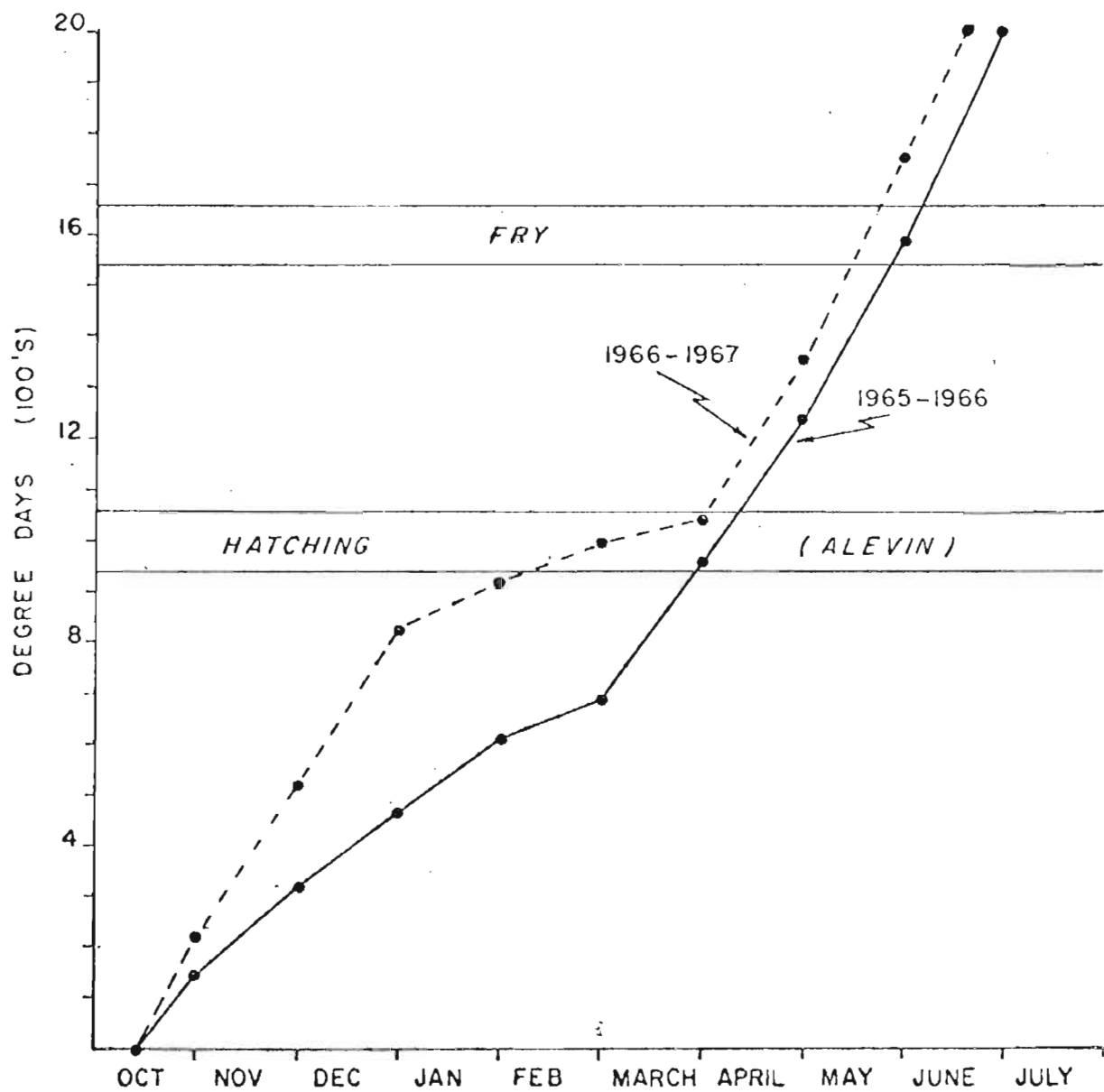


Fig. 13. Development of kokanee eggs and calculated Fahrenheit degree-day units in Meadow Creek during 1965-1966 and 1966-1967.

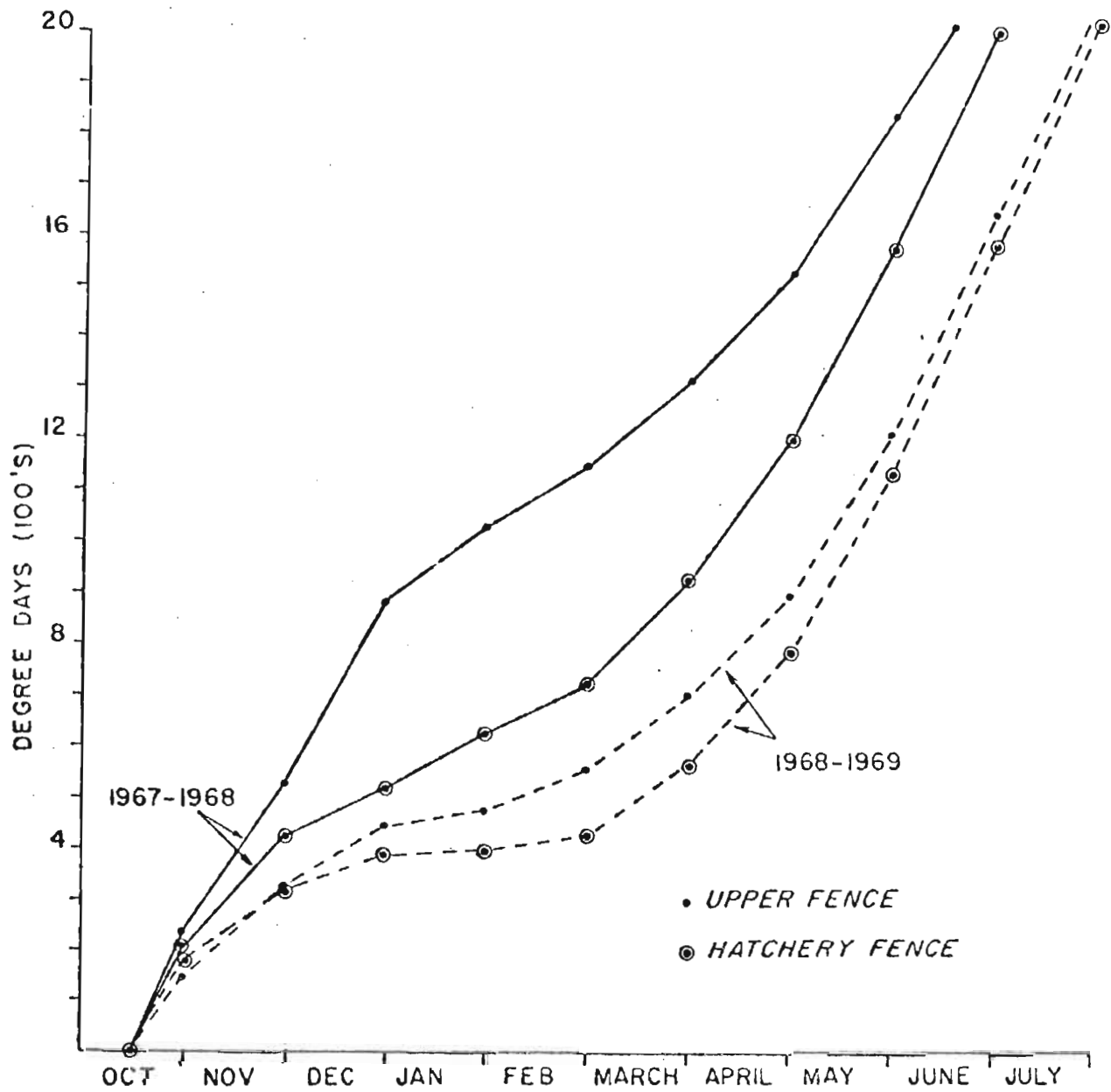


Fig. 14. Calculated Fahrenheit degree-day units in Meadow Creek during 1967-1968 and 1968-1969.

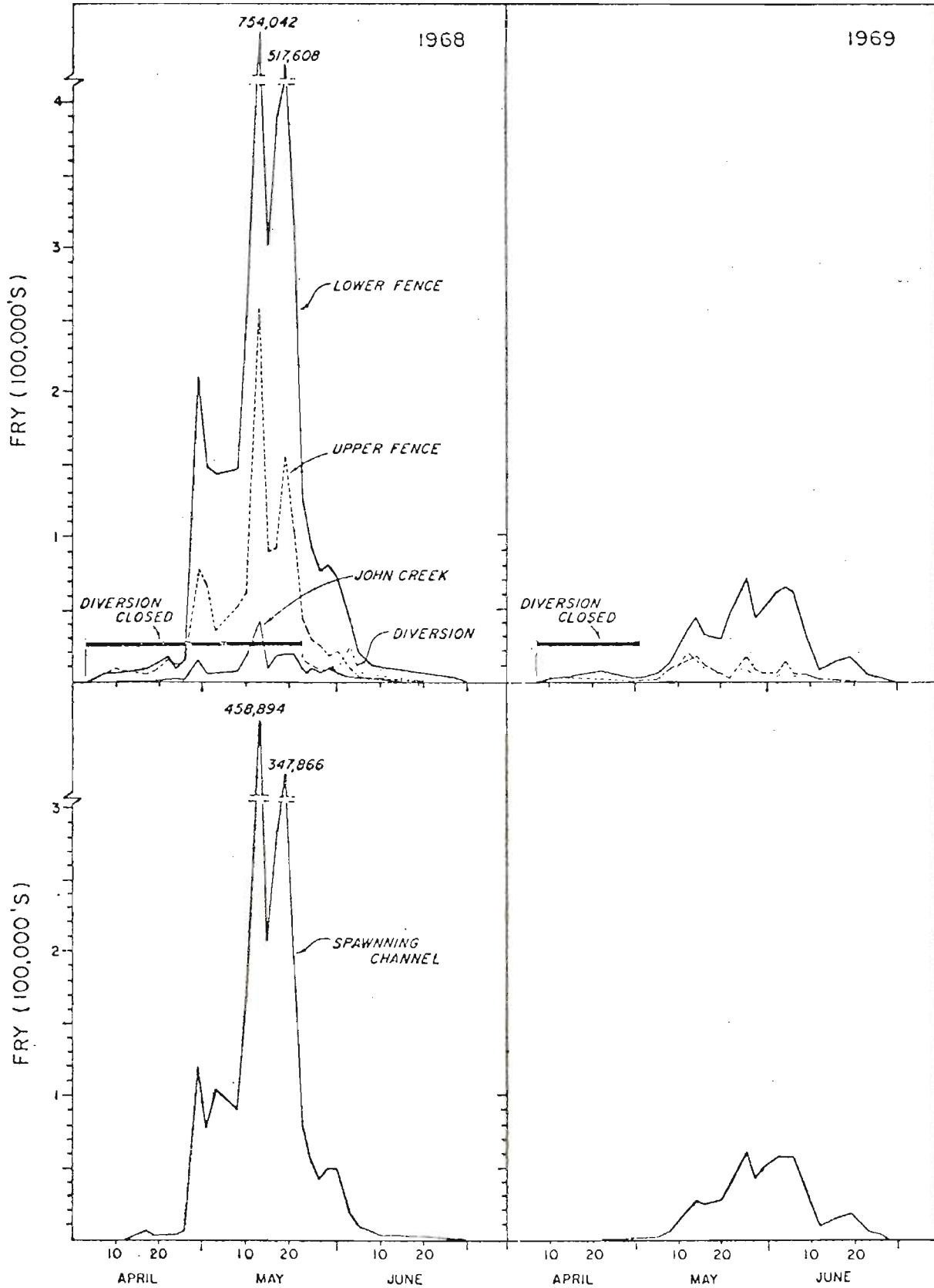


Fig. 15. Estimated nightly total fry at lower and upper diversion fences and John Creek (above); calculated nightly fry production of the spawning channel (below) in 1968 and 1969.

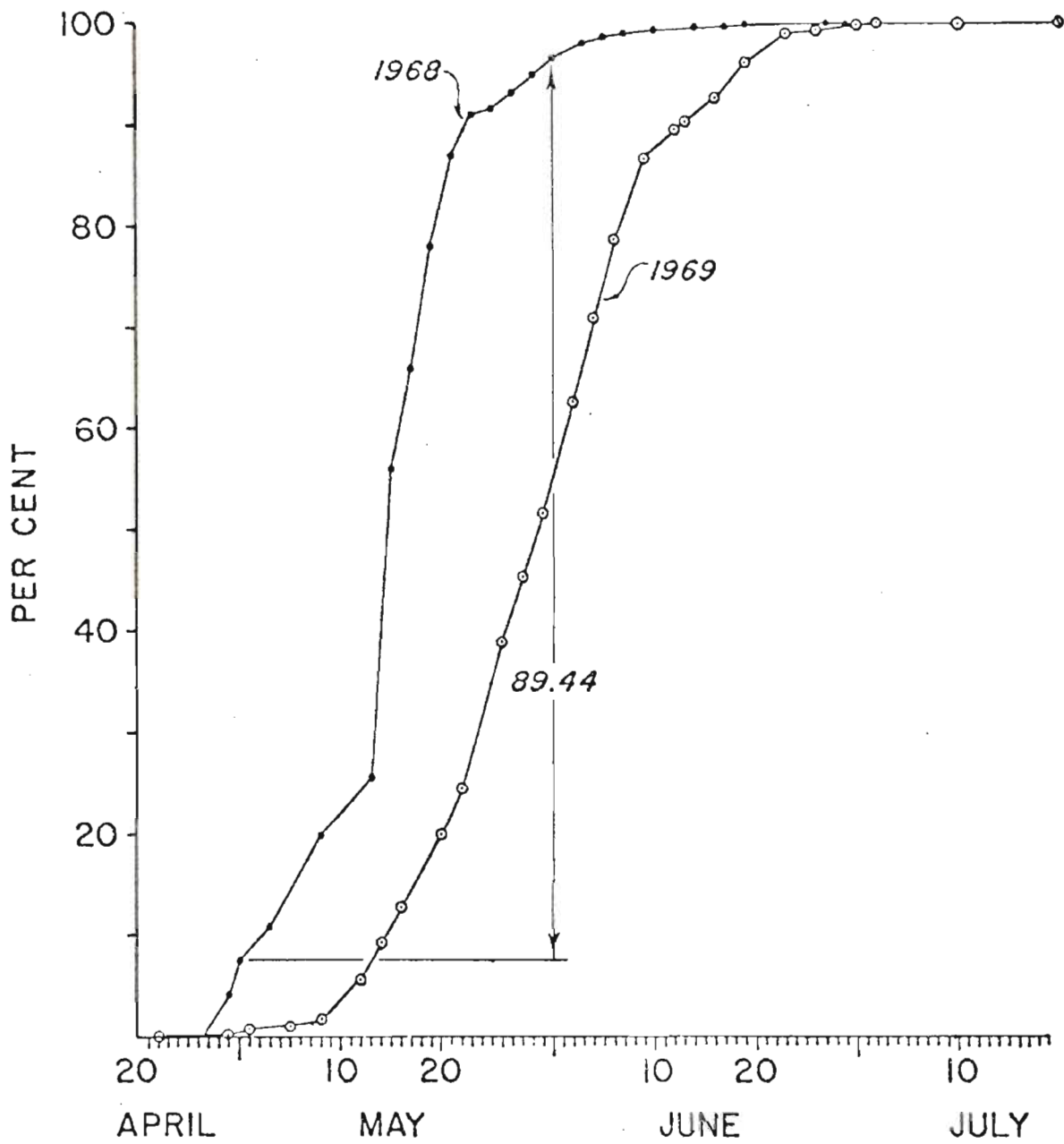


Fig. 16. Cumulative fry production of the spawning channel in 1968 and 1969.

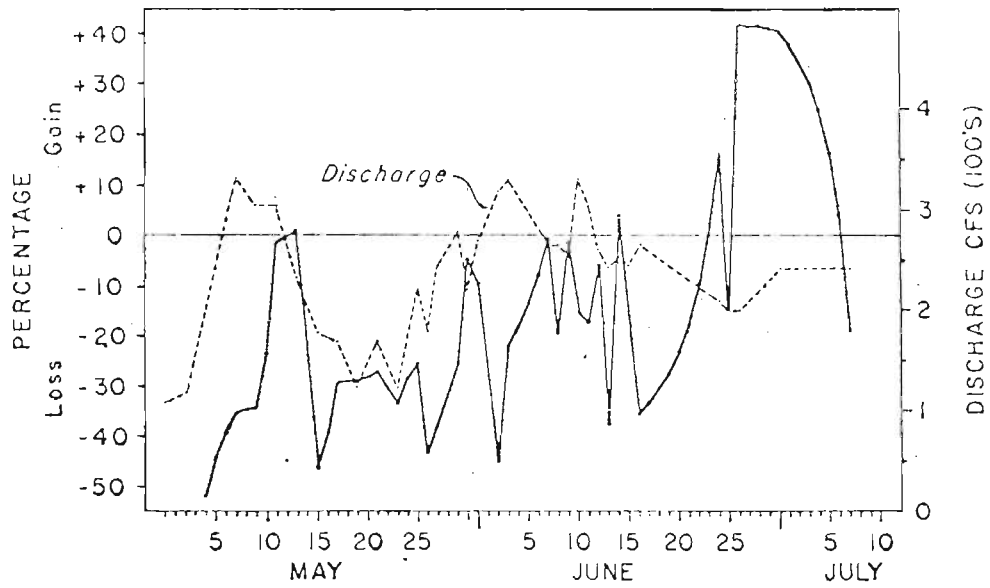


Fig. 17. Difference in kokanee fry estimates at Abey's Farm and Hatchery Fence in Meadow Creek during 1966.

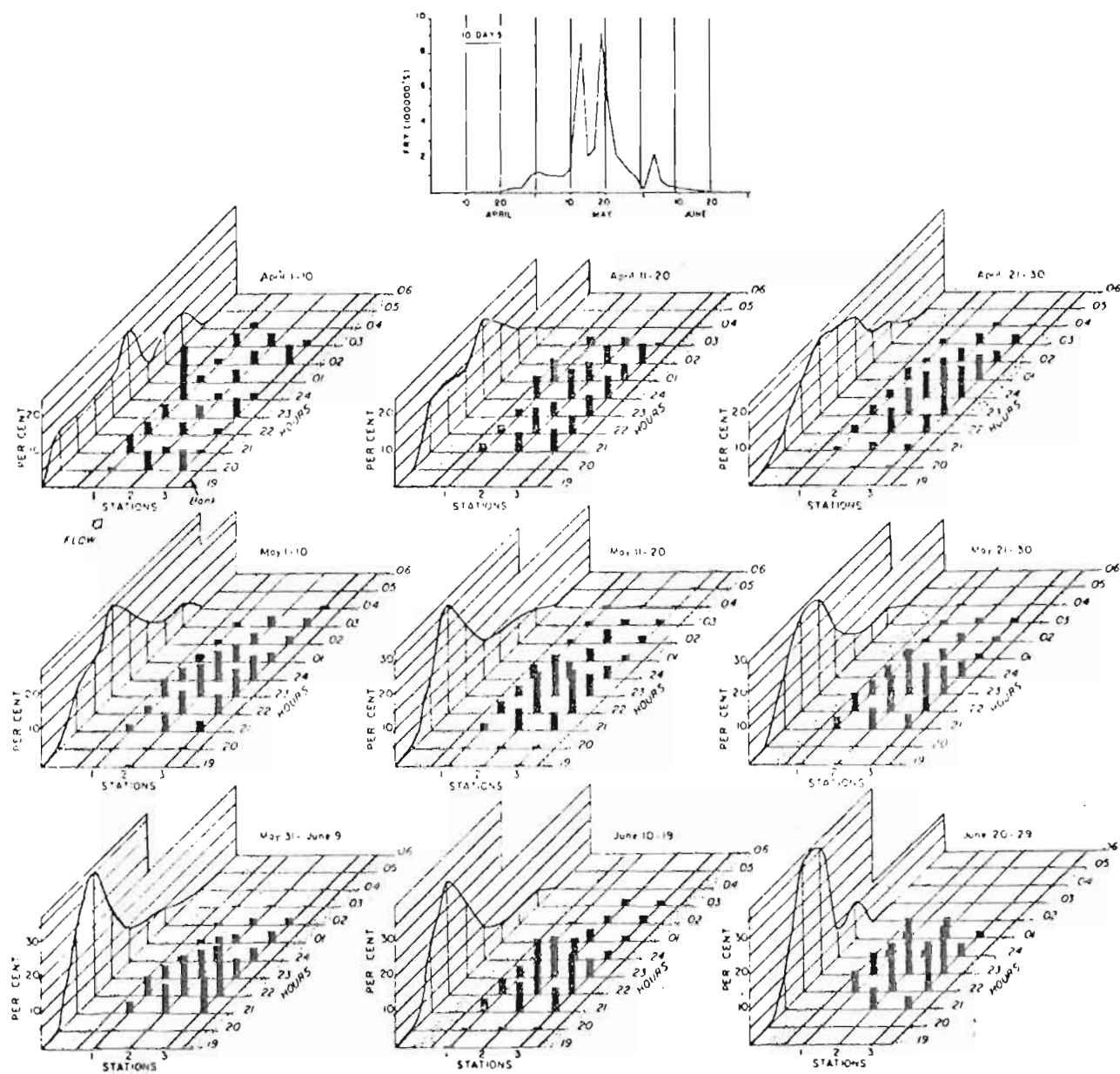


Fig. 18. Downstream migratory behaviour of kokanee fry described in 10 nights' mean diel pattern at Hatchery Fence during 1968 (Acara and Smith 1971).

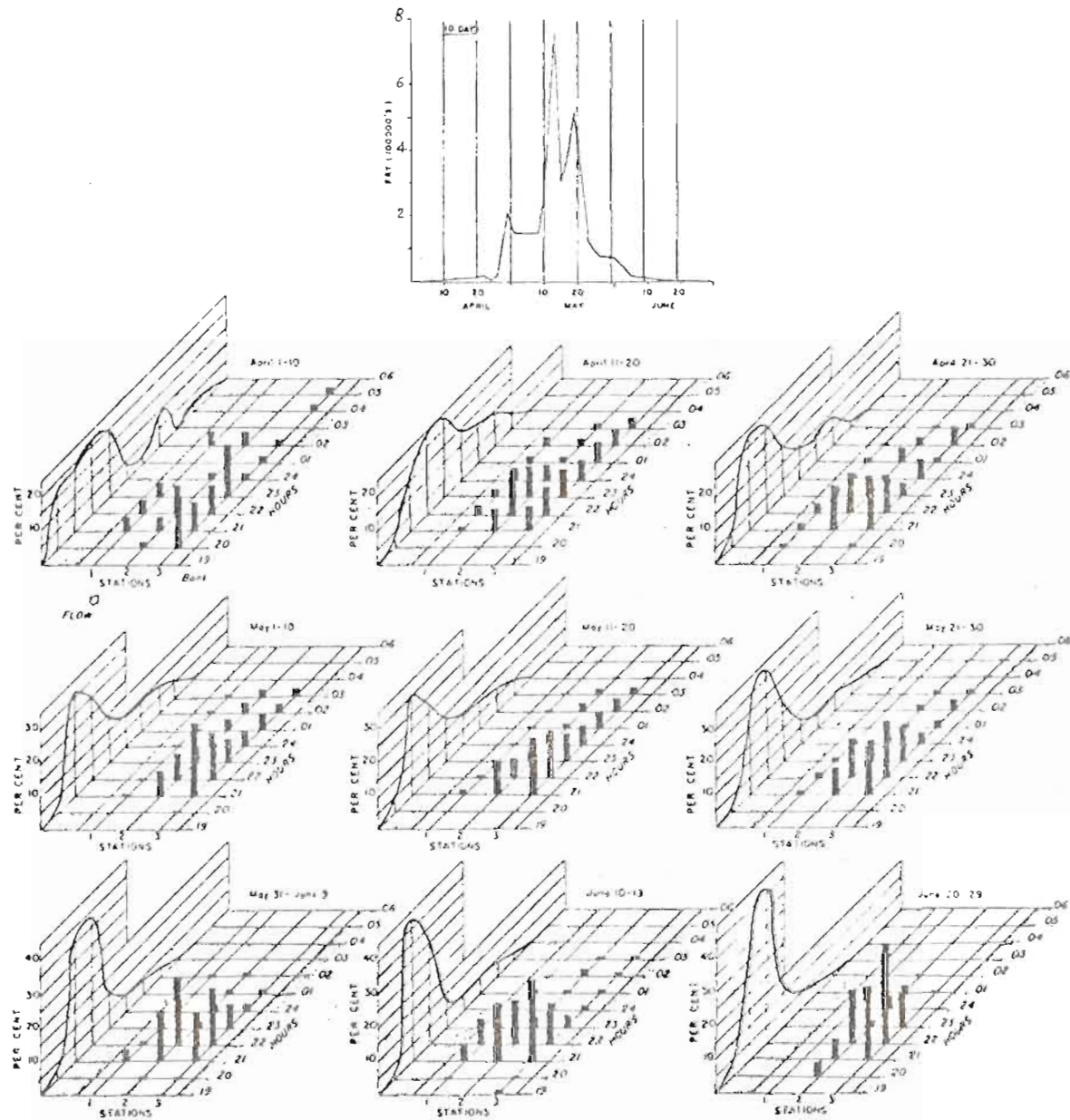


Fig. 19. Downstream migratory behaviour of kokanee fry described in 10 nights' mean diel pattern at Lower Fence, the spawning channel during 1968.

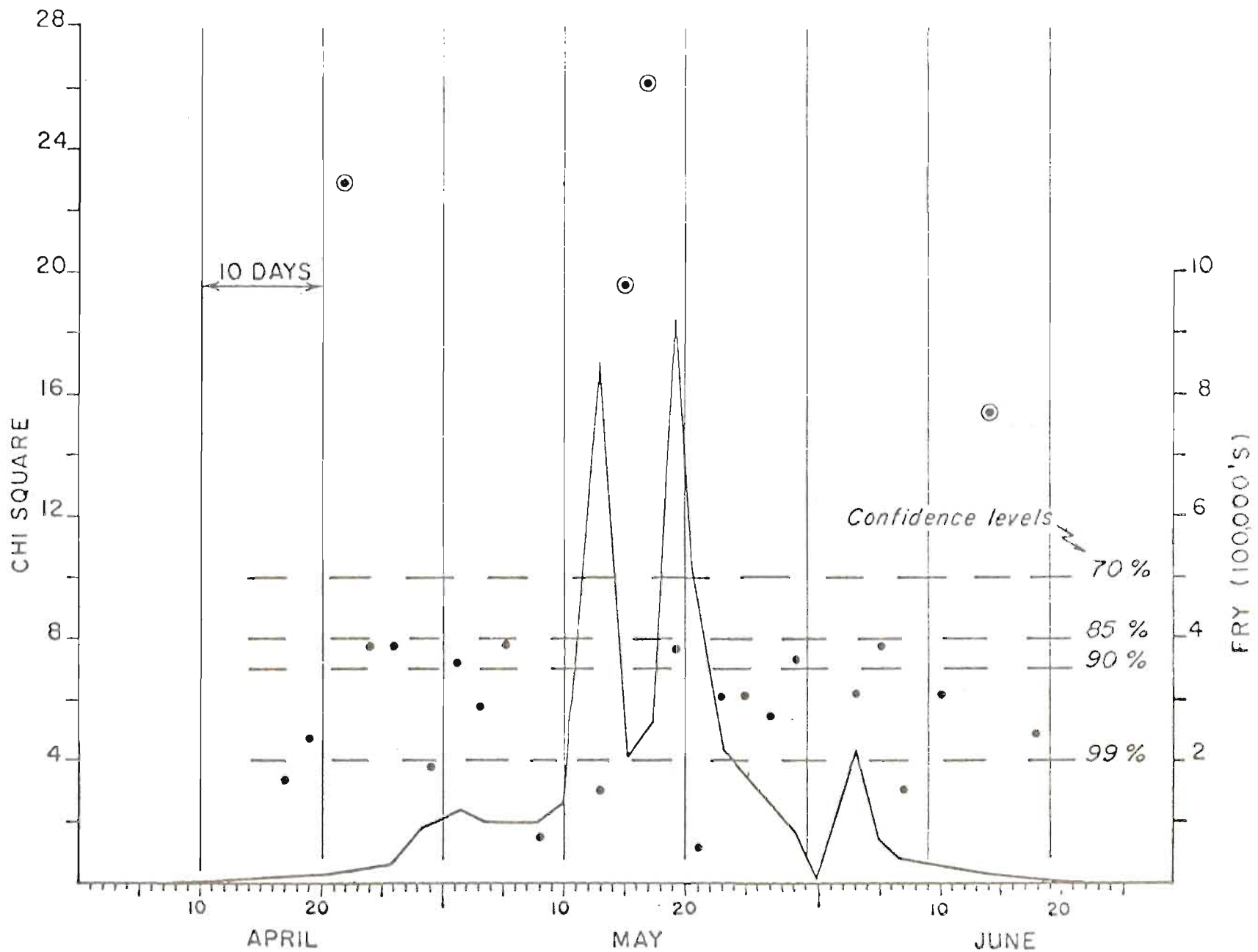


Fig. 20. Comparison of nightly and 10 nights' mean diel patterns of kokanee fry at Hatchery Fence, 1968 (Acara and Smith 1971).

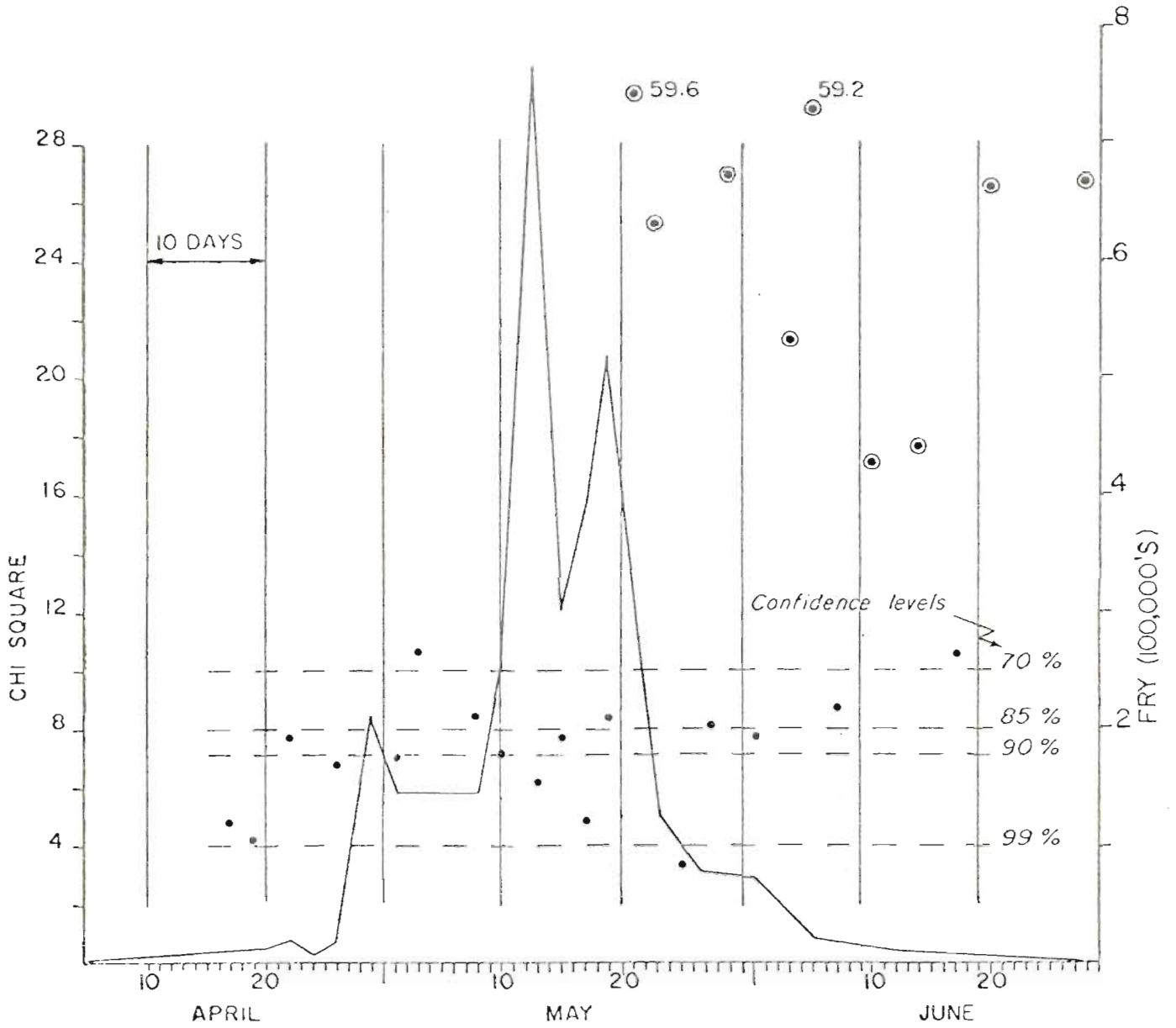


Fig. 21. Comparison of nightly and 10 nights' mean diel patterns of kokanee fry at Lower Fence, the spawning channel in 1968.